ICM Project

Grid Solutions

Toronto Hydro-Electric System Limited (THESL)

ICM Project | Grid Solutions

I EXECUTIVE SUMMARY

The Grid Solutions project consists of three segments:

1) Grid Analytics which will improve THESL's ability to analyze and act on data generated by the thousands of Transformer monitors (TM) and Power Line monitors (PLM) that THESL has installed.
2) Community Energy Storage (CES) will design, develop and install two additional CES systems on THESL's distribution grid in 2013 as part of an ongoing multi-year consortium. The CES systems are being installed to facilitate renewable solar generation. Increased penetration of intermittent supply from solar generation on a distribution feeder results in voltage fluctuations that adversely affect power quality. CES helps address the impacts of intermittent resources by storing excess energy when the demand is low and releasing it back to the grid when the demand is high.
3) The Solutions Development Centre (SDC) is a facility created to "test-drive" potential combinations of hardware, software, and communications. The SDC has been designed and setup to ensure that proof-of-concept technologies/prototypes are effectively validated before being approved for deployment.

The estimated overall cost of this project is shown in Table 1 below and detailed in the material that follows in the Work Description section.

Table 1: Grid Solutions Costs

Segment	2012 Estimated Costs ($ M)	2013 Estimated Costs ($ M)	2014 Estimated Costs ($ M)	Total Estimated Costs ($ M)
Grid Analytics	1.20	1.20	0.60	3.0
CES		1.80		1.80
SDC	1.20	0.60	0.36	2.16
TOTAL ($ M)	2.40	3.60	0.96	**6.96**

1. Grid Analytics

1.1. Description

THESL has installed over 5,600 Transformer Monitors, 100 Power Line Monitors and is in the process of installing one CES unit with two more planned for 2013. Unlike traditional assets on THESL's distribution system, these assets generate data. The value of this data depends on THESL's ability to analyze it and take action based on the analyses conducted. The Grid Analytics project will access this data and analyze it in a coordinated manner on a single software platform. Presently, the available data is not effectively utilized because it is not available in a single place and fully integrated within asset management processes.

1.2. Why the Work is Needed Now

Currently, there is no mechanism for THESL to systematically utilize the data from the grid monitoring devices and integrate it into daily operations and decision-making processes. An integrated software platform to collect, integrate and analyze the data is needed. It is clear that the investment cost associated with the integrated software platform is incremental to the costs previously incurred in the installation of the monitors.

The Grid Analytics project will make available and transform data from the Transformer Monitors, Power Line Monitors and Community Energy Storage unit into information for the use of various operational units.

1.3. Why the Project is the Preferred Alternative

THESL's preferred option is to develop the automated data collection and analysis platform discussed above. The only other viable option is to maintain the status quo and perform manual data collection and analysis. This approach would limit the value of the monitors and Community Energy Storage and preclude THESL from effectively using the data they provide in operations and planning.

2. Community Energy Storage (CES)

2.1. Description

The Community Energy Storage (CES) project is a federal-government supported initiative, undertaken by a consortium and funded in part by Sustainable Development Technology Canada (SDTC). The consortium partners include eCAMION, Dow-Kokam, Toronto Hydro-Electric Systems Limited (THESL) and the University of Toronto. Installation of the first system on THESL's grid is planned for 2012. Performance of the first CES system will be monitored and evaluated. The control system of the CES unit is configurable and the system will be fine-tuned based on the operating conditions.

The scope of the project involves design, development, installation and testing of two additional lithium-ion CES systems on the distribution grid in 2013. The CES systems include battery storage, battery management system, Power Conditioning System (PCS), controller and communications. Lithium-ion technology provides a good all-round solution for THESL objectives related to energy storage. These include facilitating intermittent renewable generation, enhanced asset utilization, reduced system losses and improved power quality.

This ICM application is for the cost of installing the two remaining CES systems. The second and third installation will incorporate design learning from the first installation. Advanced nano-technology for the lithium ion cells, made available by Dow Kokam, will be utilized for the third installation. Installation of the two remaining CES systems will allow THESL to test the performance of CES systems in variety of circumstances. THESL's distribution grid is characterized by different configurations (e.g., looped and radial) and equipment types (e.g., overhead and underground). Thus it is important to test and prove the CES performance in multiple locations that exemplify some of these differences.

2.2. Why the Work is Needed Now

This is a consortium-based activity already underway; the first CES system will be installed and integrated in THESL's distribution system in 2012. Performance of this CES system will be monitored and evaluated. The control system of the CES unit is configurable and the system is expected to be fine-tuned based on the operating conditions. The second and third installations to be funded by this application will incorporate design knowledge gained from the first installation.

THESL is a critical partner in this endeavour. Its contribution includes installing the CES systems on the distribution grid. The CES systems are being developed for THESL and will provide value to THESL's customers far in excess of the cost incurred. Without THESL's support, the work cannot continue.

2.3. Why the Project is the Preferred Alternative

While there are a number of potential options to address some of the issues that the proposed CES systems will address comprehensively, none of them, alone or in combination, provide the complete, cost-effective solution offered by CES. Thus proceeding to complete the CES work begun by the consortium is the preferred alternative.

3. Solutions Development Centre (SDC)

3.1. Description

To aid in integrating new technologies effectively, THESL's strategy is to introduce them through proof-of-concept demonstrations. These small scale demonstrations allow THESL to test the functionality and value of new grid installations and avoid unnecessary implementation costs.

The introduction of new technology typically involves a number of independent components, some new and some existing, that are required to work seamlessly together. Thus, it is not practical, nor desirable to conduct a proof-of-concept demonstration for every possible new component in isolation. To address the need to test new technologies in their future operating context, THESL engages end-to-end integration testing as a precursor to demonstration projects.[1]

THESL has built the Solutions Development Centre (SDC) to address the need to prove the end-to-end integration of new systems. Utilizing the SDC will allow THESL to make best use of limited resources for proving new technologies through proof-of-concept demonstrations. The SDC has been designed and setup to ensure that proof-of-concept technologies/prototypes are effectively validated before being approved for deployment. It will provide THESL the capability of test-driving potential combinations of hardware, software, and communications for future projects before they are deployed in the field. This will enable THESL personnel to see the full potential of an end-to-end integrated solution and determine whether they are suitable for future deployments. The advantage of this approach is that it is low cost and any teething issues that arise can be quickly and efficiently addressed without the need for field crews to retrieve and subsequently reinstall network assets.

3.2. Why the Work is Needed Now

Use of the SDC will allow THESL to move more quickly to test technologies and concepts that have the potential to improve its operations. Delaying the use of the SDC will mean that THESL will continue to use field deployments to test potential innovations at greater cost and with less flexibility than would be afforded by the SDC. Delay will also increase the risk of sub-optimal technology choices because reliance on field testing alone would mean that THESL is unable to fully test all available combinations of equipment.

3.3. Why the Project is the Preferred Alternative

To address the need to prove the end-to-end integration of new systems, THESL has built the Solutions Development Centre (SDC). Utilizing the SDC is the preferred alternative because it will allow THESL to make best use of limited resources for proving new technologies through proof-of-concept demonstrations. The SDC has been designed and setup to ensure that proof-

[1] For example, a new circuit breaker may generate performance data that requires a data collector, a communications medium, a data store, processing and analytics tools. In order to make best use of demonstration projects, it is necessary to first understand the optimum combination of components required for the new technology.

of-concept technologies/prototypes are effectively validated before being approved for field deployment. Neither maintaining the status quo nor delaying the utilization of the SDC would provide THESL with the ability to quickly and effectively test new technologies.

II GRID ANALYTICS

1. WORK DESCRIPTION

Over the last few years, THESL has installed over 5,600 Transformer Monitors, 100 Power Line Monitors and, as discussed in the next section, is in the process of installing a Community Energy Storage unit. A Transformer Monitor provides transformer load monitoring information, outage notification, restoration confirmation, voltage detection and loss detection. A Power Line Monitor provides real-time monitoring of lines. It measures current, fault current and conductor temperature and generates alarms based on set-points. It is used for fault detection, identification of power quality issues, identification of conductor loading issues and assessing the impact of increased penetration of distributed generation. A Community Energy Storage unit consists of battery storage, battery management system, central controller, power conditioning system and grid communications. It is used to mitigate the effects of intermittent generation, enhance system utilization and improve reliability.

The value from the above devices lies in the ability to use the data being captured. Data from these grid devices can be used for preventing outages (by proactively maintaining transformers and conductors to operate within their rated conditions), quickly identifying fault locations (by using Power Line Monitors), diagnosing root-cause of outages (by using Power Line Monitors) and improving transformer, conductor and switch replacement/upgrade decisions (based on asset condition assessment). The value of this data is greatly increased, when all the data-streams are available on a single platform and are correlated with system information.

The work in this segment will provide automated monitoring of these devices to monitor them for conditions that require immediate action and to collect data for planning and developing the distribution grid. The data coming from the Transformer Monitors, Power Line Monitors and Community Energy Storage unit comes in different formats and often requires an ETL (Extract, Transform, Load) tool to access data. Once the data is available in a database, the next step is making it available on a software platform along with all the other data sets and network parameters. Data analytics can then be developed for individual devices as well as the overall system.

Alarms can be generated if the readings exceed given thresholds. For example, if the current on a feeder exceeds a certain threshold for a short period of time, a momentary fault current alarm can be generated. Data collected from the Community Energy Storage unit can be analyzed to update the control algorithm for voltage regulation and power factor correction thereby maximizing the benefits of the unit. The application of analytics is two-fold: for providing information in control room operations to improve fault restoration times by integrating with the Distribution Management System and in planning to proactively take actions to prevent outages.

Table 2 - Grid Analytics Jobs and Cost

Estimate Number	Job Title	Year	Cost Estimate ($M)
23770	GSE GRID ANALYTICS FOR TRANSFORMER MONITORS, POWER LINE MONITORS, COMMUNITY ENERGY STORAGE Phase 1	2012	$1.20
23773	GSE GRID ANALYTICS FOR TRANSFORMER MONITORS, POWER LINE MONITORS, COMMUNITY ENERGY STORAGE Phase 2	2013	$1.20
23775	GSE GRID ANALYTICS FOR TRANSFORMER MONITORS, POWER LINE MONITORS, COMMUNITY ENERGY STORAGE Phase 3	2014	$0.60
		Total	**$3.00**

2. NEED

As part of this project, data from Transformer Monitors, Power Line Monitors and Community Energy Storage unit are expected to be collected and analyzed to add intelligence to the grid and make better informed decisions regarding proactive maintenance and reaction to faults. These assets generate close to 4 million data points every week. For instance, Transformer Monitors measure average demand in 15-minute intervals for each transformer. This level of granularity is required to draw meaningful conclusions from the data and utilize it for trending and loss-of-life applications. The existing 5,600 Transformer Monitors alone generate close to 3.8 million data points each week.

In the summer of 2011, data from over 2,700 Transformer Monitors was analyzed manually, a process that took more than 300 hours to complete. This manual analysis used only a subset of the Transformer Monitor data (i.e., data from 2,700 out of the total population of 5,600 Transformer Monitors) and simple tools. Based on this analysis, proactive maintenance was performed on THESL's distribution transformers leading to a CHI saving of approximately 1,650 hours (See Appendix 1, 2011 Data Analytics Report, p. 3).

Data from Transformer Monitors assist in better management of transformer assets through transformer load monitoring, detection of technical and non-technical losses through check metering with downstream smart meters and near-real-time outage detection through "last gasp" messages reporting back to THESL Control Center. By comparing the aggregate end-point meter loads to the transformer load and analyzing for discrepancies, Transformer Monitors are expected to improve the connectivity model and phase balance. Moreover, productivity savings are expected to be realized by capturing and analyzing the data in an office environment as opposed to capturing the data in the field.

In addition to the above benefits, Transformer Monitor data is also expected to improve reliability, asset management, support energy conservation by reducing losses (by detecting losses and taking measures to improve phase balancing). They can also deliver substantial social and economic benefits by helping THESL detect and address power theft through the comparison of data from Transformer Monitors and Residential Smart Meters.

In 2010, THESL installed Power Line Monitors on its distribution system. The data from 21 Power Line Monitors was analyzed for a period of one year. Based on the average time to receive a "no power" call from a customer after an outage and the average number of customers on a feeder, a potential for CHI savings of over 9,160 hours (i.e., potential SAIDI reduction of 0.78) was identified. Thus the potential for improvements in reliability indices by dispatching a crew based on event notification by the PLMs versus waiting for “no power” calls from the customers has been demonstrated.

In addition to the CHI savings, other benefits from analyzing data from Power Line Monitors include identifying power quality issues and their cause, identifying causes for momentary outages and extending the life of THESL’s distribution assets.

3. PREFERRED ALTERNATIVE

THESL’s preferred option is to develop the automated data collection and analysis platform discussed above. The only other viable option is to maintain the status quo and perform manual data collection and analysis.

3.1. Preferred Option

The preferred option involves automated monitoring of assets and collecting data periodically as well as on an exception basis. Once the data has been collected in a database, the next step is making it available on a software platform along with all the other data sets and network parameters. Data analytics can then be developed for individual devices as well as the overall system. Alarms can be generated if the readings exceed given thresholds. For example, if the current on a feeder exceeds a certain threshold for a short period of time, a momentary fault current alarm can be generated. The application of analytics is two-fold: for providing information in control room operations to improve fault restoration times by integrating with the Distribution Management System and in planning to proactively take actions to prevent outages.

The preferred option is the prudent and efficient approach to obtain information on THESL’s assets, monitor the state of the system and realize the full benefits of existing monitoring equipment and the Community Energy Storage project. It utilizes automated tools and technologies to collect and analyze the data. It is also assessed as the safer and more cost-effective approach as the data is collected remotely and the analysis is done in an office environment instead of sending the field crew to record measurements near energized field assets.

3.2. Status Quo

Maintaining the status quo would have THESL continue:

- gathering information manually through scheduled maintenance or inspection site-visits,
- relying on manual data analysis, and
- using customer "no power" calls to track outages.

The data from the Transformer Monitors, Power Line Monitors and Community Energy Storage unit comes in different formats and often requires an ETL (Extract, Transform, Load) tool to access data. Once the data is accessed, manual analytic approaches are used to gather actionable information from it.

Due to the size of THESL's distribution system (there are close to 60,000 transformers and 1,600 primary feeders), it is not physically and economically possible to manually inspect all overhead transformers and primary feeders on a frequent basis. Further, even when data is collected during these inspections, it is a single snapshot in time and may not capture the full range of conditions. The interval between updates to the data sets is also quite long, which doesn't provide sufficient information in a given time to establish patterns. It may also delay detection of an abnormal condition beyond the period where it can be dealt with through maintenance.

For example, to analyze the loss of life of a transformer, continuous historical data over a period of few years is required. This also requires a tool to view and analyze the historical data. If the status quo is maintained, given the limited number of data points for each transformer, everyday Microsoft Office tools can be utilized to analyze the data. However, the value obtained from this data is very limited as it does not provide information over the life time of the asset. Moreover, the cost of sending the field crew out to obtain data is quite high. Based on the time and cost involved in sending a crew to one transformer location, the cost of obtaining one-time loading information for 5600 transformers would be approximately $1.5 million. If this procedure is repeated twice to obtain two data snapshots, its cost would exceed the estimated costs of the Grid Analytics project.

In the case of primary feeders, the existing approach is to rely on customers to call THESL and report outages. The use of Power Line Monitors reduces the time taken to respond to outages by acting upon the real-time messages from the Power Line Monitors instantaneously. For example, based on the average time to receive a “no power” call from a customer after an outage and the average number of customers on a feeder, a potential for CHI savings of over 9,160 hours (i.e., potential SAIDI reduction of 0.78) was identified from analysis of the data from 21 Power Line Monitors in 2011.

On this basis, maintaining the status-quo is not a prudent approach. THESL would be precluded from developing the capability to provide continuous information which can be used to prevent outages, improve fault restoration times or extend the life of THESL’s assets.

III COMMUNITY ENERGY SYSTEMS

1. WORK DESCRIPTION

The Community Energy Storage (CES) project is a federal-government supported initiative, undertaken by a consortium and funded in part by Sustainable Development Technology Canada (SDTC). The consortium partners include eCAMION, Dow-Kokam, Toronto Hydro-Electric Systems Limited (THESL) and the University of Toronto. Installation of the first system on THESL's grid is planned for 2012. Performance of the first CES system will be monitored and evaluated. The control system of the CES unit is configurable and the system will be fine-tuned based on the operating conditions.

The scope of the project involves design, development, installation and testing of two additional lithium-ion CES systems on the distribution grid in 2013. The CES systems include battery storage, battery management system, Power Conditioning System (PCS), controller and communications. Lithium-ion technology provides a good all-round solution for THESL objectives related to energy storage. These include facilitating intermittent renewable generation, enhanced asset utilization, reduced system losses and improved power quality (See Appendix 2, Review of Community Energy Storage).

For the total project (three CES systems), the design, development and installation cost, including cash and in-kind contribution is $16.69 million. THESL's cash contribution is 16% ($2.66 million). Of this $0.86 million was for the first installation. The remaining $1.80 million is for the installation of the remaining two systems proposed in this application.

The 2013 spending proposed in this application will be used for development, installation and integration of two CES systems, which consist of battery storage, battery management system, Power Conditioning System (PCS), controller and communications. Following the trial period, THESL will own the CES systems.

The work in 2013 will involve:

- Purchase of two PCS units

- Construction of civil base for a total of four padmount units
- Construction of a duct between padmount units for power lines, communication and thermal management (civil work)
- Installation of the PCS and battery units
- Installation of Current Transformers and Potential Transformers
- Installation of a pole may be required if installation location is on the opposite side of the pole line
- Installation of antenna for SCADA connection
- Secondary wire connection to the padmount unit
- Electrical, communication, thermal connections between the two padmount units
- Commissioning tests
- Installation of bollards
- Landscaping as required

Table 3 - Community Energy Storage Jobs and Cost

Estimate Number	Job Title	Year	Total Estimated Costs ($M)
23822	GSE SDTC CES Installation – Unit 2	2013	$0.90
23854	GSE SDTC CES Installation – Unit 3	2013	$0.90
		Total:	**$1.80**

2. NEED

CES is a comprehensive solution that addresses four challenges – Distributed Generation (DG) integration, Power Quality (PQ), reliability, and real-time load growth management (See Appendix 3 - Electricity Energy Storage Technology Options). CES systems are distributed along a feeder. They provide the following system and site-specific benefits:

- CES systems buffer the intermittency of renewable DG by storing excess energy locally when the demand is low and providing power back to the grid when the demand is high and renewable generation is not at full capacity. They enable higher penetration of DG by compensating for voltage fluctuations.

- CES systems provide PQ solutions such as voltage regulation, phase balancing and power factor correction. They also improve asset utilization by providing volt/VAR optimization.
- CES systems provide backup power to a localized area when the grid and DG is not available. They are utilized along with local DG to form a micro-grid that operates independently of the main network and continues to provide power in case of a grid outage. They facilitate the ability of the local area to “ride-through” momentary outages, reducing the frequency of interruptions to customers with sensitive equipment that can be adversely impacted by short-duration outages.
- CES systems provide a solution for real-time load growth management. They firm up the capacity provided by DG and allow the grid to rely on DG to defer investments. They also accommodate load growth without DG.

Installation of the two CES systems planned for 2013 is required under the Consortium agreement entered into by THESL. THESL is a critical partner; its withdrawal will bring the project to a stop. Its contribution includes installing the CES systems on the distribution grid. The CES systems are being developed for THESL and without THESL’s support the project cannot continue.

The asset value of each system excluding design costs is an estimated $1.03 million; however the projected market value of each system (including design costs) is as estimated $2.33 million as shown in Table 4.

Table 4: Market Value of Each CES System

Item	Estimated Cost ($M)
Battery packs ($2000 / kWh)	0.50
System controls (master controller, CPPM, data logger, communication gateways, PLC with HMI, software systems)	0.10
System auxiliaries (cabinet, cabinet controls, climate controls, wiring, bus bars)	0.05
Power Conditioning System	0.26
Subtotal without tax	**0.91**
HST	0.12
Subtotal with tax	**1.03**
Design and engineering of the Control, Protection, and Power Management (CPPM) system	1.30
Total	**2.33**

Based on the market value, the benefit/cost ratio for THESL's proposed expenditure of $1.80 million is:

$$\frac{\text{Benefit}}{\text{Cost}} = \frac{(2 \times 2{,}332{,}029)}{1{,}800{,}000} = 2.59$$

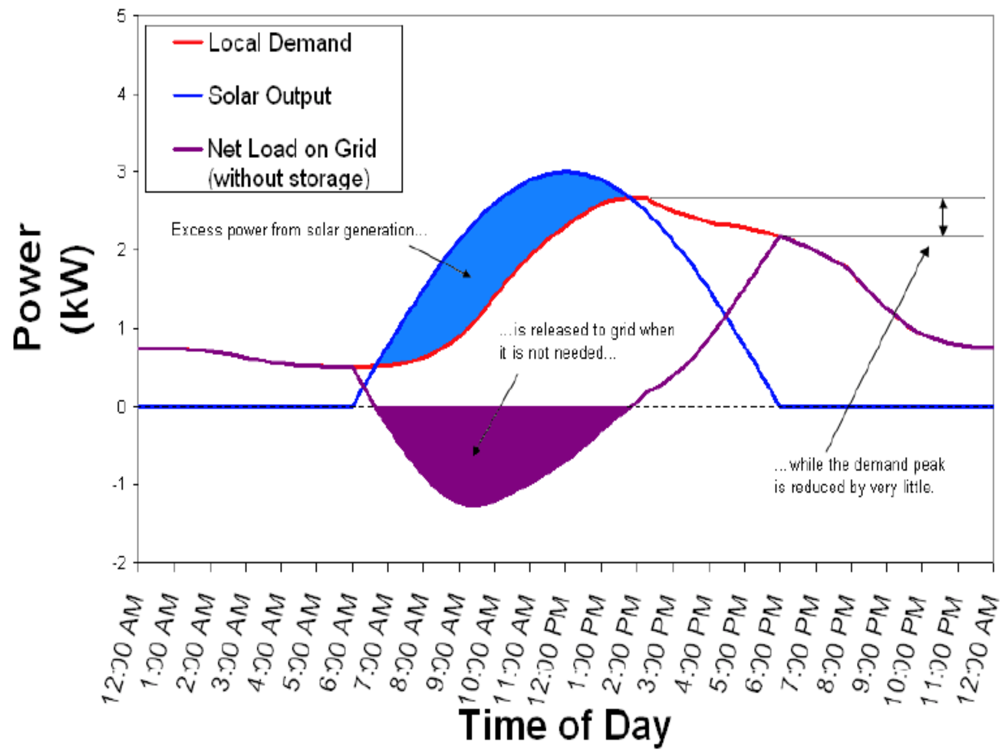
Even if the design and engineering costs were to be ignored, the resulting benefit/cost ratio is still substantially positive:

$$\frac{\text{Benefit}}{\text{Cost}} = \frac{(2 \times 1{,}032{,}029)}{1{,}800{,}000} = 1.15$$

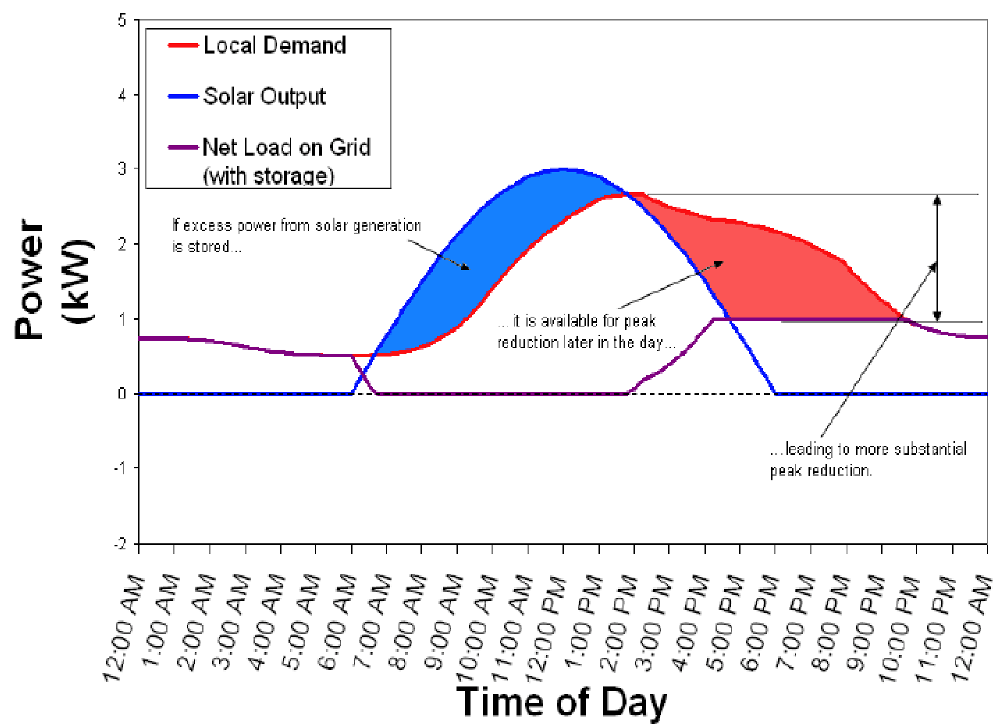
In addition to the benefits from owning the systems after the trial period, the following are the expected benefits from operating the CES systems:

- Mitigate effects of intermittent generation and demand such as from renewable generation sources, effectively functioning as grid "shock absorbers" by providing capacity relief and energy balancing;
- Enhance system utilization and efficiency while preventing system overloads through load levelling, increasing system capacity and reducing losses;
- Provide voltage regulation, loss reduction and power factor correction capabilities through active and reactive power injection;
- Provide active power filtering capabilities through transient and harmonic power injection, hence mitigating power quality effects such as harmonic distortion, voltage sags and swells and flicker, thus providing "digital grade" power quality to customers; and
- Provide backup power and ride-through capabilities during system outages and supporting micro-grid applications

Figures 1, 2, 3 and 4, below, referenced from Electric Power Research Institute (EPRI), illustrate use of CES to meet some of the THESL objectives. Figure 1 shows the effect of solar generation on the load curve without the use of energy storage. Figure 2 shows that energy storage buffers the intermittency of supply and demand and makes the energy available during peak demand.



1 **Figure 1: Load curve with distributed solar without energy storage**



2 **Figure 2: Load curves with distributed solar and energy storage**

Figure 3 illustrates the design concept of distribution systems, where the assets are designed to handle peak load.

Energy storage is used to shave off the peak as shown in Figure 4. This helps defer capital investments to accommodate load growth as the peak capability is utilized for only a very small percentage of time.

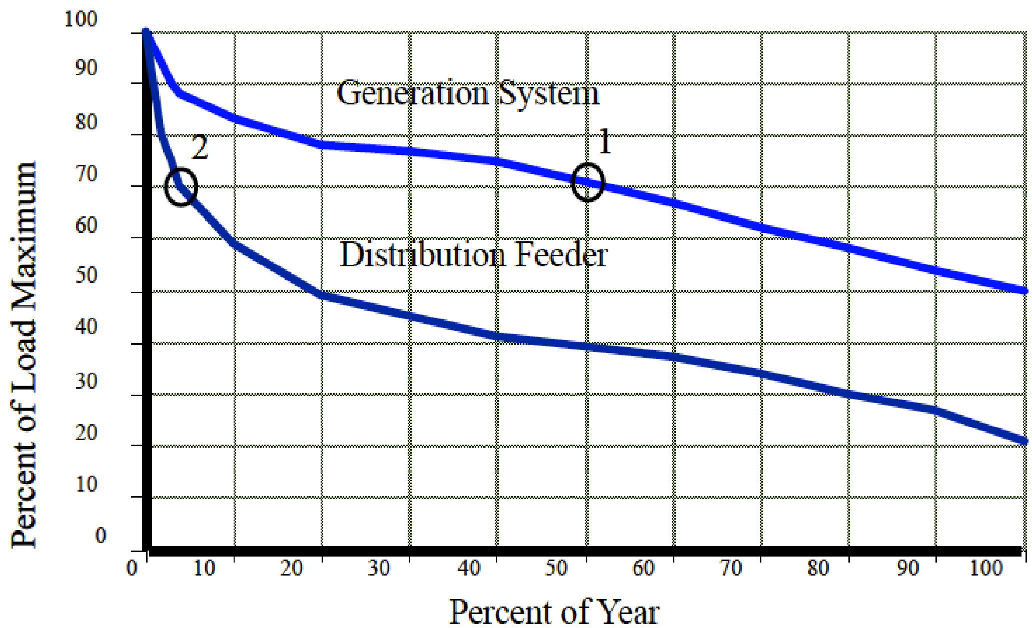


Figure 3: Assets are designed for peak demand

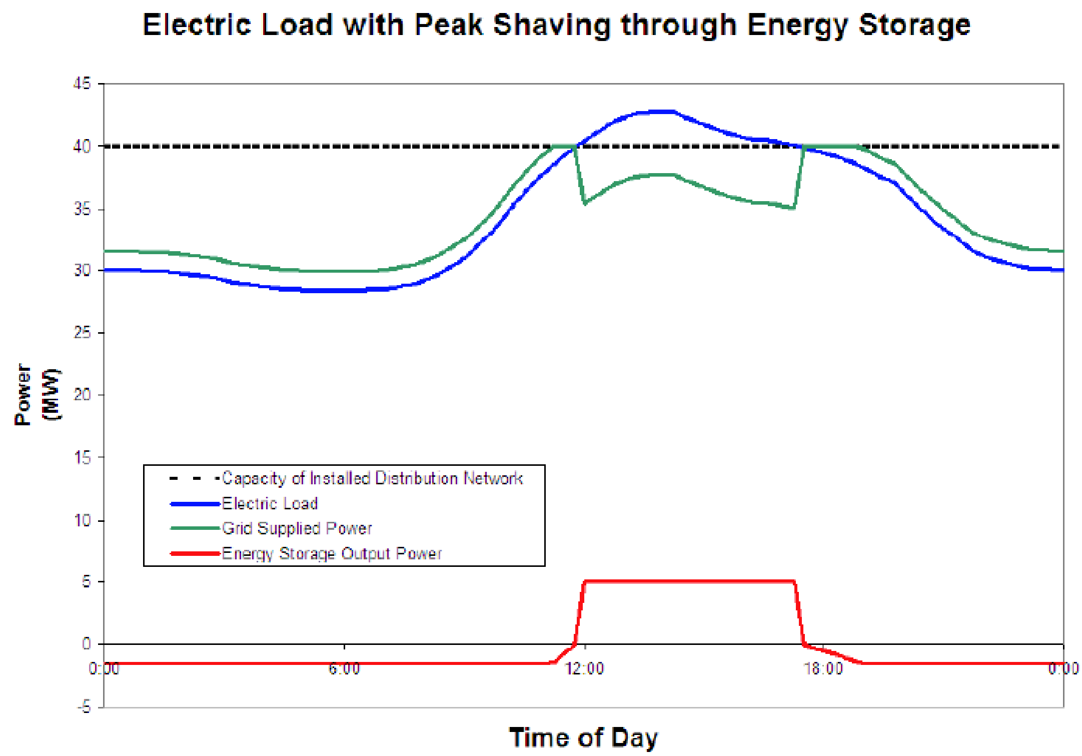


Figure 4: Load curves showing use of energy storage to shave off the peak

3. PREFERRED ALTERNATIVE

While there are a number of potential options to solve some of the issues that the CES systems are expected to address comprehensively, none of them, alone or in combination, provide the complete, cost-effective solution offered by CES. Thus proceeding to complete the CES work is the preferred alternative.

3.1. Preferred Alternative

Adoption of the CES is a comprehensive solution that addresses all four challenges - DG integration, PQ, reliability, and real-time load growth management. CES systems are distributed along a feeder. They provide system and site-specific benefits.

CES systems buffer the variable output of renewable DG by storing excess energy locally when renewable output is high relative to demand and providing power back to the grid when demand is high relative to renewable output. CES also enables higher penetration of DG by compensating for voltage fluctuations.

CES systems provide PQ solutions such as voltage regulation, phase balancing and power factor correction. They also improve asset utilization by providing volt/VAR optimization.

CES systems provide backup power to a localized area when both the grid and DG are unavailable. CES can be used along with local DG to form a micro-grid that operates independently of the main network and continues to provide power in case of a grid outage. CES also facilitates the ability to "ride-through" momentary outages, reducing the frequency of interruptions to sensitive customers.

CES systems provide a solution for real-time load growth management. They firm up the capacity provided by DG and allow the grid to rely on DG to defer investments. They also help accommodate load growth even in the absence of DG.

3.2. Alternative 1: Limit the number of DG connections on the distribution system

This option only addresses DG integration. Under this alternative, THESL would establish a threshold for an acceptable level of DG penetration per feeder. Requests for DG connection exceeding this threshold would not be accepted. This option is contrary to the GEA 2009 which mandates that THESL integrate small generation. If this option is pursued THESL's ability to support the province in meeting renewable energy targets will be constrained.

3.3. Alternative 2: Add Power Quality Devices

This option partially addresses DG integration and PQ challenges. In this scenario devices addressing PQ concerns are installed at specific customer sites or on the lateral sections of feeders. Examples of such devices include voltage regulators and Static Synchronous Compensators (STATCOM). This option can be used to mitigate the issues faced by individual customers, but not to address overall system performance because the number of devices required would be very high. Moreover, voltage regulators are not fast enough to compensate for sudden voltage disturbances when solar output is reduced due to cloud cover.

3.4. Alternative 3: Mobile backup power generators

This option addresses reliability and real-time load growth management concerns. Mobile generators are currently used to provide backup power for planned outages, redundancy during special events or temporary power to accommodate load growth. Generators depend on an external fuel source such as diesel which may be costly or a source of pollution. This approach is a short-term, not a permanent, solution. It also does not address momentary power outages.

3.5. Alternative 4: Upgrade and build new infrastructure

This option addresses DG integration, PQ and reliability concerns in whole or in part. Under this alternative, power lines are rebuilt at a higher capacity or new lines are added. This approach would allow THESL to accommodate DG connection requests that exceed the currently acceptable threshold. It also can mitigate some PQ and reliability concerns. New infrastructure has fewer outages. It will not solve all PQ problems, however, because interruptions on the station supply bus or on adjacent feeders sharing the station supply bus will continue to cause PQ problems. This alternative is impractical because rebuilding or adding infrastructure that is not otherwise required simply to address these concerns is not cost-effective.

IV SOLUTIONS DEVELOPMENT CENTRE

1. WORK DESCRIPTION

To aid in integrating new technologies effectively, THESL's strategy is to introduce them through proof-of-concept demonstrations. These small scale demonstrations allow THESL to test the functionality and value of new grid installations and avoid unnecessary implementation costs.

The introduction of new technology typically involves a number of independent components, some new and some existing, that are required to work seamlessly together. Thus, it is not practical, nor desirable to conduct a proof-of-concept demonstration for every possible new component in isolation. To address the need to test new technologies in their future operating context, THESL engages end-to-end integration testing as a precursor to demonstration projects.

The purpose of this project is to assess various control, monitoring and communication components to determine their suitability for inclusion into the THESL distribution system in a test environment. All work will be completed out of the Solutions Development Center (SDC) located at THESL's 500 Commissioners work centre. THESL proposes three types of equipment be tested:

1) Grid Control Systems affect the configuration and operating condition of the grid in order to protect equipment, workers and the public by adjusting abnormal grid configurations thereby improving safety and reliability.
2) Grid Monitoring Systems report the status of the grid and any state changes or abnormal conditions.
3) Grid Communication systems help move data into THESL's systems and thereby allow this data to be transformed into actionable information.

With respect to Grid Control Systems, the SDC will be used to develop capabilities to test microprocessor relays and feeder automation. The specific tasks will allow THESL to test the interoperability of equipment in the context of a mock transformer station. Ultimately THESL will be able to test the performance and functionality of grid control and monitoring devices and the impacts from devices such as electric vehicles, distributed generation and Community Energy Storage.

With respect to Feeder Automation, the SDC will allow THESL to work with various vendors to develop a simulation of their automation systems using software and/or a hardware mock-up. The systems will be tested to see how well they perform based on simulations using the standard messaging protocol. Each vendor’s system will be tested in phases to avoid confusion (if all were done in parallel).

For network hardware, the SDC will begin by building a working wired communication network as a necessary precursor to other testing. This will be followed by building a hybrid wired and wireless communication network within the SDC, helping simulate actual grid conditions. This setup would then be used for end-to-end testing of the communications capabilities of potential additions to the distribution grid.

Finally, for grid monitoring systems, the SDC will be used for end-to-end testing of Primary Line Monitors (PLM)/Secondary Line Monitors (SLM)/Transformer Monitors (TM) to analyze the information flow from the devices into each of their backend databases. Once the data flow has been verified, the next step for these projects is to test the integration of exception messages generated by each device in existing systems.

Table 5 - Solutions Development Centre Jobs and Cost

Estimate Number	Job Title	Year	Cost Estimate ($M)
23827	Grid Systems Integration – Component and Integration Level	2012	$1.20
23828	Grid Systems Integration – Intelligence and Value attainment Level	2013	$0.60
23829	Grid Systems Integration – Intelligence and Value attainment Level	2014	$0.36
		Total	**$2.16**

2. NEED

The Solutions Development Centre was built in order to make best of use of THESL's limited resources to minimize the risks associated with the implementation of new technologies. The intent is to make use of the SDC for the demonstration of integrated applications prior to their introduction into THESL system. The goal of the project is to utilize the SDC environment for the purpose of testing, integrating and validating grid monitoring and grid control systems (monitoring components such as Power Line Monitors and Transformer Monitors and control components such as Microprocessor Relays and Intelligent Switch/Recloser Controllers), to ensure device interoperability and future scalability.

One of THESL's priorities for new technology is to avoid having siloed systems that do not interact with one another and are only useful for one specific task. In 2011, an area at 500 Commissioners was prepared for dedicated SDC operations. In addition, the organization issued a Request for Proposal (RFP) to address THESL's needs for end-to-end integration between intelligent components on the distribution network. THESL had over 27 responses which are currently under review and which also have an expiration date. Successful proposals will go through a validation process that has been defined under the SDC.

The estimated cost for the utilization of the SDC is $2.16M. The objective is to be able to test vendor's equipment, head-to-head where applicable, in a closed loop. This will allow personnel from THESL to evaluate the equipment being tested as a whole and identify how it potentially can be used by various business groups within THESL. The SDC will also help determine if a particular solution should move forward to a field demonstration deployment.

The SDC will limit the risk that is inherent in field deployments by enabling the validation of multi-vendor device interoperability and compatibility with THESL's existing equipment. This will help THESL avoid single vendor lock-in of products and promote greater choice with respect future equipment purchases. The SDC will encourage the development of in-house knowledge of the systems being tested to ensure smooth and rapid deployment for those that go forward as field demonstrations.

The SDC will provide THESL with a suitable launch pad for testing and integration into existing work practices and systems. Furthermore, any design changes that are required can be completed in advance and actual field-ready equipment can be deployed (as opposed to prototypes). Overall, the utilization of the SDC is seen as a best practice for THESL's pilot deployments.

The SDC is expected to have direct benefits in the following areas:

- Planning
    - Deployment techniques and guidelines - If the equipment is approved for deployment, mock ups from the SDC can aid in the creation of a construction sketches and work installation procedures.
    - Project Scoping and Job Estimating - If the equipment is approved for deployment, the information required for scope packages and job estimating (e.g., labour resources and material cost) will already be known.
    - Maintenance Planning - If the equipment is approved for deployment, any impacts to existing maintenance plans can be anticipated and worked into existing practices, or a new plan can be created.

- Safety:
  - Joint Health and Safety Committee Sessions - Vendors are present at safety meetings to discuss any concerns or comments regarding changes to equipment required based on experience in the SDC.
  - Field staff Engagement and Communication sessions - Feedback from field staff can address safety concerns regarding equipment while it is being testing in SDC.
  - Engineering Safety Bulletins - If the equipment is approved for deployment, THESL can effectively communicate the need, goals and benefits of a complete end-to-end system to field staff based on the results from the testing and simulation completed in the SDC.
- Training and Integration:
  - Field staff Training - If the equipment is approved for deployment, training programs can be developed rapidly to comply with Ministry of Labour Requirements as mock-ups of field installations can be completed in SDC.
  - IT Systems Integration - IT work completed for end-to-end testing can be leveraged for a field deployment quickly as little additional work is likely to be required for backend software.
- Benefit realization - With successful component testing and any necessary design changes brought about in the SDC, benefit realization can occur faster as the majority of potential issues have been addressed already.

3. PREFERRED ALTERNATIVE

To address the need to prove the end-to-end integration of new systems; THESL has built the Solutions Development Centre (SDC). Utilizing the SDC is the preferred alternative because it will allow THESL to make best use of limited resources for proving new technologies through proof-of-concept demonstrations. The SDC has been designed and setup to ensure that proof-of-concept technologies/prototypes are effectively validated before being approved for field deployment. Neither maintaining the status quo nor delaying the utilization of the SDC would provide THESL with the ability to quickly and effectively test new technologies.

3.1. Preferred Alternative - Utilize the Solutions Development Center

To use technology to improve operations, THESL must first be sure that the technology will work as intended and interface with THESL's existing equipment. To test this, THESL's preferred approach is to evaluate concepts and equipment in a controlled environment before pursuing field installations. Utilizing the SDC will facilitate this approach. Testing potential innovations in a controlled environment will allow THESL to determine how they will interact with existing systems and applications and try different combinations of components to find the optimal combination.

Testing new technologies in the SDC will provide the following benefits:

- No field installation costs;
- No crew resources required for deployments;
- Ability to validate standards in a controlled environment;
- Flexibility to experiment with different specifications ;
- Ability to test interactions with multiple systems; and
- Ability to evaluate multi-vendor device interoperability and avoiding single vendor lock-in of products.

Finally the following indirect benefits are associated with the utilization of the SDC:

- Ability to interact with vendors to influence features and functions;
- Ability to acquire in-depth knowledge of devices; and
- Train staff that will be involved in the eventual deployment of devices being tested.

Using the SDC is expected to reduce the deployment costs of future projects, while providing THESL with maximum flexibility in terms of vendor choice and end-to-end integration, without impacting system operations. THESL personnel will be able to demonstrate the value of potential solutions to help determine if the solutions should move forward to field deployment. THE SDC is expected to also give THESL a suitable launch pad for testing and integration into existing work practices and systems. If a particular solution is selected for a field deployment, all the necessary back-end integration work will have already been completed.

3.2. Alternative One - Status Quo

This alternative involves continuing with the status quo process for proof-of-concept field demonstration deployments. The SDC would not be used for the testing and validation of proof-of-concept technologies/prototypes. The advantage of not utilizing the SDC is the upfront capital savings. The disadvantages are that THESL loses all the potential cost, developmental and collaborative benefits associated with utilizing the SDC.

The cost of pilot projects conducted in the field is high, especially when deploying prototype equipment that requires continuous troubleshooting. Deployments may be limited to one or a small number of vendors that supply similar equipment. This increases the risk of being locked into a single vendor solution as having multiple field trials of similar components becomes costly. Furthermore the potential benefits of a particular technology may not be maximized because of the inability to test multiple equipment configurations.

Specifically, in the event that the SDC is not used, THESL will likely be unable to:

- Test the interoperability of vendor equipment;
- Validate ongoing specifications for systems integration and communications ;
- Demonstrate end-to-end systems integration with new and existing systems; and
- Meet commitments to the Ontario Ministry of Energy's Smart Grid Fund and Natural Resources Canada ecoENERGY Innovation Initiative.

3.3. Alternative Two - Deferral of Solutions Development Center Utilization

This option involves deferring the utilization of the SDC into the future. The advantage of this option is that THESL preserves the ability to generate the benefits associated with SDC use at some later date, while avoiding capital expenditures right now. The disadvantages of this option are similar to those of Alternative One until such time as the SDC comes into use.

V APPENDICES

Appendix 1 - 2011 Data Analytics Report

Appendix 2 – Review of Community Energy Storage

Appendix 3 - Electricity Energy Storage Technology Options

Toronto Hydro-Electric System Limited
EB-2012-0064
Tab 4
Schedule B22, Appendix 1
ORIGINAL (13 pages)

2011 Data Analytics Report

Grid Solutions Engineering
Asset Management
January, 2012

Document Control

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Table of Contents

1 Introduction

As part of Toronto Hydro-Electric System Limited's ("Toronto Hydro") vision for improved system reliability, customer service excellence and in response to the requirements of the Green Energy and Green Economy Act (GEGEA), Toronto Hydro launched the feeder automation, transformer monitoring, power line monitoring and network automation pilot programs. The following sections give a brief overview of the projects, followed by the 2011 results from the programs. Specifically, reduction in CMO (Customer Minutes Out) and CI (Customers Interrupted) - where applicable, along with reduction in System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI) is presented.

2 Feeder Automation

2.1. Feeder Automation Overview

Toronto Hydro selected feeders in the former service area of North York to demonstrate the self-healing component of the Feeder Automation program. Ten feeders were chosen based on reliability indices. The feeders were categorized as either a worst performing feeder or a feeder that had sustained a high number of outages.

The technology chosen for this implementation was S&C SCADA-Mate switches along with IntelliTEAM II software (which contains the algorithm and logic). These switches communicate with Toronto Hydro's SCADA system via SpeedNet radios that operate in a 900 MHz open bandwidth setup.

Phase One of the project addressed the installation of all the necessary overhead field equipment (installation and/or conversion of SCADA-Mate switches and the SpeedNet Radio system) as well as field testing and commissioning of the automation system. Phase One of the proof-of-concept program was brought online in October 2010.

2.2. Results

The following table outlines the events that triggered the Feeder Automation scheme in 2011 (table contains approximate values):

Event	Fault Type	Reduction in SAIDI	Reduction in SAIFI	CMO		CI	
				Outage	Saved	Outage	Saved
1	Pole fire	0.06133	0.004718	26,062	43,095	402	3,315
2 *	Tree branch	0.013379	0.00268	16,804	9,365	1442	1,873
3 *	Lightning on Breaker	0	0	12,524	0	6262	0
4	Vehicle interference	0.04479	0.002357	57,907	31,350	1,081	1,650
5 *	Umbrella on Transmission Line	-	-	-	-	-	-

6	Defective Equipment	0.077	0.006417	194	53,904	1	4,492
7	Failed Transformer	0.03375	0.00375	10,971	23,625	789	2,625
8**	Pothead Cable	0	0	37,679	0	1,950	0
9 *	TS breaker problem	-	-	-	-	-	-
10 **	Cable Fault	0	0	125,433	0	4,082	0

*Events that occurred on the transmission level or within the substation that were out of the control of the SCADA-Mate switches
**Events where adjacent tie feeders did not have the extra capacity to conduct load transfer and thus SCADA-Mate switches remained open.

The Feeder Automation scheme operated as expected during all the events. In the event where the fault occurs and adjacent tie feeders had enough capacity, the faulted section was successfully isolated and the rest of the feeders were restored. In the cases where the tie feeder(s) did not have enough capacity, the switches opened and remained open.

Based on the above information, feeder automation helped restore 13955 customers and decreased the CMO by over 161300 minutes in 2011. These improvements could have a positive impact on Toronto Hydro's grid reliability as shown above with the reduction in SAIDI and SAIFI.

2.3. Detailed explanation of two events

The reduction in reliability indices SAIDI and SAIFI is calculated using CMO and CI saved over the total number of customers. The report is generated first by the operator through Interruption Tracking Information System (ITIS) and the event is verified by SCADA logs provided by the SCADA engineers to help ensure that they indeed operate as expected.

2.3.1. Example 1: EVENT #6

A defective cable fault led to the circuit breaker to trip and lock out. As a result, an outage occurred resulting in losing 4493 customers on the feeder. Within one minute, the fault was detected and isolated and 4492 customers were restored via a tie point from an adjacent feeder.

The SCADA-Mate switches operated as designed. In this particular case, Feeder Automation helped to improve reliability where one specific customer was isolated and the fault did not affect the rest of the customers along the same feeder. In this particular example, it took approximately another three hours to restore service to that customer.

2.3.2. Example 2: EVENT #10

A pothead cable faulted. Not all the tie points were IntelliTEAM SCADA-Mate switches and therefore, the switches stayed open. The Feeder Automation enabled tie switch did not open due to lack of capacity. As a result, the controller manually closed the tie point to adjacent feeder and restored the rest of the feeder.

This event shows that the switches have the sensing capability to not re-close on the fault and not re-close on an adjacent feeder with no spare capacity.

2.4. Conclusion

Overall, with the results acquired to date, the application and value of Feeder Automation on Toronto Hydro's network has been demonstrated. A business case can be made for further deployments of Feeder Automation schemes.

3 Transformer Monitoring

3.1. Transformer Monitoring Overview

The transformer monitoring program entailed installing monitoring devices with capabilities similar to a residential smart meter on single phase overhead distribution transformers. Since 2009, approximately 5,600 transformer monitors (TMs) have been installed, primarily in the former utility region of North York.

The purpose of this demonstration program was to test the feasibility of a transformer monitoring solution within Toronto Hydro's overhead distribution system. The TMs measure loading on distribution transformers, provide outage monitoring, data for analysis to assist in daily operations, short term and long term system studies.

3.2. Results

After the Grid Solutions Engineering team began weekly monitoring and reporting of data from approximately 2,700 TMs in June 2011, out of twelve heavily overloaded, seven transformers were proactively upgraded and five had secondary connections redistributed to help alleviate overloading. Based on the average time to upgrade an overloaded transformer proactively (74 minutes) vs. the average time to complete a reactive overhead transformer replacement between July 17th and August 7th 2011 (457 minutes), there is an approximate total CMO saving of 100,000 for all the transformers that had work done on them.

The following table provides a list of the transformers that had work done on them during 2011.

TX	Action
1	Secondary load redistributed
2	Upgraded from 50 to 100 kVA
3	Upgraded from 50 to 100 kVA
4	Upgraded from 50 to 100 kVA
5	Secondary load redistributed
6	Secondary load redistributed

7	Upgrade from 50 to 100 kVA
8	Upgrade from 50 to 100 kVA
9	Install new Transformer (TX)on same secondary bus to redistribute load
10	Upgrade from 75 to 100 kVA
11	Secondary load redistributed
12	Upgrade from 75 to 100 kVA

3.2.1. Example TX#1

TM analytics showed that this transformer was up to 80% overloaded. After taking snap meter readings, it was confirmed that both the transformer and the secondary cables were operating above rated capacity. A new TX was installed on the same secondary bus to help alleviate the load on July 21st, 2011. The before and after load profile can be seen below:

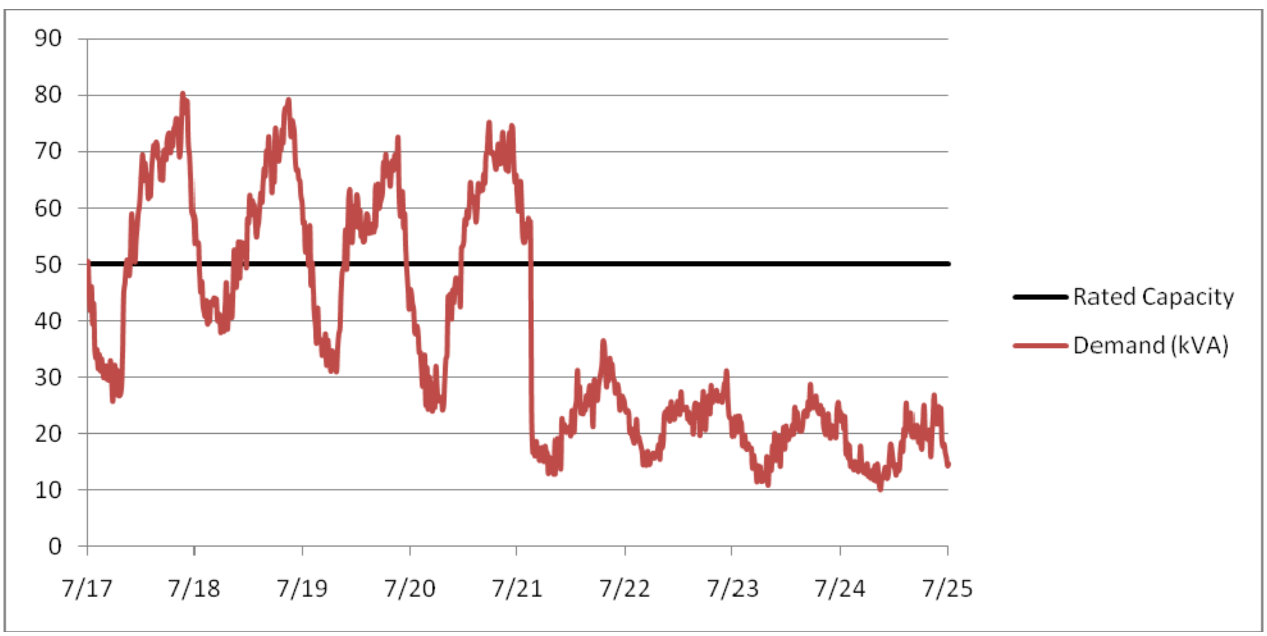

Figure 1 – Load profile of TX#1

3.2.2. Example TX#2

After being identified as a heavily loaded transformer by TM analytics, this transformer was upgraded from 75 kVA to 100 kVA, resulting in an outage of approximately 70 minutes for 31 customers. Had this upgrade not taken place, the peak demand of 128 kVA would have been 171% of the transformer's rated capacity. The before and after load profile can be seen below:

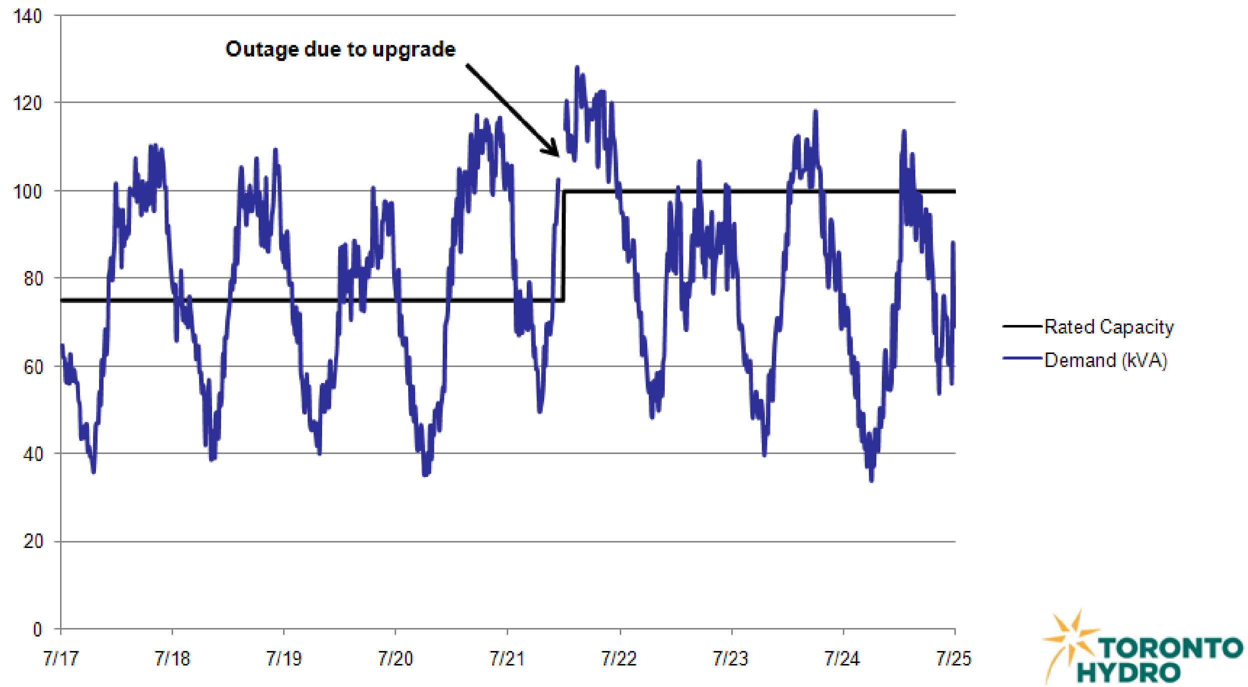

Figure 2 – Load profile of TX#2

3.3. Conclusions

The use of transformer monitor data to identify overloaded transformers prior to failure has enabled proactive work on 12 transformers, saving approximately a total of 100,000 CMO.

4 Power Line Monitoring (PLM)

4.1. PLM Overview

The PLM program entailed installing sensors and aggregators on Toronto Hydro's distribution system. In Q4 2010, PLMs were installed at five locations on one feeder and two locations on another feeder, with each location consisting of one set of three sensors (one per phase) and a data collector/aggregator. PLMs have the ability to monitor the line current, fault current with waveform capture in each phase, the conductor temperature and a measure of the approximate electric field strength. The PLMs at each location are designed to communicate with a local aggregator over Wi-Fi. The aggregators transmit the information over the cellular network to a central location for analysis and reporting using the LightHouse SMS Analytics Software.

4.2. Results

Based on the average time to receive a no power call from a customer after an outage (15 minutes) and the average number of customers on these two feeders (2450 customers), there is a potential for CMO savings of over 550,000 minutes (i.e., potential SAIDI reduction of 0.78). In addition to the savings in CMO, the life span of Toronto Hydro's assets could be prolonged as the operator would likely not have to close the breaker multiple times (thereby exposing the equipment downstream to high fault currents)

to sectionalize a fault. The information from the PLMs could be used to locate a fault between 2 PLMs locations.
The following table outlines outage-related events that were reported by the PLMs in 2011:

Event	Fault Type
1	Squirrel contact
2	Blown fuse and arrestor
3	Pole on fire
4	Blown fuse and tracking inside a vault
5	Tree contact
6	Animal contact
7	Lightning
8	Tree contact
9	Cause unknown
10	Tree contact
11	Breaker auto-reclosure
12	Defective switch
13	Blown fuse
14	Cause unknown
15	Cable fault

In addition to the above, PLMs also helped to detect line disturbances that were not related to an outage. These disturbances can be directly correlated to power quality events or vegetation management issues on the feeder.

4.3. Detailed explanation of two events

The potential for reduction in reliability index SAIDI is calculated by using CMO saved over the total number of customers. The report is generated first by the operator through ITIS and the event is verified by comparing it to the PLM event logs.

4.3.1. Example Event #1

From ITIS incident, the feeder experienced an auto-reclosure interrupting 3,315 customers. Subsequently, no power calls were received indicating power out. Crews were dispatched and found 40 customers permanently interrupted due to a blown fuse caused by permanent tree contact.
The initial tree contact event was captured by PLMs at all locations on the feeder. By analyzing the waveforms, it could be immediately determined that the fault originated between PLM location 3 and PLM location 4. If a crew was immediately dispatched to patrol the area, rather than having to wait for no power calls, the tree limb would likely have been located approximately 20 minutes earlier, resulting

in a CMO saving of 40*20 = 800. The waveforms for the event as reported by the PLMs are shown below:

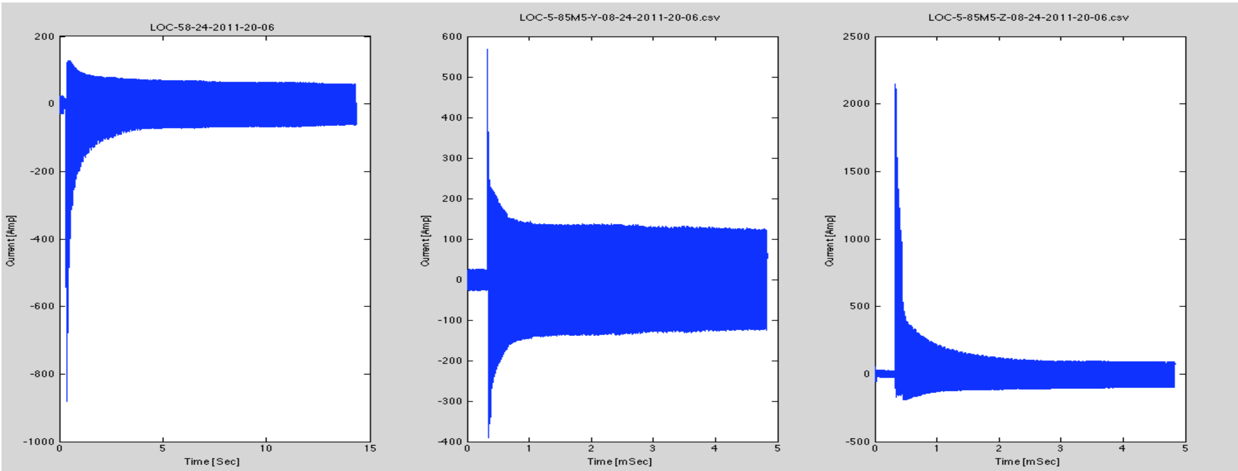

Figure 3 – Event waveform capture by PLMs

4.3.2. Example Event #2

An auto-reclosure event was experienced based on ITIS, interrupting 1,833 customers. No power calls were received at the time. Crews were dispatched and the switch was replaced and closed, restoring power to 14 customers.
The initial event was captured by PLMs at both location 1 and location 2. By using PLM data to ascertain that the event occurred downstream of location 2, crews could have been dispatched to patrol the feeder, saving potentially 19 minutes from the start of the outage to the first no power call, a potential CMO saving of 19*14 = 266. The waveforms for the event as reported by the PLMs are shown below:

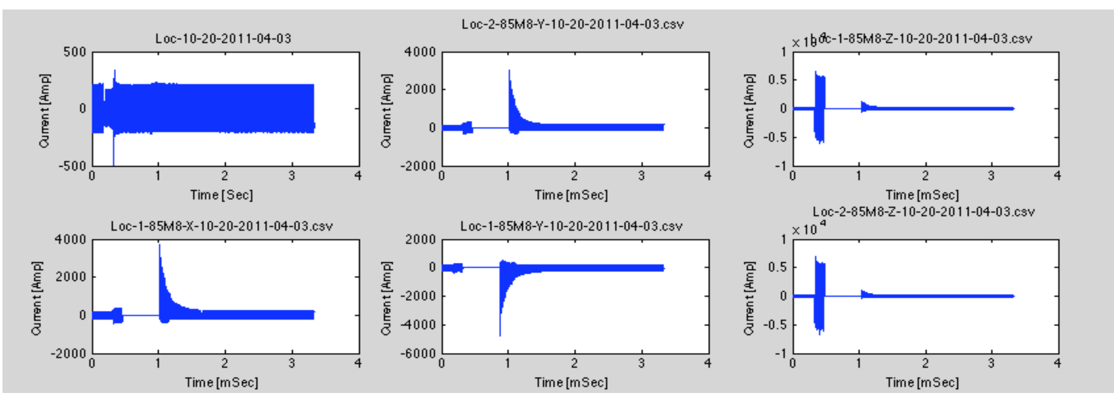

Figure 4 – Event waveform capture by PLMs

4.4. Conclusion

The concept of PLM has been demonstrated. During the course of the pilot project, the PLM system helped to capture all the events that were reported in the ITIS system. In addition, it helped to capture the fault locations of the events. The potential for improvements in reliability indices by dispatching a crew based on event notification by the PLMs versus no power calls from the customers has been demonstrated.

5 Network Automation

5.1. Network Automation Overview

Due to the complexity of the network secondary system, when the network system is under contingency, it can be difficult for operators to know which areas in the network system are overloaded or experiencing troubles. Due to the nature of the secondary cables being tied together, some network units may be overloaded over others. The initial driver for Network Automation was to help give visibility into the conditions in the vault as a method for mitigating the risks described above and also to help aid the control room operators with tools to be able to trouble shoot problematic network vaults.

Phase One of the project focused on introducing monitoring capabilities into the underground network system. It helps to provide real-time loading, protector status information, transformer and vault condition monitoring information. The information is brought back over secure fibre connection through SCADA into the Control Room. In addition, it helps to provide the ability to remotely Block (Trip)/Unblock (Auto-Close) the protector i.e., the operators would likely be able to force the protector open and enable automatic reclose of the protector with ability to override to open with the manual operation of the protector handle. Alarms are generated in the control room when one of the parameters exceeds its pre-defined set-points.

A screen-shot of the SCADA screen available to the operators is shown below:

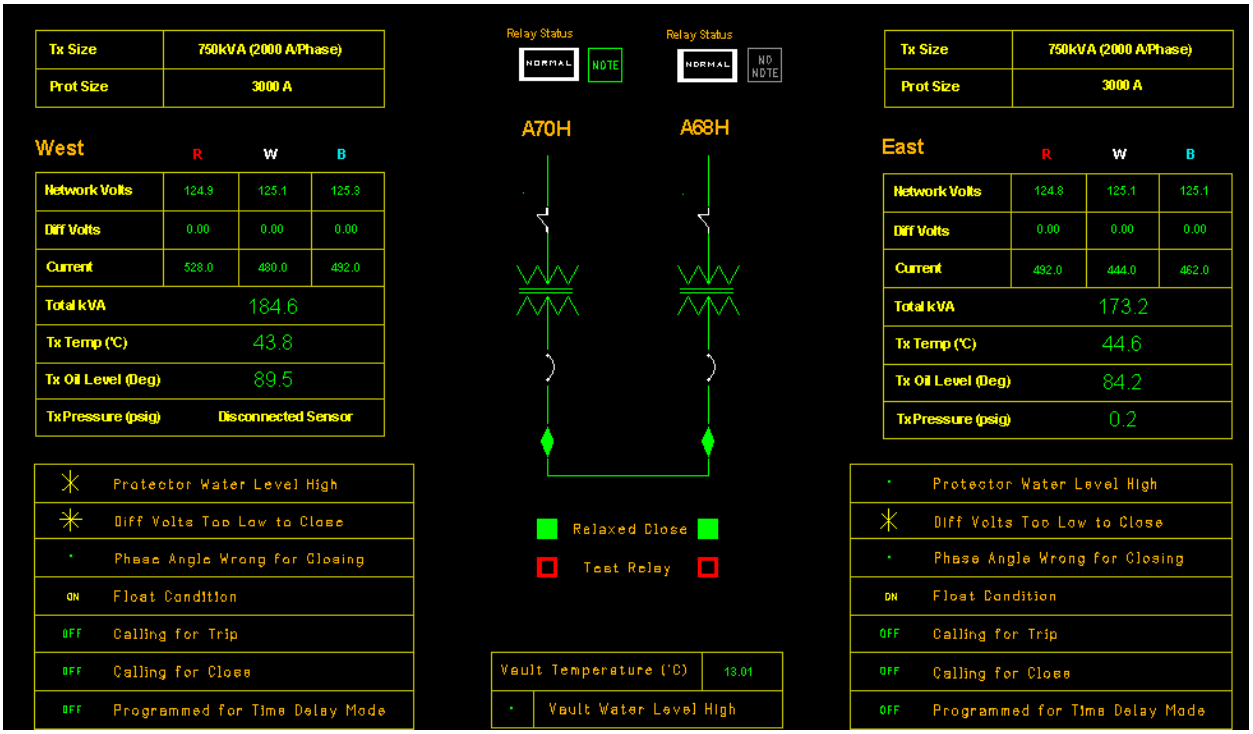

Figure 5 - Control Room SCADA Screen for Network Automation

5.2. Results

Only one event was triggered in the control room for Network Automation. See following table.

Event	Fault Type	Location	Notes
1	Oil level sensor alarm activated	V4716	Trouble crew was dispatched, expecting a low oil level in one transformer, and found that the transformer had sufficient oil. Faulty sensor is suspected.

5.3. Conclusion

Installation of Network Automation equipment in a vault could allow the operator to remotely monitor the conditions of the transformer and the vault in real-time.

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REVIEW OF
COMMUNITY ENERGY STORAGE

Presented to

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ACRONYMS& ABBREVIATIONS USED

The following acronyms are used in the report. This list excludes some terms used in equations and equipment specifications in Appendices or acronyms which are only used once.

AC	Alternating Current
AEP	American Electric Power (US utility)
ARRA	American Recovery and Reinvestment Act
BMS	Battery Management System
CAES	Compressed Air Energy Storage
C	Celsius
CES	Community Energy Storage (see also ES) *In this report CES is used to refer to a system of energy storage technologies located within a distribution system, more fully defined in section 3.*
CSA	Canadian Standards Association
CT	Current Transformer
D	Depth
DC	Direct Current
DCL	Discharge Current Limit
DESS	Distributed Energy Storage
DLC	Double Layer Capacitors
DMS	Demand Management System
DNP3	Distributed Network Protocol 3
DOD	Depth of Discharge
DOE	Department of Energy
DPDT	Double Pole Double Throw
EMI	Electromagnetic Interference
ES	Energy Storage (see also CES) *In this report ES is used as a generic term to refer to energy storage systems.*
ESA	Electricity Storage Association
FFS	Fundamental Frequency Switching
FRT	Fault Ride Through
GOOSE	Generic Object Oriented Substation Event
H	Height
HEV	Hybrid Electric Vehicle
HMI	Human Machine Interface
Hz	Hertz
IEC	International Electrotechnical Commission

IED	Intelligent Electronic Device
IEEE	Institute of Electrical and Electronics Engineers
IGT	Insulated Gate Bipolar Transistor
IT-II	IntelliteamII® (S&C Electric)
kVA	Kilovolt Ampere
kVAR	kiloVAR – kiloVolt Ampere Reactance
kW	Kilowatt
KWh	Kilowatt hours
LDC	Line Drop Compensator
LFP	Lithium iron phosphate battery (lithium ion battery using LiFeP04 cathode)
Li ion	Lithium Ion
LVRT	Low Voltage Ride Through
MATLAB	Matrix Laboratory (modelling software)
MS	Municipal Sub-station
MVA	Mega Volt Ampere
NaS	Sodium Sulphur
Navigant	Navigant Consulting, Inc.
NEMA	National Electrical Manufacturers Association
NiCd	Nickel cadmium
NiMH	Nickel-metal Hydride
NPT	National Pipe Thread Taper
NREL	National Renewable Energy Laboratory
OE	Office of Electricity Delivery and Energy Reliability
P&C	Protection and Control
PbA	Lead Acid
PbC	Carbon modified Lead Acid
PCC	Point of Common Connection
PCS	Power Conversion System
PEV	Plug- in Electric Vehicle
PHEV	Plug- in Hybrid Electric Vehicle
PHS	Pumped Hydro Storage
PSO	Particle Swarm Optimization
PT	Potential Transformer
p.u.	Per unit
PTP	Peer-to-Peer
PV	Photovoltaic
PWM	Pulse Wave Modulation
Q	Reactive Power (VAR)

R&D	Research and Development
RDSI	Renewable and Distributed Systems Integration
Redox	oxidation-reduction
RFP	Request for Proposals
RMS	Root Mean Squares (or Root of the Mean of the Squares)
SCADA	System Control and Data Acquisition
Sec	Seconds
SGD	Smart Grid Demonstration
SMES	Super Magnetic Energy Storage
SNC	Sodium-nickel Chloride
SOH	State Of Health
STATCOM	Static Synchronous Compensator
SWC	Surge Withstand Capability
THD	Total Harmonic Distortion
THESL	Toronto Hydro Electric System Ltd.
ULc	Underwriters Laboratories (Canadian approval)
UPS	Uninterruptible Power Supply
US	United States
V	Volts
VAR	Volt Ampere Reactive
VR	Vanadium Redox
VRLA	Valve-regulated Lead Acid
W	Width
WHMIS	Workplace Hazardous Materials Information System
ZnBr	Zinc Bromide

EXECUTIVE SUMMARY

Navigant Consulting Inc., (Navigant) and Kinectrics were retained to assess and compare the capabilities of available technologies to meet Toronto Hydro Electric System Ltd.'s (THESL's) objectives for an Energy Storage (ES) System, as indicated in the RFP 10P-096. THESL's four key objectives for the study include:

1. Buffer intermittency of supply and demand, for levelling system load curve,
2. Enhance asset utilisation by providing peak shaving, valley filling, and phase balancing services,
3. System loss reduction and volt/VAR optimisation, and
4. Mitigate power quality issues, including voltage regulation, sags, swells, dips, spikes, and eliminate system harmonics, by providing distribution static compensation (STATCOM) or similar capabilities.

The objectives listed above represent THESL's key ES applications and these are the main focus of this report. THESL has indicated that it also seeks to explore ES options to meet two additional objectives (5 & 6 listed below).

5. Provide up to two minutes of backup power for distribution feeders, and
6. Function in a micro-grid configuration.

The latter two objectives were assessed on a qualitative basis.

Kinectrics focused on the front-end electronics including the power conversion system (PCS) and communications for control and deployment of the stored energy into THESL's distribution system. Navigant Consulting concentrated on the matching suitable energy storage mediums to THESL's application needs.

In order to determine the most appropriate ES technologies to satisfy each objective, Navigant developed a set of "optimal" storage system characteristics associated with each Objective presented in Table ES-1. Functions in a micro-grid configuration are discussed separately, given that a micro-grid configuration can vary and thus requires different operational characteristics from an ES system.

Navigant collected both primary and secondary information on the storage technologies of interest to THESL. In order to conduct the analysis and develop recommendations, Navigant also conducted an ES industry survey. This survey focused on the characteristics of interest to THESL as outlined in the scope of work, and the results are presented in the report. Company profiles for some suppliers of utility ES systems are provided in Appendix A. Results of the survey are provided in Appendix B and contacts are provided in Appendix D.

Table ES-1. ES System Characteristics Required for Each Objective

Objective	Characteristic	Description
Objective 1a: Buffer PV Intermittency	Capacity	1-2 MW at top of feeder given that inter-hour perturbations are likely to be 1-2 MW or less
	Energy	Up to 1 hour of discharge (majority < 10 minutes)
	Response Time	< 1 minute
Objective 1b: Buffer PEV Intermittency	Capacity	1-2 MW at top of feeder given that inter-hour perturbations are likely to be 1-2 MW or less
	Energy	Up to 4 hours of discharge with 1-2 hours peak
	Response Time	10-30 minutes (4 hours of charging time)
	Other	Issues expected to be downstream on laterals. Assume 250kW on single phase lateral with about 1 ES unit per 200 homes.
Objective 2a: Peak Shaving & Valley Filing	Capacity	2-8 MW at feeder level (4 MW for 13.8kV; 8 MW for 27.6kV), proportionately lower if located on lateral.
	Energy	Depending on the feeder, 2-8 hours of discharge may be required
	Response Time	~ 10 minutes. Intermittent output is not a factor.
	Other	Device efficiency is critical as charging losses may outweigh benefits.
Objective 2b: Phase Balancing	Capacity	Up to 750 kW system
	Energy	Potentially 1-8 hours because the load changes of an individual feeder can vary significantly
	Response Time	Minutes. Response time and ability to follow load are similar to those required for Objective 1.
	Other	Device should be single-phase, with either 3 single phase devices or 1 single phase device on 'weak' phase.
Objective 3: Volt/VAR Optimization	Capacity	2-8 MW (4 MW for 13.8kV; 8 MW for 27.6kV)
	Energy	Discharge duration required is 2-8 hours, minimum
	Response Time	~ 10 minutes
	Other	Inverter specification is critical because it must be able to inject at any phase angle.
Objective 4: Mitigate PQ	Capacity	1-4 MW (on single phase lateral could be 1 MW but expect <750kV in most cases). Depends on type of perturbation.
	Energy	Discharge time of 10 seconds to 10 minutes with a much greater emphasis on the seconds time-frame.
	Response Time	Response time of sub seconds (cycles) is required. Key concern is sag mitigation but system can help other PQ issues.
Objective 5: Backup Power for Feeder	Capacity	5-20 MW (up to 10 MW for 13.8kV; 20 MW for 27.6kV)
	Energy	Discharge time of ≤2 minutes expected (though feeder reclosing sequence could take up to 5 minutes in the future with smart grid)
	Response Time	Response time of sub-seconds. Very high ramping capability is required if used for outage back-up.
	Other	High power/short duration. Re-closure carry through is key event of concern.

**Capacity levels shown are for storage located on a 27.6 kV feeder. Capacity requirements would be lower if located downstream and greater if located at the MS.*

The ES options addressed in our review include[1]:

- Battery,
- Ultracapacitor, and,
- Flywheel.

The main focus of the analysis was on battery storage technologies with an emphasis on the following battery types:

- Lead acid: wet-cell and dry-cell,
- Sodium-based: sodium sulphur (NaS), sodium metal (e.g., sodium nickel chloride ($NaNiCl_2$)),
- Nickel-based: nickel cadmium (NiCd), nickel-metal hydride (NiMH),
- Lithium-based: lithium-ion , lithium-ion polymer,
- Flow batteries.

Each of these technologies is described in the body of the report.

In order to evaluate ES technologies against the 6 objectives, each ES technology was rated on a scale of "1", "4", "7" or "10" (with a score of 10 representing the best score) for six system characteristics including:

- Power (kW),
- Energy (kWh),
- Response time (seconds or minutes),
- Cycle life (cycles),
- Volume energy density (kWh/m^3),
- Temperature tolerance (°C).

These characteristics were considered when determining the most appropriate technologies for each objective. Figure 1 ES-1 illustrates the ES technology fit for each of the objectives described above. Navigant applied equal weights to each objective to obtain the overall fit results, shown in Figure ES-2. Flow batteries have a relatively high technology fit rating but are less commercially developed than NaS or Li Ion; though a number of small ZnBr batteries are being installed in Australia and larger flow batteries are being demonstrated in the U.S. through the ARRA Smart Grid Demonstration program (described in section 3).

[1]Super-magnetic energy storage (SMES) was initially considered, but removed as a viable option due to unavailability over the short- to mid-term

Figure ES-1. ES Technology Fit for THESL Objectives

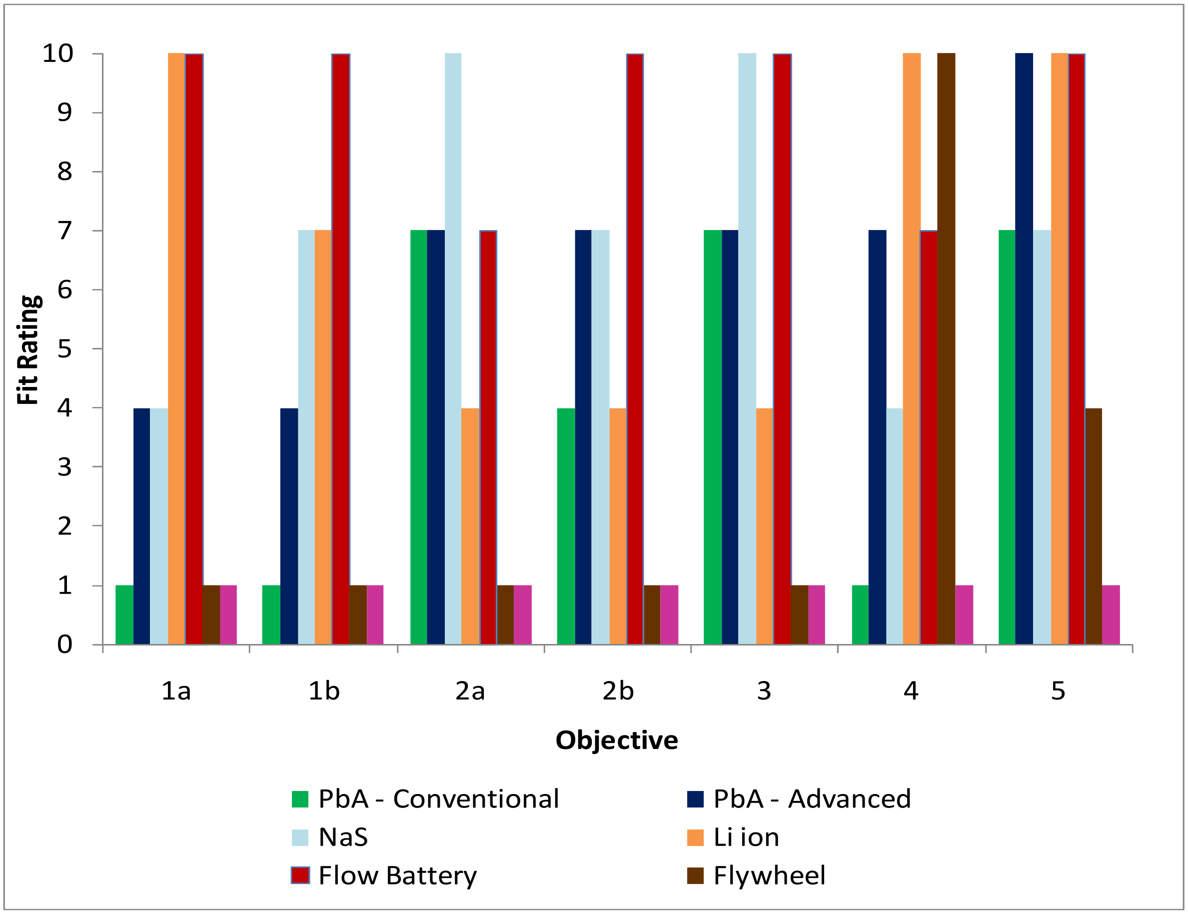
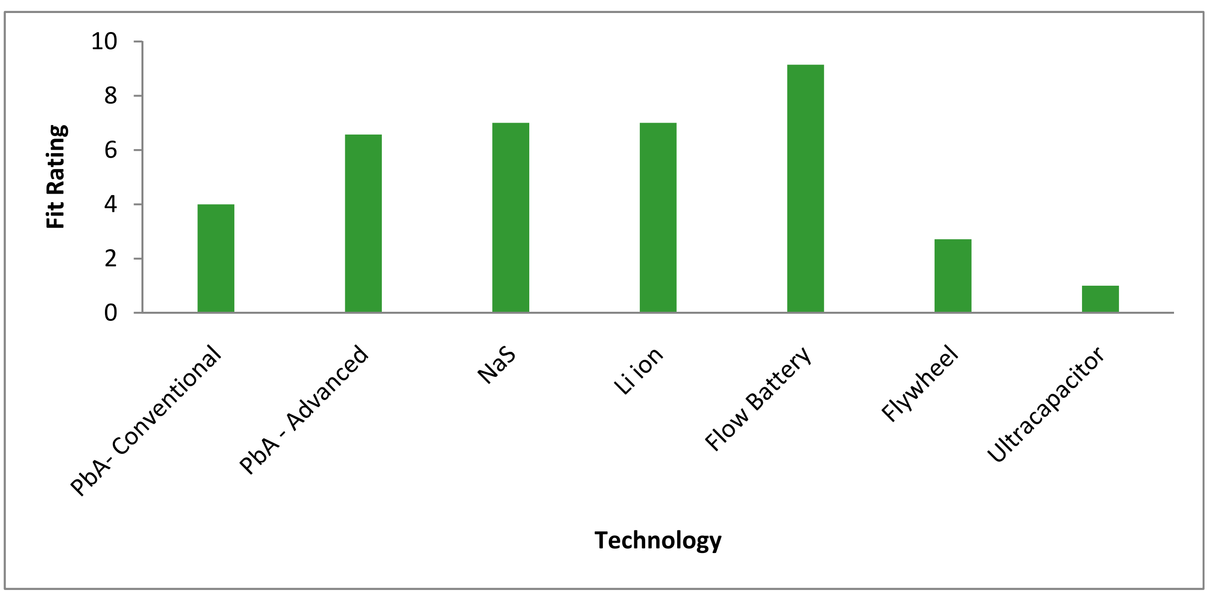


Figure ES-2. Overall ES Technology Fit



CES development in the USA, led by American Electric Power (AEP), is a major driver for pilots at the residential level. AEP has produced a set of open source functional specification CES documents for both the storage unit and control hub (Ref. -11 and -12). US DOE sponsored pilots[2] are presently being rolled out to evaluate CES based on these functional specifications.

AEP's definition of CES is small distributed energy storage (25 kVA) connected on the secondary of a transformer serving a few houses or small commercial loads. AEP's CES would be sized to sit next to or in close proximity to curbside padmount or pole top transformers in neighborhoods and therefore are limited by power output and storage capacity. By contrast, THESL prefers to scale up its ES to higher power and storage capacity (i.e. ≥ 250 kVA) concentrating on serving laterals supplying 20-30 customers. In the THESL system the average load per customer is about 5 kVA and the most common transformers are 100 and 167 kVA. THESL's approach will result in fewer installations to achieve the same net effect on the distribution system. Advantages and disadvantages to both approaches are discussed in Section 3.

In spite of the number of electric utility storage installations either existing or planned, THESL's concept has uniqueness that cannot easily capitalize on others' experience. Congestion of the aging infrastructure coupled with micro-fit and larger DG on THESL's distribution system require innovative custom solutions to ensure system stability is maintained in future. The size of the proposed ES solutions is a departure from the AEP vision of small neighbourhood CES in favour of larger installations serving lateral feeders. At this time, no off the shelf product exists to meet THESL's unique application needs. Therefore, custom built, designed to order equipment is required. To ensure this equipment is suitable, pilot installations are needed to identify any risks or other issues such that corrective action can be taken prior to wide scale deployment.

The functional specification developed by AEP does provide some insight into a product that may eventually become commercialized. The specification is a work in progress and may be further enhanced in future revisions. At this time, the functionality is limited to peak shaving, power factor correction and islanding during brief service interruptions. Other possible functions including those listed in THESL's objectives are acknowledged in the documents but are not considered a priority at this time.

Based on the pilot demonstrations that are currently underway in the US and analysis and demonstrations of power line disturbance mitigating equipment, it is conceivably possible to design and construct an ES platform that meets THESL's objectives using components available today. Assembling the hardware will be less of a challenge than developing the control software. It is highly likely this is the reasoning why AEP chose to limit the functionality of its CES to the following grid and local functions (Ref.-11):

---

[2] US DOE has committed $185 Million to energy storage from a $600 Million l Smart Grid fund.

Grid functions:

1. Serve as a load levelling, peak shaving device at the station level.
2. Serve as a power factor correction device at the station level (VAR support).
3. Be available for ancillary services through further aggregation at the grid level.

Local functions:

1. Serve as backup power for the houses connected locally.
2. Serve as local voltage control.
3. Provide efficient, convenient integration with renewable resources.

Load following during normal operation, precise voltage control or power quality functions are not part of the present requirement.

Equipment manufacturers are presently constructing CES units to utility / AEP specifications. Should the present 25 kW size fit in THESL's future plans, THESL may wish to purchase one or more of these developmental units to evaluate for its pilots. There are advantages to this approach as less risk and time are incurred.

There will be a level of risk associated with the newer battery technologies used in this application. Very little physical data exists beyond computer simulations. Although extensive modelling has been performed, real world experience is lacking. Large scale (≥1 MVA, 7.2 MWh) battery storage in transformer and distribution stations has performed well according to user reports. However penetration levels in North America have remained fairly modest.

For THESL's objectives load leveling and peak shaving will pose the greatest challenge for dispatch and control strategies. However, fine tuning the STATCOM to THESL's application may require some iteration to optimize the settings. The real challenge lies in designing a controller which can balance and prioritize its various functions when faced with dynamic power line conditions.

Effective mitigation of voltage sags using STATCOM requires careful sizing and placement. Effectiveness on a THESL feeder will depend on the circuit impedance.

The following basic steps are viewed as the path to establishing an ES pilot within THESL's service territory:

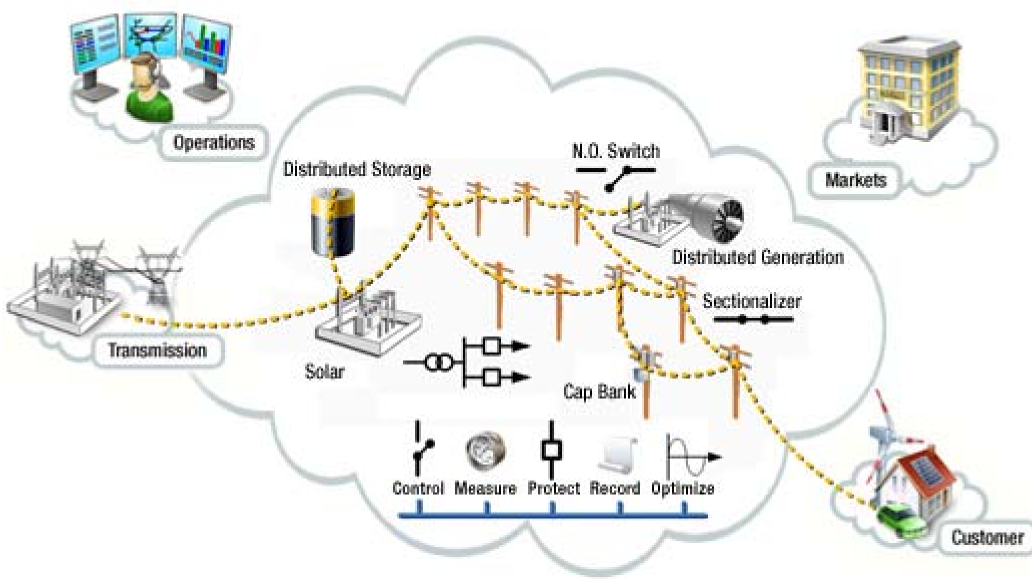
1. Identify a candidate feeder which would benefit from an ES.
2. Determine an ES size/capacity to meet the need of the candidate feeder.
3. Develop functionality requirements to meet THESL's needs.
4. Secure a suitable site on the feeder for installing the ES preferably as close to the load as practical.
5. Choose a suitable storage technology with power/energy capacity to meet THESL's objectives.
6. Select a PCS supplier to develop and build a prototype ES to meet THESL's requirements.
7. Work with the PCS supplier to interface controls between the ES and THESL Dispatch Centre.
8. Specify acceptance tests to ensure ES unit meets the performance specification.
9. Install and commission ES.
10. Monitor performance and adjust control parameters as needed to refine functionality.

Based on discussions with THESL a draft purchasing specification was developed for a 500 kVA ES. A detailed specification is presented in Appendix H.

1. INTRODUCTION

The concept of CES is relatively new. CES is defined as a packaged solution for storing energy for use at a later time. The energy is typically stored in batteries for specific energy demands. CES differs from other electric utility storage as it is installed closer to the customer load on the distribution system Figure 1. A CES is comprised of a number of main components consisting of the storage device (i.e. battery), a battery management system (BMS) to optimise battery health, an inverter to convert DC to AC and a controller. Real world experience is very limited and available technologies are changing rapidly. This includes user experience with the commercial battery technologies.

Figure 1. Energy Storage in a Distribution System[3]



Navigant Consulting Inc., (Navigant) and Kinectrics were retained to assess and compare the capabilities of available technologies to meet Toronto Hydro Electric System Ltd.'s (THESL's) objectives for an Energy Storage (ES) System, as indicated in the RFP. THESL's four key objectives include:

1. Buffer intermittency of supply and demand, for levelling system load curve.
2. Enhance asset utilisation by providing peak shaving, valley filing, and phase balancing services.

[3] IEEE SMARTGRID - Distribution

3. System loss reduction and volt/VAR optimisation.
4. Mitigate power quality issues, including voltage regulation, sags, swells, dips, spikes, and eliminating of system harmonics, by providing distribution static compensation (STATCOM) or similar capabilities.

The objectives listed above represent THESL's key objectives and will be the main focus of this report. THESL has indicated that it wishes to explore the option of preparing storage units to meet two additional objectives (5 & 6 listed below).

5. Provide up to two minutes of backup power for the feeder.
6. Function in a micro-grid configuration.

As per the RFP, this review addressed a number of storage options, including:

- Battery,
- Ultracapacitor,
- Flywheel, and,
- Super-magnetic energy storage (SMES).

As noted earlier, SMES was removed as a viable option due to unavailability over the short- to mid-term. The study focused on battery storage technologies including:

- Lead acid: wet-cell and dry-cell,
- Sodium-based: sodium sulphur (NaS), sodium metal (NaMX),
- Nickel-based: nickel cadmium (NiCd), nickel-metal hydride (NiMH),
- Lithium-based: lithium-ion and lithium-ion polymer. It should be noted that the discussion of Li-ion in this report are also applicable to Li-polymer,
- Flow batteries.

Methodology

The approach taken for this study included a literature review, surveys and interviews with equipment manufacturers and contacts with utilities piloting CES.

Consequently, part of the literature review includes papers reporting on proof of concept using computer simulation techniques.

Battery and equipment manufacturer literature were reviewed and analysed to determine the best candidate technologies presently available for CES applications and system suppliers were surveyed and interviewed in order to obtain the most current data available.

Sample THESL feeder data was used to pre-conceptualize an ES providing practical solutions to existing problems.

2. Overview of Energy Storage Technologies

The ability to store electricity to allow its use at a later time or to supply applications during power interruptions has long been a goal of the electric industry. A number of ES technologies are already commercially available or in the demonstration phase, including:

- Pumped Hydro Storage (PHS),
- Compressed Air Energy Storage (CAES),
- Flywheels,
- Ultracapacitors,
- Batteries,
- Flow Batteries.

Pumped Hydro Storage and the Compressed Air Energy Storage are well established technologies, but are not appropriate for application within THESL's system due to siting requirements and are therefore not included in this review.

Superconducting magnetic energy storage (SMES) was listed as one of the technologies in the RFP for the project. SMES systems, in which energy is stored in a magnetic field of a cryogenically cooled superconducting coil, has been studied to improve power quality in industrial applications. This technology is still in the initial research phase and is therefore not considered further in this report. Promising battery technologies that are still in the research phase include but are not limited to bipolar lead acid batteries and zinc air (or metal air) batteries[4].

Table 1 shows the commercialization status and primary vendors for each technology.

[4] Bipolar lead acid batteries and metal air batteries are not described below given that they are still in the research phase. Bipolar lead acid batteries are being researched by East Penn Manufacturing and Applied Intellectual Capital. Information on metal air batteries can be found on the ESA website: http://www.electricitystorage.org/ESA/technologies .

Table 1. Commercialization Status and Vendors of Energy Storage Technologies

Technology	Status	Primary Vendors
Lead Acid Battery (Conventional and Advanced)	Commercial	• East Penn Manufacturing • Exide Technologies • EnerSys • Xtreme Power • Axion Power
Sodium Sulfur Battery	Commercial	• NGK Insulators Ltd. • POSCO (still in development)
Sodium Metal Battery	Research and Development	• FIAMM • General Electric
Nickel Cadmium Battery	Commercial	• Saft Battery
Nickel Metal Hydride	Commercial	• Saft Battery
Lithium ion Battery	Demonstration& Commercial	• A123 • Saft Battery • Altair Nanotechnologies • International Battery • Electrovaya • Dow Kokam • Valence Tech
Vanadium Redox Flow Battery	Demonstration & Commercial	• Prudent Energy • Ashlawn Energy
Zinc Bromide Flow Battery	Demonstration & Commercial	• ZBB • Premium Power • RedFlow
Flywheel	Demonstration& Commercial	• Beacon Power • Temporal Power • Active Power
Ultracapacitor	Demonstration & Commercial	• Maxwell

ES technologies have different advantages and disadvantages, presented in Table 2 make them appropriate for certain applications. Advantages may include commercial maturity, high cycle life, and low price while disadvantages include lack of commercial experience, toxic materials, high cost, and site constraints.

Table 3 provides a summary of some of the key characteristics of commercially available storage technologies today. In addition to published information, Navigant conducted a survey on ES vendors to collect data as it relates to the storage technologies of interest to the study. Questions targeted those identified in the THESL scope of work for this engagement. Appendix B provides the survey results.

Table 2. Storage System Characteristics

Technology	Cost[5] ($/kWh)	Efficiency (%)	Lifetime (yrs.)	Lifetime (cycles)
PbA(Flooded)	150	70-80	2-4	>1,200
PbA (VRLA)	200	70-80	2-4	>1,200
NaS	450	75-80	12-15	>2,500
NiCd	600	60-65	>10	>3,000
Li ion	1,333	86-93	7-10	>16,000
ZnBr	500	70	>20	>2,000
Flywheel (High Speed)	1,000	85-90	20	>100,000
Flywheel (Low Speed)	380	>95	20	>100,000

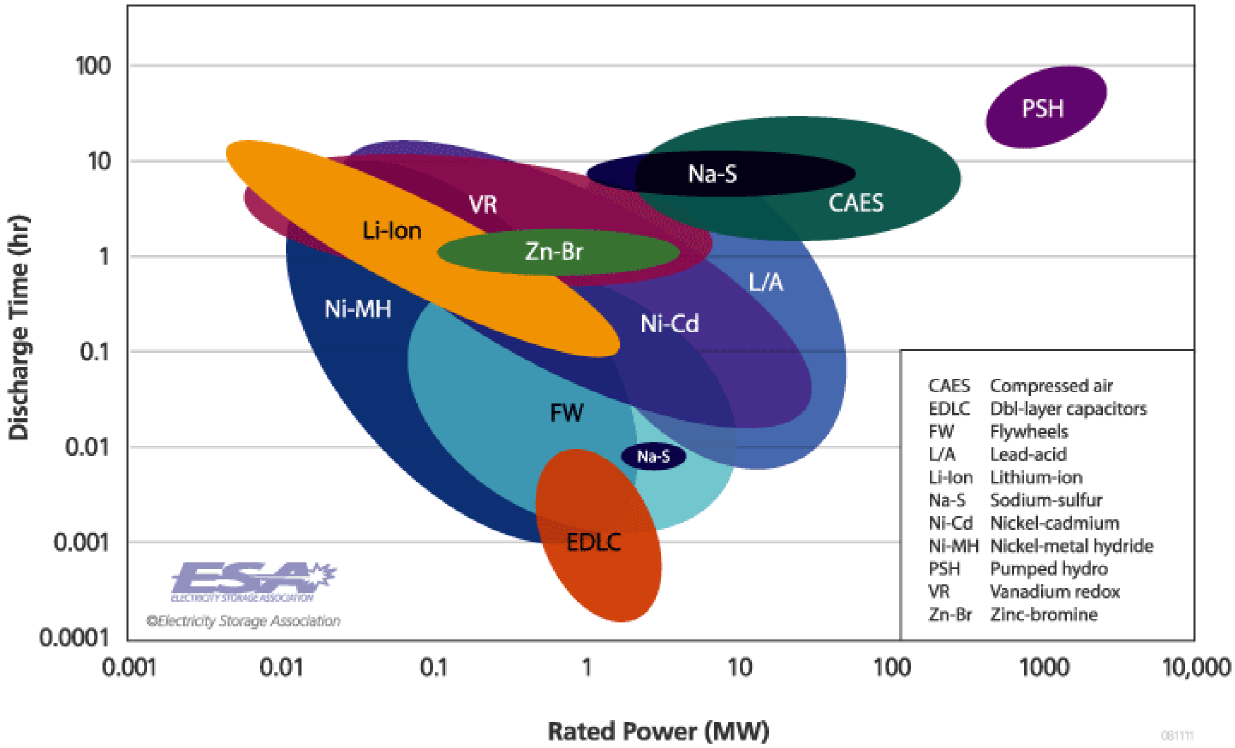
5 Rogers, Brad & Amendola, Steve. Grid Storage Technologies ESA Conference Presentation: "GST's Electrically Rechargeable Zinc Air Battery": May 5, 2010.

Table 3. Advantages and Disadvantages of ES Technologies

Technology	Power	Energy	Advantages	Disadvantages	Most Appropriate Functions
PbA (Conv.)	L	M	Mature technology; low cost	Low cycle life; low calendar life; toxic materials	End Use level functions: • Renewable Generation Integrations • Grid Stabilization
PbA (Advanced)	H	H	Higher cycle life vs. conventional PbA	Limited Commercial experience	End Use level functions: • Renewable Generation Integrations
NaS	H	H	Commercial experience	High operating temp.; High relative cost	Distribution level functions: • Renewable Generation Integration • Peak Load Shifting
NaMx	M	H	High cycle life, energy density, ambient temperature tolerance	Limited Commercial experience	End Use level functions • Grid Stabilization
NiCd	M	M	Commercial experience	Toxic materials, large footprint	End Use level functions: • Renewable Generation Integrations • Grid Stabilization
Li ion	M	L	Large potential market to reduce price	Demonstration experience only	End Use level functions: • Renewable Generation Integrations • Grid Stabilization
VR	H	H	High cycle life at any depth of discharge	1 Unit can only be scaled to 10MW due to battery chemistry	Distribution level functions: • Renewable Generation Integration • Peak Load Shifting
ZnBr	H	H	High cycle life at any depth of discharge	Demonstration experience only	Distribution level functions: • Renewable Generation Integration • Peak Load Shifting
Flywheel	H	L	High cycle life	High speed flywheels are expensive and have limited commercial experience	Bulk, transmission level functions: • Grid Operational Support End Use level functions: • Grid Stabilization
Ultra-capacitor	H	L	Mature tech.; high cycle life	Limited applications due to energy	End Use level functions: • Grid Stabilization

Note: L=Low, M= Medium, H= High

Figure 2. ES - Power & Energy



The following pages review the technology characteristics, the status of product development and the key industrial players leading the development of the following ES technologies:

- Flywheel,
- Ultracapacitor,
- Sodium Sulphur (NaS) Battery,
- Sodium metal,
- Zinc Bromide (ZnBr) Flow Battery,
- Vanadium Redox (VR) Flow Battery,
- Nickel Cadmium (NiCd) Battery,
- Nickel Metal Hydride (NiMH),
- Lithium Ion (Li ion) Battery,
- Lead Acid (PbA) Battery.

In addition a short discussion of inverter suppliers has been included.

Flywheel

Flywheels store energy in a rotating mass and release it over a very short amount of time. A flywheel ES system draws electrical energy from a primary source such as the utility grid, and stores it in a high-density rotating flywheel. The flywheel system, often referred to as a kinetic, or mechanical, battery spins a mass at very high speeds to store energy that is instantly available when needed (see Figure 3). Upon power loss, the motor driving the flywheel acts as a generator. As the flywheel continues to rotate, the generator supplies power to the customer load.

There are two major categories of flywheel ES systems:

- low-speed systems (<10,000 RPMs) and,
- high-speed systems (>30,000 RPMs).

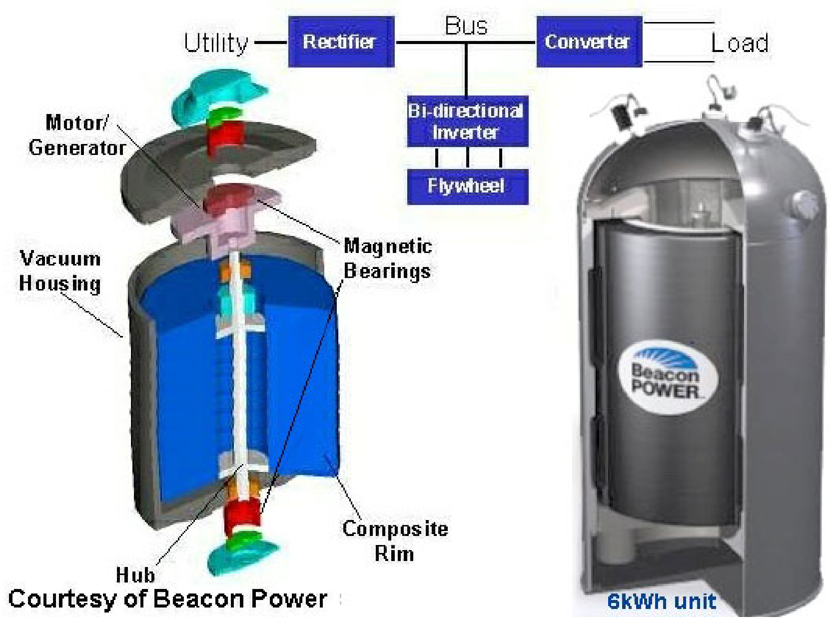
Low-speed systems consist of a high mass flywheel and power electronics to convert between DC and AC voltages. High-speed systems rely on magnetic bearings, vacuum chambers, and permanent magnet motor/generator to provide high efficiency operation and high energy density storage capability.

Despite high cycle life, flywheels are one of the most expensive technologies on a per KW basis. Estimated capital costs for higher energy flywheels are approximately $2,000/kW today. Beacon power, the dominant flywheel provider in the market, has a cost target for its next 20 MW facility of $1,250-1,500/kW[6]. Flywheels that offer lower energy (1 to 10 seconds) have significantly lower costs. Some flywheel products are commercially available but advanced flywheel technologies are still under development. Flywheels are best suited for high power, low energy applications such as frequency regulation and power quality.

Beacon Power and Active Power are leaders in the industry. A third industry leader, Pentadyne, recently sold its assets to Phillips Service Industries. Active Power & Pentadyne (now Phillips) offer lower energy (1 to 10 seconds) flywheel-based power quality technologies commercially available, and Beacon Power offers higher energy (15 minute) utility-scale flywheel systems currently being demonstrated to provide frequency regulation services. The Beacon Power flywheel design includes an integrated system of 100 kW flywheels, interconnected in a matrix to provide ES for utility-grade applications. It is designed to deliver megawatts of power for minutes, providing frequency and voltage regulation capabilities for increased grid reliability. Velkess and Amber Kinetics are two other companies currently researching advanced flywheel systems for utility applications.

[6] 2010 Energy Storage Summit. Presentation by Beacon Power. April 20, 2010.

Figure 3. Flywheel



Source: Electricity Storage Association http://www.electricitystorage.org

Ultracapacitor

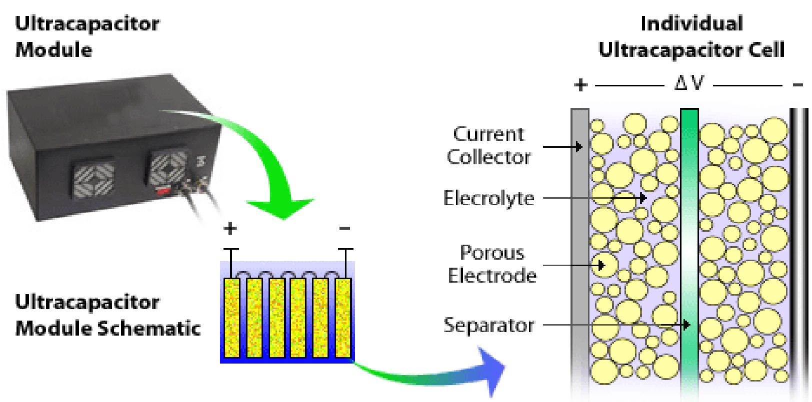
Ultracapacitors (also called ultracapacitors or electrochemical double layer capacitors) polarize an electrolytic solution to store energy electrostatically and release it quickly (see Figure 4). Though it is an electrochemical device, no chemical reactions take place. This mechanism is highly reversible, and allows the ultracapacitor to be charged and discharged hundreds of thousands of times[7]. The amount of energy stored is very large compared to a standard capacitor. However, it stores a much smaller amount of energy than a battery does. Ultracapacitors offer high cycle life and high power density, but their low energy density limits the number of appropriate applications. Ultracapacitors can release energy much more quickly (with more power) than a battery that relies on slow chemical reactions[8]. Ultracapacitors release their stored energy over a very short period of time of roughly 1 to 10 seconds, giving them a high power density but very low energy density. Their cycle life is estimated to be over 500,000 cycles. Since they are inherently low voltage devices, hundreds of cells must be series-connected to meet requirements of a utility application. Failure of just one cell can lead to failure of the entire storage system. While total capital costs in terms of power are in the range of $250/kW to $350/kW, energy costs are extremely high, ranging from $20,000/kWh to $30,000/kWh. Currently, most applications for

[7] NREL: Energy Storage - Ultracapacitors. http://www.nrel.gov/vehiclesandfuels/energystorage/ultracapacitors.html.
[8] NREL: Energy Storage - Ultracapacitors. http://www.nrel.gov/vehiclesandfuels/energystorage/ultracapacitors.html.

Ultracapacitors are focused on transportation, but there are several demonstrations of interest to the utility industry.

The Palmdale water district in California has deployed a Maxwell ultracapacitor system with a capacity of 450 kW for 30 seconds designed to maintain high power quality on protected loads at all times, provide power to protected load in case of utility sag or outage, meet the ITI (CBEMA) [9] curve during power quality events, and re-synchronize with backup power or grid as necessary. Testing and operation began in late 2008. Sacramento Light Rail also uses this storage technology in rail line application with a 1 MW ultracapacitor bank that absorbs braking energy to relieve overloading, reduce voltage sags, and increase train capacity. Testing and operation of that system also began in 2008[10].

Figure 4. Ultracapacitor



Source: NREL: Energy Storage – Ultracapacitors. http://www.nrel.gov/vehiclesandfuels /energystorage/ultracapacitors.html.

Sodium Sulphur (NaS) Battery

The sodium sulphur (NaS) battery, illustrated in Figure 5 consists of a beta alumina conductive ceramic that separates and permits ions to flow between the positive electrode (sulfur) and the negative electrode (sodium). It can be used continuously because of its reversible charging and discharging system. This type of battery is heated to approximately 300°C to reduce the internal

[9] ITI/CBEMA is the Information Technology Association/Computer and Business Equipment Manufacturers Association.

[10] *Evaluating Value Propositions for Four Modular Electricity Storage Demonstrations in California.* Distributed Utility Associates, Inc. 2007

resistance, and requires an installation area that is smaller than that for a flow battery and approximately one third for that of a lead acid battery. The typical efficiency of NaS batteries is 75-80% and the lifetime is 12-15 years with more than 2,500 cycles. NaS batteries are most appropriate for distribution-level functions, such as renewable generation integration and load shifting.

There are currently several demonstration and commercial installations in the U.S. and worldwide, however, NaS batteries remain very expensive on a per kW basis. Scaling of NaS systems is more expensive than scaling of flow batteries, and NaS-based ES projects cost approximately $2,500/kW - 3,000/kW, installed[11]. Given the backlog that NGK Insulators has in orders, the price appears to be increasing instead of decreasing over time.

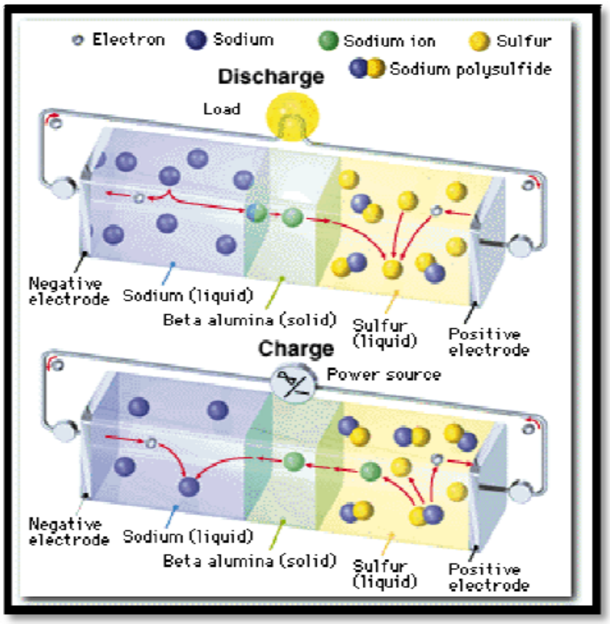
In the 1960's, Ford Motor Company developed the basic NaS principles, and by the 1990's, Ford was using NaS batteries for its electric prototype vehicles. In the 1980's, Tokyo Electric Power Company (TEPCO) began NaS technology development, and by 1998, a Joint R&D with NGK Insulators, Ltd. (NGK) in Japan led to a 6 MW NaS battery system at TEPCO's Ohito Substation[12]. After 50 demonstrations in Japan, NaS batteries were offered for commercial use in Japan in April 2002, with 40 MW produced in 2003 and 65 MW in 2004. In July 2004, the largest NaS to date was installed by TEPCO with a capacity of 9.6 MW (57.6 MWh) project for daily load shifting. In September 2002, American Electric Power (AEP) hosted the first US demonstration of a NaS battery (100 kW, 375 kWh) and by July 2006, AEP began operating a 1MW NaS battery, the first commercial-scale application outside Japan[13]. As of 2008, approximately 200 large-scale demonstrations totaling 270 MW had been installed worldwide. NGK is currently the only vendor of NaS batteries but POSCO, a Korean steel company, has announced plans to begin development of a sodium sulphur battery with commercial production by 2015.

[11] *Installation of the First Distributed Energy Storage System (DESS) at American Electric Power (AEP)*. Sandia Report (SAND2007-3580). June 2007 and personal communication with industry stakeholders.

[12] John Baker (2004): Energy Storage: Potential Technical Options and Development potential; www.dti.gov.uk/energy/sepn/johnbaker.ppt.

[13] ABB press release, September 2002: ABB Power Conditioning System utilized in North America's first-ever power quality/peak shaving sodium-sulfur-based battery system.

Figure 5. Sodium Sulphur (NaS) Battery Mechanism



Source: NGK Insulators, LTD

Sodium Metal Battery

Sodium Metal Halide batteries were initially developed by Zeolite Battery Research Africa (ZEBRA) in Africa in the 1970's. Beta Research and Development of Derby, UK refined the chemistry and constructed manufacturing processes in the 1980's. In 2009, FIAMM formed a joint venture with MES-DEA to promote the "SoNick" battery. In 2007, Beta was acquired by General Electric (GE).

Sodium-Metal-based batteries have primarily been explored for their use in electric vehicles due to their high energy densities, cycle lives and tolerance to ambient temperatures. More recently, a sodium-metal battery product was launched by GE's Energy Storage Technologies – the Durathon – focusing on the UPS backup-power market. GE is opening a new battery manufacturing plant in Schenectady, NY to manufacture the new product and expected to invest $150 M in R&D related to sodium-metal battery applications[14]. Though the first application is expected to be GE's hybrid

[14] "GE Launches Durathon Sodium-Metal Halide Battery for UPS Market." Green Car Congress: 18, May 2010

vehicle[15], the high energy density and long life characteristics of the battery system make it an attractive option relative to lead-acid devices.[16]

Given the emphasis of GE on sodium-metal batteries for UPS and vehicle applications, in the near-term, sodium metal is not expected to be commercially available for utility applications and is not included in the technology screening to meet the THESL objectives.

Zinc Bromide (ZnBr) and Vanadium Redox (VR) Flow Battery

Flow batteries are capable of storing and releasing energy through a reversible electrochemical reaction between two salt solutions (electrolytes). Since they offer power and energy with a high cycle life at any depth of discharge, they are well-suited for moderate power, long discharge duration applications such as load shifting. The capacity of a flow battery is determined by the size of the electrolyte storage tanks, while the power of the system is a function of the size of the cell stacks. At a high-level, the difference between types of flow batteries is the composition of the electrolyte solution used.

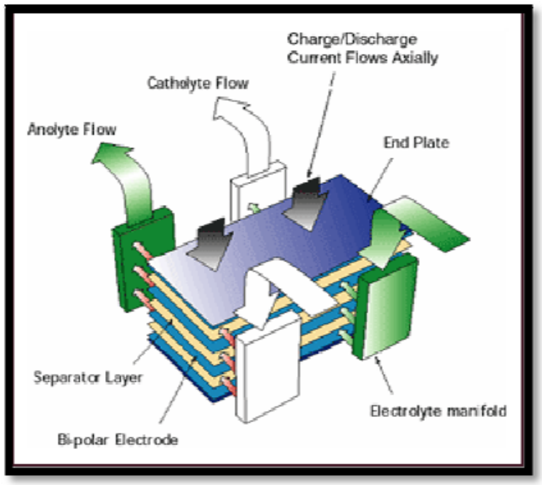
This technology has reached the demonstration stage with some small-scale products commercially available. As of 2008, the worldwide installed capacity for flow batteries was 38 MW (including two existing Regenesys projects). For applications beyond 3 hours, the cost of flow batteries is more attractive than the conventional lead acid batteries by a factor of 2 to 3. Within the next 5 years, flow batteries utilizing Zinc Bromide (ZnBr) or Vanadium Redox technologies will likely become the technology of choice for these applications since costs are expected to be significantly lower than that of NaS batteries.

In the case of ZnBr technologies, Premium Power, ZBB, and Red Flow are the main vendors. All three companies have commercially available small-scale products and are demonstrating several large-scale projects. Prudent Energy is the top industry player for the VR technology however, Ashlawn Energy is currently developing a vanadium redox battery for demonstration. A number of small ZnBr batteries are being installed in Australia and larger flow batteries are now being demonstrated in the U.S. through the ARRA Smart Grid Demonstration program.
Figure 6 illustrates Premium Power's zinc bromide technology.

[15] "GE to Open Sodium-Metal Halide Battery Plant in New York." Green Car Congress: 12 May 2009.

[16] Bourgeois, Richard."SODIUM-METAL HALIDE BATTERIES FOR STATIONARY APPLICATIONS."GE Transportation.

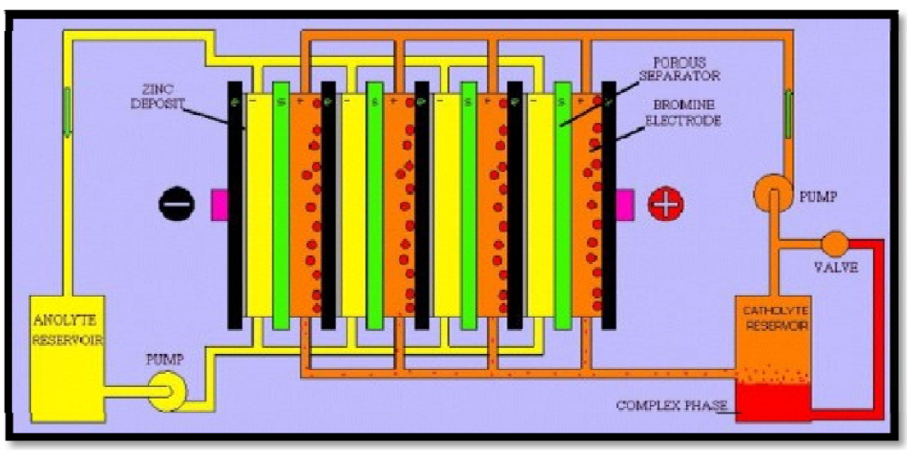
Figure 6. Premium Power's Zinc-Flow® technology



Source: www.PremiumPower.com

As Figure 7 shows, an aqueous solution of zinc bromide is circulated through the compartments of the cell from two separate reservoirs. The electrolyte stream in contact with the positive electrode contains bromide, which is maintained at the desired concentration by equilibrating with a bromide storage medium.

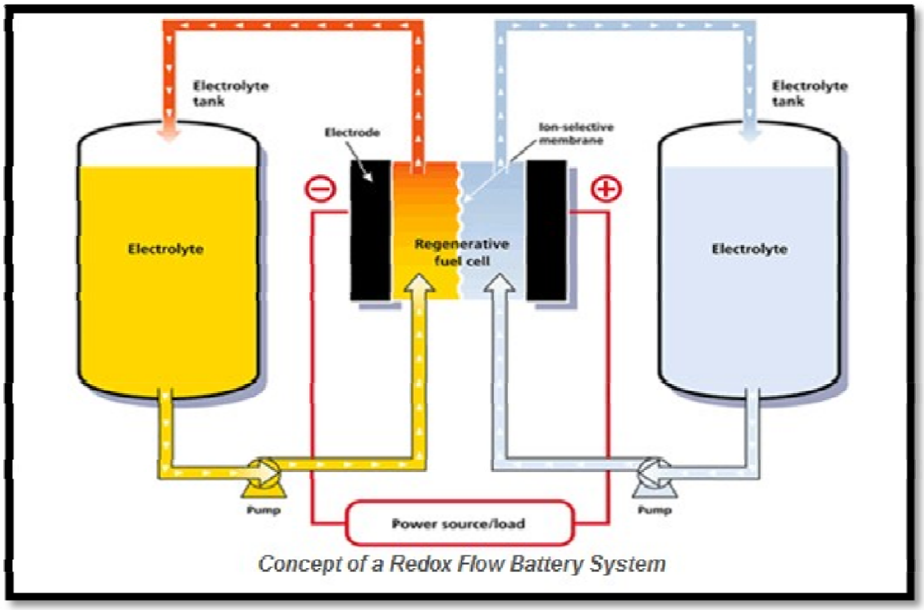
Figure 7. ZBB Zinc Energy Storage System (ZESS)



Source: www.ZBBenergy.com

As Figure 8 illustrates, VR stores energy by employing vanadium redox couples (V2+/V3+ in the negative and V4+/V5+ in the positive half-cells) that is stored in mild sulfuric acid solutions (electrolytes).

Figure 8. Concept of a Vanadium Redox Flow Battery System



Source: www.pdenergy.com

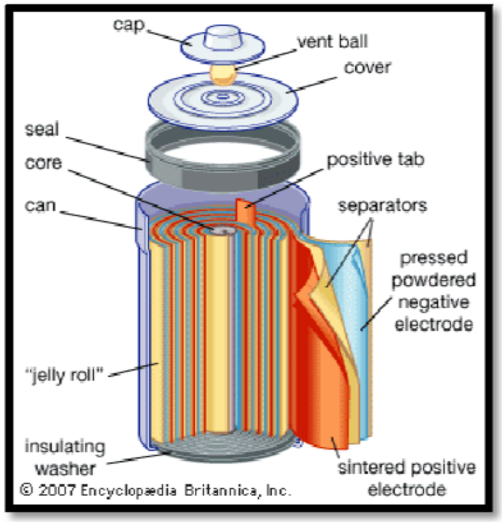
Nickel Cadmium (NiCd) Battery

Nickel cadmium (NiCd) batteries are a relatively mature technology and can easily be built into large systems. A fully charged NiCd cell, as Figure 9 shows, contains a nickel hydroxide positive electrode plate, a cadmium negative electrode plate, a separator, and an alkaline electrolyte (potassium hydroxide). During use, chemical reactions result in the release of electrons. NiCd batteries must be periodically utilized to prevent memory effect. NiCd batteries have significantly higher energy costs than lead acid batteries. In addition, high fixed material costs for NiCd batteries have limited potential for reductions in the future.

NiCd batteries offer a better cycle life, power density, and energy density than lead acid batteries. One successful utility project involving NiCd batteries is the Golden Valley Electrical Association (GVEA) battery ES system located in Fairbanks, Alaska. This system, completed in 2003, provides spinning reserve and voltage support. It is sized to provide 27 MW for 15 min or 46 MW for 5 min.

While the characteristics of the NiCd battery make it ideal for applications including power quality, load leveling, integration and backup of renewables, peak shaving, and transmission stability, the batteries contain cadmium which is toxic. To-date the industry has not developed a viable collection and recycling system. Therefore, the toxicity makes it unlikely to be a major player in these applications. NiCd batteries have achieved some commercial acceptance, but with their chemistry and large footprint, their potential uses are limited.

Figure 9. Nickel Cadmium (NiCd) Battery



Source: http://www.britannica.com

Nickel Metal Hydride (NiMH)

Nickel metal hydride batteries have greater volumetric capacity than Ni-Cd without the environmental liability, but they are more expensive and have a reduced cycle life. The distinction between Ni-Cd and NiMH is the use of a hydrogen-absorbing alloy for the negative electrode in NiMH vs. cadmium in Ni-Cd.

NiMH batteries are currently the battery of choice for power-assisted hybrid electric vehicles but are likely to be displaced by lithium-ion alternatives in the future. The other primary application of the chemistry is personal devices that require AAA and AA batteries. Given the current market focus of NiMH, the chemistry is not considered to be commercially available for utility applications in the near-term and is not included in the technology screening to meet the THESL objectives.

Lithium Ion (Li ion) Battery

Li ion batteries are amongst the newest rechargeable batteries, but within just a few years of their introduction, small Li ion batteries have taken over 50% of the small portable power market, displacing NiMH batteries. The characteristics of the Li ion battery make it ideal for commercial and residential applications including load shifting, photovoltaic integration, and electric vehicles. They are currently undergoing demonstration testing in utility applications.

Energy costs are currently higher than other battery technologies at about $2,000/kWh. However, at high production volumes, the estimated manufacturing cost could be reduced significantly. Li-ion R&D expenditures worldwide are around $1 Billion per year and technological advances may drive the price lower[17]. While relatively expensive on a per kWh basis, Li ion batteries could gain substantial market share if prices can be reduced.

When a lithium ion (Li ion) battery charges, as illustrated in Figure 10, lithium atoms in the cathode become ions and migrate through the electrolyte toward the carbon anode where they combine with external electrons and are deposited in the anode as lithium atoms. The process is reversed during discharge. Lithium ion batteries can have a variety of anode and cathode materials, which impacts the battery energy density and voltage. Lithium Iron Phosphate is considered to be the most mature of the *new* lithium ion chemistries and is being pursued by major storage vendors in the utility-application space, including A123 and International Battery.

In 2007, KEMA successfully tested a Li ion prototype developed by Altairnano Technologies for frequency regulation at a US substation. The system consisted of two 1 MW batteries based on lithium titanate battery cells. Each unit was designed with enough capacity to deliver 1 MW to a 480V electric distribution system for the duration of 15 minutes. Unit efficiency was relatively high, with application efficiencies in the low 90% range.

Developers are currently focusing on electric vehicles as a key target application for more research. This is highly desirable for utilities, as it will help to develop higher energy densities that can store more energy in smaller, lighter packages. Furthermore, Li-ion is currently being developed for use in hybrid electric vehicles (HEVs), which may eventually displace NiMH from its current dominance in this market. In 2008, Sanyo and Volkswagen AG announced that they would develop Li ion batteries for HEVs and hoped to use them by 2010[18].

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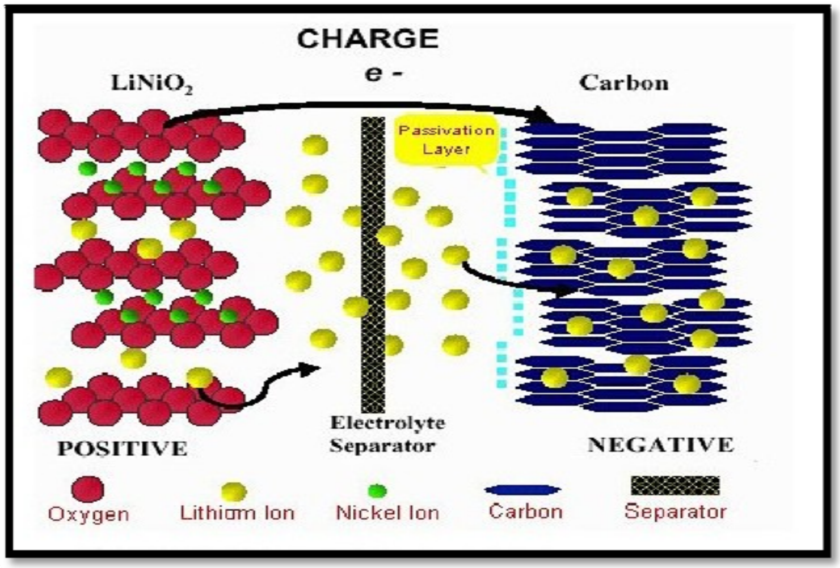
[17] "New Demand for Energy Storage."Electric Perspectives. September/October 2008 edition.

[18] The 2011 VW Touareg Hybrid uses a Sanyo NiMH battery pack. www.insideline.com/volkswagon/touareg/2011/2011-volkswagon-touareg-hybrid-first-drive.html

Figure 10. Li-ion Battery



Source: www.saftbatteries.co

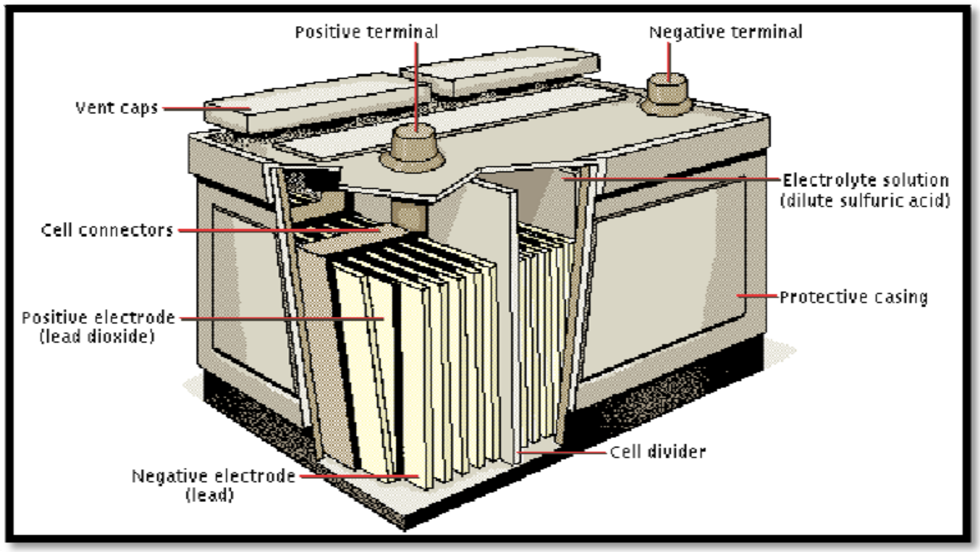
Lead Acid (PbA) Battery

Lead acid (PbA) batteries are one of the oldest and most developed battery technologies for ES and they are one of the most inexpensive battery technologies available. Each cell contains electrodes of lead metal (Pb) and lead dioxide (PbO_2) in an electrolyte of sulfuric acid (H_2SO_4). In the discharged state, both electrodes turn into lead (II) sulfate ($PbSO_4$) and the electrolyte loses its dissolved sulfuric acid and becomes primarily water (see Figure 11). Since PbA batteries contain strong acids and lead, they are environmentally unfriendly. In addition, limitations of the lead-acid chemistry restrict the voltage of a single cell to a little more than 2 volts dc, however, it is possible to produce systems with higher voltage by electrically linking cells in series.

There are two main types of conventional lead acid batteries: flooded lead acid cell and valve-regulated lead acid (VRLA). VRLA has internal gas recombination that minimizes electrolyte loss over the life of the battery and allows for mounting in any position. This technology offers a limited number of full discharge cycles. On the other hand, PbA batteries have relatively low maintenance requirements, no memory effect, and high discharge rates. PbA batteries are relatively inexpensive compared to other battery types. Though less expensive compared with other battery technologies, conventional lead acid batteries are not likely to gain a large share of market for future large-scale ES applications due to the limited number of full discharge cycles, the material toxicity, and the required footprint.

Utility-scale energy management applications for PbA batteries are limited due to the short cycle life, but they may be used for long duration, non-cyclic discharge activities. Several large-scale ES devices have been demonstrated using conventional PbA batteries such as those located in Chino, CA (10 MW), Puerto Rico (20 MW), and Germany (18 MW). There are several large players in the PbA market including East Penn Manufacturing Company, Exide Technologies, and EnerSys.

Figure 11. Lead Acid (PbA) Battery



Source: http://www.reuk.co.uk

Carbon modified lead acid (PbC) or Advanced PbA batteries have recently emerged for utility applications. The advanced device contains a traditional lead-acid battery positive electrode and an activated carbon negative electrode. The research emerged in an effort to improve the performance of lead-acid batteries under conditions similar to those required for hybrid electric vehicle operation (high-rate partial state-of-charge operation). The addition of carbon has shown to slow or prevent negative plate sulfation, which deteriorates battery performance of conventional PbA devices over time.

Technology Characteristics Summary

Table 4 provides a summary of some of the key characteristics of commercially available storage technologies today. The data was collected via interviews with storage technology vendors and other publicly available information.   Profiles of Energy Storage manufacturers are provided in Appendix A. Survey results are presented in Appendix B.

Table 4. Storage System Characteristics

Technology	Cost[19] ($/kWh)	Efficiency (%)	Lifetime (yrs.)	Lifetime (cycles)
ZnBr	500	70	>20	>2,000
NaS	450	75-80	12-15	>2,500
NiCd	600	60-65	>10	>3,000
Li ion	1,333	86-93	7-10	>16,000
PbA(Flooded)	150	70-80	2-4	>1,200
PbA (VRLA)	200	70-80	2-4	>1,200
Flywheel (High Speed)	1,000	85-90	20	>100,000
Flywheel (Low Speed)	380	>95	20	>100,000
Zinc-Air	150	75	30	10,000

Balance of Plant

Although the storage medium is crucial to the ES, the balance of plant including inverter, control system and cabinetry are essential to the feasibility of the concept. The storage medium is akin to the fuel source in an automobile. Continuing with this analogy, the PCS (inverter) is the engine, the controller is the PCM (power control module) and the cabinetry is the chassis. All need to be combined to ensure the ES will perform as expected under a wide range of operating conditions.

A number of companies supply power conversion systems (PCS) and system integration services. The four main suppliers include:

- **S&C Electric** – Founded in Chicago in 1911, S&C Electric Company designs and manufactures switching and protection products for electric power T&D systems worldwide.

- **ABB** – ABB provides power and automation products, systems, solutions, and services. The North America and global headquarters are in Norwalk, Connecticut and Zurich (ABB Group), respectively.

- **Toshiba** – Headquartered in Tokyo with 364 subsidiaries worldwide, Toshiba Corp. manufactures and markets advanced electronic and electrical products, incl. information & communications systems, Internet-based services, electronic components and materials, power systems, industrial and social infrastructure systems, and appliances.

[19] Rogers, Brad & Amendola, Steve. Grid Storage Technologies ESA Conference Presentation: "GST's Electrically Rechargeable Zinc Air Battery": May 5, 2010.

- **Meiden-sha** – Founded in 1897, Meiden-sha is the industrial arm of Sumitomo Group headquartered in Tokyo. Products include Energy (e.g., utility plants, generators, power conversion equipment), Environment (water treatment and waste disposal), Industrial Systems, Information and Communication, and other (e.g., medical).

- **IE Power** – An Ontario, Canada-based manufacturer of electrical power conversion systems, with both custom and standard designs. Among others, the energy storage industry is one target market of IE's. Its product is the Advanced Battery Energy Storage System, Power Conversion System (ABESS PCS's).

S&C Electric and ABB have provided power conversion systems and overall integration services for ES installations in the U.S. They are both PCS suppliers and integrators for AEP, NYPA, and Xcel. Toshiba and Meiden-sha have served as suppliers and integrators on ES projects outside the U.S., including Europe, the Middle East, and over 280 MW in Japan. S&C Electric, ABB, Toshiba, and Meiden-sha all use their own inverters.

Other inverter companies that may have the capability to serve as PCS suppliers, but would need to develop this as a new business offering include:

- ***Satcon*** – Satcon is headquartered in Boston, MA, with a facility in Burlington, ON. Manufactures commercial solar PV inverters, sells a line of PCS to stationary fuel cell providers, and has introduced a distributed solar PV EMS.
- ***Xantrex Technology Inc***. – Xantrex, a subsidiary of ***Schneider Electric***, is headquartered in Vancouver and develops and manufactures power electronic products and systems for the renewable and mobile power markets.
- ***Dynapower*** – Headquartered in Burlington, VT, Dynapower offers a Demand Management System (DMS) for load leveling applications from 100kW up to MW-size systems. The DMS offers peak shaving and load leveling, but primarily for end-use industrial facilities.

Maximizing the life of the storage medium is critical for extending and maintaining performance. Inverter manufacturers also have the ability to manage battery charging. However, some storage technologies may require a separate system provided by a company specializing in battery management. ABMS monitors, controls and balances the charge in the storage system. Other companies specialize in battery management systems (BMS) such as Vecture, International Battery, and Clayton Power.

The controller optimizes the functionality of the ES in addressing THESL's goals. While the inverter converts the stored energy to utility grade AC, it will sit idle until it receives a command from the controller to dispatch real and reactive power as well as drawing power for recharging the storage device. The controller acts as a "traffic cop" sensing local conditions (e.g. current and voltage) measured at the PCC (point of common coupling) as well as commands from central utility dispatch. Local line conditions including voltage sags and power factor correction may require a fast response (e.g. ¼ to ½ cycle) whereas peak shaving and load displacement actions have a slower response (e.g. seconds to minutes). Prioritizing the correct response needs to be built into the controller via algorithms and fuzzy logic to automate the ES actions. The basic controller may be either purchased off the shelf or commissioned from a variety of sources such as National Instruments, General Electric, Siemens, ABB and Schneider Electric. Custom programming the controller would still be required to meet THESL's objectives. Other companies producing proprietary control technologies suitable for ES include S&C, Greensmith and Ionex (developed for their CES products). Since CES is a new concept, shopping for a suitable generic controller manufacturer may be a challenge. If nothing appropriate can be found, commissioning of custom design control hardware may be the only option for THESL.

While the controller will need to be custom programmed, the cabinetry required may be obtained off the shelf. Cabinetry suited to Toronto's climate can be supplied by the inverter manufacturer or could be sourced separately to house all components of the ES. Considerations include weather and salt spray conditions. See Table F-1 and Table F-2 in the Appendix for CSA Standard C22.2 No. 94 approved applications for NEMA rated cabinets. NEMA/CSA rated cabinet suppliers include:

- Adalet - Cleveland, OH
- Allied Moulded Products, Inc. - Bryan, OH
- Boltswitch, Inc. - Crystal Lake, IL
- Controlled Power Corporation - Massillon, OH
- Cooper B-Line - Portland, OR
- Cooper Crouse-Hinds - Syracuse, NY
- Eaton Corporation - Pittsburgh, PA
- EGS Electrical Group - Skokie, IL
- GE Industrial Systems - Plainville, CT
- Hammond Manufacturing Inc. - North Guelph, ON Canada
- Hoffman Enclosures Inc. - Anoka, MN
- Hubbell Incorporated - Bridgeport, CT
- Hubbell Wiegmann - Freeburg, IL
- Killark Electric Mfg. Company - St. Louis, MO
- Lamson & Sessions - Cleveland, OH
- Milbank Manufacturing Company - Concordia, MO
- Moeller Electric Corporation - Franklin, MA

- Penn Panel & Box Company - Collingdale, PA
- Rittal Corporation - Springfield, OH
- Robroy Industries, Inc. - Belding, MI
- Siemens Energy & Automation, Inc. –Alpharetta, GA
- Square D Company/Schneider Electric - Lexington, KY
- Thomas & Betts Corporation - Memphis, TN

3. Industry Trends and Market innovations

The following section provides a summary of key industry trends and current large scale demonstrations/deployments of batteries storage for utility applications.

Industry Trends

In the last few years key new legislation has been introduced in the United States to spur storage deployment which is expected to support long term market development. In May 2009, Senator Ron Wyden introduced the Storage Act of 2009 into the U.S. Senate and in December 2009, Congressman Mike Thompson introduced a bill (H.R. 4210) to the U.S. House of Representatives. The "STORAGE" bill was reintroduced in 2010 (Senate Bill 3627), that would:

- allow a 20% energy tax credit for investment in ES property directly connected to the electrical grid;
- make such property eligible for new clean renewable energy bond financing;
- allow a 30% energy tax credit for investment in ES property used at the site; and
- allow a 30% non-business energy property tax credit for the installation of ES equipment in a principal residence.

In September 2010, Governor Schwarzenegger of California signed Assembly Bill 2514, establishing a process to develop ES targets for Investor and Publicly Owned Utilities.

There has not been the same level of support for storage development in Canada, though some utilities are pursuing studies and pilot efforts. As a result most of the demonstration projects discussed below are located in the U.S.. There are also a number of Canadian vendors active in the market as discussed in the following sections, however, and BC Hydro announced in late June, 2011 that it will be installing two 1 MW NaS storage systems to reduce peak loading on its transmission system[20].

[20] *BC Hydro and S&C Electric Company Partner on Energy Storage Project to Improve Reliability, Provide Peak Shaving*, Electric Energy Online, June 22, 2011. http://www.electricenergyonline.com/?page=show_news&id=157644, also see, BC Hydro Press Release, June 11, 2011 - http://www.bchydro.com/news/articles/press_releases/2011/battery_project_golden_field.html

Demonstration Projects

ES devices are well established in commercial and industrial applications such as for uninterruptible power supply and telecommunication backup power. With respect to electric grid applications, only pumped hydro storage (PHS) and compressed air energy storage (CAES) have a long history of full-scale implementation. In the 1890s, the initial PHS system prototypes were built in Italy and Switzerland. By the 1920s and early 1930s, the first pumped hydro system was built in America, and reversible pump-turbines with motor-generators became available. Since then, PHS has matured and become a widespread energy storage technology with a worldwide installed capacity in 2008 of 110,000 MW.[21]In the United States, PHS accounts for about 20GW, or 1.8 per cent of its total generating capacity.[22] There are currently only two existing CAES facilities in the world: a 290MW facility in Huntorf, Germany built in 1978; and a 110MW facility in McIntosh, Alabama built in 1991. Both PHS and CAES can have very large system sizes with high power and energy, making them ideal for utility applications such as load management and operating reserves. The disadvantage is that both PHS and CAES have geographical limitations. PHS requires a reservoir, and underground CAES requires certain geological formations for storing compressed air. If those conditions are available, then PHS and CAES are viable options for bulk grid applications.

In the 1980's and 1990's, researchers began considering other technologies including: flywheels, supercapacitors, superconducting magnetic energy storage (SMES), batteries, and flow batteries for other grid applications such as renewable energy integration, transmission and distribution upgrade deferral, ancillary services, and reliability/power quality. As shown in Table 5, Lead acid batteries were implemented during this time period by private industry in various countries for utility applications. In addition, as shown in Table 5 in the 1990's and 2000's, VRB systems and NGK insulators began deploying their ES systems in Japan and abroad.

Table 5. Lead acid battery systems implemented for utility applications in the 1980s & 1990s

Project Name	Size	Location	Time-frame	Application
Elektrizitätswerk, Hammermuehle	400kW/400kWh	Germany	1980	Peak Shaving
Osaka	1MW/4MWh	Osaka, Japan	1986	
Hagen Industrial Battery Plant	500kW/7MWh	Soest, Germany	1986	Load Leveling
Crescent Electric	500kW/500kWh	Statesville, NC	1987	
BEWAG	17MW/14.4MWh	West Germany	1987-1995	Spinning Reserve, Frequency Regulation
Johnson Controls		Milwaukee, WI	1989	

21 Chamberland, Melanie. *Opportunities for Electrical Storage Technologies and Applications in Ontario Workshop - State of Technologies.* June 18, 2008.

22 EIA http://www.eia.doe.gov/cneaf/electricity/epa/epat2p2.html

Project Name	Size	Location	Time-frame	Application
Puerto Rico Electric Power Authority (PREPA) Sabana Llana substation	20 MW/14MWh (40min)	San Juan, PR	1994-1999 Repowered 2004	Spinning Reserves, Frequency Regulation, Voltage Control

Table 6. VRB Systems and NGK Insulator systems implemented in the 1990s and 2000s

Project Name	Size	Location	Time-frame	Application
VRB Systems (Vanadium Redox Flow Battery)				
University of Alaska	10kWh	Fairbanks, AK		
Ben Gurion University	5kW for 4 hour	Israel		
Imajuko	1MW/4MWh	Japan	1990	Peak Shaving
Japanese Utility	200kW for 8 hour	Japan	1996	Peak Shaving
Japanese Utility	450kW for 2 hour	Japan	1996	Peak Shaving
Japanese Office Building	100kW for 8 hour	Japan	2000	Peak Shaving
Sumitomo Denetsu Office	3MW/800kWh	Japan	2000-present	
Japanese Golf Course	30kW for 8 hour	Japan	2001	Renewables Integration
Japanese Laboratory	170kW for 6 hour	Japan	2001	Renewables Integration
Japanese LCD manufacturer	3000kW for 1.5 s 1500kW for 1 hour	Japan	2001	Backup Power, Peak Shaving
Japanese University	500kW for 10 hour	Japan	2001	Peak Shaving
Castle Valley Wind Farm	250kW/2MWh	Castle Valley, UT	2003-present	Peak Shaving
Japanese Industries	4MW for 1.5 hour	Japan	2005	Renewables Integration
South Carolina Air National Guard	30kW/60kWh	South Carolina	2005	Backup Power
Tommamae Wind Integration	4MW/1.5 hours	Japan	2005-2008	Renewables Integration
National Research Council of Canada	10kWh	Canada	2006-2008	Backup Power
Risø National Laboratory	15kW /120kWh	Denmark	2006	Renewables Integration
University of Aalborg	5kW for 4 hour	Univ. of Aalborg	2006	Renewables Integration
Winafrique Technologies	two 5kW for 4 hour	Kenya	2007?	Backup Power
NGK Insulators (NaS batteries)				
Japan	500kW/3.2MWh	Japan	1990	
Tsuanshima	6MW/48MWh	Japan	1997	Load Leveling
AEP	100kW	Gahanna, OH	2002	Peak Shaving
Tokyo Electric Power	~200MW	Tokyo, Japan	2003-2008	
Japanese Eleccompanies	~60MW	Japan	2003-2008	
Hitachi	8MW/57.6MWh	Japan	2004	Peak Shaving
Rokkasho Wind Firm	34MW	Japan	2008	Renewables Integration
Wakkanai Project	1.5MW	Japan	2008	Renewables Integration
AEP	2MW/12MWh	Balls Gap, OH	2008	Peak Shaving
AEP	2MW/12MWh	Fort Wayne, IN	2008	Peak Shaving

Project Name	Size	Location	Time-frame	Application
AEP	2MW/12MWh	Milton, WV	2008	Peak Shaving
AEP	4MW	Marfa, TX	2009	Peak Shaving
Enercon	800kW	Germany	2009	Renewables Integration
Youcinos	1MW	Germany	2009	Renewables Integration
EDF		France	2009	
Xcel Energy	1MW	Luverne, MN	2009-present	Renewables Integration
Abu Dhabi Water & Electricity Authority	~48MW	United Arab Emirates	2010	Renewables Integration

Starting in the late 1980's, U.S. federal and state agencies began funding demonstrations of various ES technologies for utility applications. Some of these demonstration were also implemented through public/private partnerships (See *Table 7*).

In 2009, through the American Recovery and Reinvestment Act (ARRA) Smart Grid Demonstration (SGD) Program, the U.S. DOE Office of Electricity Delivery and Energy Reliability (OE) awarded $618 million in demonstrations for emerging smart grid and ES technologies. The SGD program includes 16 ES demonstrations and 16 regional smart grid demonstrations some of which include ES technologies. After the SGD was established, OE incorporated the 9 Renewable and Distributed Systems Integration (RDSI) demonstrations that had been awarded by OE in 2008. Some of the RDSI demonstrations include ES. The SGD demonstrations (including storage, regional, and RDSI demonstrations) that include ES technologies provided in Table 8.

In addition in 2009 and 2010, the DOE ARPA-E was established through ARRA, this agency awarded grants to several companies to develop ES technologies (See Table 8). Finally, there are several other demonstrations or commercial installations that have been completed or have been planned in the last few years as shown in Table 9.

Table 7. Publically funded demonstrations in the U.S.

Project	Sponsor	Vendor	Technology	Size	Location	Time-frame	Application
Chino Substation	DOE, SCE	Exide	PbA battery	10MW/40MWh	Chino, CA	1988-1997	Frequency
Metlakatla Power & Light	DOE	GNB Industrial Power	PbA Battery	1.2MW/1.4MWh	Metlakatla, AK	1997-present	Reliability
Boeing HTS Flywheel	DOE; Boeing	Boeing	HTS Flywheel	20MW 15 minute	NY	2001-2008	Design Study
Boeing HTS Flywheel	DOE; Boeing	Boeing	HTS Flywheel	50kW 6 minute	Tacoma, WA	2001 -present	Development
Golden Valley Electrical Association	DOE	Saft	NiCd	27MW/14MWh 46MW, 5 minute peak	Fairbanks, AK	2003	Spinning Reserves Voltage Support
Joint Energy Storage Initiative	DOE; CEC	ZBB	ZnBr flow battery	1MW 4 hour	PG&E DUIT	2005-2006	Peak Shaving
Joint Energy Storage Initiative	DOE; NYSERDA	Gaia	PbA battery (flooded)	11kW 3 hour	Tompkins, NY	2005-2007	Peak Shaving
Iowa Stored Energy Project	DOE; Iowa Municipal Utilities	Iowa Municipal Utilities	CAES	268MW 50 hour	Iowa	2005-present	wind smoothing
Energy Storage Initiative	DOE; CEC; CA ISO; PG&E	Beacon Power	Flywheel	100kW	San Ramon, CA	2006	Frequency
CEC Substation Peak Shaving	CEC	ZBB	ZnBr flow battery	2MW/2MWH (four 500kWh)	PG&E DUA	2006-2007	Substation Peak Shaving
AEP Substation Project	DOE; AEP	NGK	NaS battery	1.2MW/7.2MWH	Charleston, WV	2006-2007	Peak Shaving
Joint Energy Storage Initiative	DOE; NYSERDA	Beacon Power	Flywheel	100kW	Amsterdam, NY	2006-2007	Frequency
Joint Energy Storage Initiative	DOE; CEC	Palmdale, CA	Supercapacitor	450kW	Palmdale, CA	June 2007 - June 2008	Backup Power, Microgrid Balance
Joint Energy Storage Initiative	DOE; CEC; SMUD	VRB	VRB flow battery	20kW	Sacramento, CA	2008	Load Management
Joint Energy Storage Initiative	DOE; NYSERDA; NYPA	NGK	NaS battery	1MW 6.4 hour	Long Island, NY	2008-2009	Peak Shaving
Joint Energy Storage Initiative	DOE; NYSERDA; NYPA Long Island Railroad	Pentadyne	Flywheel	2.5MW 30 sec	Merrick, NY	2009-present	Voltage Support, Peak Shaving

Project	Sponsor	Vendor	Technology	Size	Location	Time-frame	Application
Tehachapi	CEC, PGE, CAISO	Beacon Power	Flywheel	100kW/25Wh (Gen 4)	Tehachapi, CA	2010	Renewables Integration
Joint Energy Storage Initiative	DOE; CEC	NGK	NaS battery	1MW 8 hours	PG&E	Contract Pending	Substation Deferral, Peaking
Joint Energy Storage Initiative	DOE; CEC; SMUD		Super-capacitor	1MW 15 sec	Sacramento, CA	Contract Pending	Load Management

Table 8. ARRA Smart Grid Demonstration Program

Project	Vendor	Technology	Size	Location	Application
DOE ARRA SGD RDSI					
San Diego Gas & Electric	TBD	TBD	1MW	San Diego, CA	Peak Shaving
University of Hawaii	NGK	NaS	500kW	Maui, Hawaii	Peak Shaving
Allegeny Power	NGK	NaS	two 250kW	West Virginia	Peak Shaving
Chevron	TBD	TBD	TBD	Dublin, CA	Peak Shaving
Illinois Institute of Tech	TBD	TBD	150kW	Chicago, IL	UPS
University of Nevada	TBD	TBD	TBD	Las Vegas, NV	Peak Shaving
ARRA DOE SGD Regional					
Kansas City Power & Light	TBD	TBD	1 MW/1 MWh	Kansas City	
Consolidated Edison	TBD	TBD	<4kW (# of units TBD)	New York, NY	
Battelle Memorial Institute	TBD	TBD	5MW/5MWh (10 units)	Washington and 4 other states	
AEP Ohio	International Battery	Lithium Ion	80 25kW units 2MW/2MWh	Columbus, Ohio	
Center for the Commercialization of Electric Technologies	TBD	TBD	TBD	Austin, Texas	Renewables Integration
Pecan Street Project	TBD	Multiple	TBD	Austin, Texas	
Southern California Edison	TBD	Lithium Ion	50 kW, 90 kWh 2MW/1MWh	Rosemead, CA	Renewables Integration
ARRA DOE SGD Storage					
Duke Energy	TBD	TBD	20MW	Notrees, TX	Renewables Integration
Pacific Gas & Electric	TBD	CAES	300MW	Bakersfield, CA	Renewables Integration
New York State Electric & Gas	TBD	CAES	150MW	New York State	Renewables Integration
SustainX	SustainX	CAES	1MW/4MWH	TBD	Renewables Integration

Project	Vendor	Technology	Size	Location	Application
Primus Power	Primus Power	flow battery	25MW/75MWH	Modesto, CA	Renewables Integration
Ktech Corporation	Ktech Corp.	flow battery	250 kW/1 MWh	NM and CA	Renewables Integration
Beacon Power	Beacon Power	Flywheel	20MW	Chicago, IL	Frequency Regulation
Amber Kinetics	Amber Kinetics	Flywheel	1MWh (MW TBD)	Freemont, CA	Frequency Regulation
Seeo	Seeo	Lithium Ion	100kW/25kWh	TBD	CES
Detroit Edison	A123	Lithium Ion	20 25kW/50 kWh	Detroit, MI	CES
Southern California Edison	A123	Lithium Ion	8MW/32MWh	Tehachapi, CA	Renewables Integration
East Penn Manufacturing	East Penn Manuf.	PbA	3MW/1MWh	Lyon Station, PA	Frequency Regulation
Aquion	Aquion	Sodium Ion	TBD	Pittsburgh, PA	
City of Painesville, OH	Ashlawn Energy	VRB flow battery	1MW	Painesville, OH	Frequency Regulation
Public Service Company of New Mexico	TBD	ZnBr flow battery	2.8 MWH	TBD	Renewables Integration
Premium Power	Premium Power	ZnBr flow battery	6 500kW/ 2.8MWH	CA, NY	

Table 9. ARRA ARPA-E ES Research & Development

Project	Technology	Location
Arizona State University (Fluidic Energy, Inc.)		Tempe, AZ
EaglePicher Technologies LLC (Pacific Northwest National Laboratory)		Joplin, MO
Envia Systems (Argonne National Laboratory)		Hayward, CA
FastCAP Systems Corporation (MIT)		Cambridge, MA
Inorganic Specialists, Inc.		Miamisburg, OH
Massachusetts Institute of Technology		Cambridge, MA
General Compression	CAES	Newton, MA
ABB Inc	SMES	Cary, NC
Lawrence Berkeley National Laboratory	HBr flow battery	Berkeley, CA
Primus Power	flow battery	Alameda, CA
United Technologies Research Center	flow battery	East Hartford, CT
Univ. of So. California	Metal air battery	Los Angeles, CA
Proton Energy	Fuel cell	Wallingford, CT
Beacon Power Corp.	Flywheel	Tyngsboro, MA
CUNY Energy Institute	ZnMnO flow battery	New York, NY
Fluidic Energy Inc.	Metal air battery	Scottsdale, AZ
General Atomics	lead flow battery	San Diego, CA
Boeing	Flywheel	Huntington Beach, CA

Table 10. Other Recent Demonstrations and Commercial Installations

Project Name	Sponsor	Vendor	Technology	Size	Location	Time-frame	Application	Type
DynaPower Demo	VT Clean Energy Fund	DynaPower	battery		Burlington, VT	2010		Demonstration
CEC-PIER Contract 500-07-020, Agents for Renewables Project	CEC, PGE, CAISO	Beacon Power	Flywheel	100kW/25Wh (Gen 4)	Tehachapi, CA	2010	Renewables Integration	Demonstration
State of Michigan PV integration	State of Michigan	A123	Lithium Ion battery	500kW	Lavonia, MI	2010	Renewables Integration	Commercial
Sunflower Wind	Sunflower Wind	ZBB	ZnBr	50kW		2010	Renewables Integration	Commercial
Oahu Kahuku Wind Farm	First Wind DOE Load Guarantee	Xtreme Power	PbA?	15MW/10MWh	Oahu, HI	2010	Renewables Integration	Commercial
Maui Kaheawa Pastures Wind Farm	First Wind	Xtreme Power	PbA?	1.5MW	Maui, HI	2010	Renewables Integration	Demonstration
Maui Kaheawa Pastures Wind Farm II	First Wind	Xtreme Power	PbA?	10MW	Maui, HI	2010	Renewables Integration	Commercial
Lana'i Island La Ola solar farm	Castle and Cook	Xtreme Power	PbA?	1.125MW	Lanaii, HI	2010	Renewables Integration	Commercial
Montana Wind Integratin	Exergy Development	Prudent Energy	VRB flow battery	unknown	Montana	2010	Renewables Integration	Demonstration
Rubenious Mexicali, Mexico	RUBENIUS	NGK	NaS battery	1000MW	Mexicali, Mexico	2011	Renewables Integration	Commercial
Melink Corporation	Melink Corporation	Indy Power Systems	PbA battery	50kW/200kWh	Cincinnatti, OH	2011	Demand Management	Commercial
Gills Onions	Gills Onions	Prudent Energy	VRB	600kW	Oxnard, California	2011	Backup Power Demand Management	Commercial
Inversiones Energeticas	Inversiones Energeticas	Altairnano	Lithium Ion battery	10MW	El Salvador	2011	Frequency Regulation	Commercial
Pennsylvania	Pennsylvania	International	Lithium Ion	1MW/800kWh	PA	2011	Renewables Integration	Demonstration

Project Name	Sponsor	Vendor	Technology	Size	Location	Time-frame	Application	Type
Energy Development Authority (PEDA)	Energy Development Authority (PEDA)	Battery	battery				Grid Support	
Southern California Edison	Southern California Edison	LG	Lithium Ion battery	4kW/10kWh (# of units TBD)	CA	2011	Renewables Integration	Demonstration
Maui Auwahi Wind farm	Sempra	TBD	Lithium Ion battery	21MW/10MWh	Maui, HI	2012	Renewables Integration	Commercial
SunPower Corp. PV integration Pilot	California Public Utilities Commission,	ZBB Xtreme Power Ice Energy	ZnBr flow battery PbA? Thermal	500kW	CA	2009-2011	Renewables Integration	Demonstration
Beacon Power PJM demo	AEP	Beacon Power	Flywheel	1MW/250kWh	Groveport, OH	2009-present	Frequency Regulation	Demonstration
AES frequency Regulation	AES	A123	Lithium Ion battery	16MW/4MWh	Chile	2009-present	Frequency Regulation, Spinning Reserves	Commercial
AES frequency Regulation	AES	A123	Lithium Ion battery	2MW/500kWH	Huntington Beach, CA	2009-present	Frequency Regulation	Commercial
AES frequency Regulation	AES DOE Loan Guarantee	A123	Lithium Ion battery	20MW 15 minute	Johnson City, NY	2010 - ongoing	Frequency Regulation	Commercial
SCPPA	Southern California Public Power Authority (SCPPA); DOE	Ice Energy	Ice Bear air conditioning devices	53 MW (install 1.5 MW units)	California	2010-2012	Peak Shifting	Commercial
Los Angeles Dept. of Water and Power (LADWP)	Los Angeles Dept. of Water and Power (LADWP)	BYD	Lithium Ion battery	5-10MW	Tehachapi, CA	future	Renewables Integration	Demonstration
MidAmerican Pacific Power\	MidAmerican Pacific Power\	BYD	Lithium Ion battery	unknown	China	future	Renewables Integration	
AES frequency	AES	TBD	Lithium Ion	20MW 15min	NY	future	Frequency Regulation	Commercial

Project Name	Sponsor	Vendor	Technology	Size	Location	Time-frame	Application	Type
Regulation			battery					
AES frequency Regulation	AES	TBD	Lithium Ion battery	20MW 15 minute	NY	future	Frequency Regulation	Commercial
MidAmerican Pacific Power	MidAmerican Pacific Power\	BYD	Lithium Ion battery	unknown	Southern California	future	Renewables Integration	
Tres Amigas Superstation	Tres Amigas	Xtreme Power	PbA?		Clovis, NM	future	Transmission	Commercial
Duke	Duke Power	Grid Storage Technologies	Zn air battery	100kW	Charlotte, NC	late 2010		Demonstration
KEMA	Grid Storage Technologies	Grid Storage Technologies	Zn air battery	1MW	Chalfont, PA	late 2010		Demonstration
Shell-Luminant CAES plant	Shell Wind Energy and Luminant		CAES		Briscoe County, TX	future	Renewables Integration	Commercial
Magnum Energy Storage Project	CAES Development	Magnum Energy	CAES		Delta, Utah	future	Peak Shaving	Commercial
Norton CAES	CAES Development		CAES	2700MW	Norton, OH	future	Peak Shaving	Commercial
US utility	US utility	Electrovaya	Lithium Ion battery	1.5MWh	TBD	2011	Renewable Integration	Commercial
Koloa substation	Kauai Island Utility Cooperative (KIUC)	Xtreme Power	PbA?	1.5MW	Kauai, HI	2011	Renewables Integration	Commercial

CES development in the USA, led by American Electric Power (AEP), is a major driver for pilots at the residential level. AEP has produced a set of open source functional specification CES documents for both the storage unit and control hub (Ref.-11 and -12). US DOE sponsored pilots[23] are presently being rolled out to evaluate CES based on these functional specifications.

AEP's definition of CES is small distributed energy storage (25 kVA) connected on the secondary of a transformer serving a few houses or small commercial loads. AEP's CES would be sized to sit next to or in close proximity to curbside padmount or pole top transformers in neighborhoods and therefore are limited by power output and storage capacity. By contrast, THESL prefers to scale up its ES to higher power and storage capacity (i.e. ≥ 250 kVA) concentrating on serving laterals supplying 20-30 customers. In the THESL system the average load per customer is about 5 kVA and the most common transformers are 100 and 167 kVA. THESL's approach will result in fewer installations to achieve the same net effect on the distribution system. Advantages and disadvantages to both approaches are listed in Table 11 below.

Table 11. Comparison of AEP CES to THESL ES

Factor	AEP	THESL
Size	25 kVA	250 kVA plus
Location	Close to customers – near pad or pole transformer.	Further from some customers –physical size will dictate site selection THESL plans to locate units downstream of the transformer on the secondary bus. Proximity to customers will depend on the physical site availability. Padmount installation are currently planned but future installations could be submersible or pole-mount depending on available technology.
Aesthetics	Relatively small but may be objectionable to some customers	Physically large – will require siting where sightlines are not an issue.

[23] US DOE has committed $185 Million to energy storage from a $600 Million Smart Grid fund.

Factor	AEP	THESL
Installation	• More intensive/kVA installed (i.e. more CES units are needed for equivalent kVA as they are significantly smaller than the sizes envisioned by THESL). • Excavation required to conceal batteries in residential neighborhoods to reduce footprint. • Multiple connections to distribution system (i.e. one connection / avg. 4 customers).	• Less intensive/kVA installed • Can be padmounted. • One connection to distribution system / average 50 customers.
Capital	• Initially higher cost/kVA due to parts and packaging costs. • Mass deployment could drive down price of hardware. • Long term battery cost and performance unknown.	• Potential for lower cost due to economy of scale. • Energy storage technology selection more flexible. • Custom design of first units may require larger volume/print. • Initial higher cost per unit (custom build in small numbers).
Maintenance	• Potentially higher maintenance due to number/MVA. • PCS must be removed to access vaulted battery.	• Less maintenance/kVA due to concentration. • Equipment / batteries should be easier to access.
Security of Supply	• Close to customer – power quality benefit. • More secure – N+ 1 reliability for overall distribution system. • Will act similar to a UPS – islanding possible.	• Greater distance from some customers – power quality lower. • Less secure due to smaller number of larger units – modularity of PCS design could improve unit reliability. • Parallel connection to lateral – islanding would be greater challenge.
Load Diversity	• Fewer customers/CES = potentially less load diversity	• More customers/ES = potentially greater load diversity.

Factor	AEP	THESL
DG Fluctuation Protection	• Multiple CES needed to compensate for PV / Wind DG fluctuation on feeder. • May be less sensitive depending on PCC location.	• Compensation for multiple PV/Wind DG on lateral feeder.
PQ Mitigation	• More effective - Assuming small CES units will be located on high impedance low voltage feeders, less kVA will be needed to mitigate voltage sags than for larger, low impedance feeders).	• Less effective - Assuming larger units will be located on low impedance feeders, more kVA will be needed to mitigate voltage sags than for high impedance feeders.

The functional specification developed by AEP does provide some insight into a product that may eventually become commercialized. The specification is a work in progress and may be further enhanced in future revisions. At this time, the functionality is limited to peak shaving, power factor correction and islanding during brief service interruptions. Other possible functions including those listed in THESL's objectives are acknowledged in the documents but are not considered a priority at this time.

In spite of the number of electric utility storage installations either existing or planned, THESL's concept has uniqueness that cannot easily capitalize on others' experience. Congestion of the aging infrastructure coupled with micro-fit and larger DG on THESL's distribution system require innovative custom solutions to ensure system stability is maintained in future. The size of the proposed ES solutions is a departure from the AEP vision of small neighbourhood CES in favour of larger installations serving lateral feeders. At this time, no off-the-shelf product exists to meet THESL's unique application needs. Therefore, custom built, designed-to-order equipment is required. To ensure this equipment is suitable, pilot installations are needed to identify any risks or other issues such that corrective action can be taken prior to wide scale deployment.

4. Assessment of Storage Technologies With THESL's Objectives (Part A)

THESL Objectives

This section provides Navigant's interpretation and description of the technical attributes and distribution system impacts underlying each of the objectives set out by THESL. Based on our understanding of these objectives, Navigant developed a set of "ideal" ES system characteristics described in Table 13. The response capacity, energy and response times assigned to each objective are based on our professional judgement in consultation with THESL based on our understanding of THESL objectives and the THESL system.

Objective 1: Buffer intermittency of supply and demand, for levelling system load curve
Intermittent resources and shifts in load often create short-term perturbations of one hour or less, thereby impacting the balancing of load and supply. At the distribution level[24], a high level of intermittency on individual feeders can cause voltage regulation issues, as the time delay on load tap changing transformers or line regulators typically are not set to respond quickly enough to ensure voltages remain within prescribed limits (e.g., time delay can be up to one minute to avoid excessive contact wear). The unregulated voltage excursions can create power quality symptoms similar to those caused by "voltage flicker". Fast-response storage can buffer or mitigate the effects of both voltage regulation and non-economic operation of generating capacity to meet intermittency.

Response time for mitigation deployment will depend on the nature of the disturbance on the feeder. Voltage fluctuations can be compensated in as little as ¼ cycle whereas load fluctuations will normally dictate an initially dampened "wait and see" response for load changes such as plug-in electric vehicle (PEV) charging. The reasoning is that incremental load increases may be offset by customer load diversity. Therefore, a steady load increase can be met by ES step displacement rather than rapid load following which could deplete the stored energy more quickly than necessary.

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24 At the generation level, the impact of rapid load and supply changes associated with intermittency causes conventional generation to continually ramp upward (or downward) to follow these changes. If the level of intermittency is high, the ramp rates of committed generation may be insufficient to follow the load, thereby causing the independent control area operator to increase on-line generation capable of responding to the changes. This increases the cost of supply, as higher cost generation must be placed on-line or the existing generation mix must be operated at less efficient levels, or both. However, this benefit would only be relevant to the system operator and not to THESL, and thus is not considered in this analysis.

PEV's are anticipated to require 2.8 to 3.8 kW for level 2 charging but could be as high as 6 to 15 kW (see Table 12). Charging time can range from 2 to 8 hours depending on the charging rate and state of charge of the vehicle battery. This is a complex issue as large fleets of PEV's do not yet exist and individual driving patterns can vary.

Table 12. PEV Charging Requirements

Type	Power Level
Level 1: 120 VAC	1.2 – 2.0 kW
Level 2 (low): 208 – 240 VAC	2.8 – 3.8 kW
Level 2: (high): 208 – 240 VAC	6 – 15 kW
Level 3: 208 – 240 VAC	> 15 kW – 240 kW
Level 3: DC Charging: 600 VDC	> 15 kW – 240 kW

Objective 2: Enhance asset utilization by providing peak shaving, valley filling, and phase balancing services

The services that ES would provide for peak shaving and valley filling (Objective 2a) are longer in duration compared to intermittency buffering described in Objective 1. Typically, improved asset utilization for peak shaving or valley filling requires continuous storage output on the order of two to six hours, or longer. ES devices would need to be able to continually dispatch energy for this duration to meet the load levelling objective for up to two or three intervals daily (mid-day, early evening, and late evening/early morning). Improved asset utilization could be achieved by increasing feeder and substation effective capacity via peak shaving, thereby deferring T&D (transmission and distribution) capacity investment[25]. The size of the ES device will also be a function of feeder voltage and loading[26].

Phase balancing (Objective 2b) would be performed by smaller, single-phase storage devices using inverter technology, which would balance three-phase feeder loads, thereby improving voltage regulation, reducing losses, increasing capacity and enhancing protective relaying functions, including avoiding nuisance tripping of relays due to imbalances. Because these devices are smaller and phase balancing likely produces fewer benefits than peak shaving and valley filling, phase balancing is expected to be secondary to these higher value services.

[25] Peak shaving coupled with valley filling (Objective 2a) can store lower cost off-peak energy for use during higher cost on-peak hours, saving energy costs and reducing losses as well. Further, valley filling causes on-line third-party generation to operate more efficiently.

[26] For example, the downtown 13.8kV system typically supplies up to 10 MVa of load, whereas the 27 kV "horseshoe" can supply up to 20 MVA of load.

Table 13. ES System Characteristics Required for Each Objective

Objective	Characteristic	Description
Objective 1a: Buffer PV Intermittency	Capacity	1-2 MW at top of feeder given that inter-hour perturbations are likely to be 1-2 MW or less
	Energy	Up to 1 hour of discharge (majority < 10 minutes)
	Response Time	< 1 minute
Objective 1b: Buffer PEV Intermittency	Capacity	1-2 MW at top of feeder given that inter-hour perturbations are likely to be 1-2 MW or less
	Energy	Up to 4 hours of discharge with 1-2 hours peak
	Response Time	10-30 minutes (4 hours of charging time)
	Other	Issues expected to be downstream on laterals. Assume 250kW on single phase lateral with about 1 ES unit per 200 homes.
Objective 2a: Peak Shaving & Valley Filing	Capacity	2-8 MW at feeder level (4 MW for 13.8kV; 8 MW for 27.6kV), proportionately lower if located on lateral.
	Energy	Depending on the feeder, 2-8 hours of discharge may be required
	Response Time	~ 10 minutes. Response time is less important than for Objective 1; Intermittent output is not a factor.
	Other	Device efficiency is critical as charging losses may outweigh benefits. Charge /Discharge losses can be as high as 30%.
Objective 2b: Phase Balancing	Capacity	Up to 750 kW system
	Energy	Potentially 1-8 hours because the load changes of an individual feeder can vary significantly
	Response Time	Minutes. Response time and ability to follow load are similar to those required for Objective 1.
	Other	Device should be single-phase, with either 3 single phase devices or 1 single phase device on 'weak' phase.
Objective 3: Volt/VAR Optimization	Capacity	2-8 MW (4 MW for 13.8kV; 8 MW for 27.6kV)
	Energy	Discharge duration required is 2-8 hours, minimum
	Response Time	~ 10 minutes
	Other	Inverter specification is critical because it must be able to inject at any phase angle. Specifying a response rate of -Qmax to +Qmax in ¼ cycle should be adequate for this application (IGBT PWM based topologies can typically achieve this specification.
Objective 4: Mitigate PQ	Capacity	1-4 MW (on single phase lateral could be 1 MW but expect <750kV in most cases). Depends on type of perturbation.
	Energy	Discharge time of 10 seconds to 10 minutes with a much greater emphasis on the seconds time-frame.
	Response Time	Response time of sub seconds (cycles) is required. Key concern is sag mitigation but system can help other PQ issues.
Objective 5: Backup Power for Feeder	Capacity	5-20 MW (up to 10 MW for 13.8kV; 20 MW for 27.6kV)
	Energy	Discharge time of ≤2 minutes expected (though feeder reclosing sequence could take up to 5 minutes in the future with smart grid)
	Response Time	Response time of sub-seconds. Very high ramping capability is required if used for outage back-up.
	Other	High power/short duration. Re-closure carry through is key event of concern.

**Capacity levels shown are for storage located on a 27.6 kV feeder. Capacity requirements would be lower if located downstream and greater if located at the MS. Storage capacity is dependent on the load and load factor on the feeder. This dictates the PCS power and storage capacity needed.*

Objective 3: System loss reduction and volt/VAR optimization

Similar to Objective 2a above, longer duration storage could serve to reduce losses during periods of high loads or when lines are heavily loaded. Because peak load duration can be several hours or longer, ES devices would need to operate continuously for several hours or more. By shaving peak loads via ES, losses can be reduced significantly as losses are much higher when loads are higher.[27] Similarly, ES could be dispatched to produce VARs during periods of high reactive demand or depressed voltages.

The objective of system loss reduction will always be a secondary objective to the other objectives in this study. Therefore, it is not addressed as a distinct objective in this analysis. Given that THESL does not currently experience volt/VAR problems on its system, Navigant has developed generic system characteristics that it believes could optimally address volt/VAR problems.

For ES to provide VAR support, inverters must be able to adjust power factor either in response to changing voltages or to respond to communication signals from smart devices such as a substation or master controller. Alternatively, the inverter could adjust power factor based on local bus voltages. For the latter, the inverter will automatically respond to low or high voltages. This functionality is comparable to STATCOM technology and operating modes.

Objective 4: Mitigate power quality issues

The functionality described above is comparable to Objective 3, Volt/VAR Optimization, except the ES device would need to be able to change output levels, up or down, very rapidly to respond to fast-acting and repetitive power quality events, which includes swells and sags, and other forms of voltage perturbations. To address system harmonics, ES devices would need to be strategically placed, such that harmonic producing sources or loads would be filtered through the ES device inverters in series with the load or devices producing the harmonics. Because ES devices use inverter technology, they are able to convert AC fundamental and higher order power output waveforms to continuous 60 hertz output, thereby mitigating harmonics. Notably, since inverter technology mitigates the impacts of the voltage perturbations and power quality events, other non-storage technologies (such as STATCOM and other forms of inverter-based generation) could perform the same functions. In other words, similar to Objective 3, this objective can be satisfied by any ES device's inverter technology. THESL does not need to consider ES devices themselves relative to this objective.

[27] Losses increase in proportion to the square of the load.

Objective 5: Provide up to two minutes of backup power for the feeder

For back-up power applications, ES devices would need to be capable of producing a large amount of power for a relatively short duration. The device also would need to be able to ramp up very rapidly to full output capability if the ES acts solely as a back-up resource. Similar to peak shaving and valley filling, the size of the device will depend on loading and whether it is installed on the 13.8kV or 27.6kV distribution system.

Objective 6: Function in a micro-grid configuration

ES devices can provide a range of support services for microgrid operation, including load levelling, load following and microgrid frequency and voltage regulations. The type and size of ES will depend on the size of the microgrid, how often it is expected to operate independent of the grid, and the mix of other generating sources within the microgrid. For example, if simple gas turbines are installed to follow load, the load following capability would be less important. In contrast, for microgrids with large amounts of intermittent renewable resources, ES would need to be able to cycle and ramp up and down frequently. ES requirements within a micro-grid configurations can vary widely.

Evaluation of ES Technology Fit for THESL Objectives

In order to evaluate ES technologies relative to the 6 objectives, they were first compared to ES requirements for power, energy, response time, and cycle life. Next, a scoring framework was developed to rank ES technologies and features. As shown in Table 14, Navigant rated each ES technology on a scale of "1", "4", "7" or "10" (with a score of 10 representing the best score) for six system attributes including:[28]

- Power (kW),
- Energy (kWh),
- Response time (seconds),
- Cycle life (cycles),
- Volume energy density (kWh/m^3),

[28] Note that THESL had indicated that they would like to consider weight energy density (kWh/Kg). However, since weight energy density is not very important with respect to utility applications relative to the other characteristics, it was not included in the quantitative analysis.

- Temperature tolerance (°C).

These characteristics were considered when determining the most appropriate technologies for each objective. These final results are displayed Table 15 and Figure 12.

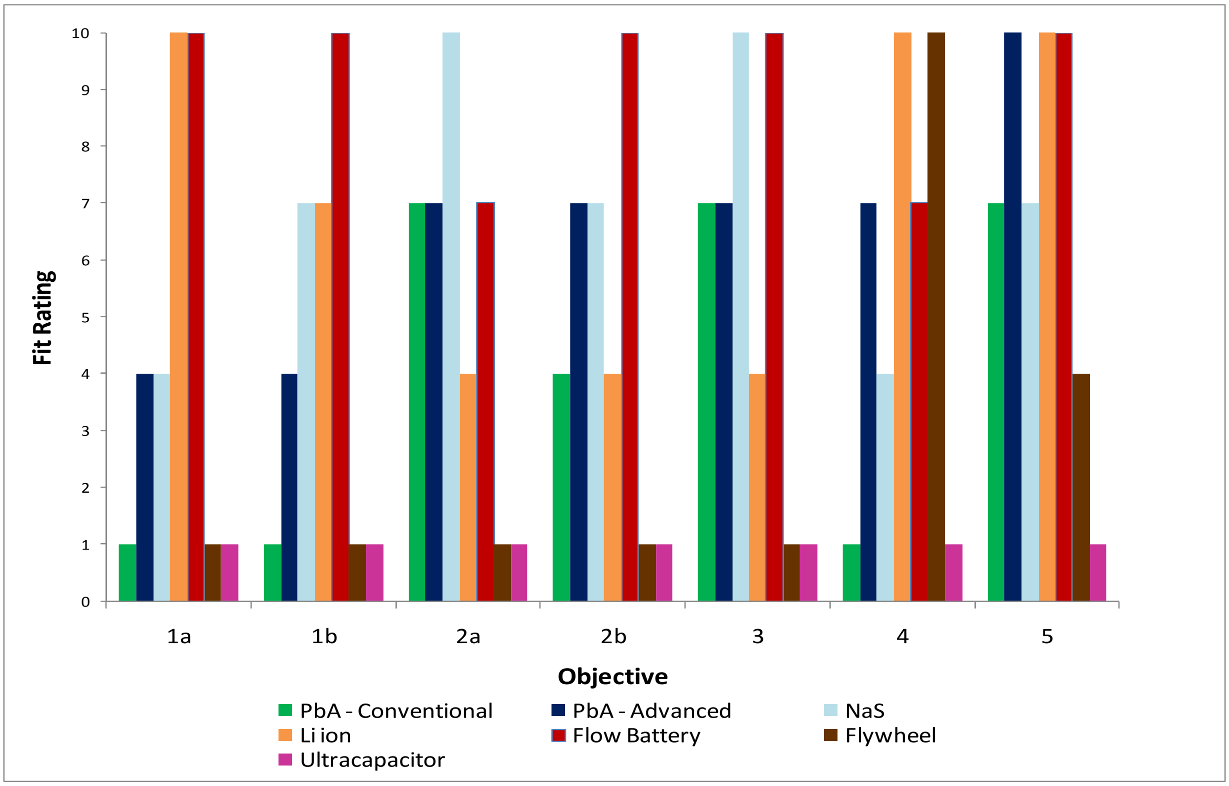
Table 14. ES Technology Characteristics

Technology	Characteristics					
	Power	Energy	Response Time	Cycle Life	Volume Energy Density	Temperature Tolerance
PbA - Conventional	7	7	4	1	4	4
PbA - Advanced	7	7	4	4	4	4
NaS	10	7	4	7	10	1
Li ion	7	4	7	7	10	7
Flow Battery	10	10	7	7	4	7
Flywheel	10	1	10	10	1	10
Ultracapacitor	10	1	10	10	1	10

Table 15. ES Technology Fit for Each Objective

Technology	Objective						
	1a	1b	2a	2b	3	4	5
PbA- Conventional	1	1	7	4	7	1	7
PbA - Advanced	4	4	7	7	7	7	10
NaS	4	7	10	7	10	4	7
Li ion	10	7	4	4	4	10	10
Flow Battery	10	10	7	10	10	7	10
Flywheel	1	1	1	1	1	10	4
Ultracapacitor	1	1	1	1	1	1	1

Figure 12. ES Technology Fit by Objective



These results indicate that Li ion and flow batteries are the most attractive options for Objective 1a, since buffering intermittency of PV systems will require significant cycling. Li ion batteries and flow batteries each have a longer cycle life than lead acid. Given the required discharge of 1 hour assumed for this objective, flywheels and ultracapacitors would not be good options. A technology with more energy, such as NaS, would be technically viable but may not be as economically viable. Flow batteries are less commercially developed than NaS or Li Ion; though a number of small ZnBr batteries are being installed in Australia and larger flow batteries are being demonstrated in the U.S. through the ARRA Smart Grid Demonstration program.

For Objective 1b, cycling duty would likely be a few times per day to buffer intermittency due to PEVs versus many times per day for PV. Objective 1a also requires a shorter response time than Objective 1b. Therefore, cycling and response are less important when compared to Objective 1a (Objective 1b requires 4 hours of discharge.). Further, flywheels and ultracapacitors don't have the required energy. Therefore, the best options are flow batteries, NaS batteries, and Li ion batteries. Advanced PbA batteries may be feasible but they have less demonstration experience than the other technologies.

NaS batteries are the most attractive for Objective 2a since this objective requires both high power and high energy. Flow batteries and PbA batteries offer sufficient power and energy but flow batteries have a lower average round-trip efficiency than NaS. PbA batteries have other disadvantages such as high weight energy density and footprint. Li ion batteries are less economically attractive at high energy. NaS has been more widely demonstrated in the field for this type of application. NaS batteries become more attractive for larger scale utility storage when several hours of stored back-up are required

Flow batteries are most attractive for Objective 2b since phase balancing requires 1-8 hours of discharge and likely significant cycling. However, NaS batteries and advanced PbA (not conventional PbA) and are both good options. Flywheels and ultracapacitors don't have the necessary energy. Li ion batteries are less economically attractive at high energy.

The requirements for Objective 3 are similar to Objective 2a. Therefore, NaS batteries are the most attractive for Objective 3, primarily since this objective requires high power and high energy.

Power Quality in Objective 4 requires 10 seconds to 10 minutes of discharge time as well as a fast response time and high cycle life. Therefore, flywheels, and Li ion batteries are most attractive. While ultracapacitors offer power, response time, and cycle life, they would not meet the 10 minute discharge criteria. Conventional PbA batteries would be at a disadvantage due to the amount of cycling.

Finally, to provide up to 2 minutes of backup power for a feeder in Objective 5, all technologies except ultracapacitors achieve minimum power and energy requirements. Assuming that backup power would only be needed periodically, cycle life is not a critical factor. With the main requirements satisfied, it is necessary to consider other parameters. For example, the footprint required for a 20MW flywheels system would be a disadvantage in this application. NaS batteries cannot tolerate large temperature ranges. Therefore, advanced PbA, Li ion, and flow batteries offer the best fit.

It is difficult to select an appropriate ES technology for Objective 6 since the configuration of a microgrid can vary significantly. ES devices offer a range of support services for microgrid operation, including load levelling, load following and microgrid frequency and voltage regulations. Ultimately, most storage devices can provide operational benefits and value in a microgrid configuration. A storage device within a microgrid configuration will be called on to provide either short-term or long-term energy. The type of islanded generation used in the microgrid will determine the storage requirement. For example, a fast-start gas turbine will require only milliseconds of storage energy while a fuel cell could require tens of seconds for start-up.

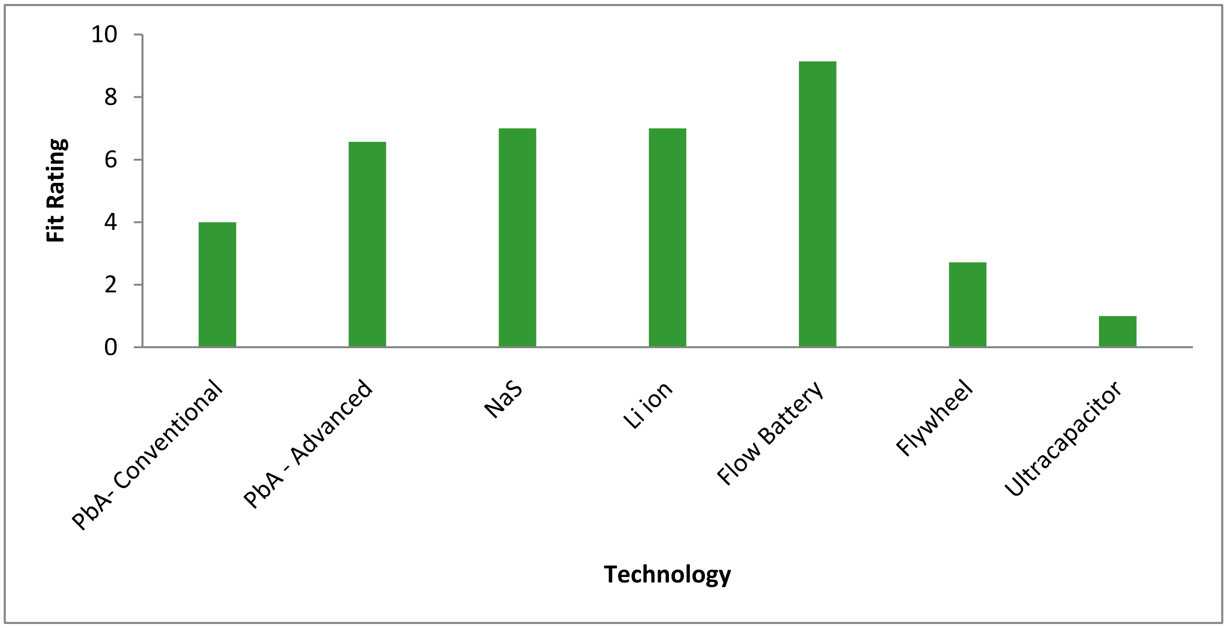
"Typical" microgrid configurations being explored across the globe at this time are shown in Table 16. Navigant has characterized the ideal characteristics of a storage device that may be selected for that particular configuration. Finally, Table 16 provides a list of storage technologies that would fall within each microgrid configuration, based on the characteristics required.

Table 16. ES Technology Fit for Microgrid Configurations

Characteristics of Microgrid Configuration	Ideal Storage Characteristics/Function	Feasible Storage Technologies
• Contains gas turbine or other base-load generation as backup power supply.	• Ride-through capability for transition from electric grid to backup power generator.	• Ultracapacitor • Flywheel • Valve-regulated PbA • Li-ion
• Renewable energy generation microgrid (i.e. no gas turbine).	• Follow load. • Long discharge duration. • High cycle life. • Fast acting storage device to maintain frequency	• Flywheel, ultracapacitor or PbA in conjunction with: o NAS o Flow Battery

Figure 13 illustrates the overall fit of each storage device under consideration, when weighing each THESL objective equally. Based on this analysis, flow batteries provide the most attractive "all round" solution to THESL's objectives. However, advanced PbA, NaS, and Li ion batteries are good options.

Figure 13. Overall ES Technology Fit



5. Integrated Storage Unit (Part B)

This section presents and discusses the various major building blocks that comprise the Energy Storage system including the methodology to make ES work within the context of an electric utility distribution.

Community Energy Storage (CES) has been a topic of discussion for many years within interest groups such as the Electricity Storage Association (ESA) whose members included manufacturers, utilities, consultants and government agencies. Utilities, mainly in the USA, have undertaken a small number of large battery-based storage installations employing traditional batteries. While there have been a few application successes, there were also lessons learned from the mistakes which occurred with these early installations. Recently, American Electric Power (AEP) prepared two open source document specifications for CES (Refs.-11, -12). These two documents form the embodiment of DOE subsidized pilot installations presently underway in the USA. The biggest thrust has been in 2009-2010. Four major utilities are known to have undertaken pilot projects as listed in Table 17.

Table 17. CES Pilots in US

Present known CES in USA[29]	
Utility	**Total Installed Capacity**
AEP	2 MW
DTE	0.5 MW
SCE	unknown
Duke Power	unknown

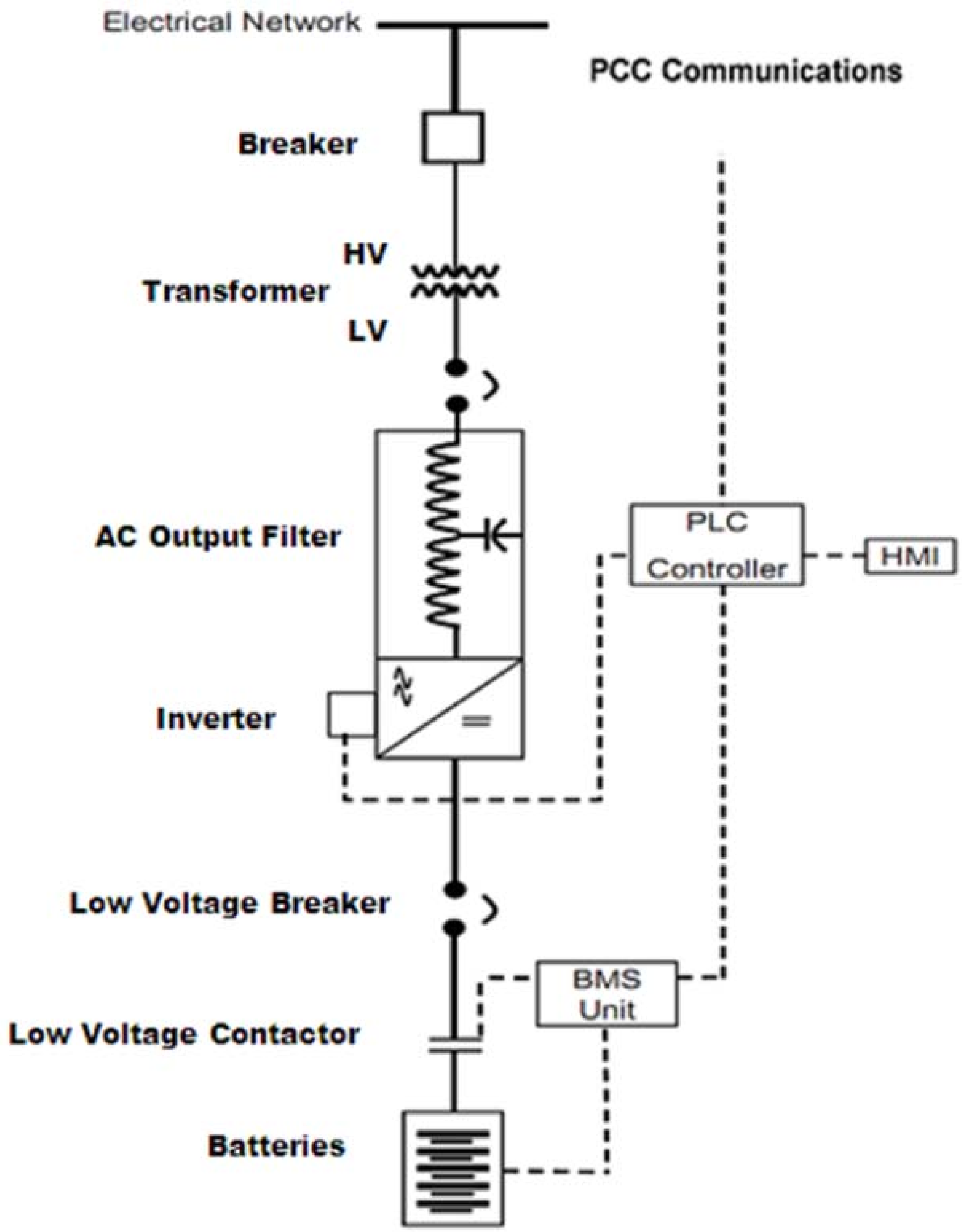
Present known suppliers of this equipment include S&C Electric and Greensmith Energy Management Systems. ABB has built DESS for AEP and others and should also have the capability to develop ES (Ref. -14). In Canada, SatCon and IE Power should have the capability to design similar prototype equipment (see Appendices A and D for potential ES Manufacturers). Since ES will likely be installed outdoors and subject to harsh environmental conditions including salt spray, moisture and potential intrusion by wildlife, the manufacturer should have a demonstrated capability for producing utility grade outdoor equipment. Figure

[29] Email response from Dr. Ali Nourai, Chairman of ESA Board of Directors, dated November 13, 2010.

14 illustrates the typical components that comprise an ES. Note on the low voltage DC side of the circuit there is both a contactor and a breaker in series. This is common in control circuits. The interrupting capability of the contactor can be lower than the breaker. The contactor is for switching under normal loads while the breaker only operates to clear faults should such a condition occur.

Figure 14. ES Single Line Drawing

Batteries are favoured for these applications.



THESL Focus on ES

THESL has requested NAVIGANT and Kinectrics to focus on a range of potential ES sizes. Compared to the pilot CES favoured by AEP and other US utilities, THESL is focusing on significantly larger capacities more suited to three phase and single phase laterals and distribution feeders to buffer intermittency of supply, enhance asset utilization, reduce system losses, and mitigate power quality issues. THESL is concerned about the impact of large grid connected DG on its system such that the smaller CES used elsewhere would not be an appropriate mitigating solution. Depending on the intended application, sizes range between 250 kW on a three phase or single phase lateral to 20 MW on a feeder. Storage capacity will vary depending on the intended application and need.

The suitability of each size will be largely dependent on placement in THESL's network. The largest sizes would be more suited to transformer and distribution stations while progressively smaller ES systems would be a better fit for commercial, industrial and residential locations. While the larger storage systems could be applied to a major energy user such as a shopping centre or large office tower, the space requirement may be difficult to accommodate depending on the power and energy capability desired.

Battery

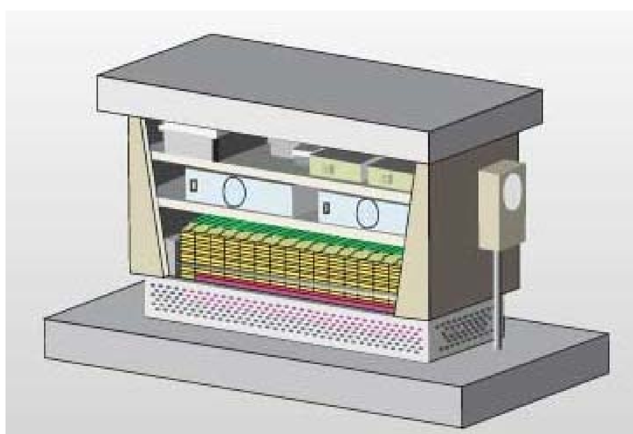
The battery can be housed in the same cabinet as the balance of plant. However, in some situations the battery may be housed in a separate cabinet or building. The latter is often employed in very large installations. Fans and heaters may be required to cool or warm the battery depending on its ambient requirements. Many battery chemistries are rated at 25^{o}C (exceptions such as the NaS battery operate in their own ambient environment). Most perform best when operated within their prescribed limits. Overheated batteries have a shorter life while cold batteries deliver less energy and are more difficult to charge. Li-Ion batteries are a preferred storage source[30] for CES owing to their high energy and power density and reasonable life expectancy, predicted at 3000 to 4000 cycles or 8 to 10 years. Large format Li-Ion batteries are favoured for these applications (see Figure 15).

[30] S&C initially chose International Battery Large Format Li-Ion cells (lithium iron phosphate cathode) for their CES battery.

Figure 15. Large Format Li-Ion Battery[31]

Figure 16 is an example of a CES employing Li-Ion batteries in a single package. The manufacturer, Greensmith, has focused on relatively small CES systems rated at up to 5 kW / 20 kWh. Additional information on Greensmith CES systems is found in Appendix F.

Figure 16. Greensmith Storage Component of Community Energy Storage System (CES)



Low Voltage Contactor

The low voltage contactor is used to disconnect the battery should the battery experience a problem. This is controlled by the BMS.

31 International Battery Lithium-Iron Phosphate Cells (LiFePO4).

Low Voltage DC Breaker

The low voltage DC breaker provides fault and overcurrent protection on the DC side of the inverter.

BMS (Battery Management System)

A Battery Management System (BMS) is typically a separate device used to monitor and maximize the life of the energy storage component. Depending on the battery type, a BMS can be critical for safe battery operation. While not absolutely essential for all batteries (e.g. lead acid), a BMS can reduce the need for frequent inspection by identifying, isolating and notifying the utility should any potential problem occur.

Maximizing the life of the storage medium is critical for extending and maintaining the performance of the system. Inverters have the ability to manage battery charging, depending on the manufacturer, but some storage technologies may require a separate system provided by a company specializing in battery management. A BMS monitors, controls and balances the charge in the storage system. Companies that specialize in battery management systems (BMS) include Vecture, International Battery, and Clayton Power.

Some battery technologies have management systems built into each cell or group of cells (e.g. Li-Ion battery) as charging and discharging is critical for safe operation and optimum life. Cell balancing is important as charging and discharging a series/parallel combination of batteries can result in uneven state of charge. Over time, left unattended, problems such as cell reversals can occur which leads to failure. A BMS can level the charge without necessitating "equalizing" the entire battery. Over time, some cells in the string become more discharged than others such that the normal charge cutoff point does not sufficiently charge all cells. The traditional way of "equalizing" the charge is by overcharging the battery. While the weaker cells are fully charged, many of the stronger cells are overcharged in the process which is not ideal. By applying charge to only the weaker cells, the health of the stronger cells is not compromised. This is particularly prevalent in batteries such as lead acid and NiMH batteries.

PCS

A power conversion system (PCS) converts the stored DC energy into AC which is injected into the power network. Since the inverter is connected to the utility as a distributed generator, it must meet either CSA or ULc approved safety standards. At this time, the governing standard for utility connected inverters is C22.2 No. 107.1-01 (Ref. -20). Appendix C provides listings of CSA and ULc approved inverter manufacturers. However, the majority of manufacturers listed produce products intended for the distributed generation market, notably photovoltaic. Therefore, only a small number of companies will have the experience necessary to design and build a custom PCS suitable for a utility ES. The PCS for an ES application will most likely need to be a custom-built prototype. This equipment will require ESA and/or CSA field inspection approval[32] prior to installation and the selected manufacturer may not be on the CSA or ULc approved list. Furthermore, functionality that is desirable to THESL, such as low voltage ride through capability, may contravene the present CSA and ULc standards.

The lowest DC battery voltage during discharge should ideally be twice the AC RMS voltage. For example, a 240 V single phase inverter would be ideally supplied by a battery with a nominal voltage of 480 V DC. While lower DC voltages are possible, the PCS will become larger and costlier due to addition of DC to DC converters to provide higher DC voltages to the inverter or the installation of a step-up isolation transformer to boost the inverter output voltage.

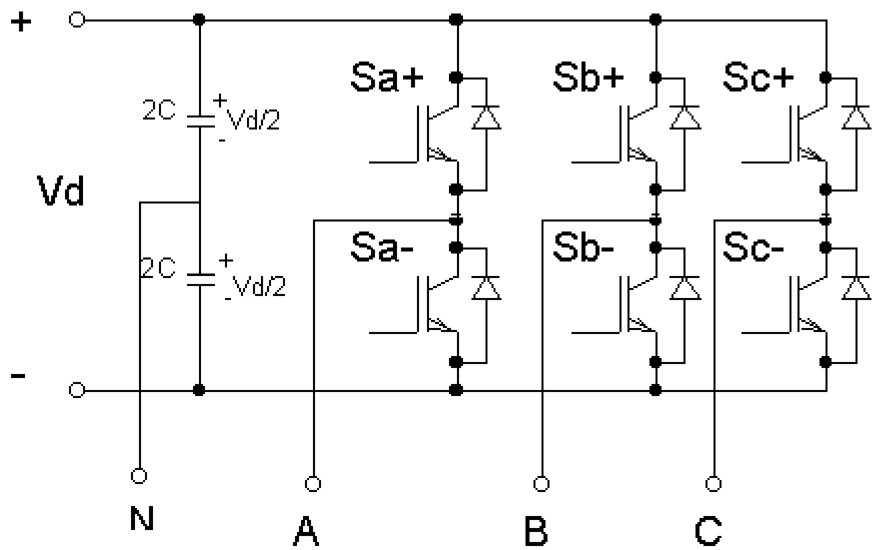
Converter/Inverter

This subsection focuses on the voltage converter/inverter hardware design considerations including modularization, battery voltage impact, and cooling requirements.

The converter or inverter for the majority of battery storage systems generally use similar configuration involving a 4-quadrant topology (i.e. real power in/out and reactive power in/out; see Figure 17 for a simplified 3-phase inverter schematic). IGBT (Insulated Gate Bipolar Transistor) designs are preferred for regulating charging and discharging the battery at distribution voltages below 4 kV due to high frequency switching capability and low conduction losses. Since the size and output of the storage system can vary significantly, many PCS manufacturers tend to prefer a modular approach to PCS assembly. For example, a 25 kW PCS could have one modular power block while a 100 kW PCS could consist of four 25 kW blocks driven by a single controller. This approach facilitates manufacturing and parts inventory thus helping to keep costs down. As well, a measure of redundancy is inherent in such a system as the failure of one module can leave the remainder in a reduced operating mode until maintenance is performed. Examples of manufacturers capable of producing custom electric utility grade PCS equipment are listed in the Appendix D.

32 Custom units for CES applications are typically not CSA or UL_c approved. The cost to obtain certification is a lengthy process which could exceed the cost of a single CES. Field ESA or CSA approval is available to ensure the equipment is electrically safe. The PCS can be built to meet a standard or part thereof (e.g. C22.2 No. 107.1-01 or UL 1741). At this time there is no specific standard for CES.

Figure 17. Simplified 3-Phase Inverter Circuit



The battery type and voltage range can influence the PCS design and cost. For example, in order to maintain a constant voltage and power output over the full operating range of the battery, the inverter designer needs to accommodate the full battery operating range. The higher the spread between charged and discharged states, the more costly the inverter due to increased current handling at the lower end of the voltage ranges. Some components in the PCS may be common to multiple designs (e.g. IGBT modules) while other parts such as the charge/discharge controller may be battery/application specific.

The lower voltage dictates the maximum current handling capability of the IGBT's. Table 18 provides a table of DC voltages needed to achieve the nominal AC output voltage plus 10%. While having a higher DC voltage range than this minimum value is desirable with respect to the PCS requirements, high DC voltages can also increase the costs of harmonic current filtering due to the narrow pulse width needed to modulate the output current when the voltage is at the high end. This in turn increases the harmonic levels that need to be filtered out.

As well, if the DC voltage exceeds 1250 VDC, a higher class of IGBT is required which can also significantly increase the cost of the PCS. Alternatively, an isolating transformer can be used to step up the AC voltage at the expense of the transformer cost, space requirement and loss of efficiency in and out of the PCS (about 2% each way). A coupling transformer may be required depending on the distribution voltage level and isolation requirements to match the inverter output to the distribution system. Alternatively, a DC-DC converter can be used to raise the DC bus voltage to the inverter.

Table 18. Minimum DC Discharge Voltage to Achieve Nominal AC Output Voltage

Nominal AC Voltage (+10%) VAC	Minimum DC Voltage – Discharge Cut-off[33] VDC
208	325
480	750
600	938

Cooling is an important consideration in PCS design. Direct fan cooling may be employed. However, additional air filters may be required plus cleaning of the power module heat sinks will incur added maintenance. As capacity increases while maintaining a small footprint, liquid cooling is often preferred. PCS used outdoors normally require a glycol-water solution to prevent freezing.

PCS Efficiency

PCS efficiency is often specified at full load output. This can be a high number between 95% and 98% (excluding transformer losses). Partial-load efficiency can be lower due to the generally fixed losses associated with the power electronics and transformer. One way of addressing this is to also express overall efficiency as a weighted average. Therefore weighted efficiency might be 95% while full load efficiency might be as high as 98%. At very low outputs the PCS will appear very inefficient due to the proportion of fixed losses compared to power output.

If the battery voltage is too low to drive the inverter directly, then DC to DC converter circuitry is needed to raise the voltage sufficiently to provide the necessary input into the inverter. Adding these components increases the PCS volume requirement and may lower efficiency compared to floating the battery across the inverter directly.

An alternative would be to increase the isolating transformer ratio accordingly.

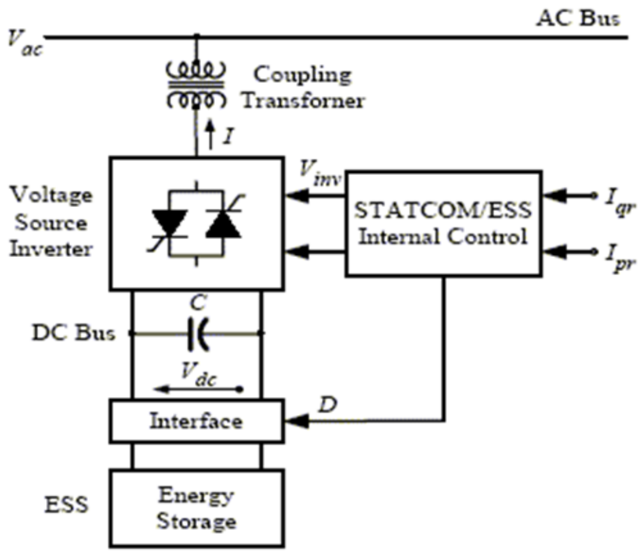
Converter/Inverter with STATCOM Capabilities

A PCS with STATCOM34 (also D-STATCOM35 or D-VAR36) capability enhances the functionality of the storage device (See Figure 18).

33 Maximum full charge voltage not to exceed 1250 V DC.

34 STATCOM – Distribution Static Compensator.

Figure 18. Simplified Depiction of a STATCOM / ESS (Ref. -2)



Typically, no battery energy is required when the PCS injects VARs into the system. With added control logic, the PCS can also provide STATCOM functionality including:

1. voltage regulation and reactive power compensation,
2. power factor correction; and,
3. reduction of current harmonics.

PWM (pulse wave modulation) control of the output is generally favoured over FFS (fundamental frequency switching) for STATCOM applications. FFS is preferred in FACTS[37] applications.

The advantage of energy storage with STATCOM functionality over a stand-alone STATCOM is that real and reactive power can be injected into the AC bus as required as opposed to only reactive power injection.

Although no battery energy is typically required for pure STATCOM operation, the rating of the DC storage device plus the impedance of the distribution circuit will ultimately determine

35 D-STATCOM is found literature interchangeably with STATCOM. However, S&C Electric have registered D-STATCOM as one of their trade marks as "PureWave DSTATCOM®". Therefore the term STATCOM has been used throughout this report to avoid any confusion with this product.

36 D-VAR® for STATCOM from American Semiconductor.

37 FACTS – Flexible AC Transmission System.

the effectiveness of power quality mitigation (Ref. -1). Therefore care is needed in modeling a PCS to the intended application to successfully cover the range of disturbances anticipated.

Considerations for Inverter Sizing for Islanding

Intentional islanding occurs when the feeder or lateral is isolated from the grid but remains powered. The duration can range from minutes to hours depending on the storage capacity and connected load. In such an islanding scenario, the PCS must be designed to accommodate the worst case load requirement including momentary motor inrush currents. Therefore, a continuous rated 25 kW PCS may need to have a momentary rating of 50 kW or more to handle such excursions. If the design includes an islanding function, the PCS will supply connected loads downstream while being safely islanded from the utility supply. The challenge presented for islanding mode is the unpredictable load diversity in the micro grid. The micro grid does not exhibit the relatively smooth load curves the utility observes back at the substation. Utilities typically view their systems in 15-minute or 1-hour increments whereas PCS manufacturers view loads in ¼ cycle segments. Sufficient contingency is needed in the ES to handle unpredictable coincident loads. Careful sizing of the ES is needed in conjunction with smart load management control of customer discretionary loads. The latter helps tailor the coincident switching of loads such as central air conditioning, electric water heaters, PHEV's, etc. PCS inherently have little margin for sustained overloading unless the capability is built-in. For example AEP's 100 kW DESS has 500 kW overload capability for 30 seconds (Ref -14). The power electronics need to be designed to handle the 500 kW load. Cooling requirements are less stringent as the overloads are not continuous. However, the frequency of such events is necessarily limited to allow sufficient cooling to occur. Many islanding schemes are "break before make" primarily to keep the cost down. A seamless transfer (e.g. a ¼ cycle or less) requires a solid state static switch. Fast acting switches can represent 30% to 50% of the PCS cost.

The first step in determining the correct size for a PCS is to review the historic peak demand of the connected loads over at least 2 years of metered data. Following that, a careful study of cyclic loads, including large motor inrush, that could add transient currents to the base load should be factored in. IGBTs typically have an overcurrent capability of less than one second after which permanent damage is likely to occur. Therefore, additional measures are needed to ensure the ES can safely supply the connected load when isolated from the utility.

Figure 19, 20 and 21 represent real hourly kW demand data for a commercial building[38]. Figure 19 represents hourly interval meter consumption starting January 1 ending December 31. As

[38] Customer name is confidential.

expected, the summer air conditioning load increases the average hourly demand. Figure 20 is the same data sorted from high to low and shows the relatively few hours per year that hourly demand exceeds 200 kW (less than 6.7% of the time). The blue area on the graph represents the total yearly consumption of 1,276,477.7 kWh or an average hourly consumption of 145.7 kW. Figure 21 is the day (July 16, 2008) when the peak 238.73 occurred at the 4:00 p.m. reading.

Sizing an ES to island this sample customer load would require understanding the peak transient loads that could coincidentally occur during the hour. To help keep the instantaneous peak down, demand management techniques could be applied to stage or use soft starters on the larger loads (e.g. HVAC compressors).

For this example an ES with a rating between 300 kVA and 400 kVA would prove adequate for supporting a temporary island mode year round.

Figure 19. Hourly Demand for a Sample Commercial Building – One Calendar Year

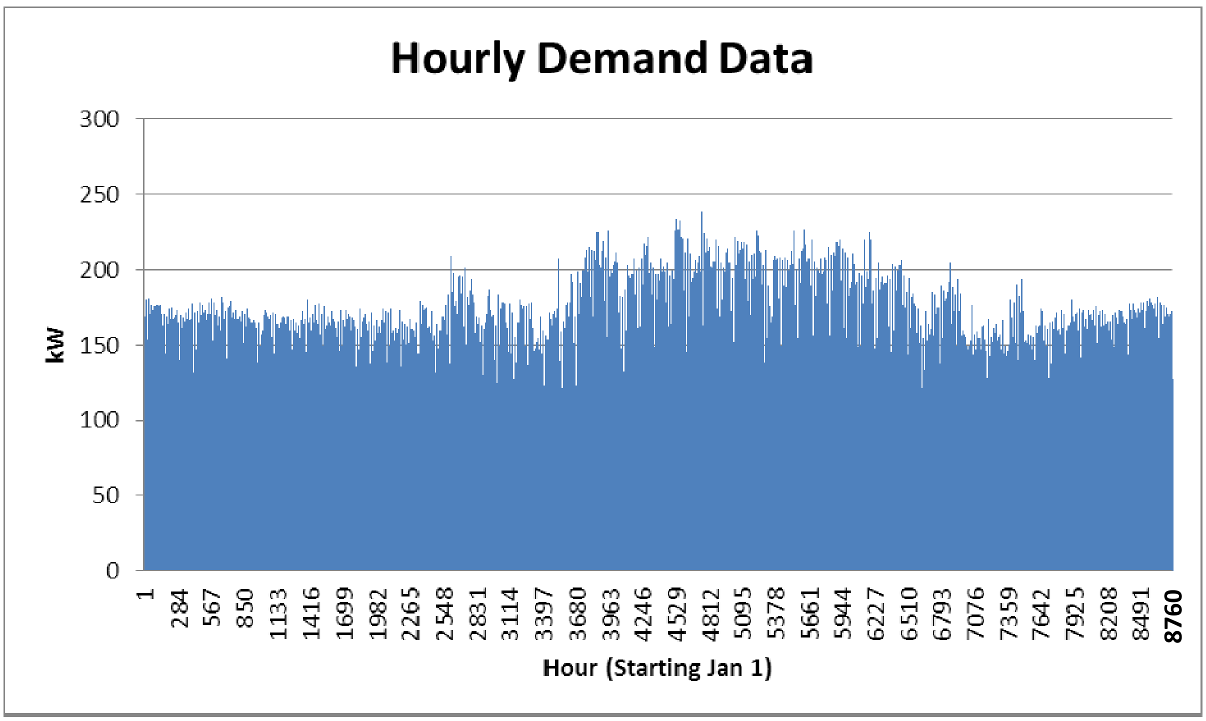


Figure 20. Hourly Demand Data for Sample Commercial Building Sorted – One Calendar Year

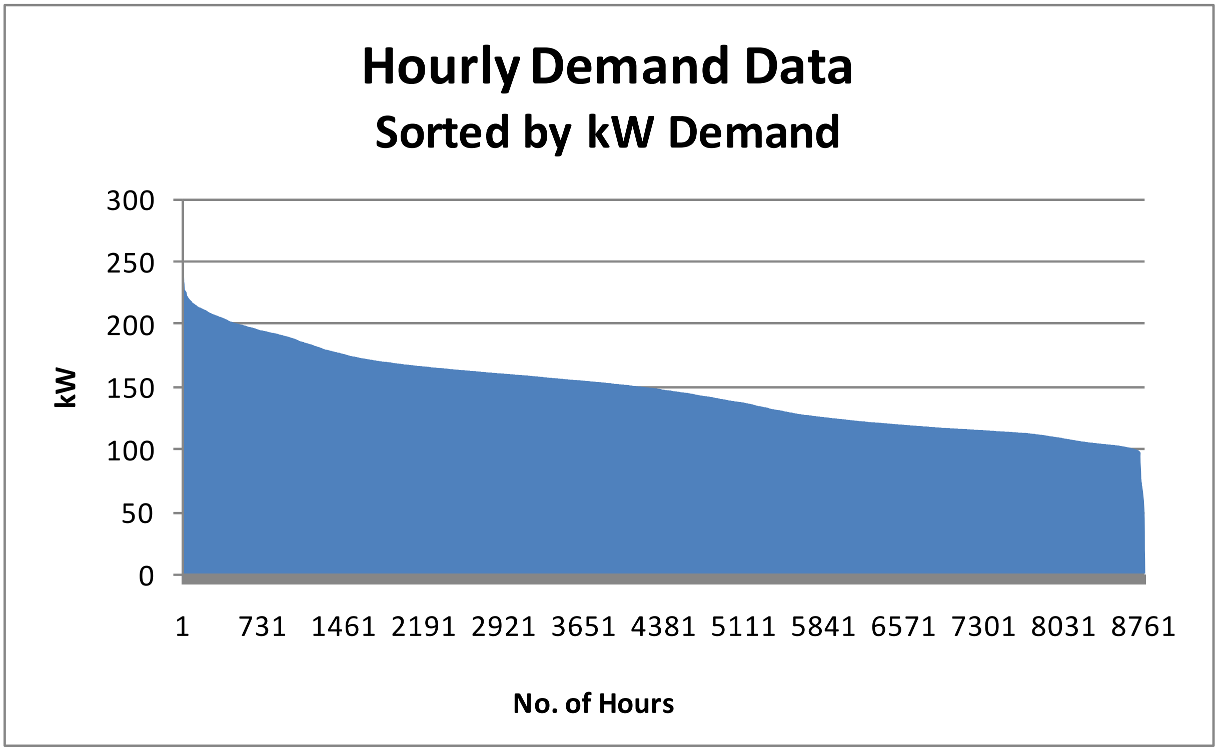
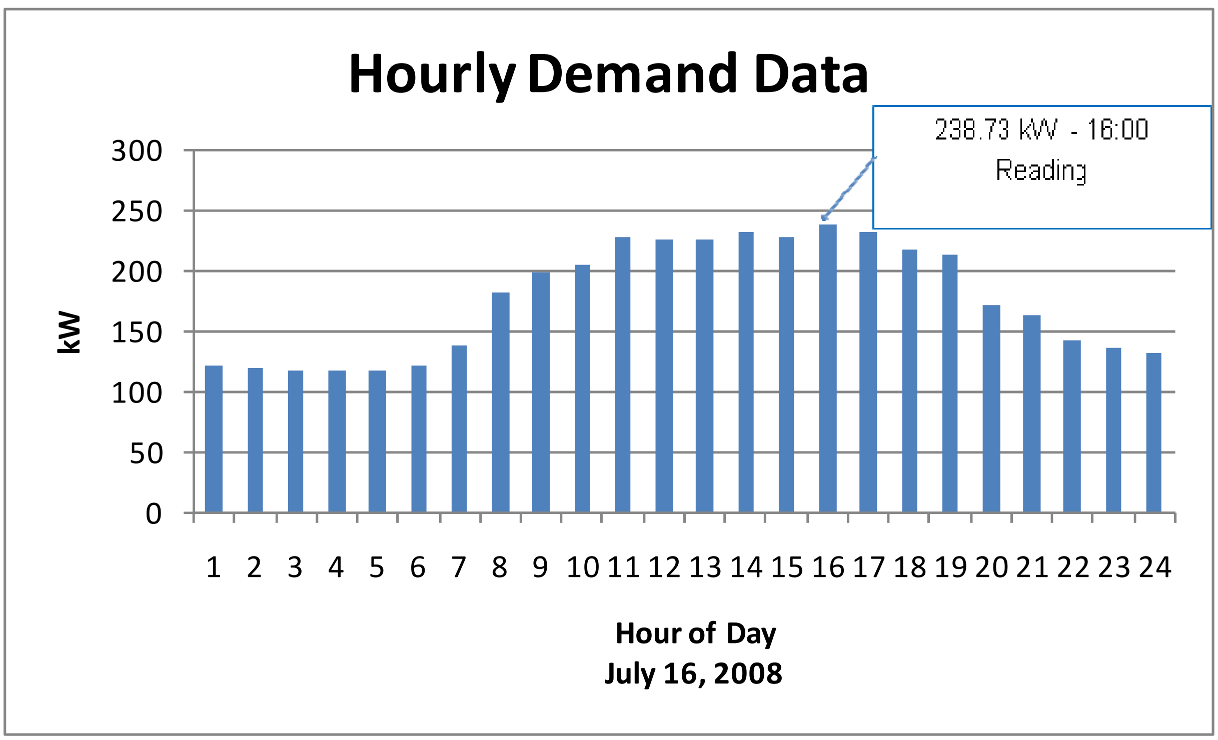


Figure 21. Hourly Demand Data – Peak Day of Year (July 16, 2008)



AC Output Filter

The output of the inverter contains L-C filters to smooth the output waveform and reduce harmonic distortion. The interconnection transformer can also aid in filtering harmonics.

Power Quality Requirements for Inverter

Power quality of any inverter based generator connected to the utility is subject to meeting the requirements of CSA Standard C22.2 No. 107.1-01 (Ref.-20). The CSA standard was developed for power inverters connected to the grid such as found in renewable generation applications.

Harmonics

Typically 5% current THD or less at full rated output is considered typical for inverters. At lower output, this value will typically increase since the absolute value of harmonic distortion changes little with current output.

Resonance

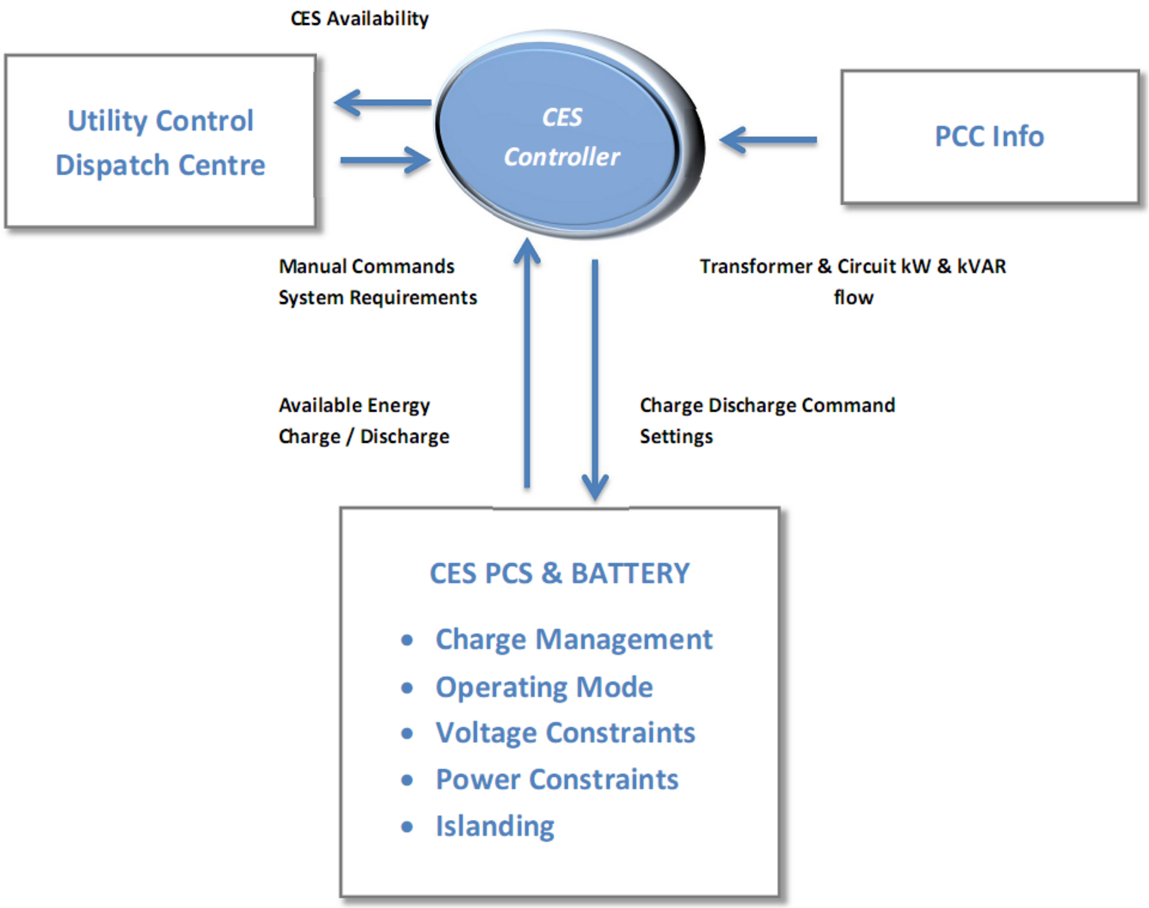
The effect of capacitance in the inverter circuit could introduce resonance in the AC circuit. Depending on the load in island mode, this effect could be enhanced. If this is determined to be an issue, additional output filtering may be warranted to mitigate resonance.

Control System

The basic controller may be either purchased off the shelf or commissioned from a variety of suppliers such as National Instruments, General Electric, Siemens, ABB and Schneider Electric. Custom programming of the controller would still be required to meet THESL's objectives. Other companies producing proprietary control technologies suitable for ES include S&C, Greensmith and Ionex (developed for their CES products). Since CES is a new concept, shopping for a suitable controller manufacturer may be a challenge. It is presumed that manufacturers who manufacture STATCOM and distributed energy storage systems are unlikely to sell their controller separately as the controller is the heart of their IP. Therefore, custom controller development is likely to be the only option open to THESL.

Figure 22 illustrates the basic CES control architecture which includes exchange between the CES, CES Controller, Utility Dispatch Centre and PCC.

Figure 22 CES Control Architecture



Since the STATCOM is a major part of the ES, a better understanding of its basic control functionality is presented. Numerous academic papers have been written on the subject of STATCOM. MATLAB® is the preferred modelling software package for analysing STATCOM control scenarios. However, no evidence could be found that the algorithms developed for the published papers were ever validated using actual hardware. Moreover, it is presumed the companies who manufacture STATCOM-based devices in the interest of protecting their controller IP and are unlikely to provide detailed models or algorithms. Appendix J is derived from a paper which covers the fundamentals (ref. -28).

Interconnection Equipment

Step-Up Transformer

While a transformer can be used to provide additional isolation from the distribution system, it is possible for the PCS to connect directly at low voltages. Introducing a transformer into the design increases the losses in and out of the PCS by about 2% each way, adding 4% to the overall losses. However, there may be instances when an isolating transformer is preferred especially when the STATCOM voltage is lower than the distribution voltage. Ideally, the transformer should be dry core for indoor or outdoor applications or oil filled for outdoor applications with a kVA rating to handle the highest anticipated output conforming to CSA efficiency standard CAN/CSA-C802.2-0639. Also a minimum K-factor[40] of K-13 is recommended to better tolerate harmonic currents generated in accordance with ANSI/IEEE C57.110-198641.

US companies such as S&C Electric build 480 VAC Distributed Energy Systems. A step-up transformer is needed for 600 VAC for typical Canadian commercial / industrial operation.

The isolating transformer need not be installed in the same cabinet as the PCS. However, for relatively low output voltage of the PCS compared to the distribution system, locating the transformer as close as possible to the PCS will help minimize line losses.

Harmonic injection attenuates above the 7th order value when an isolation transformer is used.

ES Monitoring Equipment

The ES monitors voltage and current both at the AC and DC bus. Temperature of the power semiconductor (IGBT) cooling system is also measured.

Communication

Communications may occur between the utility command centre and the ES, between the ES and the customer and between the command centre and the customer. The following section

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39 CAN/CSA-C802.2-06CSA "Standard Minimum Efficiency Values for Dry-Type Transformers"

40 Underwriters laboratory (UL) recognized the potential safety hazards associated with using standard transformers with nonlinear loads and developed a K-factor rating system to indicate the capability of a transformer to handle harmonic loads while operating within the temperature limits of its insulating system.

41 C57.110-1986 "IEEE Recommended Practice for Establishing Transformer Capability When Supplying Non-sinusoidal Load Currents".

discusses the communication protocols applicable for each type of communication as well as communication internal to the CES system.

Communication is essential between the ES and the utility command centre for:

- Protection and Control (P&C),
- Updating ES operational status and health,
- Setting kW output levels,
- Data logging,
- Charge initiation.

For security, Distributed Network Protocol 3 (DNP3) or IEC-61850 are acceptable between the utility and the ES. Between the ES and the customer loads, less robust communications such as Zigbee or Wi-Fi may be acceptable. Peer-to-peer communications speed for IEC-61850 should not exceed 0.004 seconds (Ref. -31). Communications are sent by a "GOOSE"[42]. Since messages are not confirmed by the receiving IED[43], multicasting is used in event the initial message indicating a change of state was somehow missed.

Figure 23 on the following page, illustrates a basic block diagram for the communications paths internal and external to the ES. Depending on the sophistication of the battery, direct communication may occur between the battery and inverter in addition to between the battery and BMS thus providing added security.

The preferred method of communications with a central control is wireless radio. Typically it is envisioned that a number of CES units will communicate bi-directionally with the CES regional control (Ref. -12).

The CES regional control uses a combination of Station / Feeder load data and signals from the utility distribution dispatch centre to control the individual CES units in accordance with a control strategy developed to meet the utility's needs while also managing the storage medium in accordance with the manufacturer's specifications.

Individual CES units are capable of providing power factor correction in accordance with pre-set limits. Feedback measurement at the PCC allows dynamic power factor correction without communication with the CES regional control.

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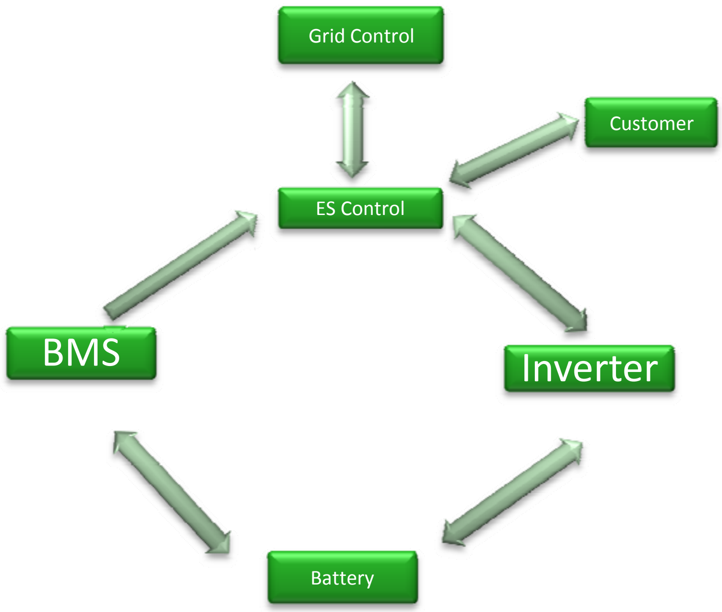
42 GOOSE – Generic Object Oriented Substation Event.

43 IED – Intelligent Electronic Device.

Figure 23. ES Communications



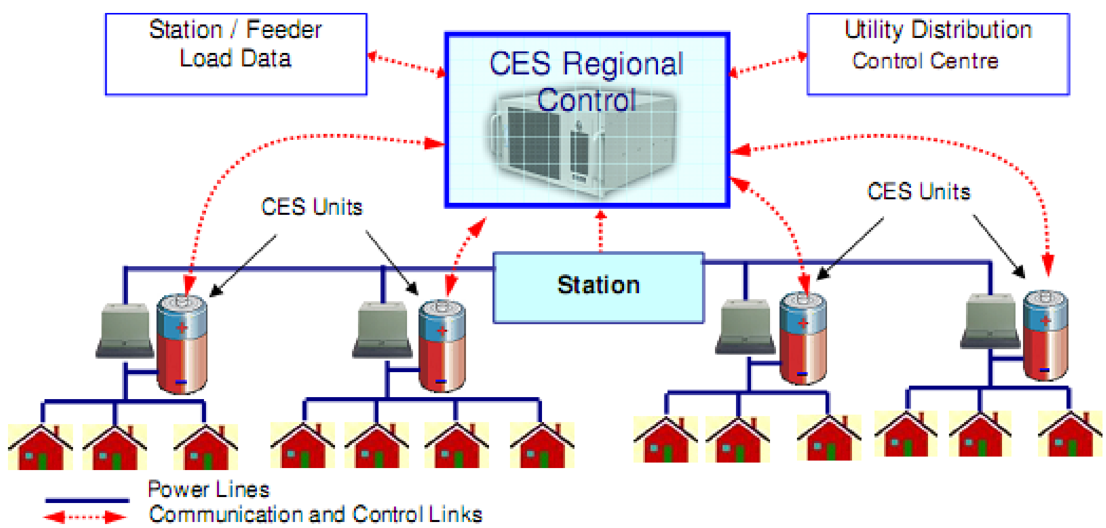
There are two competing communications protocols for utility communication with customers: Zigbee and Wi-Fi. Due to the low data rate requirements for the application, Zigbee "Smart Energy Profile 2" has become the preferred protocol of electric utilities for control and communications between utilities and customers. Coupled with home area network powerline devices conforming to HomePlug Powerline Alliance[44] standards, smart demand control of customer owned equipment can be achieved by the utility for future demand response programs (Ref.-11). Depending on the application, communication could be between the utility and the customer (e.g. broadcast load curtailment request) or CES and the customer (e.g. staged PHEV charging coordinated among customers on the same feeder).

For communication between the CES and utility control, more robust and secure protocols are preferred. The open specification produced by AEP for CES states "The preferred control interface protocol is Distributed Network Protocol 3 (DNP3). IEC-61850 is an acceptable alternative between the Hub and the CES Unit". The 'Hub' is envisioned as a self-contained control housed in an enclosure suitable for indoor or outdoor installation. It contains hardware

[44] HomePlug Powerline Alliance, Inc. is an industry-led initiative with more than 70 member companies that creates specifications and certification logo programs for using the powerlines for reliable home networking and smart grid applications. (www.homeplug.org).

and software components plus communications equipment including wireless and LAN to permit communications between the utility and the aggregated CES modules (See Figure 24).

Figure 24. CES Communication Concept (Ref. -12)



Communications between battery and BMS:

- Voltage: total voltage, voltage of periodic taps, or voltages of individual cells (monitor and control)
- Temperature: average temperature, air intake temperature, air output temperature, or temperatures of individual cells (monitor and possibly control by operating space conditioning – e.g. heating and cooling, fans) (monitor and control)
- Battery pressure (if applicable e.g. NiMH) (monitor)
- State Of Charge (SOC) to indicate the charge level of the battery (monitor)
- Charge current (monitor and control)
- Discharge current (monitor)

Communications between BMS and control system:

- State Of Health (SOH), a variously-defined measurement of the overall condition of the battery (monitor)
- Air flow: for air cooled batteries (monitor)

- Current: current in or out of the battery (monitor)
- Maximum charge current as a Charge Current Limit (CCL) (monitor)
- Maximum discharge current as a Discharge Current Limit (DCL) (monitor)
- Total energy delivered since manufacture (monitor)
- Total operating time since manufacture
- Over-voltage (during charging) (monitor)
- Under-voltage (during discharging) (monitor)
- Over-temperature (monitor)
- Under-temperature (monitor)
- Over-pressure (NiMH batteries)) (monitor)

Communications between control system and inverter

- Dispatch signal to inject a specified power level (control)
- Change Power Level output level (control)
- Reactive Power threshold set point (e.g. max-min)
- Cease output (control)
- Enter Island Mode (control)

Communications from grid to control system to CES:

- State of charge (monitor)
- Availability (monitor)
- Output contribution (kWh and kVARh) (monitor& control)
- Diagnostics data (monitor)

Other Considerations

Grounding

Grounding of the AC output of the PCS to the enclosure and to earth shall be in accordance with the requirements of standards IEEE C57.12.25. The battery terminals are not grounded and are left floating.

CSA C22.3 No. 9, Table C.1 discusses the pros and cons of the various interconnection transformer configuration and grounding arrangements for distributed generation sources (Ref. -32). The low voltage inverter side will most likely be grounded wye while the high voltage utility side could be either grounded wye or delta. Appropriate measures will need to be taken to ensure adequate ground fault protection is in place depending on the configuration used.

Isolation

A circuit breaker is normally placed at the output to isolate the CES in event of an internal fault. Semiconductor fusing is sometimes employed as well to protect the power electronics.

In the event of a supply interruption, a normally closed contactor in the CES would open effectively isolating the CES and downstream connected loads from the utility. This would permit continued supply to the connected loads until the battery is depleted or service is restored. This option would occur for an intentional islanding mode.

The transformer also provides isolation from the system.

Maintenance Considerations

A well designed ES should require little periodic maintenance. Batteries with interconnected cells may require annual checks to make sure connections are properly torqued. Batteries requiring more maintenance (e.g. electrolyte level checks) would likely be rejected as ES candidates.

The PCS portion is a low maintenance device. Annual maintenance consists of checking functionality and cleaning to remove dust accumulations which could impede heat transfer or become conductive. Some PCS may require changing of air filters and checking the coolant levels and inspecting for leaks. Electrolytic capacitors can degrade over time and may require periodic replacement per the manufacturer's recommendations.

Conceptually, the PCS would be a modular design such that components can be easily removed from the ES for replacement or service. Any maintenance would be performed on the module at a repair depot. Therefore, field repair would consist of replacing the affected PCS modules only.

If the entire PCS needs to be taken out of service, isolating breakers with visible contacts for both AC and DC circuits would facilitate isolating the PCS.

Applicable Tests and Standards

The following tests and standards are deemed applicable for ES. The list is based on the referenced standards in the AEP document (Ref. -11). One additional column has been added to the table "Canadian Equivalent or Additional Applicable International Standard". As well, Appendix E lists all IEEE standards (existing and proposed) deemed applicable to development of a smart grid (Table E-1).

Although the listed standards are applicable to ES in terms of construction, safety and general functionality, there is no standard for ES that meets all potential utility requirements at this time. Utility interactive inverter functionalities listed in UL 1741 (Ref. -21) and C22.2 No. 107.1-01(Ref.-20) have several specific requirements related to anti-islanding functions that would not meet ES requirements. For example, a utility may wish an ES to continue to feed power to a fault to help ride through whereas in accordance with the UL and CSA inverter standards, the ES would isolate itself from the line in order to be fully compliant. Therefore, designing a prototype ES to meet THESL's functionality requirements may mean that certain departures from the standards will be needed until a specific standard can be developed. IEEE 1547.4 currently under development, focuses on intentional islanding requirements[45].

The Ontario Electrical Safety Code (Ref.-17), Section 26-540 – "Storage Batteries" is primarily devoted to battery rooms and their safety requirements. Such standards and their equivalent in the US (NEC) were originally prepared based on lead acid or equivalent batteries such as alkaline. Section 86 "Electric Vehicle Charging Systems" has similar concerns based on these technologies. Combustible gases, electrolyte spills and low ambient temperature conditions are stated concerns which could be interpreted to require ventilation, spill containment, space conditioning etc. Battery technologies such as Li-Ion, NaS and ZnBr may not have these issues but could have other specific requirements peculiar to their technologies. Interpretation of safety codes has been an issue in the large UPS market USA (Ref.-18). Since there is little experience with advanced storage technologies in Ontario, some code related issues may emerge due to interpretation of existing standards. Revisions to these standards or preparation of ESA Safety Bulletins may be warranted to help avoid confusion and possible delays in implementation of hardware in future.

45 1547.4 - DR Island Systems

Table 19. Relevant CES and PCS Standards

	US Standard	Description	Canadian Equivalent or Additional Applicable International Standard
1 .	ANSI/IEEE Std C2-2007 TM	National Electrical Safety Code.	CSA Canadian Electric Code Part I
2.	ANSI C57.12.25-1990	Pad-Mounted Transformer Requirements	CSA C227.3
3.	ANSI C57.12.28-2005	Pad-Mounted Equipment Enclosure Integrity	CAN/CSA-C88-M90
4.	ANSI Z535 – 2002	Product Safety Signs and Labels.	CAN/CSA Z321-96
5.	FCC Sections 15.109 & 15.209	FCC Code of Federal Regulations Radiated Emission Limits; General Requirements.	CAN/CSA C108.3.1-M84 (R2000)
6.	IEEE Std 519-1992 TM	IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems.	CSA C22.2 No. 107.1-01
7.	IEEE Standard 1547-2003 (R 2008) TM	IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems.	C22.2 No. 257-06 and C22.3 No. 9
8.	IEEE Standard 1547.1-2005 TM	IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems	Currently being reviewed to be harmonized with C22.2 No. 107.1-01

	US Standard	Description	Canadian Equivalent or Additional Applicable International Standard
9.	IEEE Standard 1547.2-2008 TM	Interconnecting Distributed Resources with Electric Power Systems	C22.2 No. 257-06 and C22.3 No. 9
10	IEEE Standard 1547.3-2007 TM	Guide for Monitoring, Information Exchange, and Control of Distributed Resources Interconnected with Electric Power Systems in addition IEEE 1547.4, 5, 6, 7 and 8 are presently in draft form: 1547.4 - DR Island Systems 1547.5 - Transmission Electric Power System Interconnection 1547.6 - Distributed Resources Interconnected with Distribution Secondary Networks 1547.7 Draft Guide to Conducting Distribution Impact Studies for DR Interconnection 1547.8 - Recommended Practice for Establishing Methods and Procedures that Provide Supplemental Support for Implementation Strategies for Expanded Use of IEEE Standard 1547	IEC 61850 Part 7-420 DER
11	IEEE C37.90.2-2004 TM	IEEE Standard Withstand Capability of Relay Systems to Radiated Electromagnetic Interference from Transceivers.	IEC61000-4 Section 3
12	IEEE Std. C37.90.1-2002 TM	IEEE Standard for Surge Withstand Capability (SWC) Tests for Protective Relays and Relay Systems (ANSI).	IEC61000-4 Section 5

	US Standard	Description	Canadian Equivalent or Additional Applicable International Standard
13	IEEE Std. C62.41-1991(R 1995) TM	IEEE Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits.	IEC 61643-1, First Edition, 1998
14	IEEE Std. C62.41.1- 2002 TM	IEEE Guide on the Surges Environment in Low-Voltage (1000V and Less) AC Power Circuits.	NA
15	IEEE Std. C62.41.2-2002 TM	IEEE Recommended Practice on Characterization of Surges in Low-Voltage (1000 V and Less) AC Power Circuits.	NA
16	IEEE Standard C62.45-2002 TM	IEEE Recommended Practice on Characterization of Surges in Low-Voltage (1000 V and Less) AC Power Circuits.	NA
17	NFPA 704	Standard System for the Identification of the Hazards of Materials for Emergency Response.	WHMIS
18	Smart Energy Profile (SEP)	Standard system for communication with demand side management equipment	NA
19	Uniform Building Code	Applicable to seismic rating (i.e., up to 5% peak acceleration with 10% probability of being exceeded in 50 years)	NA
20	UL 1778	Underwriters Laboratory's Standard for UNINTERRUPTIBLE POWER SYSTEMS (UPS) for up to 600 V AC.	C22.2 NO. 107.3-05 (R2010)
21	UL 1741	UL Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources	C22.2 No. 107.1-01

	US Standard	Description	Canadian Equivalent or Additional Applicable International Standard
22	NEC 480-1 to 480-9	Storage Batteries, Battery Rooms, etc.	C22.1.09, 24th Edition 2009 - Section 26-540 – "Storage Batteries"

Discussion of ES Sizing

The amount of space needed for the ES will depend on the storage density of battery technology selected plus the kVA rating of the inverter and transformer. Compared to the energy density of diesel fuel, all storage technologies described in this report have relatively low energy densities such that floor space and volume become major factors when scaling up storage capacities.

THESL has expressed an interest in larger sizes of ES targeted at commercial / industrial applications. The footprint of integrated packages exceeding even 25 kVA quickly becomes too large for residential or small commercial ES. Increasing the power or storage size greatly affects the size of the package. The industry has referred to the larger size units as "distributed energy storage systems" or DESS although the term has also been used interchangeably with ES.

A local PCS (Power Conversion System) manufacturer was contacted for this investigation to gain a better understanding of dimensional specifications for a 250 kW PCS rated for utility connection. The company recently designed an indoor 250 kVA inverter with the specifications listed in Table 20.

Table 20. Sample Specification for a 250 kVA Battery Power Conditioning System Inverter[46]

Parameter	Value
DC Voltage Range	360 – 500 VDC
DC Voltage Nominal	480 VDC
Current (Max) Bi-directional	625 A DC
Rated Power – Continuous	250 kW / 250 kVA
Rated Power - 10 seconds	300 kW / 350 kVA
AC Rated Voltage – Single Phase +/- 10%	240 VAC
Real Power Regulation (% rated output)	2 %
Reactive Power Regulation (% rated output)	2 %
Output current distortion	5 %
Rated output frequency	60 Hz
Efficiency - full load	96 %
Isolation	DC fuse, motorized AC LV breaker, motorized DC disconnect switch
Ambient temperature – operating (designed for indoor operation- external operation is possible if glycol -water liquid cooling is employed and appropriate NEMA cabinetry is used instead).	0 – 45°C
Ambient temperature - storage	-55°C - +60°C
Relative Humidity (non-condensing)	95 % RH

[46] Telephone discussion with Vince Scaini, Manager, IE Power, Nov 17, 2010 re large community energy storage.

Parameter	Value
Location[47]	Indoor
Enclosure	NEMA 1
Dimensions (nominal)	40" W x 48" D x 85" H
Weight (approx.)	4500 lbs.
Location	Indoor
Enclosure	NEMA 1
Transformer Dimension (nominal)	40"W x 37"D x 46"H
Weight (approx.)	2300 lbs.

The specification in Table 20 is for a custom unit built using standard manufacturing methods. The manufacturer claims it may be possible to shrink the PCS size by 25 – 40% depending on final requirements including battery type in a commercialized version. However, there is little that can be done about reducing the transformer size. This example puts into perspective the scale of PCS for a 250 kW low voltage ES. Battery dimensions are not in the specification. For comparison, a 1.5 MW PCS, 480V AC output with 2000A DC bus would have nominal dimensions[48] of 85" x 85" x 61" not including the isolation transformer.

Examples of Actual CES/ES Sizing

AEP's vision for residential storage is presented in the CES functional specification as a 25 kW / 25 kWh unit. Eventually, the capacity ratio may increase to 25 kW / 75 kWh. The intent for the initial 25 kW / 25 kWh units are to provide approximately a 1 hour backup to approximately 5 connected residential houses. With typical residential load diversity, this operation could be placed in an islanded mode for the discharge duration. Table 21 lists nominal dimensions of actual relevant equipment.

47 This real example is intended for an indoor application. Changes to cabinet selection, cooling, etc. would be needed to site the equipment outdoors. However, it serves to provide an example of dimensions, etc. for equipment of this power rating.

48 Phone conversation with Vince Scaini, IE Power, Dec 13, 2010 describing nominal dimensions of an actual PCS being built for a customer.

Table 21. Nominal CES/ES Dimensions

Company	Size		Nominal Dimensions (inches)		
	kW / kVAR	kWh Size	Width	Depth	Height
AEP (spec)	25	25	38	40	35
AEP (spec)	25	50	38	50	35
AEP (spec)	25	75	38	50	42
S&C Electric (above ground approx. dimensions)	25	25	~36	~48	~30
Greensmith Energy Management Systems	5	20	53.1	24.5	40
IE Power (PCS only)	250	NA	40	48	85
S&C SMS™ (PCS only)	2000	NA	240	59	111

Figure 25 and Figure 26 below illustrate three permutations of CES sited on distribution network feeders. To meet the physical size requirement at this time, each CES would be relatively small in terms of kVA output and kWh storage capacity.

Figure 27 is the prototype 25 kW CES being built for AEP's pilot program by S&C Electric. The photo is the above ground PCS. The below ground battery compartment is a separate enclosure. Additional photos of the first prototype installation are included in Appendix G.

At the other end of the spectrum is S&C's 2 MW Smart Grid Storage System (Figure 28) which is sometimes referred to as a DESS (Distributed Energy Storage System). The latter, coupled with appropriate storage capacity can supply a feeder for hours at 2 MW or up to 2 MVA.

Figure 25. **CES as Padmount with Pole-top Transformer or CES Pole-top with Pole-top Transformer (Ref. -12)**

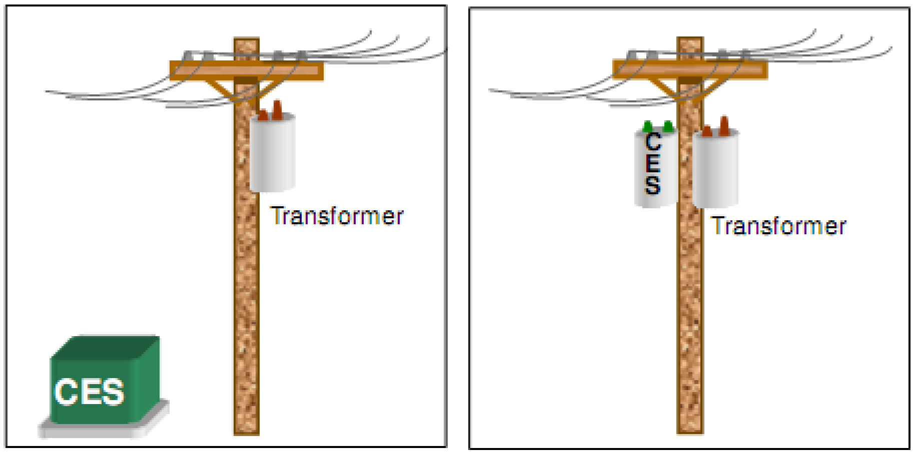


Figure 26. Padmount Community Energy Storage next to Padmount Transformer (Ref. -11)

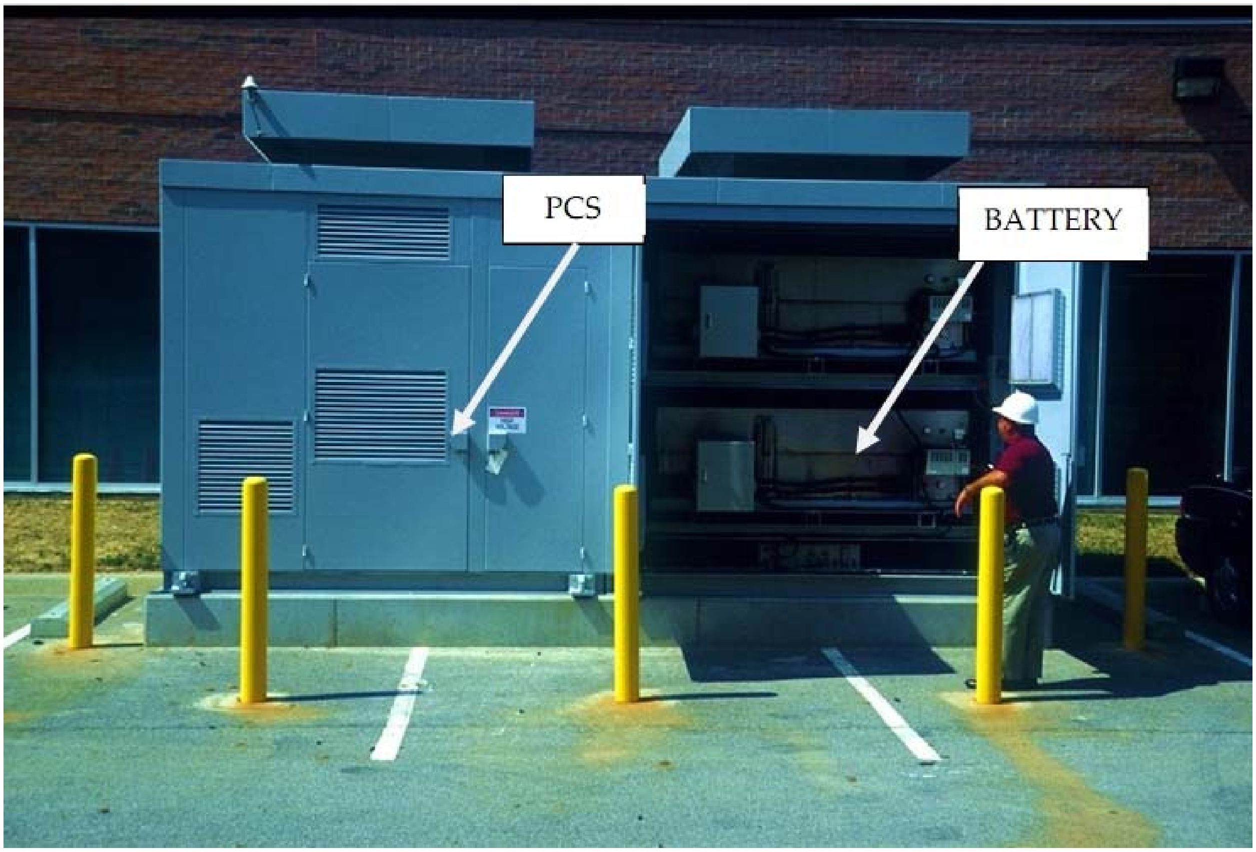
Figure 27. Prototype CES Unit (Ref.-16)

Figure 28. S&C 2.0 MW / 2.5 MVA Smart Grid SMS™ Storage Management System (Ref.-15)

Placement of the CES on a feeder as close to the customer is essential. This improves the customer's power quality and reliability, particularly if the CES can provide a temporary island in event of loss of the feeder supply.

AEP, who are credited with installing the first NaS DESS (Distributed Energy Storage System) in North America (Ref.-14), installed a 100kW pilot at an office building located in Gahanna, OH in 2002 (Figure 29 and Figure 30). The DESS was designed to provide peak shaving for up to 7.2 hours, with 500 kVA for up to 30 seconds for power quality. Note that the orientation chosen ended up requiring the equivalent of three parking spaces.

Figure 29. AEP's 100kW - 7.2 hr / 500kVA - 30s NaS Battery - Gahanna, OH 2002 (Ref. -14)



THESL envisions a 500 kVA distributed storage system for a pilot installation at a site to be determined. A sample purchasing specification is provided in Appendix H. The unit is capable of delivering a combination of real and reactive power up to 500 kVA. Lower real power output allows for higher reactive component. The storage system requires an external controller to set input and output parameters including real and reactive power injection and battery charging. The controller uses measurements taken at the point of common coupling plus commands initiated from central dispatch. Examples of controller I/O being employed in US CES pilot projects are discussed later in the report. Similar I/O could be developed for THESL's pilot requirements.

Figure 30. Inside View of 500 kVA PCS Provided by ABB for AEP Pilot

A 1.2 MW, 7.2 MWh peak shaving DESS was installed at AEP's Chemical Substation in June 2006 (Figure 31). The site was selected due to the stressed transformer and voltage regulator during the summer peak. Capital deferral of substation upgrades was the prime motivator.

Substantial site preparation was needed to support the battery's seventy-seven ton weight.

The 2006 report stated the predicted future price for an installed NaS system would be $2,500/kW US (Ref. -14). Since a 50 kW NaS module stores 360 kWh, the predicted cost per kWh would translate into $347/kWh US.

Figure 31. AEP Distributed Energy Storage (1.2 MW 7.2 MWh NaS Battery) S&C / NGK

An American Electric Power facility in Milton, West Virginia, was selected for one of the three projects. The storage system was designed to improve reliability for a radial feeder by controlling the feeder in basic elements (teams) and by providing an alternate source, the DESS. Teams are groups of IT-II[49] devices. The devices communicate with each other using UtiliNet spread-spectrum radios. Each team knows (in real time) how much load is being served. When a fault takes place, it is isolated and IT-II restores power to the non-faulted sections of the feeder by supplying the load from the DESS, creating an islanded grid section.

The system will only pick up as much load as the NaS battery has capacity to carry at the time of the fault. The system has the intelligence to monitor the load feeder and the capacity of the NaS battery. It will shrink the island to fit the capacity of the NaS battery as the outage begins to deplete the capacity or the load increases.

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49 IT-II – S&C IntelliTEAM **II**® distributes the intelligence needed to reconfigure feeders among the typical devices used for protection and sectionalizing the feeder and allows the IED's to communicate via PTP.

6. Planning and Operations (Part C)

The following focuses on a 250kW/250kWh lithium polymer system but also presents issues associated with other types of ES systems.

Site Selection

Because of the larger proposed size (250kW), NCI recommends that the proposed system be installed on a three phase feeder, relatively close to the load. Where single-phase devices are installed on feeders laterals, phase balancing studies should be performed and load transfers made to achieve minimal phase imbalance. Further, to minimize losses and improve voltage profiles, CES should be located near loads that are relatively close to the rating of the device.

For larger ES systems (e.g., greater than 1 MW), it is desirable to locate the device in a manner that will have the most impact on voltage profiles and line losses. For example, if feeder loads are near the end of the feeder, install the ES system near the end of the feeder as well; whereas, where loads are concentrated near the substation exit, the device should be located close to the substation. In the latter situation, installation within the substation fence is desirable if sufficient space is available to install the ES.

For the same kVA rating, a single phase CES will be slightly larger than a 3-phase unit. The single phase current is higher plus more filtering is required for harmonics which adds to the lower ripple frequency. Therefore, more space may be required to accommodate a single phase unit.

Sizing of Storage System and Power Conditioning

The ES capacity and energy requirements will differ depending on the type of application, as discussed above and summarized in Table ES-1 and elsewhere in this report.

For the purposes of this review, we have focused our discussion on a system with 250kW of capacity capable of one hour of output (i.e. 250kWh output) installed on a three-phase feeder. Accordingly, the following features and performance attributes should be considered:

- Power Conditioning - Inverter specifications should be designed to control harmonics and power factor,
- install an isolation transformer which may also perform a step up function (e.g. 480 V to 600 V),
- Inverter sizing should be matched with CES rating, as over-sizing can substantially increase losses,

- Consider a modular design to allow appropriate inverter size for different operational needs.

Power Quality

The following subsections address the various considerations and issues for CES regarding power quality. A CES should not degrade power quality and, if designed and controlled correctly, should substantially improve voltage regulation, flicker, unbalance, and harmonics.

Point of Common Coupling

The concept of the point of common Coupling (PCC) should be reviewed prior to discussion on the contribution of CES to the aspects of P&C. Choosing the location for the PCC relative to the CES will determine the effectiveness of buffering intermittency and load shaving.

Figure 32 and Figure 33 illustrate two scenarios for the PCC. The first is at the distribution transformer primary while the second is at the distribution transformer secondary. Locating the PCC on the primary would result in a CES that is less responsive to the local PQ conditions that the CES is intended to correct. As well, the CES may try to respond to conditions occurring on the feeder primary, which may not be optimal for the bus it is connected to. Conversely, locating the PCC on the secondary of the transformer would provide effective feedback for V – I conditions on the feeder which would better serve THESL's objectives to buffer intermittency of supply, enhance asset utilization, reduce system losses, and mitigate power quality issues.

When the PCC is located on the secondary of the distribution transformer along with the CES, the control can then instantly determine the effect of injecting real and reactive power into the line. The CES sends its output data to the controller which combined with the measurement at the PCC instantly calculates the difference between the feeder load and CES injection.

In order for a CES to be effective in mitigating power quality issues, monitoring the PCC is necessary. A number of control scenarios are possible:

- The utility monitors the PCC issuing manual commands to the CES. This would likely be in the form of a step function containing min-max settings,
- The CES injects real and reactive power into the line via auto control using data from PCC plus built in algorithms,
- A combination of both remote and local control.

Figure 32. Point of Common Coupling at Transformer Primary Where Multiple Customers are Served

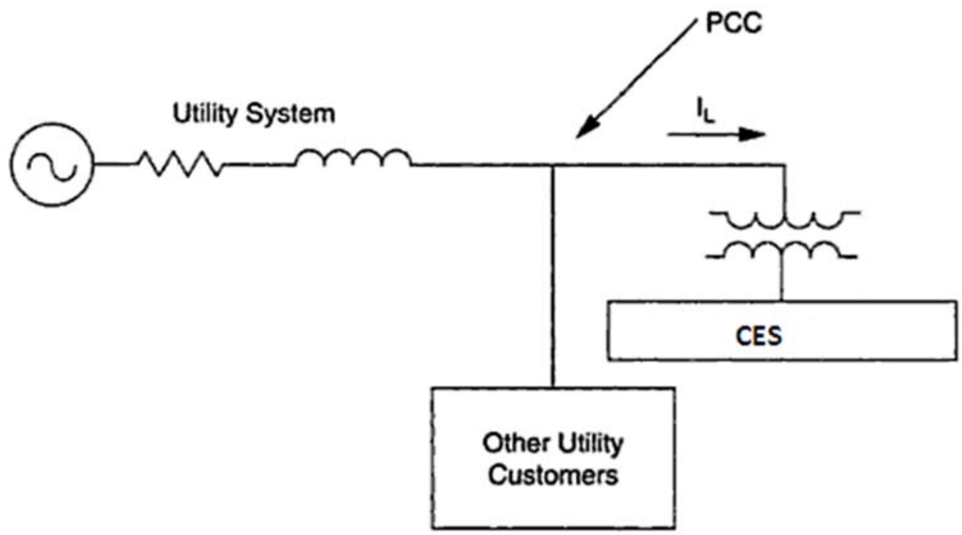
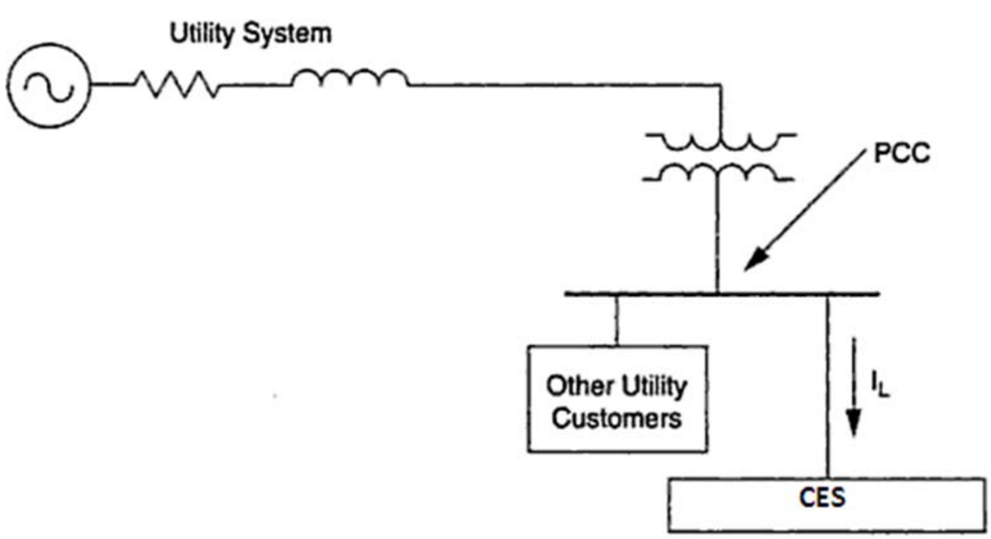


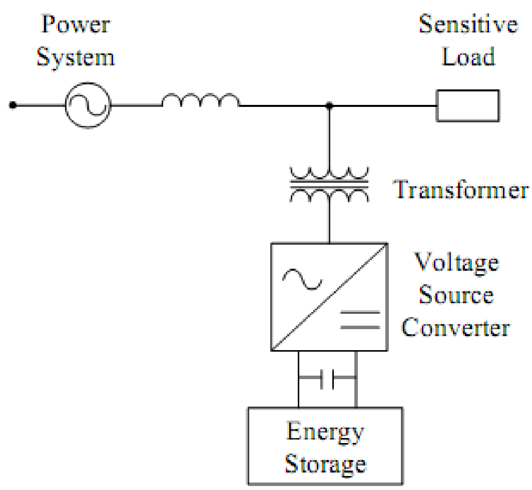
Figure 33. Point of Common Coupling at Transformer Secondary Where Multiple Customers are Served



Voltage Regulation

Battery storage can be used to provide voltage regulation by injecting real and reactive power into the feeder via a shunt connection by means of a tie reactance as illustrated in Figure 34. To obtain the maximum effectiveness, the STATCOM should be connected as close to the sensitive load as possible.

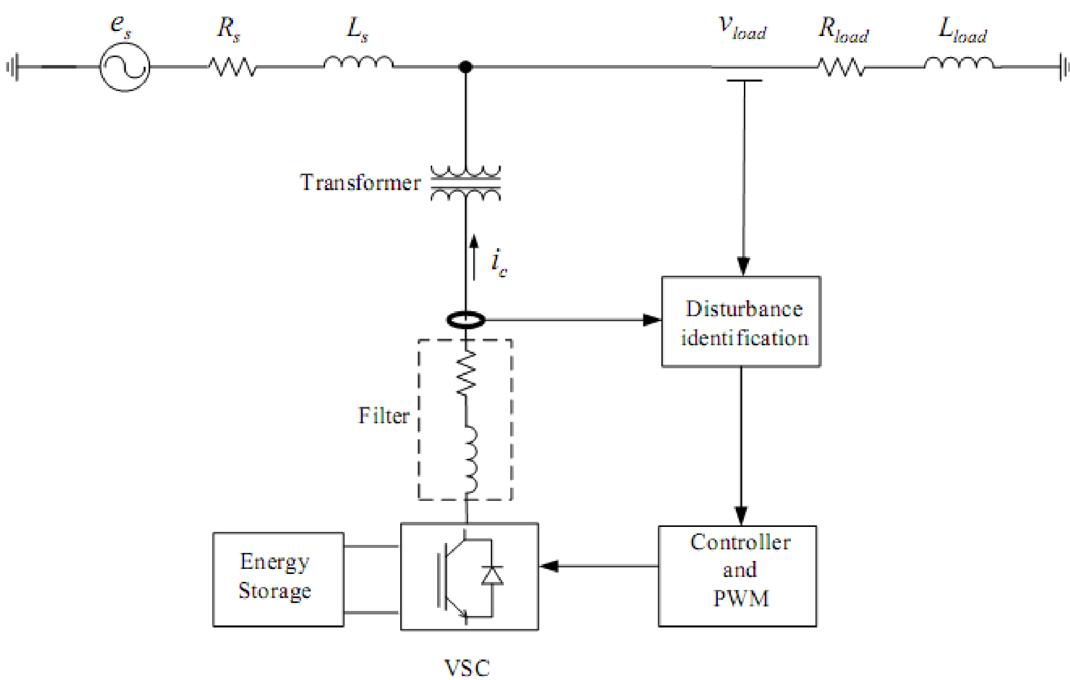
Figure 34. Voltage Regulation Using STATCOM



The contribution of the STATCOM to the load bus voltage equals the injected current times the impedance as seen from the device, which is the source impedance in parallel with the load impedance.

Figure 35 below illustrates the block diagram topology for using a STATCOM for mitigating voltage sags at the load. The STATCOM uses stored energy from the battery to inject current into the feeder to compensate for the voltage drop.

Figure 35. STATCOM for Voltage Sag / Dip Mitigation



Shunt compensation current from the STATCOM is inversely proportional to the impedance, which is the source impedance in parallel with the load impedance. Therefore, shunt compensation current increases when load power factor and source impedance decrease (Ref -3).

Power Flow Variations

Storage on distribution feeders can be set to compensate for power flow variations as needed to maintain power quality on the feeder. However, unless the utility signals the storage device to inject energy into the feeder when network constraints dictate, performing this action automatically is not advisable as constant deep cycling of any battery technology reduces its life and leaves the feeder vulnerable to power line disturbances when the battery charge is depleted.

Injecting power into a local feeder will appear to the substation as a reduction in customer load on the feeder, providing the injected power level is equal to or less than the output of the storage device. If the power consumed by the customers is less than the storage device output, then the power would flow into the substation from the feeder, such as would occur from excess embedded customer generation.

In instances where customers have renewable energy sources connected to the distribution feeder, the storage device can act as a buffer for local distribution power flow. For such applications, sizing of the storage in terms of capacity and power rating to mitigate variations in power flow are dependent on the penetration level of the DG plus the stiffness of the feeder. As well, ramp rate indexes over time are a better indicator for CES response than instantaneous measurements. To be effective for absorbing excess generation capacity, the battery should be scheduled to be in a partially discharged state to ensure charge acceptance. The charge acceptance for many battery chemistries tends to diminish at the upper end of the charging cycle.

Experience from studies of wind farm output compensation using storage would suggest the algorithms used for setting power flow limits for handling fluctuations should be set to target only specific power flow indexes to keep the duty cycle of the storage device down (Ref. -4).

Load Power Factor Consequences

When the storage device is operated as a STATCOM near a customer, load power factor seen at the supplying substation will appear closer to unity than would have occurred without the device. The degree of improvement will be limited by the rating of the STATCOM for injecting positive kVAR's into the feeder relative to the negative kVAR's from the customers' aggregated load.

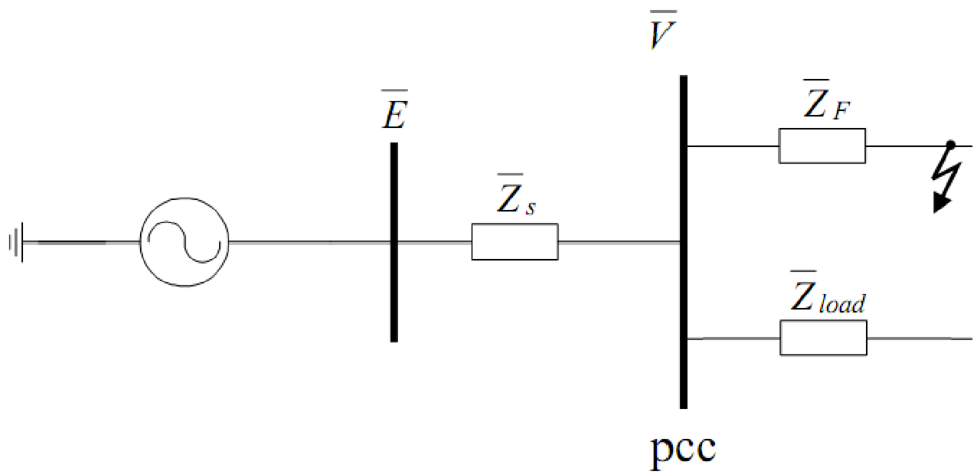
CES is typically rated in kW and kVA where kW typically equals kVA since the PCS is a current limited device. Therefore the VAR output of the CES will dictate the maximum real power output in kW. In instances where the selected battery is unable to deliver the maximum rating of the PCS, then the kVA rating may be higher than the kW rating. For example, the maximum continuous battery output could be rated at 250 kW. The inverter could be rated at 350 kVA to handle brief allowable real power overload output (e.g. 350 kW for 30 seconds). If adequate inverter cooling is provided, the inverter could supply 250 kW and 245 kVAR continuously (i.e. 350 kVA total).

Voltage Sags and Swells

Previous sections have addressed the functionality of the storage device to handle voltage sags. Injecting reactive power into the feeder will compensate for voltage dips or sags depending on the source and load impedance. This function is aptly handled by the CES unit operating in STATCOM mode. The response of the unit is dependent on the rate of sag and the control settings. Commercially available STATCOM's can provide continuous voltage support down to as low as 0.4 p.u. providing the power supply remains at nominal voltage (Ref. -6)

The most common causes of over-currents leading to voltage sags are motor starting, transformer energising, overloads and faults. Two impedances are connected to this bus (Figure 36). One is the source impedance Zs, which is the equivalent impedance of all the power system impedances upstream of the PCC, including the short circuit impedances of network and transformer, etc. The fault impedance Z_F, represents the impedance of the power system between the fault location and the PCC. Z_{load} is the downstream load impedance.

Figure 36. Voltage Sag at PCC



Assuming the supply voltage stays constant at all times, the voltage sag can be simplistically defined as:

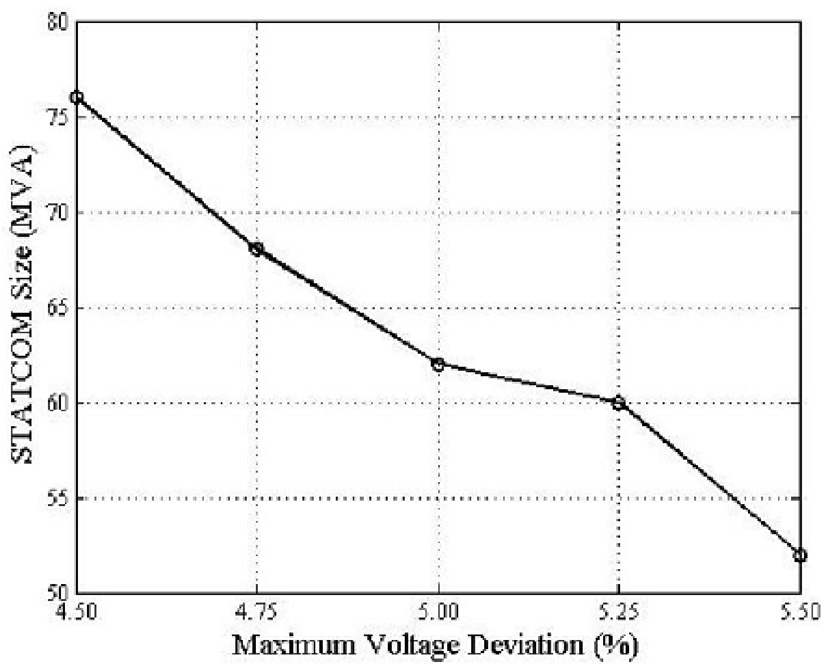
$$\bar{V}_{sag} = \bar{E} \times \frac{\bar{Z}_F}{\bar{Z}s + \bar{Z}_F}$$

The voltage dip magnitude is the absolute value of the phasor , V_{sag}.

The STATCOM needs to inject sufficient current to restore V_{sag} to the normal range of "1 p.u." voltage plus or minus 6% (e.g. 0.94 pu). This "difference or boost voltage" would be achieved by a STATCOM current multiplied by the source Z_s impedance in parallel with the load impedance Z_F. Therefore, without the circuit impedance, the effectiveness of the STATCOM is not possible to accurately predict. The closer the disturbance causing the voltage dip to the CES, the higher the current that must be injected to raise the voltage since the shunt injected current from the CES is inversely proportional to the circuit impedance. Careful measurement of a potential feeder is needed to determine CES sizing and effectiveness for voltage sag correction.

Effective mitigation of voltage sags using STATCOM requires careful sizing and placement. An analysis technique called particle swarm optimization (PSO) has been used for sizing and locating STATCOM (Ref.-27). When applied to power systems, the analysis models the stochastic changes that can occur. The paper models a section of a Brazilian power network with ~9,000 MVA generation capacity and determined that the optimum STATCOM was 62 MVA placed at a single location to regulate within +/- 5% of the nominal voltage. To illustrate the criticality of the setting of the regulation limits, the researchers found that improving regulation by a mere 0.5% increased the STATCOM power requirement by 22.6% (Figure 37). The maximum voltage change occurred on the bus the STATCOM was installed on (0.0288 p.u.) with voltage effect being lower as the distance from the STATCOM increased. This example serves to illustrate the impact of a STATCOM for a specific example. Effectiveness of a STATCOM on THESL's network would need to be analyzed.

Figure 37. STATCOM Size Vs. Maximum Voltage Deviation (Ref. -27)

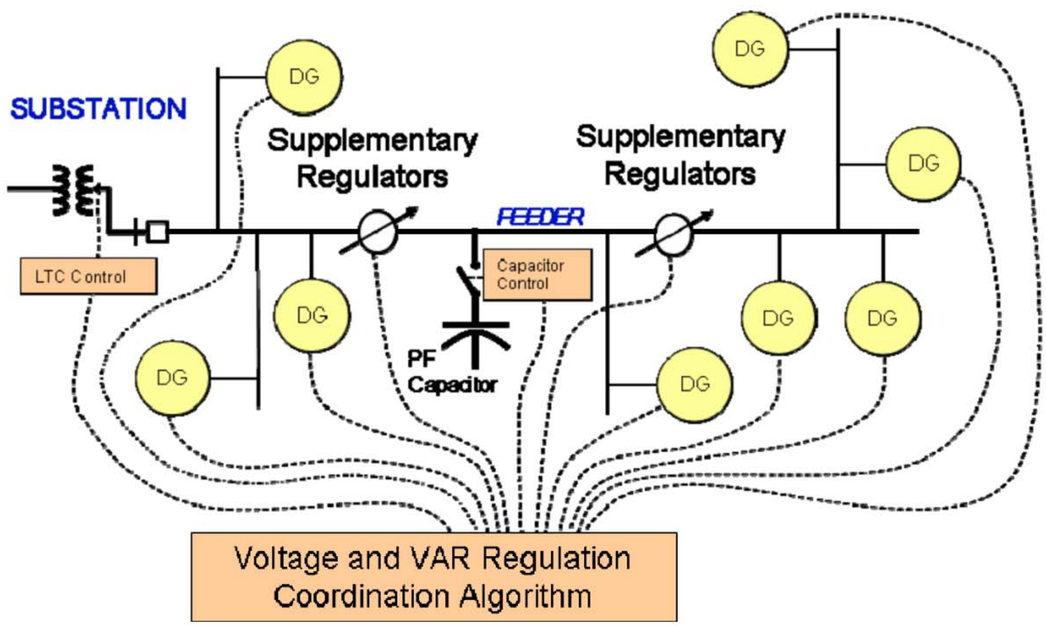


The occurrence of a voltage swell can be the result of suddenly switching off a large load on the feeder or switching on capacitor banks or a fault on one phase. Voltage swells or surges are less frequent events than voltage sags. A STATCOM can inject reactive power into the feeder to reduce the swell. The storage aspect of the battery can also lower voltage by presenting a load to the feeder but the latter's ability is dictated by the state of charge of the battery at the time of the incident. The charge acceptance of a fully charged battery is typically low compared to a discharged battery so this mode of operation cannot be depended on for handling voltage swells. In order to handle both sags and swells in a wind farm application, the battery is purposely kept at approximately 50% state of charge.

If the system impedance is low, the ability of the STATCOM to mitigate swells would be limited. In such cases, combinations of the parallel STATCOM with a series-connected SVC (Static VAR Compensator) may be a better solution for applications where voltage swells are a concern. (Ref -5).

Figure 38 below illustrates coordination of Voltage and VAR regulation employing communication from the connected DG to transformer tap changers, line voltage regulators (supplemental regulators) and switched capacitance. A CES could achieve similar functionality. Receiving voltage and current data from the individual DG could be an improvement over a single point measurement at the PCC.

Figure 38. Distributed Controller to Manage Power and System Voltage Profiles (Ref.-25)



Note: LTC = load tap changing

Fault Ride Through

Utilities may find it beneficial to have the CES continue to stay connected during grid failure. This action is sometimes referred to as Fault Ride Through (FRT). This action does not establish an island mode when a low voltage disturbance occurs. Instead, the inverter stays connected to the grid for a set time to assist in clearing a fault. To avoid damage occurring to the PCS, the output current is limited by reducing the voltage accordingly. The advantages of FRT are:

- Faster recovery of the grid after grid failures
- Reactive current supply in the event of dramatic voltage drops.

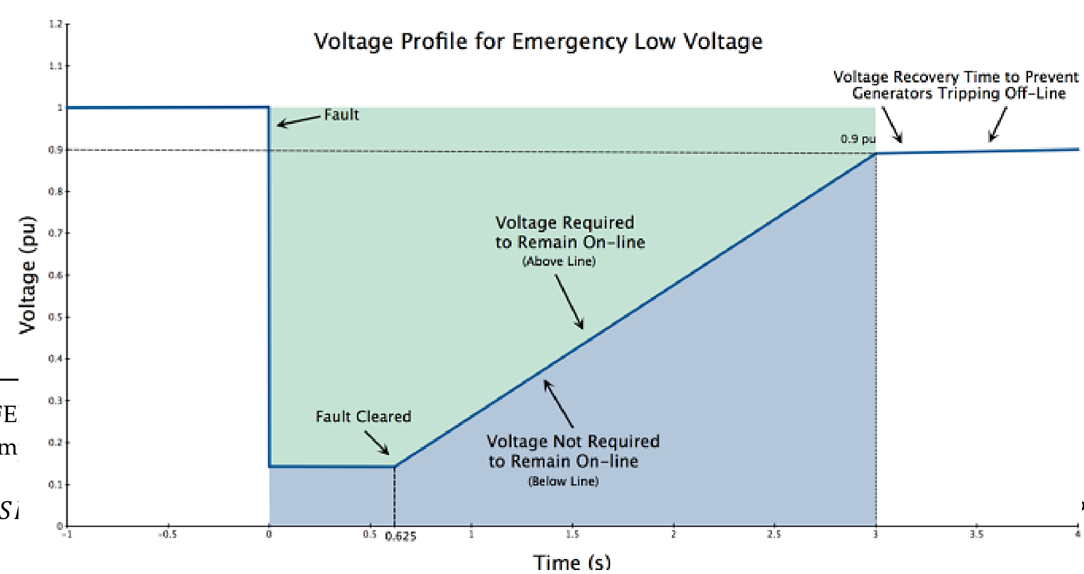
Inverter standards such as UL 1741 (Ref. -21) and C22.2 No. 107.1-01(Ref.-20) do not permit utility interactive generators to remain connected when a loss of grid occurs.

Figure 39 below illustrates low voltage ride through (LVRT) requirements for generators per FERC order 661[50]. The fault occurs at zero seconds. System voltage drops to as low as 0.2 p.u.. The fault clears at or before 0.625 seconds. During this time up to recovery, the inverter remains connected to provide support.

Table 22 lists the requirements of IEEE 1547 during low voltage incidents as referenced by UL 1741, etc. Strictly adhering to these requirements would be contrary to the benefits derived from CES including sag mitigation.

While storage capacity may indirectly affect real power injection (i.e. greater discharge current is achievable due to lower battery impedance), the real limitation is the maximum rated inverter current. When a fault occurs, the inverter output voltage is automatically reduced to limit its I_{max}. It would be a rare case when the battery would be the limiting factor except in a nearly fully discharged state.

Figure 39. LVRT Requirement per FERC Order No. 661 (Ref. -13)



[50] FE…
im…

Table 22. IEEE 1547 (Table 1) Interconnection System Response to Abnormal Voltages (Ref. -13)

Voltage Range (% of base voltage[51])	Clearing time (s)[52]
V<50	0.16
50≤V<88	2.00
110<V<120	1.00
V≥120	0.16

Distortion Due to Harmonics

A critical component of a well-designed PCS is the harmonic filtering needed to provide a clean output waveform. Inverters work best at full rated output since the total harmonic distortion is almost a constant. Harmonic THD on the current waveform will tend to increase at partial output since the harmonic content decreases only slightly and therefore appears more significant. Full load THD should be no more than 5%. Specifying a lower THD at full load will require additional filtering to achieve. The main concern is where the CES will be placed in THESL's network and what harmonic contributors are already in place.

Voltage Unbalance Due To Potential Unbalanced Allocation of Generating Resources

A PCS can easily handle unbalance by going to voltage control mode when placed in island mode. Phase unbalance is handled automatically in this mode as current is proportioned accordingly to maintain the voltage set points on the individual phases.

Potential for Flicker

A STATCOM can substantially reduce voltage flicker introduced by customers. Serious flicker can be an annoyance to other customers connected to the same feeder. A demonstration of STATCOM's effectiveness to reduce flicker from 8% down to a more acceptable level of 4% was achievable with installation of a STATCOM near the offending load (Ref -7).

Other studies have shown that a 5 MVA 4 kV STATCOM was capable of reducing the flicker of a 4000 hp metal shredder motor. The design included mitigating flicker resultant from rapid load fluctuations up to 200% motor full load current which could occur randomly due to the

51 Base voltages are the normal system voltages stated in ANSI C84.1-1995, Table 1.

52 DER≤30 kW, maximum clearing times; DER>30 kW, default clearing times.

nature of the load (Ref. -8). The AEP CES design specification does not address flicker mitigation at this time.

Fault Current Contributions from Inverter Based Generation

Unlike traditional rotating generating equipment, inverters have a relatively low bolted fault current. When a fault is detected, inverters are designed to shut down to protect their circuitry which is intolerant to extreme overloads much beyond 2 times the rated current. In AC arc flash hazard calculations, inverter power supplies are not considered to be a significant contributor to the arc flash energy.

DC current injection from faulty inverters can occur especially on single phase systems (Ref. -33). An isolating transformer can block some but not all DC into the grid should this occur. A literature search found this occurrence was more prevalent in small PV inverters less than 5 kW.

Protections for Avoiding Unintentional Islanding

Inverter equipment approved for distributed generation typically has inherent anti-islanding protection built in. Inverters that meet C22.2 No. 107.1-01 will include this feature.

However, brief support during a fault condition may be desirable as noted in the previous section (Fault Ride Through).

Protection and Control

The traditional protection and control used by utilities may be inadequate as penetration levels of PV, wind and other distributed generation increase on feeders. The impact of these installations can spread beyond the secondary feeder level in terms of short circuit currents and upstream protection coordination. Utilities such as Hydro One (ref.-29) have produced guidelines for interconnection of DG including PV to their 4-wire distribution systems. The Hydro One Guidelines are considered to be fairly robust. Even so, there have been studies (Ref. -25) that caution on future penetration rates increasing in the future. The key is improved communication between the DG, CES and the electric utility such that the status can be continuously monitored and the appropriate action is taken should trouble occur. The following examines the issues and discusses ways utilities are addressing this new challenge.

Addressing the Issues

Research labs, universities and private companies around the world are working to address the challenge of increased penetration levels of DG. One report (Ref.-25) focused on PV penetration in particular. The report identifies the following groups in particular:

- The Gridwise Consortium, led by the U.S. Department of Energy, Washington, D.C.
- The Intelligrid Consortium, led by the Electric Power Research Institute, Palo Alto, California
- The Avanti Distribution Circuit of the Future project, led by Southern California Edison, Rosemead, California
- The DisPower project, coordinated by ISET, Kassel, Germany

The report suggests a number of measures for DG but from a P&C prospective the following is more relevant:

> *"**Protective relaying schemes designed for DG**. The distribution and subtransmission systems will include more extensive use of directional relaying, communication-based transfer trips, pilot signal relaying, and impedance-based fault-protection schemes (like those used in transmission). These can work more effectively with multiple sources on the distribution system.[53]"*

Effect of Fault Currents from CES and Other Connected DG

Traditional radial utility systems assume current flows in one direction. However, when the CES and other distributed generation is grid connected on a feeder significant fault currents can flow from both directions. Table 24 lists a number of potential P&C problems that can occur with CES and high penetration DG connected to a feeder. However, compared to rotating DG, inverter-based DG (CES and PV) contribute far less fault current compared to their unit rating. Rotating machine DG can introduce up to 8 times their current rating into a fault whereas the CES and PV believed to be much lower and shorter in duration. To determine the actual magnitude and duration of inverter short circuit currents, NREL conducted a lab experiment to place a bolted fault across a 1 kW inverter terminals (Ref.-26). The results were found the current magnitude was higher than expected at 5 times rated current but the duration was only 1.6 ms or 0.1 cycle. The overall effect was substantially less than the industry accepted "rule of thumb" of 2 times rated current for 1 cycle or less.

Further testing was performed on a 500 kVA 3-phase inverter (Table 23).

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53 Mark McGranaghan, Thomas Ortmeyer, David Crudele, Thomas Key, Jeff Smith, Phil Barker "Renewable Systems Interconnection Study: Advanced Grid Planning and Operations" Sandia National Laboratories Report SAND2008-0944 P – February 2008.

Table 23. Bolted Fault Test on 500 kVA 3-Phase Inverter (Ref.-26)

Test #	Between B-C Phases	
	I-Max (kA)	Duration (ms)
1	3.14	1.1
2	2.5	1.25
3	2.52	1.75
4	3	1.2

Test #	Between A-C Phases	
	I-Max (kA)	Duration (ms)
1	2.56	4.25
2	3.92	1.25
3	3.82	1.5
4	3.65	1.2
5	3.78	1.2

Test #	Between A-B Phases	
	I-Max (kA)	Duration (ms)
1	3.72	1.5
2	3.68	1.45
3	2.44	1.65
4	3.76	1.45
5	2.66	1.35

CES inverter bolted fault current would be comparable to the NREL results. Similar results obtained from testing the 500 kVA inverter compared to the 1 kW inverter led the NREL investigators to conclude that inverters built to meet IEEE 1547 and UL 1741 (and CSA Standards C22.2 No. 107.1-01 Ref -20 and C22.3 No. 9-08 Ref. -30) standards produce fault currents anywhere between 2 to 3 times the rated peak current for 1 to 4.25 ms.

Table 24. How CES and DG Equipment Can Influence System Protection (Ref.-25)

Fault Contribution	The Issues
CES or other DG feed fault	1. Fault levels exceed the interrupting device rating 2. Alters fuse and CB coordination 3. Increase chance of conductor damage, distribution transformer failure 4. Desensitises protections thereby slowing down their response time.
Fault current flows in different direction	1. Sympathetic trip of CB or reclosers (when fault is on another feeder and DG current passes through its feeder breaker). 2. Desensitize ground fault relay protection 3. Network protectors operate unnecessarily
Increased fault clearing time	1. Increased conductor or equipment damage due to longer arcing durations or current flows 2. Defeats reclosing objective due to longer clearing times

Normally recloser breakers are set to open to protect the line fuse. However, if the CES / DG fault current is sufficiently high to open the fuse in less than 5 cycles (most reclosers take this time to act) then upstream coordination including the fuse saving strategy of the reclosers is defeated. Also, depending on the location of the fault and the upstream distribution feeder circuit breaker, the breaker does not see the level of fault current passing through the fuse.

PV generation is often fed into single phase 4-wire multi-grounded systems. From a protection and control point of view this is less than ideal. When the substation is the predominant grounding source, zero sequence ground currents tend to flow back to the sub-station. However, placing DG on the lateral, results in the zero sequence currents to originate from and flow to the other ground points. This interferes with the protective relaying in the substation due to the reduced zero sequence ground currents they would see.

Even though the sub-transmission circuits have 4 to 15 times the capacity of distribution feeders, high penetration of DG on the distribution feeders can result in problems due to currents feeding from the distribution system back up into the sub-transmission system. One major problem is ground fault overvoltage on the transmission lines due to the substation transformers having delta primaries such that the ground current ends up boosting the sub-transmission line voltage, sometimes to dangerous levels which could result in surge arrestor and other equipment failures.

To reduce the impact of faults on feeders with a high penetration of DG, new adaptive relaying schemes are used. These include more extensive use of directional relays and communication-based transfer trips and impedance-based fault protection schemes (as used in transmission systems).

Ensure the all grounding systems have been properly designed.

Table 25 below compares current P&C practices versus future needs as DG penetration levels increase.

Table 25. Comparison of Current P&C vs. Future Needs with High Penetration DG(Ref.-25)

P&C Function	Current Methods Used	Future Methods Needed for High- Penetration PV and Other DG
Anti-Islanding Protection	• Passive or active voltage and frequency relaying.	• Pilot signal or direct transfer trip signal as primary protection. • Voltage and frequency-relaying as back-up.
Overcurrent Relays &Electronic Overcurrent Sensing Devices	• Typically non-directional overcurrent relays.	• Overcurrent relays will have directional blocking capability added to prevent sympathetic trips. • Relays may need dynamic settings to adjust to changing fault levels. • Relays send out transfer trip signal to PV or other devices.

P&C Function	Current Methods Used	Future Methods Needed for High- Penetration PV and Other DG
Reclosing Practices	• Reclosing widely used on overhead feeder systems with dead times ranging from one-third of 1 s to more than 60 s; multiple shots used.	• Reclosing practices need to be altered to allow coordination with intentional islanding scheme. • Live-line blocking and/or voltage-synch check may be needed at key switchgear locations to avoid closing out of phase into live island. • Communication-based reclose "enable" or "blocking" signal may be needed.
Sectionalizing Switches	• Check for fault pass-through, then open on loss of voltage.	• More sophisticated sensing and control will be used to deal with PV-caused bidirectional fault flows and advanced islanding considerations.
Lateral Fusing	• Laterals fused mainly with thermal links.	• Electronically controlled fuses will allow better coordination with varying fault levels resulting from differing amounts of PV and other DG on the system.

P&C Function	Current Methods Used	Future Methods Needed for High- Penetration PV and Other DG
Distribution Transformer Fusing	• Current-limiting fuse on high fault-current sections; expulsion fuses on low fault-current section.	• Increasing usage of current-limiting fuses at transformers on all sections will keep tanks from rupturing in case PV and other DG sources cause higher fault levels.

Dispatching Strategies

Buffer Intermittency of Supply and Demand

Renewable energy sources connected to the feeder can cause issues with other customers, particularly when the DG source output varies rapidly (e.g. due to gusting winds for wind power and fast moving clouds for PV. Responding to these changes can be a strategic challenge for the CES dispatch control.

Both PV and wind are stochastic in nature. Gusting wind can be more dynamic than solar. The response time of the CES can be less than a ¼ cycle so the issue is the decision to dispatch or not in response to changes in the local contribution of wind or solar DG. Variability of solar irradiance can be factored into the control logic by direct feed from a pyranometer used to measure irradiance. For best results, the pyranometer should be placed close to the PV. Ultimately, the response of the CES is to the feeder voltage level. For grid connected wind and solar, a damped response by the CES is the best strategy in most circumstances.

For PV, the step response of the dispatch control depends on the type and velocity of cloud passing over the PV. Recent work by Sandia has resulted in development of a device to give utilities a heads up on PV variability described as follows:

> *"The sensors observe cloud shape, size and movement in order to provide a way for utility companies to predict and prepare for fluctuations in power output due to changes in weather. The resulting models will give utility companies data to assess potential power plant locations, ramp rates and power output."* – Joshua Stein – Researcher at Sandia – October 2010."(Ref. -34)

However, the system developed by Sandia was for an application involving very large PV relative to total generation (Hawaiian island power system). Smaller systems would not warrant this level of sophistication. The response time would depend on the relative size of the PV installation(s) to the feeder capacity / load. If the ratio is low, then the effect of PV fluctuation should be no different in treatment than the diversity effect of loads on the feeder.

For large PV connected on a feeder, variable output can result in a run-away tap changer condition or excessive hunting depending on the size and location of the PV on the feeder. A properly controlled CES could reduce the wear on the tap changer.

Advanced batteries for PHEV's are often cited as potential candidates for CES. This is due to the premise that commodity pricing will be forced lower as PHEV's become deployed in significant numbers. Also the duty cycle of the PHEV battery would closely match the vision for CES. At this time manufacturers of PHEV's are focusing on Li-Ion batteries as they offer high energy densities and a reasonable cycle life compared to other battery technologies. However, GM, the manufacturer of the Chevrolet Volt has limited the charge discharge range to between 25% and 90% of the 16 kWh capacity rating to preserve its (3000 to 4000) cycle life. Therefore only 10.6 kWh or 66% of the rated capacity is available. Based on the extensive research conducted by GM, an 8 year or 100,000 mile warranty on the battery will be included. Therefore, a CES should be designed to follow a similar constraint to maximize battery life. Logically, significantly larger capacity batteries will be required to obtain the kWh output anticipated.

CES manufacturers claim high Li-Ion battery cycle life of 3000 to 4000 cycles. Greenfield Energy Management states in their literature, the cycle life for their battery for 70% DOD is ≥3000 cycles but only ≥2000 cycles for 80% DOD (Figure G-4 Greensmith Distributed Energy Storage System (DESS) Specification Sheet – 2).

Peak Shaving, Valley Filing, and Phase Balancing Services

Peak shaving is a strategy to reduce congestion on the system and possibly take advantage of off-peak to on-peak rate differentials. In some instances the downstream load puts a strain on the upstream equipment such as transformers, etc. Injecting real power into the feeder can help reduce this congestion created by loads such as summer air conditioning and perhaps PEV loads. The strategy to dispatching the CES to inject real power into the line is to anticipate the peak load in advance by means of weather or historic data and plan the dispatch at a level and duration that will reduce the peak for the duration required. Since the storage supply is limited and maintaining a reserve capacity to serve other functions step dispatch is the recommended approach.

In order to be effective as a peak shaving device, the storage capacity and rate of discharge need to be such that the CES can supply energy for the duration of peak. For example, if the anticipated peak lasts 6 hours, a 250 kW unit will need at least 1.5 MWh of available storage to reduce the peak by 250 kW. If the stored capacity is less, then the output should be in proportion regardless of the rating of the PCS in order to provide peak reduction for the 6 hours.

Valley filling occurs when the battery is being recharged. Again, planning based on historical and weather data can be used to determine when the optimum time would be to perform this task. Normally this would occur at night but if the CES is supplying a night time PEV, charging will need to be scheduled during low points at other times including daytime. For many battery technologies, the charge load can be steady up to about 70% or 80% SOC. Following that the rate slows down until charging is complete. However, the charge rate can be varied within the parameters to perform a load leveling function.

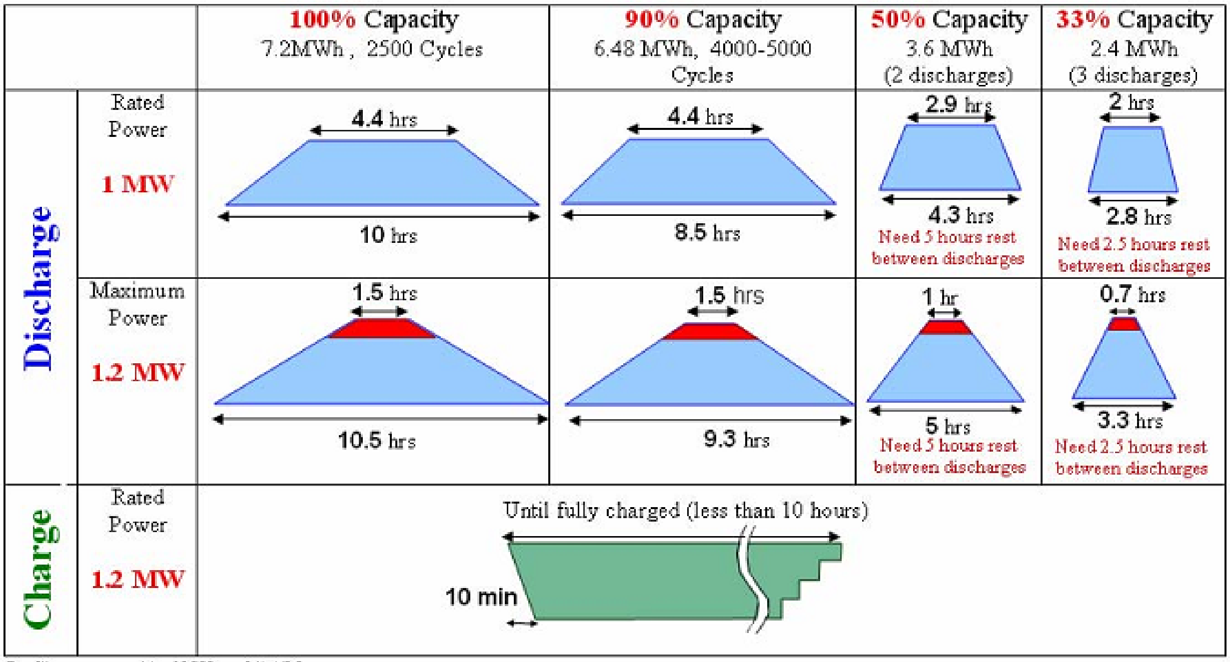
When the CES is connected to the distribution network, dispatch commands would originate from a central control location with a call to provide a constant power output to the network until a new change load or stop command is issued.

Phase balancing can be quickly addressed by the STATCOM function of the CES. The response rate should be in proportion to the ramp rate. CES is capable of restoring the voltage in less than ½ cycle and where possible should be placed closer to the load for maximum effectiveness. As well, the CES correction can be continuously variable rather than step increments. The local control issues correction commands based on voltage and current measurement at the PCC similar to a STATCOM.

In order to be effective as a peak shaving device, the storage capacity and rate of discharge need to be such that the CES can supply energy for the duration of peak. For example, if the anticipated peak lasts 6 hours, a 250 kW unit will need at least 1.5 MWh of available storage to reduce the peak by 250 kW. If the stored capacity is less, then the output should be in proportion regardless of the rating of the PCS in order to provide peak reduction for the 6 hours.

Figure 40 illustrates a number of predefined peak shaving profiles for the 1.2 MW application which were pre-approved by the battery manufacturer, NGK. Note the effect of depth of discharge on battery cycle life. Manufacturers of advanced battery systems will often define how a battery shall be used in an application to avoid negative press should performance expectations not be met through adverse operation by the customer. Some batteries (e.g. Li-Ion and Li-Ion Polymer) have built-in supervisory circuitry to protect the battery from charge / discharge extremes. Lack of this protective circuitry could have dire consequences.

Figure 40. Predefined Peak Shaving Profiles (Ref.-14)



System Loss Reduction and Volt/VAR Optimization

Low power factor can put a constraint on system capacity. Correcting as close to the affected load is preferred. VAR injection from the STATCOM helps boost the feeder voltage.

To be effective, the STATCOM needs to react quickly in response to the local control based on voltage and current measurement at the PCC.

Mitigate Power Quality Issues

Power Quality issues require a rapid response from the CES. The local control issues correction commands based on voltage and current measurement at the PCC.

Since the CES inverter maximum kVA cannot be exceeded, real power injection will reduce VAR capacity.

Provide Up To Two Minutes of Backup Power for Distribution Feeders

Providing backup power for a distribution feeder requires a substantial reserve capacity to handle the instantaneous random load diversity of the connected customers. Sizing of the CES would need to be sufficient to handle the peak instantaneous load on the feeder. Therefore detailed monitoring of the feeder would be required for proper sizing. It is highly likely the resultant size would be significantly larger than the normal operating mode of the CES. Alternatively, the feeder could be sectionalized such that only a portion of the feeder is served by the CES.

Although the energy storage output would need to be capable of supporting the inverter, for up to the 2 minute requirement, the stored capacity for most battery technologies should be considered as a secondary issue.

As this mode is essentially a UPS mode, two transfer methods are possible depending on the equipment design to put the feeder in island mode. The simplest is break before make which would isolate the feeder from the utility while the CES supplies the load. The interruption between break and restore could be up to 2 seconds for each switching action. This may be unacceptable for some customers. The second option would be via static transfer switch. While this option can result in a seamless transfer, there is a substantial cost premium.

Load following of downstream connected loads could occur in event of islanding brought about by loss of utility supply.

Function in a Micro-Grid Configuration

Operation of a CES in a micro grid is possible. Similar to the previous operating mode, islanding is required to isolate the feeder from the utility. The difference is the CES will operate in parallel with and may communicate with other connected DG while isolated from the grid.

Sizing of the CES would be similar to the forgoing example taking into account the contribution of the connected DG. Consideration of a worst case scenario is required to ensure the feeder needs are met.

Load following of downstream connected loads could occur in event of islanding brought about by loss of utility supply.

Feedback status from the CES and measurement at the point of common coupling (PCC) would assist Dispatch in monitoring the situation.

Storage Considerations

The following storage issues are common to all aspects of CES operation whenever energy is being extracted or restored to the storage device.

Charging/Discharging

Charging of CES units should be performed during off peak times when cost of energy is low. In addition, off-peak charging should also coincide with the lowest congestion on the utility network. The ideal time needed for complete continuous charging of a fully discharged CES battery is between four and eight hours. Due to the nature of battery charging profiles, balanced charging[54] on the network may be needed to reduce the peak if deemed a problem. The battery manufacturer may also permit partial opportunistic charging when loads on the system are temporarily reduced (i.e. load levelling).

Depth of Discharge

Battery discharge depth has an inverse effect on battery life. All batteries have a finite life that generally starts from the date of manufacture. Typically, shallow discharges with the occasional deep discharge will yield the greatest life. For example, one battery technology may yield several thousand 10% to 20% depth of discharge while providing less than 2000 80% depth of discharge cycles. However, battery performance will also degrade based on age alone. Depending on the battery technology selected, the predicted number of deep cycle discharges over its lifetime should be factored in. Deep discharging the CES should only be performed when the system dictates that doing so would be advantageous. Battery cycle life for some technologies can be significantly reduced when depth of discharge is increased only slightly (e.g. a 10% increase in DOD can reduce cycle life by a factor of 2).

See also “Peak Shaving, Valley Filing, and Phase Balancing Services”.

Rate of Discharge

If batteries are the chosen storage device and high power but short duration discharge capability is required, the storage capacity may need to be significantly larger than the output requirement. For example, discharging at the rate of 20 MW for up to ten minutes would produce 3.3 MWh of energy. This will require a battery with several times the energy capacity unless the battery is specifically rated for the task. The reason for this is due to chemical and

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54 Balanced charging prioritises charging such that system and feeder capacities are not exceeded during the recovery process. Batteries with the highest rate of discharge may be recharged first or utility strategy may dictate other batteries be given the top priority.

physiochemical rate determining processes occurring within the battery. For example, a sealed lead acid battery rated at 10 Ah at a 20-hour discharge rate will only deliver 8.5 Ah at a 5-hour rate and 6 Ah at a 1 hour rate (Ref.-10). In the case of a NaS battery, a 10-minute discharge at 20 MW would be achieved at 4.25 times the continuous discharge rate. Therefore, for 20 MW for 10 minutes, a minimum 4.7 MW or 34 MWh of NaS storage would be needed (derived from Figure 2 of Ref. -19).

Thermal Management

Many battery chemistries are sensitive to ambient temperature. Battery manufacturers typically rate batteries at 25^{o}C. Operating the battery at temperatures outside the specification may adversely affect life and performance. If climate conditioning is not provided, design limitations should be factored in to ensure year-round performance expectations are met.

Batteries are electrochemical devices affected by operating temperature. If not thermally managed, output will be limited at very low ambient temperatures. At temperatures above 25^{o}C, output can sometimes increase at the expense of battery life. Batteries benefit from thermal management systems when expected to operate under a wide range of temperatures.

Some batteries such as NaS are self-contained and are thermally managed within the battery to maintain the proper working temperature of 300^{o}C to 350^{o}C. Low outdoor ambient temperatures will increase the heat loss but will not adversely affect battery performance.

Table 26 illustrates the approximate relationship between operating temperature and full charge battery capacity for select battery technologies. An electrochemical battery may have a significantly reduced full charge terminal voltage at lower operating temperatures. Battery manufacturers rate their batteries in terms of Ah (Ampere-hours) and therefore discharge rates are expressed in Amperes, the PCS will increase the discharge rate in order to maintain constant power output as the battery voltage decreases. If the battery voltage drops with temperature, less energy will be available than predicted in

Table 26.(Ref. -10)

Table 26. Battery Full Charge Capacity vs. Operating Temperature[55]

Temperature °C	Li-ion Polymer (%)	Lead Acid (%)	NiMH %	NiCad %
40	98	107	90	95
30	100	103	100	102
20	99	94	105	100
10	96	90	100	90
0	90	80	80	80
-10	70	68	50	70
-20	44	55	20	50

Cycling Considerations

All electrochemical batteries effectively have an internal resistance. Rapid charging and discharging of large batteries can result in an increased core temperature. Advanced batteries monitor and limit temperature rise to maximize life. This could limit the number of charge and discharge cycles per day.

As noted in the previous subsection (Depth of Discharge), management of cycling over the battery's life is essential to maximizing the benefit over the battery's expected life.

For example, a battery with a cycle life of 2000 full discharge cycle life could only be deep cycled four times per week over a 10 year period before reaching its expected end of life. Alternatively, the same battery could be subjected to daily 50% average discharge cycles for the same period, with only an occasional full discharge.

Table 27 illustrates the effect of depth of discharge, expressed as a percentage below full charge on the number of cycles one might expect from a particular battery chemistry. Battery manufacturers often predict widely differing cycle life for their products even for similar chemistries. Many have never been actually cycle tested to the extremes but rather predict based on data extrapolation.

55 Relative to full charge capacity at nominal 25°C conditions.

Laboratory testing typically varies one parameter at a time[56] such that results can be plotted and interpolated or extrapolated. Actual life is determined through field experience.

Table 27. Effect of Depth of Discharge on Cycle Life[57]

DOD (%)	Life (Cycles)				
	Li-ion Polymer	Deep Cycle Lead Acid	NiMH	NiCad	NaS
80	675	500	1200	4000	4500
70	1500	650	8000	4300	6000
60	5000	800	10000	4600	7500
50	8000	1000	14000	4800	9000
40	11000	1400	50000	5200	12000
30	45000	1800	90000	8000	14000
20	80000	2800	110000	14000	23000
10	180000	5100	900000	45000	43000

If the CES is used for peak shaving, a minimum reserve should be maintained for power quality applications. For example, if the maximum safe level for the battery is 80% depth of discharge (DOD), and 20% of capacity is reserved for correcting power quality events, the battery should not be allowed to go beyond 60% DOD. Therefore a minimum 20% reserve is available for handling power quality events. Similarly, if the CES is expected to absorb power surges the battery should not be charged beyond 50% DOD to provide room for charge acceptance.

56 One exception is hybrid electric vehicle manufacturers who use simulated driving cycles to evaluate battery performance. The tests use a real driving route (e.g. urban streets in Boston) to test the battery in a climatic chamber. The cycle is repeated to evaluate cyclic performance.

57 Data obtained from a number of sources typically graphic plots from which cycle life was visually approximated.

Networking Storage

CES units can be networked via radio communication. The combined output of the CES units can be aggregated into the utility's advanced metering infrastructure or from a local SCADA located at the substation. For example, 80 CES units (25 kW each) distributed in a local grid (Figure 24) would provide the same function as a 2-MW substation battery (Ref. -9).

CES Communications Strategy

The concept CES deployment in a "smart grid" is a relatively new concept with little reported field data available. The most comprehensive self-contained document available to the public is AEP's Functional Specification for CES Control Hub (Ref.-12). The following, derived from this specification, is intended to provide a guideline which utilities can revise accordingly. The PCS and control strategy/communications will dictate the functionality of the CES within THESL's distribution network. Quick response to mitigate voltage sags necessitates local supervisory control while system requirements will rely on remote dispatch control for power in and out of the CES.

CES control functions will depend on the needs of the utility. Some functions, such as power quality improvement, will need to be built into the local CES controller to ensure fast response. Other functions, such as peak shaving and charging, can be handled remotely.

Figure 41, below, conceptualizes the control structure for CES (Ref.-12). The CES Control Hub processes and prioritizes inputs from the Utility Distribution Dispatch Centre (typically manual commands), local station (SCADA), and the CES unit. Future provision exists for customer load data and control.

Figure 42, below, illustrates the data flow for charging and discharging the CES (Ref. -12). Data flows from the individual CES units to the CES HUB. The intent of the flow drawing is to illustrate possible exchange of data in and out of the CES HUB. The Hub provides a link between the aggregated CES and the various levels of utility control and data gathering. Therefore, the utility is kept apprised of the status of all connected CES units including overall health and storage status. With this data, the utility can schedule charge/discharge of individual or collective CES units to best meet the needs of the utility.

Figure 43 (Ref. -12) illustrates the charge/discharge profile for a group of CES on a feeder. Note that the feeder's charge and discharge needs are divided among the connected CES according to their size and state of charge. Collectively, they can be dispatched to reduce the peak on the feeder.

Figure 41. CES Communication and Control Structure

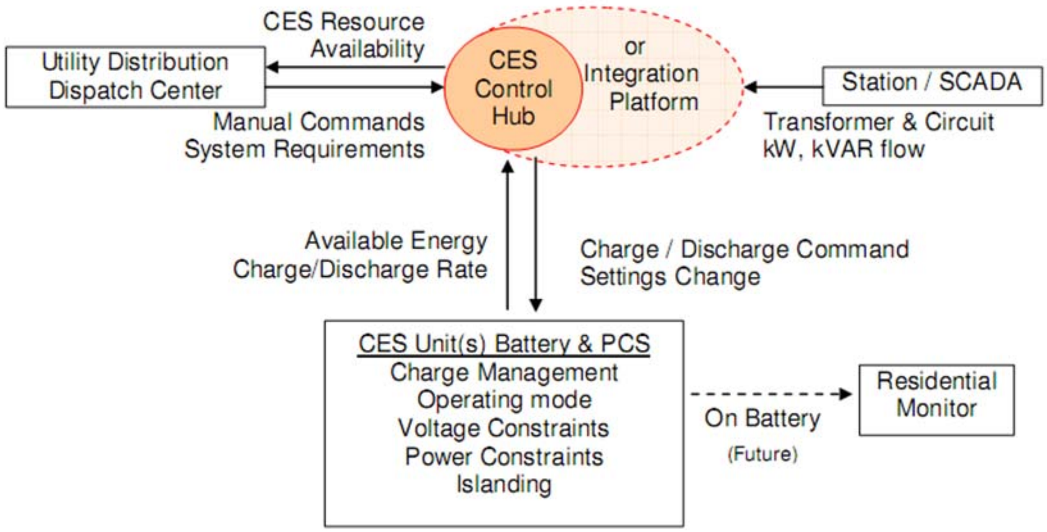


Figure 42. CES Charge / Discharge Cycle – Data Flow

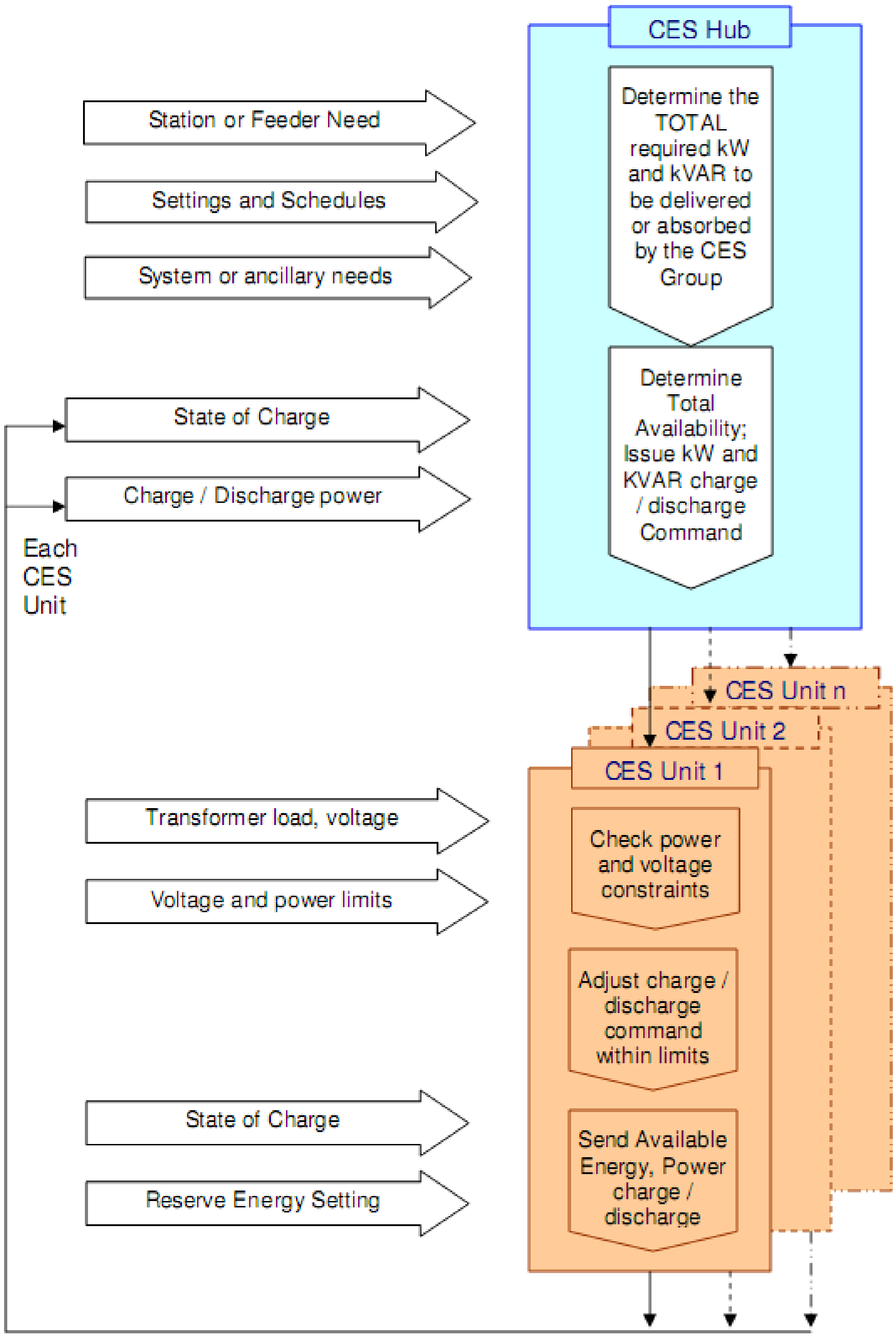


Figure 43. Feeder Level Demand Profile for Charge/Discharge CES Units

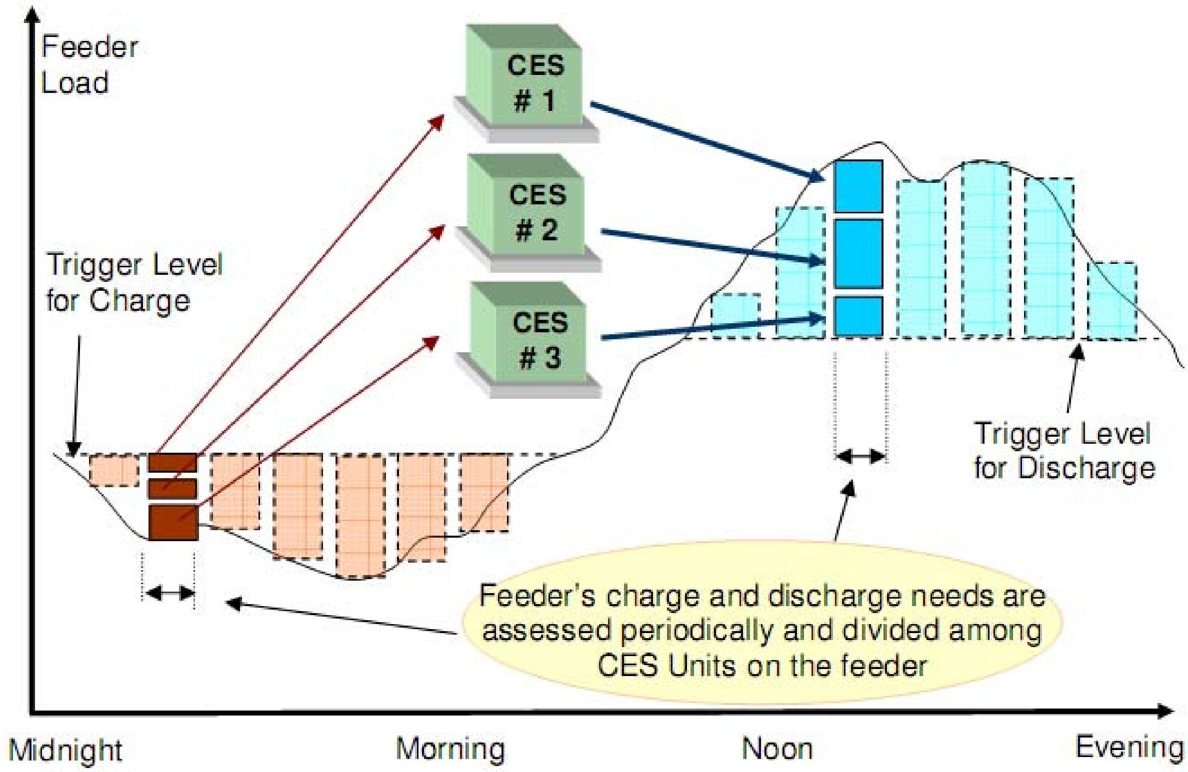


Figure 44 and Figure 45 below illustrate the sharing of multiple CES units on a feeder during charging and discharging. The snapshot charge state of the individual CES is identical for both discharging and charging for both scenarios. Note that the availability for supplying reactive power is inversely proportional to the flow of real power in and out of the CES. The reason for this is the PCS by nature has limited current handling ability such that the total current in or out of the PCS can never be more than the maximum current rating.

Figure 44. Participation of Multiple CES Units in Discharging (Ref. -12)

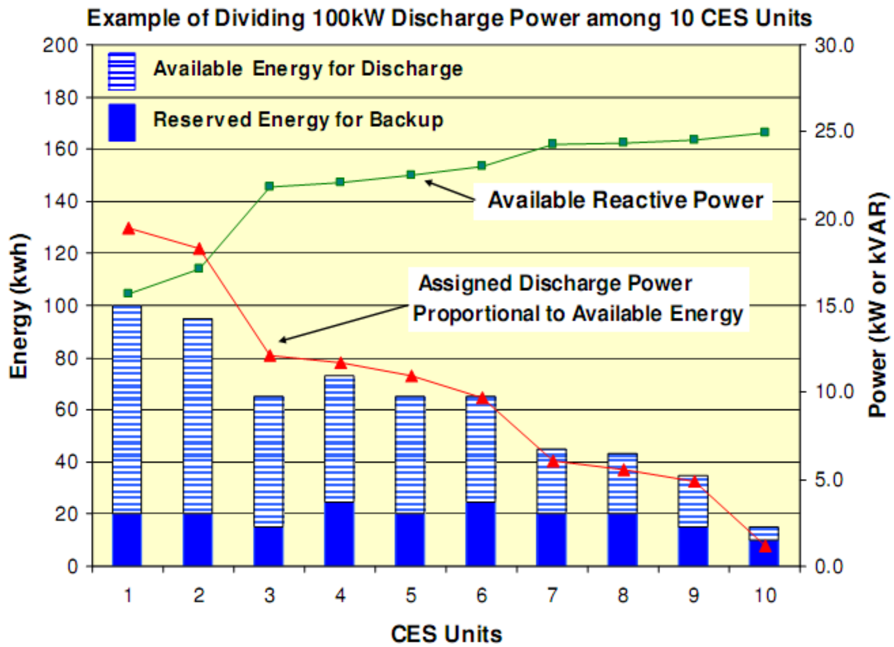
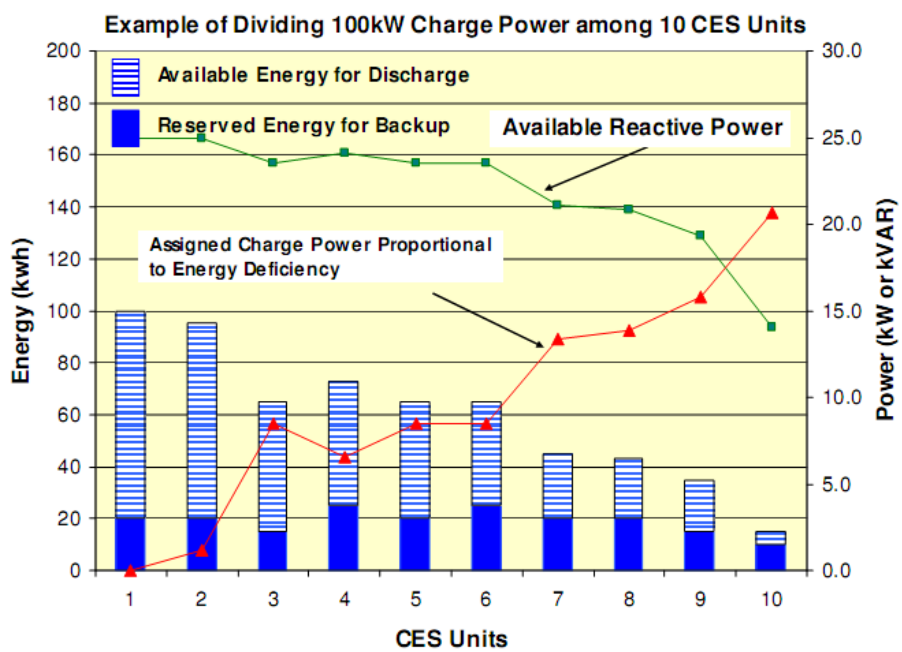


Figure 45. Participation of Multiple CES Units in Charging (Ref. -12)



Safety Practices and Operating Procedures

The following highlights key safety features and operating procedures that should be considered for ES systems[58].

The ES systems and technologies described in prior sections should meet all provincial and local safety and installation codes. The Company also will need to develop procedures and protocols for CES and interconnection equipment maintenance. Energy Storage suppliers will likely need to provide training or third-party support for equipment maintenance, as THESL personnel may not be familiar ES equipment[59]. It may be preferable to procure outside assistance for preventive maintenance – such as the equipment supplier – due to the unique features and PM requirements for CES. THESL should also ensure that existing procurement specifications applied to high voltage power delivery equipment is appropriate for ES equipment.

Navigant also obtained survey responses from several ES suppliers that addressed equipment safety for Lithium-base ES technologies, including those listed below.

Safety features for Electrovaya's Li Ion system listed in their response include:

- Access to the batteries is from the outside of the ESS enclosure: risk of being trapped in a high-voltage/high energy environment is minimized.
- Each battery module has "finger-safe" connectors and no exposed electrical conductor. The modules are therefore safe to handle and store without undertaking elaborate electrical safety precautions.
- The battery modules connect to the electrical bus via a plug-and-socket system, instead of nuts and bolts, for easy and safe replacement.

International Battery provided the following comments for their Li Ion battery:

> *"No safety issue. International Battery uses safe materials (LFP), safe cell design and a BMS for redundant protection and monitoring."*

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[58] Note that some of the existing standards for battery systems were developed for lead acid battery technologies and therefore may not be relevant to technologies available today.

[59] There may be additional issue regarding labor agreement and classification, as current agreements may be oriented to electric distribution equipment. The ES systems may be viewed as power generation technology not current covered in the labor agreements.

Nonetheless, all ES systems present a range of safety issues similar to any other high-voltage device which can generate power into the distribution system, as discussed above. In addition to these risks, the chemistry and operating characteristics of some technologies present additional safety and environmental issues.

The Company also will need to update or modify current operating procedures to address CES, which represents an active power generation source located on distribution lines. Specific issues that will need to be address and incorporated into operating procedures include:

- Coordination with control center personnel regarding switching orders and tagging,
- Procedures for CES shut down and start-up for equipment maintenance or when outages occur,
- Operational procedures for feeder ties and transfers, including limiting CES output under abnormal conditions or for temporary transfers,
- Incorporation of CES operations into safety procedures,
- Other THESL procedures not listed above.

Table 28 lists safety issues relating to other battery types:

Table 28. Safety and Environmental Issues

Technology	*Safety/Environmental Issues*
ZnBr	*The electrolyte pH rating varies between vendors, being variously described as having a PH of 2.8, similar to lead acid battery acid (approx. 0.5), or as equivalent to coca-cola (2.5 to 3). The end use customer or utility is not expected to have any exposure to electrolyte.*
VR	*Vanadium element is dissolved in dilute sulphuric acid. Containment of any spilled electrolyte is the only safety/environmental issue reported.*
NaS	*High operating temperatures (approx. 300°C.).*
NiCd	*Toxic materials (cadmium) used in system.*
PbA	*Toxic materials (strong acids and lead) used in battery.* *Batteries are completely recyclable.*
Advance PbA	*Toxic materials (same as PbA above)*
Flywheel	*High speed device operates with high levels of kinetic energy.*
Ultra-capacitor	*No additional issues beyond electrical safety.*

Batteries are capable of storing significant amounts of energy. The battery bus is capable of delivering lethal shock voltage. Inadvertently shorting the battery terminals could result in fire or explosion of the battery. Personnel need to be properly trained in proper handling of the battery. Additionally, DC is not covered under the arc flash provision of Canadian safety standards (i.e. CSA Z462) such that there is no recognized method for calculating the DC arc hazard. DC arcs are known to be more severe than AC arcs at equivalent voltage and bolted fault levels since they are less likely to self-extinguish; this infers that there is a potential for greater arc energy should an incident occur. Therefore, extreme caution should be taken whenever coming in contact with or handling batteries.

PPE rated for arc flash, including face shield and gloves, is highly recommended when performing installation, maintenance, or removal for disposal. Each battery type will have specific handling requirements depending on configuration and chemistry.

Whenever working on the CES, it is highly recommended that the CES be electrically isolated via visible break disconnect switches and grounded. The possibility of arc flash does exist on both the AC and DC sides of the equipment. Therefore, the DC side should also be electrically isolated using visible break disconnect switches.

Chemical leakages or spills are very possible incidents that could be faced. These materials may pose as environmental hazards. Depending on the battery chemistry, release of hydrogen gas in explosive concentrations or toxic gasses (e.g. stibine and arsene[60]) could occur. The battery manufacturer's MSDS[61] sheets for the specific battery chemistry should be referred to for additional precautions in handling and clean-up. For example, batteries such as lead acid may require no open flames in their vicinity if hydrogen gas is vented. Others may react with water or have high temperatures (e.g. NaS).

Disconnecting the PCS from the battery and isolating from the system may still have safety concerns if the capacitors retain a charge. Care should be taken to check the capacitors for residual charge and safely discharge as necessary via a suitable resistor before handling the components. Once discharged, applying shorting jumpers is recommended to ensure no residual charge remains.

60 Lead acid batteries can have chemical additives . Charging sometimes results in release of these compounds in the form of gas in small quantities. Adequate ventilation is recommended to prevent concentrations of these gasses from forming.

61 Material Safety Data sheets.

The CES should incorporate means in the design to protect itself from internal failures and utility grid disturbances including faults and other abnormal conditions. This would include self-protecting for AC or DC component failures.

Systems should be designed to minimize risk and potential harm to workers and the public.

The CES including storage component should be self-contained such that there is no need for THESL to construct additional measures (e.g. spill containment).

Utility and local fire personnel should be notified of particular safety issues in case of an emergency and the appropriate response. (Ref.-22)

Communications and Integrated Control

We anticipate that the communications media used for Smart Meter applications may be applicable for smaller, distributed ES systems. For the initial pilot applications for the 250kW CES, use of conventional SCADA with smaller remote terminal units (RTUs) that include basic monitoring and control functionality may be sufficient. However, as the number of devices increase, care should be exercised to ensure control center personnel are not burdened with the responsibility of monitoring numerous CES devices. It may be preferable to provide limited SCADA access to the CES devices (e.g., no SCADA access to other distribution equipment) to off-load device monitoring and control. The latter assumes that CES operation follows IEEE 1547 standards regarding disconnection, isolation and resynchronization, among other THESL-specific requirements. Table 29 to Table 33 on the following pages list examples of the monitored and controlled parameters associated with CES as envisioned in the AEP CES concept document (Ref. -11). These tables have been reproduced here in order to provide a starting point from which THESL can develop their own CES communications tables. Many of the monitored parameters are useful for record keeping purposes while a select few will be more vital for daily operations.

Table 29 lists time stamped alarms sent from the CES to the Hub including battery and PCS warnings and trip events. Some will require manual intervention to reset while others such as battery temperature can be set to auto reset.

Table 30 is a list of CES unit status signals sent to the Hub. This data would in turn be aggregated by feeder to provide central dispatch with a clear picture of the present state of the CES system. This data is to be considered the minimum set from which operational decisions can be made. Posting on this table assumes the individual CES units are in a healthy state.

Table 31 lists CES settings. This table posts the various settings associated with the CES including time delays, etc. Once set, they are not normally part of daily operations.

Table 32 to Table 33 list the operational commands from the Hub to the CES and response from the CES to the Hub respectively. Based on status information, the hub can request both real and reactive power output from the CES to the system. In its simplest form, this command can be in the an incremental step command (i.e. 50 kW, 75 kW, 50 kVAR, 75 kVAR, etc.). Data fed back from the CES to the Hub will ensure the command was received plus vital information including reserve energy remaining from which future commands can be determined thus maximizing the benefit of CES on the system.

Table 29. CES Time Stamped Alarms

Alarm	Action	Reset
Overvoltage	Trip	Manual
Undervoltage	Warning	Manual
Battery Temp	Inhibit	Auto
Reserve Energy	Inhibit	Auto
Minimum Energy	Trip	Manual
PCS Temp	Trip	Manual
Unit Capacity	Trip	Manual
Trans Capacity	Trip	Manual
DC Bus Voltage	Warning	Auto
Unit Shutdown	Trip	Manual
Comm Failure	Warning	Auto

Table 30. CES Unit Status to Aggregator (Hub) for Dispatch Centre (Ref. -11)

Mode	Standby/Tripped/Available	Units
Unit Real Power	In / Out	kW
Unit Reactive Power	In / Out	kVAR
AC Voltage 2	240/120	Volts
Trans Power	In / Out	kVA
Island	Duration	Min
State of Charge		%

Table 31: CES Unit Settings – Accessible Locally or Remotely (Ref. -11)

Setting	Instance	Measurement	Units	Default
Charge Level Timeout	On loss of communications	Time	Minutes	15
Discharge Level Timeout	On loss of communications	Time	Minutes	15
Communications retry	On loss of communications	Time	Minutes	5
Command Interval	From hub	Time	Minutes	5
Short Analysis Interval Schedule	Log / analysis	Date / Time	Date / Time	start
Short Analysis Interval	Log / analysis	Time	Minutes	60

Setting	Instance	Measurement	Units	Default
Duration				
Long Analysis Interval Schedule	Log / analysis	Date / Time	Date / Time	start
Long Analysis Interval Duration	Log / analysis	Time	Hours	24
Daily Log Life	Log maintenance	Time	Hours	24
Weekly Log Life	Log maintenance	Time	Hours	168
Performance Exclusions	Data bounds	Multiple Definitions	As Needed	multiple
Overcurrent pickup	In Service	Current	Amps	
Overvoltage Limit	In Service	Voltage	Volts	126
Overvoltage Time	In Service	Time	Seconds	15
Undervoltage Limit	In Service	Voltage	Volts	114
Undervoltage Time	In Service	Time	Seconds	15
Rated power	Fixed	Power	KVA	
Rated energy	Fixed	Energy	kWh	
Power Limit	Fixed	Power	kVA	Rating
Secondary P Limit	Fixed	Power	KVA	Tran rating
Transformer Rating	Fixed	Power		

Setting	Instance	Measurement	Units	Default
Transformer Impedance	Fixed	Impedance	%	1.5
Transformer X/R	Fixed	X/R Ratio		1
Reserve Energy	In Service	Energy	% of rated	20
Depleted Energy	In Service	Energy	% of rated	1
V Regulated	Islanded	Voltage	Volts	117
System Stable Delay	Islanded	Time	Minutes	5
Return Delay Base	Islanded	Time	Seconds	10
Return Number Range	Islanded	Integer	Max	100
System V Min	Islanded	Voltage	Volts	115
System V Max	Islanded	Voltage	Volts	126
System Freq Min	Islanded	Frequency	Hz	59.3
System Freq Max	Islanded	Frequency	Hz	60.5
Synch Angle	Islanded	V Angle	Degrees	5

Table 32. Commands from Hub to CES (Ref. -11)

Mode	Additional Detail	Units
Reactive Power Request	In / Out	%
Real Power Request	In / Out	%

Table 33. Outputs from CES to Hub (Ref. -11)

Mode	Additional Detail	Units
Real Power Actual	In / Out	kW
Reactive Power Actual	In / Out	kVAR
Available Energy	SOC - Reserve	kWh
Voltage	Each Leg at PCS	V

Hub Communications

Table 34 to Table 36 below provide examples of interaction between the HUB, CES and electric utility upstream control.

Table 34 lists HUB alarms that could be used to relay basic warning messages on the collective status of the CES units. Additional alarms could be added as deemed necessary such as inverter failure, etc. Table 35 lists HUB status to the Distribution Dispatch Centre information as envisioned in the open source AEP HUB document (Ref. -12). Table 36 lists the local HUB settings adjustable via a local PC connection, for example.

Table 34. Sample Alarms from HUB (Ref. -12)

Alarm	Action	Reset
Communication Failure	Warning	Auto
Power Deficit	Warning	Manual
Energy Deficit	Warning	Manual

Table 35. CES HUB Status to the Distribution Dispatch Centre Display (Ref. -12)

Parameter	Reporting	Units	Additional Info.
Station Load		kW, kVAR	
Feeder Load		kW, kVAR	
Station Voltage		PU	
Group Active	Unit Reports	Status	ID
Active Power	Unit Reports	Total Power In/Out	kW
Active VAR	Unit Reports	Total VAR In/Out	kVAR
Available Energy	Unit Reports	Total Available Energy	kWh
Group Exceptions	Unit Reports	Units Unavailable	cause
Weak Units	Unit Reports	Outliers; Variation from Average	

Parameter	Reporting	Units	Additional Info.
Station Load		kW, kVAR	
Island Event	Unit Reports		

Table 36. CES HUB Settings (Accessible Locally via PC Connection) (Ref. -12)

Setting	Instance	Measurement	Units	Default
DDC Comm Retry	On Loss of Communications	Time	Minutes	5
Command Interval		Time	Minutes	5
Fleet Members		ID	Address	
Group Power Rating	Group Rating Total	Power	kW	
Group Energy Rating	Group Rating Total	Energy	kWh	
Group Reserve Capacity	Group Total		%	
Trigger Mode	Set Manually	Schedule / Triggered		Trigger
VAR Mode	Set Manually	Schedule / Triggered		Schedule
Station Load Trigger		Station Load	kW	
Station VAR Trigger		Station Load	kVAR	

Setting	Instance	Measurement	Units	Default
Station Charge Trigger		Station Load	kVA	
Feeder Load Trigger		Feeder Load	kW	
feeder VAR Trigger		Feeder Load	kVAR	
Feeder Charge Trigger		Feeder Load	kVA	

7. Conclusions and Recommendations

Energy storage technologies have evolved rapidly in the past few decades and continue to evolve, as discussed in the review of individual technologies presented in section 4. Some technologies, such as pumped hydro and compressed air storage have been used for several decades, though their potential is very site specific and therefore not applicable for THESL. A review of utility industry experience with energy storage systems indicates that Pba systems were widely used in the 1980's and 1990's for grid applications, and a number of VRB and NaS applications were implemented in the 1990's and 2000's.

Interest in energy storage systems has risen considerably in the past decade, due in part to the growing interest in renewable forms of energy and the potential for the development of Smart Grid capabilities. Research and funding for energy storage has risen under various Smart Grid initiatives and in the U.S. as a result of increased funding under the American Recovery and Reinvestment Act (ARRA).

THESL defined six objectives that it wished to achieve by incorporating community energy storage into the electricity distribution system. These objectives were defined in terms of changes in operating conditions that would result from the use of an energy storage system. Navigant translated these objectives into energy and power terms and identified storage capabilities associated with each objective. The different power, energy and response time characteristics associated with each objective, were then matched to different storage technologies based on the characteristics of each technology as measured by its relative "attractiveness" and the "fit" of each technology to THESL's needs. For some objectives, the capabilities of the inverter were identified as being critical to meeting THESL's objective.

In spite of the number of electric utility storage installations either existing or planned, THESL's concept has uniqueness that cannot easily capitalize on others' experience. Congestion of the aging infrastructure coupled with micro-fit and larger DG on THESL's distribution system require innovative custom solutions to ensure system stability is maintained in future.

The results of this analysis are presented Table 37 below. The most appropriate storage technologies to meet each of THESL's objectives were identified based on an analysis of their attractiveness and fit.

Table 37. Technology Choices for THESL Objectives

Objective			
Objective 1: Buffer Intermittency	**Capacity**	1 – 2 MW	• Lithium ion storage device is the most attractive solution. • Given the maximum discharge of 1 hour, a longer-duration device such as NaS or a Flow Battery are unnecessary.
	Energy	< 10 minutes	
	Response	~ 1 minute	
Objective 2a: Peak Shaving & Valley Filing	**Capacity**	2 – 8 MW	• NaS and Flow Batteries are the most attractive solution as objective requires both a high power and energy device. • Flow Batteries have a lower average efficiency however NaS has been more widely demonstrated in the field for this type of application
	Energy	2-8 hours	
	Response	~10 minutes	
Objective 2b: Phase Balancing	**Capacity**	<= 0.75 MW	• Lithium ion and lead-acid devices are most attractive for meeting the phase balancing application.
	Energy	1-8 hours	
	Response	Minutes	
Objective 3: Volt/VAR Optimization	**Capacity**	2 – 8	• Sodium sulphur and flow battery devices are most attractive for meeting the system loss reduction and volt/VAR optimization.
	Energy	2 – 8 hours	
	Response	~10 minutes	
Objective 4: Mitigate Power Quality	**Capacity**	1 - 4	• Flywheels, super capacitors and lead acid devices are most attractive for meeting the phase balancing application.
	Energy	10 seconds to 10 minutes	
	Response	Sub-seconds (cycles)	
Objective 5: Backup Power for Feeder	**Capacity**	5 - 20	• Flywheels offer the greatest fit for this objective based on a requirement to provide up to 2 minutes of backup power for a feeder.
	Energy	<= 2 minutes	
	Response	Sub-seconds (cycles)	
All Round Solution	**Capacity**	Varies	• ***Li-ion and NaS storage systems provide the most attractive "all round" solution to THESL's Objectives.***
	Energy	Varies	
	Response	Varies	

In general:

- Lithium Ion battery systems were found to be appropriate for applications requiring relatively lower levels of energy and a moderate response time (minutes).
- Flywheels and super capacitors were found to be most appropriate for applications requiring a very fast but relatively short duration.
- Flow and NaS batteries were found to be most appropriate for high energy, long duration applications.

Developing a CES that meets THESL's objectives using available technology is feasible. The CES will have the ability to correct voltage sags plus inject real and reactive power into the system as required. The challenge will be in the development of a control system tied to THESL Dispatch to optimize "Smart Grid" support.

The emergence of new customer loads such as EV's and PHEV's are a concern to electric utilities due to congestion at the local distribution level especially on the 240 V secondary of the transformer. Kinectrics' past experience with EV committees[62] suggests utility control of the charging load through smart technology two-way communication (i.e. load management) be considered first before implementing a storage solution.

Careful charge-discharge management is key to battery longevity. Keeping detailed operation and maintenance records are recommended to help assess long term performance and reliability.

At this time, development of pilot CES will be based on existing standards with some necessary exceptions. As CES evolves, a dedicated standard will be needed to address its unique utility requirements. For example, FERC 661 requirements for utility connected inverters is recommended to ensure provision for low voltage ride through and VAR support for sag mitigation. By staying connected during a temporary fault, post-fault voltage support is maintained which helps maintain grid stability.

At this time, no off the shelf product exists to meet THESL's unique application needs. Therefore, custom built, designed to order equipment is required. To ensure this equipment is suitable, pilot installations are needed to identify any risks or other issues such that corrective action can be taken prior to wide scale deployment.

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62 EPRI National Electric Transportation Infrastructure Working Council (IWC) and Electric Vehicle Association of Canada (EVAC).

The following basic steps are viewed as the path to establishing a CES pilot within THESL's service territory:

1. Identify a candidate feeder which would benefit from a CES.
2. Determine a CES size/capacity to meet the need of the candidate feeder.
3. Develop functionality requirements to meet THESL's needs
4. Secure a suitable site on the feeder for installing the CES preferably as close to the load as practical.
5. Choose a suitable storage technology with power/energy capacity to meet THESL's objectives.
6. Select a PCS supplier to develop and build a prototype CES to meet THESL's requirements.
7. Work with the PCS supplier to interface controls between the CES and THESL Dispatch Centre.
8. Specify acceptance tests to ensure CES unit meets the performance specification.
9. Install and commission CES.
10. Monitor performance and adjust control parameters as needed to refine functionality.

Based on discussions with THESL a draft purchasing specification was developed for a 500 kVA CES. A detailed specification is presented in Appendix H.

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32. CSA Standard "Interconnection of distributed resources and electricity supply systems" CSA C22.3 No. 9.

33. Lars Gertmar,Per Karlsson, Olof Samuelsson, "On DC Injection to AC Grids from Distributed Generation" LTH/IEA, Lund University, Lund, Sweden, ISBN : 90-75815-08-5, EPE 2005 - Dresden

34. A. Pasolini "New System Can Help Predict Photovoltaic Solar Output Variability" Energy Refuge, October 14, 2010

Appendix A: Company Profiles

Data in Appendix A is based on Navigant industry expertise, secondary research and industry survey results.

A123 Systems

Website: http://www.a123systems.com

Overview:

- Founded in 2001, A123 Systems is now one of the world's leading suppliers of high-power Li-ion batteries. Its proprietary technology is built on a new nanoscale materials initially developed at MIT.
- A123 operates 400,000 sq. ft. of automotive class manufacturing facilities in Hopkinton, MA; China; and Korea, with capacity to scale to millions of battery packs per year.
- Markets include: portable power; grid stabilization incl. standby reserve capacity and frequency regulation services; custom solutions for govt./military; and transportation (passenger, heavy duty, aerospace)
- Core competencies include: science and development expertise; battery design capabilities; battery systems engineering and integration expertise; vertical integration from battery chemistry to battery system design services; industry leading partners in focused markets; high-quality, volume manufacturing facilities and proprietary process technologies.

Technology Background:

- Technology and Leading Grid Applications: A123's battery technology is Nanophosphate™ lithium ion which is a 2MW modular storage system named the Hybrid-Ancillary Power Unit (Hybrid-APU). The primary applications of frequency regulation and spinning reserves could be extended to: intermittent renewable resource output 'smoothing'; fast response/ramping for assuring normal-condition frequency stability; and fast response/damping modulation for infrequent emergency-condition dynamic stability.
- Power and Energy Ratings for a Typical Module: 2 MW, 500 kWh self-contained in modular containers that can be paralleled for project power/interface capacities ranging from 2 to 100's of MW.
- Interface with Inverter: This system uses a 960Vdc nominal electrical interface between battery and inverters including PLC control to coordinate the battery management system (BMS), inverter, and the grid interface. MODBUS and CAN open protocols are used for communications between battery subsystems, BMS, and PLC.
- Flexibility to Use Other Manufacturer's Inverter: generally, if the inverter can accommodate 960Vdc nominal DC bus voltage level.

Technology Status:

- A123 technology is mass produced for DeWALT and Black & Decker.

- This battery technology is at the demonstration stage for frequency regulation applications and commercial stage for PHEVs and other small applications.
- The Hybrid-APU have been built and deployed for commercial applications including Frequency Regulation and Spinning Reserves Ancillary Services in international electric power markets.
- A123 is working with 7 major North American and European OEMs on 19 different HEVs, PHEVs, and EV vehicle models.
- In Nov. 2008, A123 installed a 2 MW H-APU at one of AES' Southern California power plants. A123 is under contract to provide H-APU's in 2009 for use in grid stabilization applications in AES facilities worldwide
- A123 received DOE USABC awards of $27.5M for HEV and PHEV battery development.
- In January 2009, A123 applied for $1.84 billion in direct loans for construction of Li-ion battery manufacturing facilities in the US for full production volume (5 million HEV or 500,000 PHEV per year by 2013) under US DOE's Advanced Technology Vehicles Manufacturing Incentive Program .

Operating Characteristics

- Cycle Life, Calendar Life: The life is dependant on application and environment. For frequency regulation, battery life expectancy is 15 yrs. The cycling capability (to 80% of remaining life) of their batteries can range from 7,000 to multiple-10,000's of cycles.
- Efficiency: Battery and system efficiencies are application dependent. Round trip efficiency is about 94%-96% DC for typical 0.5C - 1.0C cycles.
- Reliability, Availability: A 95% system-level (through inverter) availability assumption is recommended for planning purposes, including planned and forced outages.
- Maintenance Requirements & Costs: Maintenance is application dependent. In general, minimal maintenance is required for the battery over normal operating ranges and life-cycle. Batteries are continuously monitored and additional periodic condition-related testing and reporting is conducted through automated systems. Project balance of plant would drive most of the manual maintenance scope and cost. Primary balance of plant systems include; inverters, house power and lighting, air conditioning, fire suppression systems, and grid interconnection equipment.
- Operating Limits: operating temperature range within container are -10°C to +40°C. Standby/storage temperature limits within container are -30°C + 60°C.
- Disposal: End of life management would be negotiated.

Altair Nanotechnologies

Website: http://www.altairnano.com

Overview:

- Altairnano specializes in the creation and delivery of advanced materials and ES products. Altairnano has three divisions: Power and Energy, Performance Materials; and Life Sciences. Lithium ion batteries (called nano lithium Titanate) are developed in the Power and Energy Group.
- Marketing efforts are made in markets currently dominated by Nickel Cadmium and Nickel Metal Hydride batteries, such as automobiles and stationary power applications.
- Developments are focused on rapid charging, long cycle life, long calendar life, low maintenance, and tolerance to temperature extremes, which could prove advantageous in these markets.

Technology Background

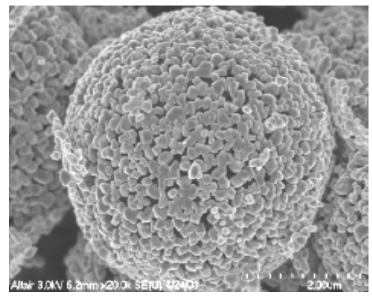
- Technology and Leading Grid Applications: Altairnano nLTO (*nano Lithium Titanate Oxide*) provides an anode material for lithium ion cells that provide unmatched characteristics. The cells are positioned on the Ragone plot between a battery and a super capacitor. This allows the technology to provide power storage as opposed to ES. The leading grid applications are Frequency Regulation, wind low voltage ride through, and photovoltaic smoothing.
- Power, Energy Ratings for a Typical Module and System: The base system is a 1 MW, 250 kWh module which can be built into various systems.
- Interface with Inverter: The existing system uses 1000 volts and 1000 amps nominal. Other voltages and currents are available.
- Flexibility to Use Other Manufacturer's Inverter: Inverters from various vendors are available (e.g., ABB, Parker Hannifin, and S&C.)

Technology Status

- The battery technology is at a demonstration stage with expected commercial development by 2010.
- In January 2007, Altairnano entered into an agreement with Phoenix Motorcars, to use the batteries in electric vehicles. In September 2006, Altairnano signed an agreement with Alcoa's AFL Automotive business to jointly develop a battery pack system.

- Altairnano is working with AES Corporation to supply battery packs at strategic points within the electrical grid to deal with congestion, peak energy and real-time fluctuations. They have already supplied two 1 MW batteries that are used by AES for regulation and voltage control.
- Altairnano received Congressional support for the funding of several key projects, including $2.5 million of funding for design and development of a 2.4 MW stationary power supply to replace emergency diesel-powered generators on Navy ships.

Altairnano Super Module 6.4 kWh
(Nominal 18.4 V 2800 Ah)



Altairnano'snano-titanate
material NanoSafe

Operating Characteristics

- Cycle Life, Calendar Life: Cycle life depends on the dispatch cycle. The calendar life is 25 years @ 25°C.
- Efficiency: Total round-trip efficiency, including inverters and transformers, is 88% to 96% depending on the dispatch.
- Reliability, Availability: A warranty is available with customer dispatch cycle information provided.
- Maintenance Requirements & Costs: Requirements are minimal and include replacing air-conditioning filters and monitoring the fire suppression system.
- Operating Limits: Operating temperatures range from -40°C (-40°F) to 55°C (131°F)
- Disposal: All materials are recyclable.

Axion Power International, Inc.

Website: www.axionpower.com

Overview:

- Axion can manufacture both conventional lead-acid and its patented PbC™ (lead carbon) batteries. Axion has a 65,000 sq. ft. manufacturing facility, which can produce 3,000 batteries per day; a 10,000 sq. ft. warehouse; and a new 55,000 sq. ft. facility for carbon electrode manufacturing.
- Axion has tested PbC™ prototypes since April 2004 – claiming that these batteries have withstood >1,600 cycles before failure at a complete charge-discharge cycle every 7 hours to a 90% DoD (most lead-acid batteries designed for deep discharge applications can only survive 300 to 500 cycles under these conditions). They also claim performance advantages of higher power delivery and recharge rates; longer cycle lives in deep discharge applications; less lead; and zero maintenance.
- Markets include HEV/EV/PEV; Hybrid Truck/Bus/Train; Grid-based ES (Power Cube® is a highly mobile ES system that can be configured to deliver up to 1 MW of power for 30 minutes or 100 KW of power for 10 hours); Truck Auxiliary Power Unit; Military Applications; and Others, such as UPS (SureEnergy® batteries) and TurboStart (16V racing batteries and sealed collector car batteries).

Technology Background

- Technology and Leading Grid Applications: Technology is lead-acid, with carbon power negative electrodes. Grid applications could include transmission smoothing.
- Power, Energy Ratings for a Typical Module and System: The module rating is 12 V/500 Wh. The Power Cube (trailer), Axion's first system, is rated 75 kW/225 kWh.
- Interface with Inverter: There should not be an issue interfacing with inverters.
- Flexibility to Use Other Manufacturer's Inverter: Axion does not manufacture inverters.

Technology Status

- Growth strategies include the sale and manufacture of both conventional lead acid and PbC™ batteries, and further development of PbC™ batteries.
- Axion has at least 6 patents, with applications for at least 6 more.
- In Feb. 2009, Pennsylvania granted Axion $800,000 to study its batteries in electric vehicles.
- In Oct. 2008, Axion received a $1.2 million Dept. of Defense grant to develop batteries for use in Marine Corps vehicles.
- In Feb. 2008, Axion announced PbC™ ultra-capacitors demonstration projects with the U.S. Army and Penn State University.
- In Oct. 2007, Axion agreed to provide batteries for a New York state-funded demonstration to provide additional peak power capacity.

- Axion entered into an MOU with East Penn Manufacturing Company, Inc., for a three-phase joint development and testing program of pre-commercial PbC™ prototypes.

Operating Characteristics

- Cycle Life, Calendar Life: The cycle life is > 2,000 cycles and thee calendar life is 7-10 years.
- Efficiency: Efficiency is close to 100%.
- Reliability, Availability: Reliability and Availability are high.
- Maintenance Requirements & Costs: Power Cube trailer comes with remote monitoring system.
- Operating Limits: Operating temperatures range from -35°F to +60°C.
- Disposal: The battery is completely recyclable.

Deka/East Penn Manufacturing

Website: http://www.eastpenn-deka.com/

Overview:

- East Penn Manufacturing Co. is recognized as a world leader of the highest quality and most innovative lead-acid battery technology since 1946. They manufacture thousands of different types of batteries, cable and wire products, and battery accessory products.
- East Penn's >2 million sq. ft Lyon Station, PA plant on a >490 acre plant site is the largest single battery manufacturing facility in their industry with computer monitoring and control systems. The Quality System is certified to ISO 9001 for the entire plant site and all divisions.

Technology Background

- Technology and Leading Grid Applications: Lead-acid batteries can be used for Grid applications. Regulation services and spinning or non-spinning reserve are options.
- Power & Energy Ratings for a Typical Module and System: East Penn is proposing a 2 MW system but larger systems are possible. A proposed system has a battery sized for 2 MW and capable of 5-hours backup or a 10 MWh system.
- Interface with Inverter: East Penn's lead-acid batteries are capable of interfacing with inverters, but they do not design the power conversion equipment.
- Flexibility to Use Other Manufacturer's Inverter: Batteries should be fine with any inverter.

Technology Status

- Applications include industrial, automotive, commercial, marine, stationary and specialty markets.
- In Sept. 2008, East Penn entered into an agreement with Furukawa Battery Co., LTD to release the UltraBattery, which will be manufactured by East Penn. It combines an enhanced power negative electrode in a lead-acid battery, accepting and delivering high levels of power with low levels of electrical resistance similar to an ultracapacitor. The UltraBattery is suited for HEVs, which rely on a battery operated electric motor to meet peak power needs during acceleration and recapture energy normally wasted through braking to recharge the battery. The UltraBattery exceeded life cycles of its Ni-MH counterpart for HEV applications in tests, utilizes a less cost-intensive technology, and is easier to recycle than Ni-MH and Li-ion batteries.

Operating Characteristics

- Cycle Life, Calendar Life: Cycle life depends on the battery type, environment, depth of discharge, etc. East Penn has batteries that cycle for over five years, if applied properly.
- Efficiency: East Penn does not produce power conversion equipment. Batteries require 5–10% additional amp hours on recharge, when fully recharging the batteries.
- Reliability & Availability: There is no data on reliability in grid applications.
- Maintenance Requirements & Costs: IEEE standards suggest quarterly checks for valve-regulated batteries. Costs are unknown.
- Operating Limits: Batteries will operate at -35°F but at a very low capacity. A much larger system is required if a continuous, -35°F system is involved. This is not suggested.
- Disposal: Lead-acid batteries are 100% recycled in East Penn's Smelter.

Electrovaya

Website: www.electrovaya.com

Overview:

- Electrovaya is a leader in the design, development and manufacture of its proprietary Li-ion SuperPolymer® battery systems. Electrovaya's mission is to accelerate clean transportation as a commercial reality with its advanced power systems for all classes of zero-emission electric vehicles and PHEVs. Electrovaya also offers battery-related consumer products primarily focused on the healthcare market.
- Electrovaya's expansion strategy is to provide automotive batteries globally as a supplier, strategic partner, and joint venture partner; as well as providing stationary ES& other large battery systems.

Technology Background

- Technology and Leading Grid Applications: Li-ion SuperPolymer® battery technology has over 150 patents and superior energy density. It has a prismatic cell design and large-format cells are available. Electrovaya offers integrated iBMS™, systems expertise, and a zero-emission manufacturing process.
- Power & Energy Ratings for a Typical Module and System: This is customizable to the application. This technology has one of the highest energy densities (kWh/kg) in the industry, particularly for large battery systems. Cell-level specs are <100Ah cell sizes. All cells are prismatic with 180Wh/kg energy density, 2,000 W/kg power density for 10 seconds; 2C continuous or 10C peak power.
- Interface with Inverter: Electrovaya has a flexible design and experience with single and bidirectional invertors. Communications protocol CANBus is preferred, but RS332 is available.
- Flexibility to Use Other Manufacturer's Inverter: Inverters from different manufacturers will likely need the battery electronics to be reprogrammed. Nominal battery voltage below 700V (the lower the better) is preferred. Electrovaya would work with any manufacturer selected once the program has begun.

Technology Status

- Clean Transportation Division

  Focus:

  — Zero-emission battery electric vehicles (BEVs)

  — Plug-in hybrid electric vehicles (PHEVs)

  Highlights:

  — Joint venture with Tata Motors/Norsk Hydro

  — Global Marketing collaboration with ExxonMobil

— Memo of Understanding signed with Chana International (China's 4th largest automaker)

Applications:

— Passenger Vehicles - Tata Motors, Phoenix Motorcars, others in discussion
— Urban Vehicles - Maya300, others in discussion
— Off-Road Vehicles - several partners – confidential
— Specialty Vehicles - autonomous vehicles, military vehicles, others
— Medium-duty & Heavy-duty – buses, delivery vans, multiple partners

- Battery Division – over 150 patents
- Industry involvement: Vice-Chair of Electric Mobility Canada; ES Chair for Canadian Electric Vehicle Roadmap; Co-founder of Plug-in Hybrid Development Consortium with PG&E, Southern Cal. Edison, Maxwell Technology.

Operating Characteristics

- Cycle Life, Calendar Life: Cycle life is in line with other automotive grade Li-ion batteries with performance related to usage characteristics. Cycle life, at 100% DOD @1C charge/ discharge rates, is 4,000 cycles to reach 80% of initial capacity. At 50% DOD @ C/2 charge/ discharge rates the cells are expected to reach 80% of initial capacity after 9,700 cycles. Calendar life is >7 yrs.
- Efficiency: Cell efficiency is in line with all Li-ion batteries with charge/ discharge efficiencies >99%. System efficiency will vary according to design.
- Reliability & Availability: Electrovaya follows strict safety requirements for the automotive and aviation industries and are tested and pass the Underwriters Laboratory tests specified in the UL 2054 standard in addition to the International Air Transport Association (IATA) tests. Systems are available at least 80% of time. Cells are currently in production and are available shortly following purchase orders.
- Maintenance Requirements, Costs: Minimal maintenance is required. The site needs to be within a optimal temperature window (below 55°C).
- Operating Limits: Cells are optimized to perform between –20°C and 55°C.
- Disposal: Recycling is recommended. (e.g. TOXCO, Kinsbursky)

NGK Insulators, Ltd.

Website: http://www.ngk.co.jp/english/index.html

Overview:

- NGK manufactures and sells power-related equipment (e.g., insulators) and industrial ceramic and beryllium copper products.
- The Power Business Division manufactures NAS batteries and promotes joint R&D with electric power companies. NGK's NAS system is the world leader in large-scale ES systems.

Technology Background

- Technology and Leading Grid Applications: The NAS battery was jointly developed by Tokyo Electric Power Company (TEPCO) and NGK over the past two decades for utility, industrial, and commercial applications requiring multi-MW power for discharge over several hours. Grid applications include load leveling, which consists of feeder reliability enhancement and upgrade deferral for T&D utilities and peak shaving, emergency backup, and power quality for customers; renewable energy, which consists of time-shifting generation and fluctuation smoothing for wind & solar generators; and ancillary services (e.g., ISO markets), which consists of frequency regulation, energy arbitrage, and spinning reserves.
- Power & Energy Ratings for a Typical Module and System: NAS battery installations are deployed in 1 MW blocks nominally rated at 6 to 7 hours discharge energy, with recent installations typically in the range of 2 to 8 MW
- Interface with Inverter: The NAS Battery System has a nominal DC bus voltage of 640 Vdc and operates over 465 Vdc (minimum discharge) to 780 Vdc (maximum charge). The battery management system supplied by NGK monitors voltage and temperature, and prevents over-charge and over-discharge.
- Flexibility to Use Other Manufacturer's Inverter: The NAS battery has been supplied with inverters (power conversion systems) provided by vendors including S&C Electric and ABB in the U.S., and Toshiba, Meiden-sha and others in Japan.

Technology Status

- In 1998, a 48 MWh NAS load leveling battery that delivers 6 MW for 8 hours was installed by NGK for TEPCO's Ohito Substation.
- After 50 demonstrations in Japan, NAS batteries were offered for commercial sale in Japan in April 2002. NGK produced 40 MW in 2003 and 65 MW in 2004. Over 280 MW have been installed in Japan.
- NGK entered the North American market in 2006 with AEP's installation.

- NGK is supplying a 1 MW NAS battery to Younicos, a distributor of solar cell-based generators in Germany.
- 50 MW currently under construction in the Middle East.
- NGK announced that it will expand annual production capacity for NAS batteries from 90 to 150 MW. NGK is also developing batteries tailored to overseas markets. Over 200 projects have been deployed.

Operating Characteristics

- Cycle Life, Calendar Life: Projected cycle life is 4,500, 6 MWh discharge-charge cycles (e.g., 300, 6 MWh cycles per year) and calendar life is 15 years.
- Efficiency: Average DC efficiency for full 6 MWh discharge-charge cycles is projected @ 85%. When equipped with bi-directional PCS with rectifier and inverter efficiencies of 95% or better, projected AC efficiency is over 76%.
- Reliability & Availability: Assuming a 3-year mean-time-to-repair interval, system availability to deliver 6 MWh per cycle is projected to exceed 98%.
- Maintenance Requirements, Costs: NGK recommends continuous remote monitoring, routine housekeeping, and inspections at 3-year intervals which include inspecting for unusual vibrations, noise or odors, abnormal conditions of connecting cables and the exterior enclosure, and insulation resistance; re-torquing connections; collecting and analyzing battery resistance and open circuit voltage data; confirming the accuracy of DC voltage, DC current, and temperature sensors; adjusting module enclosure insulation to control standby heat loss (at intervals of 1,000 cycles); consumables include equipment fuses, controller LCD, DC power supply, controller memory batteries, etc. The cost of maintaining the NAS Battery system is projected to range from $10 to $15/kW-year.
- Operating Limits: Temperatures range from -20 to +40°C (standard outdoor installations).
- Disposal: NAS battery cells are incinerated. When justified by demand for such services, over 98% of NAS battery module materials can be recycled.

Premium Power

Website: http://www.premiumpower.com

Overview:

- Power and ES products are based on proprietary Zinc-Flow® ES system. Applications include:
- Electric power back-up of mission-critical equipment in locations such as wireless cell sites, POP's, Central Office, cable communications headends and data centers
    - Reserve power for electric utility facilities that provide transmission and distribution of electricity
    - Bulk ES for renewable energy generation assets including wind and solar, to provide firming, energy arbitrage and reduction of curtailments
    - Peak-shaving (load shifting) to reduce electricity costs by lowering peak demand and time-of-use energy charges

Technology Background

- Technology and Leading Grid Applications:
- Power, Energy Ratings for a Typical Module and System: The Transflow 2000 module size is 500kW / 2.8MWh.
- Interface with Inverter: Unknown
- Flexibility to Use Other Manufacturer's Inverter: Unknown

Technology Status

- Premium Power has provided demonstration units for utility applications and PV as well as for commercial for backup power.

Operating Characteristics

- Cycle Life, Calendar Life: Calendar Life is 30 years at 100% DOD.
- Efficiency: Efficiency is estimated at 70%.
- Reliability, Availability:
- Maintenance Requirements, Costs:
- Operating Limits:
- Disposal:

Prudent Energy

Prudent Energy

Website: http://www.pdenergy.com/

Overview:

- Prudent Energy Inc., based in Beijing, China, is an ES technology developer, manufacturer and systems integrator, specializing in the patented VRB ES System (VRB-ESSTM). Founded as a VC in 2006, Prudent Energy has developed several low cost VRB-ESS system components.
- Prudent Energy announced its acquisition of the assets, IP and know-how, of VRB Power Systems Inc. on January 29, 2009, with the core technical team of VRB Power joining Prudent Energy. Prudent Energy International is the Canadian branch, while the head office and manufacturing are located in Beijing.
- Prudent Energy has 11 patents in application and about 50 employees.

Technology Background

- Technology and Leading Grid Applications: The VRB-ESS™ is an electrical ES system based on the patented vanadium-based REDOX regenerative fuel cell that converts chemical energy into electrical energy. Prudent Energy's systems are built on a 150 kW modular basis with a broad range of applications including: Remote Area Power Supply; Renewable Energy for stabilization and frequency regulation; Power Grid ES for peak shaving; Remote Telecom Stations that require cycling the VRB-ESS repeatedly.
- Power & Energy Ratings for a Typical Module and System: VRB-ESS™ is a multi-MW system with 6 to 8 hours of storage and 50% pulse for 10 minutes (once per hour). Multiple 125 kW blocks are connected in parallel to deliver the required rating of the system.
- Interface with Inverter: Maximum (fully charged) and minimum d.c. voltages (fully discharged) are 600Vdc (discharged) to 750Vdc (fully charged) open-circuit.
- Flexibility to Use Other Manufacturer's Inverter: Prudent will use any qualified PCS and controllers. Its only proprietary systems are stack, design, and IP.

Technology Status

- First commercial VRB installation occurred in Japan in 1996.
- Castle Valley, US: A 250 kW/2 MWh VRB-ESS was installed on a remote section of power line in South-Central Utah. The battery provided peak shaving and load leveling

to support loads in times of peak electricity demand. The system enabled PacifiCorp to defer a new sub-station and power-line, and included control interface applications.

- Remote Mobile Telecom Stations, Kenya: Two 5 kW/20 kWh VRB-ESS support off-grid wind-powered mobile telecom stations. They have operated for over a year, reducing diesel usage by close to 70%.
- Risoe, Denmark: A 20 kVA RAPS installation is coupled to several small wind turbines, PV panels, and loads operating in an isolated grid.
- There are several Sumitomo VRB-ESS installations in Japan, including a 4MW x 1.5 hour (50% pulse factor) VRB-ESS grid-coupled wind smoothing system in Tomamae, Japan.

Operating Characteristics

- Cycle Life, Calendar Life: The VRB-ESS is capable of tens of thousands of deep cycles as its electrolyte never wears out. >20-year life is expected for most system components, with 10-year life expected for cell stacks (change out 50% in year 10) and 10-year life with 5-year maintenance for pumps. SOC of the VRB-ESS is known at all times via direct measurement.
- Efficiency: Efficiency is ~80% DC-DC and 70+% AC-AC.
- Reliability & Availability: Reliability of 96.69% (equiv. to 12 days per year of unavailability) is expected for a single 125 kW unit given 6 monthly planned maintenance intervals, and a limited voting scheme of transducers. Reliability rises to 99.916% (equiv. to 3 days per year of unavailability) for 3 modules of 125 kW. Reliability rises as modules are added in parallel. Each 125 kW block can deliver a continuous overload of 50%, so when the system rating is 375 kW or greater, then complete redundancy exits for any single block failure. As the size increases, this redundancy rises proportionally.
- Maintenance Requirements, Costs: Maintenance costs for a single 125 kW module with 6 hours of electrolyte storage and daily cycling over a 10-year period are $9,000 to $12,000/year (inclusive of labor). Adding pump rebuilds and electrolyte rebalancing increases costs to $15,000 to $20,000/year. 1 MW and 10 MW plants with 6 hours storage will have annual O&M costs of $52,000 and $320,000/year, respectively.
- Operating Limits: The plant is designed to manage operating temperature of the electrolyte around 35°C. The amount of cooling required is a function of ambient temperatures and cycling and pulsing regimen.
- Disposal: The electrolyte is fully reusable as it never wears out. Prudent will repurchase it for use in another system or recycle it and extract the vanadium. The stacks are refurbished and the pipes (plastic) are disposed of as light hazardous waste.

Saft Batteries

Website: http://www.saftbatteries.com

Overview:

- Saft is a leading designer, developer, and manufacturer of advanced technology batteries for industrial and defense applications. Saft has three worldwide divisions: Industrial Battery Group (IBG), Specialty Battery Group (SBG), and Rechargeable Battery Group (RBS)
- Saft is a manufacturer of industrial Ni-Cd batteries for use in air and rail transportation, standby power applications, emergency lighting. They also produce Li-ion batteries for the electronics and defense industries.
- There are opportunities in traditional nickel-based applications, Li-ion technology in industrial applications (commercial aviation, telecom networks, renewables), and HEVs through Johnson Controls-Saft.

Technology Background

- Technology and Leading Grid Applications: Li-ion (close to commercial stage) is expected to be used for renewable applications on the grid. NiCd (commercial stage) uses technology for rail cars, mass transit and some grid applications.
- Power & Energy Ratings for a Typical Module and System: 10 MW, 5 MWh system can easily be scaled up.
- Interface with Inverter: Saft typically uses a CAN bus interface, with robust communication used on electric vehicles.
- Flexibility to Use Other Manufacturer's Inverter: It would be necessary to reprogram the system to use on another inverter (e.g. adapt the alarm responses).

Technology Status

- Saft NiCd batteries are being put into a trolley bus in Hawaii for a zero-emission vehicle demo. Saft's NiCd batteries are mostly being used for transit projects such as this, with railways also being important customers.
- Saft and ABB have a joint effort to demonstrate a 200kWh, 600kW/15 min Li-ion battery with ABB's Static VAR Compensator (SVC light).
- In Feb. 2009, Saft Nife, the Middle East rep, launched a new Uptimax range of Ni-Cd batteries for high temperature stationary applications in the electricity, O&G, and utility industries.

- In Feb. 2009, Johnson Controls-Saft will supply a battery system for Ford Motor Company's 1st series production PHEV, to be introduced in 2012.

Operating Characteristics

- Cycle Life, Calendar Life: Calendar life is 15-20 years depending on the cycling. At 80% DOD, cycle life is 3000-4000 cycles. A test for hybrid vehicle applications showed > 1 million cycles @ 3% DOD.
- Efficiency: Efficiency is 92%-100% depending on discharge rate.
- Reliability & Availability: This depends on the system voltage (how many units you have stringed together), whether you go to ASICS, a single chip versus a bunch of components, and application etc. Small telecom systems last 440,000 hours for MTBF. For a utility it would be much less, however ASICS would give it a huge increase.
- Maintenance Requirements & Costs: No scheduled maintenance or routine service calls are required. The system is self-diagnostic and will shut itself down and call for service. This is limited to component replacement and possibly some service on ventilation systems.
- Operating Limits: Li-ion can operate at full output between 20°C and 40°C. Charge/discharge power is reduced at higher/lower temp. For MW-level installations, it would not make sense for temp to go outside the optimum range, so a full HVAC system would likely be used. NiCd can operate down to -40°C. But a 10 MW should always operated under controlled conditions at 20°C to achieve high power.
- Disposal: Saft will dispose of it if the user pays for transportation.

Dow Kokam

Website: http://www.dowkokam.com

Overview:

- Dow Kokam was established in 2009 to develop and manufacture battery solutions for the transportation, defense, industrial and medical industries. The company is owned by The Dow Chemical Company, TK Advanced Battery LLC and Groupe Industriel Marcel Dassault (Dassault).

Technology Background

- Technology and Leading Grid Applications: Dow Kokam offers a liquid cooled high-energy lithium-ion battery pack for vehicle applications. In combination, Dow Kokam manufactures a management system that monitor the voltage and temperature of each cell.
- Power & Energy Ratings for a Typical Module and System: 16kW continuous output in discharge/ 7kWh packs.

Technology Status

- Dow Kokam has reached commercialization of its product. Currently, its new manufacturing facility in Midland, Michigan is under construction and will have a capacity to produce li-ion packs to meet the demand of 30,000 fully electric vehicles per year.

Operating Characteristics

- Cycle Life, Calendar Life: 10-year lifetime
- Efficiency: N/A
- Reliability & Availability: High reliability and availability. nickel metal cobalt technology
- Maintenance Requirements & Costs: No specific maintenance requirements.
- Operating Limits: N/A
- Disposal: No extraordinary disposal requirements.

Temporal Power

Website: http://www.temporal-power.com/

Overview:

- Temporal Power is a new entrant to the mid- to large-scale flywheel storage market. The company was incorporated in January of 2010 and is located in Burlington, Ontario. The company has received funding from both the provincial and Federal government as well as utility industry partners.

Technology Background

- Technology and Leading Grid Applications: Temporal Power offers a flywheel product based on a passive permanent magnetic bearing, which results in a 0% electric parasitic loss (vs. a Beacon flywheel with 2% loss). Temporal is focusing on utility grid market applications such as power quality.
- The Temporal flywheel is based on 250kW modules, which have a footprint of ~1 square meter and energy density of 15Wh/kg. The company's current 5 MW project will consist of arrays of the 250kW unit.
- Power & Energy Ratings for a Typical Module and System: 250kW/50kWh modules.
- Interface with Inverter: The product is expected to come with the inverter ready for grid connection.

Technology Status

- Temporal Power is at the demonstration stage for utility applications. The company is slated to install a lab demonstration of 50kWh/50kW generators for 5-6 minutes of operation After lab testing, Temporal anticipates connecting to the grid at end of 2011, followed by a 6-month impact assessment.

Operating Characteristics

- Cycle Life, Calendar Life: 20-year lifetime with potential for bearing replacement, but overall maintenance requirement is low.
- Efficiency: The AC-AC round-trip efficiency is 80%
- Reliability & Availability: High reliability and availability. After 8 hours of idleness, device will still have 85% capacity remaining.
- Maintenance Requirements & Costs: As mentioned above, the system is designed to require very little maintenance over its lifetime.
- Operating Limits: Very high tolerance for extreme ambient temperatures given that the systems are installed under ground.
- Disposal: No extraordinary disposal requirements.

ZBB Energy Corporation

Website: http://www.zbbenergy.com

Overview:

- ZBB Technologies Ltd. was formed in 1982 to develop commercial applications for zinc-bromine research. ZBB Technologies, Inc., the U.S. operating subsidiary, was established in 1994 in WI to acquire the zinc-bromine technology assets of Johnson Controls, Inc. ZBB Energy Corporation was formed in 1998 in WI as a holding company for ZBB Technologies Ltd. and ZBB Technologies, Inc.

Technology Background

- Technology and Leading Grid Applications: The ZBB Zinc ES System (ZESS) is a proprietary and patented regenerative fuel cell based on zinc/bromide technology. The ZESS technology is based on the reaction between the two chemicals, zinc and bromide. Grid applications include: utility companies, peak shaving, plant deferral, asset optimization, renewable energy support, distribution benefits. Commercial/Industrial applications include: Arbitrage, Peak Shaving/load leveling, Capital deferral, Improving electric service reliability, and reducing environmental impacts. Renewable Energy applications include: time shifting, and smoothing.
- The ZESS 500 consists of ten 50 kWh modules, a Power Conversion System (PCS), and an overall system control package. It achieves maximum continuous power (250kW) and sustains it for 2 hours (500 kWh) with 200% peaking capability.
- Power & Energy Ratings for a Typical Module and System: ZESS 500 = 0.5MWh, 0.25MW peak
- Interface with Inverter: The product comes with the inverter ready for grid connection.
- Flexibility to Use Other Manufacturer's Inverter: Other inverters could be used.

Technology Status

- The ZESS 500 is at the demonstration stage for utility applications and is commercial for smaller PV applications.
- In December 2008, ZBB received an order for a standard, modular, ZESS 500 system to be installed with an existing 850 kW wind turbine at the Centre for Renewable Energy, Dundalk Institute of Technology in the Republic of Ireland.
- In July 2008, ZBB signed a MOU w/ Envision Solar International to provide ZESS 50™ systems as part of "LifeVillage™" solar project in Cote d'Ivoire.
- ZBB supplied two 50 kWh units to Greenpoint Manufacturing and Design Center in New York City in 2003.

- Other installations include: Future House USA Beijing Olympic Games (Beijing, China); United Energy Limited (Melbourne, Australia); Sumitomo Corporation (Tokyo, Japan); Detroit Edison (Detroit, US Sandia National Laboratories (Albuquerque, US)

Operating Characteristics

- Cycle Life, Calendar Life: Cycle life @ 100% DOD is 10 yrs. for 10% capacity degradation.
- Efficiency: The round-trip efficiency at the cell stacks is 77% and the roundtrip efficiency inclusive of the pump AUX power is 68%.
- Reliability & Availability: The ZESS system inclusive of the PCS has an availability of 98%.
- Maintenance Requirements & Costs: Standard electrical inspection equates to approximately $4k (based on 1 person / day, travel and living expenses) to $20k (based on 2 people / week, travel and living expenses). There is an option for ZBB to train and certify people to further reduce costs.
- Operating Limits: Standard operating temperature is ideally an ambient temperature of 0-40°C; however, the option for a hot/cold package which can be customized to operate within your required temperature range is available.
- Disposal: The electrolyte is environmentally safe with a PH factor of 2.5. The electrolyte can be returned to ZBB at the end of life. Cell stacks are manufactured completely with recyclable plastic.

Figure 46. Transporting ZESS 500

Appendix B: Survey Results

Table B- 1. Survey Responses and Results

Storage Vendor	Technology	Modularity of design:	Tolerance for over-charging or over-discharging:	Memory effects due to cycling:	Safety Issues
RedFlow Limited	ZnBr	• 200kW/400kWh building blocks (20 foot container format). • Each container connects to a separate 3-phase transformer (the rest of the PCS is included in each container). • Multiple units can be connected in an array.	Cannot be over discharged as it is designed for 100% DoD. Over charging auto shutdown as each battery module has on-board intelligence.	None - Zinc-bromine batteries are electroplating machines that plate onto plastic electrodes.	Leak of water-based electrolyte - mitigated with internal bundling. Electrolyte is Class 8 chemical like lead-acid battery acid
ZBB Energy Corp	ZnBr	• ZESS 50 module = 25kW / 50kWH • ZESS LOW POWR PECC = <200kW/800kWH (4-hour rate) • ZESS 500 container = 250kW/500kW • ZESS HIGH POWER PECC = <2000kW/80000kWH (4-hour rate)	Self regulating, cannot happen.	None	Zinc - Bromine electrolyte has a pH rating of 2.8 and can cause minor skin / eye irritations if exposed. Liquid electrolyte is 100& recombinant and end-customer never has required exposure to it
Premium Power Corporation	ZnBr	• All Premium Power Zinc Bromide flow battery products are built around a core 10 kW, 10 kWh cell-stack module. • By adding cell-stacks into a variety of designs, the technology is able to address applications ranging from the residential market (single-kW) to the large-scale utility market (multi-	Premium Power's ZincFlow flow battery technology is a fully reversible process, with no physical degradation from operation. During charging, zinc is reduced to metal on the anode from solution, protected from excessive overcharging as all of the available zinc is used up during operation. Likewise, during discharge zinc moves back into solution, protected from over-discharging as the reaction ends when	Premium Power's ZincFlow battery can be cycled an unlimited number of times at any depth of discharge over its life with no reduction in system performance.	Zinc-Bromide chemistry is a clean and safe ES options. ZincFlowâ technology operates at low temperature and the electrolyte PH is about the same as Coke-a-Cola and can be recycled or disposed of easily. The core building blocks of all products are fully UL certified, meet FCC, NEC and CSA requirements.

Storage Vendor	Technology	Modularity of design:	Tolerance for over-charging or over-discharging:	Memory effects due to cycling:	Safety Issues
		megawatt).	the zinc is fully converted.		
EnerSys	VRLA PbA	• modular for VRLA.	Shortens life.	none	typical of lead acid
Electrovaya	Li-Ion	• Modular design composed of multiple strings (cabinets) • Each cabinet with 94kWh capacity • 16 strings capacity in 23ft containerized format • can be expanded for other container formats (or reduced)	- BMS will prevent over-charging and over discharging. - Further protection from chosen PCS equipment (ABB preferred). - Further redundancy as ESS equipment is de-rated and therefore has window available for over-charge/discharge.	No memory effect	At the system level, the following are some of the design features that enhance safety of the BESS: • Large Format cells: Electrovaya plans to use its large format cells in this project. Larger cells require fewer cell to cell connections thus lowering the chances of failures. • Each string of batteries is housed in its own 19" wide 48U seismically rated (NEBS Zone 4 and GR-63-CORE) enclosure conforming to standard computing equipment standards, which provides seismic protection as well as reducing the risk of fire propagation. • Access to the batteries is from the outside of the ESS enclosure: risk of being trapped in a high-voltage/high energy environment is minimized. • Each battery module has "finger-safe" connectors and no exposed electrical conductor. The modules are therefore safe to handle and store without undertaking elaborate

Storage Vendor	Technology	Modularity of design:	Tolerance for over-charging or over-discharging:	Memory effects due to cycling:	Safety Issues
					electrical safety precautions. • The battery modules connect to the electrical bus via a plug-and-socket system, instead of nuts and bolts, for easy and safe replacement.
Prudent Energy Corporation	VRB	• MW scale systems use modules of 175/200kW to achieve ratings up to 10MW.	Overcharging is self-limiting. System can be discharged to zero SOC without impact on life. System can be provided with pulse capability, typically 150% of rating for 10 minutes every hour.	None	Vanadium element is dissolved in dilute sulphuric acid. Containment of any spilled electrolyte is only safety/environmental issue
International Battery	Li-ion	• International Battery provides ES systems based on large format Lithium-Ion cells made in the USA. Our cells are 512 Wh each and are building blocks for designs ranging from 4kWh to 10MWh.	Products are based on Lithium Iron Phosphate which is widely recognized as the most abuse tolerant chemistry in the industry. Safety data is available upon request and testing has been performed by UN agencies, government labs and many customers.	None	None. International Battery uses safe materials (LFP), safe cell design and a BMS for redundant protection and monitoring.
Temporal Power	Flywheel	• Design is based on a standard 50 kWh flywheel. By combining this flywheel with various sized motor generators, the desired power rating can be achieved (10-500 kW per flywheel). Flywheels can then be connected in parallel to achieve the desired energy and power rating.	Units are capable of 175% of their rated power for short periods of time (<1 min).	None	The design is extremely safe with factors of safety based on airline industry standards. It is also buried below grade to prevent any damage in the case of an external event causing damage.

Appendix C: CSA & ULC Approved Inverter Manufacturers for Distributed Power Systems

Table C- 1 and Table C-2 list CSA and ULc approved for distributed power generation systems. The majority are solar and some may be too small for utility purposes. However, the manufacturers of larger inverters such as Eaton Yale, SatCon, etc. may have the expertise and interest to develop CES for utilities. At this time the focus is on renewables such as wind and solar.

Table C- 1. List of CSA Approved Inverter Manufacturers for Distributed Power Generation Systems[63]

Company	Prov/State	Country	Class	Class Description	File Number
Advanced Energy Industries, Inc.	CO	USA	5311-09	POWER SUPPLIES-Distributed Generation Power Systems Equipment	106911_0_000
Akeena Solar, Inc.	CA	USA	5311-09	POWER SUPPLIES-Distributed Generation Power Systems Equipment	240838
Alpha Technologies, Inc.	WA	USA	5311-09	POWER SUPPLIES-Distributed Generation Power Systems Equipment	040855_0_000
Ampt, LLC	CO	USA	5311-09	POWER SUPPLIES-Distributed Generation Power Systems Equipment	244294
Andalay Solar, Inc.	CA	USA	5311-09	POWER SUPPLIES-Distributed Generation Power Systems Equipment	249992
Applied Solar, LLC	CA	USA	5311-09	POWER SUPPLIES-Distributed Generation Power Systems Equipment	220768
Cleanfield Energy Corp	ON	Canada	5311-09	POWER SUPPLIES-Distributed Generation Power Systems Equipment	243897
Diehl Ako Stiftung & Co.KG		Germany	5311-09	POWER SUPPLIES-Distributed Generation Power Systems Equipment	079465_0_000
Diehl Ako Stiftung & Co.KG		Germany	5311-09	POWER SUPPLIES-Distributed Generation Power Systems Equipment	247810
Eaton Yale Company	ON	Canada	5311-09	POWER SUPPLIES-Distributed Generation Power Systems Equipment	047169_0_000
Enphase Energy	CA	USA	5311-09	POWER SUPPLIES-Distributed Generation Power Systems Equipment	240080
Fronius International GmbH		Austria	5311-09	POWER SUPPLIES-Distributed Generation Power Systems Equipment	203213
Ingeteam S.A.		Spain	5311-09	POWER SUPPLIES-Distributed Generation Power Systems Equipment	243647
Petra Solar Inc	NJ	USA	5311-09	POWER SUPPLIES-Distributed Generation Power Systems Equipment	242893
Power-One, Inc	CA	USA	5311-09	POWER SUPPLIES-Distributed Generation Power Systems Equipment	056325_0_000
Satcon Technology Corporation	ON	Canada	5311-09	POWER SUPPLIES-Distributed Generation Power Systems Equipment	238200
Satcon Technology Corporation	MA	USA	5311-09	POWER SUPPLIES-Distributed Generation Power Systems Equipment	247126
Silent Power Inc	MN	USA	5311-09	POWER SUPPLIES-Distributed Generation Power Systems Equipment	245330
SunPower Corp	CA	USA	5311-09	POWER SUPPLIES-Distributed Generation Power Systems Equipment	245329
Sustainable Energy Technologies	ON	Canada	5311-09	POWER SUPPLIES-Distributed Generation Power Systems Equipment	238973
TenKsolar	MN	USA	5311-09	POWER SUPPLIES-Distributed Generation Power Systems Equipment	248152
Tigo Energy Inc	CA	USA	5311-09	POWER SUPPLIES-Distributed Generation Power Systems Equipment	247725

[63] Source – CSA.

Table C-2. List of UL Approved Manufacturers of Inverters for Distributed Power Generation Systems in Canada[64]

Company Name	Category Name	Link to File
DIVERSIFIED TECHNOLOGY INC	Static Inverters, Converters and Accessories for Use in Independent Power Systems Certified for Canada	*QIKH7.E317627*
Guide Information	Static Inverters, Converters and Accessories for Use in Independent Power Systems Certified for Canada	*QIKH7.GuideInfo*
INVERTERS UNLIMITED INC	Static Inverters, Converters and Accessories for Use in Independent Power Systems Certified for Canada	*QIKH7.E248499*
SCHUCO USA L P	Static Inverters, Converters and Accessories for Use in Independent Power Systems Certified for Canada	*QIKH7.E330683*
SMA SOLAR TECHNOLOGY AG	Static Inverters, Converters and Accessories for Use in Independent Power Systems Certified for Canada	*QIKH7.E210376*
SUNPOWER CORP	Static Inverters, Converters and Accessories for Use in Independent Power Systems Certified for Canada	*QIKH7.E314937*

Model number information is not published for all product categories. If you require information about a specific model number, please contact Customer Service for further assistance.

64 Source – Underwriters Laboratories Inc.

Appendix D: CES Manufacturer Contacts

The following are manufacturers that are most likely capable of producing CES for electric utilities.

S&C Electric Company
5251 West Franklin Drive
Franklin, WI 53132
Main: (414)423-8776 or (877) 642-7201
Fax: (414) 423-8766
Contact: Troy Miller
www.SandC.com

IE Power
4170 Sladeview Crescent, Unit 1
Mississauga, Ontario
L5L 0A1
Canada
(905) 813-8900
Contact: Vince Scaini
www.iepower.com/

SatCon Power Systems Canada Ltd
835 Harrington Court
Burlington, ON L7N 3P3
(905) 639-4692
Contact: support@satcon.com
http://www.satcon.com

ABB INC.

10300 boulevard Henri-Bourassa O
H4S 1N6 Montréal
Québec
Contact: Marc Mitges
Phone +1 514 832 6503
Fax +1 905 639 8639
www.abb.com

Greensmith Energy Management Systems
6701 Democracy Boulevard,
Suite 300
Bethesda, Maryland 20817
Contact: info@greensmith.us.com
Phone: 888.882.7430 (U.S. & Canada)

Xtreme Power, Inc.
1120 Goforth St.
Kyle, TX 78640
Contact: Jenna Gelgand
Jgelgand@xtremepower.com
Phone: 512-268-8191
www.xtremepower.com

Beckett Energy Systems
38251 Center Ridge Rd., North Ridgeville,
OH 44039

Phone: 440-327-1060

sales@beckettenergy.com.

Appendix E: IEEE Standards Relevant to Smart Grid and Possibly CES

Table E-1. List of IEEE Standards – Approved and in Development Related to Smart Grid and Possibly CES

IEEE

IEEE Approved Standards Related to Smart Grid

Sponsoring Society & SCC	Standard No.	Title
SCC21 Fuel Cells, Photovoltaics, Dispersed Generation & Energy Storage	1547-2003	IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems
SCC21 Fuel Cells, Photovoltaics, Dispersed Generation & Energy Storage	1547.1-2005	Standard for Conformance Tests Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems
SCC21 Fuel Cells, Photovoltaics, Dispersed Generation & Energy Storage	1547.2-2008	Application Guide for IEEE Standard 1547, Interconnecting Distributed Resources with Electric Power Systems
SCC21 Fuel Cells, Photovoltaics, Dispersed Generation & Energy Storage	1547.3-2003	Guide For Monitoring, Information Exchange, and Control of Distributed Resources Interconnected With Electric Power Systems
SCC22 Power Quality	1159.3-2003	IEEE Recommended Practice for the Transfer of Power Quality Data
Computer/ Local and Metropolitan Area Networks Committee	802-2001	IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture
Computer/ Local and Metropolitan Area Networks Committee	802.1AB-2005	IEEE Standard for Local and metropolitan area networks -- Station and Media Access Control Connectivity Discovery
Computer/ Local and Metropolitan Area Networks Committee	802.2-1989	IEEE Standard for Information Technology - Telecommunications and Information Exchange Between Systems - Local and Metropolitan Area Networks - Specific Requirements - Part 2: Logical Link Control
Computer/ Local and Metropolitan Area Networks Committee	802.3-2005	IEEE Standard for Information technology--Telecommunications and information exchange between systems--Local and metropolitan area networks--Specific requirements Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications
Computer/ Local and Metropolitan Area Networks Committee	802.11-2007	IEEE Standard for Information Technology - Telecommunications and Information Exchange Between Systems - Local and Metropolitan Area Networks - Specific Requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications
Computer/ Local and Metropolitan Area Networks Committee	802.15.1-2005	IEEE Standard for Information Technology - telecommunications and information exchange Systems between systems - Local and metropolitan area networks-Specific requirements - Part 15.1a: Wireless Medium Access Control (MAC) and Physical Layer (PHY) specifications for Wireless Personal Area Networks (WPAN)
Computer/ Local and Metropolitan Area Networks Committee	802.15.4-2006	IEEE Standard for Information Technology - Telecommunications and Information Exchange Between Systems - Local and Metropolitan Area Networks - Specific Requirements - Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low Rate Wireless Personal Area Networks (WPANs)
Computer/ Local and Metropolitan Area Networks Committee	802.16-2009	IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Broadband Wireless Access Systems
Computer/ Local and Metropolitan Area Networks Committee	802.20-2008	IEEE Standard for Local and Metropolitan Area Networks - Part 20: Air Interface for Mobile Broadband Wireless Access Systems Supporting Vehicular Mobility -- Physical and Media Access Control Layer Specification
Instrumentation & Measurement Society/TC-9, Sensor Technology	1588-2008	IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems
Power & Energy/Power Systems Communication Committee	1675-2008	IEEE Standard for Broadband over Power Line Hardware
Power & Energy/Power Systems Instrumentation & Measurement Committee	1459-2000	IEEE Standard Definitions for the Measurement of Electric Power Quantities under Sinusoidal Non-Sinusoidal Balanced or Unbalanced Conditions
Power & Energy/Power Systems Relaying Committee	C37.101-2006	IEEE Guide for Generator Ground Protection
Power & Energy/Power Systems Relaying Committee	C37.101-2006/Cor 1-2007	IEEE Guide for Generator Ground Protection - Corrigendum 1: Annex A.2 Phasor Analysis (Informative)
Power & Energy/Power Systems Relaying Committee	C37.102-2006	IEEE Guide for AC Generator Protection
Power & Energy/Power Systems Relaying Committee	C37.104-2002	IEEE Guide for Automatic Reclosing of Line Circuit Breakers for AC Distribution and Transmission Lines
Power & Energy/Power Systems Relaying Committee	C37.106-2003	IEEE Guide for Abnormal Frequency Protection for Power Generating Plants
Power & Energy/Power Systems Relaying Committee	C37.111-1999	IEEE Standard Common Format for Transient Data Exchange (COMTRADE) for Power Systems
Power & Energy/Power Systems Relaying	C37.112-	IEEE Standard Inverse-Time Characteristic Equations for Overcurrent Relays

Committee	1996	
Power & Energy/Power Systems Relaying Committee	C37.114-2004	IEEE Guide for Determining Fault Location on AC Transmission and Distribution Lines
Power & Energy/Power Systems Relaying Committee	C37.115-2003	IEEE Standard Test Method for Use in the Evaluation of Message Communications Between Intelligent Electronic Devices in an Integrated Substation Protection Control and Data Acquisition System
Power & Energy/Power Systems Relaying Committee	C37.116-2007	IEEE Guide for Protective Relay Application to Transmission-Line Series Capacitor Banks
Power & Energy/Power Systems Relaying Committee	C37.117-2007	IEEE Guide for the Application of Protective Relays Used for Abnormal Frequency Load Shedding and Restoration
Power & Energy/Power Systems Relaying Committee	C37.118-2005	IEEE Standard for Synchrophasors for Power Systems
Power & Energy/Power Systems Relaying Committee	C37.230-2007	IEEE Guide for Protective Relay Applications to Distribution Lines
Power & Energy/Power Systems Relaying Committee	C37.231-2006	IEEE Recommended Practice for Microprocessor-Based Protection Equipment Firmware Control
Power & Energy/Power Systems Relaying Committee	C37.232-2007	IEEE Recommended Practice for Naming Time Sequence Data Files
Power & Energy/Power Systems Relaying Committee	C37.90.2-2004	IEEE Standard for Withstand Capability of Relay Systems to Radiated Electromagnetic Interference from Transceivers
Power & Energy/Power Systems Relaying Committee	C37.91-2008	IEEE Guide for Protecting Power Transformers
Power & Energy/Power Systems Relaying Committee	C37.92-2005	IEEE Standard for Analog Inputs to Protective Relays From Electronic Voltage and Current Transducers
Power & Energy/Power Systems Relaying Committee	C37.93-2004	IEEE Guide for Power System Protective Relay Applications of Audio Tones Over Voice Grade Channels
Power & Energy/Power Systems Relaying Committee	C37.94-2004	IEEE Standard for N Times 64 Kilobit Per Second Optical Fiber Interfaces Between Teleprotection and Multiplexer Equipment
Power & Energy/Power Systems Relaying Committee	C37.95-2002	IEEE Guide for Protective Relaying of Utility-Consumer Interconnections
Power & Energy/Surge Protective Device Committee/High Voltage	C62.11-2005	IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (> 1 kV)
Power & Energy/Surge Protective Device Committee/High Voltage	C62.11a-2008	IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (>1 kV) Amendment 1: Short-Circuit Tests for Station Intermediate and Distribution Arresters
Power & Energy/Substations Committee	81-1983	IEEE Guide for Measuring Earth Resistivity Ground Impedance and Earth Surface Potentials of a Ground System Part 1: Normal Measurements
Power & Energy/Substations Committee	81.2-1991	IEEE Guide for Measurement of Impedance and Safety Characteristics of Large Extended or Interconnected Grounding Systems
Power & Energy/Substations Committee	1127-1998	IEEE Guide for the Design Construction and Operation of Electric Power Substations for Community Acceptance and Environmental Compatibility
Power & Energy/Substations Committee	1379-2000	IEEE Recommended Practice for Data Communications Between Remote Terminal Units and Intelligent Electronic Devices in a Substation
Power & Energy/Substations Committee	1402-2000	IEEE Guide for Electric Power Substation Physical and Electronic Security
Power & Energy/Substations Committee	1615-2007	IEEE Recommended Practice for Network Communication in Electric Power Substations
Power & Energy/Substations Committee	1646-2004	IEEE Standard Communication Delivery Time Performance Requirements for Electric Power Substation Automation
Power & Energy/Substations Committee	1686-2007	IEEE Standard for Substation Intelligent Electronic Devices (IEDs) Cyber Security Capabilities
Power & Energy/Substations Committee	C37.1-2007	IEEE Standard for SCADA and Automation Systems
Power & Energy/Substations Committee	C37.2-2008	IEEE Standard Electrical Power System Device Function Numbers Acronyms and Contact Designations
Power & Energy/Switchgear Committee	1247-2005	IEEE Standard for Interrupter Switches for Alternating Current Rated Above 1000 Volts
Power & Energy/Switchgear Committee	1325-1996	IEEE Recommended Practice for Reporting Field Failure Data for Power Circuit Breakers
Power & Energy/Switchgear Committee	C37.100-1992	IEEE Standard Definitions for Power Switchgear
Power & Energy/Transmission & Distribution Committee	6441994	IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines
Power & Energy/Transmission & Distribution Committee	656-1992	IEEE Standard for the Measurement of Audible Noise from Overhead Transmission Lines
Power & Energy/Transmission & Distribution Committee	1250-1995	IEEE Guide for Service to Equipment Sensitive to Momentary Voltage Disturbances
Power & Energy/Transmission & Distribution Committee	1453-2004	IEEE Recommended Practice for Measurement and Limits of Voltage Fluctuations and Associated Light Flicker on AC Power Systems
Power & Energy/Transformers Committee	C57.120-1991	IEEE Loss Evaluation Guide for Power Transformers and Reactors

IEEE Standards in Development Related to Smart Grid

Sponsoring Society/Committee & SCC	Open Projects	Title
SCC21 Fuel Cells, Photovoltaics, Dispersed Generating & Energy Storage	**P2030**	Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), and End-Use Applications and Loads
SCC31 Automatic Meter Reading & Energy Management	**P1377**	Standard for Utility Industry Metering Communication Protocol Application Layer Standard (End Device Data Tables)
SCC31 Automatic Meter Reading & Energy Management	**P1701**	Standard for Optical Port Communication Protocol to complement the Utility Industry End Device Data Tables
SCC31 Automatic Meter Reading & Energy Management	**P1702**	Standard for Telephone Modem Communication Protocol to complement the Utility Industry End Device Data Tables
SCC31 Automatic Meter Reading & Energy Management	**P1703**	Standard for Local Area Network/Wide Area Network (LAN/WAN) Node Communication Protocol to complement the Utility Industry End Device Data Tables
Computer/ Local & Metropolitan Area Networks Committee	**P802**	IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture
Computer/ Local & Metropolitan Area Networks Committee	**P802.11**	EEE Standard for Information Technology - Telecommunications and Information Exchange Between Systems - Local and Metropolitan Area Networks - Specific Requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications
Communications Society	**P1901**	Standard for Broadband over Power Line Networks: Medium Access Control and Physical Layer Specifications
Power & Energy/ Power Systems Communication Committee/ Electromagnetic Compatibility/Standards Development Committee & Communications Society	**P1775**	Standard for Powerline Communication Equipment - Electromagnetic Compatibility (EMC) Requirements - Testing and Measurement Methods
Power & Energy/Energy Development & Power Generation Committee	**P1020**	Guide for Control of Small (100 kVA to 5 MVA)Hydroelectric Power Plants
Power & Energy/Energy Development & Power Generation Committee	**P1595**	Standard for Quantifying Greenhouse Gas Emission Credits from Small Hydro and Wind Power Projects and for Grid Baseline Conditions
Power & Energy/Energy Development & Power Generation Committee	**P1797**	Guide for Design and Application of Solar Technology in Commercial Power Generating Stations
Power & Energy/Power Systems Communications Committee	**P1777**	Recommended Practice for Using Wireless Data Communications in Power System Operations
Power & Energy/Power Systems Instrumentation & Measurement Committee	**P1459**	Standard Definitions for the Measurement of Electric Power Quantities under Sinusoidal Non-Sinusoidal Balanced or Unbalanced Conditions
Power & Energy/Power System Relaying Committee	**PC37.104**	Guide for Automatic Reclosing of Circuit Breakers for AC Distribution and Transmission Lines
Power & Energy/Power System Relaying Committee	**PC37.111**	Standard for Common Format for Transient Data Exchange (COMTRADE) for Power Systems
Power & Energy/Power System Relaying Committee	**PC37.118**	Standard for Synchrophasors for Power Systems
Power & Energy/Power System Relaying Committee	**PC37.236**	Guide for Power System Protective Relay Applications over Digital Communication Channels
Power & Energy/Power System Relaying Committee	**PC37.237**	Recommended Practice for Time Tagging of Power System Protection Events
Power & Energy/Power System Relaying Committee	**PC37.238**	Standard Profile for Use of IEEE Std. 1588 Precision Time Protocol in Power System Applications
Power & Energy/Power System Relaying Committee	**PC37.239**	Standard Common Format for Event Data Exchange (COMFEDE) for Power Systems
Power & Energy/Power System Relaying Committee	**PC37.95**	Guide for Protective Relaying of Utility-Consumer Interconnections
Power & Energy/Surge Protective Device Committee/High Voltage	**PC62.11**	Standard for Metal-Oxide Surge Arresters for AC Power Circuits (> 1 kV)
Power & Energy/Surge Protective Device Committee/Low Voltage	**PC62.39**	Standard for Test Methods for Self-Restoring Current Limiter Components used in Telecommunication Surge Protectors
Power & Energy/Substations Committee	**P81**	Guide for Measuring Earth Resistivity Ground Impedance and Earth Surface Potentials of a Grounding System
Power & Energy/Substations Committee	**P1031**	Guide for the Functional Specification of Transmission Static Var Compensators
Power & Energy/Substations Committee	**1127a**	IEEE Guide for the Design Construction and Operation of Electric Power Substations for Community Acceptance and Environmental Compatibility - Amendment to remove references to Substation Slide Library
Power & Energy/Substations Committee	**P1711**	Trial Use Standard for a Cryptographic Protocol for Cyber Security of Substation Serial Links
Power & Energy/Switchgear Committee	**PC37.13**	Standard for Low-Voltage AC Power Circuit Breakers Used in Enclosures
Power & Energy/Transmission & Distribution Committee	**P1250**	Guide for Identifying and Improving Voltage Quality in Power Systems
Power & Energy/Transmission & Distribution Committee	**P1409**	Guide for the Application of Power Electronics for Power Quality Improvement on Distribution Systems Rated 1 kV Through 38 kV
Power & Energy/Transmission & Distribution Committee	**P1695**	Trial-Use Guide for Assessing Voltages at Publicly and Privately Accessible Locations
Power & Energy/Transformers Committee	**PC57.123**	Guide for Transformer Loss Measurement

Appendix F: Cross Reference NEMA, UL and CSA Cabinets

CES Enclosures

CES sited near the end of distribution feeders adjacent to customer feeds will be specified with CSA cabinets not unlike present padmount transformers (Table F-1). A minimum CSA Type 3 (Ref. 24) enclosure is needed for outdoor locations. Where salt spray and water ingress are a concern, higher categories such as CSA Type 4 or 4X may be required (see Table F-2) to meet the sprinkler / water spray test for outdoor inverters as listed in UL 1741[65]. As well, having a relatively small footprint is both a desirable and necessary feature as is having the overall cabinet height limited to less than four feet to maintain sight lines for safety and aesthetics. Consequently, a trade-off between desired capacity and storage volume requirement will dictate. Even higher energy density batteries can occupy a significant volume compared to the amount of useful energy they store and may not meet the AEP above ground specification necessitating installation below grade. Flywheel storage is typically installed below grade for safety in concrete or steel lined vaults per the flywheel manufacturers' installation requirements. However, for some flywheel designs, the vacuum chamber they are sealed in is considered sufficient protection if the wheels are designed for failsafe operation.

Table F-1. Comparison of Specific Applications of Enclosures for Outdoor Nonhazardous Locations[66]

Provides a Degree of Protection Against the Following Conditions	Type of Enclosure									
	3	3X	3R*	3RX*	3S	3SX	4	4X	6	6P
Access to hazardous parts	X	X	X	X	X	X	X	X	X	X
Ingress of water (Rain, snow, and sleet **)	X	X	X	X	X	X	X	X	X	X
Sleet ***	...	...	...	...	X	X	...	...	...	...
Ingress of solid foreign objects (Windblown dust, lint, fibres, etc.)	X	X	...	...	X	X	X	X	X	X
Ingress of water (Hosedown)	...	...	...	...	...	...	X	X	X	X
Corrosive agents	...	X	...	X	...	X	...	X	...	X
Ingress of water (Occasional temporary submersion)	...	...	...	...	...	...	...	...	X	X
Ingress of water (Occasional prolonged submersion)	...	...	...	...	...	...	...	...	...	X

* These enclosures may be ventilated.
** External operating mechanisms are not required to be operable when the enclosure is ice covered.
*** External operating mechanisms are operable when the enclosure is ice covered.

65 UL 1741 Clause 61.3 requires outdoor ground-mounted inverter cabinets to be subjected to a 2-hour horizontal water spray (20 psi) to all four sides when turned on a vertical axis.

66 From NEMA 250-2003.

Table F-2. CSA, UL and NEMA Cabinet Designations

Enclosure Rating	National Electrical Manufacturers Association (NEMA Standard 250) and Electrical and Electronic Mfg. Association of Canada (EEMAC)	Underwriters Laboratories Inc.(UL 50 and UL 508)	Canadian Standards Association (Standard C22.2 No. 94)
Type 1	Enclosures are intended for indoor use primarily to provide a degree of protection against contact with the enclosed equipment or locations where unusual service conditions do not exist.	Indoor use primarily to provide protection against contact with the enclosed equipment and against a limited amount of falling dirt.	General purpose enclosure. Protects against accidental contact with live parts.
Type 2	Enclosures are intended for indoor use primarily to provide a degree of protection against limited amounts of falling water and dirt.	Indoor use to provide a degree of protection against limited amounts of falling water and dirt.	Indoor use to provide a degree of protection against dripping and light splashing of noncorrosive liquids and falling dirt.
Type 3	Enclosures are intended for outdoor use primarily to provide a degree of protection against windblown dust, rain, and sleet; undamaged by the formation of ice on the enclosure.	Outdoor use to provide a degree of protection against windblown dust and windblown rain; undamaged by the formation of ice on the enclosure.	Indoor or outdoor use; provides a degree of protection against rain, snow, and windblown dust; undamaged by the external formation of ice on the enclosure.
Type 3R	Enclosures are intended for outdoor use primarily to provide a degree of protection against falling rain sleet; undamaged by the formation of ice on the enclosure.	Outdoor use to provide a degree of protection against falling rain; undamaged by the formation of ice on the enclosure.	Indoor or outdoor use; provides a degree of protection against rain and snow; undamaged by the external formation of ice on the enclosure.
Type 4	Enclosures are intended for indoor or outdoor use primarily to provide a degree of protection against windblown dust and rain, splashing water, and hose-directed water; undamaged by the formation of ice on the enclosure.	Either indoor or outdoor use to provide a degree of protection against falling rain, splashing water, and hose-directed water; undamaged by the formation of ice on the enclosure.	Indoor or outdoor use; provides a degree of protection against rain, snow, windblown dust, splashing and hose-directed water; undamaged by the formation of ice on on the enclosure.
Type 4X	Enclosures are intended for indoor or outdoor use primarily to provide a degree of protection against corrosion, windblown dust and rain, splashing water, and hose-directed water; undamaged by the formation of ice on the enclosure.	Either indoor or outdoor use to provide a degree of protection against falling rain, splashing water, and hose-directed water; undamaged by the formation of ice of ice on the enclosure; resists corrosion.	Indoor or outdoor use; provides a degree of protection against rain, snow, windblown dust, splashing and hose-directed water; undamaged by the external formation of ice on the enclosure; resists corrosion.
Type 6	Enclosures are intended for use indoors or outdoors where occasional submersion is encountered. limited depth; undamaged by the formation of ice on the enclosure.	Indoor or outdoor use to provide a degree of protection against entry of water during temporary submersion at a at a limited depth; undamaged by the external formation of ice on the enclosure.	Indoor or outdoor use; provides a degree of protection against the entry of water during temporary submersionat a limited depth. Undamaged by the external formation of ice on the enclosure; resists corrosion.
Type 12	Enclosures are intended for indoor use primarily to provide a degree of protection against dust, falling dirt, and dripping noncorrosive liquids.	Indoor use to provide a degree of protection against dust, dirt, fiber flyings, dripping water, and external condensation of noncorrosive liquids.	Indoor use; provides a degree of protection against circulating dust, lint, fibers, and flyings; dripping and light splashing of non-corrosive liquids; not provided with knockouts.
Type 13	Enclosures are intended for indoor use primarily to provide a degree of protection against dust, spraying of water, oil, and noncorrosive coolant.	Indoor use to provide a degree of protection against lint, dust seepage, external condensation and spraying of water, oil, and noncorrosive liquids.	Indoor use; provides a degree of protection against circulating dust, lint, fibers, and flyings; seepage and spraying of non-corrosive liquids, including oils and coolants.

APPENDIX G: MANUFACTURERS' LITERATURE

The following figures in this section include selected manufacturers' literature related to CES.

Figure G-1. S&C CES Brochure (Page 1 & 4)

Figure G-2. S&C CES Brochure – Page 2 & 3

Smart Grid CES
Community Energy Storage

Your goal is simple: Keep the power flowing to your customers. Achieving that goal isn't always so easy, however. That's where **S&C's Smart Grid CES Community Energy Storage** shines.

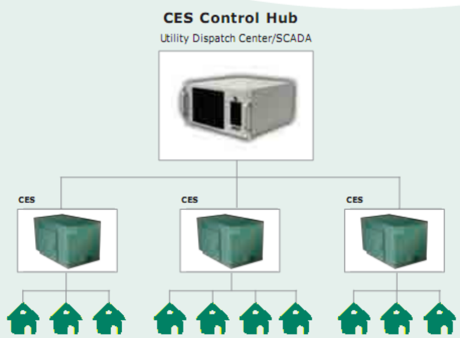
In the event of a power outage, Smart Grid CES automatically restores power in seconds . . . *a major goal of the self-healing Smart Grid*. By placing distributed energy storage in close proximity to customers, reliable supplemental power is available to them instantly. Offering 25 kW for one, two, or three hours, Smart Grid CES has enough capacity to supply power to a group of customers for the duration of most typical outages. Deployment of these units on a broad scale will significantly improve your customer minutes served–an important index of grid reliability–while greatly reducing your emergency dispatch costs. With its ability to utilize buried distributed batteries, the Smart Grid CES provides a small footprint that does not change as the energy storage is scaled.

Ratings, Dimensions, and Weight	
Active and Reactive Power	25 kVA
Energy	25 - 75 kWh
Secondary Voltage	240 / 120V
Battery	Li-Ion
Round-Trip AC Energy Efficiency	> 85%
Dimensions (CES only)	50"L x 34"W x 32"H
Weight (CES only)	Approx. 750lbs.

When a large number of CES units are required, S&C can furnish a **CES Hub Control System** that acts as a "distributed power plant." This integrated system can provide the equivalent peaking reserve of a peaking power plant, at a fraction of the cost and with much greater flexibility in meeting distribution system capacity constraints. The installed base of units affords voltage control at multiple points across a feeder, which can substantially reduce losses . . . *another major goal of the Smart Grid*.

An installed base of CES units also facilitates integration of the community's renewable power sources into the grid, permitting this generation to be dispatched when it's needed . . . *yet another goal of the Smart Grid*. It buffers the outputs from these sources and helps the grid handle peak power demands caused by loads such as plug-in electric vehicles. The CES Hub Control System includes a self-contained, rack-mounted controller that can be installed in a central office or substation.

Turn to **S&C Electric Company** as your power partner. We offer the latest energy technologies that will reduce your service costs. Contact our **Community Energy Storage** specialists today to shed more light on the benefits of the Smart Grid CES. ***Don't be left in the dark!***



Smart Grid CES
Control Hub Features

- State-of-the-art energy dispatch
- DNP communication supports SCADA
- Convenient real-time and archival data storage
- Seamless integration with all central office systems
- User-authenticated log-in/log-out maintains system security

Reliability Benefits

Customer Friendly

- Supports multiple customers for hours
- Momentary outage is barely perceptible
- Customers are isolated from repeated operations and transients
- Seamless return to normal
- Customers experience "premium" power

System Friendly

- Reduced SAIDI. Power is maintained to customers
- Reduced MAIFI/SAIFI. Customers experience one or zero operations
- After an interruption, system experiences reduced load, reduced inrush
- System can be set for staged return, reducing cold load pickup

Smart Grid CES
Design Features

1. Maintenance-free power electronics comply with IEEE 1547 and UL 1741
2. SCADA radio control
3. Real-time analog/digital input/output
4. Hard-wired bypass available for installation and maintenance
5. Status and control panel

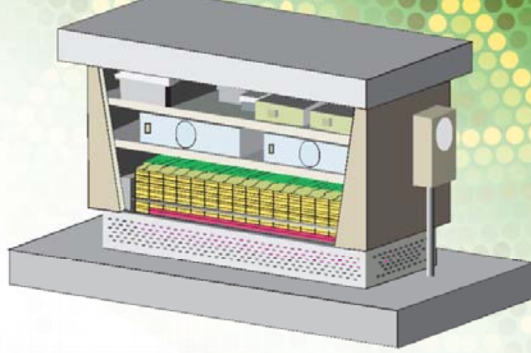
S&C ELECTRIC COMPANY

Figure G- 3 Greensmith Distributed Energy Storage System (DESS) Specification Sheet - 1

GREENSMITH
energy management systems

One of the electric industry's first commercially available Smart Storage solutions, the ***Greensmith Distributed Energy Storage System (DESS)*** harnesses advanced lithium-ion battery technology to deliver numerous benefits to utilities and consumers alike. Proprietary advances in intelligent control allow Greensmith's Smart Storage Systems to interact with both advanced environments utilizing Smart Meters and the Smart Grid, and legacy environments not yet upgraded.

Two primary components of the DESS system, the DESS Client and the DESS Server, work together to improve overall system performance.



DESS CLIENT ENCLOSURE: Weatherproof, tamper-resistant metal enclosure suitable for mounting outdoors. Horizontal design model presented with an open front-facing view of the internal components.

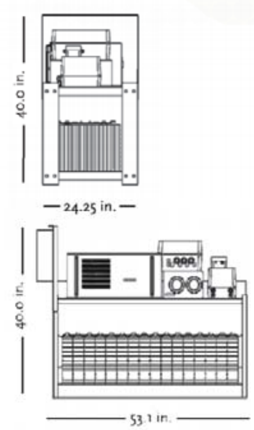
Safe & Reliable Technology

Greensmith's highly durable Advanced Lithium-Ion Iron Phosphate Battery and proprietary Battery Management System perform at high efficiency for *at least 3000 life cycles*, and their real-time monitoring capabilities ensure *safety and compliance* within operating parameters.

Each unit connects through secure, platform-independent web services to optimize complex and comprehensive relationships. Modeled after the Department of Energy approved 'Open Automated Demand Response,' the Greensmith DESS leads the industry with its event-based asset management architecture and easily integrates into any utility framework.

Lithium-Ion Iron Phosphate (LiFePO4) Battery Pack	
Number of Battery Cells	16
Individual Cell Nominal Capacity	400 Ah
Individual Cell Operating Voltage	
Charge	4.25 V
Discharge	2.5 V
Max Charge Current	<=2
Max Discharge Current	
Constant current	<=2 ca
Impulse current	<=10
Standard Charge/Discharge Current	0.3 ca
Cycle Life, Cycles	
80% DOD	>=2000 times
70% DOD	>=3000 times
Temperature Durability of Case	<=250
Operating Temperature	
Charge	-25°–75°
Discharge	-25°–75°
Self Discharge Rate	<=3% (Monthly)
Individual Cell Weight	13.5 kg

GREENSMITH SMART STORAGE UNIT



6701 Democracy Boulevard, Suite 300 | Bethesda, MD 20817
www.GREENSMITH.us.com | info@GREENSMITH.us.com

Figure G-4 Greensmith Distributed Energy Storage System (DESS) Specification Sheet – 2

Inverter Specifications, Model SC48-60 (Two per DESS Unit)

DC Input	
Input rated voltage (VDC)	48
Range of DC voltage (VDC)	40~60
Range discharging current (A)	60
DC current ripple (A)	<5%
AC Grid	
Rated grid voltage (Vac)	220
Range of grid voltage (Vac)	180-260
Rated grid current (A)	12
Distortion of grid current (THD)	<4%
Frequency range	48~52 (or 58~62 for 60Hz grid)
Grid-connected power factor (PF)	0.99
Efficiency	88%
Environmental Condition	
Installation environment	Indoor
Operating temperature	-10°C to 40°C
Storage temperature	-20°C to 60°C
Safety Insulation (M 'Ω)	
Insulating resistance	>5
Insulation strength	1500Vac per minute
Mechanical Parameters	
Size (L x W x H)	465 x 609.6 x 132.5
Weight (Kg)	17
Noise	<45
Grade of protection	IP21
Cooling method	Air cooling

Charger Specifications (Two per DESS Unit)

Input voltage	
AC	70. . .264 Vac 1-phase
DC	70. . .369Vdc
Efficiency	89% at full load, >90% at 50% load
Input Current	16 A (max)
Frequency	47-63Hz
Power Factor	>0.98
Inrush Current	Soft start
Output Ripple	<300mVrms
Mechanics	Wall mounting
Connectors	
Input	Input power cord
Output	Models 12V, 24V, 36V, 48V: copper bus-bar terminals
	Models 110V, 160V, 220V: 6mm2 1.5m output calbes
Enclosure	Aluminum case, IP20
Weight	7.1 kg without cables
Output Grounding	Floating
Ambient Temperature Range	-20°C. . .+40°C at full load
Over-Temperature Protection	Processor controlled
Over-Current Protection	Electrical current limit
Reverse Polarity Protection	With fuse
Standards Safety	Class 1
EMC	EN55022 Class A

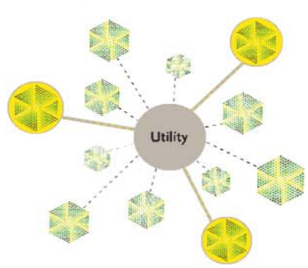
GREENSMITH
energy management systems

How does Distributed Storage function like Centralized Storage?

An integrated modular unit, the DESS Client combines a Lithium-Ion Iron Phosphate (LFP) battery pack, a proprietary Battery Management System (BMS), a power conversion system, a remote communication layer, and an enclosure. Installed at the edges of the networks (220 V-240 V), the DESS Client provides local energy storage, available for variable power-level charge and discharge cycles, within the operating constraints of the battery management system. Depending on consumer needs, they deliver power of at least 5kw with total nominal and available energy of at least 20kwh and 15kwh, respectively.

Through a secure web-based user interface designed for either human interaction or automated machine-to-machine integration, the DESS Server remotely manages one or many DESS Clients through an event-based application with administrative configuration and reporting capabilities.

The highly flexible and reliable DESS executes charge/discharge under multiple parameters, and the open information architecture supports extended logic/application at both local and server levels. Greensmith's optimization of deployment allows a utility to tailor different groups of DESS clients to specific needs, while retaining the ability to centrally control any or all units. Additionally, the DESS allows for less specialized installation personnel due to lower voltage and turn-key solutions.



*The **Greensmith** DESS allows for centralized remote monitoring, control, and reporting, enabling the utility to not only respond to demand and grid events, but also to dispatch power across some or all of the deployed units.*

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Figure G-5 International Battery Lithium-Iron Phosphate Cells (LiFePO4) Specification Sheet – 1

international battery™

World Class. American Made.

High Energy Large Prismatic Rechargeable Cell

Lithium-Iron Phosphate Cells (LiFePO4)

International Battery, Inc.'s Iron Phosphate rechargeable cells are available in a rugged prismatic format in capacities ranging from 40 - 160Ah. LiFePO4 is an intrinsically safe cathode material. LiFePO4 cells do not incinerate or explode under extreme conditions. LiFePO4 cells have a high discharge current, are not toxic and have a high cycle life. The specific geometries of these cells allow for even electrode utilization, good heat dissipation and efficient packaging. IB's cells offer a low self-discharge rate and have excellent operating temperature characteristics. The excellent thermal stability and safety performance of the Lithium Iron Phosphate electrochemical system is well suited for variety of commercial, military and industrial applications.

Features: Very High Specific Energy, Long Cycle Life

Applications: Electric vehicles, electric buses, electric scooters, military applications, communications, backup power, energy storage (wind, solar, tidal).

LiFePO4 Packaged Cells

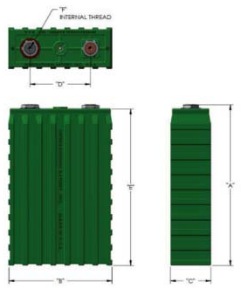
Specification	Condition	IB-B-FHE-40	IB-B-FHE-60	IB-B-FHE-160
Nominal Voltage	(C/3)	3.2 Volts	3.2 Volts	3.2 Volts
Nominal Capacity	(C/3)	40 Ah	60 Ah	160 Ah
Nominal Energy	(C/3)	128 Wh	192 Wh	512 Wh
Specific Energy	(C/3)	88 Wh/Kg	87 Wh/Kg	94 Wh/Kg
Peak Power (60% DOD)	30 sec, 2/3 OCV, 60%	750 W (517 W/Kg)	1300 W (517 W/Kg)	3000 W (555 W/Kg)
Peak Power (60% DOD)	30 sec, 2/3 OCV, 60%, Active Cooling	1050 W (724 W/Kg)	1800 W (818 W/Kg)	4200 W (778 W/Kg)
DC Pulse Resistance	10 sec, 5C, 60% DOD	3.0 mΩ	2.0 mΩ	.75 mΩ
Self-Discharge Rate	Monthly, RT	<3%	<3%	<3%
Cycle Life @ 25 °C	100% DOD	>2000 Cycles	>2000 Cycles	>2000 Cycles
Cycle Life @ 55 °C	100% DOD, 1C, Active Cooling	>1000 Cycles	>1000 Cycles	>1000 Cycles
Cell Weight	Integrated Cell	1.45 Kg	2.2 Kg	5.4 Kg
Recommended Cutoff Voltages	Charge Discharge	3.6 Volts 2.5 Volts	3.5 Volts 2.5 Volts	3.6 Volts 2.5 Volts
Safe Operating Ranges	Max Min	3.6 Volts 2.5 Volts	3.5 Volts 2.5 Volts	3.6 Volts 2.5 Volts
Max Pulse Current (<30 sec)	>2.5 Volts	200 A (5C)	300 A (5C)	800 A (5C)
Max Pulse Current (<30 sec)	>2.5 Volts, Active Cooling	280 A (7C)	420 A (7C)	1120 A (7C)
Max Continuous Charge Current	100% DOD	20 A (C/2)	30 A (C/2)	80 A (C/2)
Max Continuous Charge Current	100% DOD, Active Cooling	40 A (C)	60 A (C)	160 A (C)
Max Continuous Discharge Current	10% to 90% DOD	40 A (C)	60 A (C)	160 A (C)
Max Continuous Discharge Current	10% to 90% DOD, Active Cooling	120 A (3C)	180 A (3C)	480 A (3C)
Charging Efficiency (Ratio of charge/discharge time)	100% DOC @ C/3 10% to 90% DOC @ C/3	96% 99%	94% 98%	90% 98%
Operating Temperature	Charge Discharge	0°C to 50°C -20°C to 55°C	0°C to 50°C -20°C to 55°C	0°C to 50°C -20°C to 55°C
Storage Temperature		-30°C to 60°C	-30°C to 60°C	-30°C to 60°C
Calender Life		10 years	10 years	10 years

Figure G-6. International Battery Lithium-Iron Phosphate Cells (LiFePO4) Specification Sheet

international battery™

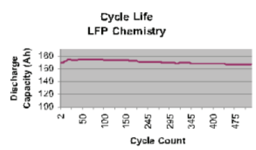
World Class. American Made.

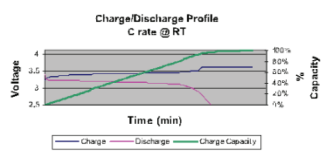
Dimensions

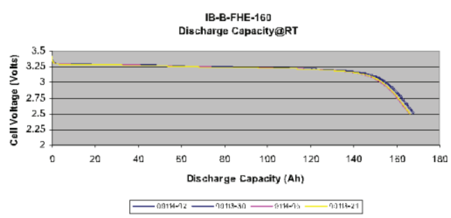


	IB-B-FHE-40		IB-B-FHE-60		IB-B-FHE-160	
A	7.394"	[187.8]	8.180"	[207.8]	11.060"	[280.9]
B	4.500"	[114.3]	4.500"	[114.3]	7.166"	[182.0]
C	1.812"	[46.0]	2.380"	[60.5]	2.800"	[71.1]
D	2.400"	[61.0]	2.400"	[61.0]	4.170"	[105.9]
E	7.140"	[181.4]	7.925"	[201.3]	10.766"	[273.5]
F	M6 x 1.00		M6 x 1.00		M8 x 1.25	

Discharge Data







International Battery, Inc.
6845 Snowdrift Road Allentown, PA 18106
Telephone: 610.366.3925 Facsimile: 610.366.3929
www.internationalbattery.com

Version: 1.3
Date: 9/21/09

– 2

Figure G-7. S&C Smart Grid SMS™ Storage Management System (Ref.15)

2.0-MW/2.5-MVA system.

Table 38. System Specifications S&C Smart Grid SMS™ Storage Management System (Ref.15)

SYSTEM SPECIFICATIONS	
Current Source AC Ratings	
Power Nominal, Per Inverter	−1 MW (charge) to +1 MW (discharge)
VA Nominal, Per Inverter	1.25 MVA
Voltage	480 Vac ± 10%
Current Nominal	1504 A
Frequency Range	58.5 to 61 Hz or 48.5 to 51 Hz
Current Harmonics	Less than 5% of nominal current if voltage distortion is less than 5%
Voltage Source AC Ratings	
Power Maximum	2.0 MW
VA Maximum	2.5 MVA
Voltage	480 Vac ± 3%
Current Maximum	3008 A
Frequency	60 Hz ± 0.1 Hz
Voltage Harmonics	Less than 3% if load current harmonic distortion is below 5%
DC Input Ratings (each of the two inputs)	
Voltage	460 Vdc to 800 Vdc
Current in Current Source Mode	−1145 A dc (charge) to 1150 A dc (discharge)
Current in Voltage Source Mode	0 to 1374 A dc (discharge—up to 100 seconds above 1 MW)
Ripple Current	Typical
Ripple Voltage	Less than 4 volts RMS

Figure G-8. Xtreme Power Utility Energy Storage – Page 1[67]

Xtreme Power

DPR™ 15-100C

Xtreme Power offers a utility-scale Dynamic Power Resource™ (DPR™), ideal for a variety of applications. The DPR™ 15-100C is a standard, containerized unit comprised of 1.5 MVA bi-directional power electronics, 1 MWh of hyper-efficient energy storage technology, and a versatile, programmable control system, all integrated to operate with your specific generation, grid, or load application.

Proven Performance

Proven by rigorous field applications in commercial service, Xtreme Power™'s DPR™ is capable of so much more than just storing off-peak energy for use on-peak. The DPR™ efficiently provides quality, on-demand power.

- *Micro-second response and power precision within 10 kW*
- *Round-trip efficiency > 90% (AC-DC-AC and DC-AC-DC)*
- *One solution to simultaneously provide varying services*
- *Capable of supplying or absorbing real and reactive power*
- *Performs thousands to millions of cycles over a broad range of uses and depths of discharge*

Safe and Environmently Friendly

The Xtreme Power™ PowerCell™ eliminates risks associated with other energy storage technologies, bringing peace of mind and a better bottom line.

- *Non-Hazmat Rated and no special site permitting required*
- *Operates at ambient temperatures*
- *95% of PowerCell™ materials recovered and recycled*

Competitive Cost

Not only does the DPR™ have a competitive initial cost, but the lowest total cost of ownership in the industry.

- *Complete engineered, integrated solution whose initial cost includes storage, power management and controls*
- *No pumps, no tanks, no extensive or expensive O&M*
- *Designed for 20 year life with easy PowerCell™ replacement*

Containerized Unit

Xtreme Power offers its DPR™ 15-100C in a convenient, shippable container. Pictured above, the ISO certified container has been specifically designed to incorporate additional benefits.

- *May be transported to a number of different sites*
- *Exterior roll-up doors allow for easy maintenance without requiring additional square footage*
- *Easy installation and quick set-up*
- *Automatically shuts down if an entrance is tampered with*
- *Easily retrofitted for operation in extreme climates*
- *Durable steel frame, welded in-house*

67 www.xtremepower.com.

Figure G-9. Xtreme Power Utility Energy Storage – Page 2[68]

Specifications

Dynamic Power Resource™

Rated Power	1.5 MVA (Bi-directional)
Energy Storage	1 MWh
System Container Dimensions	40'L x 10'W x 10'H
Total System Weight	< 100,000 lbs
Power Delivery	
Max Instantaneous	200% of rated power, for 3 seconds
Max Continuous	150% of rated power, for 5 seconds
VAR Capability	± 1.5 MVAR
AC Voltage (Input/Output)	480 VAC 3-phase*
DC Bus Voltage	750 - 1,200 VDC
Output Normal Frequency	50 Hz or 60 Hz
Total Parasitic Load	10 kW per MW
Round Trip Efficiency	> 90%
Cooling Requirements	Ventilation only**
Relative Humidity	95% RH non-condensing
Ambient Temperature Range	-20°F to 110°F without derating
Altitude Range	Sea Level to 5,000' without derating
Seismic Load Level	Any seismic zone
Other Environmental Restrictions	No siting restrictions

**Can be stepped up to any required voltage*
***Except for liquid cooled IGBT*

Power Electronics

Dimensions	82"L x 96"W x 84"H
Weight	< 9,000 lbs
Operational Input Voltage	750 - 1,200 VDC
Rated Input/Output Power	2,000 Amps DC
Rated Output Voltage	480 VAC 3-phase
Real Power Regulation	± 2% of rated power
Reactive Power Regulation	± 2% of rated power
Output Current & Voltage Distortion	Total Harmonic Distortion << 5%
Rated Output Frequency	50 Hz or 60 Hz, ± 0.1%
Efficiency	> 98% at full load
Environment, without derating	
Ambient Temperature Range	-20°F to 110°F
Stored Temperature Range	-30°F to 150°F
IGBT Cooling System	Liquid cooled
Compliance	IEEE 519, IEEE 1547, UL 1741

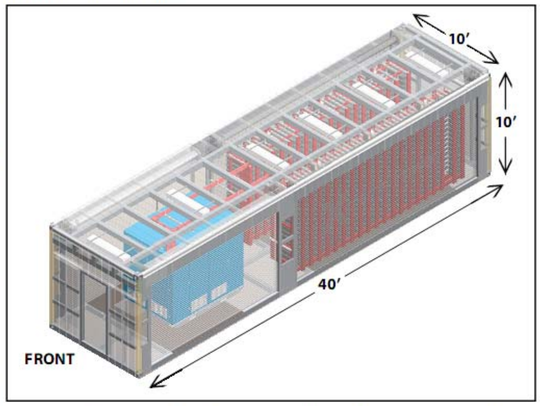
Control System Capabilities

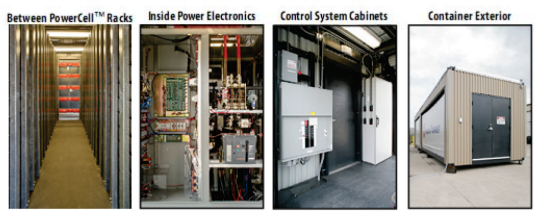
- Multi-tiered Control System (SCADA, PLC, FCB) for Redundant Safety
- Fully Automated Sub Micro-second Response Time
- 24/7 Intelligent Fault Response System with Text Notification
- Real Time Remote Interface
- Comprehensive HMI for Total System Control & Real-Time Monitoring
- Auto & Manual Modes of Operation
- Flexible Programmable Response for Any Application Inputs
- Micro-second Data Acquisition & Historical Performance Data Logging
- Interoperability with External SCADA Devices
- Employs LAN for Component Communication within Control Room
- Remote Access through Secure VPN Connection

PowerCells™

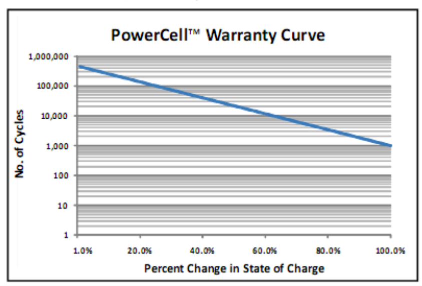
Dimensions	30"L x 5"W x 5"H
Weight	58 lbs
Cell Voltage	12 VDC
Current	2,500 Amps for 30 seconds
Energy	1 kWh @ 3 hour rate
Instant Power Capacity	50 kW
Cycle Efficiency	95% - 99%
Cycle Life	
@10% Depth of Discharge	> 250,000 Warranty
@50% Depth of Discharge	> 20,000 Warranty
Self Discharge Rate	< 1% per month for 3 months
Ambient Temperature Range	-20°F to 120°F without derating
Operating Temperature	Ambient + 3°F
Environmental Impact	Non-Hazmat Rated, 95% Recyclable Potential

As depicted in the CAD drawing, the power electronics (in blue) sit at the front of the DPR™ container. PowerCells™ are placed in two parallel racks (in red and black), each holding 500 kWh of storage. Controls (not illustrated) are placed on both sides of the front door.





While PowerCell™ life cycle is warranted according to the graph below, previous PowerCells™ have shown > 3,000,000 cycles in the field.



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APPENDIX H: INSTALLATION PHOTOS - AEP 25 KW CES

The following are installation photos of the 25 kW prototype CES at AEP (Ref.23).

Figure H-1. Installing Below Ground Battery Vault – 25 kW AEP CES

Figure H-2. 25 kWh Li-ion Battery Container for AEP CES

Figure H-3. Lowering 25 kWh Battery Container into Subterranean Vault

Figure H-4. Installing Above Ground 25 kW PCS Portion of CES

Figure H-5. Completed 25 kW CES Installation at AEP

Appendix I: Sample Purchasing Specification for 500 kVA CES[69]

Four Quadrant Bi-directional Grid Tied Inverter 500 kVA, 600 VAC, 3-Phase 60Hz +/- 800 Amps DC

Control Specification:

Operation Mode:

a. Operate in Grid Tied Mode (Accept P and Q commands at 100 Hz)
   i. PQ mode
b. Operate in Stand Alone Mode (Maintain 1 pu Voltage and Frequency)
c. Transfer from Grid-Tied to Standalone mode and back (in off state)[70]
d. Local HMI operation **(Human Machine Interface)**
e. SCADA Remote Operation via DNP3 communication (*IEC-61850 also an option)*

Monitoring, Sensing and HMI Display

a. Fault Detection and Prevention
b. AC and DC Power Quality monitoring
c. Temperature sense (All critical components)
d. At a minimum of HMI Display (± 1% accuracy)
   i. Grid Voltage
   ii. Total system Current, true RMS
   iii. Total System kVA
   iv. Total System kVAR
   v. Power Factor
   vi. Total System Power (kW)
   vii. DC bus Voltage
   viii. DC Current
   ix. Stop/Run Status
   x. Fault/No Fault Status
e. All HMI displayed values available on internal customer control panel (See section 6 below) and via DNP3 link

---

69 Modified from original document provided by IE Power to suit THESL CES requirements

70 Seamless bi-directional transfer is an option but would require significant hardware and communications changes.

Fault Protection

a. Over temperature (including water coolant, individual IGBT, AC Line Filters, etc)
b. AC, DC side Short Circuit Protection
c. DC ground fault detection and protection w/ DPDT Alarm Contacts
d. Over voltage protection, under voltage protection, over current protection
e. Overfrequency / Underfrequency

Information Exchange

a. Information exchange by DNP3, from PCS to XP SCADA
b. Full command list to be provided by inverter manufacturer
c. State Diagram to be provided by inverter manufacturer
d. Full Data Points list with register/address
e. Ability to read data point from PCS at rate greater 100Hz

Battery Pack Monitoring and protection

a. Voltage (Real time signal access via DC Link – direct analog out)
b. Current (Real time signal access via DC Link – direct analog out)
c. Limit P command based on DCV(limit standalone mode based on DCV)

Internal Customer Panel Access to real time signals

a. DC Voltage and Current (direct analog out)
b. AC Voltages and Currents (direct analog out via meter-grade PT's & CT's)
c. Temperature (critical components, individual IGBTs junction temp, chokes, heat sink temperature and internal coolant temperatures)
d. Customer measurements require a dedicated set of meter-grade instruments and transducers

Response

a. P command over digital link
b. Additional P command via analog input to inverter
c. Q command over digital link
d. Additional Q command via analog input to inverter
e. Step Response from –Pmax to Pmax < 4.2 ms (i.e. <1/4 cycle)
f. Step Response from –Qmax to Qmax < 4.2 ms (i.e <1/4 cycle)
g. For maximum S, limit Q command or P command (selectable P or Q priority)

PCS Power Specification

General Requirements

Rated Input / Output Power	**500 kVA**, ± 800 Amps DC (Bi-Directional)
Converter Type	NPT-IGBT, PWM, 3rd harmonic injection
Dimensions	96"W x 48" H x 48"D Nominal
Mounting:	Brackets and bolts to floor. Container mountable
Weight	<7000 lbs. (500 kVA)
Enclosure	NEMA 4 for AC filter & line side components, NEMA 4 for inverter, controls and DC components. Single cabinet containing complete bidirectional unit

Electrical

Rated Output Voltage (standalone)	600 VAC ±2% 3 phase
AC Output Voltage Set (standalone mode)	600 VAC ±10%
Rated Output Frequency (standalone)	60 Hz ± 0.5 Hz
AC Output Frequency Set (standalone mode)	60 Hz ± 0 Hz
Step Response (standalone mode)	STEPLOAD 500 kVA 50% VOLTAGE CHANGE STEPLOAD 340 kVA 40% VOLTAGE CHANGE STEPLOAD 160 kVA 24% VOLTAGE CHANGE STEPLOAD 17 kW 5% VOLTAGE CHANGE
Power Factor	Full lead and lag up to nameplate rating
Operational DC voltage	432- 590 VDC, 480 VDC Nominal
Number of phases / wires	3 phase / 4-wire
Overload capacity	i.e. ≤ 30 seconds
Real Power Regulation	± 1% of rated power

Reactive Power Regulation	± 1% of rated power
Line Current Imbalance between phases	< ±1%
Output Current & Voltage Distortion	THD < 5% at full load <(**TBD**)% at 25% load **(To be supplied)**
Efficiency	>**97%** at full load & Full Voltage; Efficiency measured in each direction individually (isolation transformer not included).
AC/ DC Disconnects	Internal Main 2500AF, 3 Pole, Electrically Operated, Adjustable Trip, 100 kA min AC Circuit Breaker. Main DC Disconnect Switch motorized w/ manual operation ability.
Design Margin	All Components and temperatures shall be rated at 110% of full power or full temperature value.
UPS	120VAC UPS provided by customer or manufacturer to power control equipment providing 45 minutes of run time.
Isolation Transformer	THESL to supply (or can be supplied by PCS manufacturer).

Operating Temperature & Cooling

a. Environment, without derating, continuous operation

i.	Ambient Temperature Range	-30^{0}C to +50^{0}C
ii.	Storage Temperature Range	-40^{0}C to +60^{0}C
iii.	Relative Humidity	10% - 100% Condensing
iv.	Altitude	-250' to 5000' above sea level
v.	Seismic	Uniform Building Code Zone 4

b. Cooling System

Liquid cooling requirements;

i. Coolant used (50/50 - Water / Glycol mix per manufacturer's specification)

ii. Cooling Low DP Heat exchanger (Air to Liquid or Liquid to Liquid) ***(Note to THESL: Heat exchanger can be supplied by equipment manufacturer)***

iii. Cooling Pump PSI 10 PSI
(Note to THESL: Pump can be supplied by equipment manufacturer)
iv. Temp. of heat exchanger inlet ≤55⁰C
v. Cooling Flow rate 2 gallons per minute
vi. Heat rejection to Liquid @ F.L. ≤3 kW (250 kVA unit)
vii. Heat Rejection to Ambient @ F.L. ≤1.5 kW (250 kVA unit)
viii. Coolant connection lines shall be on the AC end, at the bottom
ix. Inlet/Outlet npt sizes ¾" npt female threads
x. Liquid to Air Heat Exchanger 600 cubic feet per minute.

Bus Termination

c. AC Cable entry for the AC line is made through the bottom of the enclosure.
d. DC Bus entry is made at the non-operator side of the enclosure on the upper half of the unit
e. All bus terminations must be accessible.
f. AC & DC Bus connections shall be on the non-operator side and on opposite ends of the machine.
g. All AC bus work shall be covered with a clear Lexan™ shield for personnel protection.

Operation and Metering

a. Locally mounted Operator Terminal w/ the following control/indication:
    i. Status Modes
        1. Off, Charged, Gating, CB1 On, Run, Fault, Local/Remote
    ii. Faults
        1. AC overcurrent, DC overcurrent, AC over/undervoltage, DC over/undervoltage, Control Power Failure, External Fault, IGBT failure, DC Undervoltage warning
    iii. Input Control Signals
        1. Grid-Tied Mode
            a. Real Power Setpoint
            b. Reactive Power Setpoint
        2. Stand-Alone Mode
            a. Voltage Setpoint **(±10% Adjustable)**
            b. Frequency Setpoint **(60Hz)**
    iv. Metering

1. AC output voltage per phase
2. AC output current per phase (true RMS, accuracy ≤ 1% of FLC)
3. DC Voltage (accuracy ≤ 1% of nominal voltage)
4. DC Current (accuracy ≤ 1% of FLC)

b. Remote interface w/ the following control/indication:
   i. Status Modes
      1. Off, Charged, Gating, CB1 On, Run, Fault, Local/Remote,
   ii. Control Modes
      1. Charge, Gate, CB1 On, PQ on/UF on, Reset, Off, Grid-Tied/Stand-alone Mode
   iii. Faults
      1. AC overcurrent, DC overcurrent, AC over/undervoltage, DC over/undervoltage, Control Power Failure, External Fault, IGBT failure, DC Undervoltage warning
   iv. Analog Inputs, -10V to +10V (Grid-tied mode / Standalone mode)
      1. Real Power Setpoint / Voltage Setpoint
      2. Reactive Power Input / frequency setpoint
   v. Analog Outputs (0 to +10V), accuracy on all measurements ≤ 1%
      1. AC Output line voltage per phase (true RMS)
      2. AC Output line current per phase (true RMS)
      3. DC Voltage
      4. DC Current
      5. Real Power
      6. Reactive Power
      7. Battery Temperature,
      8. Inverter Temperature,
      9. Reserve Energy (Battery) (pass through from Battery Mfg. controller)

Battery Charging

Battery charging profile shall be in accordance with the battery supplier's specifications as provided by battery mfg. charge controller:

Constant current charging:	e.g. 75 A to 540 VDC
Constant voltage charging to completion:	e.g. 590 VDC

Note: Charge initiation shall be via remote interface.

Battery Discharging

Battery cut-off voltage during discharge shall be	e.g. 425 VDC (as per battery mfg. controller or as specified by THESL)

Compliance

Highest priority items are marked with an asterisk (*). All items are intended to be compliance, not certification. See below for certification.

IEEE	IEEE 519*, IEEE 587, IEEE 1547*,
NEC	(NEC 690.47C for Photovoltaic System)
EMI Noise Suppression	IEC, IEEE
Safety	CSA*

Certification

Units should be certified to the below standards.

NONE

AC Voltage and AC Frequency Protection and Ride through

Table I-1. CES Response to Grid Voltage Condition

Grid Voltage	Timer (Seconds)	Stay Synchronized	Mode during Timer Count Down	Timer Expires	Timer Does Not Expire
> 1.22 PU	0.010 s	Yes	PQon	Unit Faults Grid Over Voltage	Stays in PQon
1.10 PU ≤ Grid Voltage < 1.22 PU	30.0 s	Yes	PQon	Unit Faults Grid Over Voltage	Stays in PQon
0.8 PU ≤ Grid Voltage < 1.10 PU	No Timer	Yes	PQon	Not Applicable	Stays in PQon
0.70 PU ≤ Grid Voltage0 < 0.8 PU	2.0 s	Yes	PQon	Unit Faults Grid Under Voltage	Stays in PQon
0.00 PU ≤ Grid Voltage < 0.70 PU	0.6 s	Yes	PQon	Unit Faults Grid Under Voltage	Stays in PQon

<u>**Note**</u>: In Standby Mode of operation, the inverter's gating are off, all the contactors are closed, and the only current supplied to the grid is the AC filter capacitor current.

Table I-2. CES Response to Grid Frequency Condition

Grid Frequency	Timer (Seconds)	Stay Synchronized	Mode during Timer Count Down	Timer Expires	Timer Does Not Expire
66.1 Hz <F	0.1s	No	Stand By	Unit Faults Grid over Frequency	Stays in PQon
66 Hz ≤ F ≤66.1 Hz	0.16 s	Yes	PQon	Unit Faults Grid over Frequency	Stays in PQon
62.5 Hz ≤ F < 66 Hz	2 s	Yes	PQon	Unit Faults Grid over Frequency	Stays in PQon
56 Hz ≤ F < 62.5 Hz	No Timer	Yes	PQon	Not Applicable	Stays in PQon
54 Hz ≤ F < 56.4 Hz	2 s	Yes	PQon	Unit Faults Grid Under Frequency	Stays in PQon
54 Hz ≤ F < 54 Hz	0.16 s	Yes	PQon	Unit Faults Grid Under Frequency	Stays in PQon
F < 54 Hz	0.1 s	No	Stand By	Unit Faults Grid Under Frequency	Stays in PQon

APPENDIX J: BASIC CONTROL THEORY FOR STATCOM

Numerous papers can be found on the subject of STATCOM control theory. The following has been derived from one paper which describes the function of STATCOM in relatively simple terms (ref. 28).

Figure 47. Block Diagram for STATCOM Control (ref. 28)

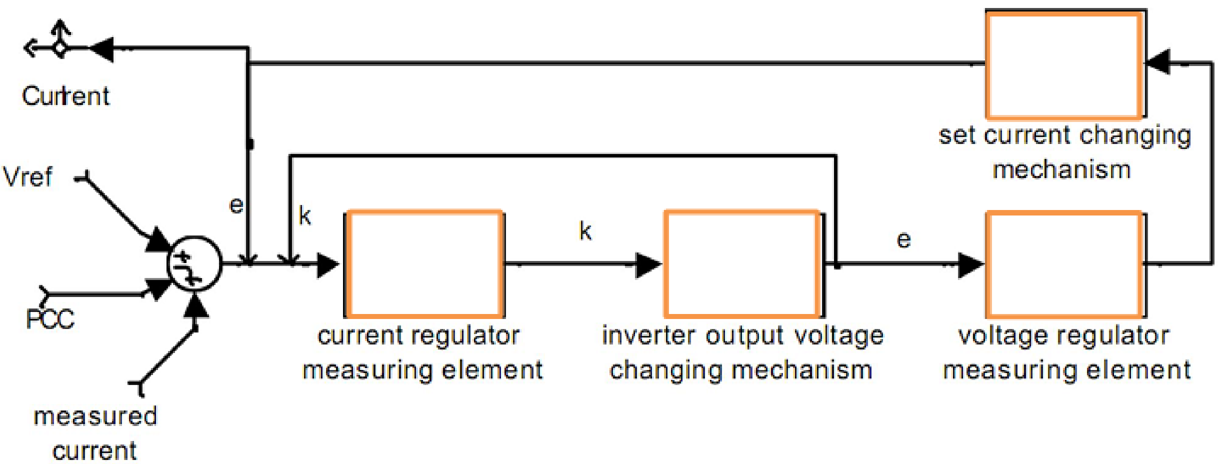

Figure 47 above illustrates the block diagram of a STATCOM which has the following major components:

- Current measuring element
- Voltage regulator measuring element
- Current regulator measuring element
- Set current changing mechanism
- Inverter output voltage-changing mechanism.

Using Figure 47 as a guide, the following explains the basic control theory for a STATCOM. In practice, dead band and damping functions are built into the controller to prevent hunting and other issues. Similarly, the function to dispatch and absorb real power by an automated means would require development of custom algorithms tailored to THESL's specific requirements based on factors including but not limited to:

- THESL's operating strategy including pricing
- Supply constraints
- Time of day

- Battery technology including storage capacity
- Connected feeder load dynamics

Basic STATCOM Control Algorithms **(ref. 28)**:

- Current measurement element:

$$I_S = \left| \frac{S^*}{V^*} \right|$$

Where:

I_S	Current from the STATCOM
S	Complex power supplied by the STATCOM
V	STATCOM voltage

- The voltage regulator measuring element:

$$V_{error} = V_{reference} - V_{measure}$$

Where:

V_{error}	Voltage correction
$V_{reference}$	reference voltage in p.u.

$V_{measureed}$ measured voltage after line drop compensator (LDC) added at the PCC, in p.u. (A LDC is utilized to provide constant voltage at the load.)

- Output from the voltage regulator measuring element:

$$e = \begin{cases} 0 \; if -DB \leq V_{error} \leq +DB \\ 0 \; if \; V_{error} \leq DB, V_{error} \geq 0 \\ 0 \; if \; V_{error} \geq -(DB), V_{error} \leq 0 \\ 1 \; if \; V_{error} > DB \\ -1 \; if \; V_{error} < -(DB) \end{cases}$$

Where:

DB adjustable dead band of the regulator in p.u.

- Current regulator measuring element:

$$I_{error} = I_{set} - I_{measured}$$

Where:

I_{set} reference current in p.u.

$I_{measured}$ measured current magnitude

- Output from the current measuring element is:

$$k = \begin{cases} 0 \; if - DB \leq I_{error} \leq +DB \\ 0 \; if \; I_{error} \leq DB \; , I_{error} \geq 0 \\ 0 \; if \; I_{error} \geq -(DB), I_{error} \leq 0 \\ 1 \; if \; I_{error} > DB \\ -1 \; if \; I_{error} < -(DB) \end{cases}$$

Where:

DB adjustable dead band of the regulator in p.u.

- Set current changing mechanism:

$$if \; e = 1 \, , \quad increase \; I_{set}$$

$$if \; e = -1 \, , \quad decrease \; I_{set}$$

$$if \; e = 0 \, , \quad maintain \; I_{set}$$

- Set voltage changing mechanism:

$$if \; k = 1 \, , \quad decrease \; V_{set}$$

$$if \; k = -1 \, , \quad increase \; V_{set}$$

$$if \; k = 0 \, , \quad maintain \; V_{set}$$