Public Interest Energy Research (PIER) Program
FINAL PROJECT REPORT

SITRAS® STATIC ENERGY STORAGE (SES) SYSTEM DEMONSTRATION PROGRAM

Prepared for: California Energy Commission
Prepared by: Sacramento Municipal Utility District

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PREFACE

The California Energy Commission Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

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- Transportation

Sitras® Static Energy Storage System Demonstration Program is the interim and final report for the Static Energy Storage Project for light rail, contract number 500-06-055, conducted by the Sacramento Municipal Utility District. The information from this project contributes to PIER's Transportation Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

ABSTRACT

The Sacramento Regional Transit District's light rail system experiences low voltage during peak operating periods in portions of the older "starter line", known as the Folsom Line, which can result in quality of service issues. The purpose of this research project was to determine if rail energy storage might help to mitigate low voltage occurrences, which would reduce line contactor maintenance on the vehicles.

Siemens Transportation Systems developed an ultracapacitor-based energy storage system for the rail that was deployed in Europe and later in China to boost voltage on light rail lines in locations where a new conventional substation was unable to be built.

During the due diligence phase of this project, simulations were developed by Siemens with data input and assistance from Regional Transit. It was predicted that two Static Energy Storage units placed between Traction Power Substations F3 and F5 on the Folsom Line would raise minimum train voltage by 65 volts from 570 volts to 635 volts, which is sufficient to avoid low-voltage quality of service problems. An additional simulation was run with one Static Energy Storage unit on the Folsom Line which showed a boost of 54 volts, also sufficient to avoid low-voltage quality of service problems. Because a single unit simulation had shown a significant voltage boost, a decision was made to proceed with only one test unit.

Early in the project it was determined that staffing support costs to implement this research project would be much greater than originally estimated, and at the same time local team members were hard hit by budget and staffing reductions. After attempting to find ways to proceed, a decision was made to terminate the project before the Static Energy Storage System was purchased or installed. This report summarizes the findings from the due diligence phase of the project.

Keywords: Energy storage, ultracapacitor energy storage, Sitras® Static Energy Storage Energy storage for light rail

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EXECUTIVE SUMMARY

The Static Energy Storage Project was first discussed in 2005 at a meeting which involved Siemens Transportation Systems, Sacramento Regional Transit District, the Sacramento Municipal Utility District and the California Energy Commission. Because the technology had been successfully deployed at several European transit properties, it seemed like a good technology transfer opportunity for the United States. Regional Transit was experiencing low voltage along segments of its light rail line, so the Static Energy Storage System from Siemens was a potential solution to the low voltage problems. Accordingly, Regional Transit and Siemens signed a contract for Siemens to simulate the potential benefits of installing one or two Static Energy Storage units on the Regional Transit light rail line.

The results from this simulation looked promising; therefore in the spring of 2007 the Sacramento Municipal Utility District submitted a proposal to the Energy Commission for a joint Static Energy Storage System Demonstration Project with Sacramento Regional Transit. The Energy Commission awarded the proposal in the summer of 2007 and the funded project was launched.

Work began with all parties commencing contract discussions and detailed planning. In early 2008, Regional Transit management asked the project staff to more closely review all of the costs that might be associated with this demonstration project, including staffing support costs. This effort identified substantially greater costs to Regional Transit than were previously estimated, roughly doubling the budget from $1.1 million to $2.1 million, leaving a $900,000 budget shortfall. The cost increases were mainly in staffing support costs to implement the pilot program.

At the same time, the economy in California was slowly deteriorating and this was impacting the budgets of municipal and State agencies, including Regional Transit, the Sacramento Municipal Utility District and the Energy Commission. All parties met over a period of many months to determine if there were some way to carry out the project given the higher budget requirements, but no solution was found. Ultimately, it was decided that the most appropriate path would be to terminate the project, which was agreed on in August 2009. Accordingly, a Static Energy Storage system was not installed nor tested.

A lot was learned, however, about the Static Energy Storage technology and ultra-capacitor applications for rail energy storage. This report focuses on aspects of the Static Energy Storage technology that would have been important to a successful project design and ongoing operation.

CHAPTER 1: Introduction

Background

The Sacramento Light Rail System has marginal voltage at peak service in the older section of the Folsom Line. In particular, data taken on the Folsom Line between substations F2, F3, F4 and F5 in June 2006 showed voltages at peak service hours in the 600V and lower range, which is below a minimum voltage target of 650V. Optimal train operating performance requires voltages in the 750V to 880V range. The low voltage observed on the Sacramento Regional Transit District (RT) Folsom Line requires train operators to accelerate slowly from these stations during peak hours in order to avoid rough train acceleration, which otherwise would amount to a quality of service problem. It also is apparent that low-to-marginal voltage will cause excessive line contactor cycling, leading to excessive wear and shortened life on the contactors. In the future, RT would face significant operational issues when train frequencies are increased on the Folsom Line. In order to bring peak hour voltage levels up to minimum requirements at these substations, RT faces a choice of adding new conventional substations or finding alternatives to accomplish the same objective.

Overview

Energy storage offers the potential to provide voltage support on light rail systems in areas of marginal voltage. Siemens Transportation Systems (STS) developed an energy storage technology called the SITRAS® Static Energy Storage (SES) System that uses ultracapacitors to form a 1 MW peak power supply capable of discharging 1,400A over a 20-30 second period of time. The length of the discharge period was designed to provide a voltage boost from the time a train accelerates from a station until it reaches normal operating speed, or “track” speed.

Development of this energy storage product at Siemens began in 2000. Prototypes were developed and tested. Units were installed and operated at transit properties in Dresden and Cologne, Germany and in Madrid, Spain beginning in 2002/2003 with energy savings and voltage stabilization benefits. In the same timeframe, an early prototype was also tested in Portland, Oregon. However, six months after commissioning the unit failed due to a voltage conversion component failure which was supplying power to the cooling fans. Additionally, three installations were initially planned for China in 2007/2008. The SES System proposed for Sacramento RT represented the first planned test of a commercial SES product in the U.S.

Prior to the California Energy Commission (CEC) grant award, RT and the Sacramento Municipal Utility District (SMUD) also investigated possible application of flywheel technology (Siemens, Urenco, Vycon) and traction battery technology (Impulse) for light rail systems, but at the time the only operational technology with demonstrated potential benefits for light rail was the Sitras SES.

A significant barrier to market entry of rail energy storage technology in the U.S. is the lack of technology demonstration. Transit properties place a high premium on utilizing proven and reliable technology at reasonable cost. Demonstrating technology viability is critical to market entry. Therefore, one of the purposes of this project was to provide a demonstration and evaluation of SES technology to be shared with other transit properties in California.

Project Objectives

The objectives of this Project were to:

- Establish the baseline performance of the Light Rail system without SES;
- Install an SES unit on the RT light rail line and measure energy use (kWh), peak demand impacts (kW), load leveling potential (kW) and voltage (V) impacts of the SES technology; and
- Quantify the benefits, performance and costs of the proposed SES technology in a light rail application.

Report Organization

This report focuses on the ultracapacitor technology and how this information is key to a successful project design and ongoing operation.

CHAPTER 2:
Project Approach

The original project approach was to install two SES units on the RT Folsom line, collect system impact data on these two units and then conduct a value proposition analysis to determine the costs and benefits of the SES technology.

Shortly after the CEC awarded funding for the project, Siemens submitted its final simulations for two different scenarios -- one with two SES units installed and a second with a single SES unit installed on the Folsom Line. The simulations showed that much of the benefit from a demonstration program would be achieved by installing a single SES unit at the weakest point on the light rail line which was projected to provide a voltage boost of 54 VDC, even though two units would provide a 65 VDC boost over a longer section of track.

Subsequently, RT and SMUD staff requested more detailed costing information from Siemens on the SES System. The rough cost estimates submitted by Siemens were higher, due in part to exchange rate fluctuations, but also because RT requested additional items in the estimate, including warranty provisions, spare parts, air conditioning, commissioning/training, a performance bond and the addition of an exterior blue light to indicate a fault condition to train operators. Shortly thereafter, it was decided that the installation of only one SES unit would be sufficient to test the merits of this technology, and it would better fit the budget amount that was available for the project.

At the same time, RT and SMUD staff recognized that more due diligence was needed before ordering the SES System. This consisted of many steps, including:

- Additional simulation work on the impacts of only 1 SES unit on the RT light rail line.
- Further investigation of systems that already existed in Europe.
- A Critical Project Review with the Siemens SES chief engineer.
- Partnering with Sandia National Laboratory (SNL) in two areas.
    1. SNL would contract with Distributed Utility Associates (DUA) to provide for the development of an economic model to compare the SES System cost with that of a conventional substation, known as the Value Proposition Analysis.
    2. SNL would contract with EPRI to measure and analyze the load impact of the SES unit on the light rail system and on the SMUD electrical distribution system.
- The development of a Project Evaluation outline with data requirements defined.
- The development of detailed cost estimates for data recorders needed to collect required data.
- A better understanding of potential failure modes and life cycle issues that might be experienced with the ultracapacitor technology, particularly the impact of over-voltage and over-heating on the life of the ultracaps.

- A site visit to Portland, Oregon by RT and SMUD (where a prototype SES unit was operated for several months) to better understand the failure mode of the prototype.
- Development of the Project Advisory Team for broader input from other light rail systems in California.
- Support of the joint Rail Energy Storage Committee formed by the American Public Transit Association (APTA) and the Electric Power Research Institute (EPRI) which included several transit authorities throughout the U.S.

Project Outcomes

Due to increases in cost estimates, and budget and staffing shortages within the partner team, a decision was made to terminate the project before installation of an SES unit. However, information on SES system performance parameters was developed and is summarized in this report.

CHAPTER 3: Technical Information

The following technical information was developed from project commencement through the early phase of the project build process.

System Configuration and Output

- The SES unit consists of 1,344 ultracapacitors divided into 32 drawers. Each drawer contains 42 ultracaps.
- The building block of the system is the BoostCap 3000 capacitor from Maxwell Technologies, configured in a custom module, the BMOD 2570, with 6 ultracapacitors per module rated at 16V and 7 modules per drawer.
- There are a total of 224 modules in the system.
- These drawers are contained in four cabinets with each cabinet containing 8 drawers along with cooling fans and temperature sensors.
- The SITRAS® Static Energy Storage System provides 1 MW of peak power supply capable of discharging 1,400A of DC power to rail over a 20-30 second period of time in order to stabilize rail system voltage.
- The SES system is used primarily for operation in two different modes. One is Energy Savings Mode whereby electricity stored in the ultracaps is allowed to discharge to rail for use by passing trains in lieu of the train drawing more electricity from the nearest Traction Power Substation (TPSS).
- The other is Voltage Stabilization Mode whereby electricity stored in the ultracaps is retained in the caps until the SES unit senses a low voltage event at which point electricity is discharged to rail to provide a voltage boost and thereby avoid a low voltage condition.
- The SES System may be programmed to operate in either mode at any given point in time. For example, RT was planning to operate the SES System in Energy Savings Mode during off-peak hours (non-commute hours) and in Voltage Stabilization Mode during peak hours (commute hours).
- The SES unit equalizes the stored energy and voltage of all the caps each night during hours when the light rail system is not operating.

System Life Cycle and Protection Parameters

- Siemens' engineers in Germany stated that a 10 year SES System life is likely with proper air conditioning and 1 to 2 spare drawers of ultracapacitors.

- The two events most likely to shorten the life cycle of the SES unit are over-voltage and high temperatures over an extended period of time.
- The SES unit contains controls for over-voltages. If specified voltage (2.7V) is exceeded at any single cap or with a single row, the unit shuts down.
- The SES unit also contains controls for over-temperature events. If a high temperature event occurs, the unit automatically shuts down. There are more than a dozen temperature probes or relays built into the system at different points to protect against over-heating.
- STS recommended that ambient air intake temperature not exceed 95ºF (35ºC) when operated in Energy Savings Mode (discharging ultracaps to rail whenever possible in order to save energy) and not exceed 104ºF (40ºC) in Voltage Stabilization Mode (retaining electricity until needed for voltage boost).
- Since Sacramento ambient air temperature during the summer often exceeds 95ºF, Siemens agreed to add an after-market, wall-mounted air conditioning unit to provide conditioned air along with ambient air in order for the mixed air temperature not to exceed 95ºF.
- The SES installations in Europe were in locations where the ambient area was cooler than in Sacramento and provided sufficient cooling to keep the ultracaps within specified temperatures.
- At the time the SES project was being planned for Sacramento, STS had 3 to 5 years of commercial operating experience with SES units at different locations in Europe, but did not have a full 10 years of operating experience using the BoostCap 2570 ultracapacitor module.
- If the initial set of ultracapacitors expires after 10 years, it is not likely feasible to replace the initial caps with a new set of caps in order to extend the SES System life to 20 years, due to the need for other system upgrades and replacements.
- Other than unexpected failures, ultracaps normally fail gently at the end of their life, i.e. there is steady performance until the very end of life. Output declines over a period of time (months) and it's easy to anticipate the need for cap replacement by observing decreased module voltage.
- Siemens advised RT that the purchase of two spare drawers at roughly $7,500 each should be sufficient to provide for a 10 year operating life.
- Siemens also advised the purchase of miscellaneous spare parts in addition to the 2 drawers, estimated to cost approximately $10,000, to ensure a 10 year operating life.

Modification of SES System for Sacramento

There were two areas where the SES System technology needed to be modified for installation in Sacramento, including:

- Auxiliary equipment in the SES unit had not yet been adapted to USA voltage and frequency (Europe has 200V/400V and 50 Hz), but Siemens stated it would make necessary modifications prior to shipment to the USA.
- Air conditioning was to be added to the SES unit by a Sacramento commercial air conditioning contractor, which would be operated independently of the SES system controls, and not be integrated with the SES system controls. In a fully developed commercial SES unit, the air conditioning controls would most likely be integrated with the SES system temperature controls.

Ultracap Replacement

Information on ultracap replacement for the demonstration project was developed and is summarized below:

- A single ultracap failure will cause the entire unit to shut down.
- Since the caps come in a custom module consisting of 6 caps, if one cap fails, the module must be replaced, which in turn requires that the entire drawer be replaced since the system was not designed for module by module replacement.
- The failed drawer would be replaced with one of two spare drawers kept in inventory for this purpose.
- The failed drawer would be sent back to Germany where the custom module with the failed ultracap would be rebuilt at the Siemens ultracap module integration facility. The rebuilt module would be sent back to Sacramento for inventory.

System Shut-Down Notification

- At the time of initial discussions with Siemens, it was explained that an ultracap failure caused either by an over-temperature shut-down or by an over-voltage shut-down, would be detected when the unit equalizes at night, but not necessarily when it occurs. In this situation the user would not know about system shut-down until the unit equalizes during the night hours. Thus, train and system operators would not be notified of a failure until the evening hours following the failure occurrence.
- RT stated it was necessary for RT system and train operators to know when the SES unit was not operating and requested the installation of a blue light on the outside of the SES unit to signal unit shut down. Siemens agreed to the installation of a blue light to signal SES system shut-down, which is the typical application at RT's TPSS.

Problem Statement

- The nominal voltage on the Sacramento Light Rail line is 750V.
- RT experiences voltages below 600V along the old Folsom line, and has measured voltages as low as 570V.
- When voltages drop close below 600V, line contactors will cycle off and on, shutting down the traction equipment and then turning it back on in a continuous off/on cycle, which will cause premature wear on the line contactors and degrade train performance.
- When voltage drops below 600V, train operators must accelerate the trains slowly from the stations in order to avoid rough train starts or to avoid further depressing the DC voltage. This operator-based solution to a low voltage problem is considered to lower the quality of customer service, and is not looked upon as a permanent fix.
- Low voltage issues would need to be solved before express trains or other enhancements to light rail service on the old starter line would be added.

Simulation Findings

The Siemens' engineering group in Germany performed several sets of simulations for the addition of one and two SES units on the Sacramento Light Rail System. Initially Siemens performed a simulation with two SES units located near RT Traction Power Substations F04 and F05, but the results of this simulation did not demonstrate significant voltage boost. After discussion with RT, Siemens agreed to perform another simulation with two SES units located at mid-points between TPSS F04 and F05 with one located between the University and Power Inn passenger stations and the other between Power Inn and College Greens passenger stations. Over time, as the costs of the project were more clearly identified, it was decided that one SES unit would be sufficient to test and demonstrate the SES technology, especially given cost constraints.

With a single SES unit in proximity to RT substation F04 the simulation results also were not promising, but with one SES unit between F04 and College Greens and in proximity to College Greens passenger station (roughly ½ mile to the west of the station), the results were promising, as follows:

- Predicted voltage boost of 54VDC at College Greens passenger station at time of lowest voltages, boosting the voltage from ~ 570V up to 620V, sufficient to solve the immediate low voltage problem.
- Little or no voltage boost was evident at the Watt/Manlove passenger Station (one station to the East of College Greens station) or at the Power Inn passenger Station (one station to the West).
- The level of cost savings from peak demand reduction (kW) associated with the SES unit was not clear. A peak reduction achieved in any given month would need to be achieved for an entire year, based on SMUD's ratchet style of demand charge for large commercial customers. (Once a new peak kW load is measured by the meter, the

monthly demand charge is based on that higher peak kW load magnitude for the next 12 months.)

- The regenerative energy savings from the SES unit was estimated at 82,500 kWhs annually, which would amount to about $8,000 per year of energy cost savings. This estimate was based on a mix of 50% CAF cars with regeneration capability and 50% Siemens cars which do not have regeneration capacity. The original Siemens simulation assumed 100% CAF cars with regeneration capability on the Folsom line, but subsequently RT changed its operations to 50% CAF cars and 50% Siemens cars on the Folsom line.

Air Conditioning Findings

Overheating of the ultracapacitors was identified by SMUD and RT staff as a potential life cycle issue for the SES unit, due to the high summertime temperatures experienced in Sacramento. This had not been an issue with the cooler climate of the locations in Germany and the Madrid application was located underground in a subway where it was not exposed to high ambient air temperatures. Siemens initially stated that the SES unit in Sacramento probably would not need air conditioning – that ambient air cooling would be sufficient to keep the caps from over-heating, but neither RT nor SMUD were satisfied that ambient cooling would provide a 10 year life for the ultracaps if they were to be deployed during peak hours of the summer months. Accordingly, the following steps were taken:

- Siemens sent their lead SES engineer to Sacramento in October 2007 for review of site specific integration issues, including AC requirements. Peters Engineering, a local engineering and commercial air conditioning company, participated in the discussion on AC requirements.
- Siemens lead SES engineer agreed that it would be advisable to provide cooler conditioned air on hot Sacramento days in order to avoid shutting down the system to protect the ultracaps.
- Peters Engineering suggested a wall installation of a high-efficiency, mini-split air conditioner from Mitsubishi in such a way that the conditioned air would mix with the ambient air flow from the 3 fans in order to provide for a lower mixed air temperature while maintaining a high air volume flow.
- It was agreed that the operational objective would be for the mixed air temperature not to exceed 95ºF (35ºC), instead of using 104ºF (40ºC) as a target temperature. The lower target temperature would also allow the unit to operate in Energy Savings mode whenever possible (since Energy Savings mode causes the ultracaps to heat up to a greater extent).
- A second site review meeting was scheduled for early to mid 2008, but this did not take place because the lead Siemens engineer on the project was assigned to a different project within Siemens.

Warranty Findings

RT and SMUD staff asked Siemens about the possibility of a warranty since the commercial SES product was not yet tested in the US, with the following results:

- Siemens was willing to provide a 100% warranty on the SES unit and ultracaps for the 18 to 24 month period of the pilot program at no cost to RT.
- At the request of RT and SMUD, Siemens provided a quote for an extended warranty over a 10 year period. The cost estimate provided by Siemens roughly equaled the initial cost of the SES unit, and covered the SES unit but not the ultracaps themselves, so it was clear that an extended 10 year warranty was not feasible.

Project Evaluation

A project evaluation outline was developed, and showed the data collection steps to be taken for the evaluation phase. Sandia agreed to contract with EPRI to handle data collection and monitoring for the project and to contract with DUA to handle the Value Proposition Analysis (benefit cost study). EPRI suggested that contact be made with Square D about necessary data monitoring equipment, which was also done.

Many meetings were held with Square D, RT, DUA, EPRI and SMUD to discuss the Project Evaluation methodology. Ultimately, it was decided to use data from four sources for the project evaluation, as follows:

A. Data from the Train – determine the voltage boost as seen by the train

RT planned to use a Vision XP data logger located on a light rail car to sample voltage and current data in order to record data as seen by the train. The plan was to collect this data "with" and "without" the SES unit turned on so to measure the difference in voltage and energy savings. After SES installation, data was to be collected from multiple train runs under different conditions (time of day, day of week, by season, for different consist configurations – mix of Siemens and CAF cars) with the SES system turned on and with the SES system turned off.

B. EPRI Independent Evaluation – measure voltage levels at TPSS F04 and F05 and at the SES unit

EPRI suggested that baseline data be collected for a period of 4 to 6 months prior to operation of the SES unit in order to facilitate a high level of confidence in impact measurements. To accomplish this, the plan was to collect DC and AC voltage, current (A) and power quality data using two Square D ION 8600 meters, one at TPSS F04 and one at TPSS F05, for a period of 4 to 6 months. EPRI planned to directly query these meters on a daily basis for upload of the data to the EPRI server.

Additionally, at the time of SES installation, the plan was to install a Square D ION 7650 meter at the SES unit to record DC voltage, current (A) and power quality data. This data was to be transferred to the computer located inside the SES unit which EPRI could query daily through the onsite modem.

Also, once SES operation commenced, data would be collected by the two ION 8600 meters located at TPSS F04 and F05. The plan was for the data from these two meters to be time-sequenced with the ION 7650 meter located at the SES unit in order to accurately measure the voltage impact of the SES unit at the SES unit and at the two TPSS's.

Since rail voltage is direct current (DC) and the ION meters collect AC data, an Adam Module DC-AC converter was to be used in line with each ION 7650/8600 meter to convert DC data to AC data.

C. Siemens Data at SES unit – measure voltage levels at the SES unit by means of the Siemens' data recorder located inside the SES unit

System data (DC voltage, current and temperature) was to be recorded by the measuring PC located inside the SES unit and uploaded daily to the Siemens server via DSL modem for monitoring by Siemens. This data also was to be made available to EPRI, RT and SMUD.

D. 15 minute interval data from the SMUD meters at TPSS F04 and F05

The plan was to time-sequence the data from the three ION meters with the data from two SMUD meters at TPSS F04 and F05 to validate kW demand reductions as well as energy savings.

By using data from all four of these sources, time-sequenced and cross validated, it was believed that a high degree of confidence would be achieved in the impact/data analysis.

DUA recommended that the value proposition analysis be conducted after the SES unit was installed, using actual performance data from the four sources.

Technology Transfer

Prior to the decision to terminate the SES project in Sacramento, a committee was formed by the American Public Transit Association (APTA) and the Electric Power Research Institute (EPRI), called the APTA-EPRI Rail Energy Storage Committee to explore the feasibility of rail energy storage for rail systems in the US. Support for the Rail Energy Storage Committee was considered a worthy Technology Transfer activity by the CEC under the grant for the SES System demonstration program. In fact, support for the APTA-EPRI Rail Energy Storage Committee also fit perfectly with development of the SES Project Advisory Committee (PAC) required by the CEC grant. Accordingly, RT and SMUD supported various activities of this committee, including several conference calls and meetings at Los Angeles Metropolitan Transit District (LA Metro) and at Sacramento RT to explore the details and potential benefits of rail energy storage.

Conclusions

Despite the fact that the SES system was not installed, the due diligence phase of the project produced valuable information about the use of ultracapacitors for large-scale energy with light rail systems. Key conclusions were:

- The voltage boost simulated for a single SES unit at College Greens, 54 VDC, was sufficient to boost low voltage from the 570V level up to 620V, which is sufficient to remedy the low voltage condition experienced on this section of the Folsom light rail line.
- The energy savings from regeneration turned out to be lower than anticipated, $8,000 annually, which was due to the fact that RT runs 15 minute headways on the light rail line (infrequent compared to European train systems) and the fact that only about half the RT cars have regeneration (CAF cars) and half the cars do not have regeneration (Siemens cars).
- Energy savings from regeneration would be greater for rail applications where headways are more frequent than once every 15 minutes, such as in Los Angeles, Seattle, Portland or at transit properties on the East Coast, and where all the cars have regeneration capability.
- European rail lines have headways as frequent as 4 minutes, which makes the regeneration benefit much greater, even justifying the installation of an SES unit on the basis of regeneration energy savings alone. Similar frequent headway applications in the US might prove more feasible than applications with less frequent headways.
- Although ultracapacitors generally have a life cycle that ends in a gradual and predictable loss of capacity, the failure of a single ultracap in the SES unit will cause the entire unit to shut down. This type of failure mode should be taken into consideration when evaluating TPSS solutions on a light rail line.
- The Siemens' simulation did not provide an estimate for the peak kW reduction benefit with only one SES unit, and even if one had been provided, it was not clear that an estimated value would hold for an entire 12 month period in order for RT to benefit from the reduction.

Recommendations

The due diligence phase of this project would suggest the following considerations:

- Clearly define the problem/issue in quantitative terms, whether low voltage or other, which in many cases will involve data collection and analysis.
- Conduct system simulations of the storage unit on the rail line prior to seeking project funding in order to determine if the SES technology would be viewed as a substitute for conventional substation additions or upgrades, or an enhancement or augmentation of the existing TPSS system.
- A value proposition analysis would be appropriate for any light rail properties interested in considering energy storage as an option to conventional substation additions or upgrades.

- Identify conventional alternatives as well as energy storage options. Perform simulations with specific conventional alternatives, as well as value propositions. For low voltage conditions, these may include:
    - Conventional ½ MW or 1 MW DC substation additions
    - Conventional 2 MW DC substation upgrade
    - Doubling the power conductor between TPSS
- The ultracapacitor technology appears to be a good fit with light rail low voltage conditions and merits testing under circumstances where the participants are comfortable with the simulation results and have sufficient staffing and funding to conduct a demonstration program.
- Recent developments of flywheel and battery energy storage technology may also warrant consideration as rail energy storage demonstrations.

Public Benefits to California

Energy and demand savings from rail energy storage is an area of significant potential benefit to the State of California, transit properties, electric utilities and electric utility ratepayers. Even though the SES Project was terminated during the due diligence phase of the project, the information developed provides a basis for the CEC to consider future rail energy storage projects in California.

CHAPTER 4:
References

Andrew Burke, University of California, Davis, Researcher

John R. Miller, President, JME Inc.

Stan Atcitty, Sandia National Laboratories

CHAPTER 5: Glossary

AC	Alternating Current
APTA	American Public Transit Association
A	Amps
CEC	California Energy Commission
DC	Direct Current
DUA	Distributed Utility Associates
EPRI	Electric Public Research Institute
kW	Kilowatt
kWh	Kilowatt hour
LA Metro	Los Angeles Metropolitan Transit District
PAC	Project Advisory Committee
PIER	Public Interest Energy Research
RD&D	Research, development and demonstration
SMUD	Sacramento Municipal Utility District
RT	Sacramento Regional Transit District
STS	Siemens Transportation Systems, Inc.
SES	Sitras® Static Energy Storage System
TPSS	Traction Power Substation
ultracap, or cap	Ultracapacitor
V	Volt

CHAPTER 6: Bibliography

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