Hybrid Energy Storage Integration with Artificial Intelligence to Support Remote Communities

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Abstract

This paper is intended to support remote community power needs by improving management of generating equipment. It presents a hybrid Energy Storage system (thermal + electric energy storage, or hybrid storage) with Artificial Intelligence (AI). It is an integrated solution that exploits the advantages of SMART TES/M technology - to support remote communities. The highlighted project allows for improved resilience of the power infrastructure for future generations and operates responsible energy supply that benefits remote communities, improving environmental footprint and economic advancement, helping achieve many of the Sustainable Development Goals.

This low-carbon SMART TES/M solution is firmly aligned with smart community initiatives, such as Smart Buildings (Save energy and improve sustainability) and Distributed Energy Resources (DER to Improve sustainability, efficiency and reliability). This solution allows for financial mechanisms built on engaging end-users and the whole community through cost reduction and a shared savings approach while benefiting of Earning adjustment mechanism (EAM) or Platform service revenue (PSR).

While the hybridization is innovative and more "community-engaging" compared to many other energy-related solutions in the field, it is based on 20 years of R&D and implementation in the field for more than a decade. Modelling of this integration has shown substantial benefits: Avoided Generation Capacity Cost (AGCC) with Environmental Value (Avoided CO_2, SO_2 & NO_x emissions) for Onsite Emitting Generation and significant potential for Avoided Transmission and Distribution Capacity Infrastructure while reducing outage risks with the inherent Hybrid Storage capacity used as a backup. The Present Value of the Benefits has been compared to the net present value of the project for a B/C Ratio of 2.29.

Introduction

Energy has always represented a challenge for remote communities. This challenge is now bigger in many regions of the World. Notably, in Canada, the Standing Senate Committee on Energy, the Environment and Natural Resources noted in its 2015 report that much of the diesel generation infrastructure in Canada's Northern communities has already reached its life expectancy. Of the 25 diesel-powered electricity plants currently operating in the Nunavut Territory, only 10 have life expectancies that reach at least 2026.

Of the remaining 15, 14 have already exceeded their expected end-of-life, with another that has only one year of intended life remaining.

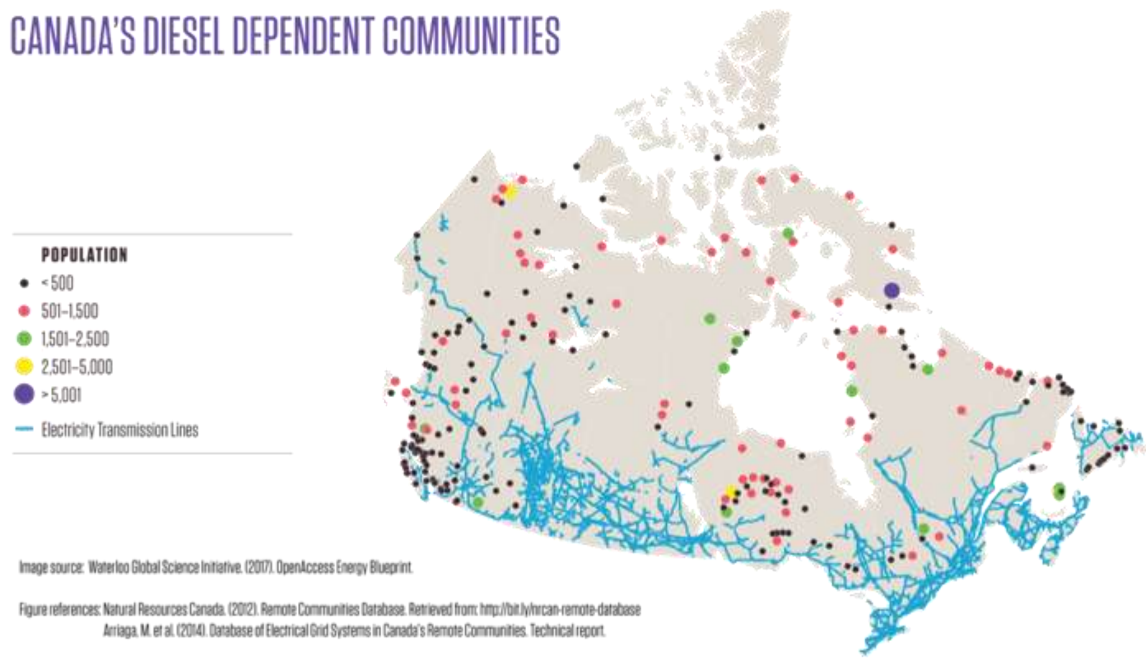

Fig. 1. Map of remote communities in Canada. Source: Waterloo Global Science Initiative

A big portion of these communities have aging diesel generators. These diesel-generator plants, which remain operational despite reaching their life expectancy, are more expensive to maintain and operate than newer ones and may need to be replaced in the near future. This is just an example of what many communities remotely located from high density centers are facing.

The increasing demand in power represents a challenge for existing electrical networks and future smart grids in remote communities. It contributes to electricity peak demand, which are also increasing substantially. In this context, renewables (RE) can play an important role in shaving the peak demand burdening the electrical grid as soon as it is well integrated in the electric supply. The solution here, combining RE with a mix of energy storage technologies including Artificial intelligence (AI) will allow for improved village infrastructure and operation, and responsible energy supply that benefits these communities. This approach improves economic development and delivers environmental sustainability for future generations as well as local grid stability and resiliency.

Indeed, AI and integrated energy storage can be used to develop demand side management (DSM) strategies able to shift the load from peak to off-peak hours (thus exploiting potential for price arbitrage) even in presence of renewable energy production. Demand side management is a means to increase the overall efficiency of the entire electricity network - from generation to the end use - which consists of optimizing the allocation of resources, limiting the peak demand and shaping the demand profile depending on the necessity of the grid. This paper presents Hybrid storage integrating Electric Energy Storage (EES) and Thermal Energy Storage (TES) using a Synthetic Phase Change Material (SPCM) to optimize energy efficiency and load leveling for Renewable Energy and Critical Processes.

Fig. 2. Implemented Hybrid Thermal and Electric Energy Storage System

What we generally see in the energy storage field are different storage technologies acting as competitors and not as potential collaborators. This is the paradigm. In fact, no single technology could easily compete with the energy density of cheap fossil fuel. It is important to find ways for these technologies to work together. That would not only help to increase system efficiency, but also lead to better energy management.

Through an advanced hybridization control strategy, the generated power could solely be used on the chosen Clinton County, New York site, or to contribute to the community's peak demand, with the local electric utility receiving the extra output from the hybrid facility, they could deliver the power to their local grid. In the latter case, the Hybrid Energy storage with AI solution would allow for better energy management (load levelling, peak shaving, etc.) as well as DER (Distributed Energy Resources) utilization optimization. Unlike the current alternatives, these improvements are done without a reduction in services and even with improved resilience in case of failure/"black-start".

We do this by engaging customers and the whole Community through costs reduction and a shared savings approach while benefiting of Earning adjustment mechanism (EAM) or Platform Service Revenue (PSR); optimizing financial mechanisms in close collaboration with the utility as we have organized elsewhere, including different prior experience in other jurisdictions.

This is what this paper is all about: integrating three complementary storage technologies into an integrated/hybrid approach.

Technology description

On top of the intelligent combination of technology, the SMART TES/M low-carbon solution is also quasi mobile and integrates a Power Conditioning System (PCS) to convert electric power from one form to another; for example, converting between direct current (DC) and alternating current (AC), and providing specific power qualities or voltage optimizing the way electricity is generated, stored, delivered, and used, as well as the way mechanical systems are actuated. This gives much more flexibility and resilience especially important for remote applications.

The SMART TES/M Hybrid mobile energy storage unit is being monitored for use as an alternative to diesel generators in various remote/emergency/military applications. Diesel fuel, especially fuel that must be delivered to remote areas, is extremely expensive, and after transportation costs are factored in, can cost $30 per gallon or more. Recent storms, floods, and forest fires are making this more and more relevant. The SMART TES/M mobile unit would offset the high costs of transportation by generating additional, renewable energy on site.

Fig. 3. Thermal/electrical energy storage unit being delivered

On the other hand, only a fraction of power generators on the grid today are PCS-based (i.e. with Power Conditioning System). The integration of a smart (AI-based) PCS allows for the optimal addition of renewable/clean energy sources that produce DC (photovoltaic and fuel cell) or variable AC (wind turbines) and thus require a PCS to invert to AC meeting interconnection requirements. The distributed nature of solar energy also poses unique challenges in simultaneously meeting the requirements to provide the microgrid stability by remaining connected during abnormal conditions. The SMART TES/M, while ensuring safety by de-energizing, allows for separating into a microgrid island when the distribution grid goes down. The mobile unit also provides resiliency and power quality advantages and can contribute to overall stability of a grid in a rebuilding/recovery mode. The Novacab smart grid-interactive PCS-based generator and microgrid functions enable solutions to these and many other issues and, with the help of Machine Learning, could even enable distributed generators to provide grid interactive functions that increase their value proposition.

A sustainable grid architecture could involve several (stacked) mobile TES/M units, as stationary microgrids or tactical mobile microgrids, that would play a critical role during disaster response involving wide-area electricity outages by enabling individual microgrids to continue to operate or to be brought back up before transmission lines and substations are restored. Thus, this would allow mini-grid, with many small communities (interconnected or not with other communities) to have a better disaster response whether it's caused by Blizzards, Floods, Forest Fires or other events.

SMART TES/M could be used as a tactical mobile microgrids consisting of compact, high efficiency units on trucks to rapidly integrate renewable generators, storage, loads and feeders during wide area disaster recovery efforts. Disaster-recovery capability is integrated within the SMART TES/M power conditioning units for critical infrastructure equipment such as power plant cooling systems, hospital operation rooms, or municipal/community flood pump stations so that they can rapidly interface with alternate electricity sources during disaster recovery.

Integration of Thermal energy storage with SPCM

Using this joint/collaborative approach and using our work in the hybrid energy storage for vehicles, different SPCM (Synthetic Phase Change Material) have been developed in order to accommodate their integration in the TES/M: The Hybrid Thermal and Electric Energy Storage system.

The medium used along with the electric storage media is a Synthetic Phase Change Material. The phase change taking place in the thermal storage is from liquid to solid and vice-versa. This change in phase allows for managing (absorbing or releasing) a large quantity of energy in small volume compared to conventional electric storage. Phase change is a natural thermal process driven by temperature level. Energy is either captured or released. Melting reguires energy capture. Freezing requires energy release. There are no moving parts involved, no maintenance items to check.

Through the last two decades, Novacab has developed 30 different SPCM mixtures with a melting points from -40°C (-40°F) to +125°C(+255°F); a selection range of nearly 300 F. Also, unlike water or even eutectic salt which have substantial expansion factor (while solidifying), our SPCM has a small negative expansion factor in the solid phase, which results in negligible stress on storage components.

Also, the SPCM need very low maintenance and have a life span of up to 15,000 cycles and they are non-toxic, non-corrosive, non-bio-accumulative, non-carcinogen. All ingredients are listed on the EPA TSCA list designations.

These capabilities allow for better use of the Energy Storage and for better integration of EES and TES to maximize:

- Operational flexibility and stability
- Performance improvement in the operation.
- Demand-Side Management with Predictability
- Reliability in the operation

Combined Control Strategy

The control of the system is based on an anticipatory regulation strategy using fuzzy logic and a combined feedforward plus feedback control that can handle simultaneously the storage and retrieval of both electricity and solar energy.

It takes into account the operating conditions such as load, outside air temperature, and optimizes the off and the on-peak periods for electrical heating. The combined strategy can significantly improve performance over simple feedback control whenever there is fluctuations or disturbances. The regulation strategy depends on a PID controller which regulates the air flow from an electric fan in order to maintain the room temperature at the set point.

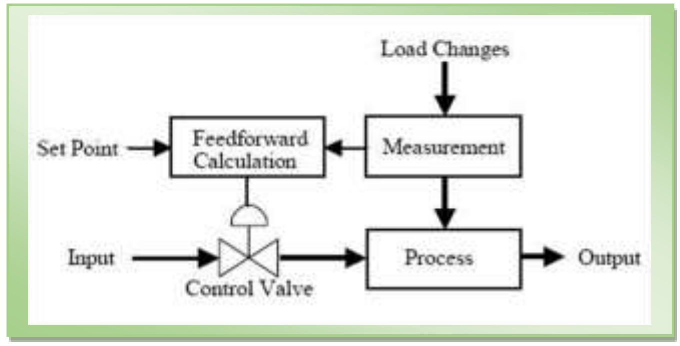

Fig. 4. Feedforward Control strategy

Remote communities and small grid applications

So far, the SMART TES/M systems have been installed and monitored in various facilities. The results show that they can have a significant impact on the grid itself.

Remote communities and small grid applications were quickly identified as good applications of the technology because their energy consumption is critical and energy costs are growing fast with the needs of the communities. They create both electricity and thermal loads, . which are critical for the facility's operation. In fact, the heating and cooling systems are often the largest consumers of power. In many cases, it is also one of the most inefficient systems in a small community grid.

As illustrated in Fig. 3, fossil fuels are the largest source of power that supports the Remote Communities in Canada Primary Electricity Sources. In many cases it is the most inefficient source of energy, and the biggest emitter of CO2. The diesel generators are often over-provisioned for redundancy, resulting in partially loaded equipment and energy inefficiencies. To illustrates another challenge: the cost of energy, Fig. 4 compares Electricity Rates in Remote Communities in Canada's Territories vs average. In some areas, it's 3 to 5 times more expensive than the Canadian average, adding to the challenges that the communities are facing.

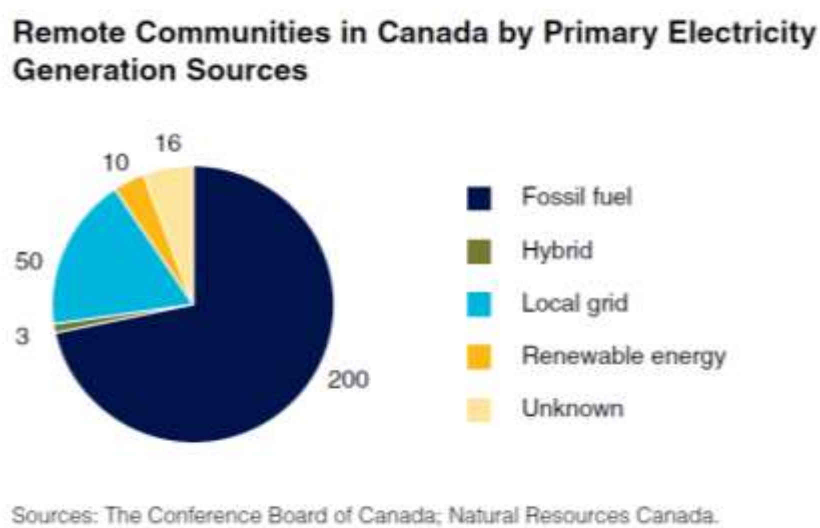

Fig. 5. Remote Communities in Canada Primary Electricity Sources

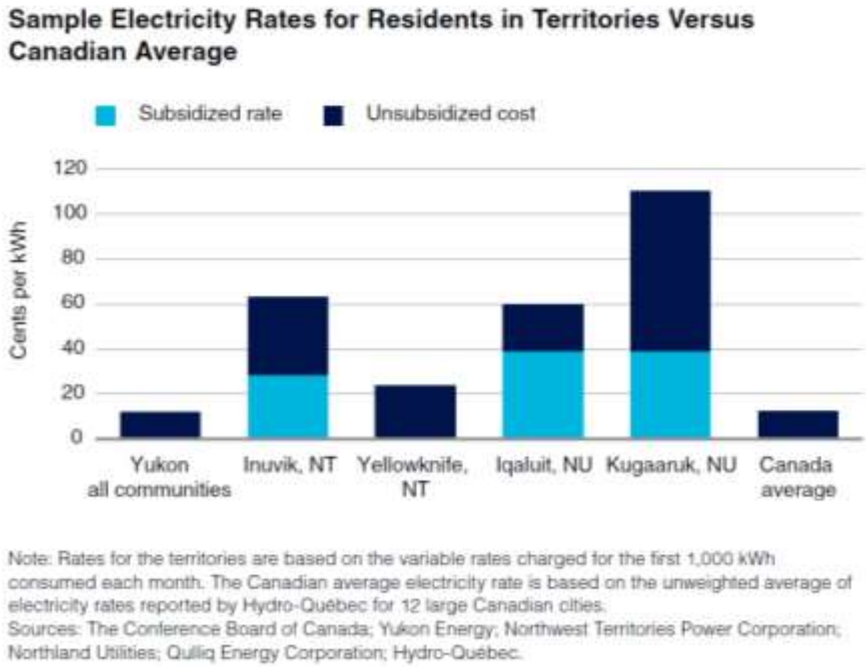

Fig. 6. Electricity Rates in Remote Communities in Canada's Territories vs average

High energy costs are typically addressed through government programs that subsidize and equalize electricity rates and provide discounts for heating fuels. The unique geographical and logistical constraints of remote communities (i.e. how difficult it is to bring in fuel and supplies) also have a major impact on energy prices. The following table illustrates the high cost of diesel fuel in a few representative communities and shows how remoteness and access affect costs.

Community	Access	Bulk price of diesel fuel ($/litre)
Fort Severn, Ontario	Air/long-distance barge	2.36
Kasabonica, Ontario	Air/winter road	1.49
Akulivik, Quebec	Tanker vessel	1.40
Kugaaruk, Nunavut	Tanker vessel	1.32
Aklavik, Northwest Territories	Winter road	1.22
François, Newfoundland and Labrador	Barge	0.99
Gull Bay, Ontario	All-season road	0.86
Whitehorse, Yukon	Highway	0.69

Table 1 Diesel prices in remote communities (3.78 litres = 1 U.S. gall.) (Source: Pembina Institute)

Most of Canada's Northern and remote communities are small—only about 20 per cent have populations greater than 1,000 people. Such small communities typically show large variation between the peaks and troughs of electricity demand. Because communities need to have sufficient generation capacity to meet peak demand that may be substantially higher than average demand, the diesel generators in remote communities often operate well below capacity. Because such “low-load” operation is inefficient, this high variance in electricity demand indirectly drives generation costs up further.

Further, many remote communities have peak electricity demand that is rapidly approaching or has already reached their generation capacity. Once a community’s peak demand reaches 75 to 85 per cent of “prime-rated” capacity, the community must stop permitting new connections to its local grid to ensure that the system does not become overloaded. If the electricity supply is not expanded, this limits community growth, as no new housing, industrial, or commercial developments can receive electricity. This can result in lost economic opportunities and overcrowded housing situations.

As an example of the situation in Northern communities, Arriaga and others* identified seven remote communities in Ontario where peak loads equal at least 75 per cent of total generation capacity(*Arriaga, Cañizares, and Kazerani, “Renewable Energy Alternatives,” 663 https://ieeexplore.ieee.org/abstract/document/6461123). While Natural Resources Canada’s Remote Communities Database contains an additional four such communities outside of Ontario, peak demand estimates are available only for 46 of the 279 communities, so it is possible that this problem could be much more widespread than these data indicate.

To better understand, we might look at how typical facilities in communities operate today. The electric components are separated from the thermal (heating or cooling) component that are considered “support” systems. As a consequence, variability in load leads to partially loaded, and outside/weather conditions are controlling the efficiency of the process

As a response to these issues, a SMART TES/M device is installed between the HVAC systems and the rest of the building. See Fig. 5. The systems can then be run at optimal utilization for highest efficiency. The integration of Electric and Thermal components in the SMART TES/M system allows for saving both electricity and surviving to power failure. It is also allows reduction in the size of the generator or other back-up power.

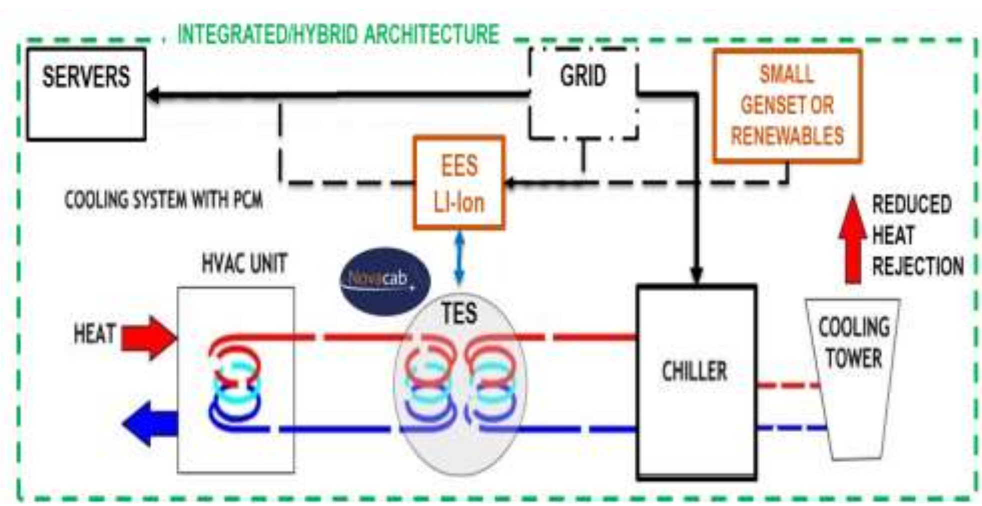

Fig. 7. Example of Integrated Architecture/Configuration in a multifunctional building with chillers and servers

Reducing Part Load is an example of how an integrated system can improve efficiency. The following performance equation (1) represents actual measurements (with R^2=0.94) of the impact of Part Load on efficiency (kW/Ton) from a centrifugal chiller operating with constant 21°C (70°F) entering condenser water and 5.5°C (42°F) exiting evaporator water.

$$kW/Ton = -0.66\,\lambda^3 + 1.98\,\lambda^2 - 1.85\,\lambda + 1.11 \qquad (1)$$

kW/Ton = Chiller Efficiency
λ = (Part) Load = Demand / Capacity

The operation is now integrating a “Charge Mode” during off-peak hours when outside temperature is more favorable and use the grid when it is more effective and a “Discharge Mode” during on-peaks hours when it can absorb transient increases in data center cooling load, avoiding startup of additional chillers, reducing the load on the grid. This hybridization not only helps the end-user/operator, but also the energy provider, the utility itself unlocking on-peak power for other use.

On-site Performance and monitoring

An implementation with extensive monitoring has been done with using a system with 18 units in 2 sets: one for energy efficiency purposes (including peak shaving) and the other for safety reason, as a redundancy.

A hybrid approach that integrated the solution with a central power manager was the only viable solution, and ultimately the program successfully met all of its goals. The onsite monitoring shows a 10% to 23% reduction of the electricity consumption for the cooling. That represents approximately 2 Million kWh per year and up to 0.8 MW in peak shaving.

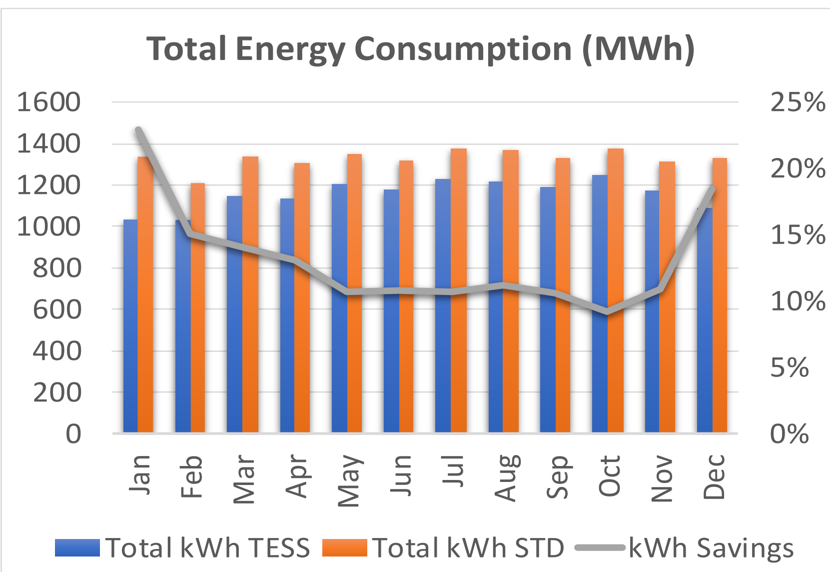

Fig. 8. Energy Consumption for Standard and Integrated (SMART TES/M) System

The results illustrated in figure 6 show that the monthly averaged consumption values vary significantly because of the variation in mechanical cooling needs depending upon OA conditions. The efficiency can be improved from 12% to 27% by the proposed system under the given operating conditions.

With the integrated configuration, the power consumption has a significant lower impact on the total data center power consumption with the integration.

The following figure shows that Electric Peak can be improved (shaved) from 913 kW to 617 kW by the system.

Fig. 9. Monthly Peak Shaving profile

Discussions and Recommendations

The integration of TES and EES was designed with energy efficiency and sustainability in mind, setting it up to be 47% more efficient for cooling than typical data centers, and from 10% to 23% more efficient than state of the art facilities operating today. Almost 80% of the energy is going directly to its core purpose.

Ramp up and Ramp down of the equipment were reduced and the Supply and Return process temperatures were stabilized. To summarize the Measured Operational Cost Savings and the other benefits of using a SMART TES/M in the field:

- Peak Shaving of up to almost 1000 kW
- Reduction of 13 % in the yearly overall electric consumption (35% reduction for cooling)
- 2 GWH/year & 0.8 MW average load leveling.

Other applications of the SMART TES/M include Industrial plants, hospitals that need both electric and thermal energy. In such critical processes, a significant portion of the fluctuations in the load are taken by the SMART TES/M. The SPCM is acting as a shock absorber in the thermal process.

The SMART TES/M hybridization not only helps the end-user/operator, but also the energy provider, the utility itself unlocking on-peak power for other use. From the extensive monitoring, many items can be outlined for the stakeholders such as the Renewable Energy provider, the end-user or the facility manager:

- It Reduces Peak Loads (kW) and Energy Consumption (kWh)
- Because it works on Energy Efficiency, incremental peak shaving boosted free cooling
- While it is Minimizing Stops & Starts, Overdesign, and Part Loads

- It improves energy efficiency, reducing the total power consumed by a datacenter to get closer to the power consumed by the IT equipment of the facility.

The energy storage industry has just begun exploring grid-scale hybrid solutions that combine two or more energy storage technologies with complementary characteristics to provide an optimal solution not achievable by any one technology. The implementation and monitoring that were achieved here are a good example of the potential of such a strategy.

The tested systems include storage technologies that separately cover sprinter loads required for fast response or marathon loads required for peak shaving and load shifting. By combining two technologies, the SMART TES/M make this issue much less of a concern.

In addition, the hybrid system has demonstrated that it could simultaneously provide multiple services that allow for various value streams concurrently for the utility/grid especially in remote communities' smaller grid, the impact is also substantial:

- Smoothing the load profile optimizing
- Demand side management
- Reducing the amount of fuel that has to be delivered in remote locations
- Redundant and predictable energy distribution
- Lower energy consumption and transmission losses
- Lower operating costs and improved asset utilization
- Deferred construction and capital expenditure requirements

Fig. 10. Integrated TES/M with Solar PV

Conclusions

Our experience has shown that the integration is allowing for significant improvement and stability in the operation in a critical application such as remote communities and small grid applications and other isolated and critical thermal/electric processes. The data analysis has shown that the integration of Electric and Thermal components in the system allows for saving both electricity and surviving a power failure. A significant portion of the fluctuations in the load is taken by the SMART TES/M. The SPCM is acting as a shock absorber in the thermal process. The outcomes of the combination systems were highlighted by the monitoring including on-site operational data, reliability, and performance.

The results have shown that optimum results are obtained when initial fluctuating conditions were observed. Improved performance and stability were measured and have shown that Ramp up and Ramp down of the equipment are reduced and the Supply and Return process temperatures are stabilized. The SMART TES/M allows reduction the size of the conventional generator or other back-up power.

The measured advantages are lower cost, increased system efficiency, and increased system lifetime due to optimized operation and the ability for hybrids to do more and last longer with less overall storage capacity. Hybrid systems could open up even more revenue streams for facility managers, operators and smart grids not currently possible with a single energy storage technology.

This low carbon solution advances the possibility for remote and small communities to take advantage of “Smart Cities” & “Climate Goals” such as Smart Buildings (Save energy & improve sustainability) and Distributed Energy Resources (DER), Improve sustainability, efficiency and reliability. On the DSP side, our Hybrid Storage & AI solution is a Non-wires alternative allowing to defer infrastructure investments by procuring DER while improving system reliability. Potentially built as a Demo partnership in a sharing business model, the project is aligned with 3 sustainability objectives: to boost system reliability & resilience, to improve efficiency and to reduce CO2 emissions, while Hybrid Storage enables new markets & leverage contributions, customers use DER more efficiently.

The integrated hybrid energy storage systems merit a closer look for many other stationary applications as part of comprehensive energy storage deployment strategies. The technology has demonstrated the potential to achieve double-digit percent decreases in CAPEX and OPEX, increase system operating life, and boost revenues by simultaneously providing multiple services, this hybrid solution may be a change in the ‘single storage’ paradigm. Of course, the energy management hardware and software needed to manage two different storage technologies for multiple use cases are not trivial, and development will definitely continue with the applications. The ultimate objective, with this solution, is to help the many remote communities that have peak electricity demand rapidly approaching or have already reached their generation capacity.

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