# Hybrid Thermal and Electric and Energy Storage System

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***Abstract*- Electric Energy Storage (EES) and Thermal Energy Storage (TES) have been integrated in a hybrid approach to optimize energy efficiency and load leveling. This integration is allowing for significant improvement and stability in the operation in critical applications such as hospital, datacenters, military facilities, manufacturing plants, and other critical thermal + electric demand-side management. Using the extensive experience in the hybrid energy storage for vehicles and mobile applications, a special Synthetic Phase Change Material (SPCM) has been developed to act as a shock absorber in stationary thermal processes. The Hybrid Thermal and Electrical Energy Storage System (HTEES) maximizes the flexibility and the overall performance of the equipment on the grid. Monitoring in a datacenter has 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. It allows for performance improvement and more reliability in the operation. For the grid, the impact would also be substantial: smoothing the load profile and optimizing demand side management; and improved redundancy and predictability of the energy distribution. The integration and combined outcomes of the HTEES system is highlighted in the paper, including onsite operational data, Power Usage Effectiveness (PUE), reliability, and performance.***

***Keywords*- hybrid system, thermal energy storage, phase change material, renewable energy, smart grid**

## I. INTRODUCTION

### *A. Background*

The continuously rising cooling demand represents a challenge for existing electrical networks and future smart grids since it contributes to electricity peak demand, which is increasing substantially. In this context, well integrated in the electric supply, thermal energy storage can play an important role in shaving the peak demand, burdening the electrical grid. Hybrid energy storage can be used to develop demand-side management strategies able to shift the load from peak to off-peak hours (exploiting potential for price arbitrage) even in the presence of renewable energy production. Hybrid-demand side management is a mean 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 depending on the necessity of the grid.

### *B. Foregoing and Related Works*

This paper presents hybrid systems, integrating Electric Energy Storage (EES) and Thermal Energy Storage (TES) that have been implemented in order to optimize energy efficiency and load leveling for Renewable Energy and Critical Processes.

Using the extensive experience in the hybrid energy storage for vehicles, a special Synthetic Phase Change Material (SPCM) has been developed.

What we generally see in the energy storage field, is that the different storage technologies are considered only as competitors and not as potential collaborators. Seeing the different technologies in a competitive mode; this is the paradigm. In fact, no single technologies could easily compete with the energy density of the cheap fossil fuel. It is important to find ways for these technologies to make the new technologies to work together. That would not only help to increase the efficiency of the whole process, but also it would lead to better energy management. This is what this paper is all about: integrating two storage complementary technologies in a hybrid approach: the HTEES.

## II. TECHNOLOGY DESCRIPTION

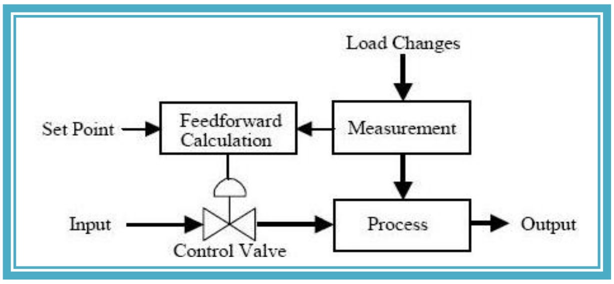
### *A. Hybridization with Regulation Strategy Combining Thermal and Electric Capacities*

Using this joint/collaborative approach and using our work in the hybrid energy storage for vehicles, we have developed special SPCM and the HTEES.

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 electricity and solar energy. It takes into account the operating conditions such as load and outside air temperature, and optimizes the off- and on-peak periods for electrical heating. The combined strategy can significantly improve performance over simple feedback control whenever there are fluctuations or disturbances. The regulation strategy depends on a PID

controller that regulates the air flow from an electric fan to maintain the room temperature at the set point.

Fig. 1. Feedforward HTEES Control strategy.




In a dynamic system, the Total Energy Storage Capacity "Σ" is the sum of the actual Thermal Energy Storage "τ, the actual Electrical Energy Storage "ε" and a supplementary useful equivalent storage capacity "δ":

$$\Sigma = \tau + \varepsilon + \delta \quad (1)$$

It is important to note that "τ" and "ε" in Eq. (1) are not the nominal (theoretical) values, but rather the actual capacities, taking into account the operational conditions. They represent the useful portion of the nominal capacity in the context (e.g., temperature, cycling, heat rejections, ramp up, and ramp down

In such a dynamic system, the Total Energy Storage Capacity "Σ" can be assimilated to an Electrical + Thermal "Uninterruptible" Supply (UPS+UTS) that is considering the system in which it is operating.

As a consequence, the Projected (or predicted) Energy Storage Capacity "Σp(t)" is not only a summation of the nominal capacities. It is the value that is changing in real time, a dynamic value:

$$\Sigma p(\tau) = \tau(\tau) + \varepsilon(\tau) + \delta(\tau) \quad (2)$$

The supplementary useful equivalent storage capacity "δ(t)" is the sum of the additional energies sources at time "t" (e.g., reduced losses, improved capacities due to temperature management, and equipment efficiencies). This new parameter is introduced in the feedforward control. The operation is integrating an optimized "Charge Mode" during off-peak hours, when outside temperature is more favorable. It is using the grid when it is more effective and using a "Discharge Mode" during on-peak hours, when it can absorb transient increases in datacenter cooling load, avoiding startup of additional chillers and reducing the load on the grid.

This "predictive" approach is allowing for a better use of the Energy Storage, but also for a 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.

### *B. Thermal Energy Storage with SPCM*

Developed to be operated on a 24/7 basis, the SPCM act as a buffer to mitigate the fluctuations in the load. The SPCM used in conjunction 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.

Through the last 2 decades, Novacab has developed 30 different SPCM mixtures with a melting point from -40°F to + 250°F; unlike only 32°F like for the liquid water to ice phase change. And also unlike water or even eutectic salt that have a substantial expansion factor (while solidifying), SPCM has a small negative expansion factor in the solid phase that results in negligible stress on components. These mixtures need very low maintenance and have a life span of up to 15,000 cycles while they are non-toxic, non-corrosive, nonbio-accumulative, and non-carcinogen.

## III. Performance Experiments and On-Site Monitoring

The HTEES were implemented and monitored in various facilities (e.g., Fig. 2). The results show that they might have a significant impact on the grid itself. Datacenters were quickly identified amongst the good applications of the technology because their energy consumption is huge and growing fast, although they are consuming electricity and cooling.

Fig. 2. Implemented system.

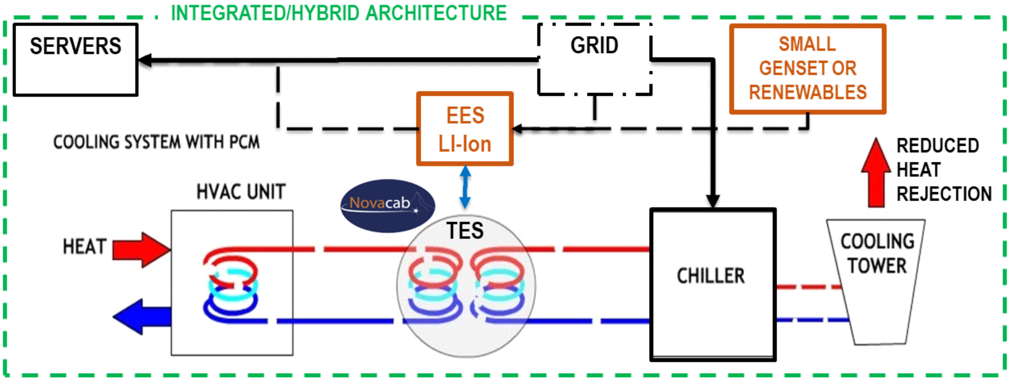



Fig. 4. HTEES integrated architecture/configuration.

### *A. Applications in Datacenters*

The thermal and electrical loads are critical for the datacenters operation. In fact, the cooling systems are often the largest single consumers of power. In many cases, it is also one of the most inefficient systems in a datacenter. While the servers are becoming more and more efficient, their growing numbers (in terms of capacity and power) reverse the effect, and the consumption is still growing. According to the U.S. Department of Energy (2016 report), it will reach 73 billion kWh/year in 2020.

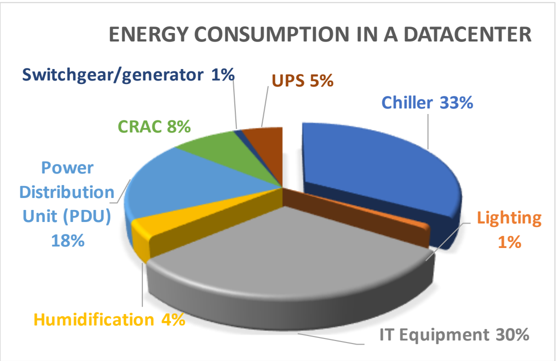



Fig. 3. Datacenters distributed power consumption.

As illustrated in Fig. 3, the cooling systems (33 percent for chiller and cooling tower) are the largest consumers of power that support the datacenter – in many cases it is the most inefficient. The chiller plant is often over-provisioned for redundancy, resulting in partially loaded equipment and energy inefficiencies.

To better understand, we look at how many datacenters operate today. The electric components are separated from the thermal (cooling) components that are considered "support" systems. Doing so, the biggest consumption point of the datacenter (the cooling) is often set apart from the main backup system. The hotter the outside temperature, the harder the chillers and cooling towers must work and the more difficult it is for the electric grid. Chiller size must account for such extreme conditions that they are often over-designed. Consequently, the variability in a datacenter cooling load leads to partially-loaded, inefficient chiller operation. Because cooling is required and critical to the operation, over-designed generators would be installed to compensate for that risk. A server room would fall down if the temperature rises too fast. It is difficult to do real climate controls to optimize operation with systems that are less efficient when the demand is higher. In short, the outside weather conditions are controlling the efficiency of the process.

As a response to these issues, an HTEES device is installed between the chillers and the datacenter (see Fig. 4). Chillers can be run at optimal utilization for highest efficiency. It is "Charged" during off-peak hours, when the outside temperature is more favorable and using the grid when it more effective. It is "Discharged" during on-peaks hours, when it can absorb transient increases in datacenter cooling load, avoiding startup of additional chillers and reducing the load on the grid.

### *B. Power Usage Effectiveness*

Power usage effectiveness (PUE) is a common indicator representing the energy efficiency of a datacenter. PUE reflects how much of the facility's power consumption is used for the primary computing purpose, as opposed to support functions like cooling.

PUE is the ratio of the total amount of annual power usage of the datacenter to the annual power usage of IT equipment, as described by Eq. (3).

$$PUE = \frac{T}{IT} = \frac{K + Y + O + IT}{IT} \quad (3)$$

PUE = Power Usage Effectiveness
T = Total Energy Consumption; IT = IT Energy
K = Cooling Energy; Y = UPS Energy
O = Other Energy Consumption (i.e., PDU, lighting, etc.)

To better characterize the impact of the outside conditions on the efficiency, Mechanical Power usage effectiveness (PUEm) is a special indicator representing the energy efficiency of the mechanical cooling in a datacenter. PUEm is the ratio of the total amount of annual power usage of the cooling systems to the annual power usage of IT equipment, as described by Eq. (4).

$$PUEm = \frac{K}{IT} \quad (4)$$

PUEm = Mechanical Power Usage Effectiveness
IT = IT Energy; K = Cooling Energy (i.e., chillers, pumps, cooling towers, air handling, etc.)

Reducing Part Load is an example of how an integrated HTEES with feedforward control can improve PUE. The performance curve in Eq. (5) 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 70°F entering condenser water and 42°F exiting evaporator water.

$$kW/Ton = -0.66\,\lambda^3 + 1.98\,\lambda^2 - 1.85\,\lambda + 1.11 \quad (5)$$

kW/Ton = Chiller Efficiency
$\lambda$ = (Part) Load = Demand/Capacity

The idea here is to optimize the PUE through the chiller electric supply in regular operations (see Fig. 5 for the substantial impact of outside temperature on PUE and PUEm), and in fail safe-mode (e.g., during a power or mechanical failure).

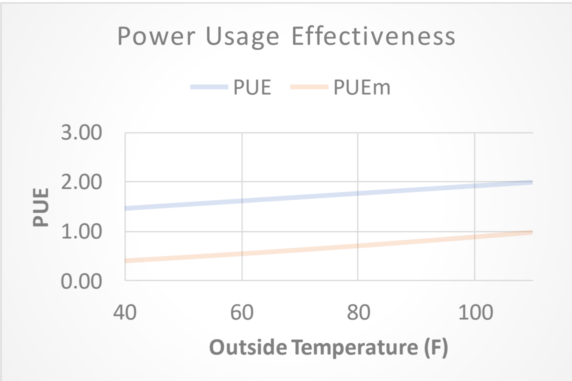



Fig. 5. PUE & PUEm as a function of outside temperature.

*C. Onsite Monitoring*

An implementation with extensive monitoring has been deployed at a major datacenter, located in ahigh rise building. Eighteen units in two sets: one for energy efficiency purposes, including peak shaving, and the other for safety reasons, as a redundancy for the server cooling. A hybrid approach that integrated the solution with a central power manager was the only viable solution; ultimately, the program successfully met all of its goals. The onsite monitoring shows a 10 percent to 23 percent 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.

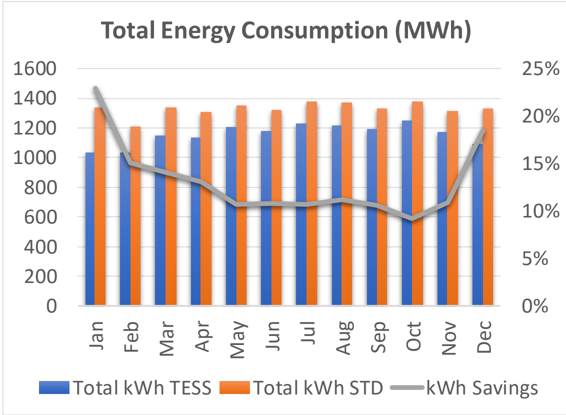



Fig. 6. Energy Consumption for Standard and HTEES.

With the HTEES, the cooling load from server racks is reduced substantially for all the OA conditions. In addition, the power consumption has a significant lower impact on the total datacenter power consumption with the HTEES. The Fig. 7 shows that Electric Peak can be improved (shaved) from 617 kW to 913 kW by the proposed system, under the given operating conditions.

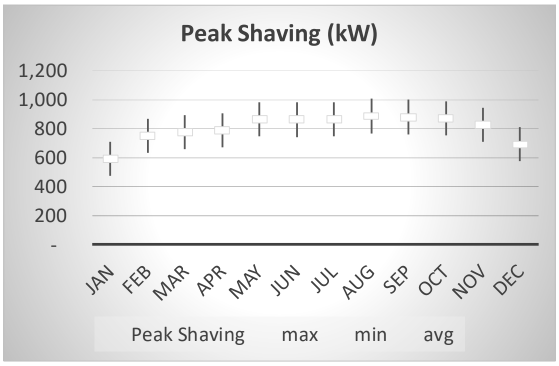



Fig. 7. Peak shaving with HTEES.

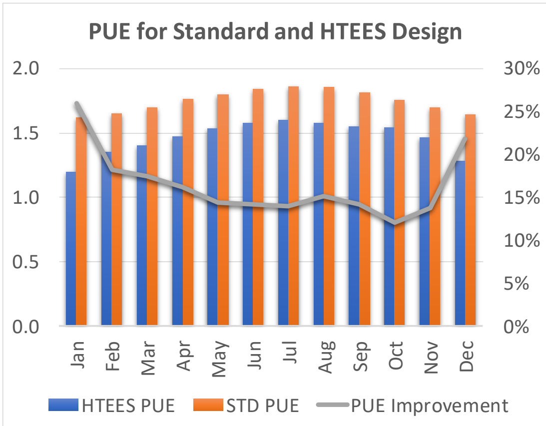



Fig. 8. PUE for Standard and HTEES Configuration.

The results illustrated in Fig. 7 show that the monthly averaged PUE values vary significantly because of the variation in mechanical cooling needs depending upon OA conditions. Figure? also shows that the average PUE with the standard design is above 1.7, whereas the monthly PUE values with the HTEES are averaging a value lower than 1.6, regardless of OA conditions.

Fig. 8 outlines that the PUE can be improved from 12% to 27% by the proposed system, under the given operating conditions.

## IV. Discussions

### *A. Implementation and Outcomes of Onsite Monitoring*

The HTEES was designed with energy efficiency and sustainability in mind, setting it up to be 47% more efficient for cooling than typical datacenters, 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 are reduced and the Supply and Return process temperatures are stabilized. To summarize, the Measured Operational Cost Savings and other benefits of using an HTEES in the field are as follows:

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

Other applications of the HTEES include industrial plants and hospitals that need electric and thermal energy. In such critical processes, a significant portion of the fluctuations in the load is taken by the HTEES. The SPCM is acting as a shock absorber in the thermal process.

With the HTEES, the PUE index is designed to stay under 1.5 as much as possible. This means that less than 20% of the energy for the entire complex will go to functions outside of the computing itself. Typical modern datacenters have a PUE index around 1.7 to 1.8, with many facilities operating at 2.0. The HTEES hybridization not only helps the end-user/operator, but also the energy provider; the utility itself unlocking on-peak power for other use.

In addition, the data can already allow for an evaluation of the Return on Investment of such an implementation. The simple Payback is ranging from 2.8 to 4.2 years, while the Net Present Value (NPV) is averaged to $2.7M over 10 years (with an average 4% discount rate extrapolated over the period). Longterm data collection (for more than a decade) would be required to allow for an even more accurate value of the NPV or of the life cycle costs (LCC) since the Lifespan of such a system is estimated to be around 20 to 25 years.

From the extensive monitoring, many items can be outlined for the stakeholders:

The end-user or the facility manager:

- Reduces peak loads (kW) and energy consumption (kWh)
- Allows for better energy efficiency, incremental peak shaving, and boosted free cooling
- Minimizes equipment Stops and Starts, Overdesign, and Part Loads
- Improves the PUE, reducing the total power, consumed by a datacenter, to get closer to the power consumed by the IT equipment of the facility.

The utility or the smart-grid operator:

- Smooth load profile optimization
- Demand-side management
- Redundant and predictable energy distribution.
- Lower energy consumption and transmission losses
- Lower operating costs and improved asset utilization
- Deferred construction and capital expenditure requirements.

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 HTEES makes this issue much less of a concern. In addition, the hybrid system has demonstrated that it could simultaneously provide multiple services that allow for two value streams concurrently.

## V. Conclusion

The project has shown that the integration of Electric and Thermal components in the HTEES allows for saving electricity and surviving power failure. The outcomes of the HTEES was highlighted by the monitoring, including onsite operational data, PUE, reliability, and performance.

Monitoring in a datacenter has 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. With the HTEES, the PUE index would stay under 1.5, starting from value up to 2.0. This means that less than 20% of the energy for the entire complex will go to functions outside of computing, while the cooling consumption is reduced by more than 35%. It is also allowing to reduce the size of the generator or other backup power.

The same hybrid approach merits exploration for providing stationary energy storage solutions for other applications. The combined systems, properly controlled, would allow for significant improvement and stability in the operation in a critical application such as hospitals, datacenters, military facilities, manufacturing plants, and other critical processes.

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.

The HTEES merit a closer look for many other stationary applications as part of comprehensive energy storage deployment strategies. HTEES 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 new applications coming in.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**Michael L.** Carty, President/CEO


Michael brings decades of corporate leadership along with experience in development of new technologies, he has more than 40 years of experience in business and product development, marketing, strategic deployment, and event organizer. Vast experience in sales and merchandising in Canada and USA. Projects and product development with Northern Telecom production of printed circuits Bell Canada. Entrepreneur in the automotive industry, car dealership owner (General manager and Vice President of a Chrysler Dealership), and trainer for Manufacturers. Michael L. Carty can rely on the services of expert partners in different fields of activities worldwide.


**Chris Mashburn,** VP/General Manager


Former Captain with the Texas Highway Patrol and Detail Leader for President Bush's Executive Protection Detail. Prior to joining Novacab, served as CEO and President of Penfield's Office Solutions since 2006, a specialty business center tailored for the hospitality industry. Prior to that, he founded a private physical security and outsourced staffing firm in 2001, serving as President and CEO, expanded the company's growth in the airline and commercial industries, and drove development of internal processes and controls resulting in a fully ISO 9000 compliant company.


**Ross Quick**, VP/CSO


With Novacab since 2015, he has been previously involved in the commercial industry cultivating sales teams for fortune 500 companies over the last 20 years. Ross worked as a broker for Strategic Energy, Reliant Energy and others while building and training a team of 34 representatives resulting in $200 million in contract value. With his previous partners in Admiral Energy, LLC back in 2007, he won the $1.6 billion dollars project to rebuild the former Clark Air Force Base located in the Philippines.