Small Thermal Energy Storage and Its Role in Our Clean Energy Future

Jonathan Hart, Center for Sustainable Energy
Greg Miller, Ice Energy
Amrit Robbins, Axiom Exergy

ABSTRACT

Thermal energy storage (TES) is a technology that blends energy efficiency and storage to provide benefits to both customers and electricity grid operators. Traditionally, TES is used in large commercial buildings and industrial facilities that have the capital, space and demand for large-scale TES. However, with the recent introduction of smaller plug-and-play TES technologies for space air conditioning and refrigeration, TES is now available for small to mid-size commercial customers and residential use. Additionally, utilities can aggregate small TES systems to decrease grid stress in locations and at times that yield the most value and to defer the need to upgrade distribution grid infrastructure. TES is also becoming increasingly important when used in combination with solar or wind power for load shifting. The recent inclusion of small TES into California's Self-Generation Incentive Program and a growing number of utility procurements of small TES systems have poised this technology to play an increasingly important role in grid operations.

This paper analyzes data from existing and proposed small TES projects across the country, including California, New York, Maine, and Massachusetts, and describe how small TES systems can improve grid efficiency, decrease peak load growth, defer distribution grid upgrades, integrate renewables, and reduce greenhouse gas and criteria air pollutant emissions. This paper also examines how small TES can be implemented into current and future demand response programs to maximize the value of these technologies to utilities and ratepayers.

Introduction

Electricity has become the fuel of modern society; and as buildings, homes, cars, and various devices and appliances increasingly rely upon electricity, innovations in renewable generation, efficiency, and storage will become more valuable. Many national, state, and local regulatory leaders are looking for innovative, cost-effective, and commercially available solutions to increase the efficiency of the electrical system while simultaneously decreasing the negative environmental impacts that electricity generation can produce. This paper will discuss how two relatively new types of small-scale thermal energy storage (TES), namely heating, ventilating, and air conditioning (HVAC)-integrated TES and refrigeration-integrated TES (collectively "small TES"), can provide grid and environmental benefits, improving electricity generation and distribution's cost-effectiveness and reliability. Namely, this paper will analyze the ability of small TES to improve grid efficiency, decrease peak load growth, defer distribution grid upgrades, integrate renewables, reduce greenhouse gas and criteria air pollutant emissions, and use environmentally friendly materials. Additionally, this paper will discuss small TES's role in existing and potential future demand response programs to fully capture the value of these technologies.

TES technologies have traditionally been used in large commercial and industrial facilities that have the demand, space, and available capital to install these types of systems. While large TES systems can offer many benefits to customers and grid operators, they are limited to a few locations, leaving this technology unavailable to the majority of residential and commercial customers. However, TES has recently become available to a much wider range of customer locations through the development of HVAC-integrated and refrigeration-integrated TES, offering numerous grid and environmental benefits to more customers.

Both types of small TES typically use less-expensive nighttime electricity to turn water into ice, "charging" the systems for the next day's use, and store the ice in tanks. Throughout the day, when onsite HVAC or refrigeration systems would typically operate and consume large amounts of peak-hour electricity, the TES technologies turn off the existing HVAC system's compressors or refrigeration system's compressors and condensers and use the stored ice to provide space conditioning or refrigeration, requiring minimal amounts of electricity to run pumps and fans. HVAC-integrated TES typically integrates with commercial HVAC systems up to twenty tons in size, while refrigeration-integrated TES integrates with refrigeration systems typically ranging from 60-120 tons. Both types of small TES can be aggregated across customer sites and remotely operated as a fleet or as individual resources and can offset electricity consumption from the respective HVAC or refrigeration systems for an average of six hours, depending on site-specific conditions. Ice Energy, a manufacturer of HVAC-integrated TES systems called the Ice Bear, offers commercial and residential systems. Ice Energy's Ice Bear commercial product has been available since 2008, and it has more than 1,000 units installed across North America, totaling more than 10 megawatts (MW) of installed capacity. Ice Energy released its residential Ice Bear system in February, 2016. Axiom Exergy, a manufacturer of refrigeration-integrated TES systems called the Refrigeration Battery, offers systems for commercial refrigeration, ideal in grocery stores and food manufacturing facilities. Axiom Exergy's Refrigeration Battery has been available since 2014, and it is currently installing its first systems at commercial sites. This paper will analyze data from Ice Energy's installed Ice Bear and Axiom Exergy's Refrigeration Battery systems.

Grid Benefits

Small TES provides substantial benefits to transmission and distribution grids (collectively the "grid") by improving the efficiency of the grid, reducing peak generation, and deferring grid upgrades. Strategically locating these resources in constrained or otherwise critical areas of the grid provides the greatest benefits, as seen in the Maine and Massachusetts examples discussed below, and can provide significant financial benefits to utilities and their ratepayers.

Small TES can significantly improve the efficiency of the electrical grid by reducing peak-hour generation and grid congestion and the associated heating and efficiency losses of electrical lines. Typically, as seasonal and daily temperatures rise, existing HVAC and refrigeration systems must draw more current to provide cooling. Thus, with increased temperatures, HVAC and refrigeration systems become less efficient and increase electric demand during the hottest hours of the day and year, increasing the temperature of electric lines and the heat losses that they experience (RAP 2011, 4). Additionally, increasing ambient temperature further heats the electrical lines and exacerbates efficiency losses.

However, small TES can significantly reduce efficiency losses, especially during peak temperature days and seasons, by offsetting peak-hour electricity use of HVAC and refrigerator systems, two of the highest energy-demanding appliances. The energy efficiency of standard refrigerant-based air conditioning and refrigeration degrades as a function of increasing temperature. For example, as ambient temperature increases above 95 degrees Fahrenheit (°F), the efficiency of air conditioning cooling systems using R-22 refrigerant degrades by 1.2% per degree above 95°F, commonly equating to a 15% or greater nameplate energy efficiency loss. R-410A (the refrigerant now commonly replacing R-22 in HVAC applications) exhibits a more aggressive decay, estimated at about 1.6% per degree above 95°F. Consequentially, HVAC and refrigeration systems running during peak hours put increased stress on the electrical grid as ambient temperatures increase, exacerbating grid congestion and heat losses. Conversely however, air conditioning unit efficiency improves as temperatures fall below 95°F. Small TES takes full advantage of this diurnal temperature swing by turning off compressors and condensers when they are least efficient (during the hottest part of the day) and running compressors to make ice when they operate most efficiently (in the cool of the night), relieving grid congestion during peak daytime hours and making ice at night when utility grid congestion is at its lowest level. Typically, small TES systems operate around 70-85% round-trip efficiency.[1] However, in climates that have large daily diurnal temperature swings, small TES systems can even operate at greater than 100% round-trip efficiency, offsetting more peak energy than the energy they require to charge. Studies have estimated that reducing peak consumption from equipment such as air conditioners and refrigerators can reduce marginal line losses from congestion and heat by 20% during peak hours (RAP 2011, 1).

In addition, utilities must maintain reserve generation capacity, typically in the form of peaker plants that operate at less than 10% capacity factor, to meet the highest expected peak demand (Energy Commission 2014, 6; RAP 2011, 6). This causes the generation capacity to typically be oversized, inefficient, and expensive, with ratepayers covering the costs. In climates that have summer peak demand caused by air conditioning, small TES systems reduce peak air conditioning demand, permanently decreasing peak generation needs and the necessity to procure additional peaker capacity. Moreover, refrigeration-integrated small TES systems provide year-round load shifting and peak load reduction, even in cold climates, as businesses providing cold food storage use refrigerators all year. Unlike many other types of energy storage that experience efficiency degradation when they are fully discharged on a regular basis, such as different battery chemistries, small TES fully discharges its energy capacity daily without experiencing efficiency degradation, permanently shifting, on average, six hours of peak demand to off-peak. The Regulatory Assistance Project (RAP) estimates that offsetting the use of peak-coincident appliances such as HVAC and refrigeration systems has a total capacity benefit of 1.44 kW by reducing line losses and reducing generation reserves (RAP 2011, 7). In other words, every peak-coincident kW that small TES systems permanently offset reduces the need for utilities to procure up to 1.44 kW of generation capacity. Because refrigeration and space cooling combined account for roughly 17% of energy use for commercial customers in the United States, small TES could significantly reduce the need for utilities to procure peak generation to meet peak cooling and refrigeration needs (Navigant 2009, 16).

Small TES further increases the efficiency of the grid when the systems are located where they will provide the most value, potentially deferring the need to invest in transmission and distribution upgrades. Three recent examples, a demonstration project in Maine, a proposed pilot

[1] This is highly dependent on day and nighttime outdoor air temperature, duration of charge and discharge events, and the hours in which charging and discharging take place. Round-trip efficiency is defined as $kWh_{avoided}/kWh_{consumed}$.

in Massachusetts, and a large project underway in New York City, illustrate small TES's locational benefits and role in grid upgrade deferrals. Unlike large TES systems that must have site-specific characteristics and demands that allow for the installation of the system, small TES can be located at nearly any location that requires space cooling or refrigeration, making them ideal for peak load reduction in critical areas of the grid.

For example, Central Maine Power (CMP), Maine's largest electricity transmission and distribution utility, has been able to place HVAC-integrated TES systems at customer locations to offset peak demand and defer the need to invest in a transmission line upgrade as part of the Boothbay Sub-Region Smart Grid Reliability Pilot (Smart Grid Pilot). Operated by Grid Solar, the Smart Grid Pilot is using energy efficiency, solar photovoltaics (PV), back-up generators, battery storage, and demand response/peak load shifting technologies, including more than 250 kW of commercial HVAC-integrated TES, to defer transmission line upgrades. Due to growing electric demand in the Boothbay sub-region of Central Maine Power's electric grid, the Maine Public Utilities Commission (MPUC) determined the 34.5-kV electric line from Newcastle to Boothbay Harbor would need to be rebuilt by 2025, costing estimated $18 million (Grid Solar 2015, 2). Alternatively, the MPUC proposed a "Non-Transmission Alternative" that would use cost-effective energy efficiency, generation, demand response, and storage to reduce load by 2 MW and defer the need to upgrade the transmission line. As a result, the Smart Grid Pilot was developed to reduce load in strategic areas of the Boothbay sub-region to defer the transmission line upgrade until at least 2025, and at a fraction of the cost of rebuilding the transmission line. The Smart Grid Pilot costs less than $6 million, resulting in a three-year payback and saving the utility and ratepayers more than $12 million over the lifetime of the project (Grid Solar 2015, 2). The Smart Grid Pilot is currently in its third year of operation, and Grid Solar has reported that the resources, including the HVAC-integrated TES, are meeting or exceeding expected load reductions and the project is running within budget. In its latest report, issued October 28, 2015, Grid Solar reported that 97.9% of the fleet was available for dispatch throughout the entire 2015 summer peak season, acting as an invaluable resource in decreasing peak load and deferring the transmission line upgrade (Grid Solar 2015, 3).

A similar proposal in Massachusetts would place HVAC-integrated TES at residential locations on Nantucket Island where residential HVAC loads are projected to significantly increase peak demand. On January 11, 2016, Massachusetts Electric Company and Nantucket Electric Company (collectively referred to as "National Grid") filed a petition to the Massachusetts Department of Public Utilities to approve its proposed Non-Wires Alternative (NWA) Pilot. The pilot seeks to defer installation of a third undersea supply cable to accommodate the projected load growth of Nantucket Island. Nantucket currently has two undersea supply cables that provide electricity to the island, and National Grid has estimated that, due to projected high electricity demand growth on Nantucket in the coming decade, a third submarine supply cable will be needed to reliably serve Nantucket during a contingency period until approximately 2029 (National Grid 2016, 4). Alternatively, National Grid has proposed implementing a pilot project, NWA, which would use targeted energy efficiency, energy storage, and demand response technologies, including 2.5 MW of residential HVAC-integrated TES, on Nantucket to defer installation of the additional undersea supply cable until 2023 (National Grid 2016, 27, 47). Installing an additional undersea supply cable would cost an estimated $23.4 million, while the NWA pilot would cost an estimated $20.6 million, saving National Grid and its rate payers an estimated $2.8 million in net present value over the next seven years. National Grid has cited HVAC-integrated TES' successful role in Maine's Boothbay Smart Grid Pilot as evidence that small TES is a valuable, reliable asset to include in this proposed pilot (National Grid 2016, 47). National Grid anticipates that the pilot would provide learning opportunities to inform future grid investment deferrals and increase the reliability of Nantucket's electrical grid through the proliferation of efficiency and load-modifying resources.

Additionally, a project with Consolidated Edison in New York City, the Brooklyn Queens Demand Management (BQDM) Program, will place refrigeration-integrated TES systems at approximately 15 supermarkets (totaling 1.5 MW of load reduction capacity) in specific areas of Brooklyn and Queens where peak summer electricity loads are projected to overload the Brownsville No. 1 and Brownsville No. 2 area substations during the summers of 2017 and 2018. The BQDM Program is designed to defer approximately $1 billion in capital infrastructure investment by deploying non-traditional utility-side and customer-side solutions. This program is targeting 41 MW of customer-side load reductions during the summers of 2017 and 2018, including 1.5 MW of refrigeration-integrated TES systems, at a total cost of $150 million, inclusive of capital costs and incentive payments, for an estimated average cost of $3.7 million per MW. The program is also targeting 11 MW of non-traditional utility-side reductions at a total cost of $50 million, for an estimated average cost of $4.5 million per MW. The refrigeration-integrated TES systems installed as part of this project will provide peak load reductions when called upon by Con Edison's Commercial System Relief Program. In addition, the systems will provide the host supermarkets with ongoing electricity bill reductions, the ability to participate in demand response programs, and backup cooling services during power outages[2] for the entire duration of the projects' expected useful lifespans.

Small TES can provide additional grid benefits by integrating intermittent renewable generation, such as wind or solar PV, which might have otherwise been curtailed or contributed to "overgeneration" onto the grid. While small TES technologies typically charge at night and provide long-duration energy discharge during the day, they can also charge during the day when there is excess generation or be operated dynamically, going between charging and discharging cycles almost instantaneously when required to do so. Thus, small TES can be used to either smooth intermittent generation or to store excess generation for later use, especially for systems located in areas of the grid where overgeneration is a problem.

Operators of HVAC-integrated TES systems have been operated in parallel with onsite solar PV systems. Figure 1, comprised of customer demand, onsite solar PV generation, and HVAC-integrated TES operational data, illustrates how small TES has been used to integrate renewable generation during a typical business day at a commercial customer location to decrease peak-hour[3] demand. The TES is able to significantly reduce load during evening peak hours when the customer's demand would have normally peaked due to running the HVAC system and little or no solar PV generation. The TES discharges its energy during this evening peak, reducing both the energy and peak-hour demand charges of the customer and significantly reducing evening peak demand on the grid.

[2] If the host supermarket chooses to include this optional feature in the scope of the project

[3] Customer peak hours defined as 12:00 PM to 6:00 PM.

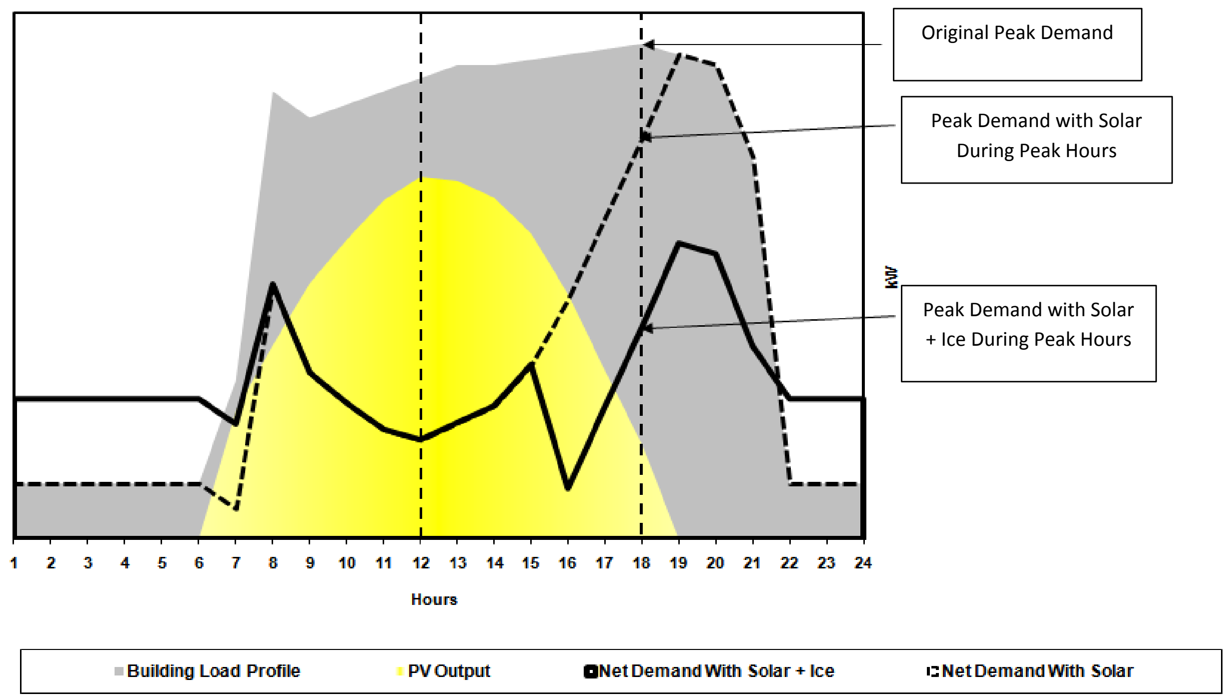

Figure 1 HVAC-integrated TES integrating with solar PV at a commercial installation to reduce demand during the customer's peak hours of 12:00 PM to 6:00 PM and to reduce overall evening peak demand on the grid.

Residential HVAC-integrated TES can also be paired with residential rooftop solar PV. These systems are able to claim an additional 30% federal Investment Tax Credit (ITC) for charging at least 75% of their storage system with their onsite solar PV. At these locations, the excess solar PV typically discharges to the grid in the afternoon when onsite load is low, then in the evenings the solar PV ramps down its generation and onsite load peaks as residents come home from work and turn on appliances. As intermittent renewables proliferate, grid operators experience periods of low afternoon demand followed by high evening peaks that require utility-scale generators to quickly ramp up generation to meet load. Many grid operators are trying to develop policies and implement strategies to mitigate this problem.[4] Residential HVAC-integrated TES systems help mitigate both overgeneration and high evening peaks when air conditioning is wanted by charging the system in the late morning to early afternoon when the solar PV would typically be exporting to the grid, reducing the amount of overgeneration. Then in the late afternoon to early evening, when solar PV production would begin to ramp down and buildings call for cooling, the TES system discharges its energy, turning off the compressors of the HVAC system and reducing onsite peak demand while still providing cooling. By aggregating several of these systems in critical areas of the grid, as Massachusetts is proposing to do on Nantucket Island, utilities can significantly reduce overgeneration and high evening peak, reducing the need to invest in new grid infrastructure. Residential time-of-use (TOU) rates that take into account early afternoon overgeneration and high evening peaks, such as those being piloted by Southern California Edison (SCE), San Diego Gas and Electric (SDG&E), and Pacific Gas and Electric (PG&E) in California, would further encourage residential customers to operate

[4] For example, the CAISO is revising its Flexible Ramping Product to better integrate intermittent renewable generation. See: https://www.caiso.com/informed/Pages/StakeholderProcesses/FlexibleRampingProduct.aspx

their solar PV and small TES systems in this way, providing financial benefits to customers, increasing the efficiency of the grid, and reducing peak demand.

Lastly, small TES systems do not pose the electrical safety hazards to the grid that electricity-discharging types of energy storage pose. Small TES systems are typically installed on roofs or next to a customer's building and are always installed "behind" the customer's electric meter to offset cooling loads within the building. Even though they reduce customer peak demand, they do not inject electricity into the building or utility grid like most types of energy storage. Thus, they do not interconnect with the utility grid, do not require safety disconnects, and do not impact ground fault or relay protection schemes which can compromise grid reliably. With their thermal connection to buildings, they do not present an "electrical islanding"[5] risk and do not back feed current into a utility distribution system. As small TES systems avoid these requirements, they are installed quickly and inexpensively without threat to grid stability.

Environmental Benefits

Through their energy efficiency, peak load-reducing, and renewable-integrating attributes, small TES can provide numerous environmental benefits, including greenhouse gas (GHG) and criteria air pollutant (CAP) emissions reductions. The environmental benefits that small TES provides depend largely on the electricity mix that is being offset, the typical operation of the existing HVAC and refrigeration systems without the use of TES and the operation of the TES systems. Small TES will reduce the most GHG and CAP emissions in areas that use a higher percentage of polluting fossil fuels and less-efficient combustion technologies to generate electricity. However, even in areas that have relatively clean sources of electricity generation, such as California that has roughly 30% renewable electricity generation, small TES can offer considerable GHG and CAP emissions reductions.

For example, two reports conducted by E^3 Ventures, Inc (E^3) analyzed the CO_2 and NOx emissions reductions of small TES in Sacramento (2005) and Los Angeles (2007) when shifting peak electricity generation from peaker plants to off-peak electricity generation from more efficient combined cycle generators (E^3 2007, 6). While the studies were conducted in 2005 and 2007, the methodology and findings are still relevant today as less-efficient peaker plants are still used to meet marginal peak demand and more-efficient combined-cycle plants still make up the majority of baseload, night-time generation (Energy Commission 2014, 3-7). E^3 found that in Sacramento Municipal Utility District's (SMUD's) service territory, a single HVAC-integrated TES system coupled with a 6-ton commercial HVAC unit, equivalent to roughly 7 kW capacity,[6] decreases net[7] nitrogen oxide (NOx) emissions by 8.24 grams per day (E^3 2005, 11). Similarly in Los Angeles Department of Water and Power's (LADWP's) service territory, a single HVAC-integrated TES system unit coupled with a 9-ton commercial HVAC unit, equivalent to roughly 10 kW capacity, decreases net CO_2 and NOx emissions per day by 5.5 kilograms and 7.3 grams, respectively, equivalent to roughly half the daily CO_2 and NOx emissions of a typical passenger vehicle (E^3 2007, 7). Applying the same methodology and findings to a single 75 kW

[5] Electrical islanding occurs when distributed energy resource continues to provide electricity to the location when the utility grid is no longer functioning.

[6] kW capacity can change depending on climate zone and the manufacturing date of the HVAC unit. Hotter climates and older HVAC units increase the kW offset of the TES system.

[7] The NOx emissions created to charge the system at night have been netted out of total emissions reductions.

refrigeration-integrated TES system in LADWP's territory, a single system would reduce CO_2 and NOx emissions by 40.9 kilograms and 54.8 grams per day, respectively, equivalent to taking approximately three typical passenger cars off the road every day (EPA 2015).

More recently, in 2015, HVAC-integrated TES systems were able to reduce peak demand and associated GHG emissions in Southern California Edison's (SCE's) service territory during SCE's highest peak demand hours. From July through September 2015, in response to extremely high electricity demand during the hottest season of the year, SCE announced twelve Critical Peak Pricing (CPP) events in which it significantly increased the price of electricity to encourage customers to decrease electricity consumption during 2:00-6:00 PM. As peak demand increased, SCE had to call upon its peaker plants, the least efficient and most polluting sources of electricity generation, to meet the demand. Additionally, as ambient temperatures and electricity demand increased, line losses increased, and generating each additional kW became increasingly less efficient and more expensive.

However, just as the efficiency of the grid decreased and associated GHG emissions increased, HVAC-integrated TES reduced peak demand by turning off onsite air conditioners, one of the main causes of the increased peak demand. For all twelve 2015 CPP events, an aggregated fleet of 1 MW of HVAC-integrated TES systems located in Los Angeles Basin, California Climate Zone 9, offset a total of 26.6 MWh of peak generation that most likely would have been supplied by natural gas peaker generators. According to the California Energy Commission's most recent data on the thermal efficiency of natural gas-fired generation in California,[8] the TES systems reduced a total of 14,476 kg CO_2 for all twelve CPP events (Energy Commission 2014, 6). Furthermore, according to methane and nitrous oxide emissions data from the Environmental Protection Agency's (EPA's) 2012 GHG Annual Output Emission Rates for California, the TES systems reduced a total of 454 grams of methane[9] and 72 grams of nitrous oxide[10] (EPA 2012). Additionally, if we were to assume that line losses were as high as 20% during the highest peak demand events, as RAP suggests, the peaker plants would have had to generate 32 MWh to supply the 26.6 MWh of demand that the TES systems offset during the twelve CPP events, resulting in 17,370.7 kg CO_2, or the equivalent of CO_2 tailpipe emissions from 112 passenger vehicles during the twelve-day period (EPA 2015). While small TES systems typically reduce GHG emissions every day they operate by replacing less efficient with more efficient generation, the GHG reductions from these twelve CPP events in SCE's territory highlight the benefit these systems can provide over a short period.

Finally, small TES systems are built out of environmentally friendly, earth-abundant materials, limiting negative environmental impacts from manufacturing, operating, and decommissioning systems. While many types of batteries use rare and often toxic chemicals and materials in their systems, both the HVAC and refrigeration –integrated TES systems use tap water[11] as their storage medium. The systems are typically filled only one time, at project

[8] Peaker plant's thermal efficiency is 10.268 Btu/MWh (higher heating value or HHV). Using the industry-standard assumption that 100% thermal efficiency of natural gas is 3.414 Btu/MWh (HHV), peaker plants are 33.2% (3,414/10268) efficient. Using the California Air Resources Board's default CO_2 emissions rate of natural gas, 53.02 kg CO_2/mmBtu, a peaker plant operating at 33.2% efficiency (HHV) would emit CO_2 emissions at a rate of 544 kg CO_2/MWh using the equation (53.02 kg CO_2/mmBtu*3.414Btu/MWh)/(3.414Btu/MWh/10.268Btu/MWh).

[9] Methane has a global warming potential 25 times greater than CO_2 over a 100 year period http://www3.epa.gov/climatechange/ghgemissions/gases/ch4.html.

[10] Nitrous oxide has a global warming potential 300 times greater than CO_2 http://www3.epa.gov/climatechange/ghgemissions/gases/n2o.html.

[11] Sometimes, inorganic salt are included as additives to adjust the thermal characteristics of the storage medium.

commissioning, and do not need to be refilled throughout the life of the project. All materials used within the systems are recyclable and present no hazardous waste or disposal concerns. The systems do not require explosion or fire-proof enclosures either, allowing the enclosure to be made of recyclable plastic or other metals. Additionally, a refrigeration-integrated TES system compatible with low global warming potential (GWP) refrigeration systems is being developed. Many direct expansion refrigeration systems use chemicals such as CFCs, HFCs, and HCFCs that can have higher GWP than that of CO_2 (EPA 2016). The new refrigeration TES system will be integrated with direct expansion refrigeration systems that use CO_2 rather than higher GWP chemicals, significantly reducing GHG emissions from direct expansion refrigeration systems. Currently, there are no other refrigeration TES systems that offer storage for low GWP direct expansion systems.

Current and Future Demand Response Market Opportunities

Participation in demand response (DR) programs is another opportunity for small TES to provide greater grid and environmental benefits, specific to the needs of the local utility or independent system operator (ISO). Small TES is ideal for aggregation into DR programs because entire fleets can be controlled and optimized remotely through cloud-based servers that communicate with systems on a thirty-second to two-minute basis. Each system can respond to signals almost instantaneously to charge or discharge energy, optimizing the efficiency of the grid where they are located.

Aggregated HVAC-integrated TES systems have integrated several megawatts of systems into multiple utility DR programs. 6 MW of aggregated systems were installed in Redding Electric Utility's service territory in Redding, California. The utility has access to the systems and can call upon them at any time to either charge or discharge their systems, depending on the needs of the grid. Similarly, 5 MW of aggregated HVAC-integrated TES systems are currently being installed throughout Riverside Public Utility's service territory in Riverside, California, with which the utility can communicate and call upon to charge or discharge at any time. In both situations, the utilities have integrated the TES systems into their communication protocols and can control them remotely as a fleet or individually to respond to grid needs. The systems are typically used every day in which the customer desires air conditioning. Customers benefit from the systems in that they provide cooling and reduce peak load; and the utilities benefit in that they can control load on their distribution systems. These DR programs allow the utilities to optimize the operation of the systems in the exact locations and times that they are needed. HVAC-integrated TES systems have also been integrated into wholesale energy markets. Grid Solar, the Boothbay Smart Grid Pilot operator, is able to bid the 250 kW of aggregated TES systems into the New England Independent System Operator's (ISO NE) energy market, providing energy reductions at times that provide high value to the ISO and creating an additional value stream from these systems.

Furthermore, due to increased intermittent renewables, energy storage, energy efficiency, and distributed energy resources, many utilities and ISOs are revising existing DR programs and creating new ones to address the changing nature of the grid. These new and future DR programs will allow small TES to provide even greater grid and environmental benefits as their operation is optimized with the needs of the grid. California's efforts to create new DR programs offer an example of how DR markets are evolving to meet changing grid needs. The California Public Utilities Commission (CPUC) is currently revising all of its utility DR programs with the goal to create load-modifying and supply-side DR programs by 2018. Resources participating in load-modifying programs will respond to utility signals, such as price changes or requests to decrease load, similar to the Redding and Riverside examples. The new load-modifying programs will more accurately value and compensate resources that participate in load-modifying DR programs, providing greater incentive to participate in these programs. Resources participating in supply-side programs will be able to participate in the California ISO (CAISO) energy markets and count as resource adequacy for utilities, receiving both a capacity payment from the utility and awards for winning and fulfilling bids in the CAISO markets.

To test behind-the-meter resources' ability to participate in the CAISO market, the CPUC is piloting the Demand Response Auction Mechanism (DRAM), which allows distributed energy resources (DERs) to be aggregated as a single resource and bid into the wholesale market under the CAISO's Proxy Demand Resource (PDR) product. To participate in the DRAM as PDRs, aggregated resources must be able to reduce at least 100 kW sustained over four hours, or in other words, they must be able to provide a minimum of 100 kW, 400 kWh of aggregated load reduction. For many types of energy storage, such as lithium-ion batteries, the four-hour duration might be difficult to meet as these systems are designed to discharge their power capacity for a maximum of one to two hours, and fully discharging these systems on a regular basis can significantly degrade the batteries' performance and life expectancy. However, small TES, due to its inherent long-duration attributes and ability to perform full discharges with virtually no degradation, can easily meet the minimum requirements of PDRs. Furthermore, because the typical refrigeration-integrated TES system is between 60-120 kW and discharge for six hours, on average, only a handful of these systems aggregated together are needed to meet the PDR requirements and participate in the wholesale market. Refrigeration-integrated TES has recently been awarded a grant from the California Energy Commission to demonstrate its ability to simultaneously provide onsite energy storage and customer savings, bid into the CAISO energy market as DR, and provide frequency regulation, a CAISO market product not currently available to PDRs. This project will demonstrate how DR, energy storage, and specifically small TES can be used to maximize their value to customers and to the grid as a whole by providing reliable, cost-effective peak load reduction.

Further, as DERs continue to proliferate, future DR programs and markets will need to evolve to accommodate new and innovative technologies, such as small TES. For example, some wholesale markets do not have rules in place to allow DR resources to provide regulation services. As mentioned previously, the CAISO does not allow PDRs or resources participating in the DRAM to provide frequency regulation, although many of these technologies are fully capable of providing these products. Utility and wholesale DR programs will need to address requirements regarding interconnection, metering, wholesale and retail rates and jurisdiction, and available market products in order to allow DERs to fully participate in and provide maximum value through these programs. These DR programs will need to recognize technical capabilities and differences between small TES systems and electricity-discharging energy storage and define the rules accordingly. The CAISO, for example, is revising metering requirements for energy storage systems so that they have the option to directly meter the electricity discharged rather than relying on historical baseline data to demonstrate load reduction. However, small TES does not meter electricity discharge, but instead meters factors that determine the amount of electricity offset. As future DR programs and markets become cognizant of important differences between small TES and other types of energy storage, these programs can be designed to allow small TES to fully participate in and provide grid and environmental benefits through these programs.

Conclusion

Through its use at customer locations and participation in emerging DR markets, small TES provides numerous grid and environmental benefits. As customer load profiles continue to change through increased adoption of DERs and energy efficiency, it will become increasingly important for small TES to participate in and provide benefits to the changing grid. As climate change, worsening air quality, and other environmental concerns must be mitigated through cost-effective means, small TES provides customers, grid operators, and system planners a unique opportunity to use these innovative technologies as a viable solution to these problems.

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