Assessment of battery energy storage characteristics to perform residential peak demand shaving

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Abstract

This article presents the model and results of residential scale electricity peak shaving battery energy storage systems. Electricity profiles of the four major energy end-uses were simulated using the Canadian Hybrid Residential End-use Energy and GHG Emissions Model. The electricity profiles were then input to an energy storage model with the objective of reducing the peak electricity demand seen by the electricity grid. The model enabled the performance assessment for a range of battery and inverter sizes. Based on this work, system sizes range from 5 kWh / 2.6 kW for the least electricity intense region (AB, SK, MB) to 22 kWh / 4.4 kW for the most electricity intense region (Quebec). Based on the storage system cycling profile the battery life was estimated to be in the range of 10 to 20 years.

1 Introduction

The storage of electricity for the purposes of peak shaving and/or renewable energy integration has been an area of great interest in the past several years, with numerous pilot projects being conducted in several countries (Chen et al. 2009). Demand management is becoming more important to electricity utilities as additional non-dispatchable generators, such as wind turbine generators, are brought online. Daily peaking events can be costly and difficult to manage for utilities and one possible method to address these events is the use of small scale residential battery energy storage systems (BESS). To assess the potential for such BESS it is important to understand the daily electricity demand profiles as well as the requirements of the energy storage technology while performing peak demand shaving.

1.1 Electricity Storage

Grid coupled distributed electricity energy storage is becoming a viable alternative to historical methods of generation/demand management. It provides a new and effective tool to fulfill grid support functions including peak demand shaving and renewable energy integration (Dell, Rand 2001, Denholm et al. 2010, Hall, Bain 2008, Perrin et al. 2005). Historically, these grid support functions have been met with conventional generating technologies operating at part load (e.g. natural gas turbines). More recently, energy storage has been implemented on large centralized scales using technologies such as pumped hydro storage, compressed air energy storage and megawatt-hour class BESS (Chen et al. 2009, Dell, Rand 2001). These central storage technologies are used in many parts of the world, storing up to 2.5% (USA), 10% (Europe), and 15% (Japan) of all electricity produced (EPRI-DOE 2003). Despite the usefulness of central energy storage, there are issues that large central storage cannot address. These are primarily related to the distribution grid and include: congestion, integration of variable renewable energy generators, and voltage drop.

Figure 1 shows the Nova Scotia average hourly load profile for February 2nd 2010. This load profile is very typical for a heating climate and displays two distinct peaks, one in the early morning hours and another during evening hours. These peaks are primarily caused by residential electricity use during these periods as a result of occupant activities including cooking, cleaning, and simply turning on the lights.

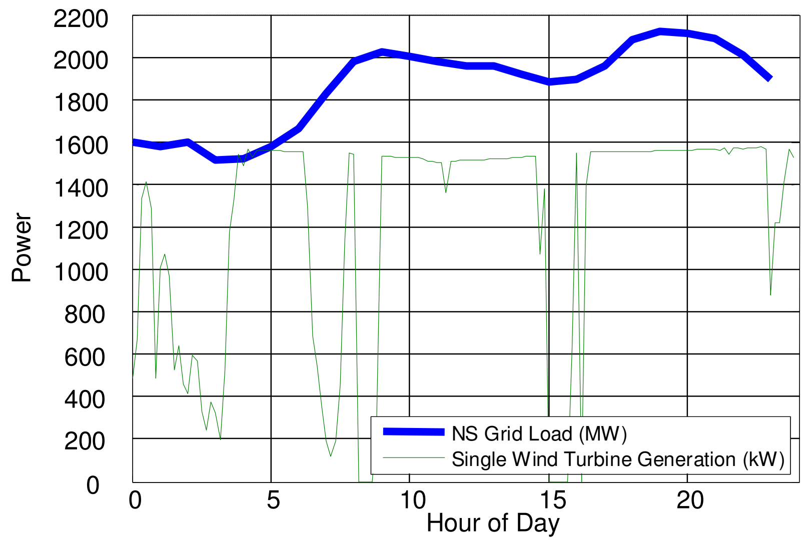

Figure 1: Single Day Load Profile for the Nova Scotia Electricity Grid Feb 2, 2010 with 1.5 MW Wind Turbine Output Based on (Nova Scotia Power Inc. 2011)

The consequence of these peaks from an electricity generation perspective is high demand levels that change rapidly. This requires non-optimal operation of expensive peaking and spinning reserve generation facilities. Additionally, these peaks cause local and overall grid congestion and in some cases require costly expansion of the distribution and/or transmission grid (DeCesaro, Porter 2009).

With the recent legislation for renewable electricity (Nova Scotia Department of Energy 2010) and the introduction of wind turbines and solar photovoltaics throughout Canada and the world alike, the problem of generation management has become even more difficult. Wind, solar, and tidal are non-dispatchable resources, which means the resource itself drives the generation behaviour and therefore additional integration infrastructure (or increased/modified use of existing grid flexibility infrastructure) is required (Denholm et al. 2010). Wind is particularly challenging to integrate at high penetration levels as it is difficult to predict, highly intermittent, causes grid disturbances (e.g. flicker), and is often connected within small or weak distribution grids. Also seen in Figure 1 is the overlay of a single wind turbine output (windy day) which does not align with the demand profile.

Distributed energy storage is one solution to such issues by providing a means to store electricity during off-peak and/or high production times, and utilize this stored energy to meet peak residential electricity demands. The simulated peak shaving method that is the topic of this article addresses peak loads directly, which indirectly supports renewable energy integration by reducing maximum demands and thereby reducing grid congestion. This allows more residential loads to be met through locally produced renewable electricity and therefore reduces the reliance on centrally generated, often fossil-fuel fired electricity. In Canada, 30% of installed generation capacity is fossil-fuel based, and in some regions significantly more (Statistics Canada 2007).

Selection of appropriate energy storage technology is dependent on a variety of factors; however, for a residential scale installation options are limited to smaller scale, highly reliable/safe technologies requiring minimal maintenance from the building owner. Fortunately, several battery technologies are consistent with this description when coupled with appropriate management systems. Additionally, several battery technologies also have appropriate energy to power ratios for peak shaving applications allowing them to be completely discharged in as little as 30 minutes (a 2C rate) to meet even the most demanding daily peaks (Chen et al. 2009). Lithium-ion batteries were selected over lead-acid and other chemistries based on their favourable power and energy characteristics, cycle life, and declining costs (Chen et al. 2009).

1.2 Simulation of Electricity Profiles

Realistic electricity demand profiles for all electrical end-uses are required to properly assess energy storage system size and performance for peak demand shaving applications. The use of building performance simulation uniquely identifies each end-use within a residence: space heating (SH), space cooling (SC), domestic hot water (DHW), and appliances and lighting (AL). Electricity may be used to meet all of the end-uses. Nearly all SC and AL is provided by electricity; however, SH and DHW may be met with other energy sources such as natural gas, heating oil, and wood.

Assessment of SH and SC energy consumption may be estimated using "engineering" techniques by applying thermodynamic and heat-transfer relationships using finite-difference method. Several building performance simulators exist which employ these methods (e.g. ESP-r) (Clarke 2001, Crawley 2004).

Whereas SH and SC are dominated by the building characteristics and climate, assessment of DHW and AL energy consumption is complicated by the influence of occupant use. A review of statistical modeling methods found neural network models to most accurately predict the annual energy consumption of DHW and AL end-uses (Aydinalp-Koksal, Ugursal 2008). Several sets of typical electricity demand profiles for the Canadian housing stock were developed using a bottom-up approach considering each appliance and lighting requirement individually (Armstrong et al. 2009). A tool for assessing DHW use profiles was created for the International Energy Agency's Solar Heating and Cooling Program (Jordan, Vajen 2001).

Swan et al. combined the engineering simulation methods for SH and SC with statistical neural networks and DHW and AL profiles to create a hybrid residential modeling tool (Swan, Ugursal & Beausoleil-Morrison 2011a, 2011b). This Canadian Hybrid Residential End-Use Energy and GHG Emissions Model (CHREM) estimates the energy consumption and resultant greenhouse gas emissions of the residential sector by simulating nearly 17,000 individual houses that statistically represent the Canadian housing stock (Swan, Ugursal & Beausoleil-Morrison 2009). The CHREM is capable of distinguishing the electricity demand profile associated with each end-use within a residence.

1.3 Objective

The objective of this work is to model and examine the effect of using a residential scale, grid-interconnected BESS to reduce the peaks in electricity demand. The energy storage system consists of a rechargeable battery, a bi-directional grid-integrated inverter/charger, and a controller as seen in Figure 2. In Figure 2 thin black arrows indicate sensing or communication links, and thick red arrows indicate power flows.

The inverter/charger cycles the battery to reduce the residence demand peaks as seen by the electricity grid. If the battery becomes fully charged or depleted then a "failure to provide" condition will occur. This article examines a range of sizes of battery packs for residences located in different regions and determines the most appropriate size to achieve the objective.

The following sections discuss the simulation method, results of the electricity demand and battery energy storage simulations, and give recommendations on sizing of energy storage unique to residential characteristics of the five major regions of Canada.

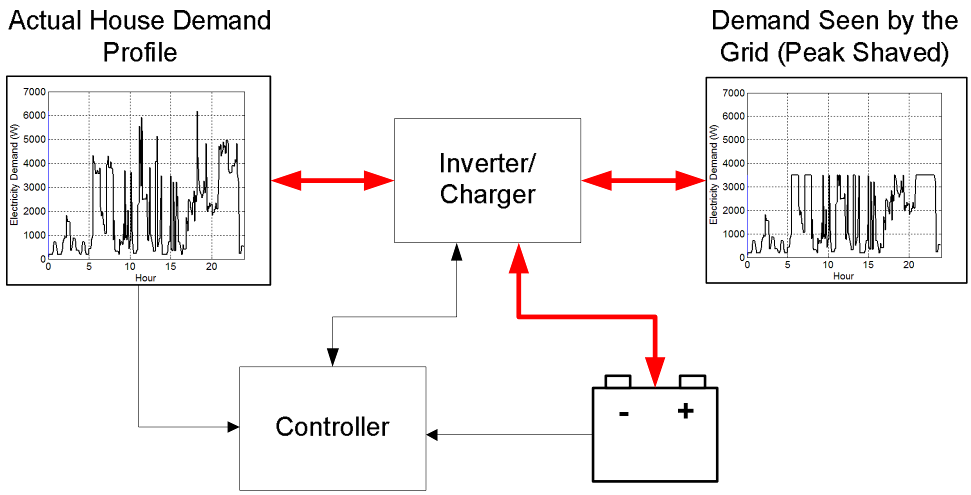

Figure 2: Peak Shaving BESS System

2 Method

Assessment of energy storage system performance requires information on the electricity demand of the residence as well as the battery system models.

First, the CHREM database is reviewed to identify and select typical houses from each of the five major Canadian regions. The major regions are Atlantic (provinces NF, PE, NS, NB), Quebec, Ontario, Prairies (provinces MB, SK, AB), and British Columbia. Second, an annual energy simulation of these houses is conducted on a five-minute interval so as to appropriately capture the peaks in electricity demand from the four major end-uses. Third, a battery energy storage model is applied to the electricity demand profiles to determine the energy storage and power characteristics required of the battery to reduce peak demand of the house as seen by the grid.

2.1 House Selection and Simulation

To size a BESS system for residential use in each region of Canada, the typical home in each region has to be defined. The CHREM database was examined for parameters that would significantly influence electricity consumption of the four major end-uses. SH and SC are primarily influenced by heating/cooling system type, heated floor area, and thermal resistance of the building envelope. The following parameters from the database were used: heating energy source, DHW energy source, air conditioner (i.e. SC) presence, city, heated floor area, annual AL energy consumption, annual DHW volume consumption, construction year, window area, exterior wall thermal resistance, and air leakage characteristics.

A histogram for each selected database parameter for each of the five major Canadian regions was created and used to identify the average values and appropriate selection range for each parameter. The values were then chosen by progressively adjusting a filter on each parameter towards the average value for a given region until only 1 or 2 houses of the possible 16,952 houses in the CHREM database met the specified values.

The selection was done to provide data that represents a typical house found in each major region of the Canadian housing stock. Study of system size as a function of appliances, demand intensity, house size, and other variables was considered; however, the region selection method provides more realistic and representative systems that are actually applicable to the average consumer in various regions of the Canadian market.

The simulation of electric load profiles was performed in ESP-r for the various selected houses using five minute time steps. This time step was selected based on (Armstrong et al. 2009, Saldanha, Beausoleil-Morrison 2010) who showed that it captures the demand peaks associated with nearly all systems.

2.2 BESS Operation and Simulation

The BESS is operated to charge and discharge with the intention of decoupling a portion of the peak house demand from the electricity grid. First, a maximum household electricity grid demand limit is defined. If the house demand is above this limit, the BESS activates and the inverter discharges the batteries to meet any house demand beyond this limit, thereby maintaining the grid demand at the specified maximum grid demand limit. The BESS operates the battery between 15% and 85% state of charge (SOC) to extend cycle life and ensure the system remains within safe operating conditions. Operation at SOC outside this range decreases cycle life and has the potential to cause malfunction (Reddy 2001). The system recharges fully (to 85% SOC) during a 6 hour nightly period when house demand is at a minimum and additional loads are easily supported by utilities. This period is evidenced by the favourable time-of-use rates offered by utilities in many jurisdictions throughout Canada.

The model does not attempt to estimate operating voltage, thermal considerations, or any other advanced operating parameters; instead the simulation only considers the efficiency of the BESS, defined as the ratio of output electricity to input electricity. Calculation of remaining energy storage during each time step is conducted by adding/subtracting the energy used for a given time step from the previous time step value. A round trip efficiency of 80% was assumed in the model as this agrees with reported system efficiency values for lithium-ion BESS including inverter/charger (Chen et al. 2009). This assumption translates into 89% one-way efficiency.

Selection of the grid demand limit has a significant impact on the required energy storage and power capacities of the BESS. Selection of a demand limit is based on percentile selection method using the house demand. Percentile selection method uses a statistical analysis to obtain the value of house demand below which 98.0%, 98.5% or 99.0% of the power draws occur. This method aligns well with grid requirements for peak shaving, as several articles highlight that the top 1 to 2% of power draws are the most expensive and challenging periods of operation of an electricity grid (EPRI-DOE 2003). By selecting a system that addresses these brief periods of high power requirement, the system size can be minimized. Sizing based on percentile selection allows the BESS in each region to operate during the same number of hours in a given year, thereby creating consistency in sizing methodology.

Once the grid demand limit has been determined using the above method, the system is simulated in MatLab and failure events are assessed for each BESS power (inverter size) and energy-storage (battery size) combination. A failure event occurs when the BESS is incapable of supplying sufficient electricity to maintain the demand as seen by the grid within the limit. Following simulation of a large number of system options the failure event data can be reviewed and plotted in various ways to choose a BESS that results in few or no failure events. Choosing a larger (power, energy) system will increase the cost and performance beyond the objective. Choosing a smaller system will result in increased failures.

3 Results and Discussion

The results of simulation include examination of the selected typical houses as well as their corresponding electricity profiles. Using the produced electricity profiles the BESS simulation is conducted and results analysed to select appropriate system sizes for houses of each region. Battery life is then estimated based on resultant cycling characteristics of the BESS during simulation.

3.1 Typical Houses

Examination of the CHREM database was conducted on the basis of 11 selection parameters as given in Table 1. A single house was selected from each of the five major regions of Canada which corresponded to typical parameter values based on histogram analysis. The results of the housing selection process are given in Table 1.

Table 1: House Selection Criteria and Results

	Regions				
Parameter	**Atlantic (AT)**	**Quebec (QC)**	**Ontario (ON)**	**Prairies (PR)**	**British Columbia (BC)**
City	Halifax	Montreal	Toronto	Edmonton	Vancouver
Heating energy source	Fuel Oil	Electricity	Natural Gas	Natural Gas	Natural Gas
DHW energy source	Electricity	Electricity	Natural Gas	Natural Gas	Natural Gas
Air conditioning	None	None	Electricity	None	None
Heated Area (m^2)	197	179	247	192	198
AL (GJ/year)	29.6	17.7	19.8	23.3	62.4
DHW (litres/day)	220	229	140	179	160
Construction year	1980	1987	1991	1980	1981
Window area (m^2)	24	22.6	17.3	24.3	23.2
Exterior wall thermal resistance (RSI)	3.0	2.1	2.1	2.1	2.1
Air leakage (ACH_{50})	7.9	4.8	4.5	6.2	9.9

Several important characteristics can be identified from this table of house parameters. First and foremost, the large variations of each parameter in different regions across Canada suggest a single optimal system does not exist and instead specific sizing is likely to be required for each region. Second, most homes in Atlantic and Quebec regions do not use natural gas as a fuel for space heating or DHW. This is significant, as space heating and DHW both constitute significant portions of residential energy consumption. Other regions which lack these electrical end-uses have significantly less electricity consumption. Third, although many houses in BC do fall under then "medium" energy intensity category defined in (Armstrong et al. 2009) a large number of houses in the BC region (much more than any other region) fall under the high demand intensity category. For comparison purposes a high demand intensity house was selected in this region.

3.2 Electricity Profile Characteristics

To be concise, detailed explanation of results will be given for the Atlantic region and any significant differences in general behaviour between regions will be listed in tables.

Figure 3 shows the annual average daily electricity profile for the Atlantic region house overlaid with a single daily electricity load profile for January 1st of the same house.

The single day electricity profile shows strong peaking due to individual appliance use. The annual average profile shows that the duration of major peaks consistently occurs in the morning and evening. The averaged profile is similar to the total grid demand figure presented in Figure 1, and shows that the contribution of residential loads is very significant to the electricity grid.

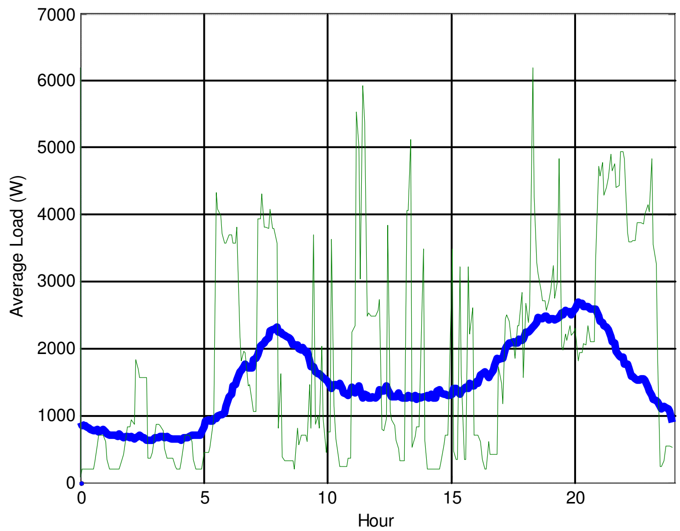

Figure 3: Daily Demand Profiles - Annual Averaged (Thick blue) and Single Day (green)

The CHREM was used to model the electricity demand of each end-use for the houses. A statistical analysis of the results is given in Table 2.

Table 2: Statistical Analysis of Regional Electricity Profiles

Region	AT	QC	ON	PR	BC
Annual electricity consumption (MWh)	13.2	32.8	8.4	5.8	17.3
Average house demand (W)	1506	3746	958	661	1976
Maximum house demand (W)	9040	15230	7188	5120	12002
Standard deviation of house demand (W)	1318	2980	858	571	1568
Maximum demand as percent of annual average demand	600%	465%	750%	775%	605%
98.0 percentile (W)	5020	10510	3540	2480	6300
98.5 percentile (W)	5260	10910	3790	2600	6630
99.0 percentile (W)	5550	11350	4130	2780	7040

Assessing the extremes in this table provides insight into the diversity of the various regions across the country. The average electric demand (and hence total electricity consumption) varies by a factor of five from the Prairies to Quebec. Maximum demand show a less diverse range than average demand with only a factor of three between the lowest and highest peak demands from different regions. Similarly, the maximum demand as a percent of the average demand appears to be larger in regions with less total consumption. The percentile rows in Table 2 represent the electric load in watts below which the listed percentages of the 5 minute load periods occur.

3.3 BESS Simulation Results

BESS sizing is performed by selectively varying parameters and counting failure events for each simulated system. Two distinct types of failure events occur. The first failure is an energy depletion event that occurs when the BESS is fully discharged, after which the system can no longer output power to offset house demand. The second type of failure occurs when there is insufficient power capability to reduce the house demand to the defined grid demand limit.

To assess the appropriate system size thousands of iterations were simulated in MatLab and failure events were counted for each BESS system. The following BESS properties were varied: energy storage capacity, inverter size (power capability), and grid demand limit. The number of failure events must be limited to zero for the system to perform its intended function. A three dimensional iso-failure plot can be created by grouping system variations (3 parameters) which limit failures to a specific value. An iso-failure surface plot (1 failure) for the Atlantic house is given in Figure 4.

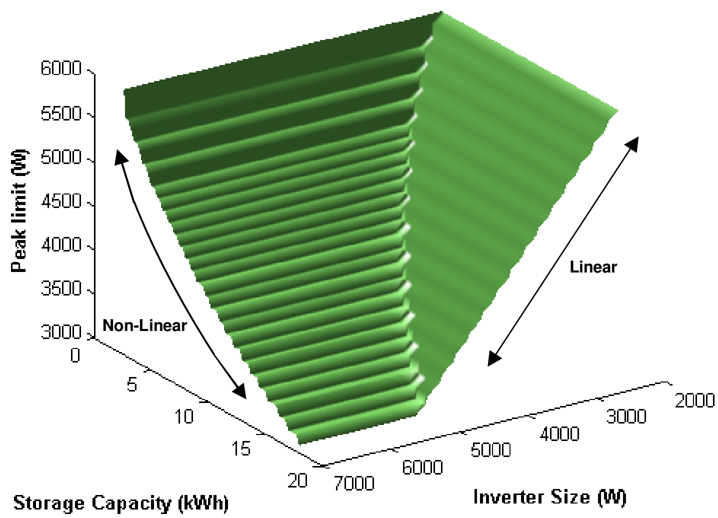

Figure 4: 3D Iso-Failure Surface Plot of energy storage and power (AT Region, 1 Failure Event Surface)

This surface reveals several interesting results that describe optimal system configurations. In the plot two “walls” of failure intersect to form a non-linear corner geometry. The “wall” on the left is the energy failure wall where complete discharge failures occur if a smaller energy capacity is selected. The “wall” on the right is where undersized power failures occur if a smaller inverter size is used. The energy failure wall displays a non-linear profile and the power failure wall displays a linear profile. Two-dimensional plots of these characteristics are given in the following BESS sizing discussion.

The system sizing method proposed involves setting the grid demand limit based on a percentile of the house demand. This requires assessment of energy storage and inverter sizes required for multiple grid demand limits. Energy storage may be assessed by assuming significantly large inverter power. This is shown in Figure 5 as a 2D iso-failure plot for the Atlantic region in which the lines represent the number of five minutes failure occurrences. A

2D slice of the one failure surface in Figure 4 is visible in Figure 5 and additional iso-failure lines have been added to represent increased failure counts.

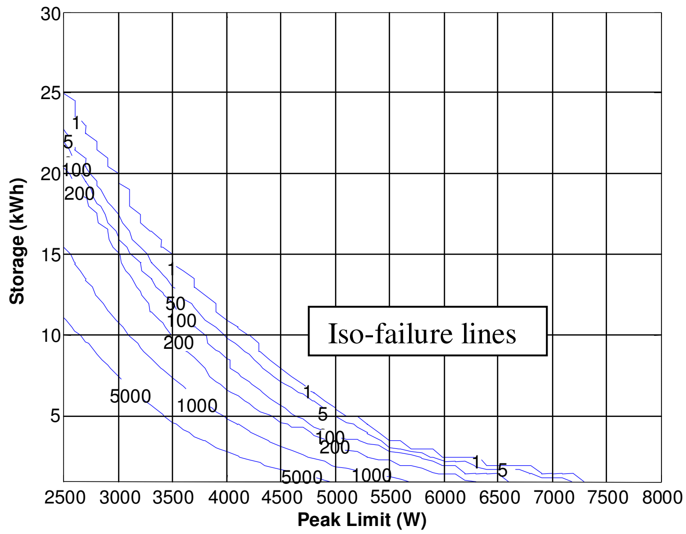

Figure 5: 2D Iso-Failure Plot of energy storage (AT Region, Storage vs. Peak Limit)

The result of the shape of this plot indicates diminishing returns with respect to increasing energy storage. A 4 kWh BESS can reduce the maximum peak by 40% (to 5500 W) while a pack twice the size (8 kWh) only reduces the peak by 51% (to 4430 W). This corresponds to doubling the pack size to gain only 25% greater demand reduction of the original BESS.

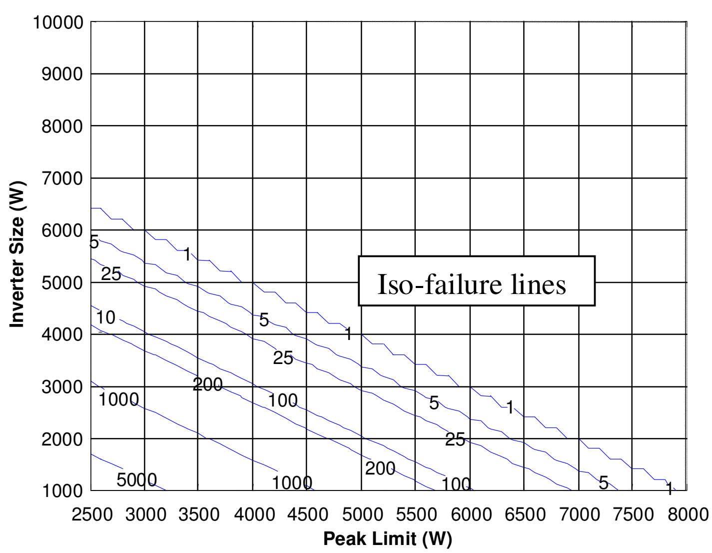

Figure 6: 2D Iso-Failure Plot of power (AT Region, Inverter Size vs. Peak Limit)

Figure 6 plots iso-failure lines of inverter size versus peak limit with a very large BESS energy storage capacity. The aforementioned linear profile of the undersized power capability failures of Figure 4 can now be verified (slightly discretized due to iterative technique). This linear behaviour is expected as inverter power corresponds directly to the amount of demand that can be offset.

3.4 BESS Sizing

Due to the diminishing returns nature of increasing battery capacity, the sizing should be conducted based on the results primarily from the energy storage vs. Peak limit plot in Figure 5. Selection of the reduced demand objective is based on the value taken from a percentile analysis of the yearly loads. The limiting returns nature of the energy vs. peak limit plot suggests the selection should be based on reducing the peak as much as possible before reaching the region of steep incline in battery capacity requirement. Additionally, a minimum peak shaving percentile level constraint of 98.5% (1.5% of system load periods) was specified as this level of peak shaving will adequately meet many of the peak shaving operations required by the electricity grid. Using the 98.5% criteria a significant reduction in peak loads are possible while approaching, but not entering, the steep battery storage slope area of the iso-failure plots.

Selection was completed by plotting storage capacity vs. inverter size for the specified peak limit determined by the 98.5 percentile load value and selecting the smallest possible system size. An example of this plot for the Atlantic region is shown in Figure 7.

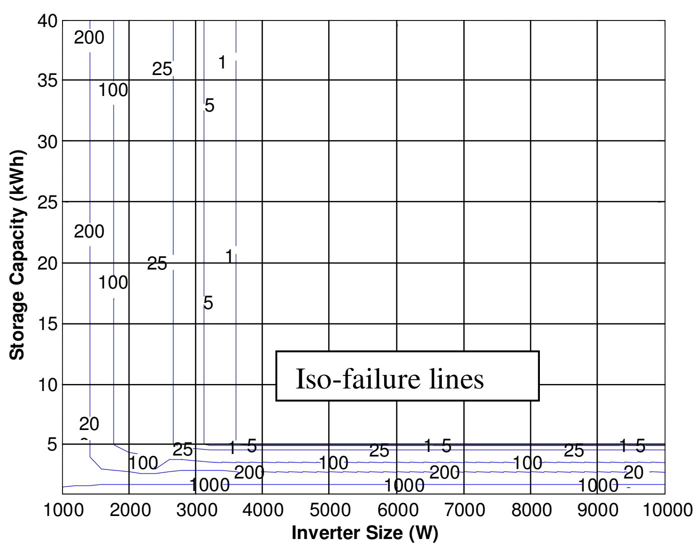

Figure 7: 2D Iso-Failure Plot (AT Region, 5260 W Peak Limit, Storage vs. Inverter Size)

A safety factor of 10% is added to the energy storage to account for any additional inefficiency not captured by the simple BESS model used for this study. Furthermore, this additional 10% energy storage capacity is advisable as the results show that under sizing the storage capacity even slightly results in many more failure events. For the inverter, 10% is not added to the size requirement as an undersized power failure will only result in the difference between capacity and load being additionally applied to the grid. Compared with an undersized power failure, an energy failure in the system causes an outright shutdown and therefore a complete inability to peak shave. The resulting system sizes and peak limit set points for each region are shown in Table 3 along with the estimated reduction in peak load.

Table 3: System Size Selection and Estimated Peak Reductions

Region	**AT**	**QC**	**ON**	**PR**	**BC**
BESS Energy Storage Capacity (kWh)	5	22	8	5	5
Inverter Power(W)	3600	4400	3200	2600	5200
Grid demand limit (W)	5260	9570	3790	2600	6630
Percent Reduction in House demand	42%	28%	47%	49%	45%

The resulting system sizes follow expectations when compared to annual average house demand and maximum house demand with the exception of the BC storage requirement. Despite having an average demand nearly three times larger than the Prairies the resulting energy storage requirement is the same in BC as it is for the Prairies. Energy consumption of the QC region is very high and both DHW and space heating are provided via electricity, so it is expected that the storage requirement is significantly higher than other regions. The Quebec house is the only one with electric heating, and despite having similar AL electricity consumption, DHW consumption, and housing parameters as the Atlantic region house, the energy storage required is four times that of the Atlantic house and the peak reduction is significantly less than any other region. This indicates electric space heating is the largest influencing factor for BESS storage requirements and can severely inhibit the BESS ability to provide adequate peak shaving. Inverter sizes line up with expectations based on maximum house demand for each region. Overall, inverter sizing displays a more consistent relationship with peak loads than energy storage requirements do with yearly consumption.

Both storage capacity and inverter sizes presented in Table 3 are feasible for installation at a typical home. Lithium-ion batteries readily achieve performance values of 50 Wh/L (Chen et al. 2009). Therefore, a 5 kWh lithium-ion battery pack will occupy a ~100 L volume (0.1 m^3) and can easily and safely fit in a small cabinet along with a 3000-5000 watt inverter for installation in a mechanical room or basement location.

The lifetime of a BESS is dependent on many factors including battery chemistry, state-of-charge, number of cycles, temperature of operation, time, and many others. Modern day lithium-ion batteries have been shown to last more than 3000 full discharge cycles (Chen et al. 2009). To assess the lifetime of the BESS for the peak shaving application, Figure 8 shows a histogram of the state of charge at the end of each day (lowest state of charge each day) for an entire year for the Atlantic region. Other regions plots are similar to the Atlantic region plot seen in Figure 8.

The operation of the system between 85% and 15% SOC is evident from this plot. On 200 of the 365 days of the year, the system either does not discharge at all, or only discharges between 0 and 2.5% of its capacity. This means that the system only experiences discharge 165 days of a given year, resulting in 165 shallow cycles per year. The cycles are generally limited to less than 20% of capacity and therefore the actual cycle life of the batteries would be much greater than the 3000+ cycle life as SOC impacts the cycle life of lithium-ion batteries. This would imply the system could continue operating for 20-30+ years; however, Lithium-Ion batteries also experience calendar aging due to parasitic reactions that gradually consume active materials and reduce capacity (Safari, Delacourt 2011). As a consequence the system will only last as long as the calendar life of the batteries themselves.

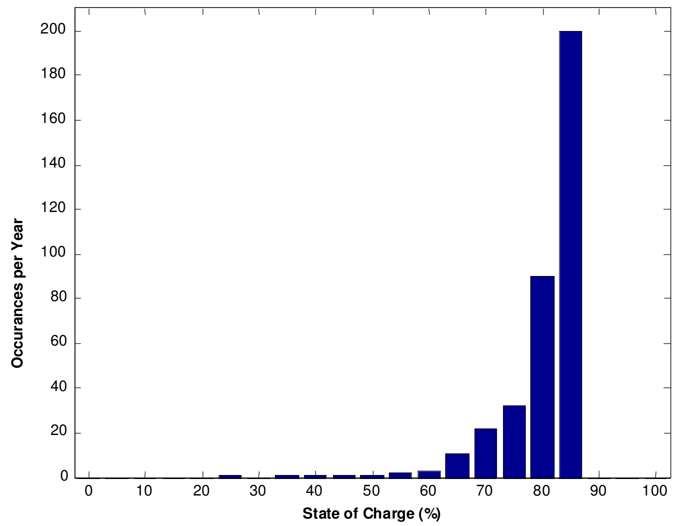

Figure 8: Histogram of Lowest Battery State of Charge Experienced Each Day of a Year (AT Region)

Tests on commercially available lithium-iron phosphate indicate that even during storage at 25 ℃, approximately 3% of capacity is lost in the first year of operation. Under constant complex cycling (24 hours/day for 365 days) 7-8% of capacity can be lost per year (Safari, Delacourt 2011). The batteries used in this energy storage system are likely to behave similarly to the "stored" capacity loss as they are minimally cycled and infrequently experience complete discharge. Assuming 4% capacity loss in the first year and 2% per year for the remaining years the system will operate for eight years before the generally accepted 80% capacity failure criterion is observed. This is a very conservative estimate, and other commercially available large format lithium battery types have estimated operational lives of 10-20 years for shallow infrequent cycling operation at 25 ℃ (Sarre, Blanchard & Broussely 2004).

With reduced capacity caused by years of operation it is advisable that the peak limit be adjusted or the inverter maximum output capacity be limited to ensure energy failure type events do not occur. Energy failure events cause complete system shutdown during the highest peak times of the year and should be avoided.

One additional point of interest raised by the knowledge of discharge occurrences for various depths is the possibility of operating the BESS between the full 0% and 100% states of charge, or at least expanding the range beyond 15-85% to perhaps 10-90% or even 5-95%. As deep discharges are so infrequent, this will have little impact on overall battery life and would allow reduction of storage requirements by 15% (in the 10-90% SOC operation case) to 42% (in the 0-100% SOC operation case). Alternatively, the sizing could be performed as presented and the allowable SOC range increased over time to accommodate the gradual capacity fade.

4 Conclusion

Using the CHREM, typical and representative residential electricity profiles were generated for 5 regions across Canada. The houses were selected based on typical values for various parameters within each region. Once simulated the profiles underwent a statistical analysis to determine electricity requirements for each region. A simple BESS model was developed in MatLab for peak shaving applications, into which the electricity demand profiles for each region were input. Through parametric study the failure levels of each system were identified and an envelope of BESS sizing based on maximum grid demand limits was determined.

The systems eventual failure method was determined to be calendar aging of the lithium-ion batteries as the batteries experience light cycling and infrequent deep discharge. More complex battery and BESS models are suggested to achieve more accurate results; however, this simple model is suitable for preliminary assessment of BESS storage and power requirements of residential peak shaving systems.

It is worthwhile to study of the benefits of aggregation of demands in a community type energy storage system. The result would be similar to averaging the peaks as the peak demands would likely not occur simultaneously between houses. Although the benefits would not be as profound as complete averaging (due to similar environmental and demographic driving factors for the peak loads) certainly some degree of communal benefit would be achieved with respect to energy storage and power capacity requirement on a per house basis.

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