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Energy Storage as a Non-wires Alternative for Distribution Asset Deferral and Customer Bill Reduction

R. RAVIKUMAR, J. PEPPANEN, J. DEBOEVER, T. HUBERT
Electric Power Research Institute
USA

SUMMARY

Distribution capacity upgrades or feeder reconfigurations have conventionally been used to address the capacity need from growing electric demand and increasing Distributed Energy Resources (DER) penetration. However, distribution capacity upgrades are based on extreme loading/generation conditions that may occur only a few times a year— resulting in lightly loaded assets for most parts of the year. Energy Storage System (ESS) has the potential to provide an alternative to conventional capacity upgrades by reducing element loading during these infrequent extreme conditions. During those time periods when ESS is not needed for the primary application, which in this case is avoiding thermal violations during peak load/generation times, it can be used for secondary applications. While providing stacked primary and secondary services with ESS may allow to capture more value, it introduces more requirements that may conflict. Assessing the requirements and value of stacked services requires site-specific and complex analysis.

This paper presents a systematic analysis methodology to assess ESS in stacked-benefit scenarios. The methodology is applied for a case study distribution feeder located in Ontario, Canada. The particular case study was analysed in this paper due to the Ontario's interesting market structure. In Ontario, a major component of commercial and industrial (C&I) customers' electricity bill depends on Global Adjustment (GA), which makes up for the cost of building new electricity infrastructure and delivering Ontario's electricity conservation programs. This regulatory structure creates an attractive scheme for assessing energy storage in stacked-service scenarios.

As a result of aggressive load growth in the area, the peak load of the case study feeder is expected to exceed the thermal capacity of the feederhead lines within the utility's distribution planning time horizon. This paper compares energy storage for addressing the feeder's load growth in stacked-service scenarios to conventional distribution upgrades. The following two cases are analysed. In base case (or the business as usual case), the feeder thermal overloads are mitigated by upgrading a section of the feederhead lines. In investment case, a utility-owned and operated ESS is deployed to mitigate the thermal overloads. In the investment case, the ESS is also used to reduce the utility bill of a large C&I customer by reducing their demand charges. In the investment case, the ESS allows deferring the

rravikumar@epri.com

distribution upgrade for a few years while also allows to reduce the customer bill. The analysis consists of three phases. First, technical analysis is performed to assess the storage requirements to address the distribution thermal overloads. Second, a customer bill analysis is performed to assess how storage should be operated to minimize the customer bill and by how much the customer bill could potentially be reduced. Third, a cost-benefit analysis is performed to understand how the storage deployment project economically compares to the conventional distribution upgrade.

KEYWORDS

Energy storage, Demand charge, Distribution system planning, Non-wires alternatives, OpenDSS, StorageVET®, Cost Benefit Analysis

INTRODUCTION

Energy storage systems (ESS) are highly flexible DER that have the capability to be leveraged for multiple kinds of applications at the distribution, transmission, market, and customer-side. These applications include services such as capacity deferral, DER integration, frequency regulation, capacity market participation, etc. However, given the high capital expenses associated with its deployment, ESS are not common grid assets, yet. This paper proposes a practical planning-based approach to screen ESS to defer distribution capacity investments while offering stacked non-distribution related “secondary services”. The proposed ESS project screening approach is demonstrated on a real distribution feeder in the Ontario, Canada.

EPRI has created a systematic Energy Storage Analysis Framework to consider distribution-connected energy storage systems as non-wires alternatives in stacked-service scenarios that involve both distribution and non-distribution services [1]. This framework was developed to provide a systematic methodology to evaluate the technical and economic feasibility of using energy storage system as a non-wires alternative to address issues at the distribution or transmission level. This framework comprises of four main steps and is illustrated in Figure 1. The first step involves defining ESS scenarios to be analysed, which includes the identification of applicable ESS services and the conventional distribution mitigation solutions to address these service(s), etc. Step 2 consists of assessing the ESS operational requirements dictated by the distribution and transmission related service(s). Step 2 also involves the determination of the ESS operational bounds for the market services that ensure that the storage does not cause adverse impacts at the transmission or distribution level. Step 3 involves the value analysis value of the ESS market services. These market services could involve multiple stakeholders. Finally, Step 4 involves performing a comprehensive economic analysis comparing the storage investment to conventional distribution and/or transmission solutions. EPRI, with its partner utilities, is continuously applying and extending this framework to a wide variety of ESS stacked-service scenarios, see, e.g.,. [2]-[5].

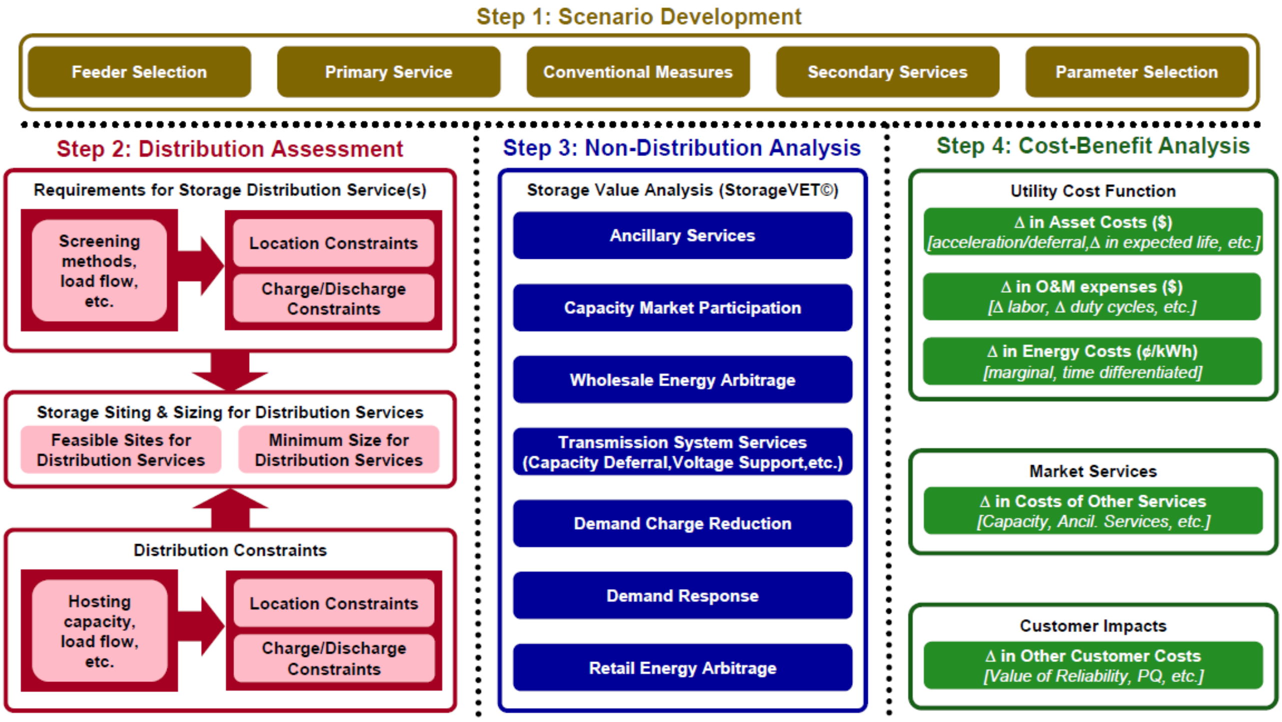

Figure 1: EPRI Energy Storage Analysis Framework

DETERMINING ENERGY STORAGE REQUIREMENTS TO MITIGATE THERMAL OVERLOADS

This section shows an approach for determining the energy storage requirements to mitigate the thermal overloads. The storage control, siting, and minimum power and energy capacities to address the distribution service requirements are discussed.

- **Storage control**: The ESS can be dispatched based on the current measurements of the monitored element when its primary goal is to perform peak demand reduction in order to avoid thermal violations. When the monitored currents exceed a specific threshold, ESS is discharged or charged depending on the power flow direction with respect to the ESS and the monitored element.

- **Storage siting**: The ESS must be sited so that it can be dispatched to reduce currents of all distribution elements that have the potential to be constrained. In some cases, when there are distribution constraints in different feeder locations, it may be necessary to site multiple storage assets at different locations. In particular, when the distribution constraints are at the feeder head, the ESS can be sited at any preferred location downstream of all the constrained feederhead elements.

- **Storage sizing**: When the distribution capacity need is at or close to the feederhead, the ESS size, i.e., the ESS power and energy capacity requirements, can be estimated from historical power and or current (and voltage) measurements recorded at the feeder head. In this case, the ESS power requirement estimate is obtained from the difference between the feeder peak demand and the current threshold. But, when the distribution capacity need is elsewhere on the feeder, the feeder head measurements cannot be accurately used for determining the required ESS power rating. This calls for a more sophisticated analysis since, different feeder elements could be overloaded at various time instances. In order to determine the ESS energy capacity requirements, ESS dispatch logic must be replicated using ESS state of charge (SOC) data that is in a time series manner.

In this phase of the analysis, storage sizing is identified leveraging the linear power flow approximation methodology explained in [2], which allows to quickly screen ESS size for a large number of scenarios, such as several feeders or feeder locations. As shown in [2], the relationship between the feeder load and current flowing through a feeder element of interest can be approximated in a linear manner with a reasonable degree of accuracy. This linear relationship between the feeder net load S (i.e. the total connected load on the feeder assuming load models with fixed kW and power factor) and the current of the element of interest I_m can be expressed with

$$I_{m(t)} = f_{(S_{(t)})} = \frac{dI_m}{dS} S_{(t)} + \mathrm{b} \qquad (1)$$

where dI_m/dS and b are the linear approximation coefficients and $*_{(t)}$ denotes time-dependent variables, which are determined based on historical feeder power measurements and simulated currents, as explained in detail in [2]. The linear approximation coefficients are unique to a given feeder element. Once the linear relationship has been determined, it is utilized to rapidly perform the time-series ESS dispatch simulation, whereby a desired type of ESS control algorithm can be represented in a time-discrete fashion while still considering the time-interdependencies in the model (e.g. $\mathrm{SOC}_{(t)}$).

CASE STUDY

The ESS analysis methods shown in this paper are demonstrated on a real utility distribution feeder in Ontario, Canada. The 27.6 kV feeder, which currently has a peak load of around 17.3 MVA, is illustrated in Figure 2. While the considered feeder loading limit is 320 A, the feeder head currents are forecast to reach 370 A over a 10-year distribution planning time-horizon, as illustrated in Figure 3. As a result, distribution capacity upgrades are expected to be required on the feeder within the planning time-horizon.

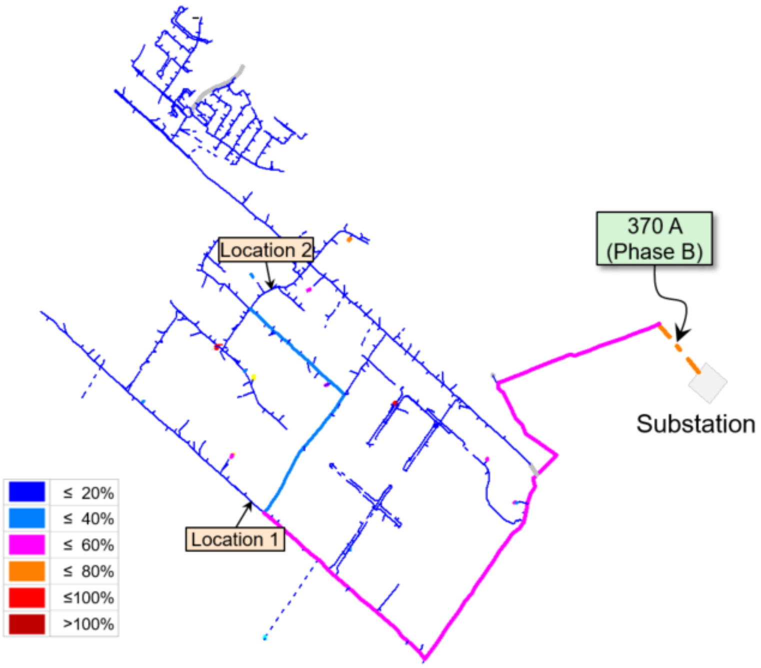

Figure 2: Utility distribution feeder line loading

Figure 4 represents the probability of the feederhead currents exceeding a specific threshold value. The curve in the figure was estimated utilizing the linear approximation (1). The “x axis” represents the probability that a certain element would experience currents above a particular threshold (“y-axis”).

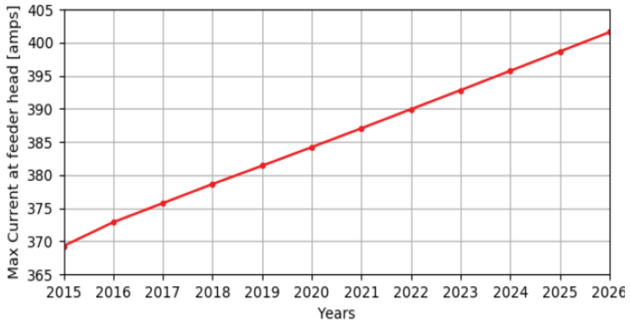

Figure 3: Feeder Head Currents based on Load Growth Forecast

The feeder current duration curve can be very helpful in choosing the ESS power rating. For example, a 0.5 MW ESS would reduce the probability of feederhead currents in excess of 320 A to about 1.2%. Alternatively, a 1 MW ESS would reduce the risk of having currents greater than 320 A to about 0.65%.

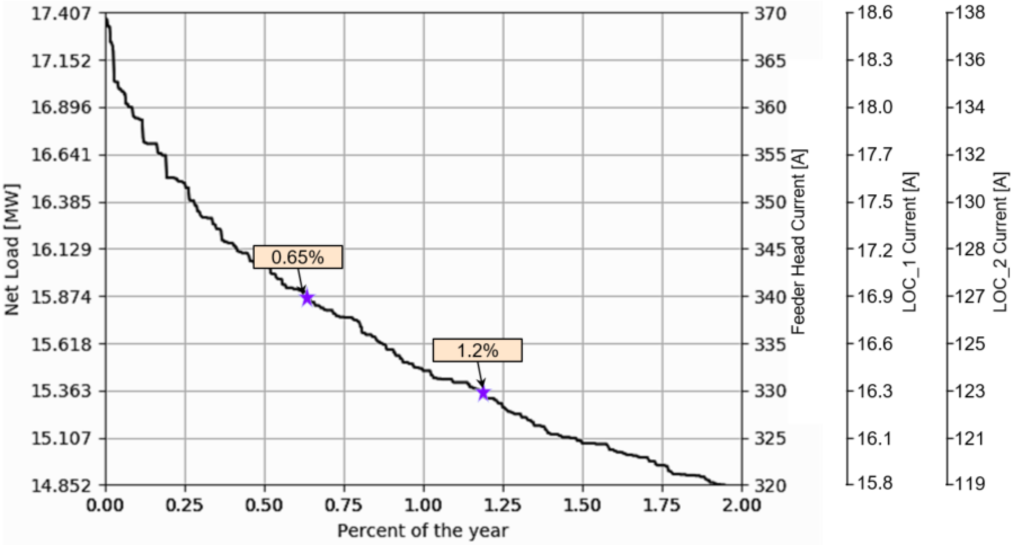

Figure 4: The Current duration curve for several elements on the feeder

Time-series storage dispatch analysis is necessary for identifying the ESS energy capacity required to address the distribution service requirements. Time-series analysis is necessary to appropriately consider the energy-constrained nature of ESS. Performing the time-series simulation based on the linear approximation as opposed to QSTS, allows one to quickly run numerous time-series simulations with different ESS ratings, locations, control logic types, etc. For instance, a 2 MWh ESS could reduce the probability of overcurrents to below 1% while a 10 MWh system would reduce the probability to ~0.2%. Based on the time-series analysis, the storage size required to keep the feederhead currents below 380 A would be roughly 0.8 MW, 2.25 MWh. Based on this, a conservative storage size of 1 MW, 3 MWh was chosen, as illustrated in Figure 5.

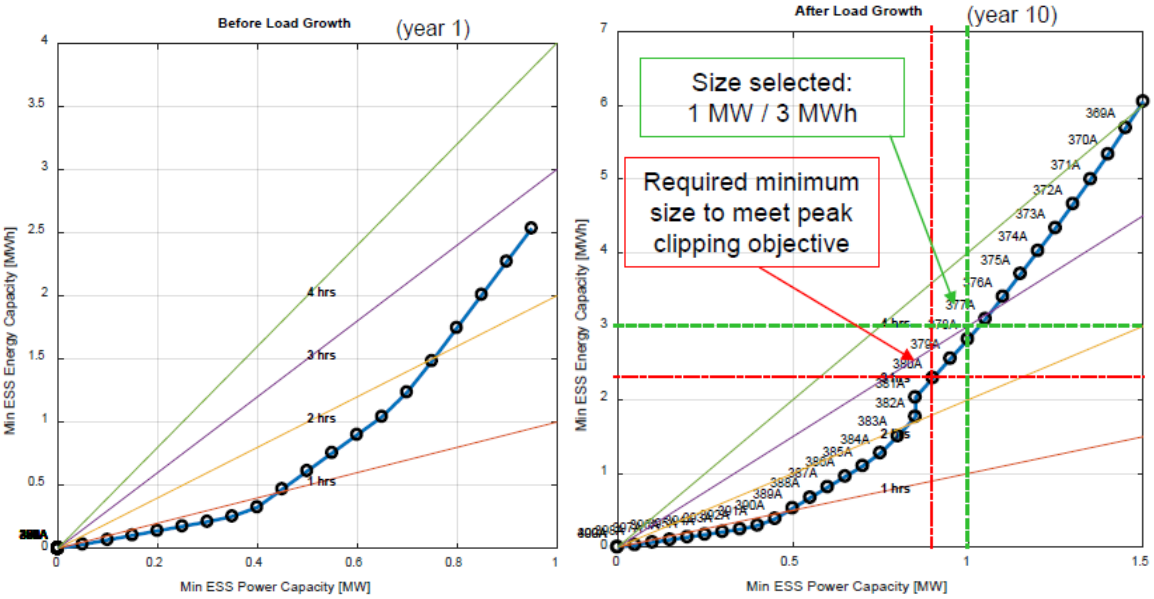

Figure 5: Storage sizing before load growth (left) and after load growth (right)

With the completion of the distribution analysis, the next step in the EPRI Energy Storage Analysis Framework is to assess the value the ESS generates by offering storage secondary services. To assess the value of the secondary services, time-series constraint profiles were calculated for the secondary service operation. This constraint profile would act as the boundary conditions within which the storage would operate for providing the secondary market services. By doing so, it ensures that the operation of the storage for the secondary market services does not cause any adverse impacts at the distribution level.

CUSTOMER TARIFF IN ONTARIO

In the non-distribution analysis, it was assumed that a C&I customer would own and operate the ESS to first, provide the distribution capacity deferral services, and second to reduce the customer electricity bill. The utility would compensate the customer for providing the distribution capacity deferral application.

In Ontario, all customers pay a special charge called "Global Adjustment (GA) [5]" which is included as a part of their utility bill. GA covers the cost of building new electrical infrastructure in the territory and delivering Ontario's electricity conservation programs. The GA to be paid by residential and small business customers are included as a part of their time of use bill. However, for the C&I customers it is charged as a separate line item on their bill. GA is calculated for each C&I customer based on their annual peak load and customer class as shown in **Error! Reference source not found.**.

Customer Annual Peak Load	Customer Class	GA Calculation Method
Greater than 5 MW	Class A	Charged based on the customer's load contribution to top 5 system load peaks
Between 50 kW and 5 MW	Class B	Charged as a volumetric energy consumption cost
Between 1 MW and 5 MW	Class B (Can opt into Class A)	Charged based on class type the customer opts into

Table 1: Determination of Customer Class based on annual peak load

An industrial customer connected on the analysed feeder was chosen for the non-distribution secondary services analysis. The annual peak load of the customer was 7.65 MW and was categorized as a Class A customer. Hence, the GA calculation for this customer was based on the customer's contribution to the top 5 system level peak demand. In addition to the GA, the customer's bill also included energy, transmission and distribution charges. These charges are summarized in the **Error! Reference source not found.** below.

Bill Component	Value	Charge Type
Energy Price	Hourly Ontario Energy Price	Based on volumetric energy consumption
Administrative Charges	$0.0123/kWh	
Transmission Charge	$5.7145/kW	Non-Coincident Demand Charge
Distribution Charge	$1.076/kW	Non-Coincident Demand Charge
Global Adjustment	Calculated based on annual IESO GA costs	Based on customer's contribution to top 5 annual coincident peaks of IESO

Table 2: Bill components of a typical Class A customer in Ontario

Error! Reference source not found. shows that, in order to maximize the bill reduction, the energy storage dispatch must be optimized based on both the energy price and the demand charge.

SECONDARY SERVICES MODELING

The GA calculation involved the estimation of the customer's load during the system's top 5 load peaks over the year. In practice, the storage would be dispatched based on the day-ahead (or another time period) forecast of the system load and the customer load. Both load forecasts would be subject to some level of uncertainty. Hence, the accuracy it was critical to understand how the load forecast accuracy would affect the overall project economics. To provide insights on this, two scenarios were defined to represent the two possible “bookend” cases between which the load forecast would most likely fall. These cases are listed in Table 3***: ESS dispatch for different load forecasting methods***

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	Perfect Foresight	No Information
System Load Forecast	Perfect foresight to the top 5 IESO annual load peaks	Limited information on the IESO’s top 5 annual peaks
ESS Dispatch strategy	ESS scheduled to dispatch 1 MW for the entire duration of the peak	ESS scheduled to dispatch 250 kW from 15:00 to 19:00 hours during summer (June-Sep) weekdays

Table 3: ESS dispatch for different load forecasting methods

In this paper, the storage secondary service valuation analysis was performed with EPRI’s StorageVET®[5]. The ESS size and operational constraint profiles were provided as input to StorageVET® along with all market related data like the energy price, demand charges and the customer’s load profile. The ESS operational constraint profile included both the ESS operation for the capacity deferral service and the storage dispatch for the GA reduction. The StorageVET® analysis dataflow is illustrated in Figure 6.

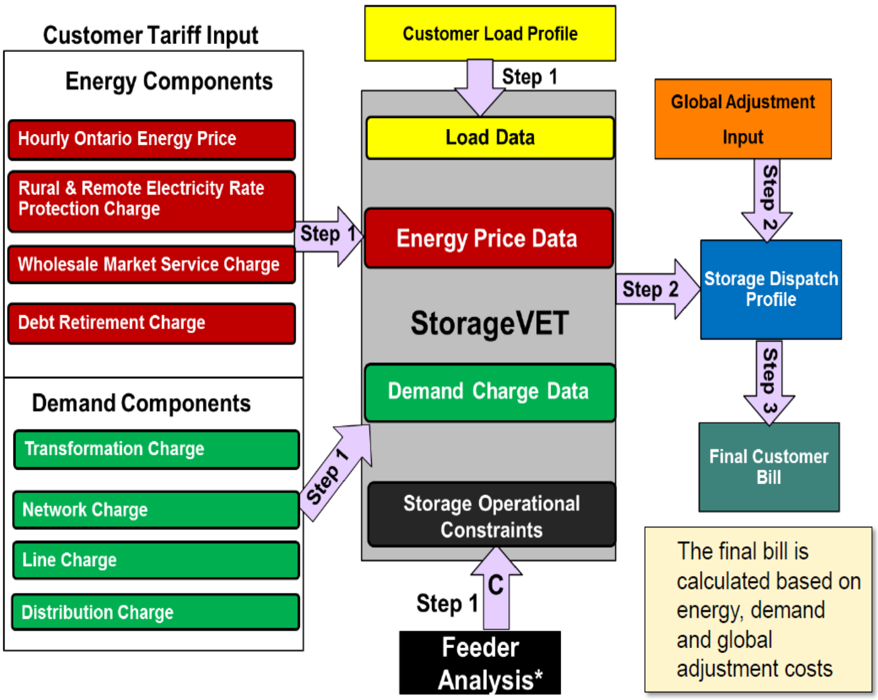

Figure 6: Stacked Benefit analysis modelling in StorageVET®

StorageVET® provides a comprehensive set of analysis results, the key results including the storage time-series power and energy (state of charge [SOC]) profiles for the analysed time period. The storage operational profile for one of the five IESO system peak load days for both scenarios 3 and 4 are illustrated in figure below. It should be noted that the IESO system load peaks from 17:00 to 18:00 during this day. The customer bill reduction is calculated based on the storage power profile.

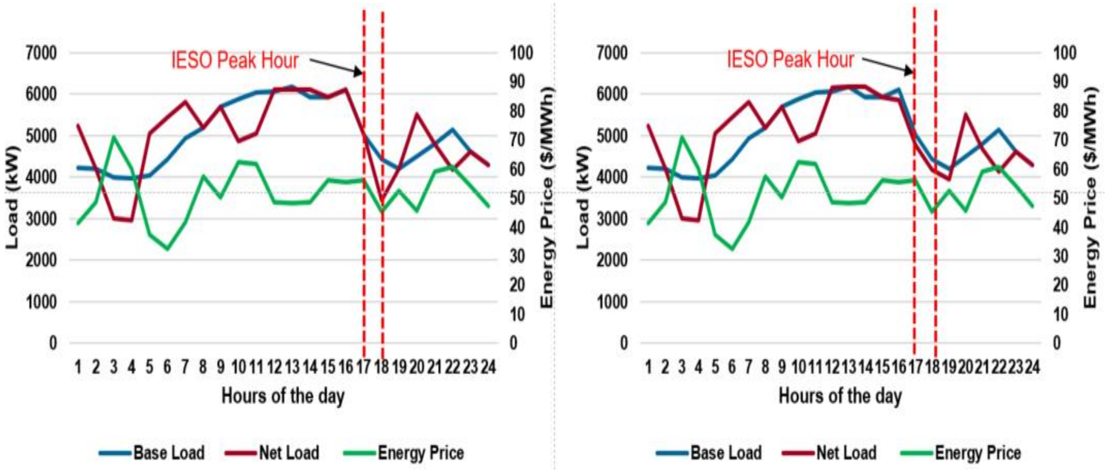

Figure 7: Storage operation for customer bill reduction for perfect foresight case (left) and no information case (right)

Figure 7 shows that the storage operating profile is very similar for the perfect foresight and the no information cases for most parts of the day. This is as the ESS operation for these hours is primarily driven by the energy price and demand charge. During these hours, the energy storage operates to perform energy arbitrage and demand charge reduction. The key difference between the two cases Figure 7 takes place during the evening hours, when the ESS discharges 1 MW from 17:00 to 18:00 in the perfect foresight case, which would result in a significant reduction in GA while it discharges only 0.25 MW from hours 15:00 to 19:00 in the no information case thus, resulting in a marginal reduction in the GA value.

COST-BENEFIT ANALYSIS

Following the secondary service analysis, the final step of the storage analysis process consisted of cost-benefit analysis (CBA), where the economic metrics of the various analysed cases were compared. The CBA was performed for the identified 1 MW, 3 MWh storage system size. The levelized cost of reconductoring was determined to be $78,200 per year over a 10-year horizon. This cost was estimated based on a given set of financial and cost parameters. Since, the ESS was assumed to be owned by the customer, but was to be primarily operated for the distribution application, the utility was expected to compensate the customer upto $78,200 in the form of annual payments. When the ESS provided both the capacity deferral and bill reduction services it resulted in a net present benefit of $780,000 over 10 years if there was limited information in load forecasting. However, the net present benefit improved significantly to $3,860,000 over a 10-year time-period in the perfect foresight case. These results were based on a storage cost of 2017. These results illustrate the importance of market revenues for this storage deployment to be cost beneficial.

CONCLUSION

This paper demonstrates the modelling and analysis of energy storage stacked-services and the associated distribution system impact and value on a real utility distribution feeder located in Ontario, Canada. This paper leverages EPRI's Energy Storage Analysis Framework, which is a systematic process to consider distribution-connected energy storage as a non-wires alternative in stacked-service scenarios that include both distribution and non-distribution services. As illustrated by this research, it is possible to consider the ESS as a viable non-wires alternative to offer multiple services of value to different stakeholders. However, it must be ensured that while doing so, there is no possibility of a conflict between these services.

To properly assess the feasibility and value of ESS stacked-service operation, the services must be prioritized and the coincidence of their requirements must be analysed thoroughly. The visibility and foresight of the service requirements can significantly impact the stacked-services' value and thus, should be properly considered. Offering wholesale and behind-the-meter market services can constitute of notable portion of the ESS revenues and thus, can ultimately determine whether a storage investment is cost-beneficial or not. The analysis process demonstrated in this paper provides insights for utility planners in how to consider ESS as a non-wires alternative in stacked-service scenarios that involve two different types of stakeholders, i.e., the utility and the customer.

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