EVALUATION OF AN ENERGY STORAGE SYSTEM ON A DISTRIBUTION FEEDER WITH DISTRIBUTED PV SYSTEMS

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ABSTRACT

This paper describes a local project that involves a battery energy storage system (BESS) for the purpose of aiding peak shaving on a feeder that will soon have a significant level of PV Penetration. Additional applications of the BESS that are compatible with peak shaving are considered, along with numerous incidental benefits that emerge from such an installation, in an effort to justify the high cost of this asset.

INTRODUCTION

The traditional method to improve the capacity factor in electric power systems is to curtail power demand during peak periods by employing Demand-Side Management (DMS) strategies. In the near future, implementation of the "smart grid" is expected to allow further improvement in the capacity factor through demand response. Energy storage is another option to augment DSM implementation. Among the energy storage technologies, the Battery Energy Storage System (BESS) is slowly becoming attractive due the emergence of new power electronics and improved battery technology, ease of installation in urban areas, short installation period, zero emission, quiet operation, and modularity. The current cost of a BESS is still high, and can be justifiable only in specific situations.

This paper describes a project whose main purpose it to aggressively reduce the peak load on an electric distribution feeder that supplies a new housing development by 65% when compared to conventional feeders. This will be accomplished through energy efficient building designs (already in place), significant distributed photovoltaic (PV) systems, load management by means of demand response, and a BESS to be installed at the substation end of the feeder. In such capacity support application, the energy storage system will be used to shift load from the peak period to the base period.

Although partially-funded by the US Department of Energy (as one of the many pilot projects to demonstrate various aspects of the smart grid), the BESS is an expensive asset that is not economically attractive when considering only the above function alone. In an attempt to justify it cost, other applications and benefits must be taken into account. There are numerous potentially complementary applications and significant benefits associated with energy storage use that could be aggregated to form a more attractive package [1]-[3]. It is important, however, that only those applications which are compatible (i.e., with no operational conflicts) can be combined for benefits aggregation.

In this article, the distribution system is first described in terms of feeder load curve, the residential PV systems and their impact on the load curve, and the BESS size and type that is being considered. This is followed by a set of combined applications of the BESS, namely, energy time-shift (peak shaving and valley filling), frequency regulation, and voltage/reactive power support. Then some of the important incidental benefits are addressed, including increased substation capacity and asset utilization, increased spinning reserve, lower losses and substation transformer operating temperature, reduced fossil fuel consumption and air emissions. The paper ends with a conclusion.

DISTRIBUTION SYSTEM DESCRIPTION

This section describes the load of the feeder being studied followed by the planned residential photovoltaic systems, the impact of these distributed resources on the daily feeder load curve, and the battery energy storage system being considered for implementation.

Feeder Load

At present, the distribution substation supplying power to the area and the feeders it serves are lightly loaded due to the fact that the neighborhood located at the edge of town is relatively new. Figure 1 below shows the daily minimum and maximum values of the MW loading on the feeder under study during the hot summer months (June-September) of 2009. Note that this particular feeder is load at nearly 25% (based on a rating of 8 MW). The daily swings are mainly caused by the air-conditioning load.

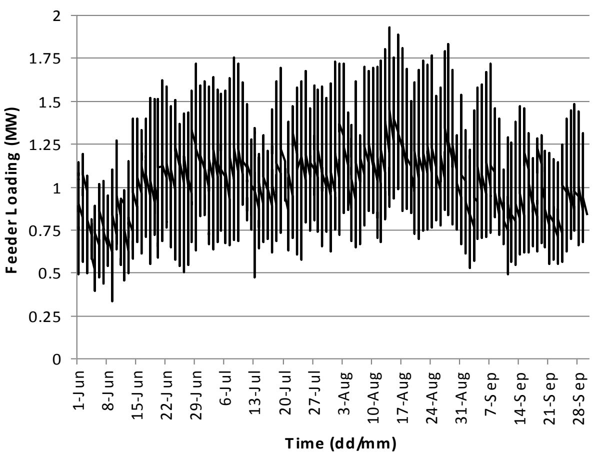

Fig. 1: Feeder Load during 2009 Summer Months.

The load profile of this feeder and the total substation load are found to correlate very well with the entire system load and ambient air temperature. During the summer period, the peak load occurs in the late afternoon hours between 4:00 pm and 7:00 pm.

Photovoltaic Systems

Part of the load in Figure 1 consists of an energy-efficient housing subdivision with 180 homes, when completed. Each of these homes will be equipped energy-star appliances, efficient lighting, high thermal insulation, and a roof-integrated PV System. The size of the PV array in standard homes is 1.75 kW, while those with upgrades will have array sizes that range between 3 kW and 6 kW. When completed, it is estimated that these PV systems will add up to nearly 350 kW. Based on the current feeder summer peak load, the latter value represents approximately 20% of PV penetration on this feeder.

Figure 2 below illustrates a measurement of power produced by the PV array, power drawn by the air-conditioning load, and the net power supplied by the utility grid on one of the standard home over a 24-hour period. Note that on this particular day, the home supplies power to the grid (i.e., negative net power) only during some periods of the early morning hours.

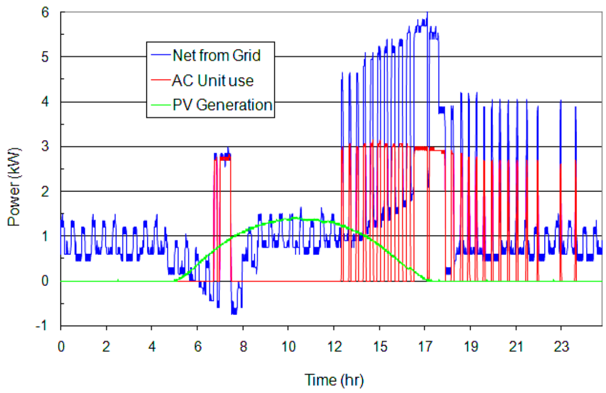

Fig. 2: Sample of Daily Residential Load Curve.

Impact of PV on Feeder Load Curve

At the moment, only 30 of the 180 PV systems are installed on the homes. As the level of PV penetration increases, its impact of the feeder load curve will clearly be noticed during the daylight hours. To illustrate, the hourly feeder load variation during one of last year's summer days is shown in Figure 3 (black color). The Figure also shows the new expected load curve (green color) and solar power produced (red color) when the PV penetration level reaches the expected 20% range.

Note that the PV system do not contribute to the reduction in the peak power demand due to the fact that these systems are installed to face a southern exposure for maximum annual energy production. It is for this reason that they stop producing power at the time when the utility peak occurs. However, they do contribute to a portion of the energy demand during the early hours of the peak time period.

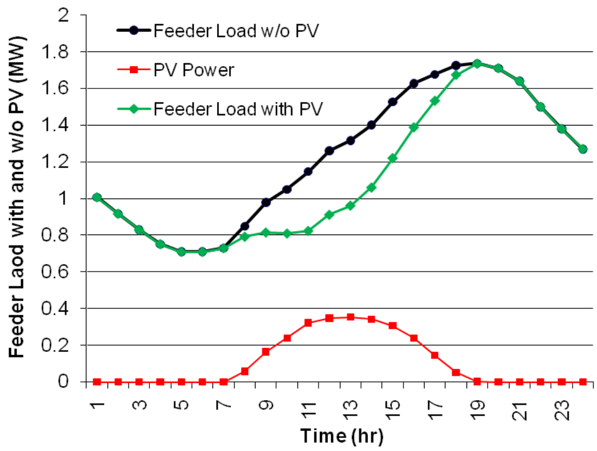

Fig. 3: Daily Variation of Feeder Load without and with 20% PV Penetration.

Battery Energy Storage System (BESS)

As indicated above, the PV systems have little to no impact on the feeder peak power demand. Consequently, peak reduction has to be achieved by other means including direct load control, demand response, and/or installing an energy storage system.

Since the peak load on the feeder is nearly 2 MW, it is determined that a 0.5 MW battery with sufficient capacity (e.g., 3 MWH) will be able to reduce the peak load by 25%. The original battery energy storage technology that was recommended for this project is the Sodium-Sulfur battery due to its reputation for long life cycle and compact footprint. But the minimum size available in the market is 1 MW/6 MWH which too large for this application. Hence, a system based on advanced lead acid batteries is seriously being considered for this project.

PRIMARY BESS APPLICATION

The primary application of the BESS described above is to shave the peak of the feeder load during the hot summer days, most likely when the local air temperature exceeds 95°F. Figure 4 below shows the daily maximum ambient temperature and system maximum peak load during the months of June through September. Note that the maximum temperature exceeds the above value nearly 90 days out of the year. Consequently, the BESS may be used for other applications for as long as 9 months of the year. The same asset can also simultaneously be used for multiple tasks (if possible) to attempt the justification of its high cost.

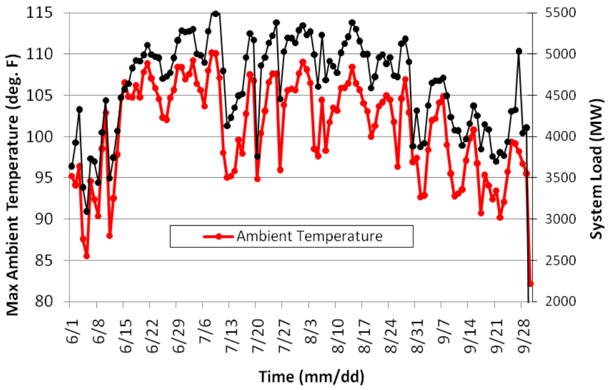

Fig. 4: Daily Peak Temperature and System Load.

There are many attributes of BESS for utilization in power distribution systems which may or may not be compatible with the primary application of peak shaving [1]. These include (but not limited to) delaying or avoiding the need for capital expenditures to upgrade a congested sub-transmission network, improving the reliability by providing support to the local distribution network, damping out the fluctuations in the power produced by distributed PV systems during days with fast-moving clouds, frequency regulation, and voltage support.

In this study it is determined that an effective utilization of this asset consists of (a) peak shaving as needed during the summer months, (b) frequency regulation during the rest of the year, (c) voltage and reactive power support during the entire year. Each of these secondary applications is briefly addressed below.

Peak Shaving (3 Months)

Peak shaving and valley filling is usually achieved by using a dispatch algorithm to estimate the benefit of such a transaction. The algorithm contains the steps needed to determine when to charge and when to discharge the BESS in order to optimize the financial benefit. Similar to generation commitment, the algorithm determines when to charge/discharge electric energy, based on cost. Generally, three items are used in conjunction with the dispatch algorithm stated above; namely, the projected hourly electric energy prices, the energy storage round-trip efficiency, and the discharge duration. The round-trip AC-AC efficiency of the BESS, including the power converter, is expected to be about 75% for advanced lead-acid batteries.

First, the hours of high energy prices, which generally coincide with the peak load period, are indentified by drawing a threshold. Before a decision is made on performing a discharge of certain duration, the financial merits of this transaction are determined based on the cost energy during the low demand period, the cost to store and to cost to discharge the energy (i.e., the cost of wear on the storage system, plus the cost of storage losses). The transaction is made only when the above cost is lower than the expected benefit. As an example, if off-peak energy costs $40/MWH and the variable operating cost of the BESS is also about $30/MWH of storage output. Then the total cost to charge and then to discharge is about $82.50/MWH, after accounting for energy losses of 25%. Hence, if the energy is worth more than $82.50/MWH during the peak hours, then the transaction is favorable. Like other generation sources, this new asset is be monitored through the Supervisory Control and Data Acquisition (SCADA) system which helps system operators monitor and control the BESS in real-time.

Frequency Regulation (9 months)

Frequency Regulation is appearing to be an attractive emerging opportunity for energy storage [4], given the fact that the need for regulation services is expected to increase to account for variability associated with higher wind penetration and cloud-induced transients in photovoltaic power systems. Because a BESS can be ramped from zero to full power within few cycles, it can provide a source of instantaneous ready reserve power.

To increase asset utilization, it is recommended that the BESS of this project be used to satisfy the frequency regulation requirements when not used for peak shaving (9 months out of the year). This will relieve half of a megawatt from the existing assets assigned for frequency control.

Voltage and Reactive Power Support (12 months)

It is envisioned that Power Conversion System (PCS) the proposed 0.5 MW Battery Energy Storage System be rated at 1 MVA rather than 0.5 MVA due to the relatively small additional cost. The oversized power electronic converter will have the ability to provide significant reactive power for voltage support and other ancillary services throughout the year, even when performing peak shaving or frequency regulation. The amount of reactive power that can be supplied the PCS depends on the real power flowing into or out of the battery. Figure 5 below indicates that the PCS provides up to 0.85 MVAR when the battery is operating at full power and up to the entire converter apparent power when the battery is at stand-still. Since residential air-conditioning loads are known to pose a considerable challenge during grid emergencies, especially when the grid is re-energized after outage, the voltage support benefit that can be provided by the BESS is of high value.

INCIDENTAL BENEFITS

Numerous benefits accrue incidentally as a result of a BESS installation. These incidental benefits can add a significant amount to the value of this asset, hence, must be taken to account when conducting an economic analysis. Some of these benefits that directly apply to the proposed BESS are listed below.

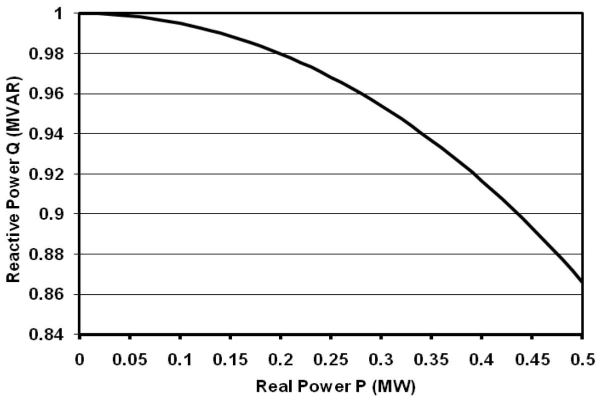

Fig. 5: Reactive Power Capability Curve of 1 MVA/0.5MW Power Conversion System.

Increased Substation Capacity and Asset Utilization

The installation of the proposed BESS for the purpose of peak shaving will result in capacity release of 0.5 MW for the substation transformer and the sub-transmission line that feeds the area. Hence, the existing asset can serve additional load of the same size when called for. From an alternative point of view, the BESS serves as an upgrade deferral tool for the utility asset upstream. Furthermore, the charging of the energy storage device during the night hours will increase the amount of electricity that is generated, transmitted and distributed using existing utility assets. This is a welcoming operation since increased asset utilization is desirable for utility companies.

Spinning Reserve

The operating benefits of a BESS as a source of spinning reserve can be significant in some cases [5]. The proposed BESS can be accounted as part of the spinning reserve fleet, while providing voltage support and frequency regulation. However, this application is in conflict with the scheduled peak shaving/valley filling application during the summer months, as the battery may be in a discharged state when called for.

Lower Losses and Equipment Operating Temperature

It is a known fact that transmission and distribution energy losses are nearly proportional to the power flow squared. Thus, losses are greatest during the hours of peak load, and shaving the peak during the summer months by x% results in a power loss reduction of $(2x - x^2)$ %. The lower current flow through the substation transformer leads to a lower operating temperature, and hence, longer life expectancy.

Reduced Fossil Fuel Consumption and Air Emissions

The proposed BESS reduces fossil fuel and air emissions by storing electric energy generated using relatively clean base-load power plants, and offsetting the use of less efficient and/or dirtier on-peak generation. Furthermore, reduced fuel use will presumably leads to reduced air emissions.

CONCLUSION

This paper discussed a local project whose main goal is to aggressively shave the peak of a residential distribution feeder by 65%. This will be achieved by a number of tools including energy efficient building designs, distributed PV systems, load management and a battery energy storage system. But the current electricity marketplace is not accommodating to energy storage due to their high cost.

To increase the utilization of the BESS and justify some of the cost, a multi-purpose use of this asset is proposed. Among its many attributes, three compatible applications have been identified for this project: peak shaving as needed during the summer months, frequency regulation during the rest of the year, and voltage and reactive power support during the entire year. In addition, a number of valuable incidental benefits are accounted for cost justification.

ACKNOWLEDGMENT

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