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Load commitment of distribution grid with high penetration of photovoltaics (PV) using hybrid series-parallel prediction algorithm and storage

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ABSTRACT

Battery energy storage system (BESS) is one of the promising solutions to deal with intermittency of renewable generation. In this paper, BESS is used for peak shaving and smoothing the distribution load curve of an actual circuit in island of Maui in Hawaii. The distribution circuit has about 850 kW of installed rooftop PV generation. This amount of PV and future expansion, raises some concerns about potential impacts on the transmission system. This paper aims to mitigate these effects. First of all, two load forecasting methods are presented. The forecast load data is then used to control BESS for two main purposes, peak shaving and smoothing. To achieve these goals, two approaches are explained. In approach I, a nonlinear programming method is utilized and equations for simultaneous load shifting and smoothing are derived. In the next approach, a real time control is developed which performs smoothing and peak shaving simultaneously. These methods are applied on 108 days of historical data and pros and cons of each approach is discussed.

1. Introduction

Hawaii clean energy incentive (HCEI) shows the roadmap for relieving the economy from fossil fuels by achieving 70% clean energy by 2030 with 30% from efficiency measures, and 40% coming from locally generated renewable sources. With strong public support for renewable energy in the state [1], researchers are investigating new methods to increase renewable energy penetration mostly in the form of solar, wind and wave energy. One of the most tangible issues in renewable integration is its intermittency which makes it hard to rely on for meeting the load demand. As a result, having a more predictable renewable energy source, gives a leverage for incorporating more of this type into the power grid. BESS is one of the most straightforward solutions for reducing the fluctuations and thus coming up with a more predictable power source. With charging and discharging capability, not only it can harness the fluctuations in the power output of renewables, but also can be used as a means for peak shaving purpose. In other words, BESS can be used to store the excess renewable energy in off-peak time periods and dump it back into the grid in the high load demand time periods [2]. In this paper, BESS is used for both purposes. A short survey of BESS application for above goals is presented here. BESS is used in [3] to smooth out the fluctuations caused by PV and wind generation in power system using real time state of charge (SOC) based control strategy. In the paper's proposed method, SOC changes around 50% while alleviating the fluctuations. SOC is a quantity that represents the ratio of available BESS capacity to its fully charged capacity [4]. Wind power smoothing is done by ramp control in [5]. In [6], a model predictive control strategy is utilized to have BESS mitigate the wind power fluctuations so that the windfarm can be dispatched in hourly basis. Dual BESS is used in [7] to maximize energy harvest from the wind without lowering grid power quality. The two BESSes try to provide wind power as a short-term dispatchable unit which can be coordinated with other units for active power scheduling. Embedding reliability criteria into objective function would add to the credibility of solution. Dynamic programming is used in [8] for designing an optimal power management mechanism for peak shaving in grid connected PV systems at lowest cost. The predictive optimization applied in the paper, save 13% on the electricity cost for the planned period of study. The results of the proposed method would improve with higher accuracy in load forecasting. In [9], the author investigates PV integration challenges and cites

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BESS as one of the solutions available to deal with intermittency of PV resources. The electric power system has several mechanisms to balance generation and demand in which BESS can help the power system operator reduce the contribution of spinning reserve for dealing with variability. On the other hand, BESS has some problems such as limited charging cycle and high cost which should be considered while finding the optimal set of solutions in a system wide perspective. It is reported that deployment of hybrid BESS and Distribution level Static COMpensator (STATCOM) provides 13% return on $25M investment on ancillary services such as frequency regulation, delayed capital investments, minimizing resource curtailment and reactive power support. In [10], different moving average algorithms are applied to smooth out PV power curve. BESS is used for residential electricity peak demand shaving in [11]. Peak shaving between 42% and 49% is reported in 5 regions in Canada except Quebec which is about 28%. It is concluded that peak shaving system is unsuitable for houses with electric heating which needs a higher storage capacity. A brief introduction of smart grid project at Public Service Company of New Mexico (PNM) is reported in [12]. The main objective of this paper is analyzing the cost effectiveness of BESS for smoothing, peak shaving and/or other ancillary services. In [13], profitability of BESS deployment at utility and residential scale is investigated. Different BESS chemical type are analyzed for six business cases and it is shown that molten salt batteries are the most promising type. Moreover, it is claimed that utility scale BESS have a higher profit potential compared with distributed storage. Peak shaving and load smoothing are discussed in [14] where it is shown that peak shaving using BESS at community level in Queensland, Australia saves about 18% in a weekly energy cost. Sizing of distributed BESS is discussed in [15]. It is shown that with current BESS price, economic profits are not likely but might improve if multiple functions are considered for BESS operation. Peak shaving and electricity cost minimization are discussed in [16] with a proposed load forecasting method suited for residential storage controller. The proposed storage controller algorithm saves cost about 80% with respect to baseline algorithm. However, none of the cited papers have discussed simultaneous peak shaving and smoothing on the distribution transformer load. Thus, this paper presents algorithms and methods to accomplish this goal so that the transmission system is relived from the aggregate fluctuations of rooftop PV generations. Next section presents the circuit and explains more about interconnection of BESS and the distribution system under study. The system model and problem statement is covered in Section 2 and proposed approaches are explained in Section 3. Simulation results are discussed in Section 4. Finally, conclusion and future work is given in Section 5.

2. System model and problem statement

The system model is defined in an island environment where several generators are meeting the load demand. The information flow diagram is depicted in Fig. 1. Several BESSes are managing the distribution load. All of the BESSes, generators and other controllable devices send the measured data to Energy Management System (EMS) which lies at the heart of data processing and command optimization. Hybrid Forecast And Load Commitment (HFALC) program is amended to EMS to manage the BESS operation.

HFALC is briefly described in Fig. 2 where parallel and series-parallel load forecasting data is utilized for optimizing BESS performance. Information flows from EMS to forecasting algorithms and optimized command is sent back to EMS. User preference is also provided for optimization and forecast algorithms. After finding the improved operation points, the required data is sent back to EMS where this information is processed more and the required commands are sent to control units. A more detailed explanation of HFALC is given in later sections.

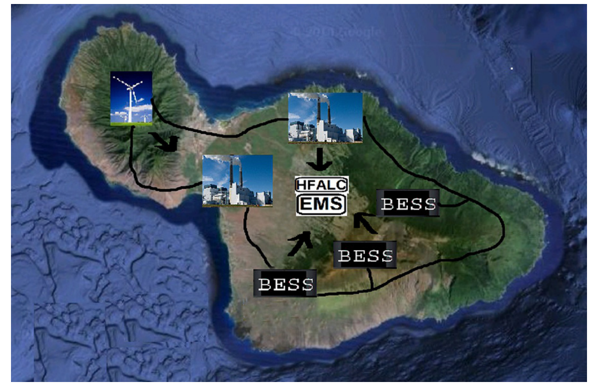

Fig. 1. Overall information flow in system model.

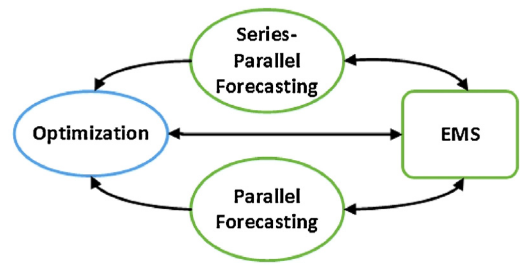

Fig. 2. Overall information flow in system model.

The electrical circuit of the BESS in the distribution is depicted in Fig. 3. The whole grid has capacity of 300 MW generation in which 40 MW is generated by wind power. A 1100 kWh/1 MW BESS is connected to a power converter whose output voltage is increased via a step-up transformer. The power of BESS goes to a distribution circuit which has 850 kW rooftop PV generation which causes some stochastic variability in the power curve. The circuit is also fed from a distribution transformer with the ration of 69 kV/12.47 kV.

BESS SOC along with some other health parameters are transmitted via SCADA system to dispatch room where an operator can control BESS operation via a GUI. The distribution transformer power flow is also measured by SCADA and is available via a database in the utility. The aim of BESS control is to mitigate the variability in the power of distribution transformer and also reduce the amount of committed generating units for meeting the demand. This can be done by charging BESS with excess renewable energy and dumping back the stored energy in the grid in the peak load time, thus replacing the conventional generating units which are not mostly environment friendly. BESS can also provide smoothing function in midday when load intermittency is pretty high due to distributed PV generation in the distribution circuit. The overall problem can be divided into two categories namely, peak shaving and smoothing. The solution approaches for the mentioned objectives is covered in the next section.

3. Proposed approaches

Two approaches are followed in this paper to achieve the mentioned goals. First method uses nonlinear programming and second approach is a simple algorithm which controls BESS SOC in real time. Both methods rely on forecasting of load curve and thus a separate subsection discusses forecasting in detail which comes subsequently. The first method uses a forecast load curve and yields a SOC trajectory for peak shaving and also smoothing. By