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Load peak shaving and power smoothing of a distribution grid with high renewable energy penetration

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ABSTRACT

High penetration of renewable energy poses a significant challenge in operation of power system. A potential solution for this problem is utilizing Battery Energy Storage System (BESS). The purpose of this paper is to analyze the effectiveness of BESS ability to peak shave and smooth the load curve of an actual circuit on the island of Maui in Hawaii. The distribution circuit has about 850 kW of installed rooftop Photo-Voltaic (PV) generation. Higher penetration of PV increases the concern about the potential impacts on the transmission system. At first, we will present two different methods for load forecasting. Reliable forecasting of daily load is required to effectively utilize the BESS system. We have employed two different methods for load forecasting in order to achieve two main purposes including peak shaving and smoothing. For reaching these goals, two approaches are analyzed. The first approach is utilizing a nonlinear programming method in terms of load shifting and smoothing. The second approach includes a real time control strategy to have smoothing and peak shaving at the same time. As a real case study, these proposed methods have been applied within 108-day data collection period and pros and cons of these methods will be discussed.

1. Introduction

Hawaii Clean Energy Incentive (HCEI) shows a road-map for reducing the use of fossil fuels by achieving 70% clean energy by 2030, of which the contribution of efficiency measures and locally generated renewable sources are 30% and 40%, respectively. Strong public support for renewable energy in the state [1], has encouraged researchers to investigate new methods to increase the renewable energy penetrations mostly in the form of solar, wind and wave energy. One of the most important issues in renewable integration is intermittency, which creates difficulties in meeting load demand. If a more effective forecasting method could be achieved, these resources could be rendered more reliable thus allowing greater percentage of renewable resources into power grid. BESS is one of the promising solutions to reduce the fluctuations an uncertainties and thus resulting in a more predictable power source. Optimal charging and discharging of BESS, not only reduces the fluctuations of the power output of renewables, but also can be used for peak shaving purposes. In other words, BESS is used to store the excess renewable energy in the off-peak time periods and dump it back into the grid in the high load demand time periods [2]. In this paper, analysis of BESS is undertaken for both purposes. This paper begins with a brief overview of BESS applications, giving context to our research results.

1.1. Literature review

State Of Charge (SOC) is a quantity that represents the ratio of available BESS capacity to its fully charged capacity [3]. Li et al. [4] proposed a method in order to smooth the fluctuations caused by PV and wind generation in the power grid using real time SOC based on a control strategy. In the described method, SOC changes around 50% while alleviating the fluctuations. Ramp rate control was used to smooth the wind power generation [5]. Teleke et al. utilized a predictive control strategy in order to mitigate the wind power fluctuations using BESS [6], so the wind farm can be dispatched in hourly basis.

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A dual BESS designing was proposed by Yao [7] to maximize the energy harvest from the wind without decreasing the power quality. The dual BESS provides wind power as a short-term dispatchable unit which can be coordinated with other units for active power scheduling. Also, the embedding reliability criteria were considered in the objective function. A dynamic programming based method was used in Ref. [8] to design an optimal and cost effective power management strategy with the purpose of peak shaving in the grid connected PV systems. The predictive optimization could save 13% on the electricity cost for the planned period of study. Additionally, its results could be improved using the higher accurate load forecasting methods.

Enslin investigated PV integration challenges and cites BESS as one of the solutions to deal with the intermittency of the PV resources [9]. There are several mechanisms to make a balance between the generation and the demand which BESS can help the grid operator to reduce the contribution of the spinning reserve in order to deal with the variability. On the other hand, BESS has some problems and limitations such as the limited charging cycles and the high costs. All of these constraints and parameters should be considered to find the optimal solution in a system. Cheng applied different moving average algorithms in order to smooth the PV power curve [10]. Leadbetter used BESS for peak demand shaving of the residential electricity [11]. Based on his method, peak shaving between 42% and 49% was reported in 5 regions in Canada except Quebec which was about 28%. The result of his research was the peak shaving system is not appropriate for the houses including electric heating.

Lavrova et al. described an introduction of the smart grid project at Public Service Company of New Mexico (PNM) [12]. The main purpose of their research is to analyze of the cost effectiveness of BESS in terms of smoothing, peak shaving and/or other ancillary services. Profitability level of BESS at utility and residential scale is investigated in Ref. [13]. In that research, Tzanetopoulou compared different chemical types of BESS for 6 business cases and as a result, he showed that the molten salt batteries were the most promising type. Additionally, he proved that utility scale BESS had a higher profit potential in comparison with the distributed storage.

Another research was done by Pezeshki et al. [14] about the peak shaving and load smoothing using BESS at the community level in Queensland, Australia. They showed about 18% of the weekly energy cost can be saved. Yang et al. [15] discussed about the capacity of the distributed BESS. They presented that with the current BESS price, the economic profits might be improved if the multiple functions are considered for the BESS operation. Wang et al. [16] proposed a load forecasting method which was appropriate for the residential storage controller. Their purpose was peak shaving and electricity cost minimization. The result of the proposed method was saving the cost about 80% with respecting to the baseline algorithm. Hoiles [17] worked on nonparametric forecasting the demand to increase the grid reliability based on Afriats theorem.

In order to solve the forecasting problems in the power systems, different computational intelligence techniques have been widely used, such as Artificial Neural Networks (ANN) [18–22], fuzzy-logic approach [23], and genetic algorithm [24,25]. Anbazhagan [26] did price forecasting for day-ahead via recurrent neural networks. A model for the wind forecasting and wind generation was proposed by Aquino et al., using ANN [27]. Combination of the load and wind power forecasting was done by Quan et al. via neural network-based prediction intervals [19].

Yona et al. [28] described a method for insolation prediction with fuzzy and then added ANN for long term ahead corrected prediction of photo-voltaic outputs. Kurbatsky et al. [29] applied two stages of adaptive neural network to have a short-time forecast of power system parameters. Lee worked on the short-term forecasting the wind power via Gaussian processes and ANN [20]. Saez et al. [30] developed a fuzzy prediction interval model for a microgrid to forecast the renewable resources and loads.

1.2. Contribution of the proposed method

The main contribution of this paper is simultaneous application of peak shaving and smoothing on the load curve of a distribution grid. The focus of this paper is proposing the algorithms and methods to achieve this goal so that the transmission system is relieved from the aggregate fluctuations of rooftop PV generations. The second section of this paper covers the system model and the problem statement. A parallel forecasting method has been developed using Complex-Valued Neural Networks (CVNN) in which the load data for the next 24 h is obtained. Load smoothing needs a fairly accurate load forecast and thus a new approach is proposed to predict the load value for 20 min ahead. The fluctuations on the load curve are removed by BESS while trying to keep the BESS SOC changes at minimum level. Peak shaving is performed along with smoothing to make the best use of the BESS capacity.

In section 2 the circuit is presented and more information about the interconnection of BESS and the distribution system is provided. In this paper two approaches are used in order to achieve the mentioned goals. The first approach uses nonlinear programming and the second method utilizes a simple algorithm to control the SOC of BESS in real time. Both methods require forecasting of the load curve and thus section 3 discusses forecasting in detail which comes subsequently.

Two heuristic approaches are presented in section 4. The first method uses a forecast load curve and yields a SOC trajectory for peak shaving and also smoothing. By injecting/absorbing the power determined by SOC trajectory, peak shaving and/or smoothing goals are reached. Next, a simple algorithm which makes use of real time control of BESS SOC is covered. This method benefits from a better forecasting method and is easy to implement. It also includes some user–interactive parameters which can be set by the operator or fed from another power system application. Section 5 includes the results of the simulations. Finally, conclusion and the future works are described in section 6.

2. System model and problem statement

The model of the system has been defined in an island where several generators meet the load demand. Fig. 1 shows the information flow diagram of the island model which several BESS units

Fig. 1. Overall information flow in system model.