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Wind Power Source Role in Sizing Battery Energy Storage System for Secondary Frequency Application

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Abstract— **The advent of battery energy storage system (BESS) to power systems introduced many ancillary services that make use of fast response of batteries. Frequency control is one of the most important applications that aid stabilizing electric networks. Secondary frequency control is one type of frequency control that uses the BESS to supply/absorb net power to bring the frequency deviation to its working limits. Renewable energy sources increasingly contribute towards utilization in microgrids for ancillary services, frequency control for instance. The frequency deviation anomaly is more prominent in case of adopting renewable energy sources, and a 30 MW wind power source is considered in this study along with the selected network in Saudi Arabia for analyzing the proper sizing of the BESS.**

Index Terms— **Battery energy storage system; renewable energy resources; Secondary frequency control; wind power**

I. INTRODUCTION

Power system stability control uses dynamic analysis to maintain frequency and voltage values to the set values to safeguard the system. Broadly, frequency control is composed of three hierarchical actions-namely, primary control, secondary control, and manual tertiary control. Secondary frequency control involves a number of generators that work on the system to restore frequency to its tolerable limits in relatively long time compared to its primary control counterpart.

Renewable resources integration to conventional grids increase steadily due to their economic feasibility, but this comes at a price. A high renewable source penetration is accompanied with several frequency-related critical issues. A system inertia response is diminished significantly, for both wind power and solar energy, which in turn, makes the system vulnerable to frequency deviations [1, 2]. Furthermore, the high penetration rate causes a reduction in the generation units kept for the reserve, which again degrades the frequency deviation [3]. Different studies consider battery energy storage system (BESS) for the frequency deviation of the output of wind power source, but they do not consider the overall load and wind power fluctuations.

This paper, a bulk power substation that spans an area with different load types: residential, commercial, and industrial is considered to study the sizing of BESS to alleviate the frequency deviations. The frequency deviations is compounded because of the added wind power frequency unbalance. The BESS sizing is dependent on the extent to which the compounded frequency deviations exceed the frequency limits. Additionally, the BESS is composed of different battery groups in which each group takes over if the previous set cannot meet the frequency regulation requirements.

Literature states that adopting energy storage devices help regulating load frequency control and yield improved results. There is different energy storage devices, such as battery energy storage, capacitive energy storage, pumped hydro, and superconductors that were explained in [4]. Also, some resources in the literature showed that various storage devices have fast response to maintain frequency and respond to sudden frequency drop [5]. Detailed descriptions of these storage techniques were described in [6].

BESS is used for several ancillary services, such as load levelling, peak shaving, active filtering, etc. Load levelling for instance is achieved simply by regulating the current at the point of common coupling irrespective to the variable load demands. Similarly, reactive power compensation is implemented through making the supplied current lagging or leading. These characteristics of controlling both active and reactive powers enable the BESS to control network instability to certain limits, and load frequency control (LFC) is a good candidate for such an approach [7, 8, 9, 10, 11]. The authors in [7] discussed the feasibility of utilizing BESS in LFC applications. Extensive researches have been made to the sizing of BESS for both primary frequency control and secondary frequency control. A study was conducted in [8] to evaluate the BESS to primary secondary control, and the outcome was interesting. In a system with 50 % of renewable generation, a 5 % of the total generation is needed to maintain the frequency within limits. An advantage of utilizing

BESS is that it meets the power and energy requirements faster than its traditional generation unit counterparts.

Renewable energy resources receive attentions in micro-grid applications, which is attributed to its economic feasibility compared to traditional energy sources. Wind power resource as other renewable resources is characterized by intermittency, and hence it injects fluctuating power to a grid, thereby jeopardizing system voltage and frequency stability. In fact, this stems from the fact that the wind power is a function of the cubic power of wind speed, which is highly variant [12]. There has been many studies handling the frequency deviations caused by wind power resource through the BESS adoption [13]. Another study in [14] proposed a scheme in which BESS integrated with an LFC technique.

The remainder of this paper is organized as follows: Section II addresses the system model. The frequency control process is presented in Section III. Section III-A discusses the BESS operation. The simulation results and the conclusion are in Section IV and Section V, respectively.

II. System Model

The proposed model is tested using real frequency measured data that has a four-second resolution over a three-month period. Furthermore, the gathered data cover different seasons in order to account for several factors that affect the frequency control. The name and location of the network is kept hidden for confidentiality purposes. Sets of batteries and a wind power compose the underlying scheme for the frequency control application. The BESS handles the over/under-frequency anomalies by compensating the mismatch energy between generation and load, whether excess of shortage. The sets of the BESS run in a coordinated manner to rectify the frequency deviations with an optimal BESS sizing target.

The battery has a couple of constraints by which all the BESS elements abide. First, the timely state-of-charge (SOC) should lie between the maximum and minimum SOC as in (1), and secondly, the batteries power values must not be exceeded as in (2). Consequently, there is a great chance that the BESS system not to accommodate the frequency regulation (FR) if not designed properly taking into consideration these constraints. The SOC is governed by the charge/discharge power as well as the battery size. If the network is in overfrequency status, the timely SOC is decremented, and vice versa as seen in (3). The battery power limits should be higher than the expected required power for the frequency regulation. This required power computation is accomplished in accordance with the principle illustrated in Fig. 1. The scheduled charge/discharge power for satisfying the FC demand and for adjusting the SOC level is between the already selected power limits for regulation up and down. The regulation-up and the regulation-down power demand are chosen to be symmetric so as to consider different initial battery SOCs. Basically, the battery releases/absorbs the scheduled amount of power as a function of the frequency deviation at that moment.

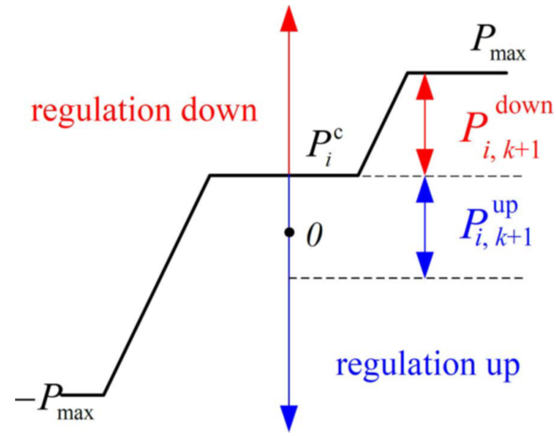

Fig. 1. Scheduled battery power for adjusting SOC level. [15]

$$SOC_{min} \leq SOC_t + x_t \leq SOC_{max} \tag{1}$$

$$\mid x_t \mid \leq P_{max} \tag{2}$$

$$SOC_{t+1} = SOC_t \pm \frac{P_{charge/discharge} \times \Delta t}{C_{bat}} \tag{3}$$

Where C_{bat} is the battery capacity.

III. Frequency Control

Frequency deviations are typically controlled via regulating generators output. The BESS resembles the generator actions through charge/discharge process in case of over/under-frequency. That is, the BESS absorbs the excessive amount of power to bring the frequency down, and discharges energy in case of power deficit to rectify the frequency abnormality. The generation-load power mismatch is the determining factor for either an overfrequency or underfrequency condition. In fact, the generation power part includes the grid scheduled generation in addition to the wind power output. In (4), the power fluctuation equation that determines the power needed to regulate the grid frequency as a result to both the scheduled power and the wind power is presented. The BESS power is added/subtracted to the equation depending on the situation at hand. The frequency compensation can be seen in (5), where the frequency at time t is subtracted/added from its previous reading based on whether it is an overfrequency or underfrequency situation.

$$\Delta P = P_{Gen} + P_{Wind} - P_{Load} \tag{4}$$

$$f_{t+1} = f_t \pm \Delta P \times k \tag{5}$$

Where k is a transformation constant that relies on the network frequency response, and it is set to 0.05 $\frac{Hz}{MW}$ throughout the whole year.

The average load capacity is 159.896 MW, the maximum loading is 188.728 MW, and the minimum is 131.549 MW.

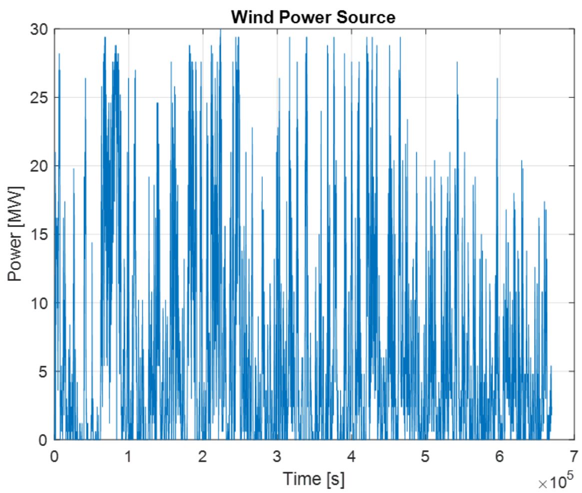

Fig. 2. Wind Power Source.

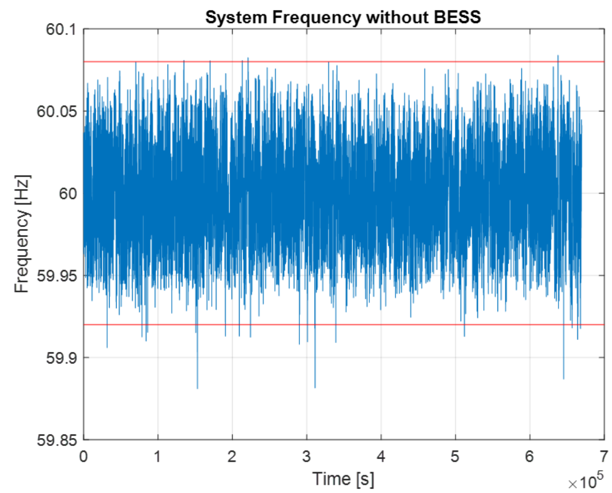

Fig. 3. System Frequency.

Moreover, the wind power has a peak power of 30 MW as displayed in Fig 2. The nominal frequency of the named network is 60 Hz and the deadband is 0.08 Hz, and thus the range within which the frequency is considered normal is between 59.92 Hz and 60.08 Hz. The proposed scheme sets priority list for the operation of the frequency control components. The battery with a higher capacity runs first to treat overfrequency cases, and if it saturates, reaches maximum SOC, the next smaller battery takes over and so on and so forth. Similarly, the same concept goes for underfrequency case. This is done to avoid cyclic charge/discharge if a smaller battery runs first.

A. BESS Output

The output of the installed BESS varies in accordance with the resultant frequency. Furthermore, the BESS follows its named constraints, so its sizing is critical, as the BESS might not meet the frequency requirements upon exceeding these constraints. As per (5) the frequency is directly related to the power deviation value ΔP; therefore, the BESS status (i.e. charge/discharge) depends on the power deviation sign. That is, the BESS injects power into the grid if the power deviation is in deficit, and vice versa. Thus, the frequency control model dealing with the wind power fluctuations as well as the load fluctuations is shown in (5). Of course, this model is employed only if the frequency is not within its deadband range.

$$\Delta P = P_{Gen} + P_{Wind} - P_{Load} \pm P_{BESS} \qquad (6)$$

IV. Simulation

The sets of BESS were introduced to the modeled system to test the effect of the grid frequency deviations with/without the wind power source on the BESS sizing. The frequency limits are selected to be within ± 0.08 Hz of the nominal frequency. In other words, the system is considered in abnormal case if its frequency is lower than 59.92 Hz, or above 60.08 Hz. The frequency measurements that are outside these limits are treated in a coordinated manner by the two-set batteries. The larger battery operates first and keeps running till reaching the maximum or the minimum capacity in which the smaller battery takes over.

The two scenarios through which the system frequency is tested for proper BESS size are with/without wind power source integration. The network frequency is shown in Fig. 3 depicting the frequency deviations in accordance with the defined deadband. The first case was to test the network without the wind power source to determine the BESS capacity in order to function as a FR. The frequency deviations, the deadband, and the initial BESS SOCs. For instance, the BESS capacity for the month of August was 298 MWh and 3 MW with initial SOC of 1 for both batteries. The reason for this is that the overfrequency conditions are only few and occur at late stages, so the first battery tackled it without exceeding the SOC maximum limit; on the other hand, the underfrequency conditions are many and span the entire interval, so having high initial SOCs, help avoid going below the minimum SOC limit. The rectification BESS process is observed in Fig. 4 that depicts the system frequency is brought back into tolerable range. The findings are different for different months in different seasons, as it is noticed in the month of December that is almost opposite to the findings of August. In other words, the overfrequency events surpass significantly its underfrequency counterparts; thus, it is more practical to impose a relatively lower initial SOCs compared to the case of August. Also, the BESS sizing increased by almost 40 % of the August month readings, while it is the highest in March 45 %. Consequently, The proper capacity of the BESS is 442 MWh to meet the FR throughout the year, assuming that the power mismatch does not go beyond the named three months since they cover different seasons in a year. Nevertheless, the initial BESS SOCs plays an important role in the BESS capacity selection. For example, if the initial SOCs in the August case was set to 0.7, the BESS would increase by about 20 %, which is significant enough to affect

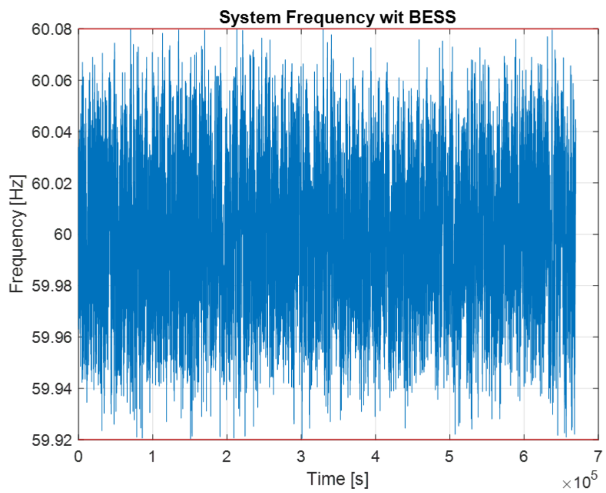

Fig. 4. System Frequency with BESS.

TABLE I
BESS TOTAL CAPACITY.

Month	BESS(MWh)	BESS(MW)
March	298	3
August	442	4
December	426	2

TABLE II
BESS TOTAL CAPACITY.

Month	BESS(MWh)	BESS(MW)
March	1280	7
August	2880	12
December	2410	9

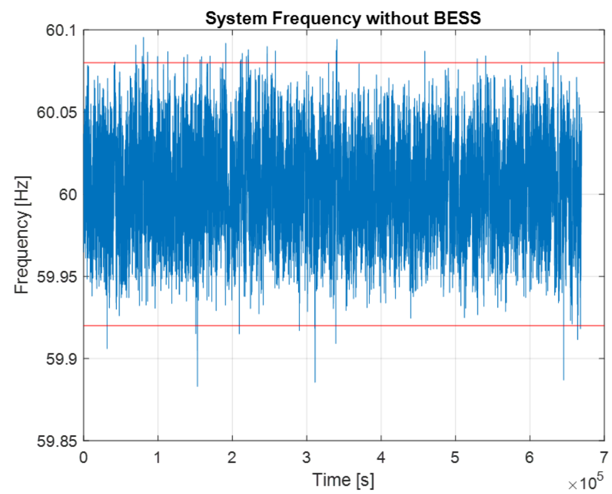

Fig. 5. System Frequency with BESS and Wind Power.

the integrity of the proposed model. Therefore, a leeway is added to the final BESS size to account for such uncertain initial SOC conditions. The summary of the BESS sizing is listed in Table I.

The second case involves the addition of the wind power to evaluate the impact against the network frequency, and it turned out significant. The frequency deviations of the month of August crossed the tolerance range much more than its first case counterpart as shown in Fig. 5. For the sake of comparison, the BESS capacity in August hit 1280 MWh to maintain the frequency range, which is more than 400 % of the no-wind-power scenario. Similarly, the other seasons experience a huge difference in the BESS capacity from the first case as listed in Table II.

Seemingly, the addition of the wind power causes lots of disturbance to the system that is rectified by the BESS, but it becomes costly prohibitively for larger wind power sources. Additionally, the wind power forms nearly 20 % of the demand load peak, yet it makes the network unstable from the frequency viewpoint. Hence, one is to seek other alternatives such as DG units, or even to relax the frequency tolerance domain in order to reduce the BESS size. Nevertheless, the wind power source helped for the underfrequency cases, as it randomly escalates the load profile, and it happens that there is a coherence between the underrequency moments and the wind power contribution. This, however, worsened the overfrequency events, thereby offsetting the earlier underfrequency advantage. Noticeably, the load variations as a result of different seasoning is manifested in the provided data for the three months. The overfreuency events are much lower than the underfrequency in the August dataset, while it is quite the opposite for the December dataset. The is expected since the load demand varies according to the seasonal factor; in summer, load rises and it decreases in winter. In addition, the over/under frequency cases are almost balanced during the March period.

V. CONCLUSION

A coordinated model of BESS was proposed in this paper for FC for the selected network in the presence and without the presence of a wind power source. The sizing of the BESS relies on the initial SOCs, frequency deviations range, and the season over which the study is considered. The wind power source hurt the frequency response of the grid and the needed BESS capacity escalated to very large values. Having adopted relatively large wind farm sources, the expected frequency deviations would eclipse any BESS unless it is utilized with other systems, like DG.

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