

Battery Energy Storage Station (BESS) Based Smoothing Control of Photovoltaic (PV) and Wind Power Generation Fluctuations

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ABSTRACT: The battery energy storage station (BESS) is the current and typical means of smoothing wind- or solar-power generation fluctuations. Such BESS-based hybrid power systems require a suitable control strategy that can effectively regulate power output levels and battery state of charge (SOC). This paper presents the results of a wind/photovoltaic (PV)/BESS hybrid power system simulation analysis undertaken to improve the smoothing performance of wind/PV/BESS hybrid power generation and the effectiveness of battery SOC control. A smoothing control method for reducing wind/PV hybrid output power fluctuations and regulating battery SOC under the typical conditions is proposed. A novel real-time BESS-based power allocation method also is proposed. The effectiveness of these methods was verified using MATLAB/SIMULINK software.

KEYWORDS: battery energy storage station, SOC control, photovoltaic system.

I. INTRODUCTION

In recent years, electricity generation by photovoltaic (PV) or wind power (WP) has received considerable attention worldwide. The State Grid Corporation of China (SGCC) is building the National Wind/PV/battery energy storage station (BESS) and Transmission Joint demonstration project and it is located in the region of Zhangbei, Hebei, China. The Zhangbei belongs to one of the country's 10 million kilowatts of wind power base[1-4]. The demonstration project is scheduled in three stages. Now, it is in the first stage and at the end of December, 2011, a 100-MW wind farm, a 40-MW PV farm, and 14-MW/63-MWh lithium-ion BESS have been built at Zhangbei.

The battery energy storage system can provide flexible energy management solutions that can improve the power quality of renewable-energy hybrid power generation systems. To that end, several control strategies and configurations for hybrid energy storage systems, such as a battery energy storage system, a superconducting magnetic energy system (SMES), a flywheel energy system (FES), an energy capacitor system (ECS), and a fuel cell/electrolyzer hybrid system, have been proposed to smooth wind power fluctuation or enhance power quality. Thanks to the rapid development of batteries, battery energy storage systems recently have begun to be utilized for multiple applications such as frequency regulation, grid stabilization, transmission loss reduction, diminished congestion, increased reliability, wind and solar energy smoothing, spinning reserve, peak-shaving, load leveling, uninterruptible power sources, grid services, electric vehicle (EV) charging stations, and others.

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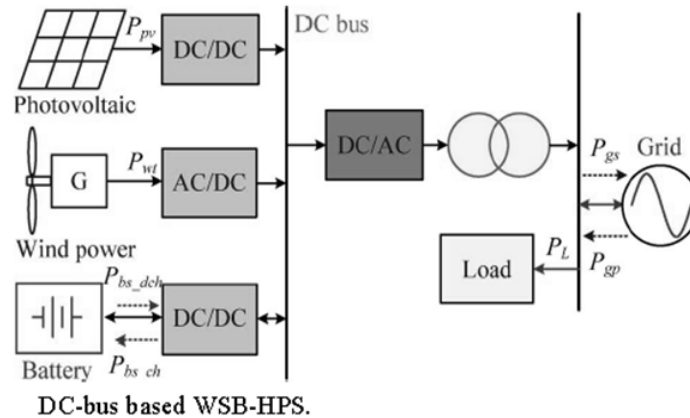


Figure: 1 Block Diagram of the BESS

These days, the issue of how power fluctuations in PV and wind power generation are to be smoothed has attracted widespread interest and attention. And even as this issue is being resolved, another one,[5-9] that of the application of an energy storage system such as BESS, has arisen. When using BESS to control PV and wind power fluctuations, there is a trade-off between battery effort and the degree of smoothness. That is, if one is willing to accept a less smooth output, the battery can be spared some effort.

Thus far, although various effective BESS-based methods of smoothing power fluctuations in renewable power generation systems have been proposed, smoothing targets for grid-connected wind and PV farms generally have not been formulated. Smoothing control by way of power fluctuation rate limits, for such systems, has rarely even been discussed. The control strategies published in were formulated mainly for small-scale BESS-based smoothing; hence, they did not consider power allocation among several BESS. A suitable and effective control strategy for large-scale BESS, therefore, remains an urgent necessity.

In the present study, under the assumptions that the capacities of the WP and PV hybrid generation system (WPPVGS) and BESS had already been determined and that we do not have ability to adjust the WPPVGS output power, a large-scale BESS was used to smooth the WPPVGS output power fluctuation. More specifically, Wind/PV/BESS hybrid power generation system along with a state of charge (SOC)-based smoothing control strategy was utilized to instantaneously smoothen WP and PV power fluctuations. This was accomplished by modifying smoothed target outputs adaptively and making flexible use of feedback adjustments of battery SOC in real-time.

II. DESIGN OF WIND TURBINE

Wind results from the air in motion. Wind causes by the uneven heating of the land and the water. The aero turbine is used to converter the wind energy into mechanical energy. The turbines are of horizontal and vertical axis turbine. The pitch control and yaw control is used in the aero turbine.

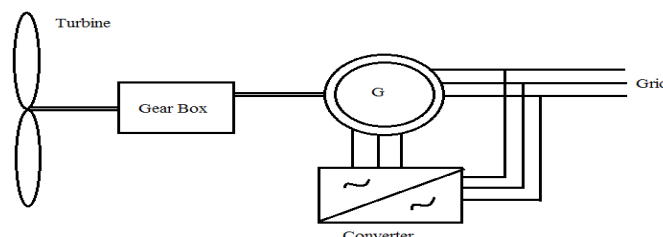


Figure: 2 wind turbine

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The gear box is used to increase the speed which prevents the turbine. Generators are used to convert the mechanical energy into the electric energy. Synchronous and induction generators are used. Double fed induction generator is most widely used generator in the wind power. Converters are used to control the rotor current. The output is given to the grid.

III. SOLAR DESIGN

Energy from the sun is the solar energy. The PV Panel is used to convert the solar energy into electrical energy. PV Panel is a group of PV cells connected in series or parallel. PV cell consists of two layers and a separation layer wired together to form a module. When the panel is exposed to sun light, the photons from the sun interact with the electrons present in the top layer of the solar cell which loses the atom [9-11]. This atom moves towards the electrons in the bottom layer of the cell. This loses the atom and moves towards the wire. The flow of electrons from the one layer to another layer through a wire is the electric current.

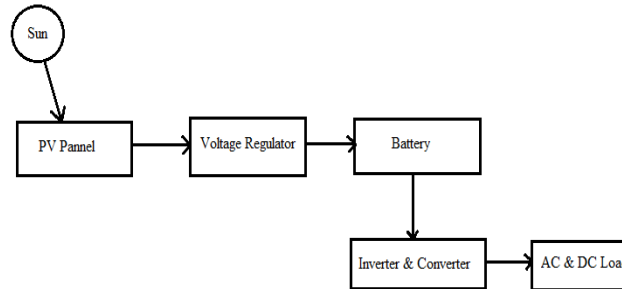


Figure: 3 Block diagram of the Solar PV

The sunlight varies due to radiations during daytime and night. So that the output of the PV panel is also varying. The voltage regulator is used to regulate the output of the PV panel. The energy can be stored in the battery for a future use. The inverter and the converters can also be used and fed to the different loads.

IV. MODELING OF BESS

A 100-kWh lithium iron phosphate (LiFePO₄) lithium ion BESS has been modeled in reference to the **R-int** model presented in [23]–[26]. The schematic diagram of battery equivalent circuit model is shown in Fig. 4. In general we know that **V-bat** can be expressed as (1). Moreover, as shown in (2) and (3), **V-ocv** and **R-int** are determined by using lookup tables based on experimental data presented in Figs. 5 and 6. Fig. 5 presents characteristics of open circuit voltage via battery SOC. Fig. 6 presents internal resistance via battery SOC. The battery SOC is calculated by using (4) and (5) and the *n* is calculated depending on battery charging/discharging status. The charging power of BESS is indicated by the “-” symbol and the discharging power of BESS is indicated by the “+” symbol, respectively. In this paper, 1-MWh BESS is considered by integrating five 200-kWh LiFePO₄ lithium-ion BESSs in parallel. Specification of 1-MWh BESS is shown in Table I.

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Index	Description
Whole system	Five 200kWh BESS in parallel
Every 200kWh BESS	two 100kWh BESS in parallel
Every 100kWh BESS	ten battery modules in series
1 module	twenty-four 120Ah single batteries in series
Single battery capacity	120Ah (two 60Ah batteries in parallel)
Rated power	5x200kW=1MW
Maximum working voltage	840V
Minimum working voltage	696V

Table -1 specification of battery energy storage system

$$V_{bat} = V_{ocv} - R_{bat}^{int} I_{bat} \quad (1)$$

Where,

$$V_{ocv} = f_1(SOC) \quad (2)$$

$$R_{bat}^{int} = \begin{cases} R_{ch} = f_2(SOC) & \text{charging} \\ R_{dis} = f_3(SOC) & \text{discharging} \end{cases} \quad (3)$$

$$SOC = SOC_{ini} - \int \frac{\eta I_{bat}}{Q_{bat}} dt \quad (4)$$

$$\eta = \begin{cases} \eta_{ch} = \frac{V_{ocv}}{V_{ocv} - I_{bat} R_{ch}} & \text{charging} \\ \eta_{dis} = \frac{V_{ocv} - I_{bat} R_{dis}}{V_{ocv}} & \text{discharging.} \end{cases} \quad (5)$$

V. SOC-BASED SMOOTHING CONTROL STRATEGY

This paper proposes a new control strategy for smoothing of wind and PV power fluctuations by means of feedback control of SOC and a large-scale BESS[11-14]. First, the smoothing problem is formulated based on the power fluctuation rate. The power fluctuation rate can be considered as an assessment indicator for PV and WP generation equipment that is connected to the power grid.

In general, in order to operate the BESS continuously, the battery SOC needs to be controlled within a certain range. As a result, it can prevent the forced shutdown of the BESS due to overcharge or over-discharge of batteries.

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Moreover, control strategies for BESS and smoothing applications need to be developed to efficiently dispatch real-time total power demand of BESS between each PCS. Meanwhile, if the individual storage unit of SOC is higher or lower, the adaptive coordination of the smoothing level and of the power distribution between energy storage units should be considered based on the SOC and the maximum available charge or discharge power constraints of battery energy storage systems[14-18]. In this paper, accordingly, the following four stages have been proposed based on the above-noted power fluctuation rate indicators for determination of the target power of the BESS and of each PCS.

1) Stage 1: Determine Initial Target Power of BESS:

Method 1: The initial power of the BESS is calculated based on the dynamic filtering controller (DFC), as shown in the following:

$$P_{BESS}^{ini}(t) = P_{WPPV}^{smooth}(t) - P_{WPPV}(t) \quad (6)$$

$$\text{if } r_{WPPV}(t) \leq \delta_{WPPV}(t)$$

$$P_{WPPV}^{smooth}(t) = P_{WPPV}(t) \quad (7)$$

$$\text{if } r_{WPPV}(t) > \delta_{WPPV}(t)$$

$$P_{WPPV}^{smooth}(t) = P_{WPPV}^{smooth}(t - \Delta t)e^{-\Delta t/T_{WPPV}} + \frac{\Delta t}{T_{WPPV}} P_{WPPV}(t) \quad (8)$$

$$r_{WPPV}^T = f_{WPPV} \left(\frac{P_{WPPV}^{max} - P_{WPPV}^{min}}{P_{WPPV}^{rated}} \right)_T \quad (9)$$

$$r_{hybrid}^T = f_{hybrid} \left(\frac{P_{hybrid}^{max} - P_{hybrid}^{min}}{P_{WPPV}^{rated}} \right)_T \quad (10)$$

$$P_{WPPV}^{rated} = \sum_{k=1}^w U_k^{WP} P_{WP_k}^{rated} + \sum_{k=1}^V U_k^{PV} P_{PV_V}^{rated} \quad (11)$$

$$P_{WPPV}^{max} = \max\{P_{WPPV}(t), P_{WPPV}(t - \Delta t), \dots, P_{WPPV}(t - (n - 1)\Delta t)\} \quad (12)$$

$$P_{WPPV}^{min} = \min\{P_{WPPV}(t), P_{WPPV}(t - \Delta t), \dots, P_{WPPV}(t - (n - 1)\Delta t)\} \quad (13)$$

$$P_{hybrid}^{max} = \max\{P_{hybrid}(t), P_{hybrid}(t - \Delta t), \dots, P_{hybrid}(t - (n - 1)\Delta t)\} \quad (14)$$

$$P_{hybrid}^{min} = \min\{P_{hybrid}(t), P_{hybrid}(t - \Delta t), \dots, P_{hybrid}(t - (n - 1)\Delta t)\} \quad (15)$$

$$P_{WPPV}(t) = P_{WP}(t) + P_{PV}(t) \quad (16)$$

$$P_{hybrid}(t) = P_{WP}(t) + P_{PV}(t) + P_{BESS}(t) \quad (17)$$

Method 2: The initial power of the BESS is calculated based on the proposed dynamic rate limiter; that is, the rate of power change at time is calculated by

$$r_{WPPV}(t) = \frac{P_{WPPV}(t) - P_{WPPV}(t - \Delta t)}{\Delta t} \quad (18)$$

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Then, the smoothing power is determined using the following rules:

$$K_{WPPV}^{drop} \leq r_{WPPV}(t) \leq K_{WPPV}^{rise}$$

$$P_{WPPV}^{DRL}(t) = P_{WPPV}(t) \quad (19)$$

$$r_{WPPV}(t) > K_{WPPV}^{rise}$$

$$P_{WPPV}^{DRL}(t) = P_{WPPV}^{DRL}(t - \Delta t) + \Delta t \cdot K_{WPPV}^{rise} \quad (20)$$

$$r_{WPPV}(t) < K_{WPPV}^{drop}$$

$$P_{WPPV}^{DRL}(t) = P_{WPPV}^{DRL}(t - \Delta t) + \Delta t \cdot K_{WPPV}^{drop} \quad (21)$$

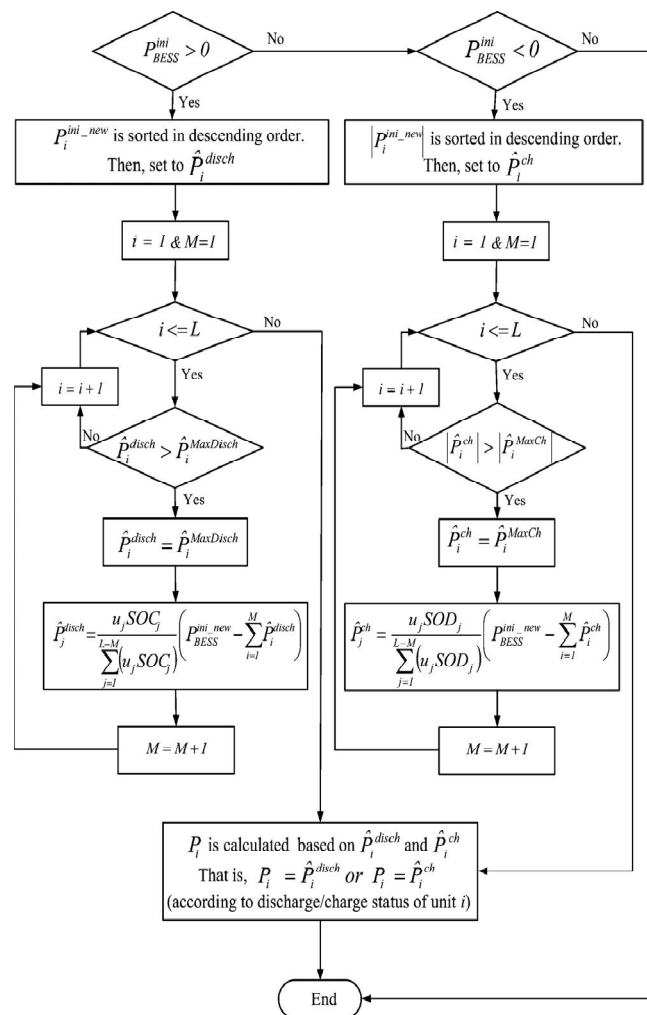


Figure: 4. Flowchart of process for meeting allowable power constraints of each BESS unit

VI. SIMULATION RESULTS

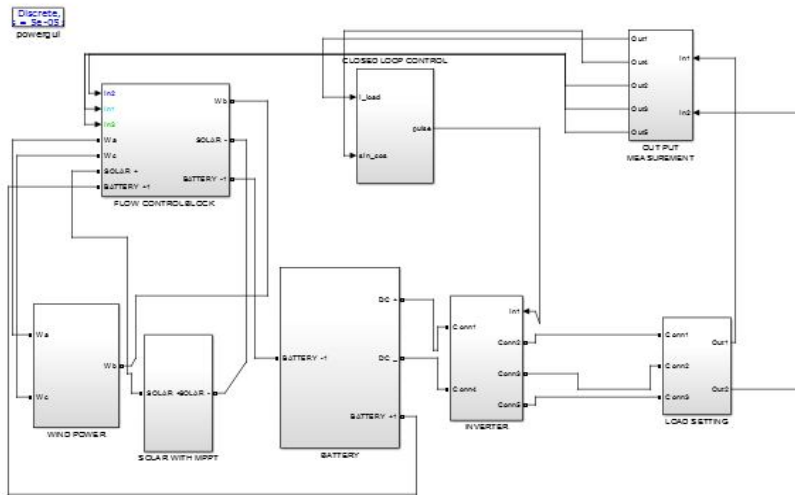


Figure: 5 simulink model

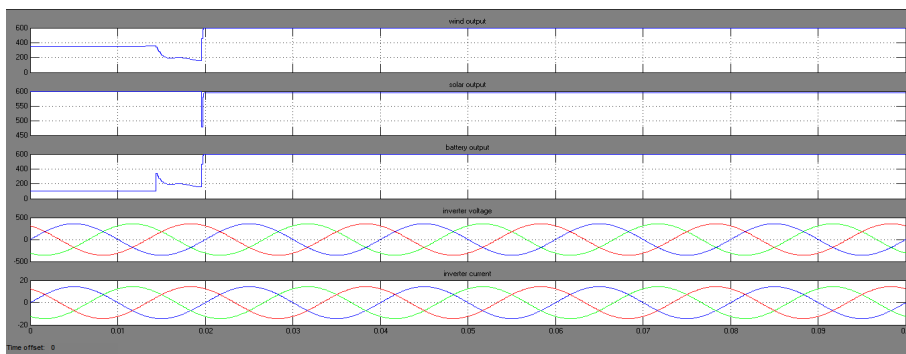


Figure: 6 output waveform

VII. CONCLUSION

From the present research results, it can be seen that by using the proposed control method, the SOC of each battery energy storage unit can gradually move toward 50% with the increase of control time although the initial SOC of the energy storage unit is different. It is also considered that this control method can make the storage unit share the load as consistently as possible, so as to achieve the effect of extending the service life of the energy storage system and, therefore, can delay the accelerated decay of the battery performance. Moreover, it should be noted that some filtering on the BESS charge and discharge power have been achieved by using a power fluctuation rate constraint as the smoothing control target to prevent excessive excursions to “chase down” every PV or wind power output fluctuation. In addition, the control strategies of BESS and smoothing based on battery capacity established conditions was focused. Another significant issue is the means by which an appropriate battery capacity for this application is to be determined.

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