Energy Management of Renewable Energy System with ESS

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Abstract

This paper discusses the effectiveness of BESS energy management method. Such BESS-based renewable energy systems require a suitable control strategy that can effectively regulate power output levels and battery state of charge (SOC) within a specified range. The control method can supervise the SOC to secure the charging level of the BESS by adjusting the target power for high and low SOC ranges. Considering the results of energy management and effectiveness of battery SOC control, regulation of battery SOC under typical conditions is proposed.

Keywords: Battery Energy Storage Station (BESS), Smoothing Control, State of charge (SOC), wind power generation.

1. Introduction

The growth of renewable energy systems has exceeded the most optimistic estimation. Wind power generation is one of the most promising renewable power generation technologies but this is highly dependent on climate. As different alternative energy sources can complement each other to some extent, hybrid multisource energy systems have great potential to provide a quality power than a single source system. Due to intermittent nature of wind energy, standalone wind system requires energy storage system to form a hybrid system [1].

Present storage devices may be kinetic, electromechanical, electromagnetic, or potential energy based. Each has specific characteristics those results in differences in terms of energy storage density, power capability, and costs. The pairing of wind power with energy storage systems would serve to mitigate many of the negative characteristics of the wind which facilitates its synchronization with the power system. Large capital investment compels intelligent management of wind and energy storage
systems operation [2]. With renewable energy, the power fluctuations are present at different frequencies which results in distorted power output. Energy storage station (BESS) is a typical means of smoothing wind power generation fluctuations as shown in Fig. 1. Such power systems require a control strategy to regulate power output levels and battery state of charge (SOC) [3].

In this study, we assume that the capacity of wind power generation and BESS has already been determined and we do not have to adjust the wind power output power, a BESS system is introduced to smooth the wind power output fluctuations. The results of target output of BESS is obtained varying in percentage of its capacity are verified.

2. System Modeling
To discover the results of SOC based controlled power management system and investigate the system performance, battery model for PSCAD/EMTDC simulation is developed.

2.1 Modeling of Wind Power Generation System
A variable speed pitch regulated wind turbine is considered in this paper, where pitch angle controller plays an important role. Wind power is directly proportional to the air density, area swept by rotor blades and the wind velocity.

<table>
<thead>
<tr>
<th>Wind Energy Conversion System (WECS)</th>
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<tbody>
<tr>
<td>Wind Turbine</td>
<td></td>
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<tr>
<td>Rated Power</td>
<td>2500 KW</td>
</tr>
<tr>
<td>Cut in speed</td>
<td>28 - 34 m/s</td>
</tr>
<tr>
<td>Rotational Speed</td>
<td>Variable</td>
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<tr>
<td>Doubly Fed Induction Generator</td>
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<tr>
<td>Rated Power</td>
<td>2500 KW</td>
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<tr>
<td>Rated Voltage</td>
<td>33 KV</td>
</tr>
<tr>
<td>Rated Frequency</td>
<td>60 Hz</td>
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The wind power generation system is modelled on a 2.5-MW wind turbine using a DFIG induction generator [1]-[3]. Wind turbine parameters are given in Table 1 and ideal wind characteristic is shown in Fig. 2.

2.2 Modelling of Battery Energy Storage System
The schematic diagram of battery equivalent circuit model is shown in Fig. 3. In general $V_{bat}$ can be expressed as

$$V_{bat} = V_{ocv} - R^{ini}_{bat} I_{bat}$$

where

$$V_{ocv} = f_1(SOC)$$

(2)

$$R^{ini}_{bat} = \begin{cases} R_{h}=f_2(SOC) & \text{charging} \\ R_{dis}=f_2(SOC) & \text{discharging} \end{cases}$$

(3)

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

(4)

$$\eta = \begin{cases} \eta_{ch} = \frac{V_{ocv}}{V_{ocv} - I_{bat} R_{dis}} \\ \eta_{dis} = \frac{V_{ocv} - I_{bat} R_{dis}}{V_{ocv}} \end{cases}$$

Battery is an electrochemical device, which consists of two electrodes, an anode, and the cathode, which are separated by an electrolyte. Both electrodes allow lithium ions to migrate towards and away from them. During insertion ions move into the electrode. During the reverse process, extraction, ions move back out. When a lithium-based cell is discharging, the positive ion is extracted from the negative electrode.
(usually graphite) and inserted into the positive electrode (lithium containing compound). When the cell is charging, the reverse occurs. A 100 KWh BESS has been modelled by using PSCAD. The SOC of a battery is its available capacity expressed as a percentage of its rated capacity. Knowing the amount of energy left in a battery, compared with the energy it had when it was new, gives the user an indication of how longer a battery will continue to perform before it needs recharging [4].

3. Energy Management Strategy
The energy management of the renewable energy system using BESS rely on the battery state of charge (SOC). For this purpose, the BESS is allowed to operate in percentage (10%, 50% and 100%) of its capacity. The target power of BESS is obtained in this zone. 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 shut down of the BESS due to overcharge or over-discharge of batteries. Control strategies for BESS and smoothing applications need to be developed to efficiently dispatch real-time total power demand of BESS between Power Converter System.

As seen from Fig. 4, instantaneous power control strategy is used. Clarke’s transformation is used to obtain reference values of power which helps in monitoring the real and reactive power. The reference signal generated by this control loop helps in monitoring the firing pulses. It is essential to use Phase Locked Loop (PLL) in order to generate the reference current. It is the fast dynamic response that makes this control method a promising solution to the challenges before engineers. Sine PWM generator generates the pulses for STATCOM controlled battery energy storage station. One of the most important reasons for obtaining smoothed power is the synchronization with the grid voltage waveforms. Converters should be properly synchronized with the grid to stay actively connected, supporting the grid services (voltage/frequency) and keeping generation up even in the case when the voltages at its point of coupling to the grid are distorted and unbalanced.

Control strategy for BESS based smoothing has the following stages:
Stage 1: Determine Initial Target Power of BESS
Stage 2: Determine Target Power of each power converter system
Stage 3: Determine Modified Target Power of each power converter system
Stage 4: Determine Target Power for each Unit

The target power obtained in stage 4 decides the charging/discharging of the BESS. By adjusting power fluctuation rate limit value, the trade-off between battery effort and some degree of smoothness can be obtained. When approaching 0% SOC, the allowable maximum discharge power of unit is set to 0 to prevent the over discharge of BESS unit. Otherwise, when approaching 100% SOC, the allowable maximum charge power of unit is set to 0 to avoid the overcharge of BESS unit. When the battery is in the discharging state, the battery discharge power is proportional to the
SOC value; conversely, when the battery in the charging state, the charging power is inversely proportional to the SOC value [3].

Target smoothing power is given as:

\[ P_{BESS} = \sum_{i=1}^{L} P_i \]  

\[ P_{BESS}^{smooth} = P_{WIND} + P_{BESS} \]  

where

\[ L \text{ – number of power converter systems} \]
\[ P_i \text{ – target power} \]
\[ P_{BESS} \text{ – target power of BESS} \]
\[ P_{WIND} \text{ – generated wind power} \]
\[ P_{BESS}^{smooth} \text{ – smoothing power} \]

The proposed smoothing control method can supervise the SOC to secure the charging level of the BESS. The effectiveness of the proposed BESS energy management method considering overcharge/over-discharge SOC conditions, the initial SOCs of the BESS unit is considered 10%, 50% and 100% respectively.

### 4. Validation

The simulation results of the system under percentage of battery capacity are obtained as follows:
Case 1: without BESS.

Case 2: with 10% BESS capacity.

Case 3: with 50% BESS capacity.
Case 4: 100% BESS capacity.

Fig. 6: without BESS, 10%, 50%, and 100% of BESS SOC control.

The graph (Fig. 6) is plotted for some cases with BESS connected to wind power utilizing 0%, 10%, 50% and 100% of battery capacity. When there is no smoothing (case 1) with the absence of ESS, the power fluctuation is very high. For 10% BESS capacity (case 2) the power is somewhat smoothed, at 50% BESS capacity (case 3) the smoothing is somewhat enhanced and at 100% BESS capacity (case 4) the desirable result is obtained.

5. Conclusion
We conclude that the effectiveness of BESS energy management method is verified. Suitable control strategy for renewable energy systems can effectively regulate power output levels and battery state of charge (SOC) within a specified range. Simulation studies have been carried out to verify the system performance under different scenarios using the wind turbine data. The simulation results given for different ESS scenario, shows the effectiveness of the overall power management strategy and the feasibility of the proposed renewable energy system.

References


