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Battery Energy Storage Station Based Smoothing Control of Wind and Photovoltaic Power Generation Fluctuations Using SOC Control Strategy

Dayana.V. John[1] and M.Marsaline Beno[2]

[1]PG student, [2]Professor, SXCCE, Nagercoil, Tamil Nadu, India

E-mail: dayana.john5@gmail.com, marsaline_me@yahoo.com]

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Abstract - **The battery energy storage system (BESS) is the current typical means of smoothing intermittent wind or solar power generation. Such BESS 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/PV/BESS hybrid power system simulation analysis under taken to improve the smoothing performance of wind and Photovoltaic (PV) power generation and the effectiveness of battery SOC control. A wavelet based power smoothing method is presented for reducing output power fluctuations of wind/PV hybrid power generation systems and regulating the battery SOC. The effectiveness of the proposed method was verified using MATLAB/SIMULINK software.**

Keywords: **Smooting control, battery energy storage station(BESS), Solar power generation, state of charge, Wind power generation**

I. Introduction

In recent years, generation of electricity using wind power has received considerable attention worldwide. When a large number of renewable power generation access to power grid, the following issues deserve us further consideration and study in order to maintain the power quality of utility- and micro-grid Power system:

1) Stabilize power quality of islanding /interconnected system
2) Smooth output fluctuation of PhotoVoltaic (PV) and WindPower (WP) generation
3) Quantify the economics of new energy generation
4) Effectively integrate intelligentized multiuser power system
5) Determineoptimal energy generation/storage capacity, etc.

On solution of 1) and 2) is to incorporate wind power generation system(WPGS) or/and PV generation system(PVGS) with the energy storage system. 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[1]–[5], [13]–[19], a superconducting magnetic energy system(SMES) [6], a flywheel energy system (FES) [7], an energy capacitor system (ECS) [8]–[12], and a fuel cell/electrolyzer hybrid system [20], [21], have been proposed to smooth wind power fluctuation or enhance power quality.

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, 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 [2],[3], [5], 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 [1]–[5], [13]–[19], [25], [26] 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.

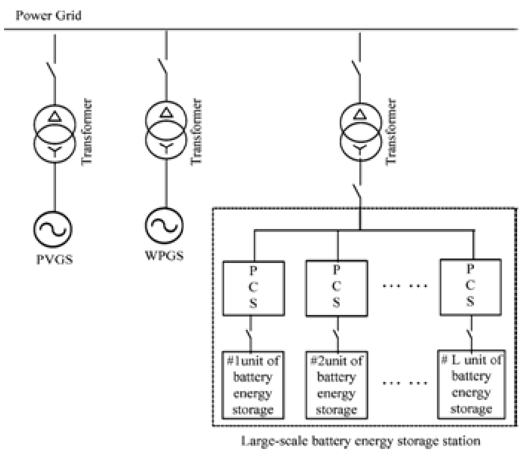

Fig.1 Wind/PV/BESS hybrid power generation system

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 (Fig. 1) 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. The detailed procedure is explained in Section III.

This paper is organized as follows. Section II presents the modeling of each power source. Section III describes a SOC-based control strategy for smoothing power fluctuations of WPPVGS output. Simulation results are discussed in section IV.section V is the conclusion.

II. Modeling of Power Sources

A. Modeling of Wind Power Generation System

The energy that can be extracted from the wind is directly proportional to the cube of the wind speed, so an understanding of the characteristics of the wind (velocity, direction, variation) is critical to all aspects of wind energy generation from the identification of suitable sites to predications of the economic viability of wind farm projects to the design of wind turbine themselves, all is dependent on characteristic of wind.

1Kinetic energy E of an object having mass M and velocity V is equal to the work done W.

$$E=W=Fs \tag{1}$$

$$E=m*(V\ \ /2s)*s \tag{2}$$

$$P=dE/dt \tag{3}$$

$$P_m= 0.5\rho AV\ \ (V^2\text{-}V^2) \tag{4}$$

$$P_m=0.5\rho\pi R^3 V_w^{\ 2} C_p(\lambda,\beta) \tag{5}$$

$$T_m=0.5\rho\pi R^3 V_w^{\ 2} C_p(\lambda,\beta)/\lambda \tag{6}$$

$$C_p= (1+ (V_d/Vu)) ((1\text{-}(V_d/V_u)^2)/2 \tag{7}$$

$$\lambda=V_d/V_u \tag{8}$$

A=area

ρ=density of air

Vu=upstream wind velocity in m/s

V_d=downstream wind velocity in m/s

C_p=power coefficient which is a function of both λ,β

λ=tip speed ratio

β =blade pitch angle

P_m=power from wind

T_m=mechanical torque of wind turbine

In this paper, wind speed is modeled by multiplying a random speed fluctuation derived from the white noise block in MATLAb/SIMULINK as shown in fig.2.

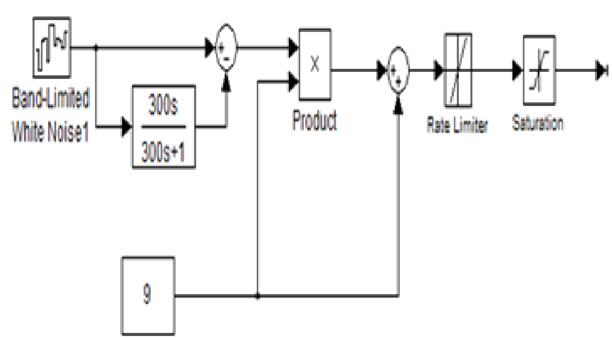

Fig.2 model of wind speed using MATLAB/simulink

B. Modeling of PV Power Generation System

In this paper, the power level of actual PV generation power is magnified.

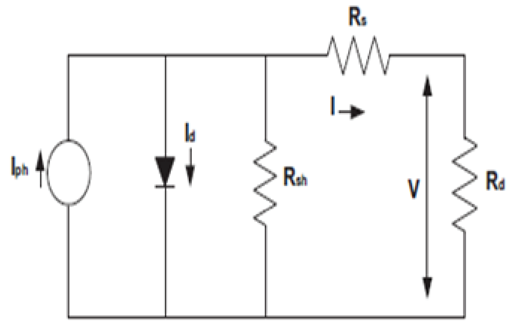

Fig.3 Equivalent circuit of a photovoltaic cell

Based on the equivalent circuit of cell, cell output current can be written as,

$$I = I_{ph} - I_D - I_{sh} \tag{9}$$

The photo current Iph depends on the solar radiation and the cell temperature as given by:

$$I_{ph} = [I_{sc} + K_i(T - 298)]\frac{\beta}{1000} \tag{10}$$

Current through diode is given by

$$I_D = I_o(e^{q\frac{V+IR_s}{KTA}} - 1) \tag{11}$$

Current through shunt resistance,

$$I_{sh} = \frac{V+IR_s}{R_{sh}} \tag{12}$$

Cell saturation current varies with cell current which can be related by the equation given below:

$$I_o = I_{rs}(\frac{T}{298})^3 \ e^{\frac{qE_g(\frac{1}{298}-\frac{1}{T})}{KA}} \tag{13}$$

So the output current of a photovoltaic cell becomes, sub (10),(11),(12) in (13)

$$I = I_{ph} - I_O(e^{\frac{q(V+IR_S)}{KTA}}\text{-}1) - \frac{V+IR_s}{R_{sh}} \tag{14}$$

The mathematical model of generalized model can be obtained as :

$$I = N_p I_{ph} - N_P I_0(e^{\frac{q\left(\frac{V}{N_S}+\frac{IR_S}{N_P}\right)}{KTA}} - 1 \tag{15}$$

C. Modeling of BESS

Battery energy storage system as the voltage regulator device is widely used in distributed power generation system. Lithium ion battery has broad application prospects in the energy storage system.

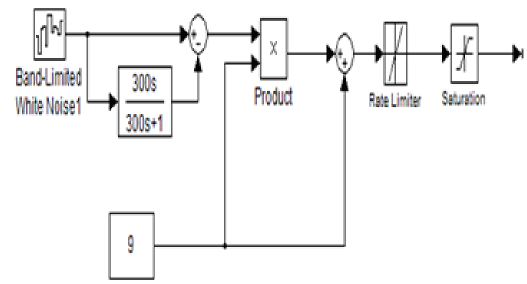

Fig. 4 Lithium ion battery equivalent circuit model

$$du^1/dt=(-1/R_1C_1)u_1+(1/C_1)I \tag{16}$$

$$du^2/dt= -(1/R_2C_2)u_2+(1/C_2)I \tag{17}$$

$$u_L=ovc(soc)+iR_0+u^1+u^2 \tag{18}$$

u_L=battery voltage across the load

u^1,u^2=respectively stands for the voltage across RC links C_1,C_2

i=the current flowing through the load

III. Soc-Based 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. 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. As (19)–(25) indicate, the power fluctuation rates over the investigated time period are used to evaluate the control effect of PV and WP smoothing both with and without the BESS. That is, as shown in equations (19)–(25).

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.

$$P_{WPPV}^{max} = \max\{P_{WPPV}(t), P_{WPPV}(t - \Delta t), \ldots\ldots P_{WPPV}[t-(n-1)\Delta t]\} \tag{19}$$

$$P_{WPPV}^{min} = \min\{P_{WPPV}(t), P_{WPPV}(t - \Delta t), \ldots\ldots P_{WPPV}[t-(n-1)\Delta t]\} \tag{20}$$

$$P_{hybrid}^{max} = \max\{P_{hybrid}(t), P_{hybrid}(t - \Delta t), \ldots\ldots P_{hybrid}[t-(n-1)\Delta t]\} \quad (21)$$

$$P_{hybrid}^{min} = \min\{P_{hybrid}(t), P_{hybrid}(t - \Delta t), \ldots\ldots P_{hybrid}[t-(n-1)\Delta t]\} \quad (22)$$

$$T = n\Delta t \quad (23)$$

$$P_{WPPV}(t) = P_{WP}(t) + P_{PV}(t) \quad (24)$$

$$P_{hybrid}(t) = P_{WP}(t) + P_{PV}(t) + P_{BESS}(t) \quad (25)$$

IV. Simulation And Results

Battery is used to smooth the output power of wind and PV. Here the battery used is the lithium ion battery. The DC output produced by the battery is converted into AC by using an inverter and the output of the inverter is fed to the power grid through transformer and breaker. Hybrid system consists of wind model, PV model and the battery model. For the wind turbine varying wind speed is given. A load is connected to the combined system after .05sec using a breaker. Then the battery is connected to the power grid after .07sec using another three phase breaker. The simulink diagram for hybrid system can be obtained as in Figure 6.

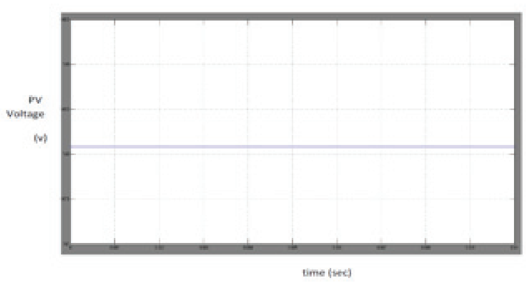

Fig. 5 Output voltage of PV array

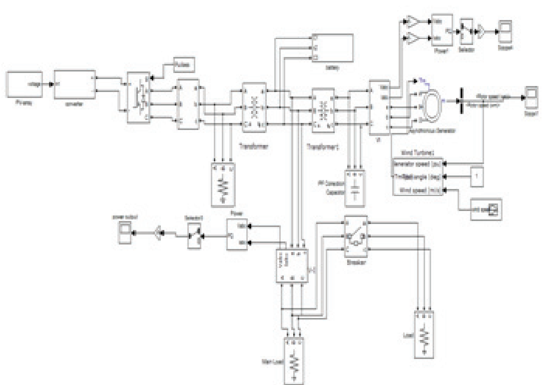

Fig. 6 Simulink model of hybrid system.

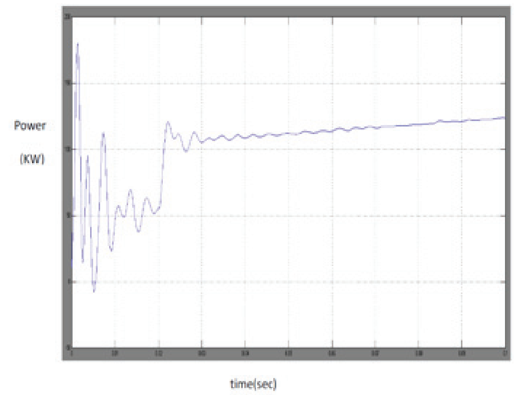

Fig. 7 Output power of wind turbine system rated capacity of wind turbine system is considered as 100KW

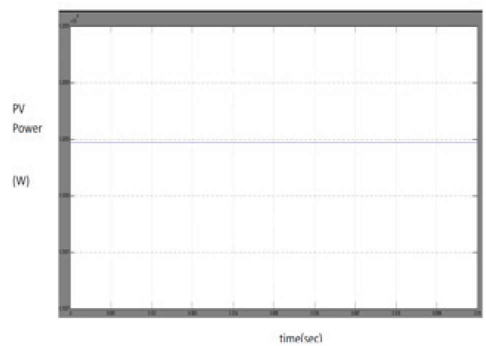

Fig. 8 Output power of PV array

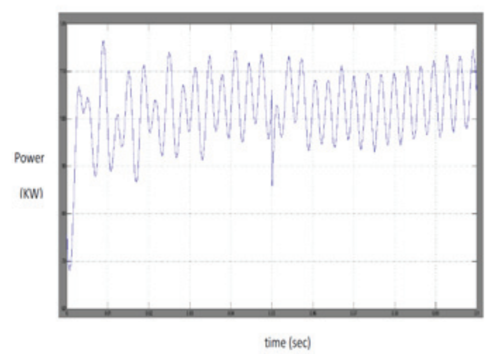

Fig. 9 Output power of combined system

From the above output waveform Figure 9, it is clear that up to .05sec fluctuations in output power occur due the change in the wind speed. At .05sec a load is connected which shows a change in the output power. At .07sec a battery is connected which smoothen the output power fluctuations.

V. Conclution

In this work, wind and PV systems change in output power are smoothened using battery energy storage system. At first the wind and PV systems were modelled separately and from that the obtained was output. Then they combined together to a power grid and thus the combined output power of wind and PV systems were obtained. The change in output power was smoothened using battery . The rated capacity of wind is considered as 100KW and the capacity of PV is considered as 10KW. Here a large scale battery is used and thus the battery charge can be controlled using SOC (state of charge) feedback control strategy.

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