International Journal of Trend in Scientific Research and Development (IJTSRD)
International Open Access Journal
ISSN No: 2456 - 6470 | www.ijtsrd.com | Volume - 2 | Issue – 5

Power Management in PV/Wind/Battery Based Hybrid Power System

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ABSTRACT

The battery energy storage system (BESS) is one of the main 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 power management method is proposed for balancing the power between different components of hybrid power system. The effectiveness of these methods was verified using MATLAB/SIMULINK software.

Keywords: *Battery energy storage systems, photovoltaic, renewables, solar, proportional integral regulator, power quality.*

I. INTRODUCTION

In recent years, electricity generation by photovoltaic (PV) or wind power (WP) has received considerable attention worldwide. 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], 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. 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.

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] were formulated mainly for single source BESS-based smoothing; hence, they did not consider power allocation among several sources BESS. A suitable and effective control strategy for multisource BESS, therefore, remains an urgent necessity.

This article presents a stand-alone wind–PV hybrid generation system with battery for remote or isolated areas. The keys are to extract the maximum power from the wind turbine and to harness the maximum power from the PV panels. Our objectives are:

1. to achieve effective control coordination among the wind generator, PV system and battery to maintain the dc-link voltage constant and
2. to maintain constant and balanced voltages at the load bus as three phase dynamic loads need a balanced three-phase supply for their proper operation. A coordinated control scheme is developed in order to manage power between the maximum power captured from the wind turbine and solar arrays, battery and consumed load power.

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

II. MODELLING OF POWER SOURCES

Because the variable nature of the output power of the WECS and PV system, the need of energy storage is very important. Consequently, temporary and/or durable energy storage, such as batteries, SMES or super-capacitors and/or hydrogen storage tanks, essential to attain a dependable and safe process and to keep the mandatory power supply during power oscillation, disturbance, failure or high power peak conditions. To attain this, system components should be designated with judgment and the control system must ensure that hybrid power system components are well achieved and scrutinized properly. This chapter will cover a brief description of the important hybrid system components used in this work:

1. PV System.
2. Wind energy conversion system.
3. Battery Energy Storage System.

A. PV System

Energy from the sun is the best option for electricity generation and the solar energy is directly converted into electrical energy by solar photovoltaic module. Electricity from the sun can be generated through the solar photovoltaic modules (SPV). The photovoltaic modules are made up of silicon cells. When many such cells are connected in series we get a solar PV module. For obtaining higher power output the solar PV modules are connected in series and parallel combinations forming solar PV arrays. Figure 1 shows the well-known equivalent circuit of the solar cell composed of a light generated current source, a diode representing the nonlinear impedance of the p-n junction, and series and parallel resistances. The series resistance R_s represents the internal losses due to the current flow. The parallel resistance R_p in parallel with the diode, this corresponds to the leakage current to the ground. The one diode model is the most commonly used circuit in the literature and the solution of the circuit is not as complicated as is the case in other models. The parameters in the circuit are; I_D, I_L, I_{SH}, R_{SH}, R_S, I and V.

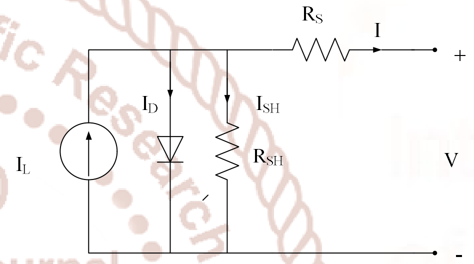

Figure 1 Equivalent circuit of a solar cell.

From the circuit;

$$I = I_{PH} - I_D - I_{SH} \qquad (1)$$

I_{PH} is photo-generated current.
While I is the output current of the cell.
From Shockley's diode equation;

$$I_D = I_0 \left[\exp\left(\frac{V + IR_S}{nV_t} \right) - 1 \right] \qquad (2)$$

Where;

$$V_t = \frac{kT}{q} \qquad (3)$$

By Ohm's Law

$$I_{SH} = \frac{V + IR_S}{R_{SH}} \qquad (4)$$

Equation (5) is the overall solar cell characteristic equation.

$$I_D = I_{PH} - I_0 \left[\exp\left(\frac{V + IR_S}{AV_t} \right) - 1 \right] - \frac{V + IR_S}{R_{SH}} \qquad (5)$$

B. WIND ENERGY COVNVERSION SYSTEM

Wind generation is classified into two major wind power generating units i.e. fixed speed generation and variable speed generation (VSG). The fixed speed generators operate at a fixed rotor speed to obtain maximum efficiency. Deviation from the pre determined speed causes reduction in efficiency. The amount of power generated by the turbine can be associated with the torque generated by the wind. The model base equation represents the mechanical power, *Pmech*, harnessed from the wind, Equation 6.

$$Pa = \frac{1}{2}\rho\pi r^2 \mathrm{C_p}(\lambda, \beta)\mathrm{V_w^3} \qquad (6)$$

$$\lambda = \frac{R\Omega}{V_w} \qquad (7)$$

Here P_a= Electrical output
πr^2 = rotor swept area
Cp= power co-efficient
λ =tip speed ratio
β = pitch angle and
V_w= wind speed.

The tip speed ratio is defined as the ratio between the blade tip speed and the wind speed V_w
Where Ω is the turbine rotor speed and R is the radius of the wind turbine blade.

The mechanical rotor power generated by the turbine as a function of the rotor speed for different wind speed is shown in Fig. 2. The optimum power is also shown in this figure.

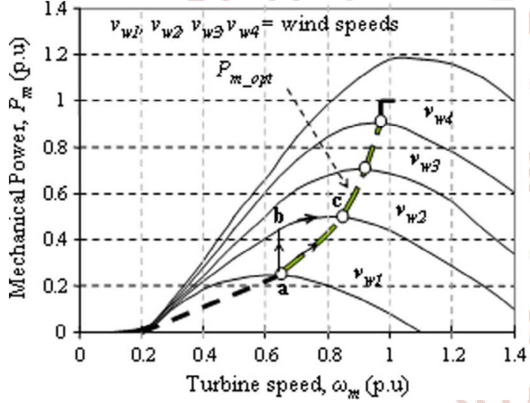

Fig.2. Mechanical power generated by the turbine as a function of the rotor speed for different wind speeds

The optimum power curve (P_{opt}) shows how maximum energy can be captured from the fluctuating wind. The function of the controller is to keep the turbine operating on this curve, as the wind velocity varies. It is observed from this figure that there is always a matching rotor speed which produces optimum power for any wind speed. If the controller can properly follow the optimum curve, the wind turbine will produce maximum power at any speed within the allowable range.

C. BATTERY ENERGY STORAGE SYSTEM (BESS)

In this paper, a generic battery model is implemented. The model uses only the battery SOC as a state variable in order to avoid the algebraic loop problem and can accurately represent four types of battery chemistries including lead acid battery.

The modeling is attempted using a simple controlled voltage source with a constant resistance as shown in Fig.3, where the controlled voltage source is described through (7) The model is implemented through a controllable voltage source regulated by Equation 7 and Equation 8.

$$E = E_0 - K\left(\frac{Q}{Q - \int i_{batt}dt}\right) + A^{-B\int i_{batt}dt} \qquad (7)$$

$$V_{batt} = E_{batt} - i_{batt}R_{batt} \qquad (8)$$

Where, E is the internal voltage, $V_{batt}$is terminal voltage and $i_{batt}$is the current. The battery parameters, A, B, K, R, Q and E_0, are defined in Table1.

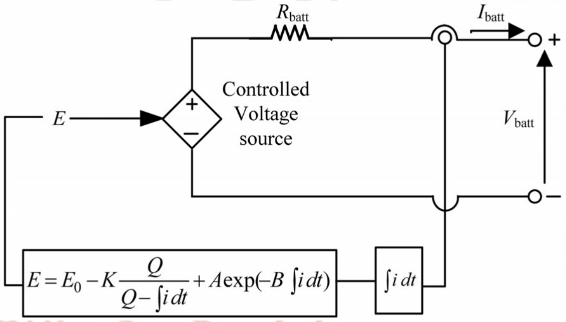

Fig.3. Generic battery model.

Table-I Parameters of BESS

Parameter	Definition
A	Exponential zone amplitude (V)
B	Exponential zone time constant inverse (Ah^{-1})
K	Polarization voltage (V)
R_{batt}	R_{batt} Battery internal resistance (Ω)
E_0	E_0 Battery constant voltage (V)
Q	Q Capacity (Ah)

III.CONTROL SCHEME

The proposed standalone PMSG-based wind turbine power system is shown in Fig. 4. Neutral wire is provided between the capacitors connected before the inverter, as shown in Fig. 3. By providing the neutral system, we can feed to both single-phase as well as three-phase loads. The battery is connected to the dc link through a dc–dc bidirectional buck-boost converter. Using a bidirectional buck-boost converter, the battery voltage can be kept lower as compared to reference dc link voltage and hence fewer batteries need to be connected in series. In the proposed system, battery voltage is kept at about 300 V while V. In this paper, the rating of the battery bank, considering 60%depth of discharge (DOD) [8], is decided based on the assumption that even when the wind power is zero and dump load not used, it should cater to the energy requirement of a 6-kW load for approximately an hour.

The schematic of the dc–dc converter controller used to regulate the charging/discharging current of the battery to maintain the dc bus voltage constant is depicted in Fig. 4. Treating the controller output as the reference current for the battery, a hysteresis band approach is adapted to switch either or of the dc–dc converter. In addition, the control signal is constrained within a limit so that the actual charging/discharging current will be as per the specification of the battery; as a result the longevity of the battery will be enhanced.

A proper real power management scheme needs to be formulated to maintain the dc bus voltage constant to keep modulation index within a reasonably practical limit, when the ac output voltage (PCC voltage) of the inverter needs to be maintained constant. In our system (Fig. 3), apart from wind there are two other devices, namely battery and dump load. Out of these equipment, the battery can act either as a source or as a sink. As a result it should discharge (charge) within specified limits when there is deficit (surplus) of wind energy due to low (high) wind speed. The dump load can only act as a sink for the system. In this work, it is assumed that, due to high wind speed, the excess energy produced is first pushed into the battery until it reaches its upper limit of charge carrying capacity and then the excess power is fed to the dump load and is regulated via the chopper control. The decision about switching on the control action is carried out by comparing the upper limit of the state of charge (SOC) of the battery and the present status of SOC. When the SOC becomes higher than its limit, the controller will increase the duty cycle as a function of over voltage in the dc bus voltage. The schematic of the control scheme is depicted in Fig. 4.In case of a long-term no-wind or low-wind condition, the battery is integrated with WECS.

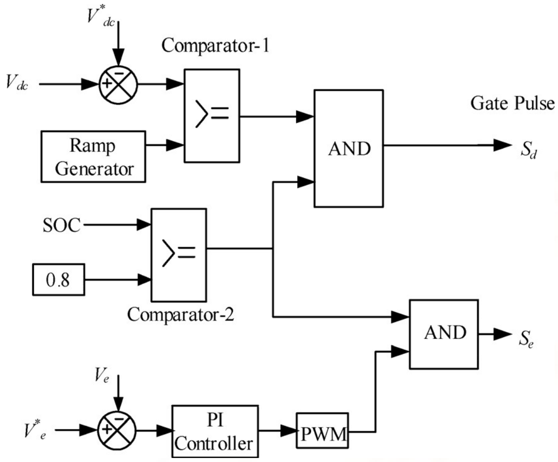

Fig.4. Proposed control scheme.

IV. Results and Discussion

The solar-wind constructed power system is demonstrated and realized in MATLAB/Simulink. The particulars of the forming are specified in section II. In this section the suggestedstructure is exposed to inconstant solar irradiance as well as inconstant wind speed. In addition to this flexible load is associated to the system. These will lead to the endless difference between supply and demand. So BESS overcome this difficult and the results are shown in the following figures. For examining the legitimacy of the solar-wind based power system is exposed to altered levels of solar irradiance. For the time interval 0-2 second the solar irradiance level is 1000 W/m^2. For second time interval between 2-6 second the solar irradiance level is reduced to 800W/m^2 shown in the figure 3. As the irradiance level is reduced the output current and the output power of the PV system also decreased. For the ease merely one time change in the solar irradiance is done else the other waveforms will be congested and cannot be evidently observable.

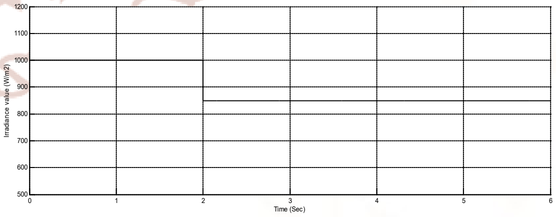

Fig. 5.Solar Irradiance level

Figure 6 is showing solar irradiance against MPPT voltage waveform. From this it is obviouslyimplicit that the irradiance level picks the MPPT voltage. As the irradiance level decreased the MPPT voltage also reduces.

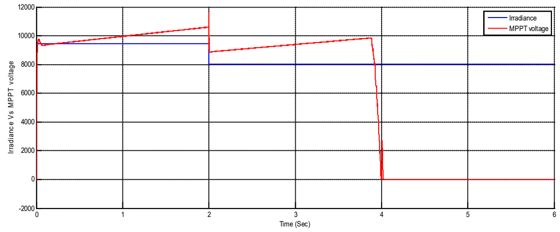

Fig. 6.Solar Irradiance level Vs PV MPPT voltage

For compensating the deficit in the PV system power BESS responds conferring to the need.

For these persistence BESS controllers gives the command to the converter circuit and further it supply power to the demand. If the BESS state of charge (SOC) less than the minimum value then BESS does not comes in to action. In the figure 7 BESS current waveform is shown. From the figure it is found that when the PV system output decreases, BESS power increased to compensate this shortfall.

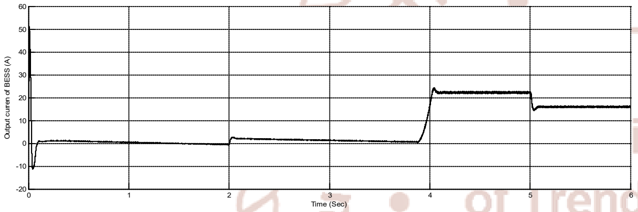

Fig. 7 Output current of the BESS.

For the second case, there is variation in load is made at the time 4 sec. firstly the system is connected to the 10 KW resistive load. There is a step increase of additional 3 KW load is made at time 4 sec. this extra load is removed at time 5 sec. Figure 8 shows the waveform of the power drawn by the load.

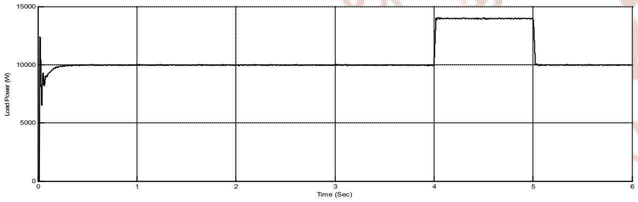

Fig.8. Power drawn by the load.

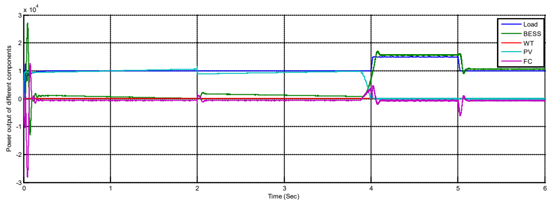

Fig. 9 Power waveform of load, WECS, PV and BESS

When the load is greater than before the HPS system start providing more current to come across the requirement. In the earlier case it is described that deficit in the PV system is recompensed by the BESS. Here also when the load surges, this extra requirement is satisfied by the BESS if the PV system WECS are not capable of meeting the need.

V. CONCLUSIONS

The modeling and performance analysis of stand-alone hybrid Wind/PV/Battery power generation system with MPPT Controllers using MATLAB/Simulink environment is presented in this paper. The variations in wind velocity, solar irradiation and dynamic load conditions are considered for the simulation study. Perturb and Observe (P&O) technique is used for maximum power tracking for wind power system.

For PV system MPPT algorithm based on incremental conductance is used to get maximum power output. The algorithm changes the duty cycle of the DC/DC converter to maximize the power output of the array and make it operate at the peak power point of the array. The PV control strategy of a DC/AC converter connected to the load has been proposed. The system is also able to meet the variable load demand while maintaining dc-link voltage constant. It has been demonstrated that the proposed hybrid system performs satisfactorily under different dynamic conditions while maintaining constant voltage and frequency.

The power balance between wind, PV power system, battery and load has been maintained while extracting maximum power for both sources. The simulation results showed the effectiveness of the integrated control strategy adopted.

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