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Energy Management of Hybrid System with Efficient Control Strategy for Smoothing of the Power Fluctuation Using Battery Energy Storage System (BESS) - A Case Study

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ABSTRACT: Hybridgeneration system plays a very important role in remote and isolated areas. A hybrid system is designed to operate independently as well as in grid connected mode, through power converter system (PCS). This paper presents suitable control strategies, which can regulate output power level of the hybrid system composed of Photo Voltaic (PV), Wind Turbine (WT) and Battery Energy Storage System (BESS). The proposed system has been carried out with case studies based on source and load priority which provides uninterruptable power to the loads. Sources are individuallycontrolled to operate at Maximum Power Point using Maximum Power Point Tracking (MPPT-IC algorithm) for PV system and Doubly Fed Induction Generator (DFIG) based Pitch control technique in WT system. State of Charging (SOC) in BESS put forward for smoothing of fluctuations based on charging and discharging of a battery. The effectiveness of the proposed technique is validated using MATLAB/SIMULINK software.

KEYWORDS:PV, WT, MPPT-IC, DFIG, PCS.

I. INTRODUCTION

The rapid increase in energy demands, diminishing of nonconventional sources and increasing pollution levels in the environment have been driving the focus on renewable energy sources. Rise in pollution levels and climatic changes are result of increase in CO_2 and emission of toxic gases from fossil fuels. Tapping the energy available from the renewable resources makes attainment of notable pollution free environment. On the other hand, drawing continuous energy from renewable sources like wind energy, solar energy, etc. is beyond human control due to unstable and unpredictable nature of these energies. Therefore, there should be an energy backup by means of energy storage devices or use of conventional sources with renewable energy systems to enhance the continuity in energy supply. Hybrid power system is popular as standalone power generation system for providing electricity to isolated and remote areas. This energy system includes more than one renewable sources. However, the main challenge of hybrid power system applications is to satisfy the load demand under constraints. Therefore, proper control and coordination of each energy generation unit is very important for the successful operation of the overall system. It is also vital to ensure robustness of the energy management system to avoid system black-outs when power from the renewable energy sources is not adequate to support all loads.

Renewable energy sources are the most essential, rudiment sustainable sources, like photo voltaic (PV) and wind turbine (WT) systemsbecauseof their omnipresence and abundance. The energy produced using these resources have gained much priority these years, as it has an effective environment friendly operation and it is pollution free.In weaker grids or isolated grids, solar/wind hybrid system is more reliable than operating individually. Indeed hybrid system also mitigates the output power fluctuation of the individual source such as PV system, with the aid of power converter system (PCS) [1]. Along with battery state of charging (SOC), interfacing the grid with hybrid system is one of the methods to improve the reliability and stability of the system. In the literature,the energy management of hybrid power system with the conventional approaches been proven it's instability in handling various changes in weather conditions[2]. Some advanced controlling techniques (such as geneticalgorithms, fuzzy logic, and artificial neural networks) exist, which can readily incorporate human intelligence in complicated control systems.

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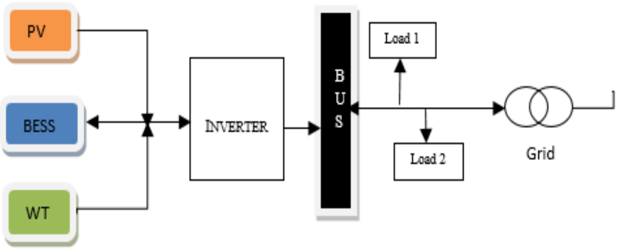

Fig-1 PV/WT/BESS hybrid power generation system.

Fig.1 as shown above is block diagram of a system which includes photo voltaic (PV) and wind turbine (WT) as source of energy and BESS as flexible energy management solution, which further improves the quality of output power along with the inverter and grid connected load1 and load2. These all components are connected to a common BUS that is Point of Common Coupling (PCC). Solar and Wind energies are regulated to obtain maximum energy output using maximum power point (MPP) technique for solar power system and pitch control technique for doubly fed induction generator (DFIG) based WT system. BESS along with SOC is used for smoothing of the output voltage fluctuations for both PV and WT systems.

The objective of this hybrid system is to provide continuous supply to the load irrespective of weather conditions such as non-linearity in PV due to irradiation variation of solar and lack of wind speed for wind system. Depending on generated energy and load priority, various case studies have been presented. Battery charging and discharging conditions are described based on sate of charge (SOC) concept. The full paper is divided into five sections in which section-I constitute Introduction. Modelling of Power sources and BESS is explained in Section II. Case studies have been carried out in Section III. Simulation results are discussed in Section IV. Finally the whole work is concluded in Section V.

II.SYSTEM CONFIGARATION AND MODELLING OF POWER SOURCES

System Configuration:

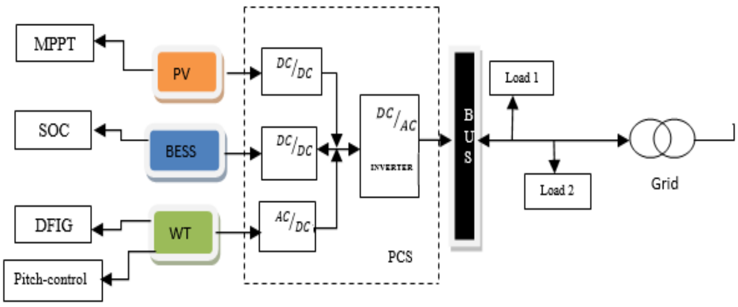

Fig-2:System configuration with PCS.

Fig.2 shows block diagram of proposed grid connected hybrid generation systemconsisting of PV array, wind turbine (WT) as power sources and battery energy storage system (BESS) with SOC as energy storage. A hybrid system has been designed to operate in grid connected mode, through power electronic interface. The power electronic interface has the ability to maintain the hybrid generation system parameters like voltage, frequency etc., at prescribed (acceptable) levels which is essential for the stable operation. To achieve this it is essential to have a good control over the power angle and the voltage level, and it has been achieved by means of an inverter which constitutes the main block of the power control system (PCS). Controlling of the inverter's output voltage and the power anglecontrol the flow of real power and reactive power into the system. Power converter system (PCS) includes various converters at each stage like DC-DC boost converter at PV side, AC-DC converter at WTsideas shown in Fig-2 to deliver more stable output power to the loads as well as to the grid. It also improves the quality of power and reduces voltage and harmonic variations of overall system.

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A.Modelling of PV system.

PV cells are grouped in larger unit called PV modules which are further connected in series-parallel configuration to form PV arrays [3]. A 100kW, 25kV, PV module is taken as reference model for the simulation. To improve the efficiency and to regulate the amount of power drawn by photovoltaic panel, it is forced to operate at maximum power point (MPP) condition.This is achieved by using MPPT, incremental conductance (IC) algorithm which controls the DC-DC converter [4]. Hence maximum power with reduced fluctuations can be obtained at converter side.

B. Modelling of Wind system.

A doubly fed induction generator (DFIG) based wind turbine (WT) system is modelled for wind speed of 13m/s, 25kV voltage and power of 100kW. DFIG based wind turbine is popular wind turbine system with its advanced control strategy to have high energy efficiency. To optimize the power extraction of WT and to prevent over power production, Pitch Angle controller is used in the simulation. Detailed pitch control scheme and pitch servo is explained in [5]. When speed of the generator exceeds rated speed pitch control is activated and pitch angle is turned on so that turbine power can be limited to the rated values.

C. Modelling of BESS.

A capacity of 31.02Ah at nominal voltage, 250V lithium iron phosphate (LiFePO4) BESS is considered for the simulation. In hybrid system**,** interfacing battery/BESS to the grid is the key to guarantee the reliability and stability of the power supply to the loads. When generation is insufficient battery works as power supply and when ample of energy is available, battery gets charged.

SOC Estimation**:** For smoothing of Wind and PV power fluctuations a new control strategy is used i.e. feed back control of SOC. In order to operate the BESS without interruption, the battery SOC needs to be controlled with in a range. SOC estimation is calculated using various methods [1][6]. On the basis of that, over charging and over discharging point has been set to improve the battery life. Flowchart in Fig-3 explains about SOC of the battery with various controllers. Detailed model has been explained in section IV using MATLAB. Here reference voltage (V_{ref}) with different values has been considered separately for charging and discharging.V_{ref1}=250V (Charging) and V_{ref2}=50V (Discharging). In charging mode if V_{ref1} is greater than actual voltage (V_o) of the battery, PI controller reduces the error generated and V_o is compared with carrier signal (CW). If V_o is greater, signal is passed to PWM converter which generates pulses to turn on the switch of the battery. If V_o is lesser, signal is send back to PI controller, which further reduces the error until the condition is satisfied.

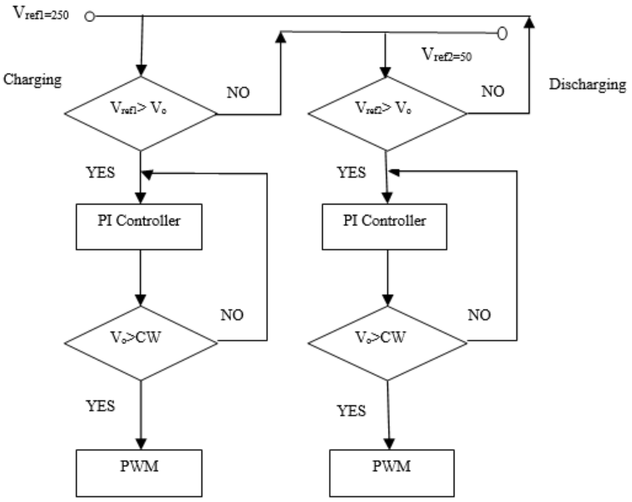

Fig-3: Flowchart of Battery SOC with V_{ref1}=250 and V_{ref2}=50.

Initially, if $V_{ref1}<V_o$, battery switches to discharging mode. If $V_{ref2}>V_o$, PI controller is triggered to reduce the error. Output of the controller is compared with carrier wave (CW). If CW is greater, controller is activated until CW is lesser than V_o. PWM is activated once condition is satisfied. If $V_{ref2}<V_o$, charging mode is activated. Hence by comparing

actual voltage of battery with reference value (V_{ref}), over charging and over discharging of thebattery has been avoided which further improves the efficiency of the battery and reduces the risk of damage.

III.ENERGY MANAGEMENT OF HYBRID SYSTEM

In this paper different types of loads are considered, for example load (L1) of 90kW and load (L2) of 170kW. The generated power supply of PV & WT system along with the BESS and loads are connected at the point of common coupling (PCC). By controlling the battery-SOC, parameters of sources and load power are automatically controlled at common bus that is at PCC. By considering the energy sources such as P_s- solar power, P_w-wind power, P_b-battery power, P_g-grid power and load powers (P_{L1}, P_{L2}), different cases have been studied based on load requirements, SOC of the battery and availability of power supply.

Case.1: P_s+P_w and L1, L2.

When both sources are available maximum power is generated, which meets loads independently with BESS. Initially both the loads (L1) and (L2) are connected to the sources. At this instant both the sources and battery provide energy, since load power is greater than the generation. After a certain period load L2 is disconnected so that the total load power decreases. Hence, battery gets charged. When load demand is more and supply is less, battery gets discharged to meet the load requirement and once load is reduced, battery starts charging. Considering a domestic and industrial locality, load demand is more as mid-day appears and industrial power demand decreases as night appears. Different cases are studied considering either of loads or both with either of sources or both. For analysing these cases, 1 second time period is considered.

When T=0;

$P_s+P_w+P_b= P_{L1}+P_{L2}$(Battery Discharging)

At T=0.5;

$P_s+P_w= P_{L1}+P_b$(Battery charging, L2 is disconnected)

Case.2: Alternate source and L1&L2.

Next case is considered as; due to climatic conditions or error in PV system, only wind turbine (WT) supplies energy to the load. As supply is less, battery acts as an alternate source to meet required load demand. Once L2 is disconnected, only P_w is sufficient to be drawn by L1. Alternatively if P_w is absent P_s will supply the loads with battery.

At T=0; and P_s=0;

$P_w+P_b = P_{L1}+P_{L2}$ (Battery discharging)

T=0.5 sec;

$P_w= P_{L1}$ (L2 is disconnected)

When

P_w=0, P_s+P_bsupply to the loads.

Case.3: P_s and P_w are insufficient

If both energy sources are not sufficient due to climatic conditions or uncertainty, load must be supplied by alternate means which are in link with the hybrid system. Here grid power comes into picture along with BESS. As grid is interfaced with hybrid system and when supply from sources are insufficient, grid supplies required power depending on the load conditions.
Here

P_s>50kW, P_w>50kW

Initially battery along with less power meets the loads, if battery is not fully charged and load demand is more, grid provides the required power to satisfy the load demand.

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Case.4:In presence of excess source power

During certain part of the season, availability of solar energy and wind speed could be more. Hence energy conversion and possibility of available power at load side could be more. Once load requirement has been fulfilled and battery gets fully charged, source energy will be supplied to the grid through multilevel inverter which matches both source and grid parameters. Table-1 shown below gives brief description of various case studies along with battery mode.

Table-1 Power control scheme for various case studies.

Source availability	**PV**	**WT**	**PG (Grid power)**	**BESS Mode**	**Loads connected**
P_s& P_w	✓	✓	–	Discharging	P_{L1}, P_{L2}
			Receiving	Charging	P_{L1}
P_w	X	✓	–	Discharging	P_{L1},P_{L2}
				Charging	P_{L1}
P_s	✓	X	–	Discharging	P_{L1},P_{L2}
				Charging	P_{L1}
NONE	X	X	Supplying	Discharging	P_{L1},P_{L2}

IV.SIMULATION RESULTS

The hybrid system with different case studies has been carried out to validate the performance of proposed system. Simulation results shown for various cases includes hybrid system (HS) power indicated with red colour, BESS with green colour, PV with blue and WT with pink colour. Negative flow of power in BESS indicates the charging of the battery.

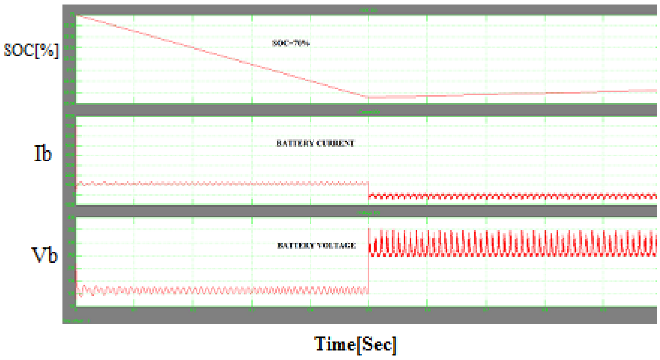

Fig-4: Battery SOC with various parameters.

In Fig-4, SOC of battery and priority of load disconnection after T=0.5 sec is shown and 70% of SOC has been considered. Maximum charging value and minimum discharging point has been fixed to avoid over charging and over discharging of battery, which reduces damage of battery and improves battery life. After load 2 has been disconnected, battery current reduces to zero and voltage increases to nominal value which confirms that battery is charging, as shown in simulation.

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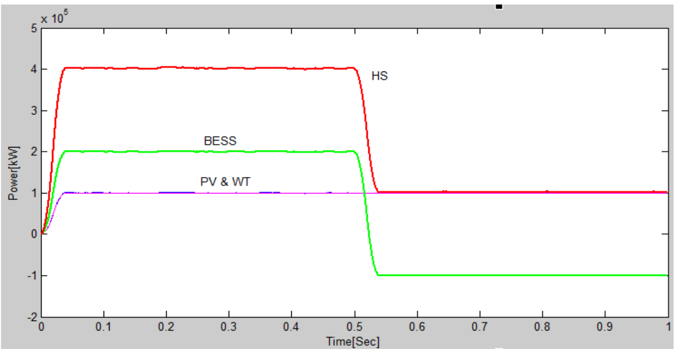

Fig-5: In presence of adequate source.

Fig-5 represents the simulation result of Case.1, when both supplies have sufficient energy production to meet the load demand. Initially both the loads L1 and L2 are connected to the supply. After a period T=0.5 seconds, load 2 is disconnected. Since the load demand is reduced, battery is disconnected and starts charging. Hybrid system power (HS) includes active and reactive power. Once power requirement by load has met, excess reactive power in HS has been absorbed by the grid. Total load connected to hybrid system is 260kW, after a period T=0.5 sec, L_2 of 170kW disconnected and 90kW of L_1 remains connected, since power at source side is greater than load demand, grid receives the excess power as explained in case.4.

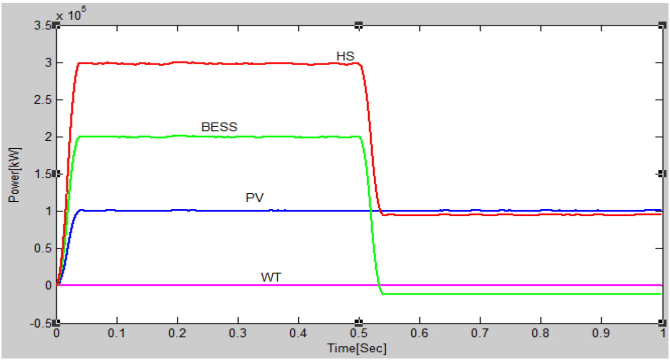

Fig-6: P_s+P_b meets load power since wind is not available.

Fig-6 and 7 explain about Case.2, when one of the sources is not connected. Battery and alternate source manages to supply the load. Fig-6 describe about wind disconnection due to environmental factors or system fault and solar with battery system supply to the load i.e. $P_s+P_b= P_{L1}+P_{L2}$.

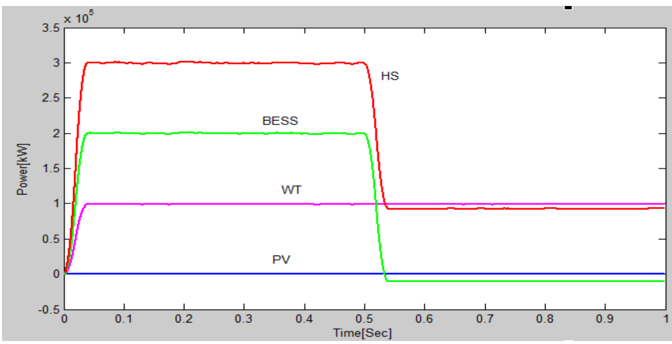

Fig-7: In absence of Solar Energy, P_w+P_b supply the load.

In fig-7 solar power is insufficient to satisfy the load; hence wind and battery take over to meet the load demand. Total power required by the load at initial period is 260kW and additional power in HS as shown in fig is reactive power,

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which is absorbed by the grid and after a period T=0.5 sec, HS power reduces to 100kW, in which 10kW is used to charge the battery.

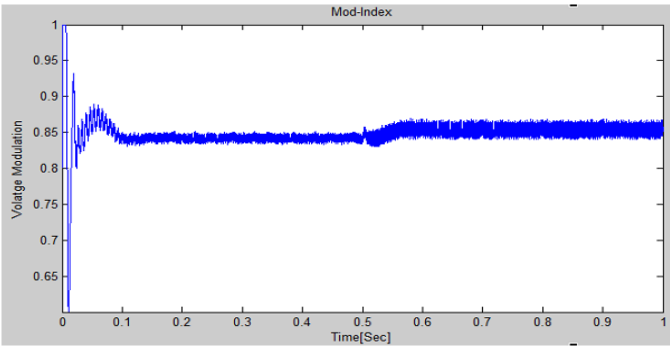

Fig-8: Battery Voltage (V_o), representing fluctuation reduction.

Since battery SOC feedback control has been used in the hybrid system, voltage (V_o) fluctuations has been reduced to maximum extent as shown in Fig-8. At the BESS side initially voltage fluctuation is maximum till 0.1sec, as time increases rate of fluctuation gradually reduces. This way source voltage fluctuation has been minimized and fed to inverter. Thus overall variation of voltage has been reduced to maximum extent.

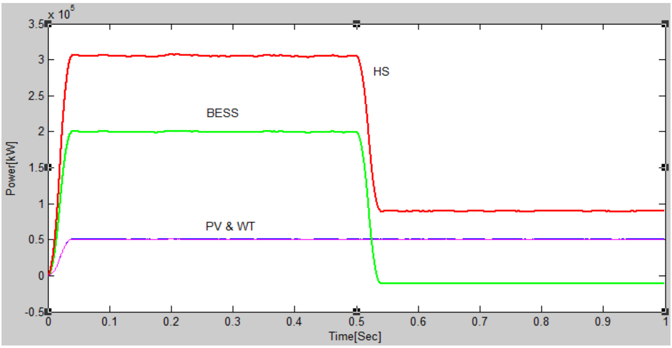

Fig-9: When both the sources are less, maximum power is delivered by BESS.

Fig-9 describes simulation of Case.3, when both supplies are less than 50kW each. Battery and grid provides power to loads. In figure as battery has full charge and load requirement is 260kW, whole power of it has discharged to the loads and in case of less power in battery, grid supplies required power to meet the loads demand.

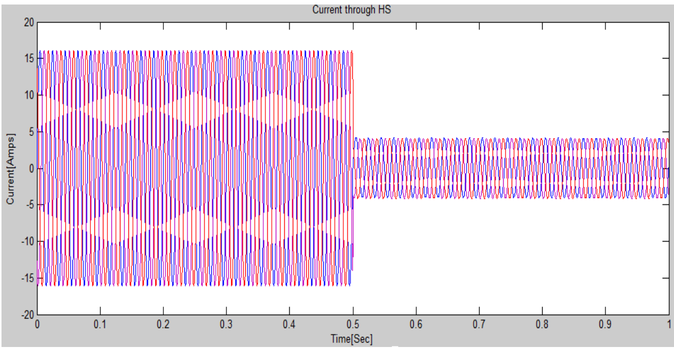

Fig-10: Current of the Hybrid system.

In Fig-10, current of the hybrid system (HS) for a time period of 1 second is shown. Till T=0.5 sec, current delivered is 16A, since source current is 4A (As per rating) and additional current is from battery. Hence total current is 16A which

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is shown in the simulation result. After T=0.5 sec, due to reduction in the load, current supplying to the load has been reduced to 4A as battery has been disconnected.

V.CONCLUSION

Integration of photovoltaic power generation system (PVGS) and Wind power Generation system (WPGS) with BESS reduces the unstable power output and negative impact on utility and grid operation. In this paper a novel SOC-based control strategy for smoothing the fluctuation of output voltage of PV and WT has been proposed. This paper also proposes various case studies by which uninterruptable power is supplied to load at all conditions which enhances the power quality to the loads and improves efficiency. In addition to these, this paper mainly concentrated on power converter system (PCS) at various stage of hybrid system, which provides smooth and reliable power to the bus, and reduces voltage variation and harmonics in the system. Hence overall system efficiency can be increased and stable operation at uncertain condition can be provided.

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