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Investigation on Control of Hybrid Solar-Wind Generation System

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***Abstract:** This paper presents simulation, modelling and control strategy for the stand-alone hybrid solar–wind energy conversion systems with battery storage. The proposed hybrid system consists of a photovoltaic (PV), wind energy conversion system (WECS), storage device, boost converter and an inverter to convert DC to AC. The PV is used as a main energy source and WECS as secondary source of supply. Battery is used as back-up energy source to increase the reliability of the system. Power delivered by different sources is controlled with the help of a supervisory controller, which set the reference signal for local control of each individual source. The modelling of proposed hybrid system is developed in MATLAB/SIMULINK environment.*

***Keywords:** Photovoltaic, Wind Energy Conversion System, DC-DC Converter, Inverter.*

I. INTRODUCTION

Due to the critical condition of fossil fuel resources which include oil, gas etc. and environmental pollution caused by them, the development of renewable energy sources is continuously improving for electricity production. Use of various renewable energy sources in hybrid manners is becoming popular for providing electricity in remote areas. A hybrid energy system usually consists of two or more renewable energy sources used together to provide increased system efficiency as well as greater balance in energy supply [1].

Out of different renewable sources solar and wind energy are the more promising renewable energy sources and are widely used in many countries for standalone applications [2]. The main drawback of wind and solar based renewable energy generation is that the output greatly depends on climatic conditions, including solar irradiance, wind speed, temperature etc. [3]. In this paper, the photovoltaic generation is combined with wind power generation in such a way that the instability of output characteristic was compensated by each other. The complementary nature of wind and solar power supply system help to makes good use of both in hybrid manner. The hybrid PV/wind power system with battery storage has higher reliability to deliver continuous power than individual source. This paper presents the modelling and simulation of standalone hybrid Photovoltaic-Wind generation system with battery using MATLAB/SIMULINK. A control strategy for the reliable operation of PV/wind/Battery hybrid system is also presented. Fig. 1 shows the block diagram of the hybrid PV/Wind/Battery generation system.

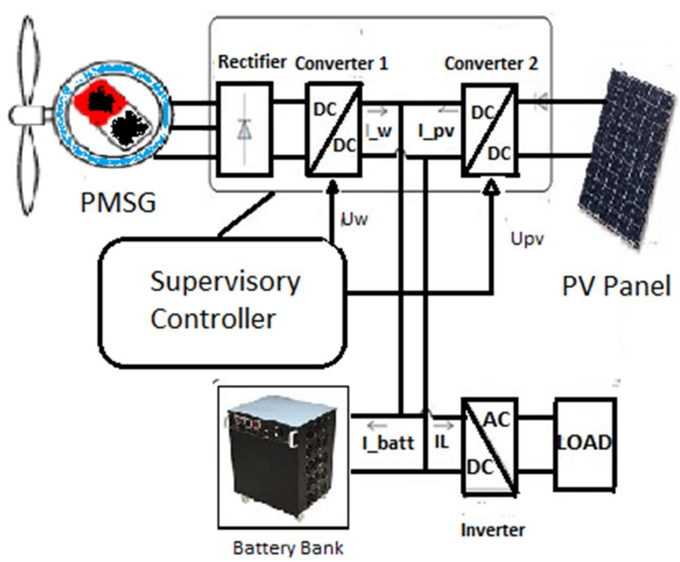


Fig. 1 Hybrid PV/Wind Generation System

II. MODELLING OF HYBRID SYSTEM COMPONENTS

A. Modeling of Photovoltaic System

The photovoltaic system converts sunlight directly to electricity without having any destructive effect on our environment. The basic unit of PV array is PV cell, which is just a simple p-n junction device. A PV array consists of a large number of PV cells in series and parallel connections. It is the combination of many PV modules. A solar cell can be modelled by a current source and a diode which is connected in parallel to it. It has its allowable series and parallel resistance [4].

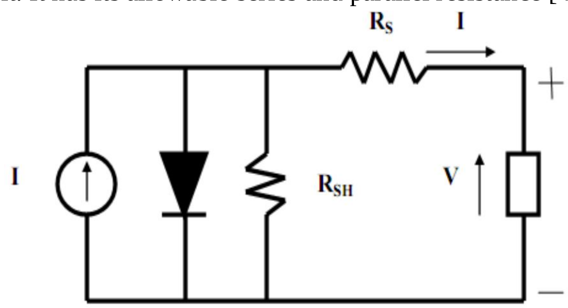


Fig.2 Equivalent circuit of a solar cell

The output current from the PV array is

$$I = I_{sc} - I_d \quad (1)$$

$$I_d = I_o(e^{\frac{qV_d}{kT}} - 1) \quad (2)$$

Where I_o = Reverse saturation current of the diode; q = Electron charge; V_d = Voltage across the diode; k = Boltzmann constant (1.38 * 10 19 J/K) and T = Junction temperature in Kelvin (^oK).

From eq. (1) and eq. (2)

$$I = I_{sc} - I_o(e^{\frac{qV_d}{kT}} - 1) \quad (3)$$

By suitable approximations,

$$I = I_{sc} - I_o(e^{q((V+IR_s)/nkT}) - 1) \quad (4)$$

Where I = Photovoltaic cell current; V = PV cell voltage; T = Temperature (in Kelvin) and n = Diode ideality factor.

B. Modeling of Wind Energy Conversion System

Wind energy is an environment friendly and endless source. Therefore, for future demand a wind energy generation system is one of the best sources of alternative energy. A wind turbine converts kinetic energy of air into mechanical power i.e. rotating motion of the turbine that can be used directly to run the machine or generator. The magnitude of this converted mechanical energy depends on the air density and the wind velocity, blade shape, the pitch angle, radius of the rotor. The wind power (P_m) that is developed by the turbine is given by the equation:

$$P_m = \frac{1}{2}\rho A v^3 C_p(\lambda, \beta) \quad (5)$$

Where,

P_m= Mechanical output power of the turbine(W); C_p = Performance coefficient of turbine; ρ = air density (kg/m^3);

A = Area of turbine blades (m^3); v = Wind velocity (m/sec); λ = Tip speed ratio; β = Blade pitch angle (deg).

The pitch angle (β) refers to the angle in which the turbine blades are aligned with respect to its longitudinal axis. The coefficient C_P is the fraction of kinetic energy which is converted by wind turbine into mechanical energy. It is related to the tip speed ratio (λ).

The term λ is the tip-speed ratio, given by the equation:

$$\lambda = \frac{R\omega_b}{v_w} \tag{6}$$

where R *and* ω_b *are* turbine radius and angular rotational speed respectively.

III. CONTROL STRATEGY FOR ENERGY MANAGEMENT OF HYBRID PV/WIND GENERATION SYSTEM

The control strategy has an important role in hybrid power system operation. A proper control system increases the power availability, system efficiency, battery life and the amount of power generation. The output of hybrid PV/Wind generation system depends on the atmospheric conditions. Operation of the hybrid generation systems is managed through the supervisor control algorithm. Supervisory control system provides the reference signal to each individual local controller. For the design of the supervisory controller, it has been considered that the PV subsystem would be the main generator, while the wind generator subsystem would be complementary. Output of both PV and wind depends on the atmospheric conditions so a battery is also used as a storage system, which can also support the hybrid PV/Wind system wherever load demand increase beyond the Hybrid PV/Wind system. The different possible modes of operation are determined by the energy balance between the total demand and the total generation as well as battery state of charge (SOC) level. The difference possible modes of operations are given in Table I.

Table I

Mode	Operating Condition
Mode 1	➢ The output power from PV is less than the load demand ($P_{pv} < P_{load}$) ➢ PV and wind meet load demand ($P_{pv} + P_{wind} > P_{load}$) ➢ High level of battery storage ($SOC \approx SOC_{max}$)
Mode 2	➢ The output power from PV is higher than the load demand ($P_{pv} > P_{load}$) ➢ PV alone can fulfill the load demand, wind tubine will not contribute for load demand. ($P_{wind} \approx 0$) ➢ High level of battery storage ($SOC \approx SOC_{max}$)
Mode 3	➢ Sum of the output power from PV and wind is less than the load demand ($P_{pv} + P_{wind} < P_{load}$) ➢ Battery will also contribute in meeting deficit load demand ($SOC_{min} < SOC \leq SOC_{max}$)
Mode 4	➢ The combined output power from PV and wind system is able to meet load demand ($P_{pv} + P_{wind} = P_{load}$) ➢ High level of battery storage ($SOC \approx SOC_{max}$)
Mode 5	➢ The output power from PV and wind is more than load demand $(P_{pv} + P_{wind} > P_{load})$ ➢ Excess power will be used to charge the battery as $(SOC_{\min} < SOC < SOC_{\max})$
Mode 6	➢ Unfavorable wind and PV generation condition ➢ Battery will be used to supply for critical load

The summary of operating points is outlined in Table I. Details of the operating conditions are described as follows:

A. *Mode 1: Low photovoltaic condition*, ($P_{pv} < P_{load}$), ($P_{pv} + P_{wind} > P_{load}$) and ($SOC \approx SOC_{max}$)

In this condition, the PV extracts the maximum available power. The wind turbine extracts optimum power that is equal to the deficit power. The battery cannot consume any power because the SOC of the battery have reached at their maximum limits.

B. Mode 2: High photovoltaic condition, $(P_{pv} \geq P_{load})$ *and* $(SOC \approx SOC_{\max})$

In this mode, the PV extracts optimum power that is equal to the load demand. PV alone is able to meet the load requirement, so no power is extracted from the wind turbine and battery also not consume any power as battery SOC is also at their maximum limit.

C. Mode 3: Insufficient PV and wind power, $(P_{pv} + P_{wind} < P_{load})$ ***and*** $(SOC_{\min} < SOC < SOC_{\max})$

In this condition, the PV and wind extracts the maximum power. The deficit power is supplied by battery till battery SOC will touch the allowable minimum SOC level.

D. Mode 4: Sufficient PV and wind Power, $(P_{pv} + P_{wind} \approx P_{load})$ and $(SOC \approx SOC_{max})$

In this condition, the PV and wind both together meet the load demand and battery not consume any power as battery SOC is already at their maximum level.

*E. Mode 5: Battery Charging Mode***,** $(P_{pv} + P_{wind} > P_{load})$ and $(SOC_{\min} < SOC < SOC_{\max})$

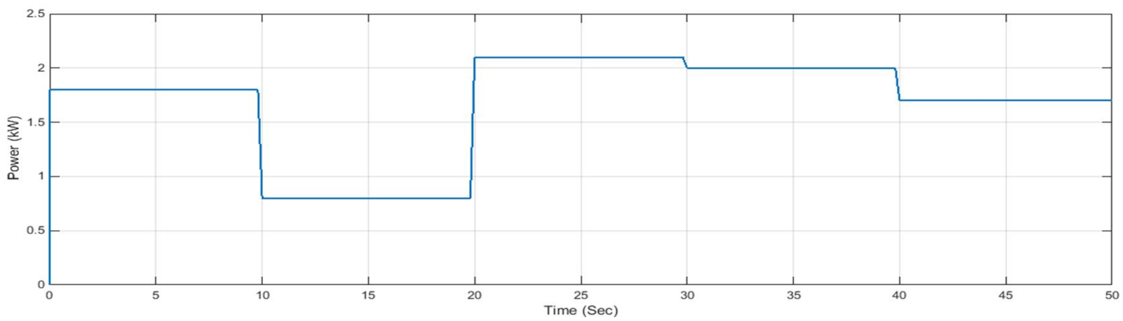
In this condition, the PV and wind system will extract the power more than the load demand; the excess power will be used to charge the battery.

F. Mode 6: Unfavourable Environmental Conditions

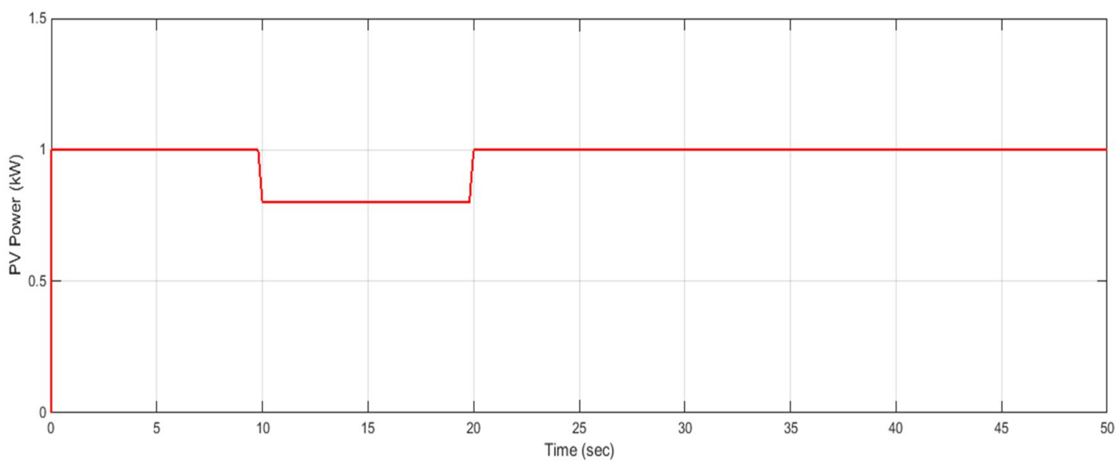
As PV and wind both output depend upon the environmental condition, so in such conditions when PV and wind both could not contribute load power. The battery alone can be used to meet urgent load demand and depend on their severity of the condition the SOC of the battery may allow to drop as low as 40 %.

IV. SIMULATION RESULTS

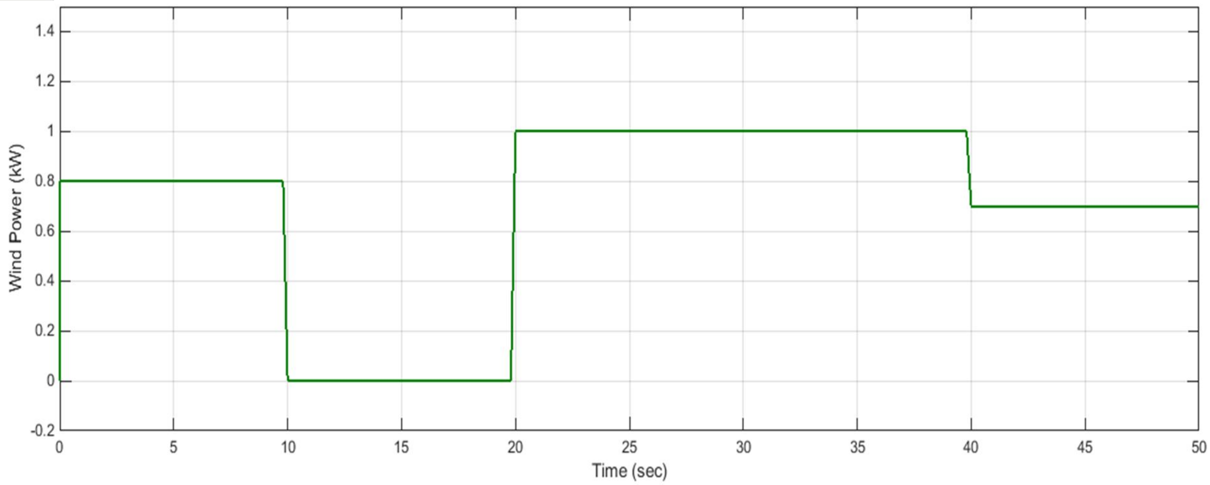
The Energy management of hybrid system is carried out as explained in section III. The performance of the local controllers is evaluated under varying load conditions. The parameters of the PV, wind turbine, permanent magnet synchronous generator and energy storage are given in appendix I. Fig. 3 (a) shows the variable load demand and PV, wind, battery output power and SOC are shown in Fig. 3 (b), Fig. 3 (c), Fig 3 (d) and Fig. 3 (e) respectively.



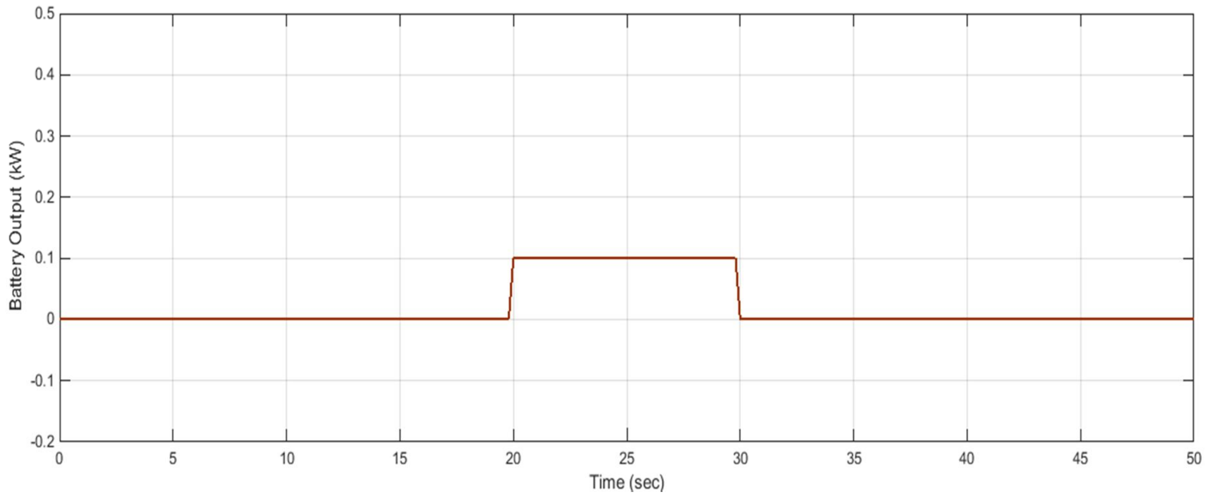
(a) Load Demand



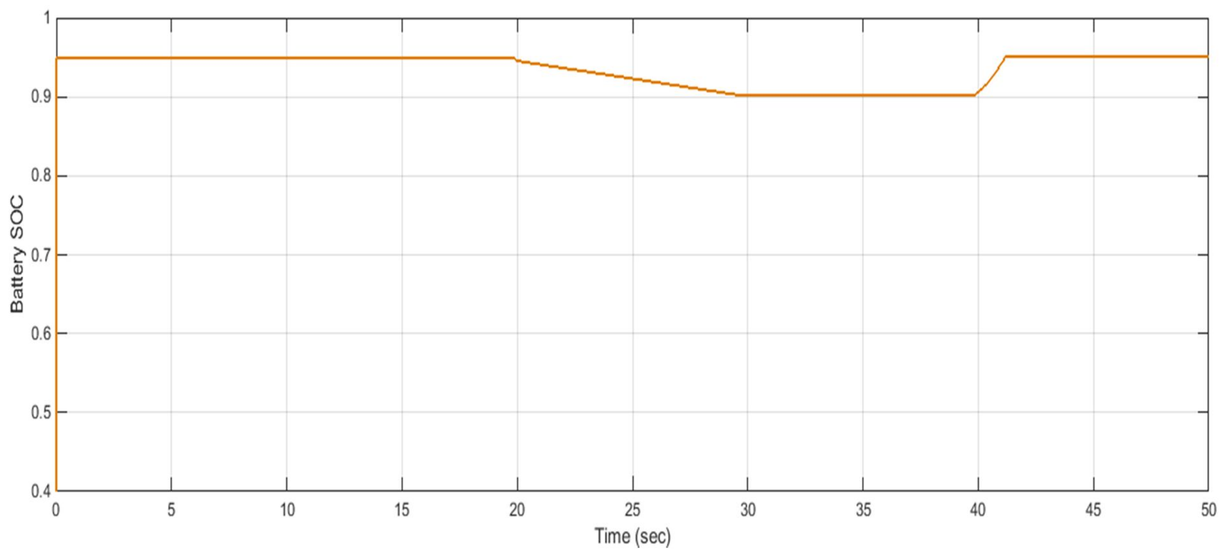
(b) Photovoltaic Power Output



(c) Wind Power Output



(d) Battery Power Output



(e) Battery SOC

Fig. 3 Hybrid Power Generation Parameters

From t=0 to t=10 sec load demand is 1.8 kW, in this case PV is operated at MPPT and deliver 1kW and remaining power is supplied by WECS. The battery SOC is at maximum limit so it will not consume any power.

From t=10 to 20 sec the load requirement reduced to 0.8 kW, which can be fulfilled by PV alone. So, in this case WECS system will not contribute in load demand and battery SOC will also remain constant.

From t=20 to 30 sec load demand suddenly increases to 2.1 kW, which is beyond the limit of PV and WECS capacity. So, in this case battery will also contribute in load supply and both PV and WECS operates on MPPT to deliver the rated power. Battery SOC starts to decrease in this case.

From t=30 to 40 sec load demand further changes to 2 kW, which are in the maximum limit of hybrid PV/Wind system. In this case both PV, WECS work on MPPT and fulfill the load demand. SOC remains constant in this duration.

From t=40 to 50 sec load demand decrease to 1.7 kW, which is lesser than the combined capacity of hybrid PV/Wind system. In this case PV operates at MPPT and wind power is regulated to supply deficit power and charge the battery. Due to charging of the battery SOC level of battery start to improve.

The above results show the developed control strategy is able to distribute the load demand among different individual sources effectively.

V. CONCLUSION

In the present work a control strategy for energy management of the developed hybrid PV/Wind/Battery system is presented. Simulation results show the power sharing of individual sources under variable load conditions. The power balance between load, battery, PV and WECS has been maintained while extracting maximum power. It reveals that hybrid system has greater reliability compare to standalone system, when either one of the generation system is not able to meet load demand another system will operate and compensate the extra load demand.

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Appendix-I

Permanent Magnet Synchronous Generator	
Number of Pole pairs	4
Rated Speed (rpm)	1260
Rated Power (kW)	1
Stator Resistance (ohm)	5.8
Direct Inductance (mH)	0.0448
Quadrature Inductance (mH)	0.1024
Inertia	0.011
Wind Turbine	
Rated Power (kW)	1
Base Wind Speed (m/s)	12
RC Filter	
Series Inductance (mH)	13
Shunt Capacitance (micro F)	20
PV Panel	
Rated Power (kW)	1
Base Irradiance (kW/m^2)	1