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Modeling and Performance Analysis of Hybrid Power System Using control Technique

Dr. Malik Rafi, Arun Kumar Singh

Abstract— **Hybrid energy system made up of two or more renewable and / or nonrenewable energy sources. Currently hybrid systems involving wind power as one of the constituent along with photovoltaic power are more interesting. The main purpose of such hybrid power systems is to overpower the intermittency and unpredictability of wind energy and to make the power supply much more genuine. Wind power system with fuel cell can avoid the disadvantages of wind energy intermittency,here fuel cell act as an energy barrier and modify the output power effectively. Wind energy and solar energy are combined into a hybrid power system, specially for the power supply to remote areas in which the transmission cost is very high. Another merit of such hybrid power system is that wind and solar energy are renewable energies, which is suitable for the environment. For delivering the continuous and reliable power to the load, a generous battery bank is required, which raises the size of the system, cost and causes environmental pollution. The hybrid system can be directly connected to the grid to avoid the battery deployment. In this paper the presented work contains modeling, simulation and performance analysis of wind and photovoltaic hybrid power system integrated to electrical grid through power electronic devices. The power conditioning system is used to control power electronic circuits and performance analysis of the system is assessed for different input power levels and load variations. In this paper MPPT (Maximum Power Point Tracking) technique has been adopted for extracting maximum power from wind and solar energy systems. Additionally, the outputs of wind energy and solar energy are integrated to maintain and sustain the continuity of supply to the load on demand at all times,. For wind generator, the complete operation depends on the assessment of the speed which is a sensor-less rotor speed estimator, which keeps away from all mechanical sensors. The rotor speed so estimated, is used to control the turbine speed by maintaining the input dc quantities (Voltage and Current) for boost converter. Simulation studies of the proposed system are implemented using MATLAB / Simulink platform, and hence results are presented.**

Index Terms— **Hybrid Power System, Photovoltaic, PV/Wind/Hybrid Power System, Renewable Energy Resources, Wind Generation conversion System, Energy system, BUCK-BOOST converter, Renewable energy, PMG of WECS, Photovoltaic system.**

I. INTRODUCTION

With the gradual rise and continuous hazards of global warming to mankind and the depletion of existing fossil fuel reserves, many countries are searching for renewable green energy solutions for preserving the resources for the coming generations. Wind energy and solar energy are considered as the preferred renewable energy, other than hydro power and thermal energy and it has the capability to satisfy the load demands. Wind energy has potential to supply large amount of power, but wind energy is highly unreliable and depends on geographical locations and availability of tall structures. Solar energy is available throughout the day but the solar radiation level changes throughout the whole day because of sun's intensity and unreliable shadows cast by clouds, birds, tall buildings and structures, trees etc. The common disadvantages of wind and solar energy are their periodic nature which make them uncertain. Hybrid energy system consists of two or more no of renewable energy sources, usually wind power and pv array power. The main merit of such hybrid power system is that, when these two power sources are utilized together, the predictability is increased at load end. Often, there is availability of sun rays, but there is intense wind. However, when wind and solar power systems are combined, power transfer efficiency, capability and reliability can be enhanced effectively. When any of these sources is unavailable or insufficient in meeting the load demands, the other energy sources can balance the inadequacy. Several hybrid wind and PV power systems are discussed by using the conventional PI controllers for lower ratings. The proposed power system made up of Wind turbine and solar PV module as inputs. Wind energy obtained from PMSG connected to grid via buck-boost converter, followed by grid side inverter. In this paper Hill Climbing Search techniques (HCS) are used for solar and wind energy system. The output power of PV and wind power system generation are fluctuating because of the randomness in solar irradiance and wind speed, which needs a proper size of storage, efficient MPPT and fast charge controller to assure the continuous power supply when the system operates under stand-alone mode and grid-connected mode.

Dr. Malik Rafi, Department of Electrical Engineering, Azad Institute of Engineering & Technology, Lucknow, India
Arun Kumar Singh, Department of Electrical Engineering, Azad Institute of Engineering & Technology, Lucknow, India

II. PROPOSED SYSTEM ARCHITECTURE

Wind turbine is mechancally coupled to PMSG, which is connected to uncontrolled three phase bridge rectifier,which is connected to Buck-Boost converter and Grid side converter. The DC-DC converter maintains fixed DC output voltage with maximum output power by providing controlled gate pulses to the converter, which is controlled by duty ratio of the PWM technique, using MPPT technique (HCS).
The solar photo-voltaic cell is connected to boost converter, to get high output voltage MPPT technique(HCS) is employed to extract maximum power. This output voltage is given to three phase inverter for converting DC voltage to AC grid voltage The block diagram of the proposed architecture is shown in Fig. 1.

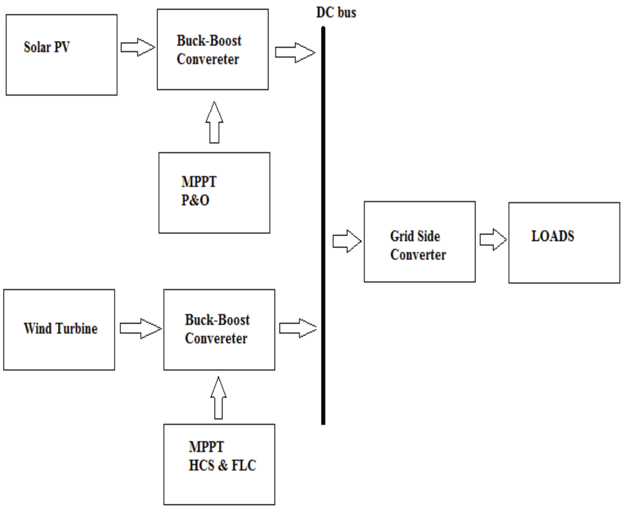

Figure 1 Block Diagram of PW-HPS

A. PV SYSTEM

The developed solar cell model depends on the PV cell electrical equivalent circuit shown in figure 4.5 [12].

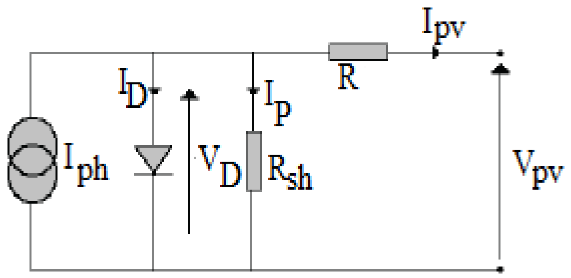

Figure 4.5 Electrical Equivalent Circuits for PV Cell

$$I_{pv} = I_{ph} - I_D - I_p$$

$$I_{pv} = I_{ph} - I_o\left(\exp\left(\frac{V_{pv} + R_s I_{pv}}{nKT/q}\right) - 1\right) - \frac{V_{pv} + R_s I_{pv}}{R_{sh}}$$

Where, I_{Ph} is the light produced current (A), I_D is the diode current (A) , I_P is the current in shunt (A), I_O is the saturation current of PV cell (A), q is the charge on electron (q =1.6 10^{-19}C), K is the Boltzmann constant (k = 1.38× 10^{-23}J/K), n is the cell ideality factor, T is the temperature of cell, R_{sh} is the shunt resistance (Ohms) and R_s is the internal series resistance (Ohms) .

B. WIND GENERATION SYSTEM

Wind turbine extracts wind energy through blades and converts the wind energy into mechanical energy, this mechanical energy runs a generator which produces electrical energy. TSR defined as ratio of turbine angular speed to the wind speed and is given by,

$$\lambda = dw/v_w$$

Where w is the rotor speed and v_w is the wind velocity.

The relationship between output power from wind turbine and wind speed is demonstrated as

$$P_{WT} = \begin{cases} c_p(\lambda,\beta)\frac{\rho A}{2} v_{wind}^3 & , v_{cut-in} \le v_{wind} \le v_{cut-out} \\ 0 & , otherwise \end{cases}$$

Where P_{WT} is the mechanical output power from the wind turbine (W),C_P is the performance coefficient of the wind turbine, ρ is the air density (kg/m^3), A is the turbine swept area (m^2), V_{cut-in} is the cut-in wind speed (m/s), V_{wind} is the speed of wind (m/s),$V_{cut-out}$ is the cut-out wind speed (m/s), λ is the ratio of the rotor blade tip speed to wind speed and β is the blade pitch angle (deg).

C. Boost Converters

DC-DC converters converts a DC voltage from one level to another level, often providing regulated output.

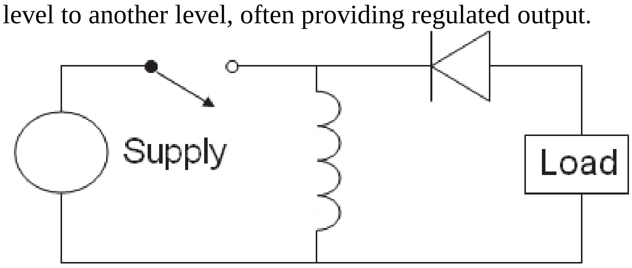

Figure 4.1

A buck-boost converter produces an output voltage that may be less or more than input voltage and the polarity of output voltage is opposite to that of input voltage. This is alsocalled as inverting regulator .The circuit arrangement of buckboost converter is shown in Fig. 4.1. In steady state, the output-to-input conversion ratio is the product of the conversion ratios of the two converters in cascade

$$V_o/V_i = D/(1-D)$$

Where V_o= Output DC voltage, V_i = Input DC voltage, D = Duty ratio. For extracting maximum power from wind, MPPT technique utilizes the duty ratio information, and hence the triggering pulses are produced.

D. Inverter

The inverter converts the DC voltage from the DC bus of 240 V into a three phase AC voltage of 240V.The inverter consists of 3-bridge arms having 6 IGBTs. A Pulse Width Modulation (PWM) generator is implemented for producing the switching signal (firing angle) which is given to the IGBTs switches. A filter made up of a three phase static VAR compensator (20 kvar, 240 V) is employed after the inverter for filtering the harmonics as well as stabilizing the system.

E. AC Load

The load is resistive load fixed at 10 kW. The parallel RLC block is implemented for representing the load in the simulink model. At the specified frequency, the load shows constant impedance.

III. MPPT CONTROLLER

HCS is a MPPT technique in which it needs power measurement. This depends on perturbing the speed of turbine shaft in small steps (Δω) and observing the turbine mechanical power increase or decrease. The types of HCS techniques are fixed, variable and dual step size.

The conventional hill climbing searching algorithm for the maximum power point tracking can be discussed in figure 2. The basic principle of the HCS algorithm is that if the previous increment of rotational speed Δw results in an increase of mechanical power ΔP then the search of Δw continues in the same direction otherwise, the search reverses its direction. Suppose that the wind turbine is operating at point A in the characteristic curve shown in figure 2. The wind turbine rotational speed is increased and the corresponding mechanical power is observed.

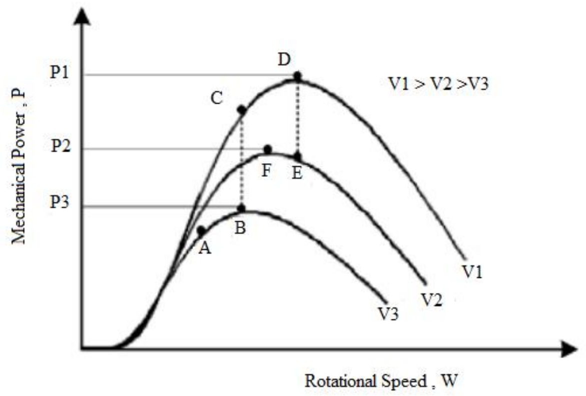

Figure 2 Principle of HCS control algorithm

Many HCS based methods utilizes the relation between output power of generator and speed of rotor. These behaviors are stored and measurements of shaft speed are to be done. The optimal output power is evaluated and compared to the actual output power of generator. The resulting error is implemented to control a power electronic interface. Such methods need the previous information about generator characteristics, which may not be present correctly. Sensors are needed for wind speed which is added to the cost of the entire system. For a solution to the above disadvantages, the proposed method depends on duty cycle of the boost converter. A detailed mathematical analysis of the used method has been represented below.

It has an influence that maximum output power of turbine P_{max} is proportional to the cube of wind speed V and therefore to the cube of optimum rotor speed ω_{opt} which maintains the TSR at its optimal value λopt for a given wind speed. Mathematically we can write,

$$P_{max} \propto V^3 \propto \omega_{opt}^3$$

For a PMSG with a constant flux, the phase back electromotive force (emf) *E* is a linear function of rotor speed of generator [9], which equals the turbine speed;

$$E = K_e \varphi \omega$$

The phase terminal voltage V_{ac} for a non-salient PMSG is written as

$$V_{ac} = E - I_{ac}(R_s + j\omega_e L_s) = K_e \varphi \omega_{opt} - I_{ac}(R_s + j\omega_e L_s)$$

$$\omega_e = p\omega_{opt}$$

Due to the diode bridge rectifier, the ac-side voltage amplitude Vac-amp and the dc side voltage V_{dc} can be expressed as [10];

$$V_{dc} = \frac{3\sqrt{3}}{\Pi} V_{ac-amp}$$

At the point of maxima, the optimal value of the rectified dc voltage $V_{dc\text{-}opt}$ at a given wind speed is proportional to the optimal rotor speed ω_{opt}

$$V_{dc-opt} \propto \omega_{opt}$$

$$P_{max} \propto V_{dc-opt}^3$$

The maximum dc-side electric power at a given wind speed can be expressed as;

$$P_{dc} = \eta P_{max} = V_{dc-opt} I_{dc-opt}$$

Idc-opt is the value of dc side current at optimum point.

$$I_{dc-opt} \propto V_{dc-opt}^2$$

Or

$$I_{dc-opt} = kV_{dc-opt}^2$$

IV. SYSTEM MODEL

The system made up of PV/Wind/Hybrid Power System to maintain and sustain the continuity and reliability of power supply to the load on demand at all times, outputs of wind energy and solar energy are integrated suitably.

For wind generator, the overall operation depends on the evaluation of the speed that is a sensor-less rotor speed estimator which in fact keeps away all mechanical sensors. The rotor speed so estimated, is used to control the turbine speed by maintaining the input dc quantities (Voltage and Current) for boost converter. The main simulink model of the test system is given in Figure 3

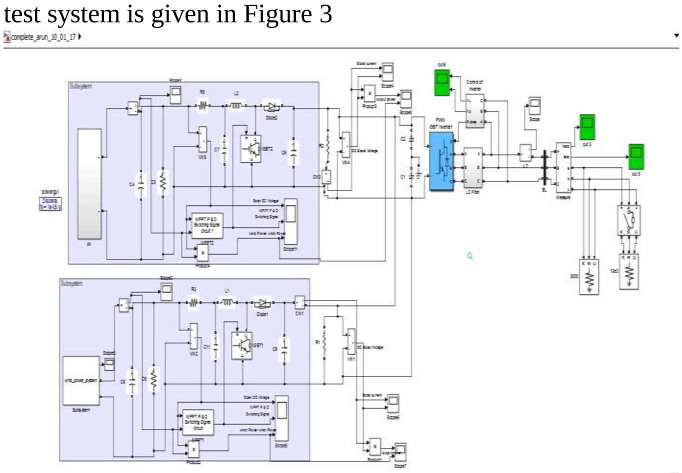

Figure 3 PWB-HPS Model

The amount of the energy incident on PV array depends not only on the energy contained in the sunlight, but also on inclination of the PV array. PV array model shown in figure 4

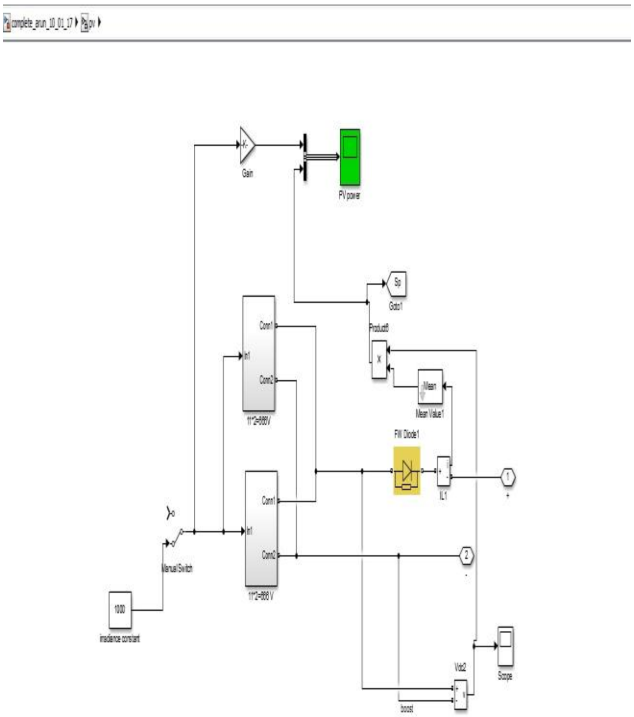

Figure 4 PV Array Model

Wind energy conversion model shown in figure 5

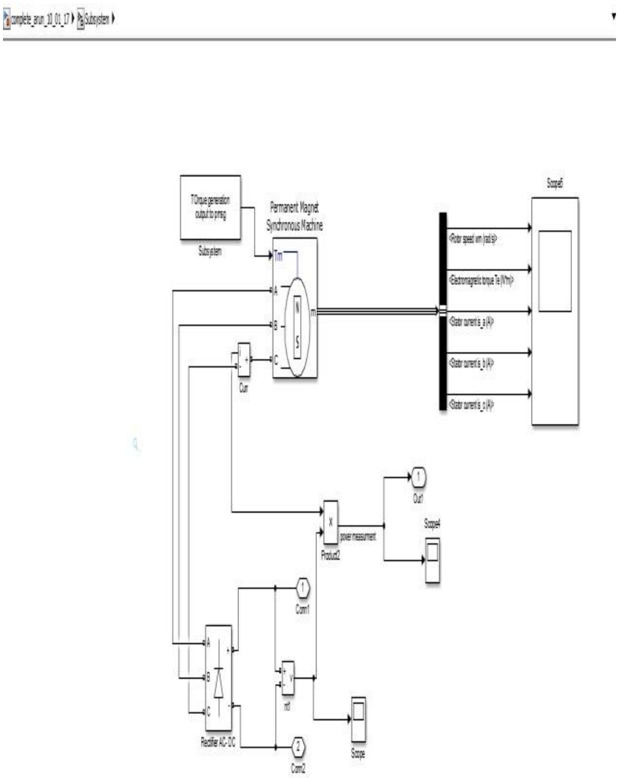

Figure 5 Wind Model

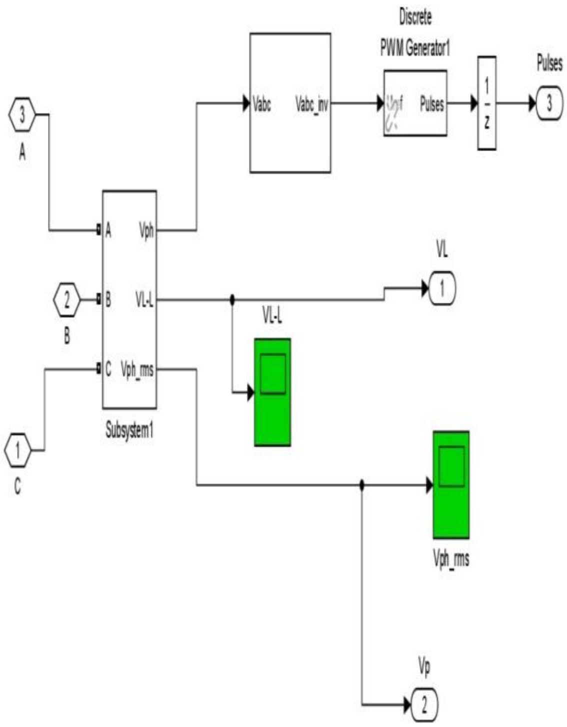

Figure 6 Control of Inverter Model

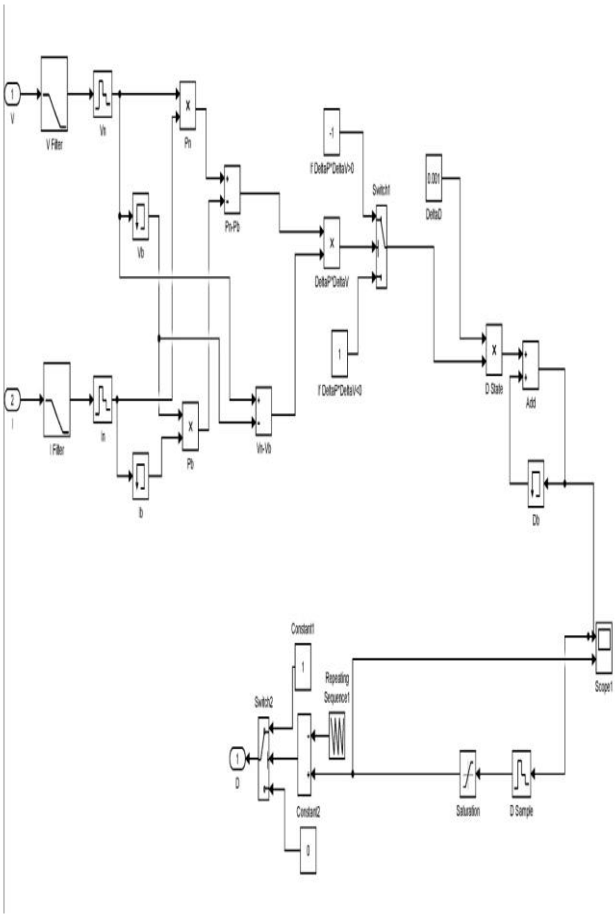

Figure 7 HCS Technique Model

V. Results

In this section simulation for hybrid model of wind and solar energy systems using Matlab/Simulink platform is carried out. Simulation studies of the proposed system are carried out using MATLAB /Simulink platform, and results are presented.

A. PV Array System

Figure 8 Shows the PV array Voltage

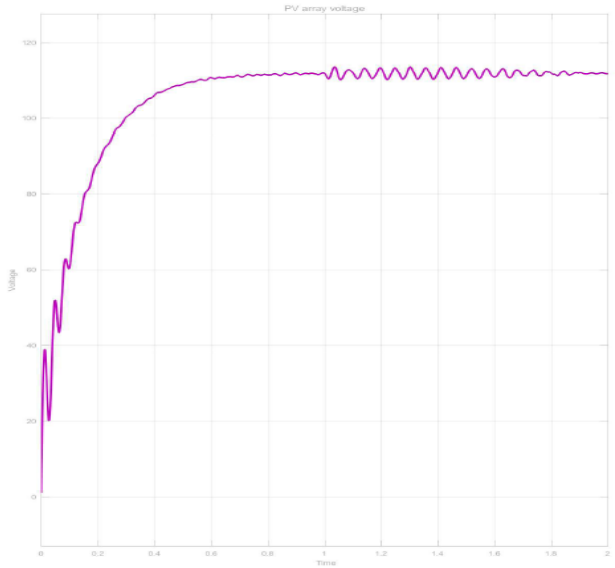

Figure 8 PV Array Voltages

In figure 9 shows a PV array Power and PV array output power

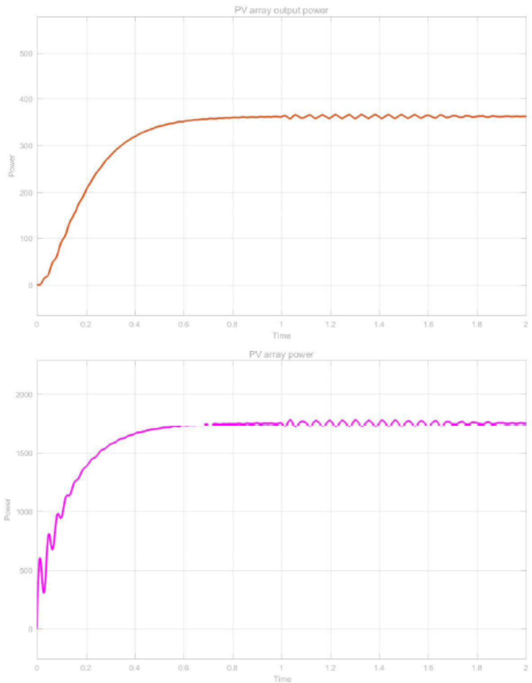

Figure 9 PV Array Output Power

In figure 10 shows a PV Boost DC Current & PV Boost DC voltage

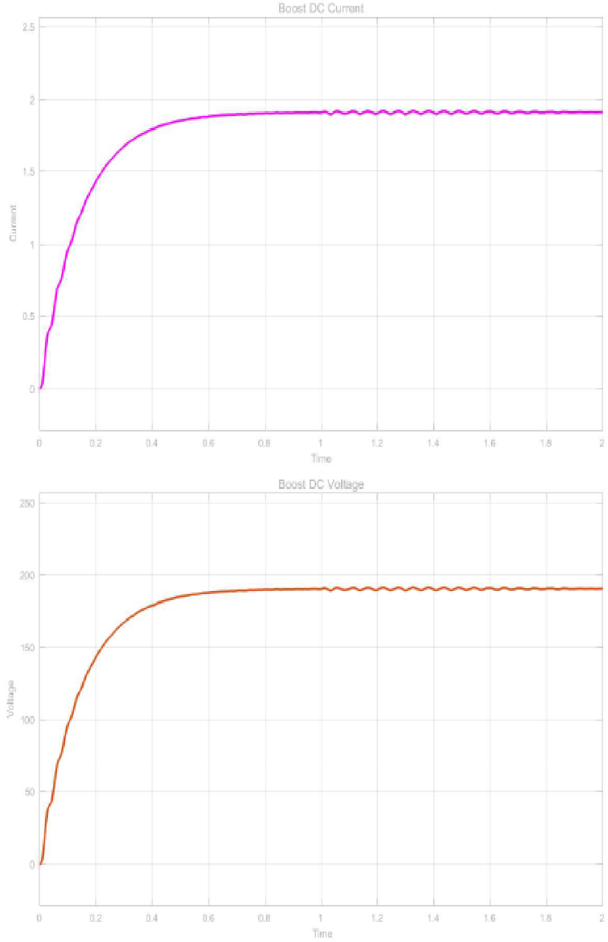

Figure 10 PV Boost DC current & DC voltage

B. Output Current/Voltage

In figure 14, 15 shows Three Phase AC Current and Three Phase AC voltage

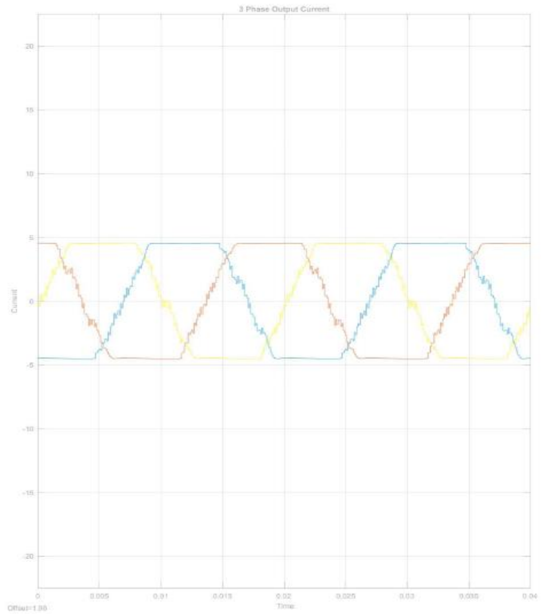

Figure 14 Three Phase AC Current

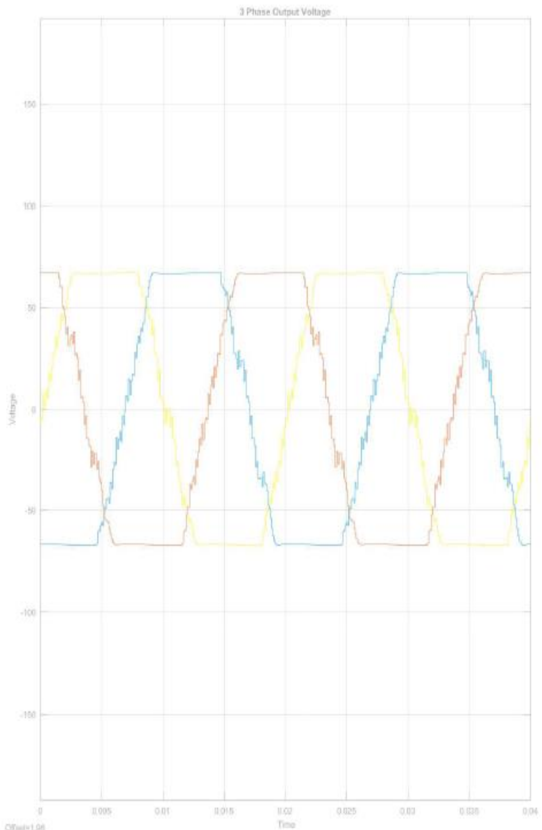

Figure 15 Three Phase AC Voltage

C. WEC at Constant wind speed

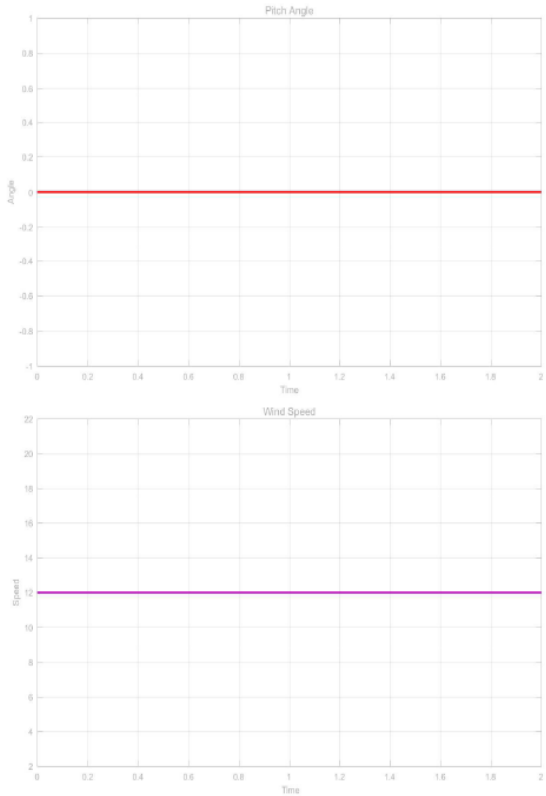

Figure 16 Constant Wind Speed

In Figure 17 shows Wind power & Wind energy conversion system output power at constant wind speed

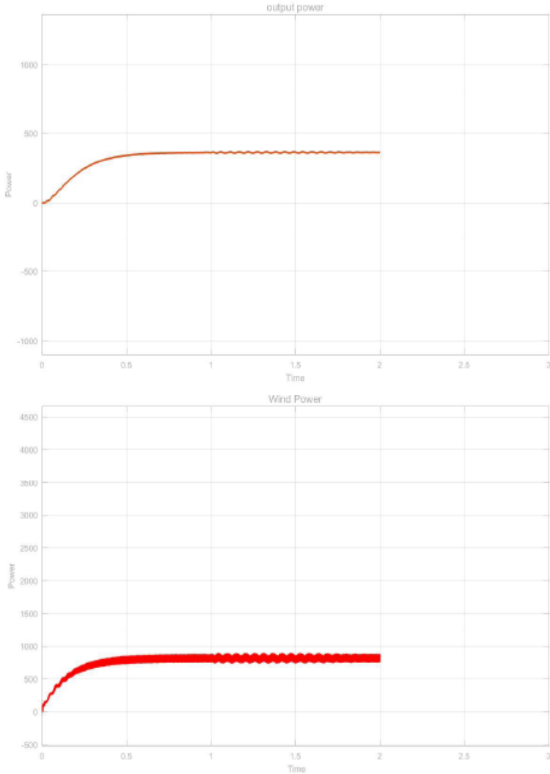

Figure 17 Wind power & output power at constant wind speed

In figure 18 shows Wind generator output voltage at constant wind speed.

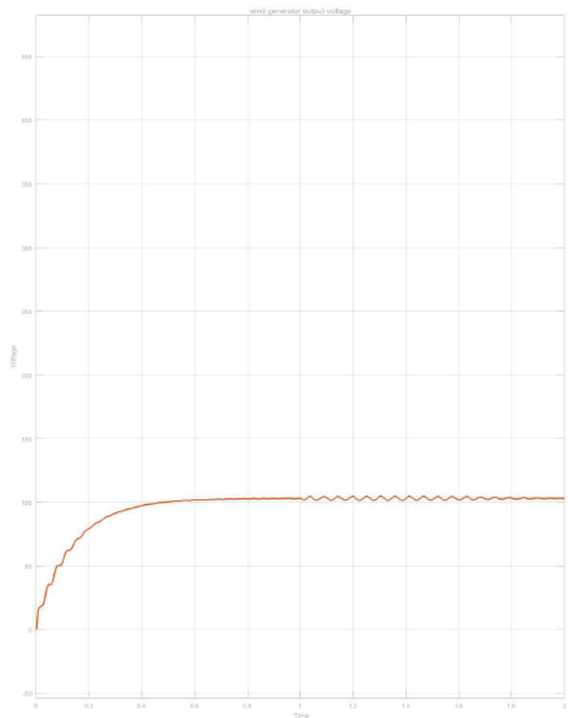

Figure 18 Wind generator output voltage at constant wind speed

In figure 19 shows Wind boost DC current and wind boost voltage at constant wind speed.

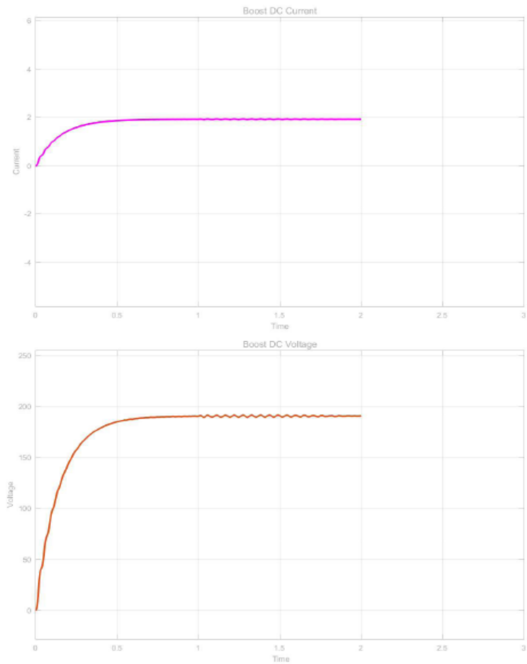

Figure 19 Wind boost DC current at constant wind speed

In figure 20 shows Permanent Magnet Synchronous Generator (PMSG) output at constant wind speed.

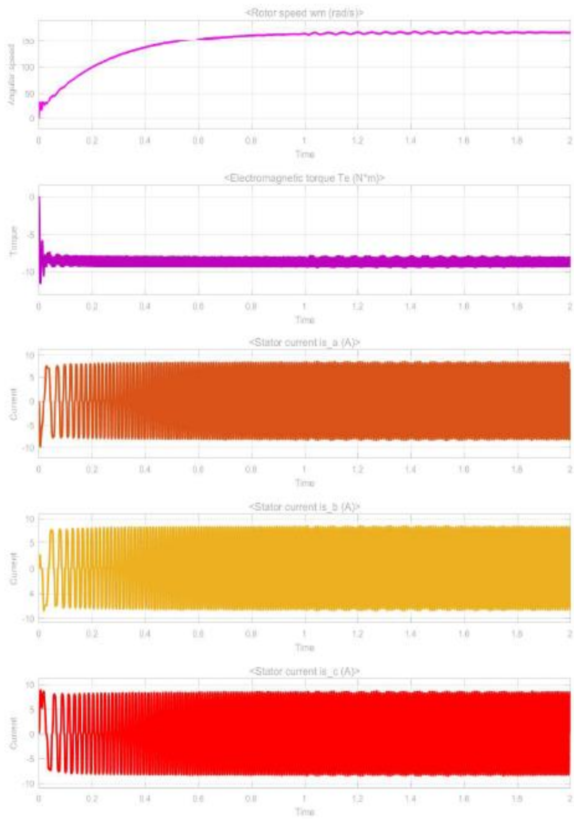

Figure 20 PMSG output at constant wind speed

D. WEC at Variable wind speed

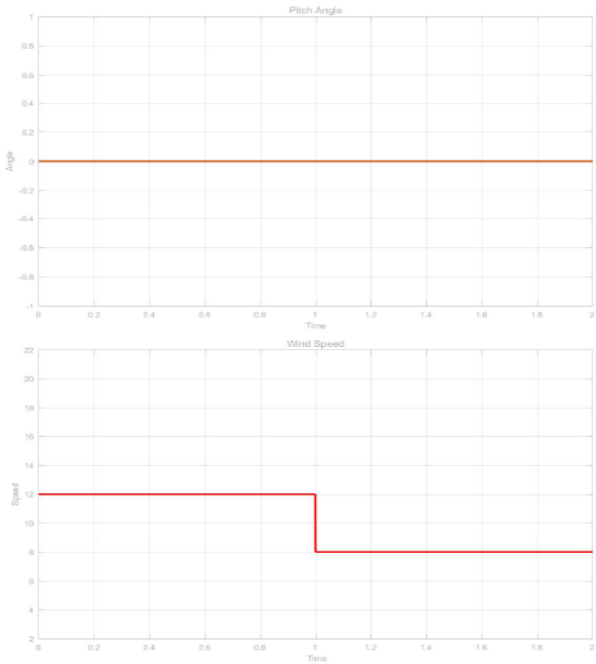

Figure 21 Variable Wind Speed

In Figure 22 shows Wind power & Wind energy conversion system output power at variable wind speed**.**

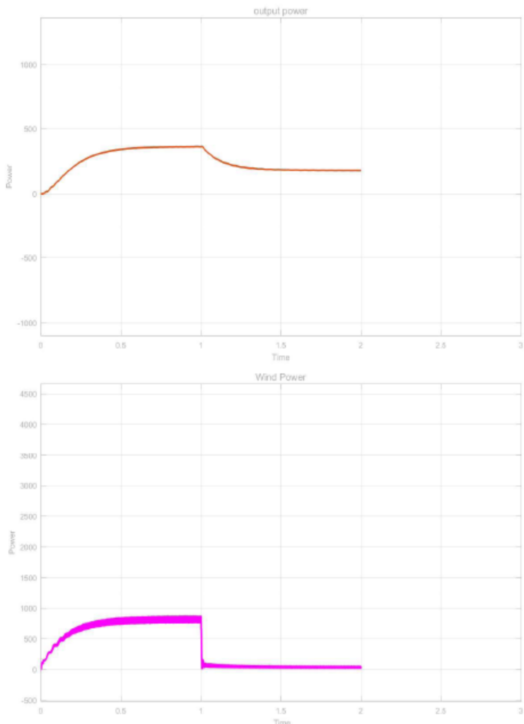

Figure 22 Wind power & output power at Variable wind speed

In figure 23 shows Wind generator output voltage at variable wind speed.

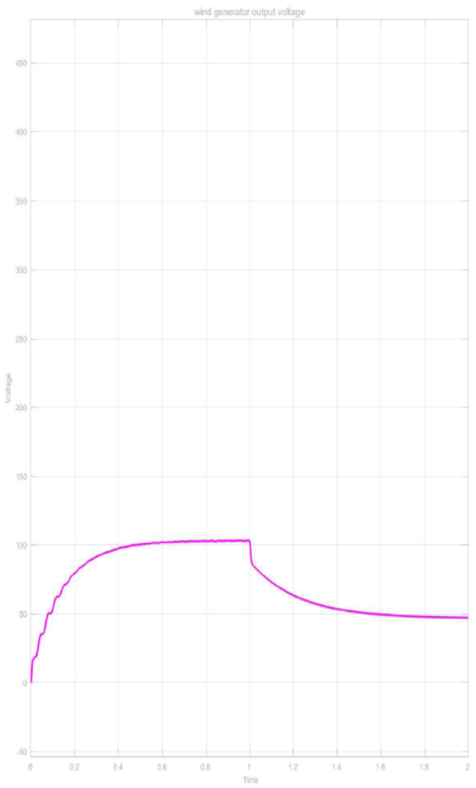

Figure 23 Wind generator voltage at Variable wind speed

In figure 24 shows Wind boost DC current and wind boost DC voltage at variable wind speed.

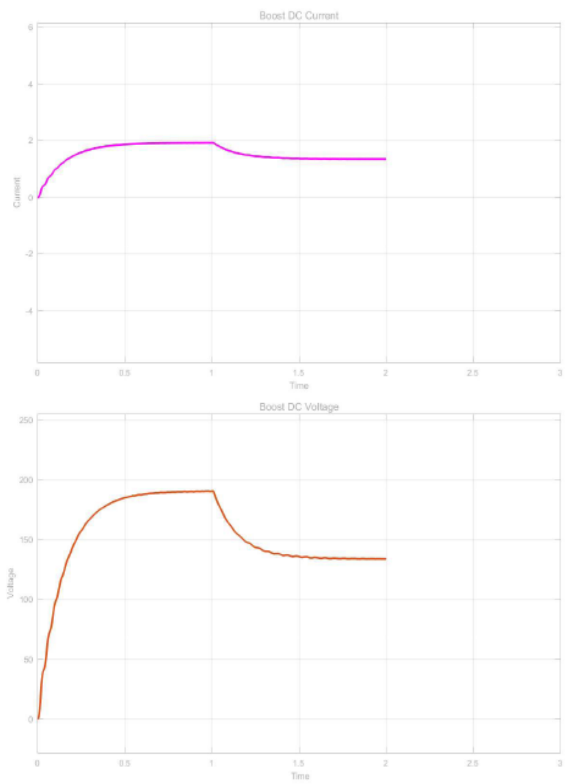

Figure 24 Wind boost DC current at Variable wind speed

In figure 25 shows Permanent Magnet Synchronous Generator (PMSG) output at variable wind speed.

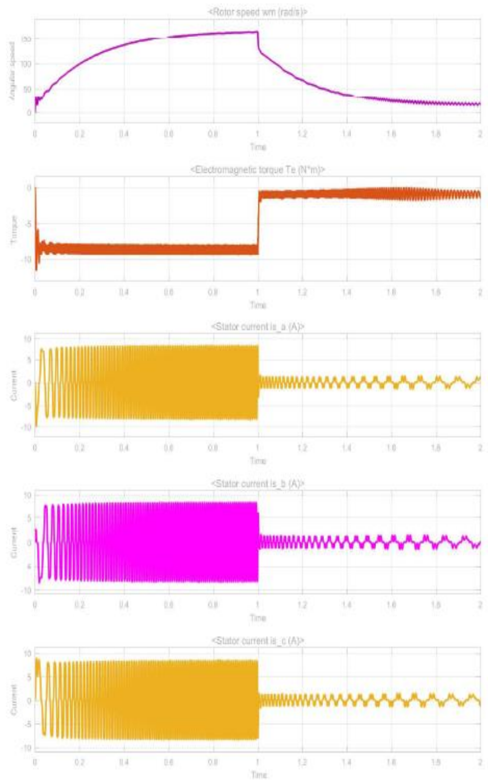

Figure 25 PMSG output at Variable wind speed

VI. Conclusion

In this paper, describes the modeling and presents simulation results on the performance analysis of a proposed PV/Wind/Battery Hybrid Power System for household applications. The proposed system is tested for the Kuala Terengganu site in Malaysia. The objective of designing such system is to optimize the utilization RES to meet the house load demand by selecting the optimal configurations for the system. The PWB-HPS takes advantage of the complementary characteristics of solar & wind power system in which when there is no solar radiation (or poor solar radiation) the load can be supplied by wind energy and vice versa. An optimal combination and integration of PV and Wind Generation System (WGS) for a given site, a proper sizing of PV and WGS system as well as battery storage will maintain the continuity of power supply to satisfy the load demand as well as increasing the efficiency of the system. The performance of the proposed system was simulated for various models. The analysis on the simulation results shows complementary characteristics between solar and wind power system that satisfies the load demand was validated in both modes.

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