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Active Power Control In Hybrid Power System Incorporated With Battery

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Abstract: *Variability and intermittency are some of the main features that characterize renewable energy sources. Intermittency usually includes both predictable and unpredictable variations. The many drawbacks of intermittency of renewable sources can be overcome by considering some special design considerations. Integrating more than one renewable energy source and including backup sources and storage systems are among the few measures to overcome these drawbacks. It has become imperative for the power and energy engineers to look out for the renewable energy sources such as sun, wind, geothermal, ocean and biomass as sustainable, cost-effective and environment friendly alternatives for conventional energy sources. However, the non-availability of these renewable energy resources all the time throughout the year has led to research in the area of hybrid renewable energy systems. In the past few years, a lot of research has taken place in the design, optimization, operation and control of the renewable hybrid energy systems. It is indeed evident that this area is still emerging and vast in scope. The main aim of this paper the research on the unit sizing, optimization, energy management and modeling of the hybrid renewable energy system components. Developments in research on modeling of hybrid energy resources (PV systems), backup energy systems (Fuel Cell, Battery, Ultra-capacitor, Diesel Generator), power conditioning units (MPPT converters, Buck/Boost converters, Battery chargers) and techniques for energy flow management have been discussed in detail. In this paper, an attempt has been made to present a comprehensive review of the research in this area in the past one decade.*

Keywords: Renewable energy resources, hybrid renewable energy, MPPT converters.

I. Introduction

Power generation from wind energy can be divided into constant speed operation and variable speed operation. Variable speed generation can be applied by aerodynamic control, power electronics control, or a combination of the two. The combination control is advantageous as it can provide maximum power point tracking at operating wind velocities. Although all older versions of commercial wind turbines are operated at constant speed, the interest nowadays lies in variable speed turbines.

T Kerekes, R Teodorescu, and E Aldabas: The advantages of variable speed wind turbines are increased energy capture and improved power quality with attenuated grid impact from wind fluctuations. The focus of this study lies on implementing a control strategy based on power electronics [17]. Reviews of controlling the wind generator in MPPT mode and high wind limiting mode are discussed in this section.

M Simoes, B Bose, and R Spiegel: A wind turbine has a maximum level of power which can be extracted from the wind, which is related to the Betz limit (59% efficiency). The power coefficient (Cp) is the percentage of power in the wind extracted by the wind turbine. The power coefficient value depends on the specific wind turbine shape, the wind velocity, the turbine rotor speed, and the turbine's blade pitch. The curve depicting this coefficient (Cp) with rotor speed has only one maximum point. Therefore, the main objective of the MPPT process is to adjust the wind turbine to work at the maximum point of that curve. The operating strategy of MPPT in wind power systems is to match the generator loading with the wind turbine characteristics. Consequently, the rotor operates continuously at speeds as close as possible to the maximum power points (MPPs) [23, 24].

T Burton, D Sharpe, N Jenkins and E Bossanyi :The turbine power can be calculated from Equation (2.1) as a function of wind velocity and the efficiency coefficient (Cp) which is a function of the tip speed ratio (TSR) and pitch angle θ. TSR is calculated from Equation [18]:

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

Where, πr^2 is the rotor swept area,C_p is the power co-efficient, λ is the tip speed ratio, β is the pitch angle while V_w being the wind speed. The tip speed ratio λ can be described as:

$$\lambda = \frac{r\Omega}{V_w}$$

M Prats et al.: Due to the nonlinear characteristics of the wind generator and the continuous rapid change in wind velocity (wind gusts), MPPT is a challenging issue for wind power generators. The MPPT for wind generator can be divided into aerodynamic control and power electronics control. Aerodynamic control is either based on the pitch method or the stall method. The purpose of pitch or stall control methods is to track the MPPs of wind turbines with changing blades pitch angle or the attack angle of wind on the blades respectively [19]. However, as the size of the turbine increases, the aerodynamic control becomes more and more complex and costly. Other drawbacks are the increased cost and the maintenance cost of the turbine. Furthermore, this kind of control will reduce the reliability and life span of the unit.

Z Chen, J Guerrero, and F Blaabjerg :The usage of power electronic converters allows for variable speed operation of the wind turbine and for enhanced maximum power extraction, supplying the load with improved quality of power. The work proposed is concerned with the power electronics control. There are many power electronic converter schemes used to control the wind generator's power output [20]. The applied power electronic scheme depends on the electrical generator type, the load supplied by the wind generator, and the control topologies used in the system.

1.1 Sensor Control

S Hao, G Hunter, V Ramsden and D Platters: Sensor control is to use, as control parameters for the control circuits, a wind velocity sensor or rotor speed sensor to measure wind velocity or rotational speed respectively. The simplest method is to measure the wind velocity, and then the power against wind velocity is fitted to the curve. The result of the curve fitting is used to adjust the operating points of the system [21]. The wind speed is measured and the reference MPP is determined accordingly. Then, the controller adjusts the system to this operating point. Wind velocity is not a satisfactory control parameter because of the following:

1. The erratic nature of wind velocity.
2. The difficulty of measuring wind velocity close to the turbine.
3. The time delay associated with the measurement of wind velocity.

N Nanayakkara, M Nakamura and H Hatazaki: One of the methods to avoid the delay of measurement results is to use neural networks to predict the wind velocity. After that, the MPP can be established from the relation between wind velocity and output power. This method is closely connected to the reduction of power fluctuation produced by pitch control [22]. The drawback of this method is the need to track wind velocity via a database for a long time before the implementation of the system. Another disadvantage is the high prediction accuracy that is required. Furthermore, the wind speed sensor is still needed. This method is not applicable to small scale generators as the site of installation is not known when the turbines are mass produced; on-site tuning of the neural network is not justifiable economically for small scale turbines.

Using a rotational speed sensor (shaft encoder) is another method proposed in the past. This method ensures maximum wind power capture by controlling the rotor speed to send the wind turbine to the maximum power point. The rotor speed is controlled by means of the electrical power from the generator which is driven by the wind turbine, and this is achieved through the power electronics interface. As an example, for a PMSG (permanent magnet synchronous generator), the generator torque is proportional to the machine's current which can be set, while the

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rotational shaft speed of the generator determines the target torque. Consequently, if the wind generator's output current is controlled to change the torque, the rotor speed will be changed to maximize the power output of the wind turbine.

II. System Configuration

This chapter focuses on the wind turbine generator side of the system. The advantages of using a horizontal axis wind turbine (HAWT) which directly drives a PMSG have already been discussed in Chapter (1). In this chapter, the control of this configuration will be proposed. The control of the wind turbine generator aims to deals with two different wind velocity scenarios:

- MPPT control in low and moderate wind velocities when the maximum power produced and rotor speed is less than the rated value.
- High wind velocity control when the output power and rotor speed of theg enerator could exceed rated values.

The study in this chapter intends to develop a controller which maximizes the power of the wind generator at low and moderate wind velocities. As the wind velocity goes beyond the rated value, the controller limits the output power and rotor speed. The high wind velocity control is found to be a general problem in HAWTs. It is not easy to be mechanically stalled because adding mechanical control to the turbine will significantly complicate the turbine and reduce its reliability. Furthermore, it will increase cost and size of the turbine. A literature review was presented in Chapter 2, discussing the different control methods for MPPT and high wind speed control. The main control action for the wind generator is provided by a boost dc-dc converter, which supplies the power to the inverter.

2.1 System Modelling

A. PMSG and Wind Turbine Modelling

The electrical circuit dynamics of the generator have little effect on the overall mechanical dynamics and can be ignored in the control design. The equivalent circuit of a permanent magnet generator and the diode rectifier can be simplified as shown in Figure (3.1) viewed from the dc side of the rectifier. The Thévenin series resistance Rw has a value of twice the per phase resistance of the generator, neglecting the commutation overlap in the rectifier as the PM generator used has low inductance.

The source emf (ew), is proportional to the generator speed (ωm).

$$e_w = k_w \omega_m \tag{3.1}$$

where K_w is a constant depending on the machine design.

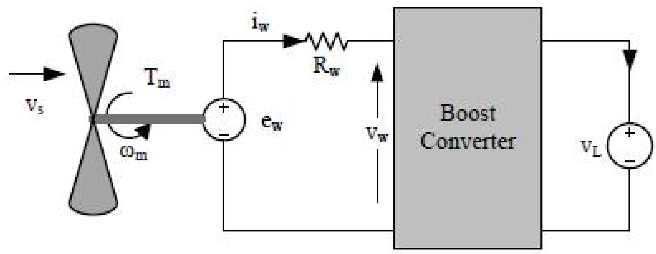

Figure (1): A simplified wind generator system

The Thévenin equivalent of the generator and diode bridge rectifier feeds a boost type dc-dc converter which supplies the dc link of the grid inverter represented as a voltage source V_L. The power drawn by the inverter from the dc link maintains the voltage constant; with a passive diode rectifier the power level is to be set by the duty cycle control of the dc-dc converter. The turbine torque is represented by the following equation.

$$T_m = \frac{1}{2}\rho A R v_s^2 C_p(\lambda)/\lambda$$

Taking into account that (λ) was proposed before in Equation (2.2) (see Chapter (2)). With a fixed pitch angle, the whole operating region of Cp can be approximated in the following quadratic form as a function of λ.

$$C_p = a_1\lambda^2 a_2\lambda + a_3$$

Neglecting damping and friction, the mechanical dynamics can be reduced to:

$$J\frac{d\omega_m}{dt} = T_m - T_e$$

$$T_e = \frac{P_e}{dt} = \frac{e_w i_w}{\omega_m} = K_w i_w$$

From equations (3.1), (3.4) and (3.5);

$$\frac{de_w}{dt} = -\frac{K_w}{J}i_w + b_1 v_s e_w + b_2 v_s^2 + b_3\frac{v_s^2}{e_w}$$

Where $b_1 = K_t R a_1/J$

$b_2 = K_t K_w a_2/J$

$b_3 = K_t K_w^2 a_3/(JR)$

$Kt = 0.5\rho AR$

On the electrical side, the relationship between the dc side voltage of the rectifier and the voltage as the input to the grid side inverter can be simplified as:

$$v_w = (1-d)v_L$$

The average dc side current can be calculated as follows.

$$i_w \frac{1}{R_w}[e_w - (1-d)v_L]$$

Table 1 PMSG and Wind Turbine Parameters

Parameters	Values
Wind turbine rated wind velocity	12 m/sec
System output power, rated value	8.5 kW
Generator Type	PMSG, Salient type
Ld, Lq	0.0082, 0.0082
Moment of Inertia	0.0119 Kg/m2

B. Pitch Angle Control

This method is implemented to control the mechanical power input at the nominal value. Whenever the velocity of wind exceeds the rated value of power, a mechanical method is implemented so as to control the blade angle of the wind turbine from being damaged. At low wind speed, a control system technique is applied so that highest amount of power can be extracted from the wind. In this case, blades are turned back for the extraction of maximum amount of energy. While during the gusty wind condition the pitch angle is adjusted to limit the power extraction. This is done by turning the blades away from the wind. A pitch controller is used to regulate the blade angle by using proper simulation technique for capturing the wind energy. The conventional PI method was used before regarding the pitch angle control.

To examine the performance of wind turbine rotor of any size the tip speed ratio and the power coefficient Cp are utilized because of the fact that they are dimensionless. The power coefficient Cp can be calculated by utilizing the theory which is based on the ratio of rotor and wind speed i.e. a given tip speed ratio. With the tip speed ratio one can develop the power coefficient of rotor at fixed rotor speed or for the variable rotor speed at constant speed. If the rotor is provided with blade pitch control then the power coefficient curves must be calculated for different blade pitch angle β which are utilized in this operation. The equation which is utilized to defines the model Cp (λ,β) based on the modeling turbine characteristics is given by:

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$$Pm = \partial E\omega / \partial Cp$$

$$Cp = 0.5176(116/\lambda - 04\beta - 5)e\frac{21}{\lambda} + 0.0068\lambda$$

Where ω =Wind speed

Cp is the performance coefficient and it depends on the turbine characteristics which creates the losses in the process of energy conversion.

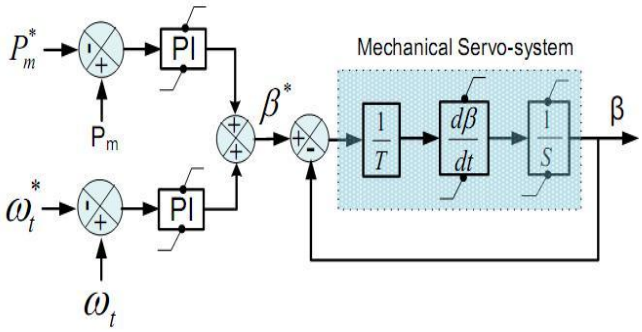

Figure (2): Scheme for the Pitch Angle Control

C. Maximum Power Point Tracking Control

Maximum power point scheme is used to extract highest amount of available energy from the wind, while it is operating over a large range of wind speed. According to maximum power point tracking the generator speed is adjusted according to the variations of wind speed. This is done so that the tip speed relation can be maintained at its optimal value λ. The conventional control schemes included the control mode of operation which used to depend on the setting of reference values.

D. Two Mass Drive Train

WECS is consists of two-mass drive train model. The mechanical dynamics is represented by the differential equation which is given as follows:-

By utilizing the Newton's second law for rotation system on the rotor, the mathematical model will be:

$$J_r\omega_t + \beta_r\omega_t = T_a - T_{ls}$$

Where Wt = angle speed

B_r = rotor damping effect J_r = moment

of inertia T_{ls} = shaft torque

T_a = applied torque

Similarly we can calculate for a driving gear and it is basically a moment of inertia which is cancelled, this will conclude:

$$J_{ls} + \beta_{ls}(\omega_t - \omega_{ls}) + K_{ls}(q_t - q_{ls}) = T_{ls}$$

Where W_{ls} = angular speed at low speed shaft

B_{ls} = damping effect

J_{ls} = moment of inertia

III. Simulation And Results

The hybrid power generation system consists of PV system, Wind Energy Conversion System and Battery Energy Storage System. PV system is subjected to variable solar irradiance. Wind Energy Conversion System is also subjected by variable wind speed. The hybrid system is connected with the load which is also variable. So these perturbances cause the difference in power supply as well as demand also. To take care of these perturbances fuzzy logic based

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controller is used. Also for getting the maximum output from the wind turbine and PV system their individual controllers are also used to extract maximum power.

The HRES shown in Fig 5.1 comprises of PV system, permanent magnet synchronous generator (PMSG) based wind systems and battery storage. The PV and wind systems having its own DC-DC boost converter equipped with MPPT controller. In this work, very well-known Perturb and Observe (P&O) MPPT technique is adopted for maximum power extraction. The battery system has its bidirectional buck-boost converter. The battery is charged or discharged depending on the availability of excess or shortage of power. A power controller is designed for the charge and discharge of the battery. The DC link capacitor is connected to the sinusoidal PWM IGBT based inverter which is fed to single phase AC load. The harmonics present in the output of the Inverter is filtered by a LC filter. The maximum power ratings of PV and wind systems considered here are 6kW and 4 kW respectively and battery rating taken here 6 kWh.

The present work proposes a PMS which ensures that the load is supplied uninterruptedly and the battery is charged within the maximum specified charging rate by means of a two stage charging technique. The control algorithm suppresses the short term fluctuations in PV and load power by the use of battery.

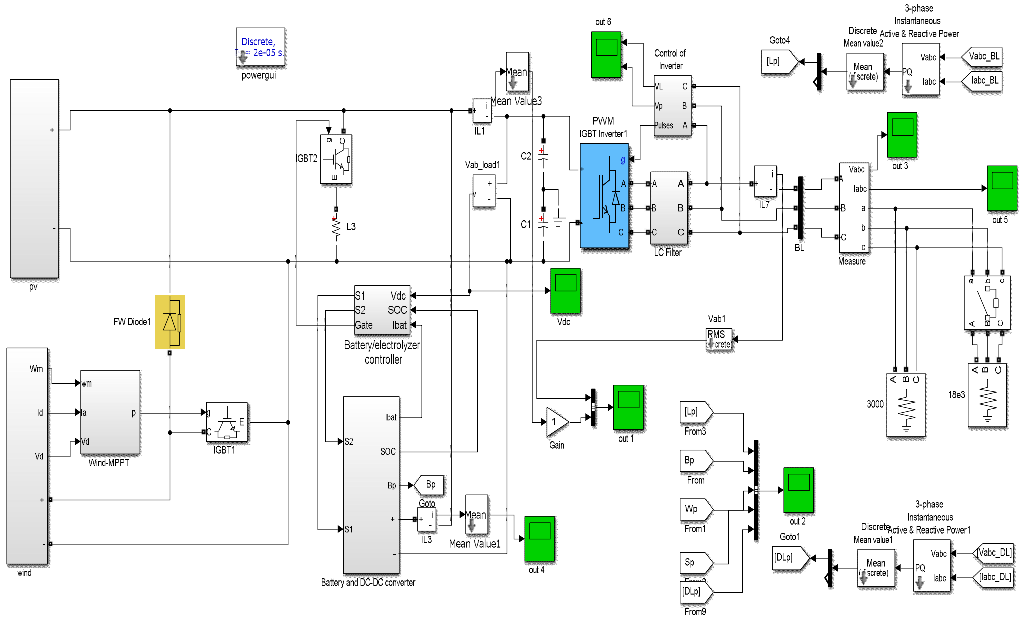

Figure (3): MATLAB/Simulink diagram of hybrid system

3.1 Results

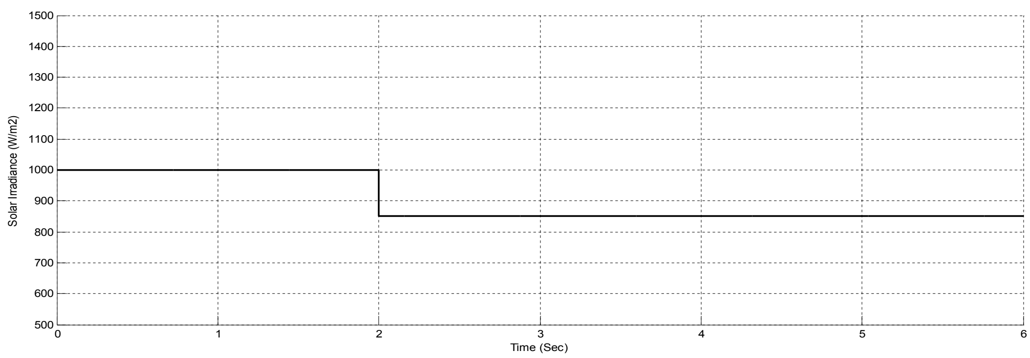

Figure (4): Solar Irradiance

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The solar irradiance is variable and it initially 100W/m2 and at time 2 sec it is reduced to 800 W/m2.This cause the dip in PV system. The solar irradiance is reduces as the PV output, i.e. shown in fig. 4.

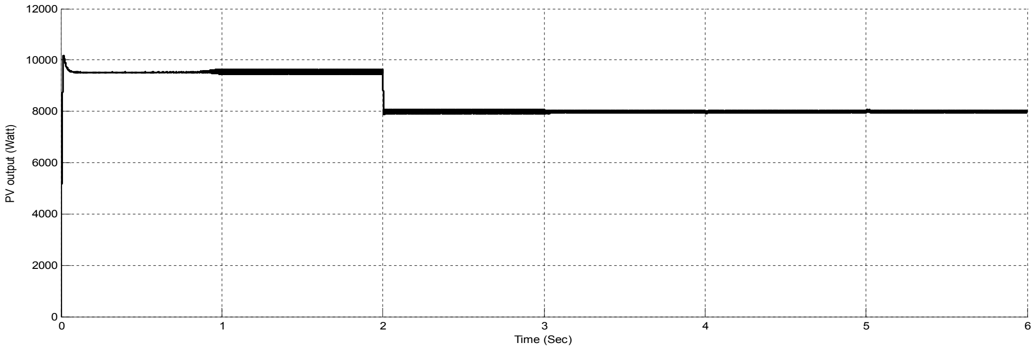

Figure (5): PV output

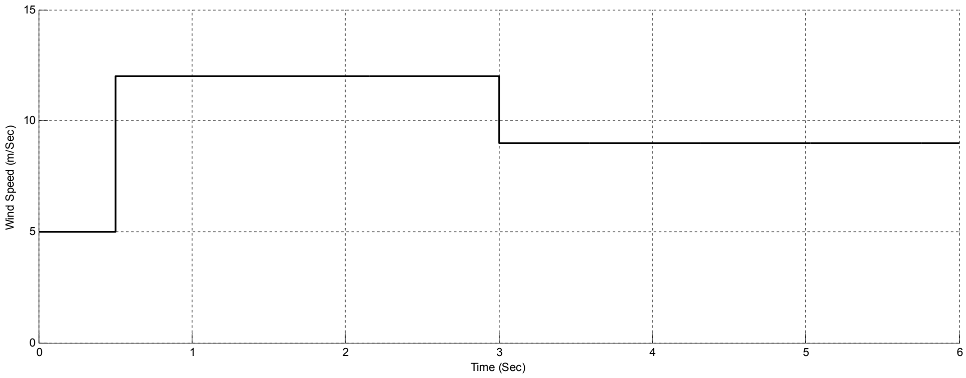

Figure (6): Wind Speed (m/sec)

Figure 5 shows the variations in the wind speed. Initially wind speed is 5 m/sec, which below the cut-in speed. Then at time 0.5 second wind speed rises to 12 m/sec. At time 3 second wind speed is again reduced to 9 m/sec. The wind speed is varies in realization of the random wind speed at a particular location. As the wind speed is not varied as steep as shown in the fig, but it is assumed that the speed is varied steeply for the sake of simplicity.

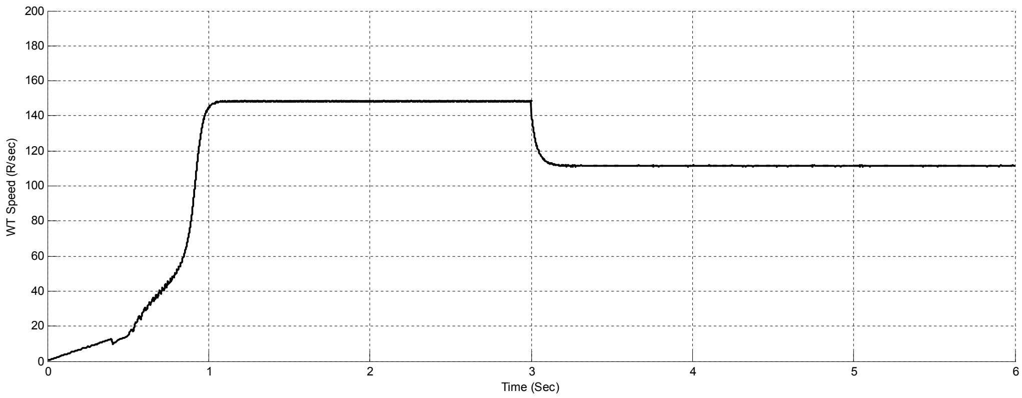

Figure (7): Wind Turbine Speed (rad/sec)

Corresponding WT is shown in fig. 6. As the time between (0-0.5 second) the speed is below cut-in speed the WT will not produce any power. This can be seen in fig. 6.5. At time wind speed increased, the WT speed also becomes more than cut-in speed and WT start producing power. The WT output power is shown in fig. 7.

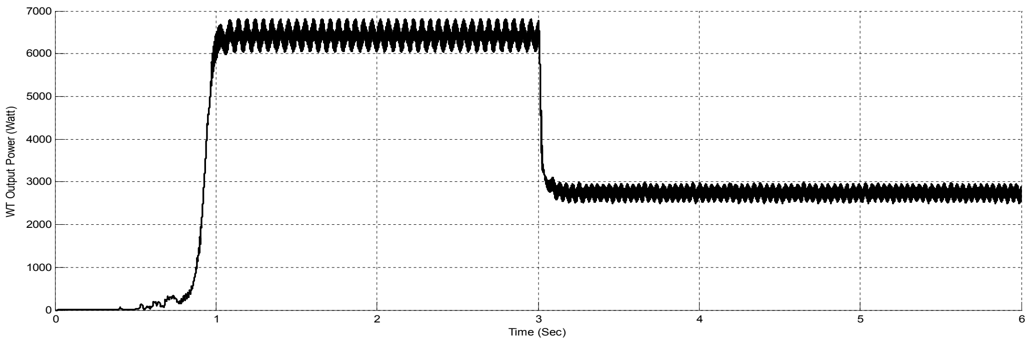

Figure (8): Wind Turbine output power

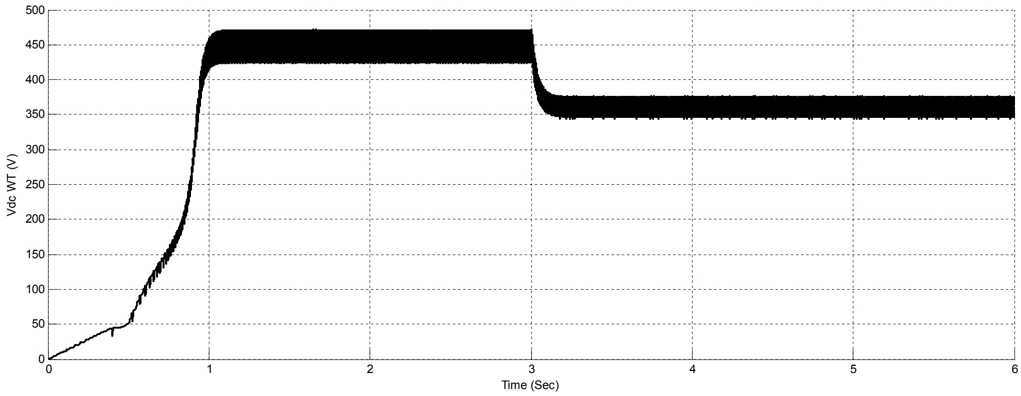

Figure (9): V_{DC} across Wind Turbine

As discussed earlier that wind turbine does not produce power below the cut-in speed, this is also shown in the fig. 7. When wind speed is 12 m/sec, the WT power is around 7000 W. When wind speed is 9 m/sec, then the WT power comes down to 3000 W.

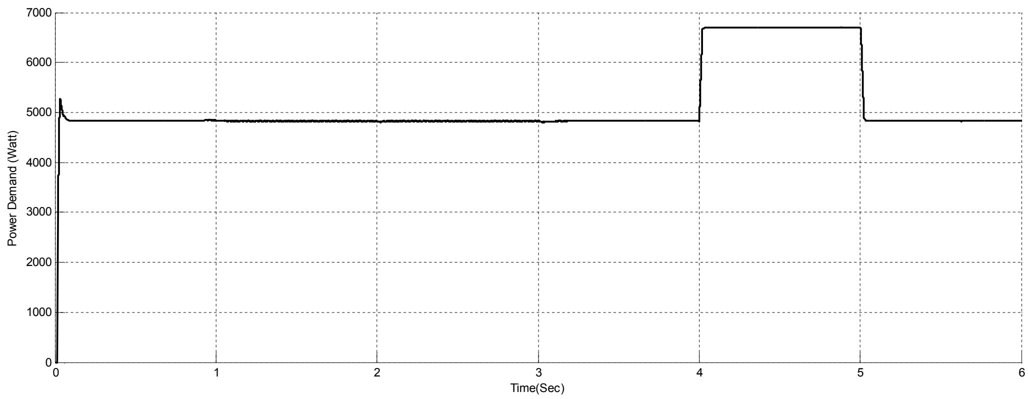

Figure (10): Variation in load

As we know the load is always variable, the variable load is applied to the hybrid power system. Initially 5000 W load is applied which is increased to 6800 W at time 4 second, again the load is reduced to 5000 W at time 5 second. The variation in load is shown in fig. 9.

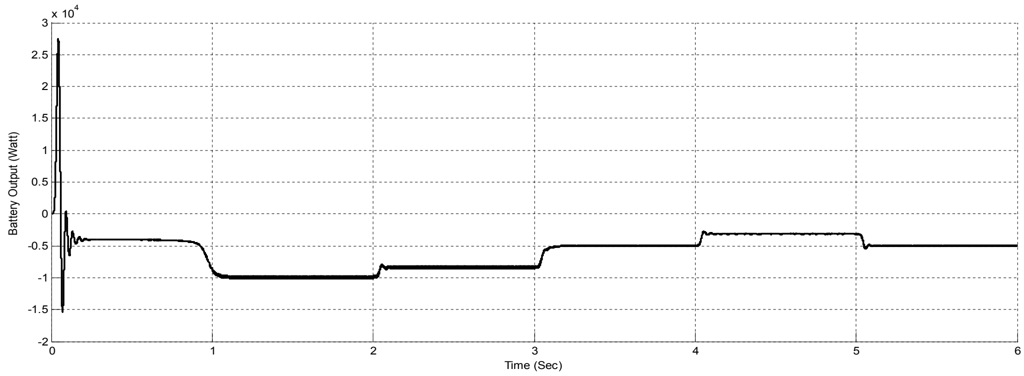

Figure (11): BESS output

The BESS is used as the backup of the system. When there is shortage of the supply then BESS supplies that shortfall in power and when the supply is more than the demand then the BESS system takes that excess power to charge the battery. This is shown in the fig. 10. Fig. 11 shows the current waveform of BESS.

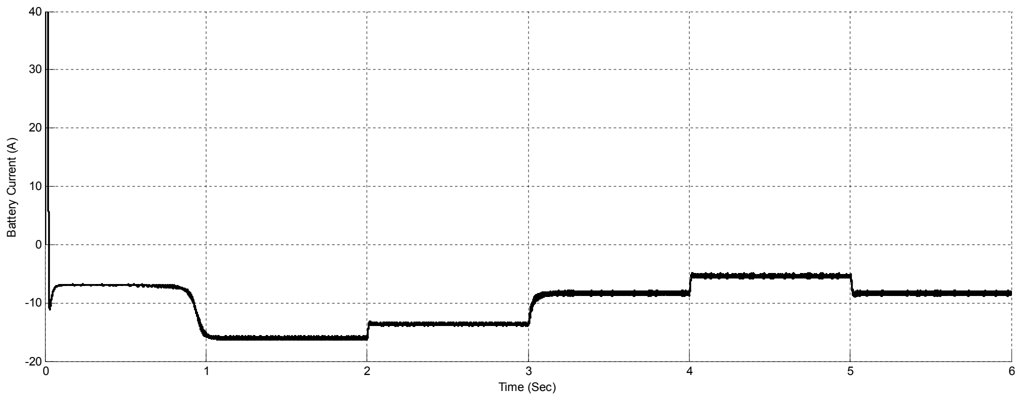

Figure (12): BESS output current

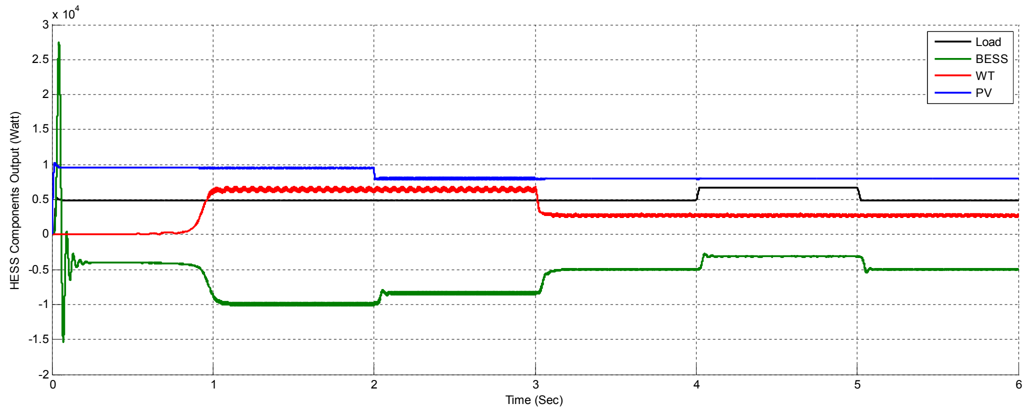

Figure (13): Output power of different components of Hybrid power system

The power output of the different components of the hybrid power system is shown in fig. 12. From the fig. it is found that when there is shortfall in the PV system output or WT output the BESS compensate this shortfall. Also when load is more than the supply the BESS comes in to the action. The BESS always maintained supply equal to the demand.

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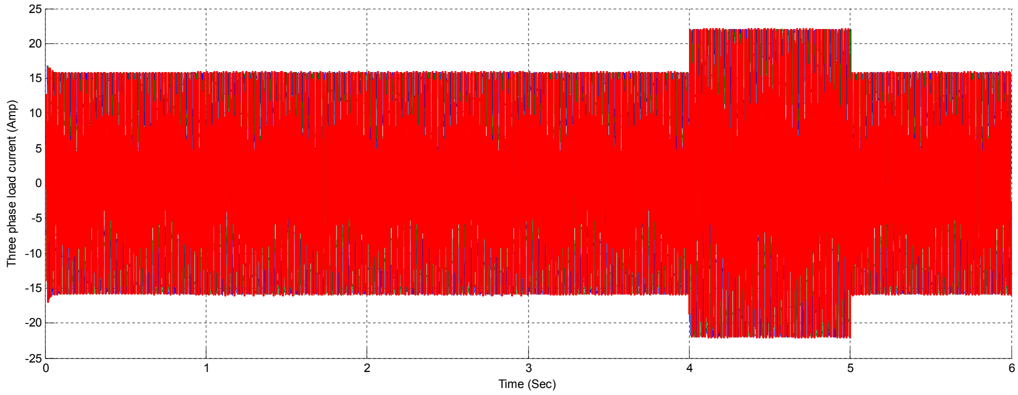

Figure (14): Load current

Fig. 13 shows the three phase load current waveform. As mentioned earlier that the load is varied between times (4-5 second), this is visible in the current waveform. As load increases the current increases and vice-versa. The load voltage is shown in the fig. 14. As the load is varied the load will draw the current according to the load but the voltage is should be same irrespective of the load as shown in fig 14.

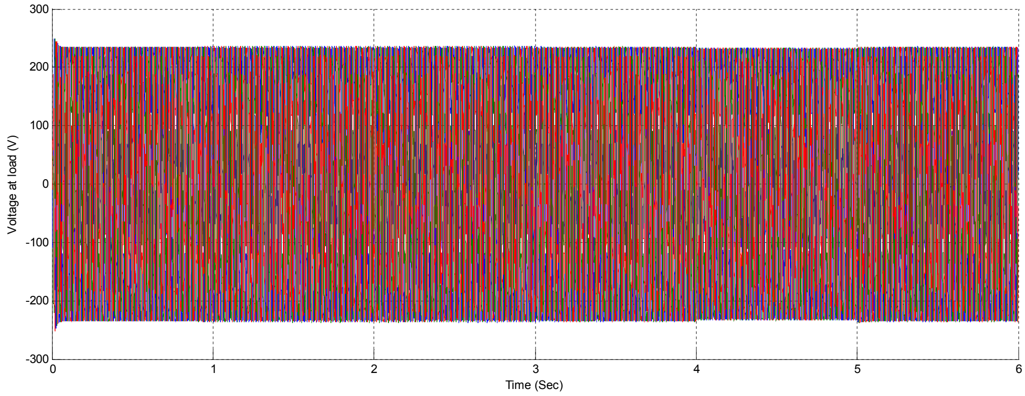

Figure (15): Voltage across load

The voltage across the load is maintained constant by the DC link voltage of the capacitor. If the voltage across the capacitor is constant the voltage across the load will also be the constant. Fig. 15 shows the DC link capacitor voltage across the capacitor.

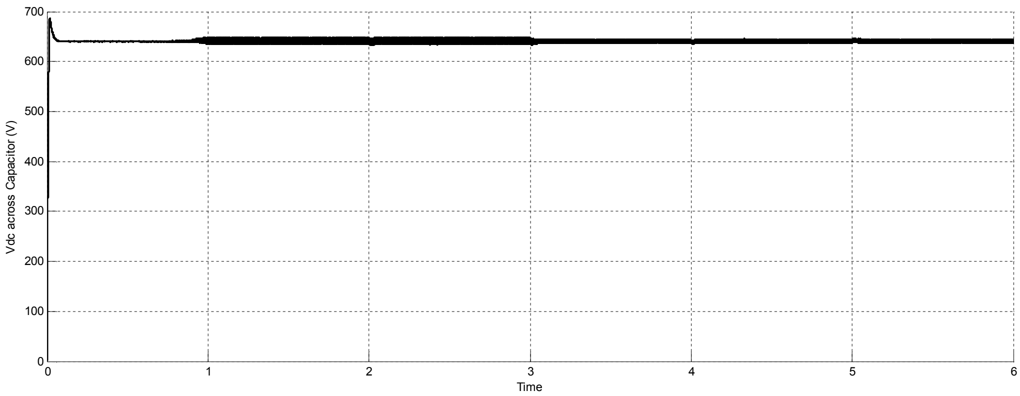

Figure (16): DC link Voltage across capacitor

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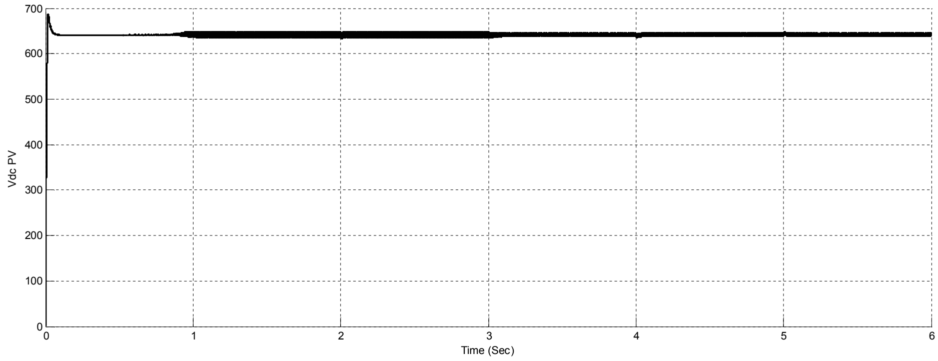

Figure (17): DC link Voltage across capacitor of PV system

3.2 Comparison Between Work Done and Base Paper

The present work is modification of paper titled “Permanent Magnet Synchronous Generator-Based Standalone Wind Energy Supply System” taken as platform of this thesis. In the base paper selected as titled above proposed a hybrid system consists of wind turbine, fuel cell and battery based power system. The fuel cell technology is not a matured technology and in developing stage. Therefore instead of adopting fuel cell as the second source, PV system is used which is widely accepted worldwide. The advantages of PV system in comparison of fuel cell are as follows:

1. Sun energy is freely available.
2. Sun energy is abandoned in nature.
3. PV system is widely accepted and a matured technology.
4. Governments provide incentives for solar system.
5. PV system cost is almost one fourth of fuel cell for same rating.

Apart from these advantages PV system response is very fast as compared to the fuel cell based power generation.

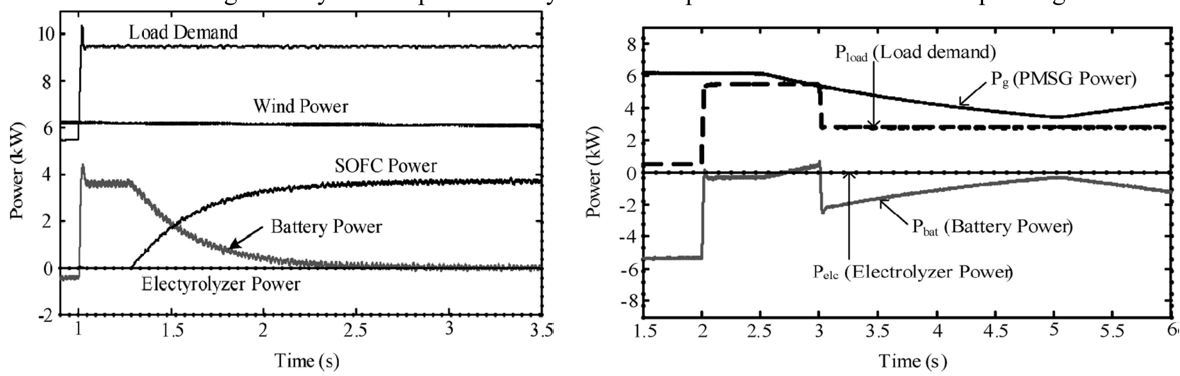

Figure (18): (a) and (b) Variations in power of different components of hybrid system adopted in base paper

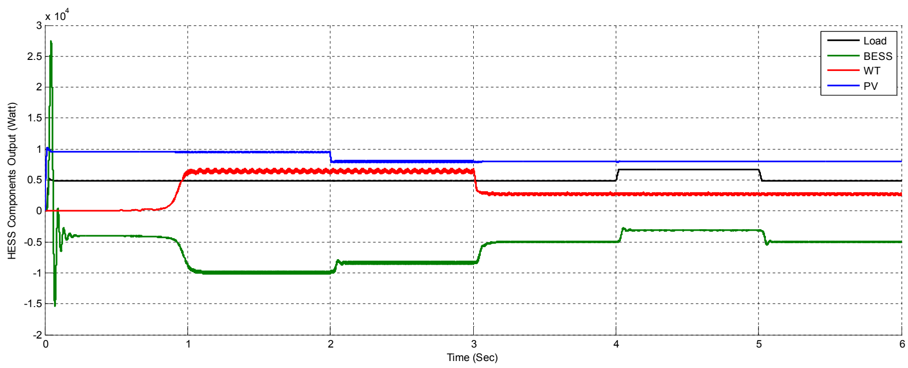

Figure (19): Variations in power of different components of hybrid system proposed work in this thesis

From the above figures it is analyzed that in fuel cell based power system with the variations in the load and wind speed, the fuel cell output power is not as responsive as the PV system output.

Also the response time of the BESS in fuel cell based power system is also slow as compared to the PV based hybrid power system. Due to this the fuel cell based hybrid system takes longer time to settle the DC link voltage and ultimately the voltage across the load which is not desirable. From the Fig. 5.18 the DC link voltage variations of both the systems can be seen. There is more variations in DC link voltage as the line is thicker. On the other hand the PV based hybrid system response has instantaneous response due to the perturbances caused by load and wind speed. The electrolyzer used in fuel cell required some power to produce hydrogen which decrease the overall output of the system.

So it can easily be said that PV-Wind-battery based hybrid power system has more advantages as compared to the PV-Fuel cell-Battery based hybrid power system in terms of response time. Overall cost and other technical aspects.

IV. Conclusion

PV cell, module and array are simulated and effect of environmental conditions on their characteristics is studied. Also the wind Energy Conversion System is modeled using PMSG. The effect of wind speed on the performance of the WT system is examined. Then the BESS using Nickel-Metal Hydride battery system the balance is maintained in supply and demand. The major contributions of the work are:

- Wind energy system has been studied and simulated
- Maximum power point of operation is tracked for both the systems using P&O algorithm
- Both the systems are integrated and the hybrid system is used for battery charging and discharging.
- Individual MPPT system is used for both WT and PV system.

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