International Journal of Science, Engineering and Technology Research (IJSETR), Volume 4, Issue 8, August 2015

Control Scheme for Grid Connected WECS Using SEIG

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Abstract: **Now-a-days wind energy is one of the pivotal options for electricity generation among all sources of energy. But, wind flow by nature is intermittent, so it results in discontinuous power to load. In order to ensure continuous power supply to load, in stand-alone systems a suitable storage technology is needed as backup. Stochastic nature of the wind results in discontinuous battery charging current which causes harmonic heating of the battery. To avoid this charge controller is required. If the wind speed exceeds its rated value it results in mechanical damages, to avoid this pitch controller is required. Till now all the stand-alone WECS are developed with single control strategy, recently an isolated WECS with integrated control schemes are developed and it is observed that this WECS works efficiently compared to systems without having integrated control schemes. If the power generated by isolated WECS is greater than the load requirements, the extra power can be saved by connecting the stand-alone WECS to grid. So, in this paper, a hybrid stand alone wind energy conversion system is designed with integrated control schemes [1], and the output of this isolated WECS is connected to grid to save extra power. This Hybrid system consists of a 4-kW battery system which is deployed to satisfy a 3-kW stand-alone dc load. Isolated WECS and grid connected WECS are developed and their performances are tested with various wind profiles using MATLAB/SIMULINK.**

Key words-**Maximum power point tracking (MPPT), Pitch control, State of charge (SoC), Wind energy conversion system (WECS).**

I. INTRODUCTION

Because of the global energy crises, the unpredictability of the non-ending price fluctuations of fossil fuels and the complexities of the construction and maintenance of the nuclear power plants, wind energy and utilization of wind farms has gained an increasing importance and interest [2]. And also wind is one of the potential sources of clean energy for the future [3]. Due to stochastic nature of wind efficient controlling is required to supply continuous power to the load. The study of isolated WECS is becoming more and more significant with each passing day. As we know the wind energy is an indirect source of power generation, it can be used to run a wind turbine which in turn drives a generator to produce electricity. For a WECS the selection of generator is an important task. By comparing synchronous and asynchronous machines, induction generators are mechanically and electrically simpler than other generator types. They are also more rugged, simple operation, requiring no brushes. In case of isolated systems induction generators build up the voltage by magnetising flux which is established by a capacitor bank connected to the machine [5]. The process of excitation of induction generator by capacitor is called self excited induction generator (SEIG). The detailed excitation phenomenon of SEIG is made in [4]-[6]. Due to erratic nature of wind flow the magnitude and frequency of generator voltage is varied it gives rise to flicker and instability at the load end. In order to avoid this problem and to ensure a regulated load voltage, a power electronic converter is needed to connect at load. To ensure continuous power supply to load an energy storage system is used. It is preferred to use a battery storage technology based on turbine maximum power point tracking to capture maximum power from the available wind. In order to extract maximum power from WECS the turbine needs to be operated at optimal angular speed [7]. As wind flow is not continuous in nature, it leads to discontinuous battery charging which results in harmonic heating of the battery. In this situation it is needed to observe the charging limitations of a battery to protect against battery over charging. To implement it a charge controller is required [8]. To avoid mechanical and electrical damage, WT speed and battery state of charge are needs to be regulated at above rated wind speeds [9]. This will be achieved by using a pitch controller. In this paper, a hybrid wind battery system with integrated control schemes is developed and the output of isolated WECS is connected to grid to save extra power.

The hybrid wind-battery system is described in section II. The charge control and pitch control schemes for stand-alone WECS is explained in section III. Section IV deals with grid connected wind energy conversion system. Section V describes the results and discussion. Section VI describes the Conclusion of this paper.

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II. STAND ALONE HYBRID WIND-BATTERY SYSTEM

The major components of a wind energy system include a wind turbine, generator, control system, gear box and interconnected apparatus. The proposed hybrid system consists of a 4-kW WECS and 400 Ah, C/10 lead acid battery bank. The system is designed for a 3-kW stand-alone dc load. The layout of the entire system along with the control strategy is shown in Fig. 1. The WECS consists of a 4.2-kW horizontal axis WT, it converts K.E produced by wind into mechanical energy (M.E). The output of WT is given to gear box having a gear ratio of 1:8 (it means gear box speed up the variable speed of generator up to 1 to 8 times the turbine speed) and the 5.4 hp SEIG, it converts M.E into E.E. For self excitation the stator terminals of SEIG are connected to capacitor banks. The ac output is rectified by three-phase uncontrolled diode rectifier. The uncontrolled dc output of the rectifier is applied to the charge controller circuit of the battery. For continuous power supply to the load the output of the buck converter is connected to the battery. The buck converter is triggered from gate pulses which are generated by implementing the MPPT logic. Pitch controller takes one of the input from gearbox and another input from rectifier based on these inputs it can regulate the speed of WT by changing the pitch angle. Fig-2 shows the Simulink model of isolated WECS.

III. CONTROL STRATEGY FOR HYBRID WIND ENERGY CONVERTION SYSTEM

The control strategy for hybrid wind-battery system includes charge controller which is used for controlled charging and discharging of battery banks and pitch controller which is used to ensure WT operation within its rated value.

A. Charge controller for battery bank

Generally, the batteries are charged at C/20, C/10, or C/5 rates, where C specifies the Ah rating of battery banks. As seen above the rating of battery is 400Ah. So it can be charged at 20, 40, or 80 A. In this paper C/10 battery bank using a dc–dc buck converter is developed. However, the current required for charging the battery bank depends on the battery SoC. A battery generally charges at a constant current (CC) mode till it reaches to 90%-98% of battery SoC. This is called as CC mode of battery charging. Beyond this SoC, the charging of battery entered into CV mode.

B. Charge Control Strategy

Fig.-3 shows the charge control logic implementation which is carried out by using three control loops. The outer most control loop operates the MPPT logic with battery SoC limit. As long as the battery SoC is below the reference SoC, the MPPT logic is implemented where the actual tip speed ratio (TSR) of turbine is compared with the optimum TSR. And this error is tuned by a PI controller to generate the battery current demand. Beyond this point, i.e., the actual SoC greater than the reference SoC the system operates in CV mode where it maintains the constant battery voltage and the current value gradually decreases. This is turn prevents the battery bank from over charging. For controlling the buck converter inductor current the actual buck converter output current (I_d) is compared with the reference ($I_b + I_0$) and the error is tuned by a PI and a lead compensator. The compensated output is compared with the inductor current (I_L) of the buck converter. The output of the comparator is applied to an SR flip flop to produce the gate pulses for the dc–dc buck converter. The frequency of the gate pulse is equal to the clock pulse frequency.

C. Modes of Battery Charging

1. CC Mode of battery charging:

If the battery actual SoC is less than the reference SoC then the charge controller operates in CC mode. In this mode, the battery charging current demand is determined from the MPPT logic. MPPT is implemented by comparing the actual and optimum TSR (λopt) and the error is tuned by a PI controller to generate the battery charging current as per the wind speed.

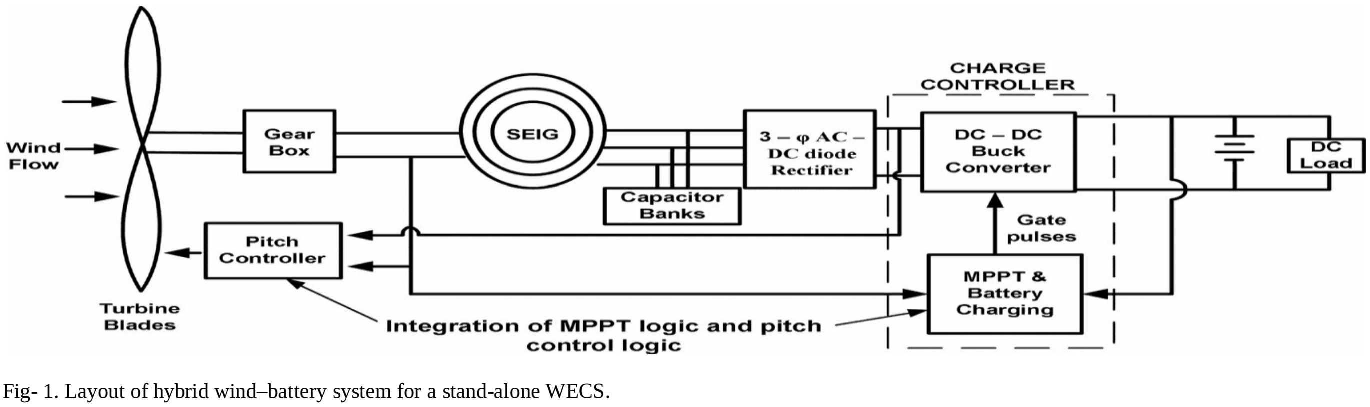


Fig- 1. Layout of hybrid wind–battery system for a stand-alone WECS.

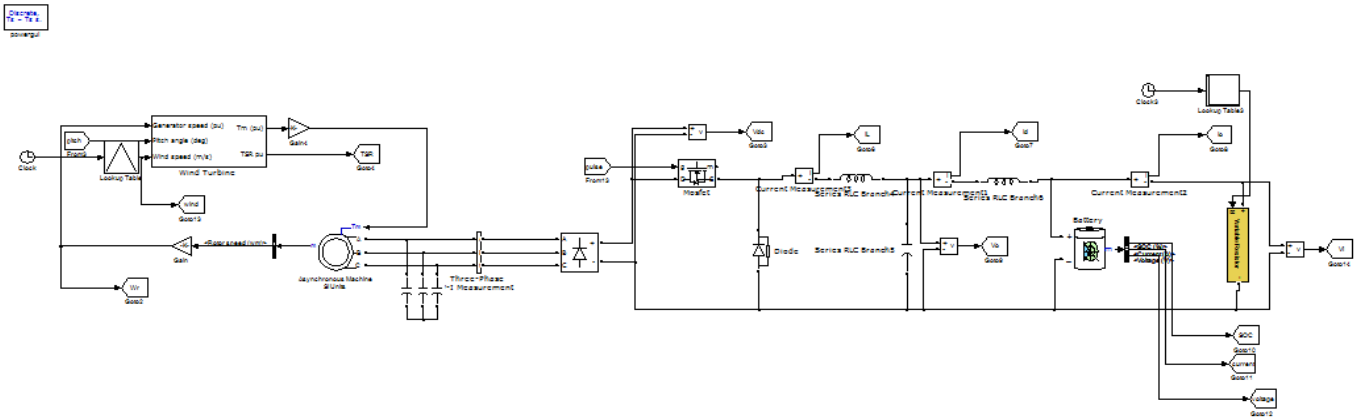


Fig-2. Simulink model for stand-alone WECS.

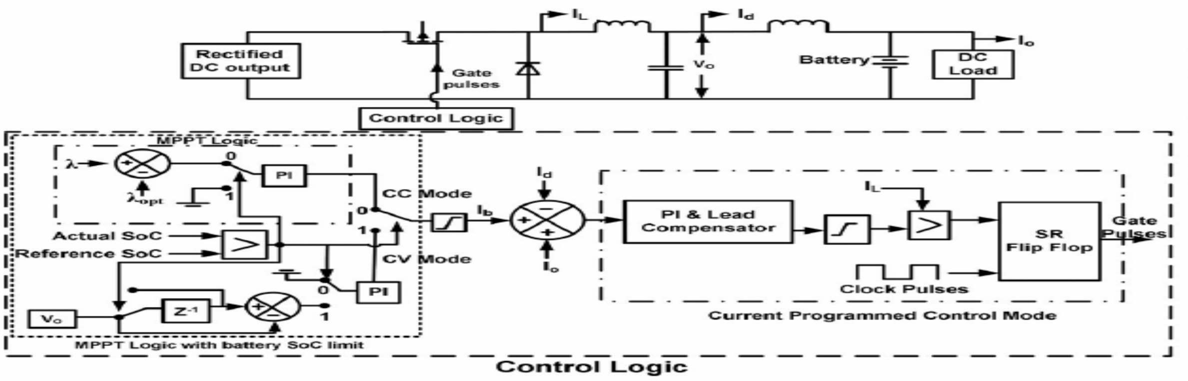


Fig-3. Schematic diagram of MPPT based charge controller.

2. CV Mode of Battery Charging

Once the battery SoC becomes equal to the reference SoC the controller must switch over from CC mode to CV mode. In CV mode, the battery charging voltage is determined from the buck converter output voltage (V_0). When the battery SoC reaches 98% then the value of the converter voltage is set as the reference value and it is compared with the actual converter output voltage. In CV mode the battery voltage and SoC rise very slowly with time as compared to CC mode. The battery charging current slowly decreases with time. Thus, in CC mode the output current is regulated while the output voltage keeps on increasing with time. In CV mode the output voltage is regulated, while the current in the circuit reduces gradually. To study the CC and CV mode of battery charging, rated value of wind speed is applied to the system. The battery parameters and the converter output parameters are observed with time. The battery charging modes at a constant wind speed of 10m/s are shown in Fig-4.

D. Pitch control Mechanism:

The WT output power is proportional to the cube of wind velocity. As the wind flow is intermittent in nature, so sometimes it results in high wind speeds. If the actual wind speed exceeds its rated value it results in mechanical instabilities like angular speed of the shaft increases which in turn leads to blade damages. To avoid that it is necessary to implement a control mechanism which regulates the speed of WT. So, a pitch control scheme is implemented to regulate the WT speed. By varying the pitch angle of the blade we can implement the pitch control mechanism.

The performance characteristics of the wind turbine gives the relationship between the coefficient of power (C_p) and tip speed ratio (TSR) with respect to pitch angle are shown in Fig-5. By increasing the pitch angle the coefficient of power (C_p) gets gradually decreases. That means the coefficient of power depends on the pitch angle and TSR. Initially by increasing the TSR the coefficient of power also gets increases gradually up to certain points. After reaching the optimum TSR the C_p value starts decreasing gradually. The maximum C_p is 0.41 at TSR 7. Based on this concept Pitch controller is designed. Below the rated values of WT the pitch angle is maintained at zero degrees whenever the wind speed exceeds the rated value pitch angle is increased there by mechanical stability is achieved.

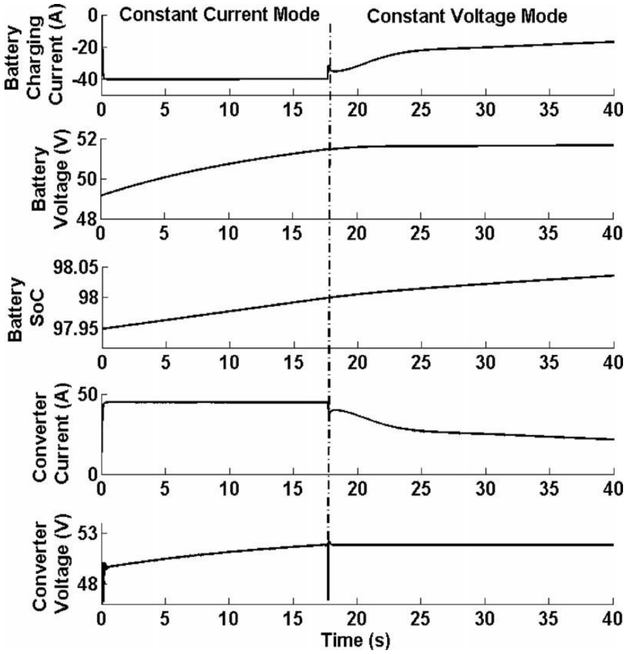


Fig-4. Battery charging modes at a constant wind speed of 10 m/s.

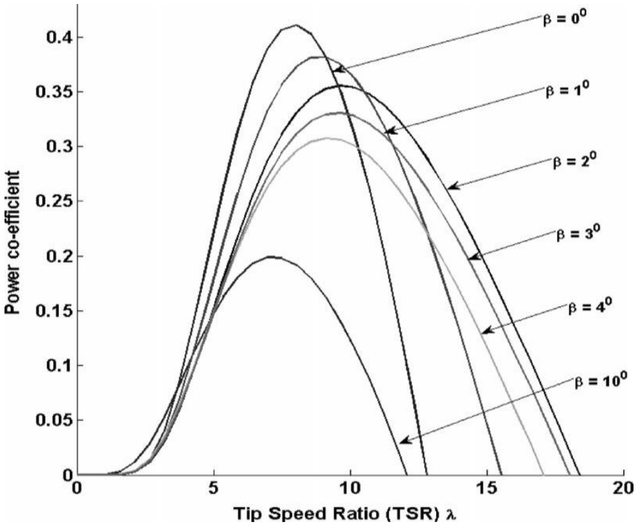


Fig-5. Power-coefficient Vs TSR with respect to Pitch angle.

1. Pitch Control Scheme

The pitch control scheme is shown in Fig-6. The per unit (p.u.) turbine power, turbine speed and rectifier output voltages are compared with 1 and the resultants are considered as errors. These errors are tuned by passing these signals through PI controllers. Among the three PI controller outputs the maximum output value is selected by using MAX block. The output of this Max block is optimized by using a limiter to either zero or greater than zero. Based on this value the output of the WT is controlled. Fig-7 shows the Simulink model of Pitch control and MPPT schemes.

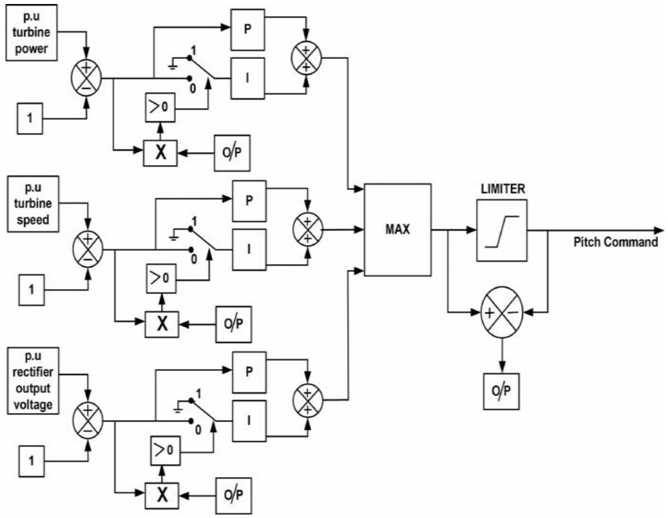


Fig-6. Pitch control scheme for stand-alone WECS.

IV. GRID CONNECTED WIND ENERGY CONVERSION SYSTEM

Recently WECS are developed to meet the requirements of both stand-alone and grid applications. The wind flow is stochastic in nature. At high wind speeds large amount of power will be generated and it is stored in the battery. If the battery stores up to its rated value the remaining power is allowed to pass through the load. Large amount of power will be wasted if the output power exceeds the load requirements. Instead of wasting the power, it is better to satisfy the substation requirements by connecting it to Grid. Through this we can’t transfer large amount of energy but only a small quantity i.e., the remaining power after satisfying the load requirements at remote area.

The output voltage of isolated WECS is DC in nature. But grid connected system always takes AC input. So, there is a need to convert DC to AC. This can be done by using a power electronic circuit called inverter. In order to convert the DC signal to continuous periodic signal a series of pulses are required for the inverter. So, by using a Pulse Width Modulator (PWM) we can generate periodic pulses. These pulses are given as one of the input to the inverter and DC signal as another input by processing, it will generate 3-phase AC signal as output. A 3-phase 2-winding transformer is required to transfer the energy from inverter to load without changing the frequency. The output of the transformer is connected to series R-load to get the active power. The layout of grid connected WECS is shown in Fig-8. Even we are saving some wastage of power by connecting isolated WECS output to grid. It is having some disadvantages like high cost to implement power electronic converters and it requires high maintenance cost. Fig-9 shows the Simulink model of grid connected WECS.

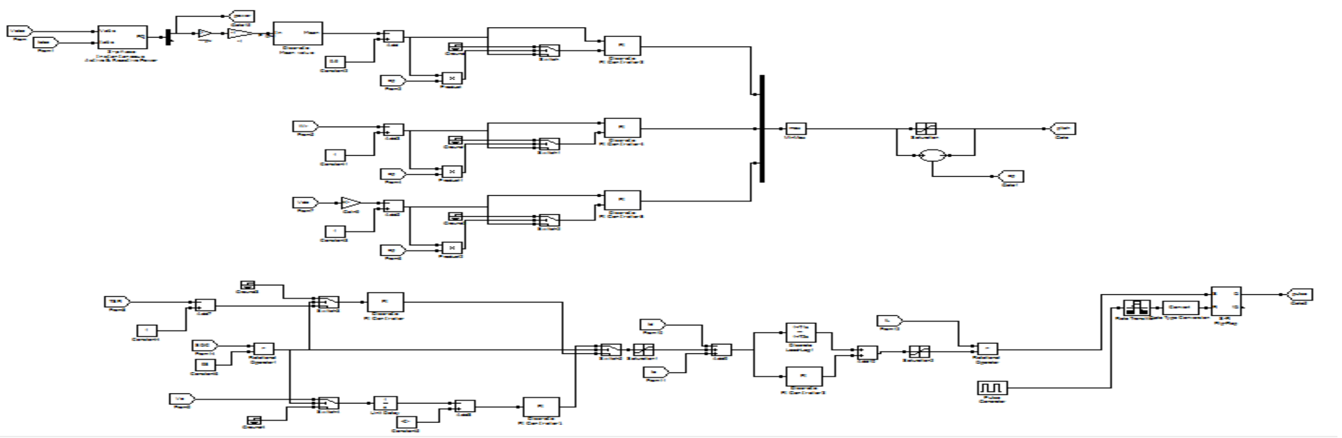


Fig-7 Simulink model of MPPT and Pitch Control scheme for a stand-alone WECS.

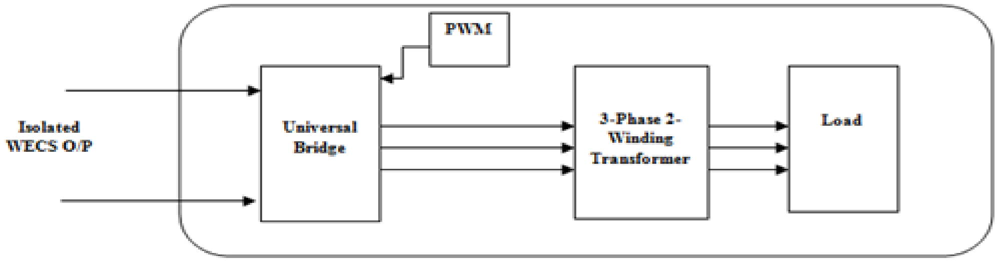


Fig-8 Layout of grid connected WECS.

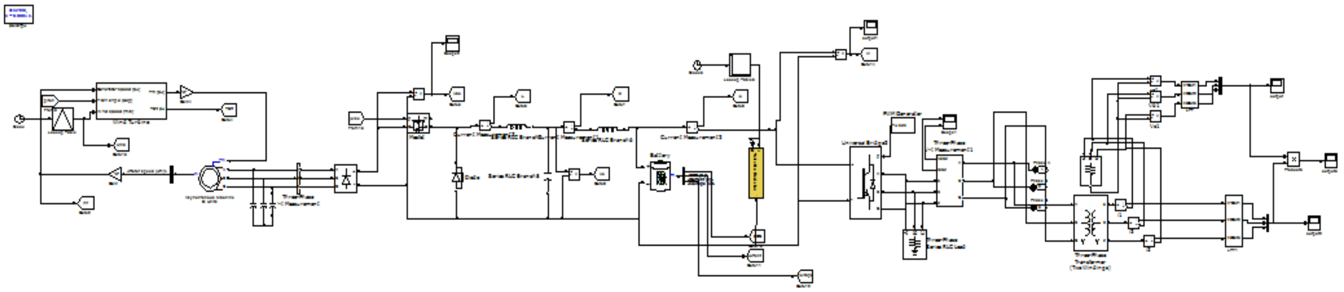


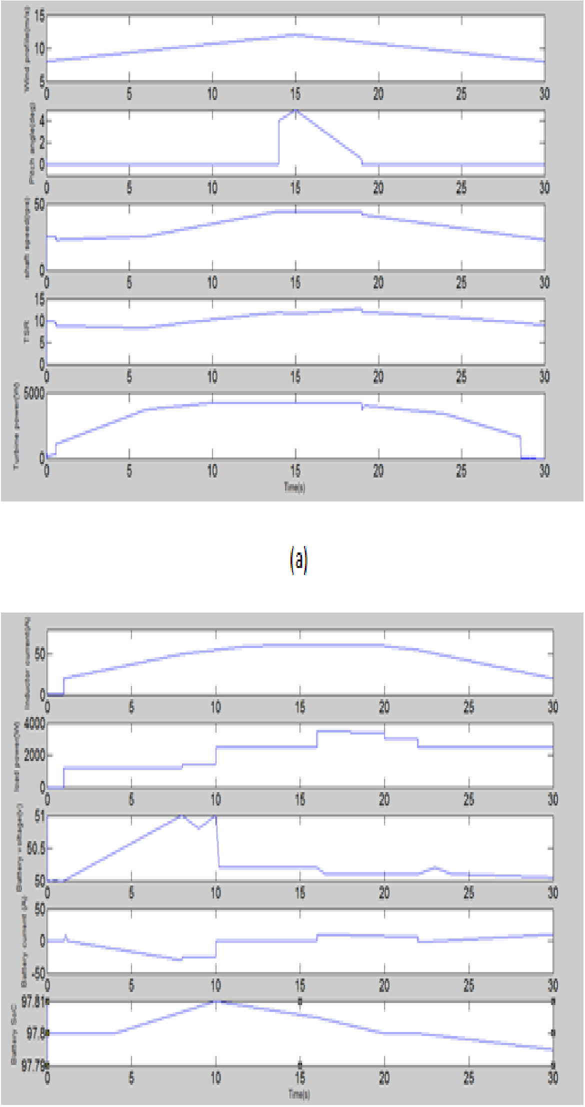
Fig-9 Simulink model for grid connected WECS.

V. RESULTS AND DISCUSSION

To ensure continuous power flow to the load efficient WECS is required. Efficient WECS is achieved by integrating the hybrid wind-energy system with suitable control strategy. This includes charge control logic and pitch control logic. To evaluate the efficiency of the system it is simulated with various loads and wind profiles. The system is connected to a load profile varying in steps from 0 to 4 kW. With variation in wind speed conditions the WT parameters like TSR, output power, pitch angle and shaft speed are measured. The battery parameters like voltage, current, SoC, load power and inductor current are also monitored. The WT and battery parameters are observed for following wind profiles.

1) Gradual rise and fall in wind speed.
2) Step variation in wind speed.
3) Arbitrary variation in wind speed.

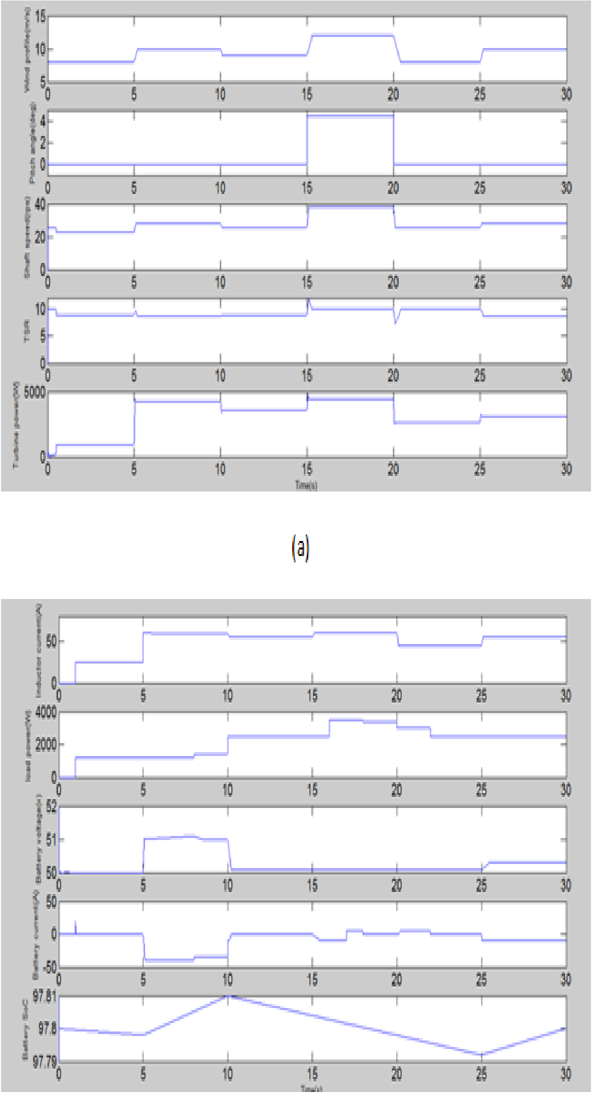
The wind Turbine and battery parameters of WECS for gradually rise and fall wind speed is as shown in fig-10. The wind speed increases from 8m/s to 12m/s in 1st 15 seconds and it decreases from 12m/s to 8m/s in next 15 seconds. For this wind profile the wind and battery parameters variation is clearly shown below. Similarly for step variation and arbitrary wind speeds the wind and battery parameters are as shown in fig-11 and fig-12. The step and



(a)

(b)

Fig-10. (a) WT and (b) Battery parameters under the influence of gradual variation of wind speed.



(a)

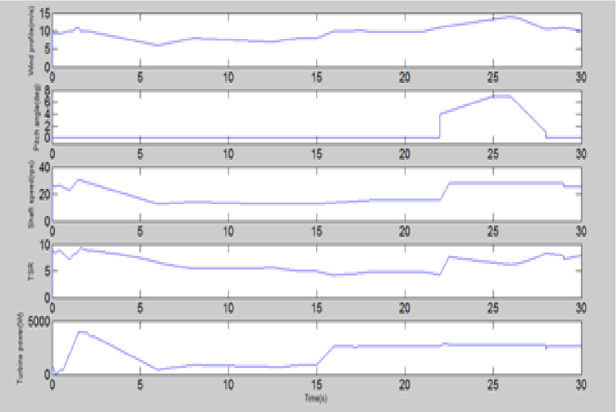
(b)

Fig-11. (a) WT and (b) Battery parameters under the influence of step variation of wind speed.

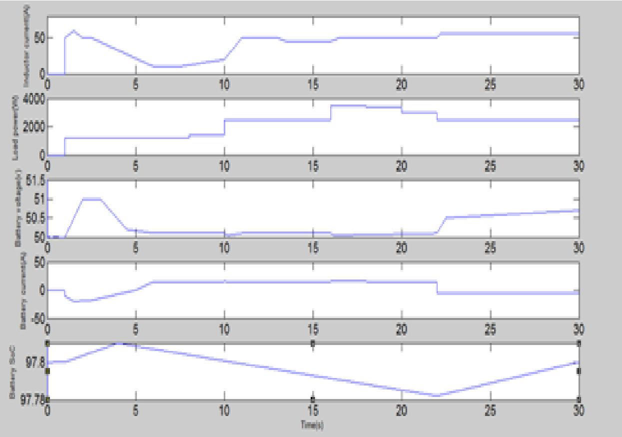
arbitrary wind speeds are also varied from 8m/s to 12m/s. By varying the wind speeds the wind parameters are clearly shown in figure (a) and battery parameters are shown in figure (b).

If the power generated by isolated WECS is greater than the load requirements, the extra power can be saved by connecting the stand-alone WECS to grid. The simulation results of grid connected WECS are as shown in fig-13. The output waveforms are verified for three different wind profiles like gradual variation, step variation and arbitrary variation in wind speed.

From stand-alone WECS results it is observed that the output load power is constant for different types of wind profiles. As we are supplying this constant load power as input to the grid connected system, the results produced by grid will remains constant. So, in this paper we are showing the simulation results of grid connected system for single profile (gradual variation). For remaining two profiles also the resultant magnitudes are same and these simulation results consist of output voltage, current and power.



(a)



(b)

Fig-12. (a) WT and (b) Battery parameters under the influence of arbitrary variation of wind speed.

VI. CONCLUSION

In this paper a hybrid wind battery system with effective control schemes are developed to supply required power to load and to maintain mechanical stability. The charge controller for battery bank is developed based on turbine Maximum Power Point Tracking and battery SoC. The charge controller charges the battery in a controlled manner by tracking maximum allowable power from wind. It also makes sure that the battery discharging current is also within the C/10 limit. During power mismatch the electrical and mechanical stability can be achieved by varying the wind turbine pitch angle. It can be done by using a pitch controller. To save the extra power after satisfying the load requirements, the off the grid wind energy conversion system is connected to grid. This entire system is developed and tested with various wind profiles by using MATLAB/SIMULINK.

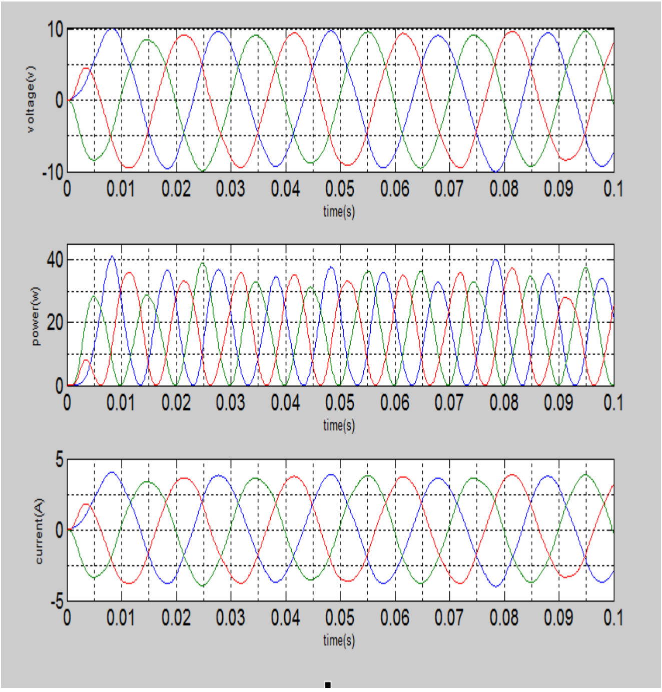


Fig-13. Simulation results of grid connected WECS.

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