Fuzzy PI Control Scheme for Off Grid DC load using Wind Power Conversion System

Mr. G.Bhavanarayana, Mr. I.Srinu, Mr. M.Rama Krishna

Abstract— At present relying on conventional energy sources may not be acceptable at all times because of increasing cost of generation and also the consistency of power supply is being reducing day by day because of unavailability of fuels corresponding to conventional energy sources. So, in order to mitigate these power interruptions and charges being posed on power consumptions it is necessary to combine the non conventional energy sources along with conventional energy sources to meet the load requirements at required levels. In this paper among the available non-conventional energy sources wind energy is taken into consideration in generating electrical power to meet stand alone loads. In order to ensure consistent and continuous power supply from wind energy a backup system was also used for storage purpose .The charging and discharging of the battery is controlled based upon the output power from wind turbine and this control is accomplished by charge controller which makes use of fuzzy controller along with PI controller and the speed of the wind turbine is controlled by using pitch control technique. Both these control techniques are simulated and the performance is tested by considering different wind profiles in MATLAB/SIMULINK.

Index Terms— *Battery State of Charge (SOC), Charge control, Fuzzy control system, Maximum Power Point Tracking (MPPT), Pitch Control, Wind Power Conversion System (WPCS).*

1 Introduction

THE Electrical power generation has become very essential for development of different sectors. As the generation of electrical power has become somewhat difficult through conventional processes so it is very much useful to for generation of electrical power through Non conventional energy sources like wind energy [1], solar energy, tidal energy etc., In this paper power generation through wind energy has been considered in delivering power to an DC load of demand 3kw. Actually the power generation from wind energy mainly depends upon the direction and speed of wind .So it is not feasible to go for synchronous generators for power generators and it is preferable to use asynchronous generators [2] as they work for different speeds. But it is known that if speed of the wind increases correspondingly the power generation also increases and if speed of the wind decreases correspondingly power generation also decreases. So whatever the power generated from wind energy may not meet the load conditions exactly as different ranges of power is being generated which is not acceptable by certain loads [3] . For some loads it is mandatory that constant power is required which cannot be achieved by the power generated by the wind energy and that power will be given to DC loads.

So in this paper in order to meet constant power generations from wind energy whatever the energy generated by self excited Induction generator (SEIG) [4] will be converted into DC power by diode rectifier and that constant DC power will be stored in the battery and that power will be given to DC loads. In this paper if the power generated from wind energy is more than the load demand that power will be stored in a battery and required amount will be given to load through that battery and if the power generated from wind energy is less than the load demand whatever the excess amount of power stored in battery will be added to this present generated power and it is applied to the load. If wind speed is less there will be no damage to generating unit like turbine but if the speed of the speed of the wind increases beyond the turbine or generator limits then there is arises the problem of mechanical and electrical safety. So in order to operate the generating system under safety measures the speed of the wind hitting the turbines blades must be controlled. In order to control the speed Maximum power tracking technique is used in this paper. Pitch control also has been adopted to control the speed of the wind. After generation DC conversion and power storage has also been controlled by making use of charge controller (buck converter) [7] based upon state of charge concept being operated under constant current and constant voltage mode.

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2 Modelling of Wind Power Conversion System (WPCS) for an Offgrid DC Load

The proposed system consists of a 4-kw WPCS and a lead acid battery bank of rating 400 Ah with a charging rate of C/10. The system is designed for off grid dc load of a 3-kW. The block diagram of the entire system along with the control scheme is shown in Fig. 1. The WPCS consists of a 4.2-kW horizontal axis WT, gear box with a gear ratio of 1:8 and a 5.4 hp SEIG as the Wind turbine generator (WTG). As the load is stand alone load capacitor bank is connected to the stator windings for self excitation. AC output is converted into DC

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power by using three phase diode rectifier. The DC output power is given to a charge controller (DC-DC buck converter).The power from charge controller is given to lead acid battery bank which is further connected to stand alone DC load. The charging of this battery by charging controller is done by MPPT technique. Pitch controller is also used in order to control the electrical and mechanical parameters corresponding to rated values. The integration of battery charge controller [5] and pitch controller ensures reliable operation of the stand-alone WPCS.

3 BATTERY CHARGING MODES

3.1 CC Mode of Battery Charging

In Constant Current (CC) mode, by using MPPT, charging current demand of battery is determined. MPPT is obtained by comparingthe actual and desired TSR (*o*pt). The difference of actual and desired value is tunedby a PI controller to generate the battery charging current with respect to wind speed. In this state , the converter output voltage increases with respective time while the MPPT logic tries to transfer more power inoreder to charge the battery.

3.2 CV Mode of Battery Charging

In the above mentioned mode the battery gets charged at faster rate with respective time.But it is to be noted that charge controlling unit should not allow the battery to get over charged. Once if the battery condition of charge gets to be equivalent to the reference SoC the controller must change over from CC mode to Constant voltage (CV) mode. In CV mode, the battery charging voltage is resolved from the buck converter yield voltage. The estimation of the converter voltage when the battery SoC achieves 98% is set as the reference value and is contrasted and the genuine converter yield voltage.The error in the voltage is then controlled by cascaded arrangement of PI controller and lead compensator to generate the inductor current reference. It is then contrasted and the real inductor current by a sensible comparator to produce gate pulses

4 CONTROLLERS OF WIND POWER CONVERSION SYSTEM (WPCS)

4.1 Fuzzy based Charge Controller for the Battery Bank

The inputs that are considered for charge controller are Tip speed ratio, output voltage of the buck converter Soc. A typical battery generally charges at a constant current (CC), i.e., C/10 rate mode till battery SoC reaches a certain level (90%–98%). This is referred to as CC mode of battery charging. The CC mode charges the battery as fast as possible. In CC mode, the battery charging current interest is resolved from the MPPT rationale. MPPT is actualized by looking at the real and ideal TSR. The error is tuned by afuzzy controller along with PI controller to produce the battery charging present according to the wind speed.In this mode, the converter output voltage rises with time while the MPPT [11] logic tries to transfer as much power as possible to charge the batteries.

Beyond this SOC, the battery is charged at a constant voltage (CV) which is denoted as CV mode of battery charging in order to maintain the battery terminal voltage. As a result, 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. The value of the converter voltage when the battery SOC reaches 98% is set as the reference value and is compared with the actual converter output voltage. The error in the voltage is then controlled by fuzzy controller and a cascaded arrangement of PI controller to generate the inductor current reference. It is then compared with the actual inductor current by a logical comparator to generate gate pulses.

3.2 Control Strategy

To execute the MPPT rationale, the real tip speed proportion (TSR) [10] of turbine is compared with the desired value. The error is tuned by a fuzzy controller along with PI controller to produce demanded battery Current as long as battery SOC is underneath the CC mode limit. Beyond this point, the SOC control logic tries to keep up consistent battery charging voltage. This diminishes the battery current demand and along these lines keeps the battery bank from overcharging. The buck con-verter inductor current summon is created in the intermediate control loop. To design the controller, it is mandatory to model the response of the battery current as for the inductor current.

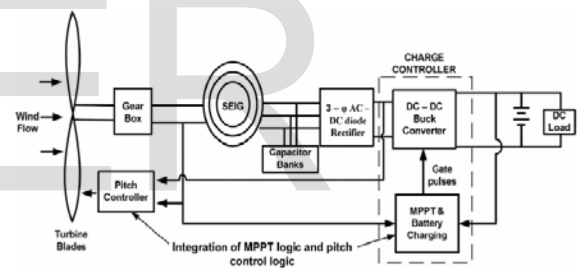

Fig. 1. Block diagram of wind energy conversion system for a stand-alone dc load.

As shown in Fig. 2, the battery is assumed to be a CV source with a small internal resistance (rb). The effective series resistances (ESR) of the capacitor (RC) and the inductor (rL) are also considered. The ESR of the capacitor and the inductor is taken to be 1mΩ each. The battery internal resistance is 10 mΩ. For regulating the peak-to-peak (p–p) ripple of battery current and converter output voltage within 2% of the rated value the L andC are calculated to be 10 mH and 5 mF, respectively.

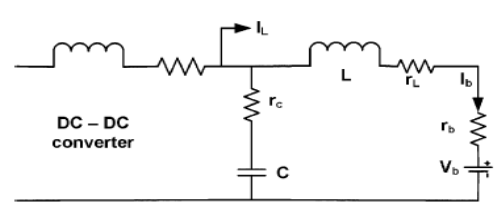

Fig.2 Circuit representation of buck converter output.

The transfer function is obtained from Fig. 2 and is given by

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$$\frac{I_b\,(s)}{I_L\,(s)} = \frac{r_c C s + 1}{LCs^2 + (r_L + r_c + r_b)\,Cs + 1}$$

For controlling the battery current the real converter yield current (Id) is compared with the reference (I+ Ian) and the error is tuned by of a PI and a lead compensator. The PI controller is modelled as an inverted zero. To keep the phase margin of the openloop system the recurrence of this zero is 50 times lower than the cross over frequency. To enhance the phase margin of the battery charging current control loop (i.e., (1) alongside the PI controller) a lead compensator is associated with the PI controller

In order to mitigate over loading of the turbine the output is first passed through a current limiter. The lower limit is set to zero and the upper limit is changed according to the utmost power available at a given wind speed. The output of this limiter is utilised as the reference for the current controller in the dc–dc converter.

The output of the intermediate loop is compared with the instantaneous inductor current of the charge controller. The resultant of the comparator is given to SR flip flop to gnerate the gate pulses for the dc–dc buck converter (charge controller). The frequency of the clock pulses is 2 kHz. The frequency of the gate pulse is equal to the clock pulse frequency. This kind of delivering gate pulses for the charge controller is known as the current customized control strategy. The benefit of this strategy is that it doesn't permit the inductor current to go beyond the permitted limit. This results in the protection of inductor from saturation

4.2 Charge control mechanism

The fuzzy control mechanism is used in charge controller which is used for providing triggering pulses for buck converter. The fuzzy controller [9] is mainly used for control of converter output voltage. A 7*7 rule base system has been developed in a fuzzy interface system. In this fuzzy interface system seven membership functions has been developed and based on these membership functions 49 rules has been developed in order to control the output voltage of the buck converter fuzzy control system for controlling of output voltage of buck converter.

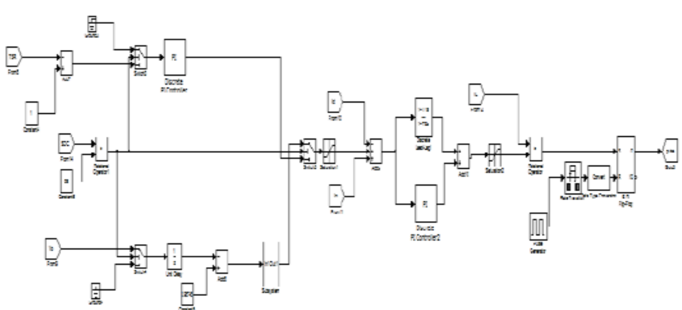

Fig. 3. Simulink model of charge control mechanism

4.3 Pitch Control Scheme

The p.u. estimation of every input is compared with 1 to figure out the error. The errors are tuned by PI controller and fuzzy logic system. The “MAX” block takes the maximum output from each PI controller and is then passed on to a limiter to produce the pitch command for the WT. The actual pitch command [8]-[12] is compared with the limited Value. The lower limit of the pitch command is set at zero. There arises an error when the actual pitch command goes above or below the specified limit. This is multiplied with the error obtained from each of the comparator.

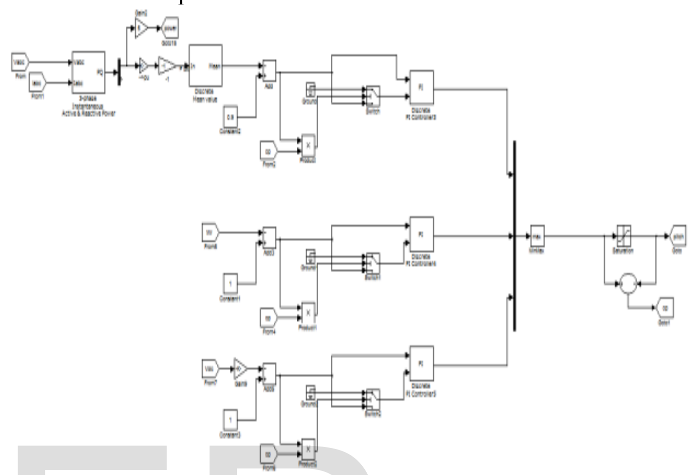

Fig. 4. Simulink model of pitch control mechanism

The product is compared with zeroto decide the switching logic for integrator. This method is continued to stay away from integrator saturation. The pitch controller changes the contribute summon inferable from variety turbine turn speed, power, and yield voltage of rectifier, which guarantees safe operation of the WPCS.

5 RESULTS

In this paper Fuzzy PI controller is used for charge control mechanism by considering three cases of wind profiles.

i) Gradual increase and decrease in wind speed
ii) Step change in wind speed
iii) Arbitrary change in wind speed

In all the first case it is taken that the speed of wind is gradually increases from 8 m/s to 12m/s during first 15 seconds and gradually decreases from 12 m/s to 8 m/s during next 15 seconds. The performances of different parameters for fuzzy PI controller are shown in figures 4 & 5.Further the performance of fuzzy PI controller is observed for step change and arbitrary change in wind speed and their results are shown in figures 6 & 7 for step change and 8 & 9 for arbitrary change in wind speed.

The performance results are also shown for conventional PI controller and Fuzzy PI controller for above mentioned wind profiles.

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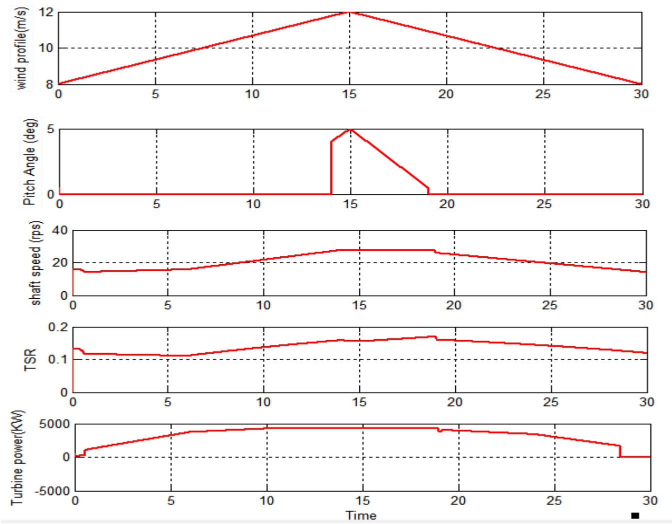

Fig. 5. Input Parameters response for gradual raise & fall in wind speed using PI controller

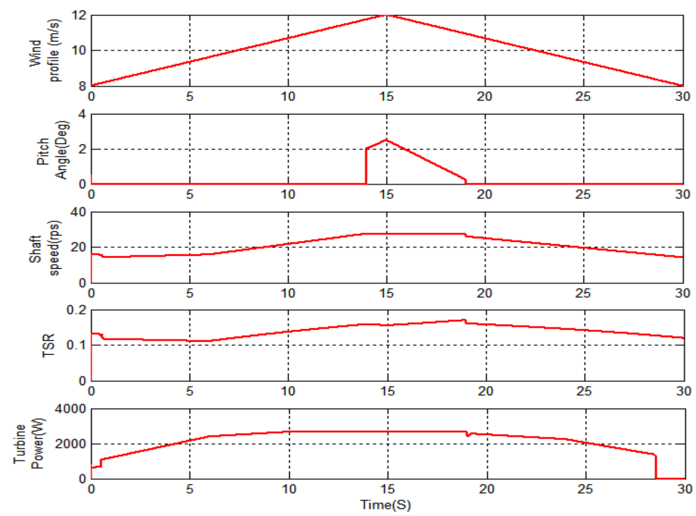

Fig. 8. Input Parameters response for gradual raise & fall in wind speed using Fuzzy PI controller

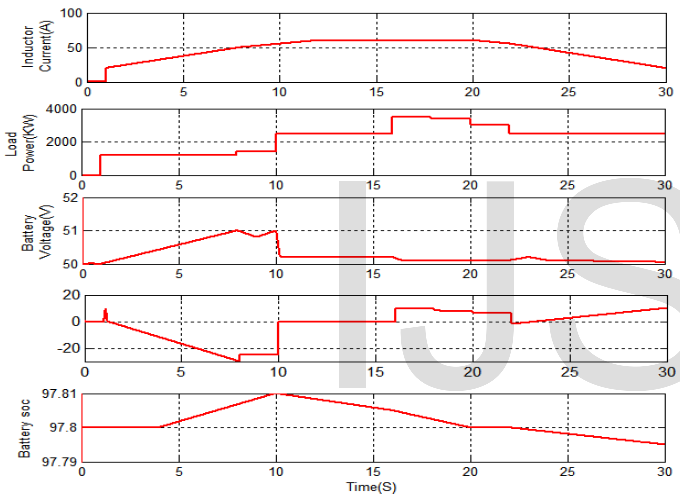

Fig. 6. Output Parameters response for gradual raise & fall in wind speed using PI controller

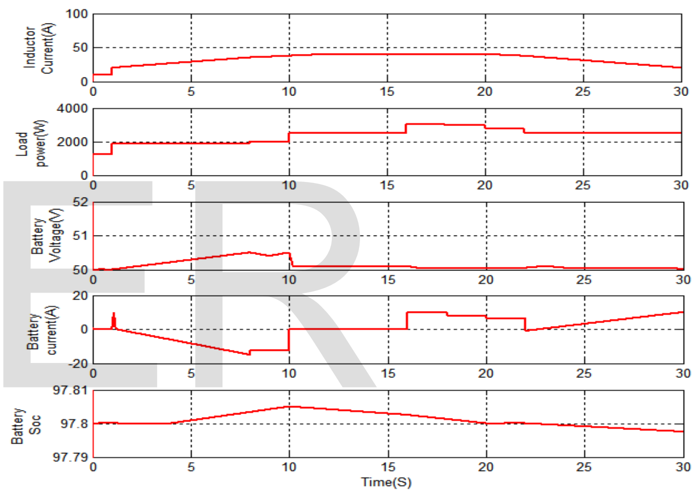

Fig. 9. Output Parameters response for gradual raise & fall in wind speed using Fuzzy PI Controller

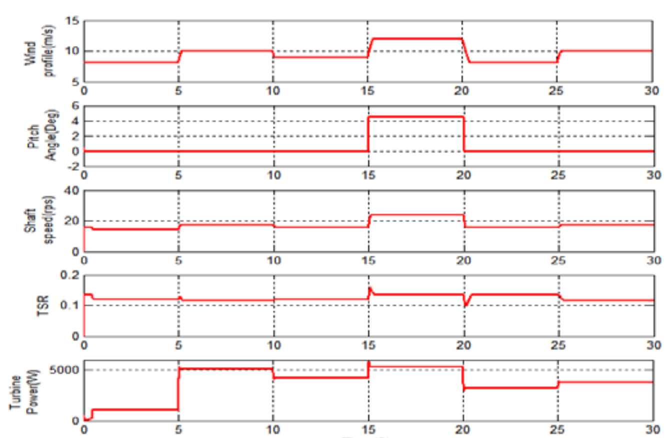

Fig. 7. Input Parameters response for step change in wind Speed using PI controller

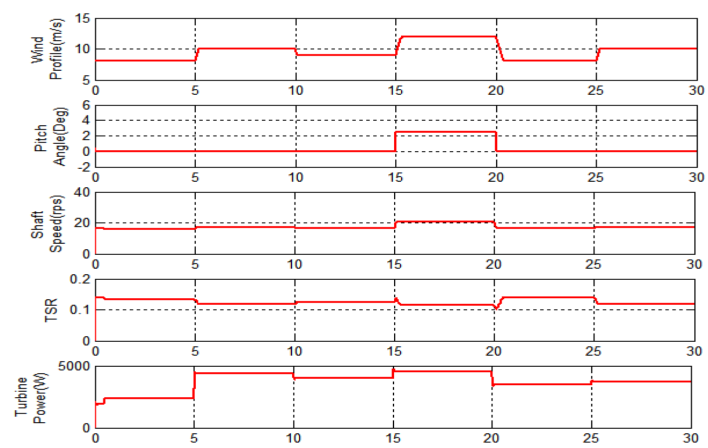

Fig. 10. Input Parameters response for step change in wind speed Fuzzy PI controller

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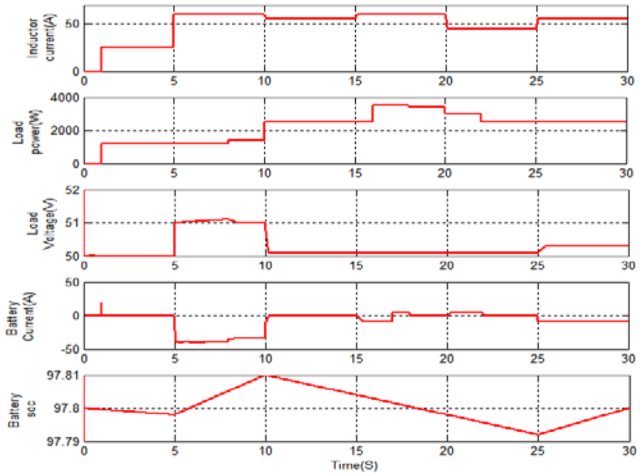

Fig. 11. Output Parameters response for step change in wind speed using PI controller

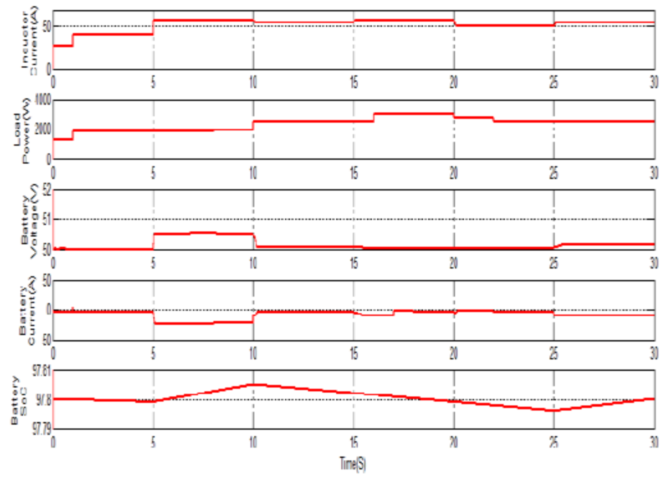

Fig. 14. Output Parameters response for step change in Wind speed using Fuzzy PI controller

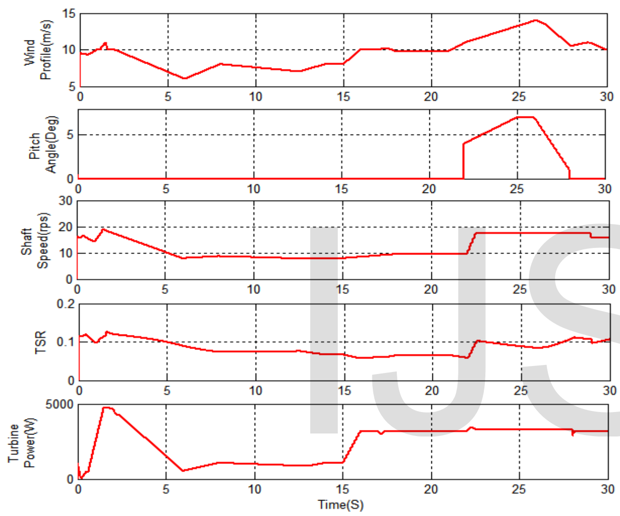

Fig. 12. Input Parameters response for arbitrary Variation in wind speed using PI controller

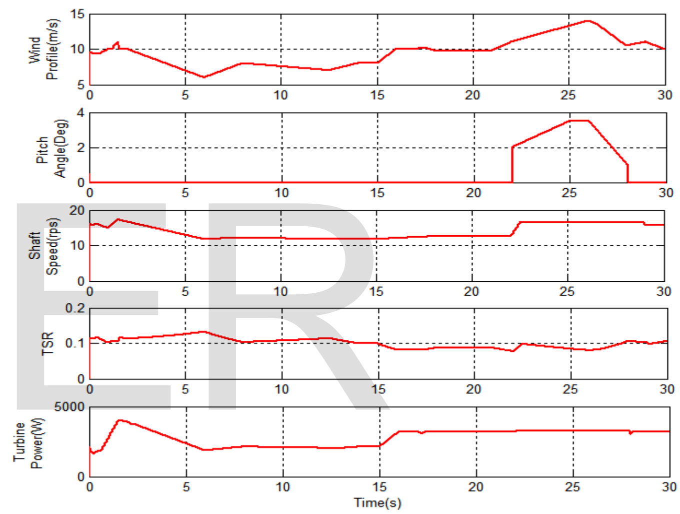

Fig. 15. Intput Parameters response for arbitrary variation in wind speed using Fuzzy PI controller

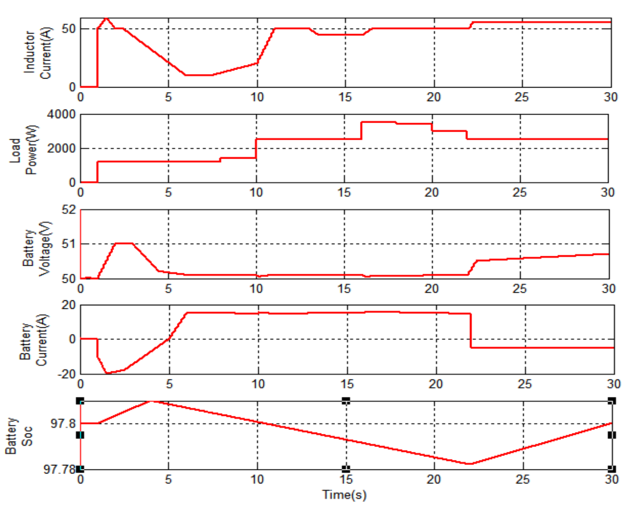

Fig. 13. Output Parameters response for arbitrary Variation in wind speed using PI controller

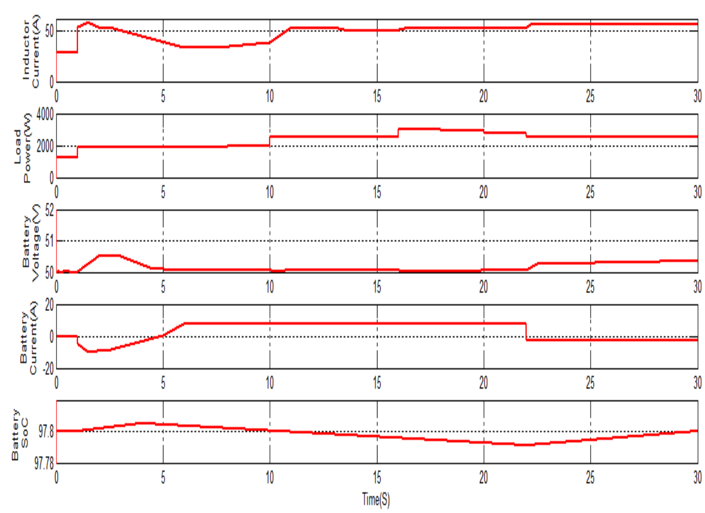

Fig. 16. Output Parameters response for arbitrary variation in wind speed using Fuzzy PI Controller

5 CONCLUSIONS

Hence in this paper Fuzzy PI controller is designed in MATLAB/SIMULINK and it is used for charge control mechanism. The performances of Fuzzy PI controller is compared with conventional charge controller which is designed using only PI controller and the following parameters are be observed.

1) By using conventional PI controller the turbine out power is observed to be greater than the rated value during the occurrence of high speed wind which is undesirable in view of safety of mechanical and electrical parameters. By using fuzzy PI controller it is observed that the turbine output power is controlled within the limits of rated value during high speed wind conditions also.

2) By using Fuzzy PI controller consistent power has been delivered to load when compared to conventional PI controller

Hence it is concluded that it is better to use fuzzy PI controller for better operation of wind energy conversion system for better performance rather than using PI controller alone.

6 APPENDIX

Table 1: Wind Turbine Specifications

Parameters	Value(units)
Rated Power	4000 W
Radius	2.3 m
Cut-in wind speed	4 m/s
Rated wind speed	10 m/s
Inertia coefficient	7 K sq.m
Optimum tip speed ratio	7
Optimum Power coefficient	0.41

Table 2: Induction Machine specifications

Parameters	Value(units)
Rated Power	5.4 hp
Stator resistnace	2.6 Ohm
Stator leakage inductance	4 mH
Mutual Inductance	240 mH
Rotor resistance	2.0 Ohm
Rotor leakage inductance	4 mH
Excitation capacitance	15 µF

Table 3:Battery specifications

Parameters	Value(units)
Ampere hour rating	400Ah
Nominal Voltage	48 V
Fully charged voltage	55V
Charging rate	C/10

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