Fuzzy Logic Controller Based Power Quality Improvement of Doubly Fed Induction Generator Wind Energy Conversion System

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Abstract

Fossils fuels will be the main fuels for the thermal power there is a fear that they will get exhausted eventually in next century therefore many countries are trying systems based on non-conventional and renewable sources. Fuzzy logic control is proposed for windmill generators to reduce the total harmonic distortion present in the conventional method which uses PI controller. PI controller is used only for linear loads. The proposed system consists of a doubly fed induction generator based variable speed wind energy conversion systems (WECS) consisting two back to back inverters with a common dc link. The gate pulses for the two converters are controlled by fyzzy logic controller. The generator side inverter controls its speed to extract maximum power at different speeds, while the grid side inverter delivers the renewable power to the power to the grid with 3P4W nonlinear load compensation simultaneously. Moreover, in the proposed system, the grid side inverter is also utilized as a harmonic, a reactive power, and unbalanced load compensator for 3P4W nonlinear load. This enables grid to always supply /absorb a balanced set of fundamental currents at unit power factor. The effectiveness of the proposed scheme is developed and simulated using MATLAB/ Sim Power System software.

Keywords: Fuzzy Logic control, doubly fed Induction Generator, Total Harmonic Distortion

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I. INTRODUCTION

The emission of fossil fuels has increased the effect of global warming and ozone depletion. To mitigate this effect power can be generated from various renewable resources. Wind energy is one of the most economic sources of energy for the production of electricity. Wind energy is economically viable renewable energy source today. The machine which is used to convert kinetic energy in the wind to electrical energy is called as wind turbine. In electrical power systems power quality distortion has become a serious problem due to the increase in number of non-linear loads. As the number of nonlinear loads increased, harmonics current is more significant generated by these loads [8]. These harmonics can lead different power system problems like distorted voltage waveforms, malfunction in system protection, excessive currents, voltage dip [7], overheating of equipment. To mitigate the harmonic distortions, unbalanced voltage, voltage flickering, active power compensation, reactive power compensation and transient conditions Active Power Filters are used which leads to more complexity of the system and increased cost. In spite of many control techniques Fuzzy Logic is a control system which is based on certain logical functions and nearer to human thinking process. The advantage of Fuzzy Logic Controller over other controller is it does not require mathematical model unlike other controllers used for linear systems. It can handle nonlinearity and can be of more robust. When compared to PI controllers Fuzzy Logic system is more efficient for nonlinear networks i.e., it minimizes harmonics and improves the quality of power. Adaptiveness cannot be achieved in the operation of fuzzy logic. The proposed system is implemented with Variable Speed Wind Turbine [6] which is more contrast than constant speed wind turbine as the power extraction is less when compared to variable speed wind turbine, so the power fluctuations can be avoided also maximum power can be obtained at variable speed condition. For vailable speed operation doubly fed induction generators are mostly used [1]-[4]. WECS is connected directly to the grid and hence the power supply to the grid must be of balanced one as the grid should be maintained at unity power factor, hence to provide grid synchronization. The use of Doubly Fed Induction Generator is more advantage as the supply to the AC mains can be from both stator and rotor as the stator is connected to the AC mains whereas rotor is connected to the control system. Normally PI controllers are suitable for linear systems where as FLC is suitable for nonlinear systems even though the distortion in harmonics is reduced for both linear and nonlinear network.

Fuzzy Logic control [5] has proven effective for complex, non-linear and imprecisely defined processes for which standard model based control techniques are impractical or impossible. Fuzzy Logic, unlike Boolean or crisp logic, deals with problems that have vagueness, uncertainty and use membership functions with values varying between 0 and 1. Fuzzy Logic tends to mimic human thinking that is often fuzzy in nature. In fuzzy logic a particular object has a degree of membership in a given set, which is in the range of 0 to 1. The essence of fuzzy control algorithms is a conditional statement between a fuzzy input variable A and a fuzzy output variable B. This is expressed by a linguistic implication statement such as

IF A THEN B

In general a fuzzy variable is expressed through a fuzzy set, which in turn is defined by a membership function μ.

Fuzzy logic is one of the most successful rapidly growing control techniques for developing sophisticated system. In past few years its growth is continuously increasing in number and variety of application of fuzzy logic. The fuzzy logic can be used in the applications such as camera, camcorder, washing machine and microwave ovens to industrial process control, medical instrumentation and decision support system. The advantage of using fuzzy controller is to control a nonlinear based procedure depending on the knowledge and experience based on human being. The fuzzy controller can work in either linear or nonlinear design parameters. A fuzzy controller can have multiple inputs & multiple output variables.

The conventional control system design mainly depends on the mathematical model of plant. If an accurate mathematical model is present with known parameters, it can be analyzed. The adaptive characteristics can achieve the robust performance of the system with uncertainty parameters variations and load disturbances.

II. BLOCK DIAGRAM OF FUZZY LOGIC CONTROLLER BASED WECS

The block diagram of the proposed fuzzy logic controller based wind energy conversion systems is shown in fig.1. It consists of two back to back converters.Fuzzy logic controller is used to control the two controllers.

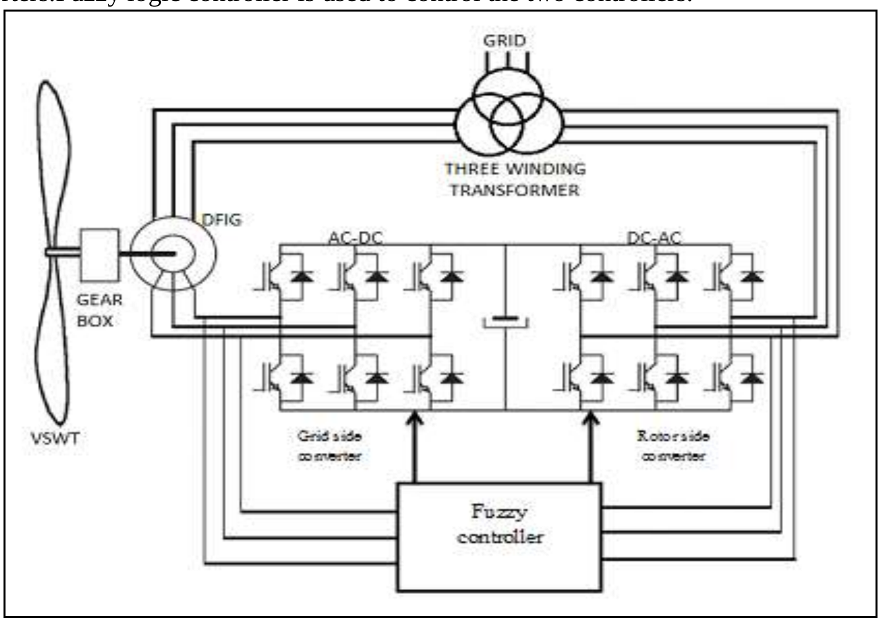

Fig. 1: Block diagram of fuzzy controller based WECS

Fuzzy Logic Control techniques is one of the form of artifical intelligence and its principles are applied to modeling and estimate.Fuzzy logic based model has helps to enhance the performance of fuzzy control in the same way as a mathematical model based conventional control gives superior performance. The increasing problems and advances in power electronic technology, has forced to change the traditional power system concepts. Use of fast reactive power compensators can improve the power system stability and hence, the maximum power transfers through the electric system. The problems are related to the load equipment and devices used in electric energy generation.

Now a days the transmission and distribution system become more sensitive to power quality variation than those used in the past. Many new devices contain microprocessor based controls and electronics power elements that are sensitive to many types of disturbances. The wind turbine generating systems are the highly variable sources of energy and wind turbine are belonging to the source of such problem.

The wind power in the electric grid system affects the voltage quality. To assess this effect, the knowledge of about the electrical characteristic of wind turbine is needed. The electrical characteristics of wind turbine are manufacturer's specification and not site specification. This means that by having the actual parameter values for a specific wind turbine the expected impact of the wind turbine on voltage quality is important. There is a need for consistent and replicable documentation of the power quality characteristics of wind turbines. With the advancement in fast switching power devices there is a trend for power supply size reduction. The current harmonics due to switching converters makes supply current distorted. The increase of electronic controllers in drives, furnaces, household equipment and SMPS are increasing the harmonic content and reactive power in electric supply. The distribution transformers apart from reactive loads draw reactive current from the supply to meet the magnetizing current. The ever-increasing demand for power is not fulfilled by increase in generation and particularly in distribution for various reasons such as environmental issues, increasing cost of natural fuel, opposition to nuclear power plants, etc. This puts excessive burden on the electric supply resulting in poor power quality.

The term power quality here refers to the variation in supply voltage, current and frequency. The excessive load demand tries to retard the turbines at generation plant. This results in reduction in voltage and more severely reduction in the supply frequency. The authorities are working for power quality improvement by using reactive compensators and active filters on supply side and penalizing consumers for polluting the power grid. Fuzzy logic control based Power converter is used in Wind energy conversion systems to enhance the power quality by reduce the total harmonic distortion.

The MATLAB high-performance language for technical computing integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Using the MATLAB product, you can solve technical computing problems faster than with traditional programming languages, such as C, C++, and FORTRAN. MATLAB is used in a wide range of applications, including signal and image processing, communications, control design, test and measurement, financial modeling and analysis, and computational biology. Add-on toolboxes (collections of special-purpose MATLAB functions, available separately) extend the MATLAB environment to solve particular classes of problems in these application areas. MATLAB provides a number of features for documenting and sharing your work. You can integrate your MATLAB code with other languages and applications, and distribute your MATLAB algorithms and applications.

The simulink model of Fuzzy Logic controller based wind energy conversion systems diagram is shown in fig.2. The simulink block diagram represents the working principle of wind energy conversion system. It includes wind turbine, DFIG, interconnections, NF controller. The output of WECS is fed to the grid connected with non-linear load. It consists of wind turbine double fed induction generator, 575 v bus Voltages, three phases step up transformer. The system is operated for variable wind speed with different loading condition.

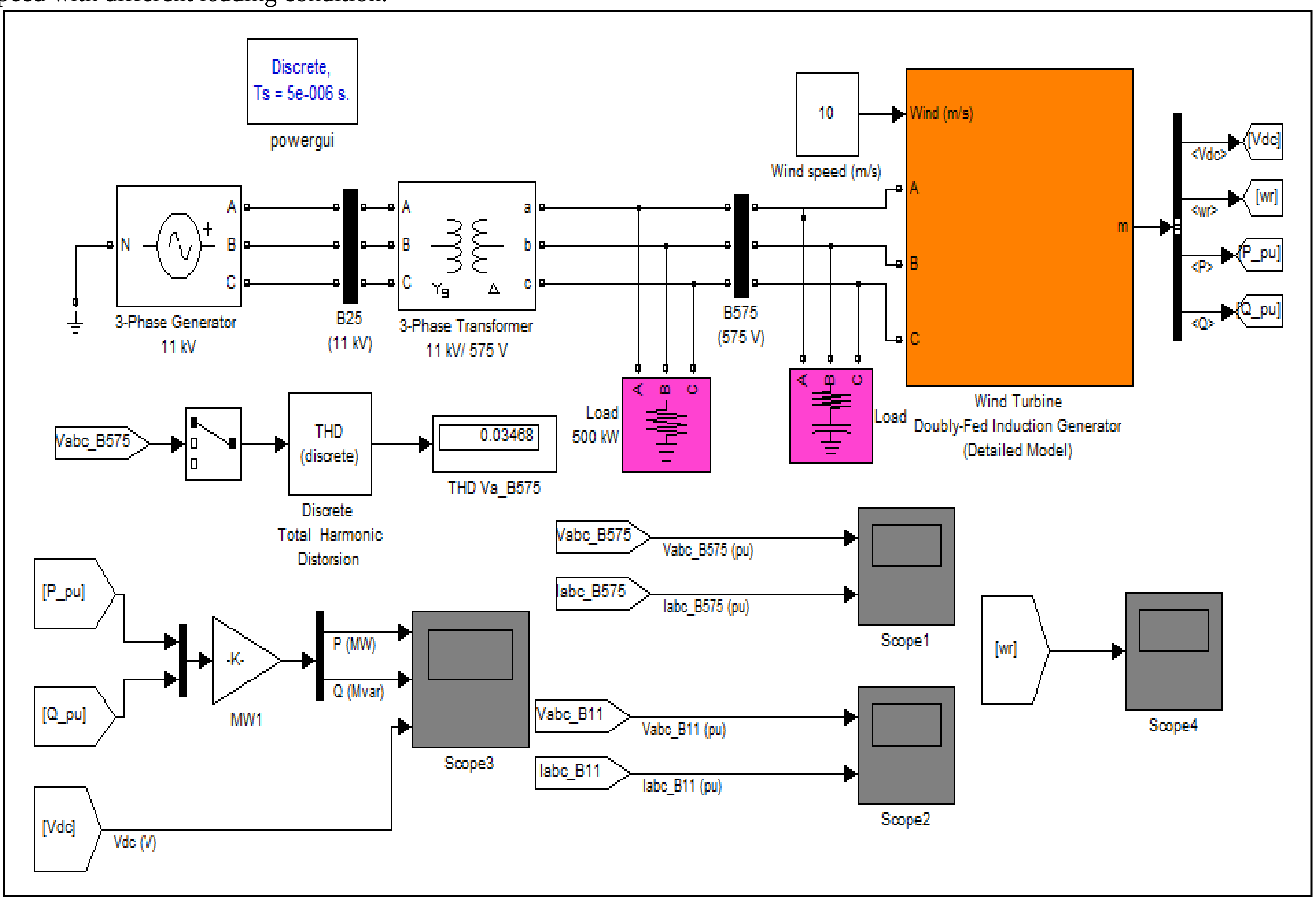

Fig. 2: Simulink model of fuzzy logic controller based WECS

The simulink model of wind turbine induction generator is shown in fig.3. The stator of doubly fed induction generator is directly connected to grid and the rotor is connected to grid through the back to back converter. The firing pulse for the back to back converter is controlled by using fuzzy logic controller. The stator and rotor parameters like voltage and current, speed, position, rotor angle, wind speed, DC link voltage, Real power, reactive power is sensed and it is fed to the fuzzy logic controller unit.

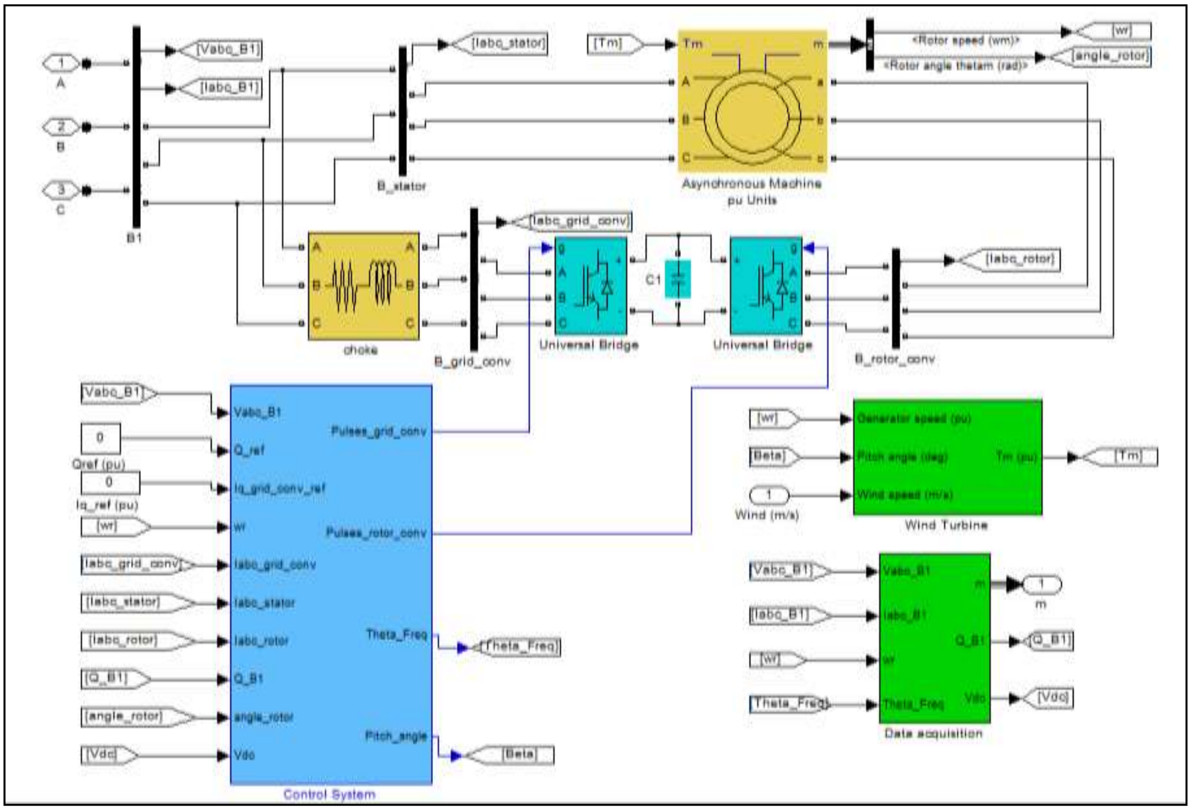

Fig. 3: Doubly fed induction generator wind turbine

The control system for the power converter is shown in fig.4. The pulse width modulation firing pulses to trigger the back to back converters is generated by using this control system. Filer circuit is used to filter the actual parameters of the system like rotor side converter output voltages, rotor side converter output currents, common link DC voltage, stator current and voltage.

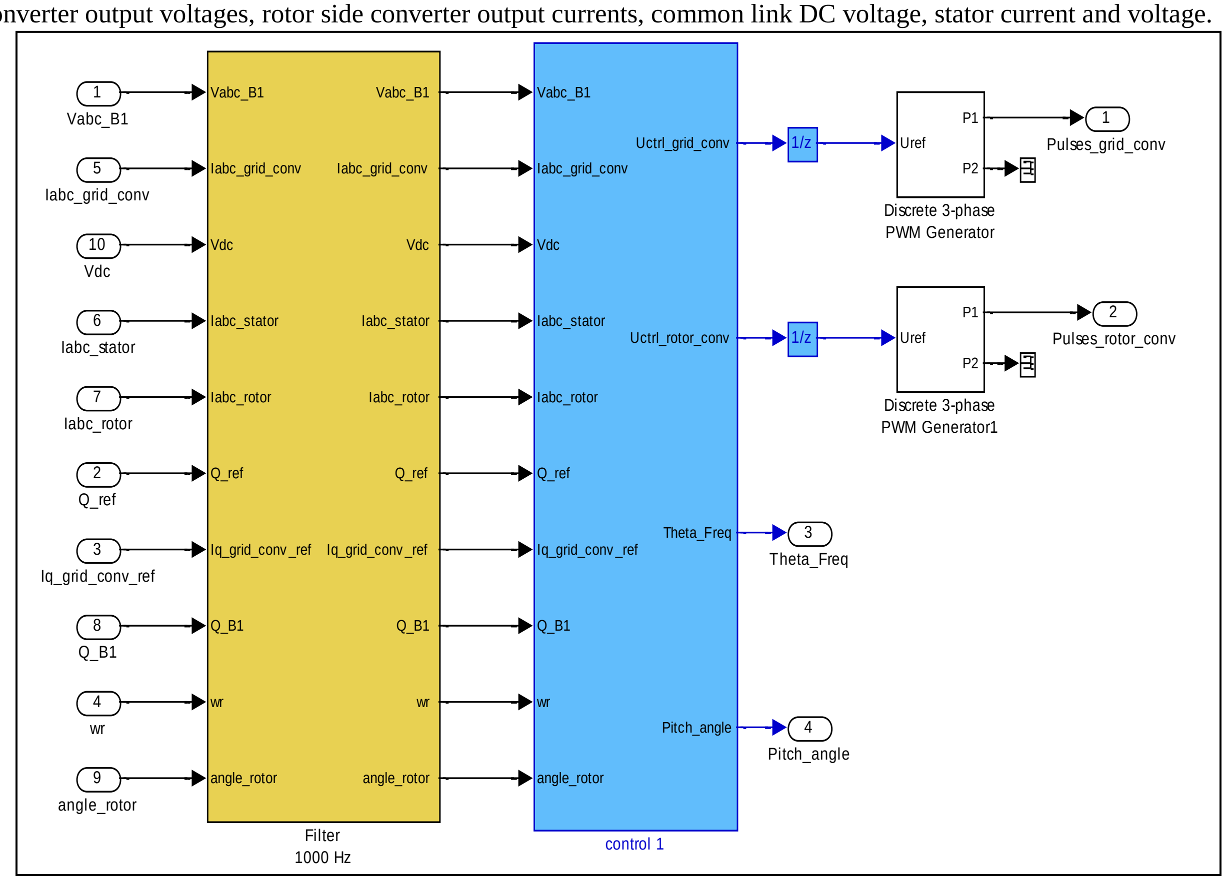

Fig.4. Back to back converter control system

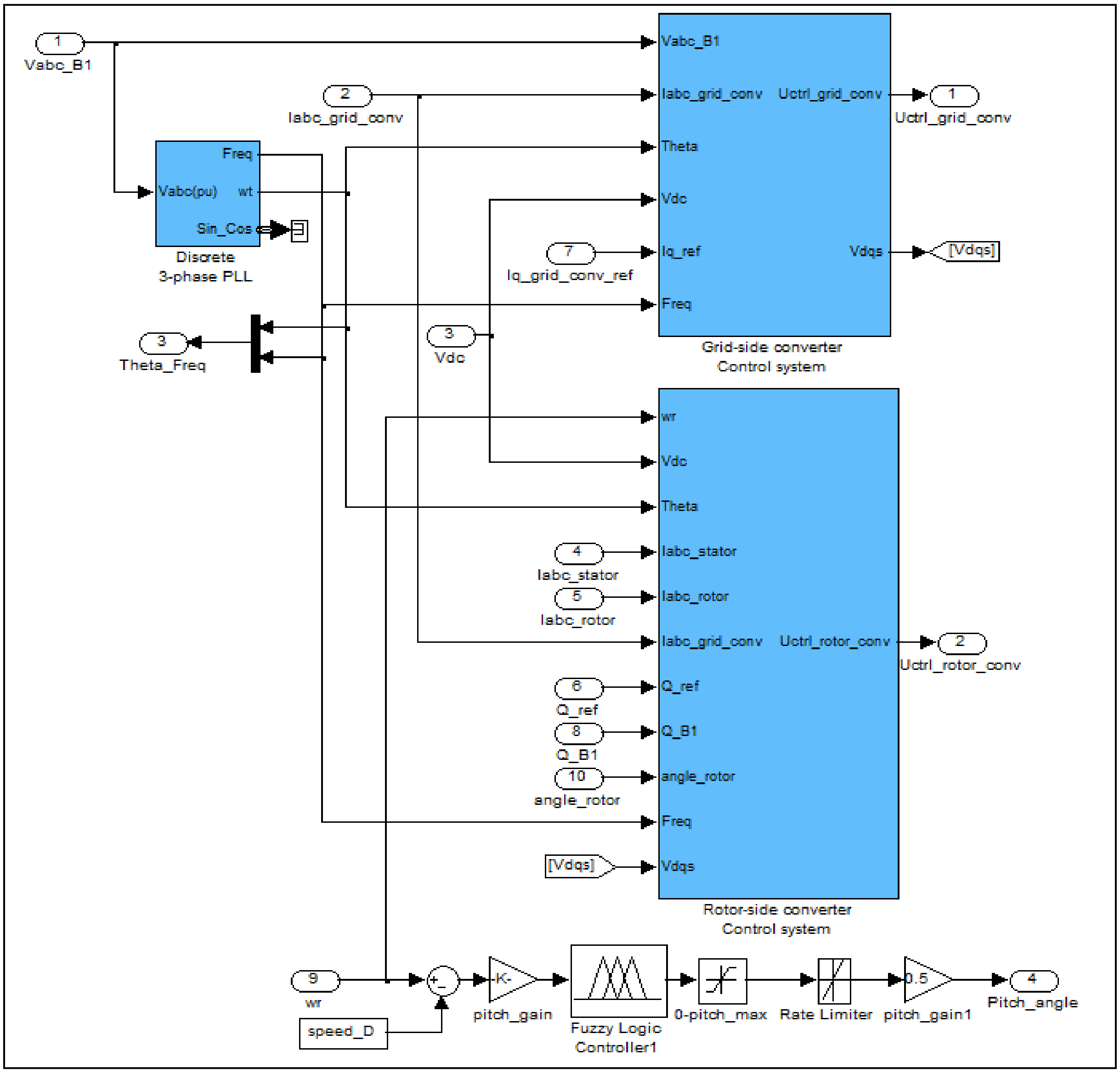

Fig. 5: Grid and rotor side control block

The Grid and rotor side controller circuit is shown in fig.5. A fuzzy logic controller used to control the pitch angle, grid side and rotor side converters. Based on the reference and the actual values the fuzzy logic controller generates the pulse width modulation firing pulse for the two converters.

Fuzzy logic based voltage regulator is shown in fig.6.The actual DC voltage is compared with the reference DC voltage and the error is fed to fuzzy logic controller. The output of fuzzy controller is set as reference DC current.

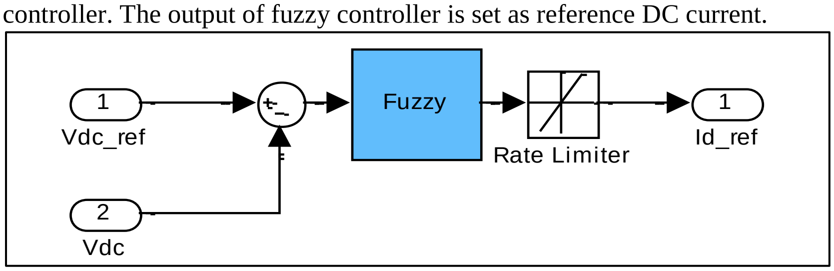

Fig. 6: Fuzzy based DC bus voltage regulator

III. RESULTS & DISCUSSION

To evaluate the performance of the system, a series of measurements has been accomplished. The simulation results are based on the MATLAB/Sim Power System model of the doubly fed induction generator based wind energy conversion systems. For a wind speed of 10 m/s and the load of 500 KW the output parameters are discussed. By varying the speed of the wind turbine and changing the load, the specified total harmonic distortion value can be found. The graph is plotted for obtaining stability in the grid and rotor side caused by the disturbances found in the converter section. The performance of fuzzy logic controller based position and speed estimation for DFIG is demonstrated through the extensive simulation results.

The gird output voltage (11 KV bus) and current waveforms are shown in the fig.7 and 8. The disturbances caused in the system is stabilized using the fuzzy logic controller, which determines the error and eliminates the harmonics found in the system. The graph is plotted for time t=0.4sec.

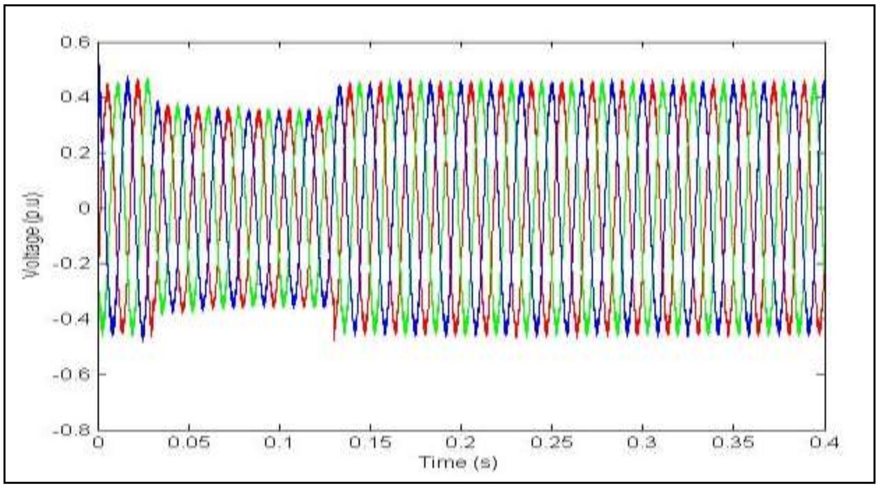

Fig. 7: Grid output voltage Vs time characteristics of fuzzy system

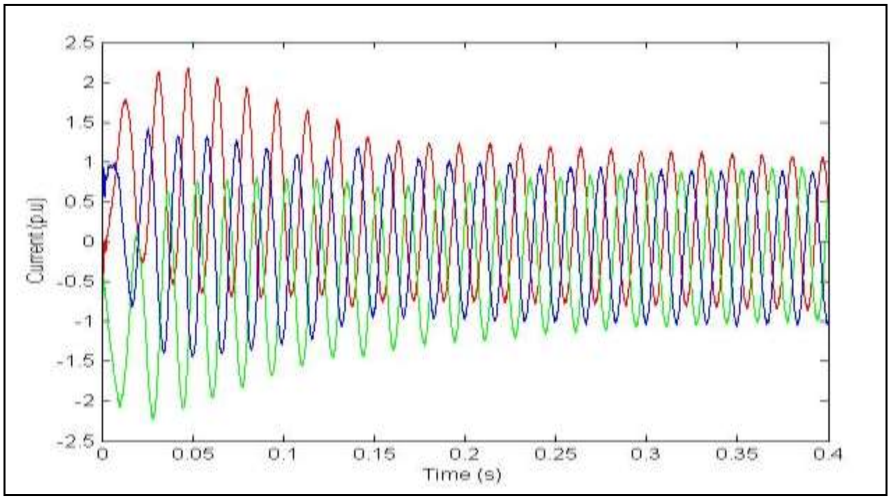

Fig. 8: Grid output current Vs time characteristics of fuzzy system

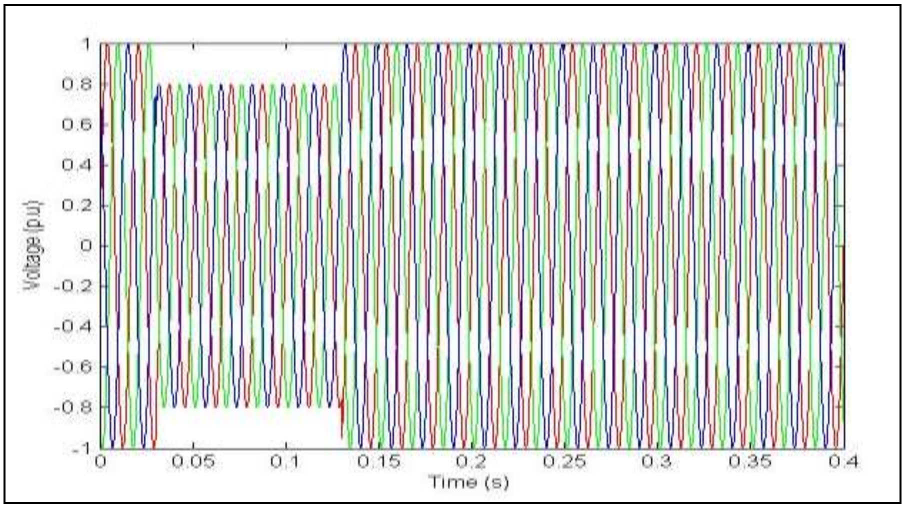

Fig. 9: Rotor side output voltage Vs time characteristics of fuzzy system

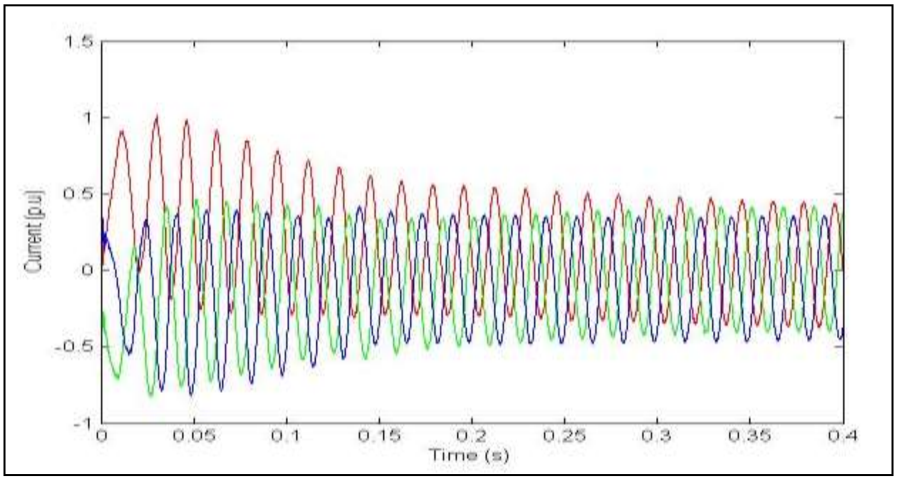

Fig. 10: Rotor side output current Vs time characteristics of fuzzy system

The Rotor side converter output voltage (575V) and current waveforms are shown in the fig.9 and 10 .Initial disturbances present in the output will be sensed by using the fuzzy logic control system,it will eliminate the harmonics formed in voltage side. The graph is plotted for time t=0.4sec.The real power Vs time characteristics of fuzzy logic controller based asynchronous machine is shown in fig.11. The real power is measured in MW.

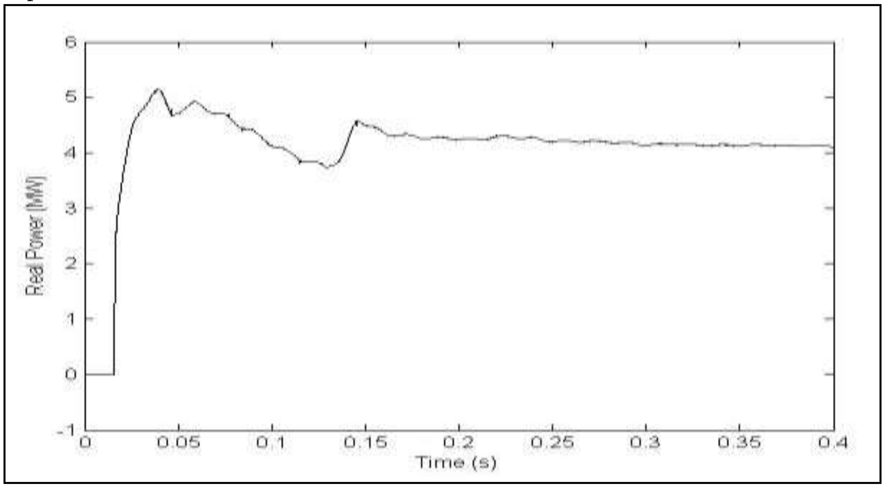

Fig. 11: Real power Vs time characteristics of fuzzy system

The reactive power Vs time characteristics of fuzzy logic controller based asynchronous machine is shown in fig.12. In this there will be a point when the reactive power falls at zero due to harmonics present in the system. This rectification will be done by the fuzzy logic control by eliminating the errors and producing a stable graph.

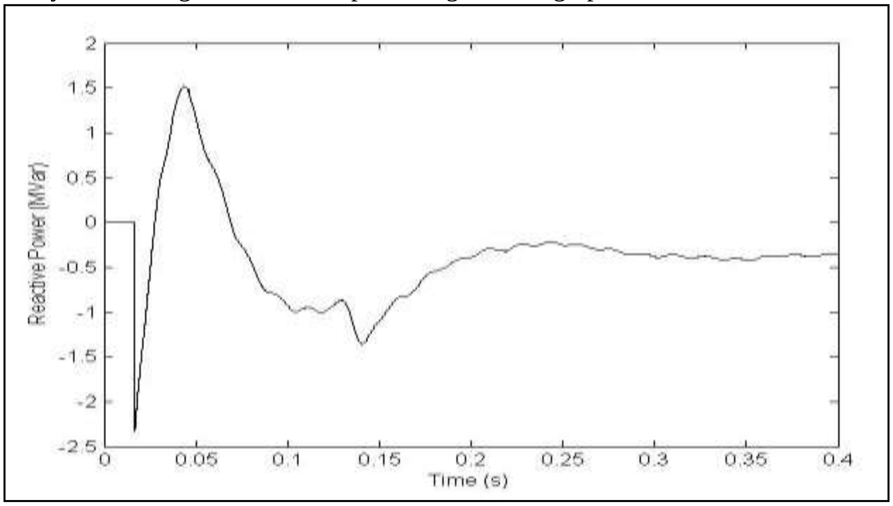

Fig. 12: Reactive power Vs time characteristics of fuzzy system

The common link DC output voltage vs time characteristics is shown in fig.13.

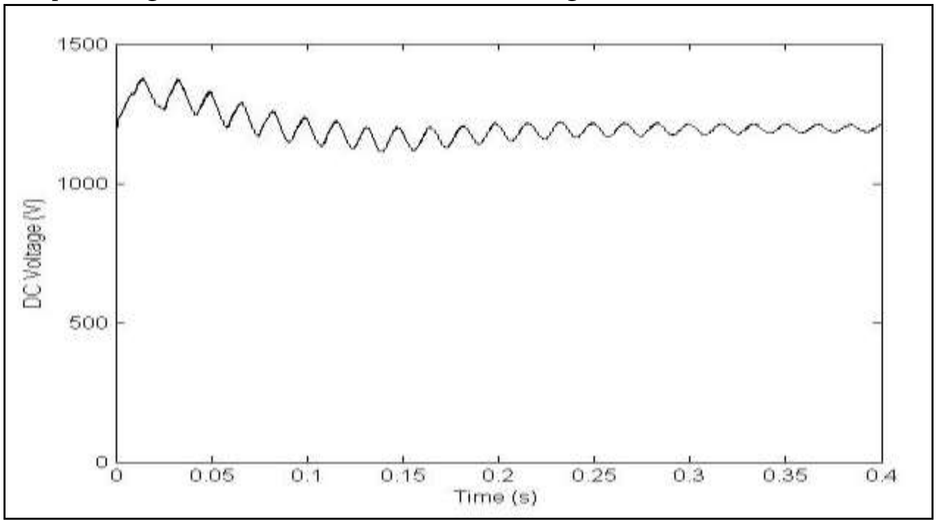

Fig. 13: Common link DC output voltage Vs time

Fig.14 describes about the rotor speed of the induction machine. The rotor speed is made constant with slight variations during the disturbances which are handled by the fuzzy logic control system.

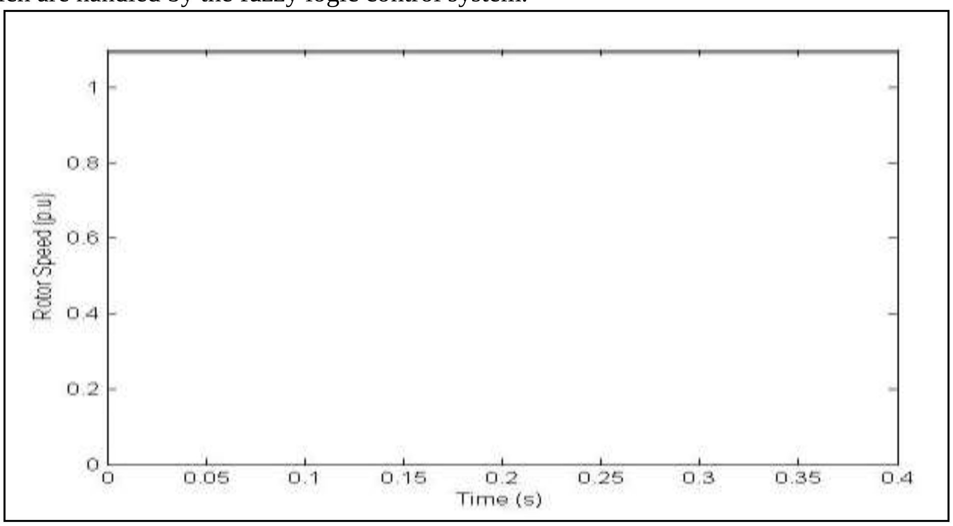

Fig. 14: Rotor speed Vs time characteristics of fuzzy system

The total harmonic distortion in the rotor side converter output voltage with variable wind speed and different loading condition using fuzzy logic controller is calculated and it is tabulated in table 1. For a wind speed of 10 m/s and the differing conditions, the total harmonic distortion of rotor side converter output voltage ranges from 0.340 to 0.0356. For a wind speed of 15 m/s and the differing conditions, the total harmonic distortion of rotor side converter output voltage ranges from 0.0336 to 0.0353. For a wind speed of 20 m/s and the differing conditions, the total harmonic distortion of rotor side converter output voltage ranges from 0.329 to 0.0346.

Table – 1
Total harmonic distortion by using fuzzy control system

Load	*THD with wind speed of 10 m/s*	*THD with wind speed of 15 m/s*	*THD with wind speed of 20 m/s*
100 kW	*0.0356*	*0.0353*	*0.0345*
200 kW	*0.0353*	*0.0349*	*0.0342*
300 kW	*0.0351*	*0.0344*	*0.0346*
400 kW	*0.0350*	*0.0343*	*0.0336*
500 kW	*0.0346*	*0.0340*	*0.0340*
600 kW	*0.0348*	*0.0343*	*0.0333*
700 kW	*0.0341*	*0.0336*	*0.0339*
800 kW	*0.0340*	*0.0333*	*0.0331*
900 kW	*0.0340*	*0.0340*	*0.0329*
1000 kW	*0.0345*	*0.0335*	*0.0330*

IV. CONCLUSION

A fuzzy logic controller based power quality improvement of variable speed wind energy conversion systems was proposed. For better efficiency doubly fed induction generator is used and the stator and rotor output of generator is connected to the grid. The rotor side converter provides active and reactive power control of the machine while the grid-side converter keeps the voltage of the DC-link constant. The output of rotor is fed to the grid through back to back converter. The firing pulse for this converter is controlled by using fuzzy logic controller. The effectiveness of the proposed scheme is developed and simulated using MATLAB/ Sim Power System software. The simulation results shows the total harmonics distortion using fuzzy logic controller is less than the conventional control techniques.

REFERENCES

[1] Bakari M. Winyiwiwa, Yangzheng Zhangv, Baik Shen and Boon – Tech Ooiv (2009) "Rotor position phase lock loop for decoupled P-Q control of double fed induction generator for wind power generation'', IEEE Transactions on Energy Conversion 24(3), 758-765.
[2] Chien- Hung Liu and Yuan- Yih Hsu (2011) "Effect of rotor excitation voltage on steady state stability and maximum output power of a doubly fed induction generator '', IEEE Transactions on Industrial Electronics 58(4), 1096–1109.
[3] Christian Wessels, Fabin Gebhardt and Fredrich Welhelm Fuchs (2011) "Fault ride through of a DFIG wind turbine using a dynamic voltage restorer during symmetrical and asymmetrical grid faults'', IEEE Transactions on Power Electronics 26(1),807-815.
[4] Etinne Tremblay, Sergio Atayde and Ambrish Chandra (2011) "Comparative study of control strategies for the doubly fed induction generator in Wind Energy Conversion systems", IEEE Transactions on Sustainable Energy 2(3), 228-299.
[5] Jamal Abd Ali1, M.A.Hannan, Azah Mohamed and Maher.G.M.Abdolraso (2016) "Fuzzy Logic Speed Controller Optimization Approach for Induction Motor Drive Using Backtracking Search Algorithm", International Journal of Measurement, Vol.78, 49-62.
[6] Marius Malino Wski,Sebastian Stynski, Wojciech Kolomyjski and Marian P. Kazmierkowski(2009), "Control of three level PWM converter applied to variable speed type Turbines'', IEEE Transactions on Industrial Electronics, Vol. 56, No.1, pp. 69–77
[7] Morren J, De Hann S. W(2005) , "Ride-through of wind Turbines with Doubly Fed Induction Generator during a voltage dip'', IEEE Transactions on Energy Conversion, Vol. 20, No. 2, pp. 435–441.
[8] Van Tung Phan and Hong – Hee Lee(2011) "Control strategy for harmonic elimination in stand- alone DFIG applications with nonlinear loads'', IEEE Transactions on Power Electronics, Vol. 26, No. 9, pp. 2662–2675.