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DOUBLY FED INDUCTION GENERATOR-BASED WIND ENERGY SYSTEM FRACTIONAL ORDER CONTROL BY INTEGRATED ARTIFICIAL INTELLIGENCE

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Abstract

This paper proposes artificial intelligence integrated fractional order robust control DFIG based wind energy system to reduce chattering phenomena in the electric signal system performance under through proposed FFORC scheme is compared with classical sliding mode control The speed tracking error is approximately zero while with SMC method peak tracking error is 0.4 radian/s.SMC method reactive power oscillates on both sides of 0.01KVAR positive side -0.01KVAR negative side of the plot FFORC control scheme offers minimum steady state error which is about 0.01 radian/s. while case of SMC with saturation function a peak value 0.6radian/s moreover the proposed FFORC minimum chattering

INTRODUCTION

The growing concern about global warming and the harmful effects of fossil-fuel emissions has created new demand for renewable energy sources. Also the global electrical energy consumption is still rising and there is a steady demand to increase the power capacity. The production, distribution and the use of the energy should be as technological efficient as possible and incentives to save energy at the end-user should be set up. The deregulation of energy has lowered the investment in larger power plants, which means the need for new electrical power sources may be very high in the near future. Two major technologies will play important roles to solve the future problems. One is to change the electrical power production sources from the conventional, fossil based energy sources to renewable energy resources. The other is to use high efficient power electronics in power systems, power production and end-user application. While 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. These are Solar, Wind, Sea, Geothermal and Biomass. Solar power on earth is 106 watts and the total world demand is 10 13 watts. If we utilize 5% of the solar energy, it will be 50 times what the world requires. If we consider the wind potential it is estimated to 1.6x107 MW, which is same as world energy consumption. So the development of non-conventional energy source is very economical.

The most emerging renewable energy source is wind energy, with the use of power electronics which means the wind energy is changing from being a minor energy source to an important power source in the energy system. Wind turbines (WTs) can either operate at fixed speed or variable speed. For a fixed speed wind turbine the generator is directly connected to the electrical grid. For a variable speed wind turbine the generator is controlled by power electronic equipment. Differential heating of the earth's surface by the sun causes the movement of large air masses on the surface of the earth, i.e., the wind, the power of which is converted to electricity. Hence by using this renewable source of energy power can be generated and the demand for power can be met at necessary condition, as it is a grid connected system.

As energy crisis is very high in case of developing countries like India. There came urgent need to look for secondary sources of energy that are clean and pollution free, as conventional sources cause much pollution. This paved path for non-conventional sources. Of all the renewable energy sources, the one that has matured to the level of being a utility generation source is wind energy. It is estimated that wind potential is 1.6x107 MW which is same as world energy requirement. But the only problem is that wind speed is highly fluctuating, which gives rise to many problems during power generation. So we mainly concentrate on the problems that occur during generation and how they can be rectified. The problems faced are due to local impacts and system impacts. Local impacts deal with the impacts that occur in the vicinity of the wind turbine or wind farm. System impacts are the impacts that affect the behavior of the system as a whole. Using modern power electronics and special type of wind turbines that suit to the conditions can solve local impacts. Designing turbines to withstand voltage variations of certain magnitudes can rectify system impacts to some extent. Controlling the rotor speed by gear mechanism can rectify problems due to high wind or computer aided techniques.

Today, doubly-fed induction generators are commonly used for larger wind turbines. The major advantage of the doubly-fed induction generator is that the power electronic equipment has to handle only a fraction of the total system power. This means that the losses in the power electronic equipment can be reduced in comparison to power electronic equipment that has to handle the total system power as for a direct-driven synchronous generator, apart from the cost saving of using a smaller converter.

The power quality is a set of parameters defining the properties of the power supply as delivered to user in normal operating condition in terms of continuity of supply and characteristics of voltage and frequency. The critical power quality issues related to integration of wind farms have been identified. The power quality in relation to a wind turbine describes the electrical performance of wind energy generating system. It reflects the generation of grid interference and the influence of a wind turbine on power and voltage quality of grid. The issue of power quality is of great importance to the wind turbines. There has been an extensive growth and quick development in the exploitation of wind energy in recent years. However, with rapidly varying voltage fluctuations due to the nature of wind, it is difficult to improve the power quality with simple compensator.

Advance reactive power compensators with fast control and power electronic have emerged to supersede the conventional reactive compensator. It has been suggested that today’s industrial development are related with generalized use of computers, adjustable speed drives and other microelectronic loads. It also becomes an increasing concern with power quality to the end customer. The presence of harmonic and reactive power in the grid is harmful, because it will cause additional power losses and malfunction of grid component. The massive penetration of electronically controlled devices and equipments in low voltage distribution network is responsible for further worsening of power-quality problem. These 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 different types of disturbances.

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. Wind turbines and their power quality will be certified on the basis of measurements according to national or international guidelines. These certifications are an important basis for utilities to evaluate the grid connection of wind turbines and wind farms. Soft computing techniques like neuro, neuro-PI controllers are used to improve the power quality of Wind Energy Conversion Systems by reducing the total harmonic distortion.

PI LOGIC CONTROLLER BASED PROPOSED WIND ENERGY CONVERSION SYSTEMS

The circuit diagram of the proposed PI logic controller based wind energy conversion systems is shown in figure 1.It consists of two back to back converters.PI logic controller is used to control the two controllers.

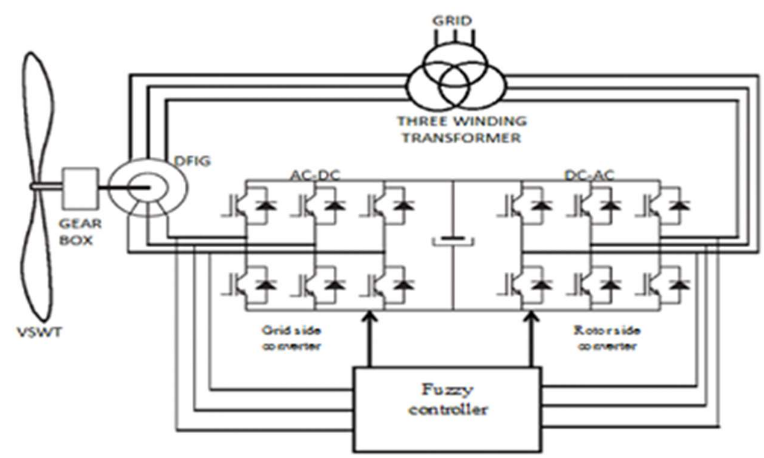

Figure 1 Circuit diagram of PI controller based WECS

PI Logic Control techniques is one of the form of artifical intelligence and its principles are applied to modeling and estimate. PI logic based model has helps to enhance the performance of PI 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.

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 equipments 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. PI 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. Features include:

High-level language for technical computing

- Development environment for managing code, files, and data
- Interactive tools for iterative exploration, design, and problem solving
- Mathematical functions for linear algebra, statistics, Fourier analysis, filtering, optimization, and numerical integration
- 2-D and 3-D graphics functions for visualizing data

Tools for building custom graphical user interfaces

Functions for integrating MATLAB based algorithms with external applications and languages, such as C, C++, Fortran, Java™, COM, and Microsoft® Excel.

Simulink Model of PI Based WECS

The simulink model of PI Logic controller based wind energy conversion systems diagram is shown in figure 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.

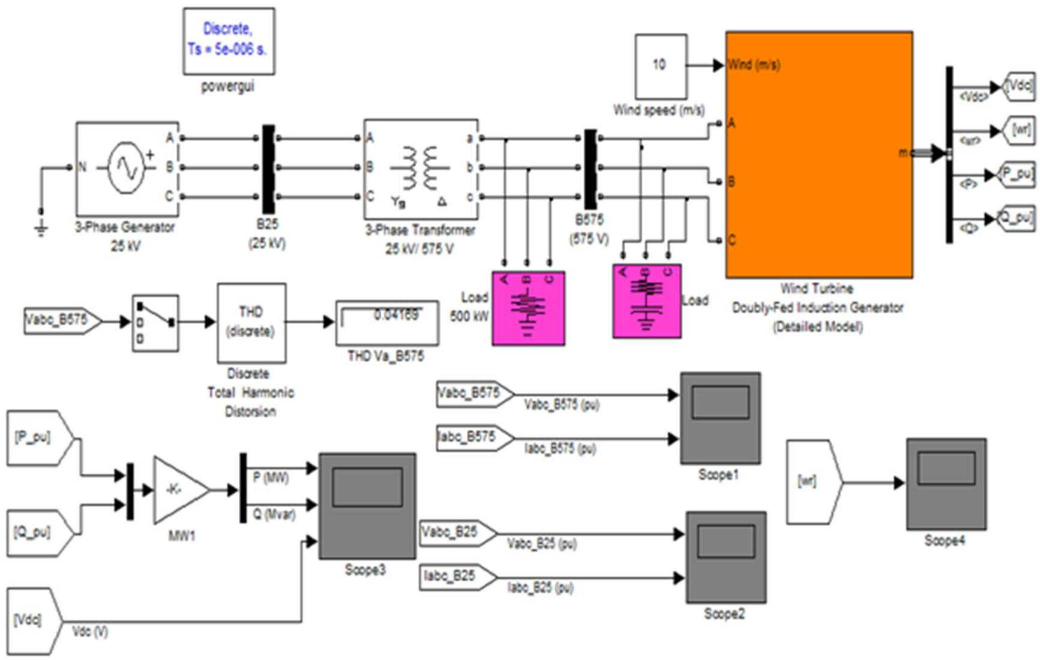

Figure 2 Simulink model of PI logic controller based WECS

The wind turbine specification of PI logic based wind energy conversion system is shown in table 1.

Table 1 Wind turbine generator specification

System Quantities	Values
Nominal Power	10 MW
Nominal Voltage	575 V
Nominal Frequency	60 Hz
Stator Resistance	0.0071 Ω
Stator Inductance	0.156 H
Rotor Resistance	0.005 Ω
Rotor Inductance	0.154 H

Magnetizing Inductance	2.9 H
Pole Pairs	3
Cut-in wind speed	5 m/s
Cut-out wind speed	25 m/s

Doubly-Fed Induction Generator Wind Turbine

The simulink model of wind turbine induction generator is shown in figure 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 PI 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 PI logic controller unit.

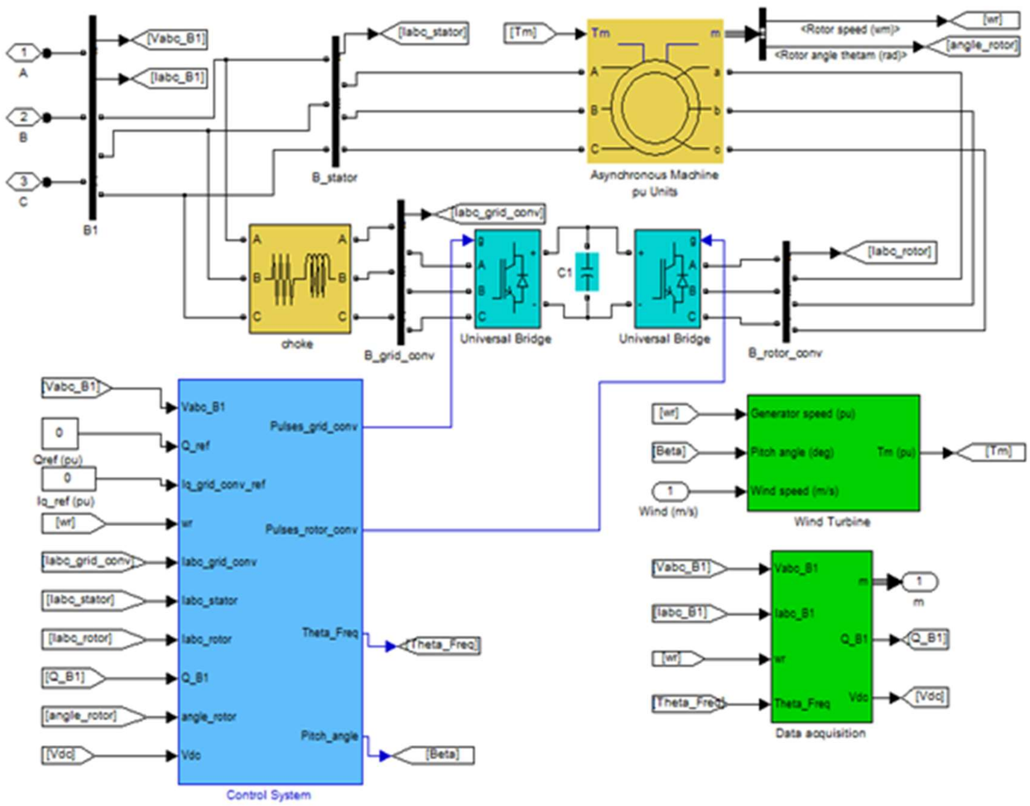

Figure 3 Doubly fed induction generator wind turbine

Simulink Model of Wind Turbine

The simulink model of wind turbine is. The mode is based on wind speed and pitch angle. The motor torque is represented by Tm. All the parameters are represented by per unit.

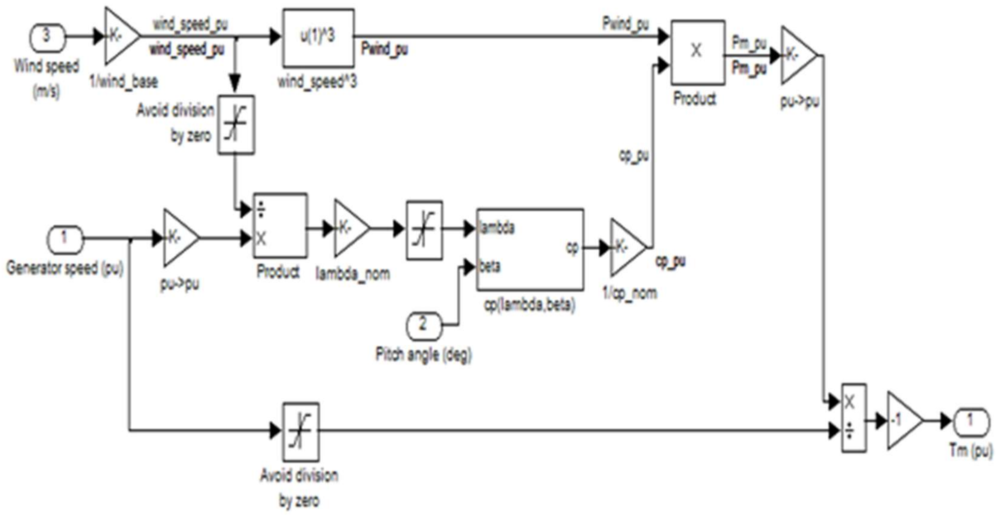

Figure 4 Simulink model of wind turbine

Back to Back Converter Control System

The control system for the power converter. 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.

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

Simulink Model for Grid Side Converter Control

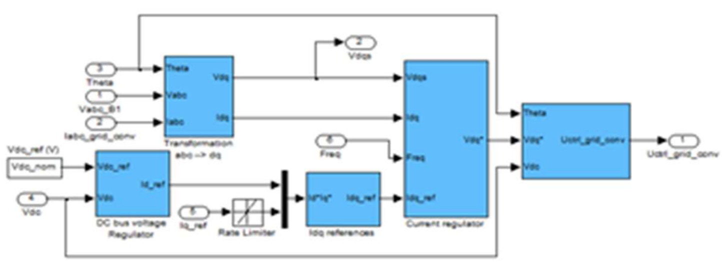

Figure 5 Grid side converter control

Simulink model for grid side converter control is shown in figure 6. It consists of abc – dq transformation block, DC voltage regulator and current regulator. In abc – dq transformation block the three phase quantity is converted to two phase quantity. The actual DC voltage is compared to the reference DC voltage and the error is set as a DC current reference. The current regulator is used to regulate the DC current.

Simulink Model for Rotor Side Converter Control

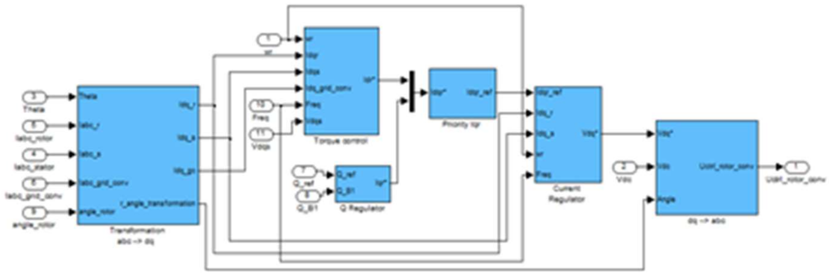

Figure 6 Simulink model for rotor side converter control

The simulink model of rotor side converter control is shown in figure 5.8. It consists of abc-dq transformation block, torque control, real power control, current regulator and abc - dq transformation block.

Simulink Model PI Logic Controller

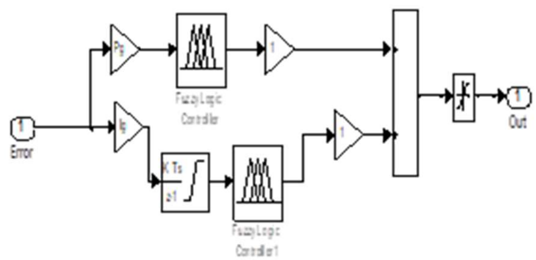

Figure 7 PI logic control used in grid side converter

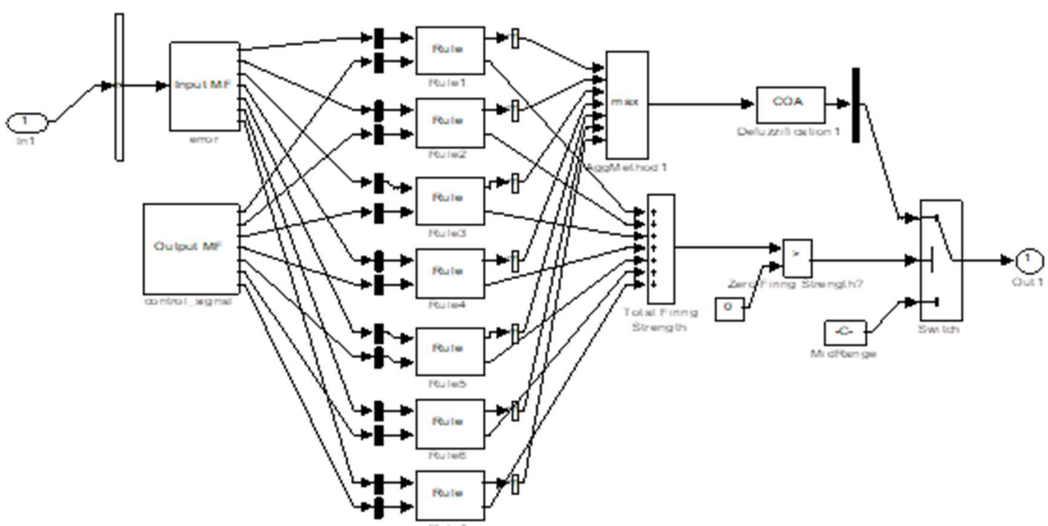

Figure 8 Simulink model PI logic controllers

The simulink model of PI logic controller is shown in figure 8. It consists of seven rules. The output of PI logic controller is pulse width modulation firing pulse for control the grid side and rotor side converters.

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 PI logic controller based position and speed estimation for DFIG is demonstrated through the extensive simulation results.

The gird output voltage (25 KV bus) and current waveforms are shown in the figure 10. The disturbances caused in the system is stabilized using the PI logic controller, which determines the error and eliminates the harmonics found in the system. The graph is plotted for time t=0.4sec.

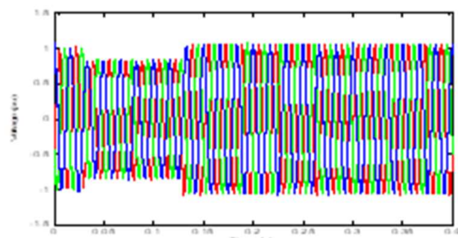

Figure 9 Grid output voltage Vs time characteristics of PI system

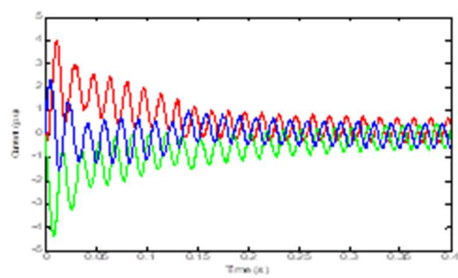

Figure 10 Grid output current Vs time characteristics of PI system

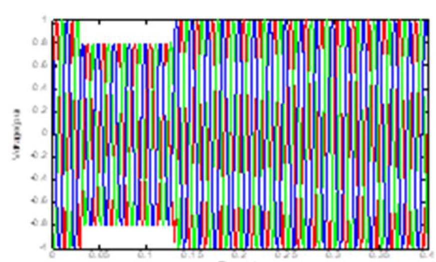

Figure 11 Rotor side output voltage Vs time characteristics of PI system

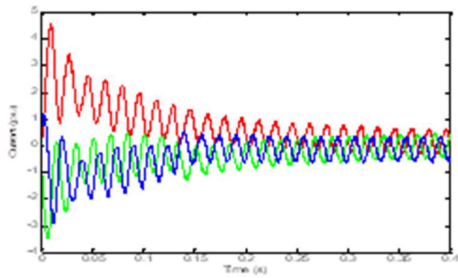

Figure 12 Rotor side output current Vs time characteristics of PI system

The Rotor side converter output voltage (575V) and current waveforms are shown in the figure 13 and 14. Initial disturbances present in the output will be sensed by using the PI 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 PI logic controller based asynchronous machine is shown in figure 7.5. The real power is measured in MW.

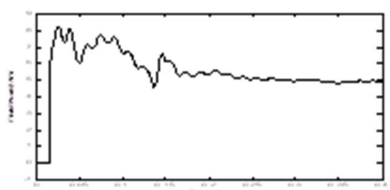

Figure 13 Real power Vs time characteristics of PI system

The reactive power Vs time characteristics of PI logic controller based asynchronous machine is shown in figure 16. 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 PI logic control by eliminating the errors and producing a stable graph.

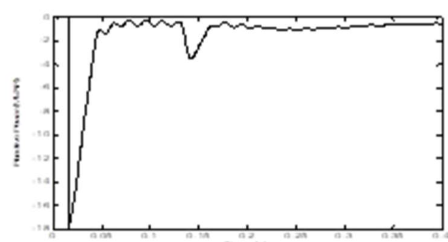

Figure 14 Reactive power Vs time characteristics of PI system

The common link DC output voltage vs time characteristics is shown in figure 7.

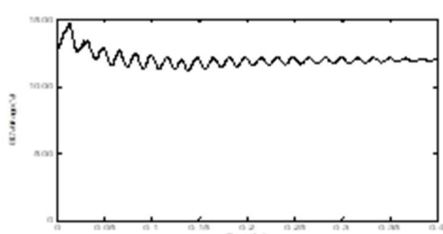

Figure 15 Common link DC output voltage Vs time

Figure 16 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 PI logic control system.

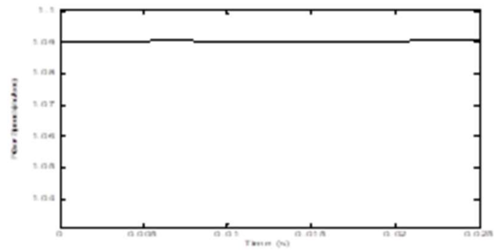

Figure 16 Rotor speed Vs time characteristics of PI system

Total Harmonic Distortion with Variable Wind Speed and Different Loading Conditions for PI System

The total harmonic distortion in the rotor side converter output voltage with variable wind speed and different loading condition using PI 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 0.041 to 0.0429. For a wind speed of 15 m/s and the differing conditions, the total harmonic distortion of rotor side converter output voltage ranges from 0.043 to 0.0426. For a wind speed of 20 m/s and the differing conditions, the total harmonic distortion of rotor side converter output voltage ranges from 0.042 to 0.0428.

Table 2 Total harmonic distortion by using PI 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	0.0429	0.0426	0.0428
200 kW	0.0425	0.0423	0.0424
300 kW	0.0421	0.0421	0.042
400 kW	0.0417	0.042	0.0418
500 kW	0.0416	0.0414	0.0415
600 kW	0.0414	0.0412	0.0412
700 kW	0.0409	0.041	0.0409
800 kW	0.0406	0.0406	0.0405
900 kW	0.0405	0.0405	0.0404
1000 kW	0.0401	0.0403	0.0402

CONCLUSION

Today, the worldwide trend of wind power penetration is increased day by day. The integration of high penetration level of wind power into existing power system has a significant impact on the power system operation. The wind turbines connected with weak grids have an important influence on power system. The weak grid is characterized by large voltage and frequency variations, which affect the wind turbines regarding their power performance, safety and allied electrical components. The strength of the distribution system is important from the point of power quality.

Soft Computing Techniques are the most rapidly advancing techniques in the field of research especially, in technological advances in wind energy conversion systems. In this thesis, Soft Computing Techniques like PI Controllers are used to enhance the power quality by reducing the Total Harmonic Distortion. The simulation results have been provided under different loading conditions and variable wind speed operation. The PI estimators are able to estimate the rotor speed and position accurately under both steady-state and dynamic conditions.

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