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Doubly Fed Induction Generator Based Wind Turbine with Adaptive Neuro Fuzzy Inference System Controller

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ABSTRACT

Wind energy has potential growth in the energy market and plays vital role to achieve the sustainable energy across the globe. Various control strategies for the speed and power control of wind turbines have been adopted and presented in Literature. These control strategies are used to control the smooth active power generated by wind turbine generator fed to power grids. However, the conventional control strategies have their own limitations such as power control at very high wind speed or turbulence, unable to control harmonics within the permissible values and instability issues at critical conditions. These limitations are overcome by intelligent controllers now-a-days in wind turbines. Artificial Intelligent (AI) controllers are generally known as adaptive controllers and used to achieve smooth grid integration. Hence, in this study, a novel adaptive control strategy for Doubly Fed Induction Generator (DFIG) based variable speed wind turbine has been presented to prove the ability of the proposed algorithm. Actual wind profile, grid code and generator characteristics have been considered as inputs for the simulation in this study. By using proposed control strategy, torque and current ripple are controlled within 0.01pu (per unit) and hence power loss is drastically reduced.

Key words: Induction generator, soft starter, ANFIS, wind turbine, pitch regulation and reactive power

INTRODUCTION

Wind energy electric systems have been built in many places around the world. In rural and isolated areas, stand alone power systems are used. When conventional machines are used as generators in these isolated systems, the output voltage will be of variable magnitude and frequency. Power electronic converters are then necessary to obtain a constant frequency supply. Synchronous and induction generators are widely used in wind energy systems and each type of these machines has its own advantages and disadvantages and also its own methods of control. This control, whether mechanical or electrical, is necessary to obtain a voltage of constant magnitude and frequency which can be connected to the grid (Radic *et al*., 2010). Power electronics technology is a major catalyst in distributed power system and integration of wind turbine into electrical grid. From last few decades, usage of power electronics converters is significantly improved due to their contributions on high power handling capability and many new power devices are being used in the newly constructed power converters. The second factor is the introduction of real-time computers with controllers that can implement advanced and complex control algorithms (Chongjaream, 2012). Due to these advantages, latest power converters are being used in grid connected applications such as wind and solar power systems. In this study, new trends in power-electronic technology for the integration of wind electric generators and energy-storage systems spread over globally are presented. Wind power is quite different from the conventional electricity generation with alternators. Further, there are some differences between the different wind-turbine designs available on the market. Based on the requirements, wind turbines are chosen for grid integration. It is very essential that wind turbine engineers must have the knowledge on power evacuation, wind turbine integration into power systems and different efficient power control strategies applied to wind turbines. Hence, this study mainly focuses on the efficient control strategy applied into a wind turbine in order to achieve smooth grid integration.

A new technology has been developed in the wind power market introducing variable-speed working conditions depending on the wind speed in order to optimize the energy captured from the wind. The advantages of variable-speed turbines are that their annual energy capture is about 5% greater than the fixed-speed technology and that the active and reactive powers generated can be easily controlled. There is also less mechanical stress and less rapid power fluctuations because the rotor acts as a flywheel (storing energy in kinetic form). In general, no flicker problems occur with variable-speed turbines. Variable speed wind turbine are used to control the reactive power in order to minimize the voltage fluctuations. Most popular terms such as Low Voltage Ride Through (LVRT) and High Voltage Ride Through (HVRT) are the salient features of wind turbines which keep the wind turbine remain connected with the power grid during high voltage and low voltage of the grid. The only disadvantage of the variable speed wind turbine is the cost due to power electronics accomplishment. The overall cost of the power electronics is about 7% of the whole wind turbine (Valenciaga, 2010). In this study, a novel topology for variable speed wind turbines has been applied to achieve the better performance in the view of smooth integration of wind electric generator with the grid, reduced total harmonic distortion, control of real and reactive power and better ride through capabilities. Novel topology introduced in this study is an adaptive intelligent controller by using neuro fuzzy approach which has been applied to four quadrant back to back connected converter in doubly fed induction generator based variable speed wind turbines.

MATERIALS AND METHODS

Power converter in doubly fed induction generator based wind turbines: Doubly Fed Induction Generator (DFIG) based wind turbines are most reliable and commercial product across the globe. Many manufacturers in Europe, China, USA and India are manufacturing these turbines and which has been highly appreciated by the renewable energy sector. Figure 1 shows the DFIG based wind turbine system with four quadrant power converter in its generator rotor circuit. DFIG is capable of delivering power from its both stator and rotor circuit. In general, 70% of nominal power is delivered from its stator windings and 30% of nominal power is delivered from its rotor winding through Insulated Gate Bipolar Transistor (IGBT) based power converter (Luu and Nasiri, 2010).

The main advantages of DFIG are:

- Wide range of variable speed operation is possible
- Stator is never been fully loaded and stress on the windings is also less and hence heat generation is also less. This leads the reliability and ruggedness of the generator

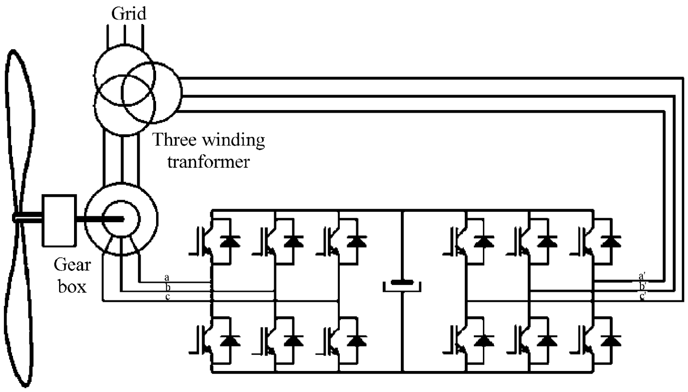

Fig. 1: Scheme of DFIG wind turbine system

- Highly capable for low wind sites in order to capture the maximum power available in the wind
- Cost of the system is less when compare to fully fed wind turbines since rating of the required power converter is just even less than the 1/3 of the nominal power
- Robust and well proven technology

Power converter for DFIG based wind turbines is chosen in such a way that to achieve bi-directional real and reactive power flow. Stator and rotor of the DFIG and grid are meeting at a common point called Point of Common Coupling (PCC) at which reactive power injection and absorption takes place normally. It is depending on the instability of the grid and grid code requirements. In this study, IGBT based four quadrant power converter has been considered for the simulation as well as real time wind turbine system.

Proposed adaptive intelligent controller: Adaptive Neuro Fuzzy Inference System (ANFIS) (Vasudevan *et al.*, 2006; Paramasivam and Arumugam, 2011; Lin *et al.*, 2011) has been used to implement the proposed adaptive intelligent controller. First, it uses the training data set to build the fuzzy system in which, membership functions are adjusted using the back propagation algorithm, allowing that the system learns with the data that it is modeling. Figure 2 shows the network structure of the Adaptive neuro fuzzy inference system that maps the inputs by the membership functions and their associated parameters and goes through the output membership functions and corresponding associated parameters. These will be the synaptic weights and bias and are associated to the membership functions that are adjusted during the learning process. The computational work to obtain the parameters and their adjustments is helped by the gradient descend technique.

The layers shown in Fig. 2, are defined as follows:

- **Layer 1:** Every node in this layer contains membership functions
- **Layer 2:** This layer chooses the minimum value of two input weights
- **Layer 3:** Every node of these layers calculates the weight, which is normalized
- **Layer 4:** This layer includes linear functions, which are functions of the input signals
- **Layer 5:** This layer sums all the incoming signals

Power converter used for DFIG considered in this study is four quadrant back to back connected IGBT based module and which is rated as 30% of the rated power of the turbine. Grid side power

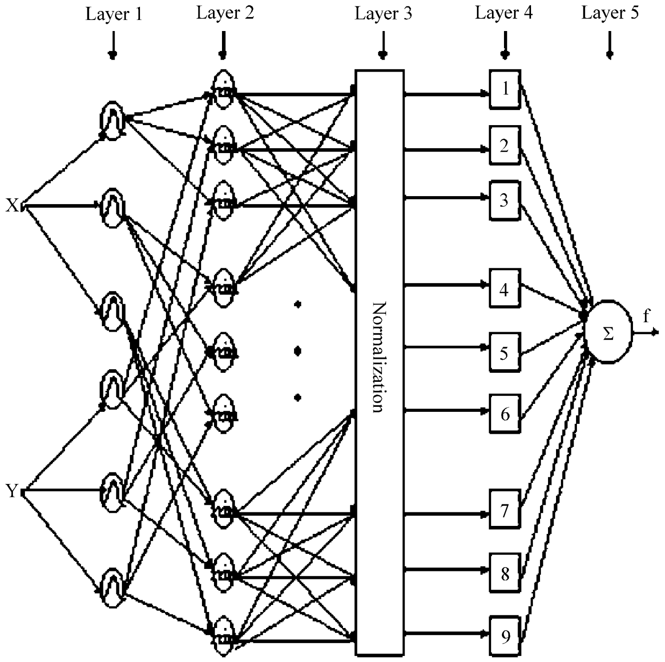

Fig. 2: Proposed neuro-fuzzy controller structure for intelligent control strategy

converter delivers power to the grid with constant frequency. Function of grid side converter is summarized as follows:

- Maintains constant DC link voltage within the limit
- Regeneration by adjusting phase angle of converter output with respect to grid voltage
- Control the reactive current into the grid by adjusting the output voltage level of the converter

To accomplish the above functions, intelligent controller has been used. Neuro Fuzzy methodology has been applied to grid side power converter to estimate the output voltage of the converter for reactive power compensation as required by the grid management system. Moreover, constant DC link voltage is also maintained by the proper estimation of the grid parameters and power flow level. Similarly, function of the generator side power converter is also properly achieved by ANFIS methodology and the same are summarized as given below:

- Feeds the reactive power to the generator at the time of starting for excitation
- Control the speed of the generator based on the wind speed
- Power demand is controlled
- Regeneration occurs and current flows through DC link
- DC link voltage rise

From the above, it is clearly understood that DC link voltage rise and maintain the value at the particular level have been achieved by four quadrant converter with the bidirectional power flow by optimum intelligent controller presented in this study. Voltage and current signals are taken from the grid as input parameters to ANFIS controller of the grid side power converter and reactive power requirement to the grid is estimated. Based on the input parameters, neurons of adaptive neural network are trained by fuzzy means and synoptic weights are added. Phase shift of the voltage and current are estimated and accordingly power factor is determined. Hence, grid side power converter is capable of operating at: (a) Constant reactive power mode (b) Constant power factor mode (3) Reactive power as function of voltage and (4) Power factor as function of real power (Nallavan *et al*., 2010; Asl *et al*., 2012).

For generator side power converter, ANFIS controller is used to regulate the active power generated by the generator. Parameters considered for this study are as given below:

- Base frequency: 50 Hz
- Base power: 1 MW
- Base voltage: 690 V
- Base peak current: 1666 A
- Base impedance: 0.24 Ohms
- Base flux linkage:1.27 web
- Base inductance: 0.85 mH
- Base synchronous Speed: 1500 rpm
- Base Torque: 6.4 kN m

RESULTS

Matlab/Simulink (MATLAB, 2002) tool is used to develop the proposed methodology presented in this study. Simulink schematic of doubly fed induction generator is shown in Fig. 3. Simulink model of doubly fed induction generator is chosen from the toolbox and used for simulation. P_s controller shown in the figure is stator active power controller and P_r controller is rotor active power controller. Proposed ANFIS control strategy is implemented in these controllers. Active power reference values and reactive power reference values are compared with the respective actual feedback values and errors are given as inputs to these controllers. Both active and reactive components are compared with the stator voltage component (v_s) and difference is given as rotor component to the motor model. Other three inputs to the motor model are stator voltage, base speed (w_k), actual speed (w_m). Output of the motor would be electromagnetic torque (T_e), stator current (i_s) and rotor current (i_r). As prescribed above, the main two parts of the wind turbine controller are classified as active power and reactive power controller. ANFIS is used as intelligent tool for both the controllers. At the time of starting, induction generator runs at a specified speed with the stator disconnected from the grid. The rotor of the generator is suddenly excited with the slip frequency voltages derived from the controllers so as to produce a commanded open circuit stator terminal voltage. Simulation considered in this study has been done in the two stages in order to capture both static and dynamic characteristics of induction generator. Induction generator considered for the simulation is modeled in a vectorized form in the synchronous frame. Results of the simulation are explained in detail in this study. Figure 4 shows the rotor voltages of doubly fed induction generator in d-q frame as dc quantities and these variables at slip frequency are derived from PI controller in which ANFIS tool is applied. Direct component voltage is 0.1 pu and quadrature component voltage is 0.3 pu as shown in Fig. 4. In the Simulink model shown in Fig. 3, dq2ab is model of direct-quadrature components (synchronously rotating frame) to sinusoidal components (stationary frame). Then these two axes sinusoidal components are converted into three phase sinusoidal components using ab2abc model. Then, three phase rotor voltage is captured. All the values captured from this model are per unit (pu) values. It is also clearly understood that P_s and

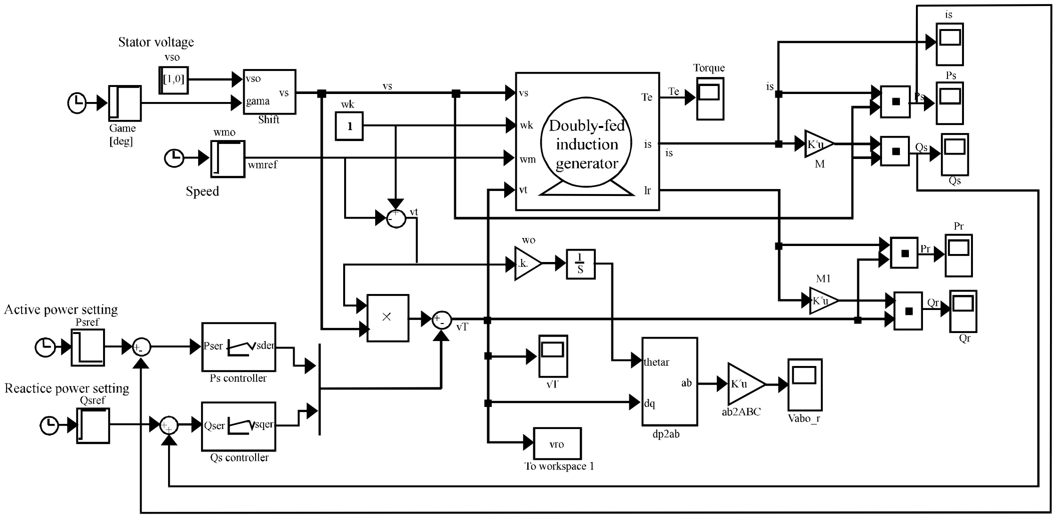

Fig. 3: SIMULINK model of proposed DFIG based variable speed wind turbine

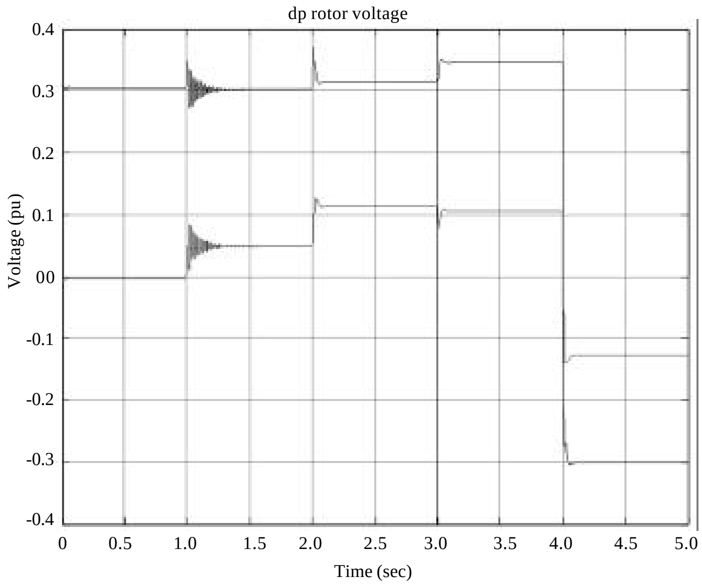

Fig. 4: Direct and quadrature (dq) rotor voltages of DFIG based variable speed wind turbine at static condition

P_r are stator and rotor active power respectively and Q_s and Q_r are stator and rotor reactive power values. Figure 5 shows the d-q axes rotor currents of 0.2 pu. These results have been captured under the static conditions of induction generator. Figure 6 shows the stator voltage and value is 0.9 pu and Fig. 7 shows the stator currents in d-q frame oscillate between 0.3-0.35 pu. Similarly, Fig. 8 and 9 show the static characteristics of active power delivered from stator and rotor, respectively and the power flow from generator to the grid. Stator and rotor power values are 0.5 and 0.25 pu, respectively. Figure 10 and 11 show the static characteristics of reactive power delivered from stator and rotor respectively and the value is 0.3 pu.

Static and dynamic speeds of the generator are shown in the Fig. 12 and 13, respectively and the values are 0.75 and 1.4 pu, respectively.

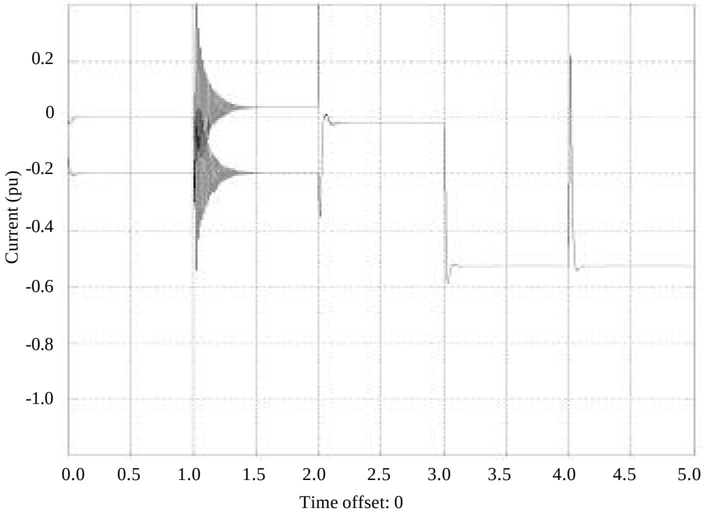

Fig. 5: Rotor current of DFIG generator based variable speed wind turbine at static condition

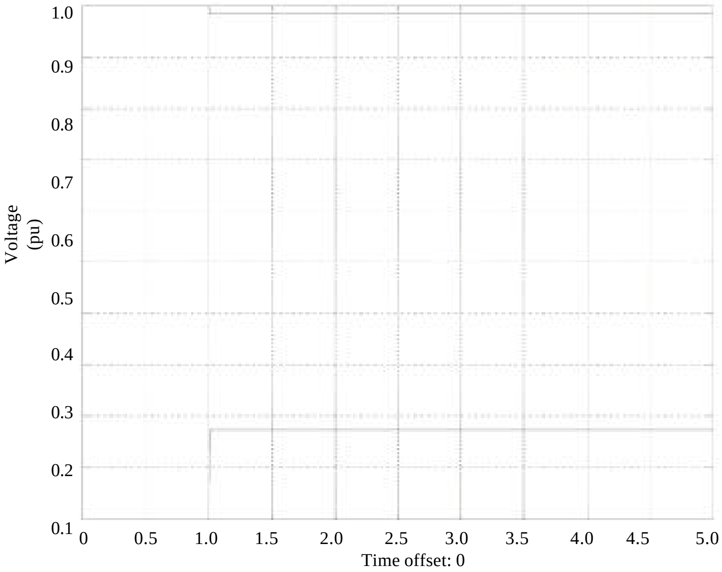

Fig. 6: Direct and quadrature (dq) stator voltages of DFIG based variable speed wind turbine at static condition

DISCUSSION

Static condition of the doubly fed induction generator is taken for the discussion in this study. Bidirectional power flow from stator and rotor to the grid is also taken for the discussion here. Both reference and actual per unit speed of generator are being compared in the Fig. 12. Reference static speed considered in this simulation is 0.7 pu continuous and the actual speed of the generator is also close to the command speed but it goes to the maximum value of 0.725 pu during transient condition. From this figure, it is clearly understood that the generator is running under sub-synchronous mode of operation. Speed of the generator at the dynamic condition is shown in Fig. 13. At this condition, speed reference is given as step command varied from sub-synchronous

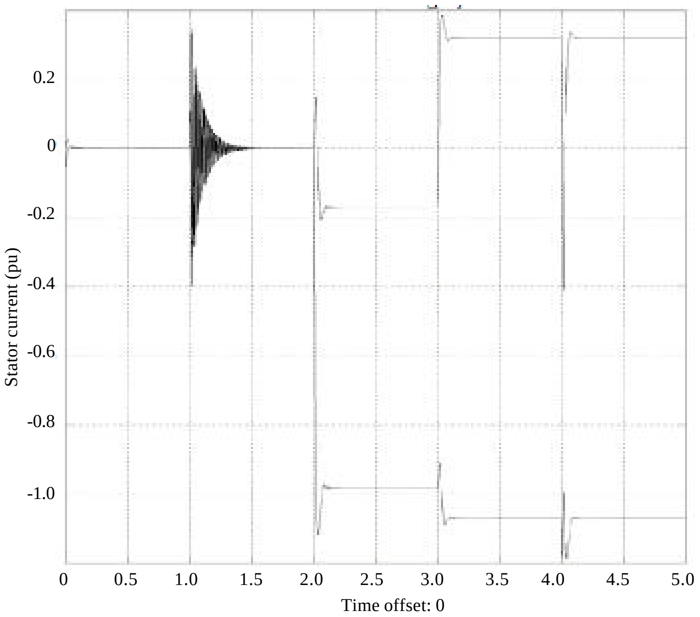

Fig. 7: Direct and quadrature (dq) stator current of DFIG based variable speed wind turbine at static condition

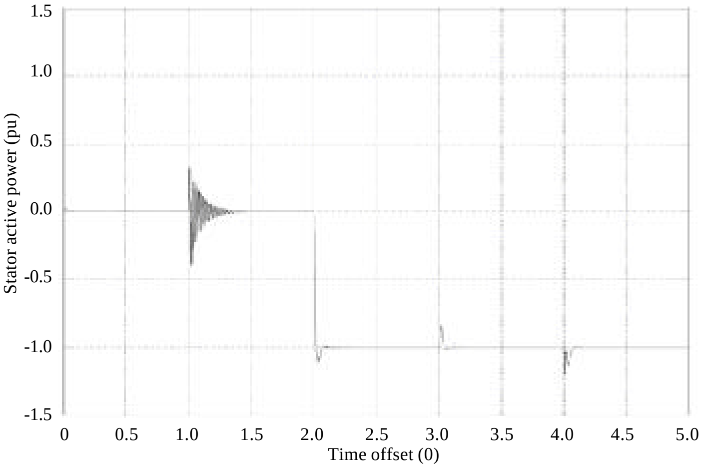

Fig. 8: DFIG stator real power for variable speed wind turbine at static condition

speed to super-synchronous speed. Sub-synchronous speed reference value starting from 0.7 pu and reaches at super-synchronous speed value of 1.3 pu. Actual dynamic speed follows the reference value and steady state error value is well within the limit. Based on the results captured from the simulation presented in this study it is clearly understood that this study mainly focuses on the active and reactive power generation at the grid connected common point of coupling. Unlike the reference (Chongjaream, 2012), this ANFIS control strategy not only used for Low Voltage Ride Through (LVRT) capability and also used for meeting reactive power requirements at the grid. In the reference (Lin *et al.*, 2011), intelligent controllers applications into wind turbine is presented,

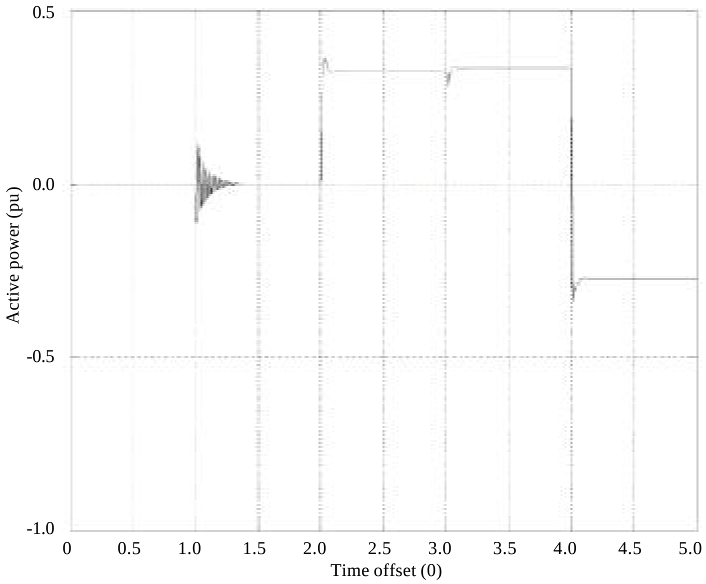

Fig. 9: DFIG rotor real power for variable speed wind turbine at static condition

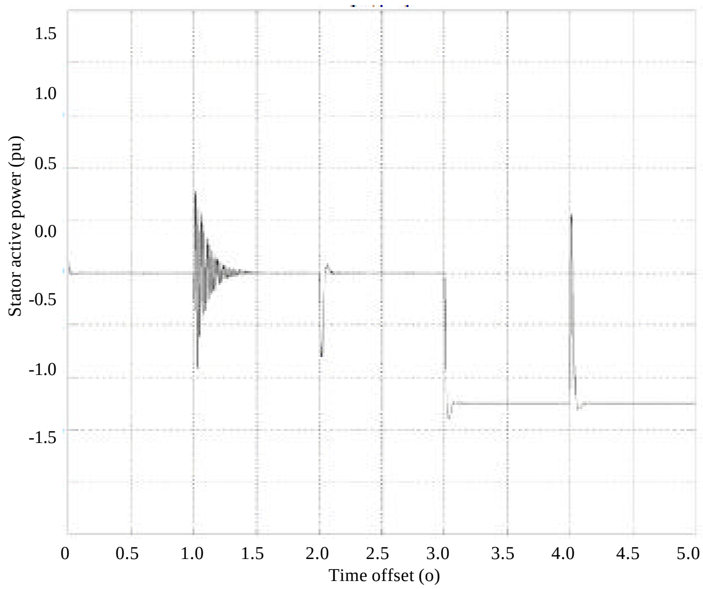

Fig. 10: DFIG stator reactive power for variable speed wind turbine at static condition

however ANFIS algorithm is not applied and this study is the first to introduce ANFIS to doubly fed induction generator based wind turbine system. Stability of the system has come to steady state condition very fast as shown in the Fig. 13. This is due to the efficiency of proposed ANFIS algorithm as given in (Vasudevan *et al.*, 2006; Paramasivam and Arumugam, 2011; Lin *et al.*, 2011).

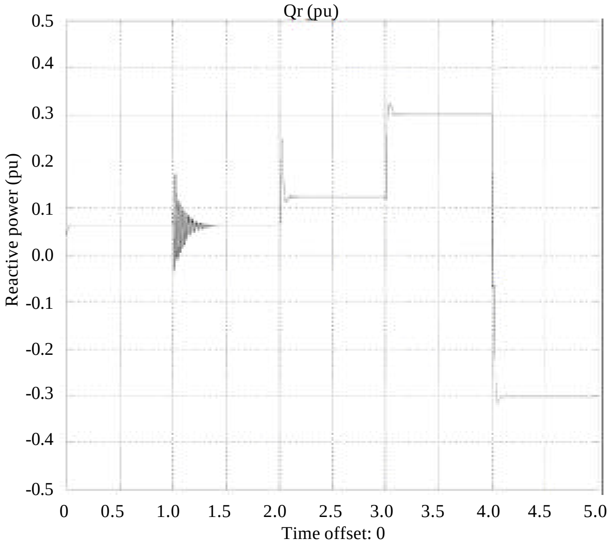

Fig. 11: DFIG rotor reactive power for variable speed wind turbine at static condition

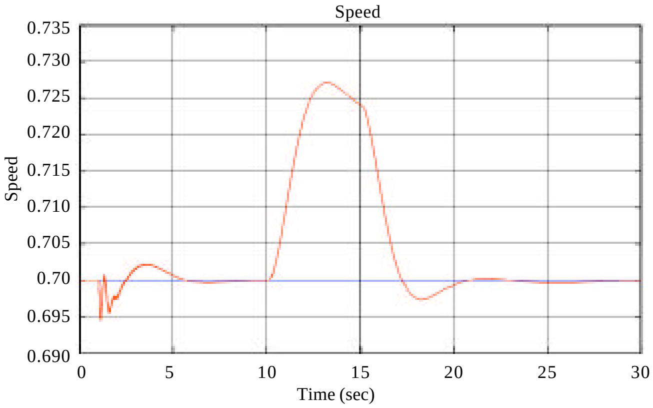

Fig. 12: Speed of the generator at static condition

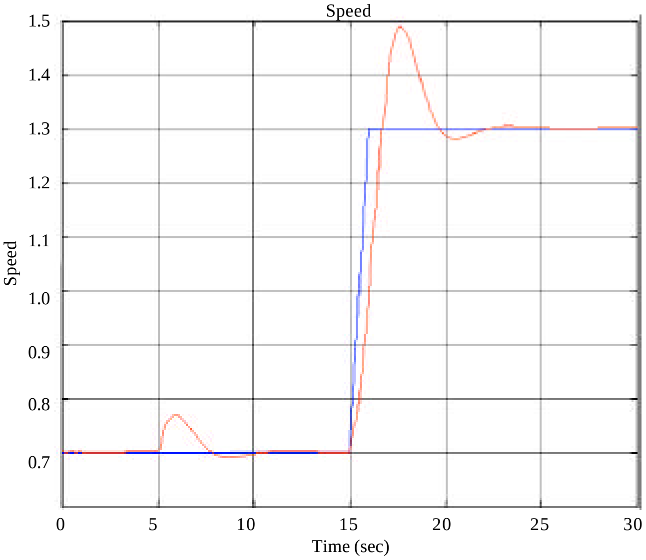

Fig. 13: Speed of the generator at dynamic condition

CONCLUSION

A novel control strategy for variable speed wind turbines has been presented in this study. An intelligent method of control strategy using neuro fuzzy structure has been used in the controller of variable speed wind turbines in order to achieve (1) Smooth grid integration (2) Energy savings (3) Reactive power compensation and (4) Effective real power flow. Comparative results presented in this study show the effectiveness and reliability of the proposed algorithm. This study also contributes towards effective reactive power compensation.

REFERENCES

Asl, M.E., S.H Abbasi and F. Shabaninia, 2012. Application of adaptive fuzzy control in the variable speed wind turbines. Lecture Not. Comput. Sci., 7530: 349-356.

Chongjaream, Y., 2012. Doubly-fed induction generator wind turbine model for fault ride-through investigation. Proceedings of the 9th International Conference on Telecommunications and Information Technology, May 16-18, 2012, Phetchaburi, pp: 1-4.

Lin, W.M., C.M. Hong and F.S. Cheng, 2011. Design of intelligent controllers for wind generation system with sensorless maximum wind energy control. Energy Conv. Manage., 52: 1086-1096.

Luu, T. and A. Nasiri, 2010. Power smoothing of doubly fed induction generator for wind turbine using ultracapacitors. Proceedings of the 36th Annual Conference on IEEE Industrial Electronics Society, November 7-10, 2010, Glendale, AZ., pp: 3293-3298.

MATLAB, 2002. Installing and using MATLAB on Mac OS X: Release 13. MATLAB® The Language of Technical Computing, The MathWorks Inc., Natick, MA., USA.

Nallavan, G., R. Dhanasekaran and L. Rajaji, 2010. Intelligent soft-starter-based grid-integrated induction generator for pitch-regulated wind turbine system. Springer Elect. Engin., 92: 57-68.

Paramasivam, S. and R. Arumugam, 2011. Hybrid fuzzy controller for speed control of switched reluctance motor drives. Energy Convers. Manage., 46: 1365-1378.

Radic, M., Z. Stajic and D. Antic, 2010. Variable speed constant capacitance operation of self-excited induction generator. Automatic Cont. Robotics, 9: 113-121.

Valenciaga, F., 2010. Second order sliding power control for a variable speed-constant frequency energy conversion system. Energy Convers. Manage., 51: 3000-3008.

Vasudevan, M., R. Arumugam and S. Paramasivam, 2006. Real time implementation of viable torque and flux controllers and torque ripple minimization algorithm for induction motor drive. Energy Convers. Manage., 47: 1359-1371.