Control of DC Link Voltage in Grid-Connected Wind Power Generation System

[1] B.V.Sai Thrinath , [2]P.Narendra
[1] Associate Professor, [2]Associate Professor
[1]Electrical & Electronics Engineering Department, et al.
B.V.S.R Engineering college , Chimakurthy, Ongole, India.

Abstract:

In order to meet increasing power demand, taking into account economical and environmental factors, wind energy conversion is gradually gaining interest as a suitable source of renewable energy. The permanent magnet Synchronous generator can offer high efficiency and power density and these advantages make it very attractive for wind power applications for variable speed operation. In the variable-speed wind energy conversion system (WECS) the wind turbine can be operated as close as possible to its optimal speed to realize maximum power point tracking for various wind speeds. To take the advantage of higher energy capture power electronics interfaces must be provided between machine and grid terminals. The back-to-back PWM converter-based power electronic interface is suitable option for the permanent magnet generator in wind power applications.

In WECS the turbulence of the wind will result in power variations which will affect the DC link voltage and the power quality in the grid. In this paper a fuzzy logic controller is designed for reducing the DC link voltage ripples of the permanent magnet wind power generation system. The modeling of WECS is developed in MATLAB- SIMULINK. The correctness and effectiveness of the proposed fuzzy logic controller are verified by the simulation results.

KEYWORDS: WECS, PWM, MPPT, CSCF, PMSM

I.INTRODUCTION

With exhausting of traditional energy resources and increasing concern of environment, renewable and clean energy is attracting more attention all over the world to overcome the increasing power demand. Out of all the renewable energy sources, Wind energy and solar energy are reliable energy sources. Now a day, Wind power is gaining a lot of importance because it is cost- effective, environmentally clean and safe renewable power source compared to fossil fuel and nuclear power generation.

A Wind Energy Conversion System (WECS) can vary in size from a few hundred kilowatts to several megawatts. The size of the WECS mostly determines the choice of the generator and converter system. Asynchronous generators are more commonly used in systems upto 2MW, beyond which direct-driven permanent magnet synchronous machines are preferred. A grid connected WECS should generate power at constant electrical frequency which is determined by the grid. Generally Squirrel cage rotor induction generators are used in medium power level grid-connected systems. The induction generator runs at near synchronous speed and draws the magnetizing current from the mains when it is connected to the constant frequency network, which results in Constant Speed Constant Frequency (CSCF) operation of generator. However the power capture due to fluctuating wind speed can be substantially improved if there is flexibility in varying the shaft speed.

The permanent magnet (PM) Synchronous generator can offer high efficiency and high power density and these advantages make it very attractive for wind power applications for variable speed operation. In the variable-speed wind power generation system, the wind turbine can be operated as close as possible to its optimal speed to realize maximum power point tracking (MPPT) for various wind speeds. To take the advantage of higher energy capture and increase in the system compliance resulting from variable speed operation, power electronics interfaces must be provided between the machine terminals and the grid. The back-to-back PWM converter-based power electronic interface is suitable option for the permanent magnet generator in wind power applications, as shown in Fig. 1. The two power electronic converters have to be co-operatively controlled to keep a constant DC link voltage, meaning that the power coming from the generator and rectifier has to be immediately transferred to the ac system through the grid side converter. The dc link voltage source enables both PWM converters to operate at high efficiency. The grid side converter plays an important role on the control of power transfer and power quality. The generator side converter keeps the wind turbine-generator system operating at an overall optimal condition by controlling the generator torque and adjusting the reactive power exchanged between the rectifier and the generator [1-5]. However, in wind power generation systems the turbulence of

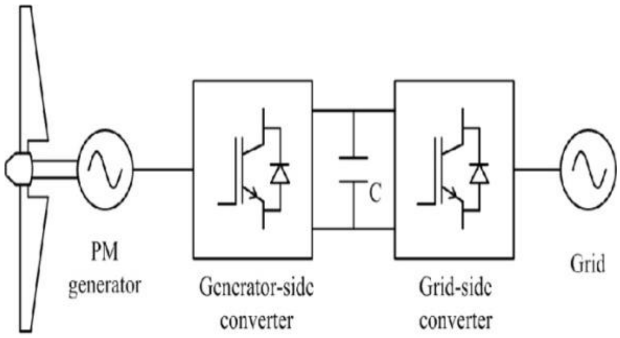

Fig. 1 Variable speed wind power generation system

the wind will result in power variations, and thus affect the DC link voltage ripples and the power quality in the grid. Then the DC link voltage control strategy becomes an important issue for the wind power generation system [6-10].

This paper proposed a new fuzzy logic controller for the DC link voltage control to reduce the DC voltage ripples and under the same power quality, the smaller DC link capacitor and filter may be used for the wind power generation system.

II. MATHEMATICAL MODELING OF THE PMSM

2.1 PERMANENT MAGNET SYNCHRONOUS GENARATOR:

Permanent magnet synchronous generator is a type of Synchronous Generator where the excitation field is provided by a permanent magnet instead of a coil. Salient-pole synchronous generators have been widely used as hydro-generators, engine generators, wind generators, and so forth. One of the problems with the conventional synchronous generators is the magnetic saturation in the field poles. The magnetic saturation limits the terminal voltage and requires more excitation power. In this paper, a new type of synchronous generators termed the PMSG is presented to reduce the magnetic saturation in the field poles. In the PMSG, permanent magnets are placed between the adjacent pole shoes, and the permanent magnets fluxes are generated in the opposite direction of the fluxes produced by the field currents. Therefore, the magnetic saturation in the field poles is reduced, and a higher voltage can be induced in the armature winding.

A PMSG's output voltage amplitude and frequency are proportional to speed. In constant speed prime mover applications, PMSGs might perform voltage self-regulation by proper design; that is, inset or interior PM Pole rotors. Small speed variation (10 to 15%) may be acceptable for diode rectified loads with series capacitors and voltage self-regulation. For automotive applications, and when motoring is not necessary, PM generators may provide controlled DC output for a 10 to 1 speed range through a diode rectifier and a one insulated gate bipolar transistor (IGBT) step-up DC–DC converter for powers above 2 to 3 kW.

The typical d-q model is uncoupled, linear and constant parameter, applied to salient pole synchronous machines. It may be inadequate for accurate modeling characteristics prediction of PMSG of interior type. It leads below to important errors when we evaluate machine performance or calculate the control circuits.

2.2 Modeling of PMSG:

The mathematical model of the PMSG for power system and converter system analysis is usually based on the following assumptions the stator windings are positioned sinusoidal along the air-gap as far as the mutual effect with the rotor is concerned; the stator slots cause no appreciable variations of the rotor inductances with rotor position; magnetic hysteresis and saturation effects are negligible; the stator winding is symmetrical; damping windings are not considered; the capacitance of all the windings can be neglected and the resistances are constant (this means that power losses are considered constant).The equivalent circuit of the PMSG in the *d*-*q* synchronous rotating reference frame are shown in Fig. 2 and Fig. 3 respectively.

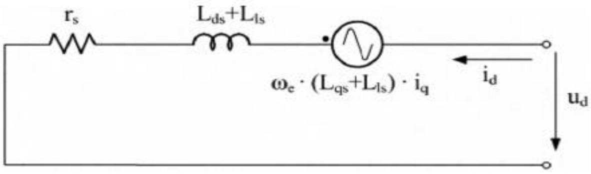

Fig .2 : d-axis equivalent circuit

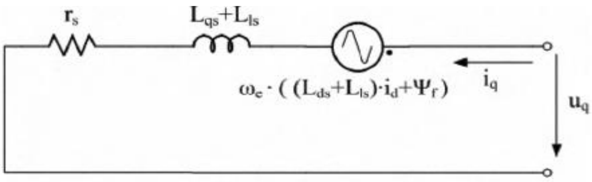

Fig .3 : q-axis equivalent circuit..

The d and q-axis stator voltages for PMSG referred to rotor reference frame may be expressed as

$$V_{ds} = R_s i_{ds} + L_d \frac{di_{ds}}{dt} - \omega_s L_q i_{qs} \quad (1)$$

$$V_{qs} = R_s i_{qs} + L_q \frac{di_{qs}}{dt} - \omega_s L_d di_{ds} + \omega_s \lambda_{af} \quad (2)$$

Where L_d and L_q are the d-and q-axis stator inductance, R_s is the stator resistance, λ_{af} is the mutual flux linkage.

The α-and β-axis variables in stationary reference frame are related to the rotor reference frame with the fallowing expression

$$\begin{bmatrix} i_{ds} \\ i_{qs} \end{bmatrix} = e^{-j\theta r} \begin{bmatrix} i_{\alpha s} \\ i_{\beta s} \end{bmatrix} \quad (3)$$

Where Θ_r is the angle between the stationary reference frame and the rotor reference frame. The developed electromagnetic torque can be expressed as

$$T_e = \left(\frac{3}{2}\right) P\{\lambda_{af} i_{qs} + (L_d - L_q) i_{ds} i_{qs}\} \quad (4)$$

The governing electromechanical equation is

$$T_e - T_L = J\frac{d\omega_r}{dt} + B\omega_r \quad (5)$$

Where T_L is the load torque

III. CONVENTIONAL CONTROL STRATEGY FOR DC LINK VOLTAGE CONTROL

The torque developed by wind turbine is applied as load on induction generator. The aerodynamic torque(T_m) and mechanical power (P_o) generated by a wind turbine is given by Equation (6) and Equation (7) respectively.

$$T_m = C_t(\lambda) \left[0.5 \frac{\rho \pi R_r^3}{\eta_{gear}} \right] V_w^2 \quad (6)$$

$$P_m = \frac{1}{2} C_p \rho A_r V_w^3 \quad (7)$$

Where P_m is the power in watts, ρ is the air density in g/m^3,C_P a dimensionless factor called power Coefficient, A_r the turbine rotor area in m^2($A_r = \pi R_r^2$, where R_r is the rotor blade radius), η_{gear} is and V_w the wind speed in m/s. The power coefficient is related to the tip speed ratio (*λ)* and rotor blade pitch angle $\boldsymbol{\beta}$ according to Equation (10)

$$Cp = 0.73\left(\frac{151}{\lambda i} - 0.58\beta - 0.002\beta^{2.14} - 13.2\right) e^{\frac{-18.4}{\lambda i}} \quad (8)$$

$$\text{Where} \boldsymbol{\lambda_i} = \frac{\mathbf{1}}{\frac{\mathbf{1}}{\boldsymbol{\lambda - 0.02\beta}} - \frac{\mathbf{0.003}}{\boldsymbol{\beta^3 + 1}}} \quad (9)$$

And $\boldsymbol{\lambda} = \frac{\boldsymbol{\omega_r R_r}}{\boldsymbol{V_w}}$ (10)

$C_t = \frac{C_p}{\lambda}$ (11)

In equation (10), ω_r is the angular speed of the turbine shaft. The theoretical limit for C_P is 0.59 according to Betz's Law, but its practical range of variation is 0.2-0.4.

The mechanical power is transferred into the electrical power by the PM generator and output to the generator-side converter. From the diagram of the DC link capacitor shown in Fig. 2, the relationship between the DC voltage of the capacitor and the current can be obtained as

$C\frac{dV_{dc}}{dt} = i_{dcg} - i_{dc}$ (12)

Where C is the capacitance of the capacitor, v_{dc} is the DC voltage of the capacitor, i_{dcg} is the current of the generator-side converter output to the DC link, i_{dc} is the Current of the DC link output to the grid. It can be seen from Equation (12) that the ripples of the DC link voltage reflect the unbalance of the input current i_{dcg} and output current i_{dc}. Then the DC link voltage controller is widely used in the control of the grid-side converter. Traditionally PI based vector control strategy of the grid-side converter is used for DC link voltage control and current control.

IV FUZZY LOGIC CONTROL STRATEGY FOR DC LINK VOLTAGE CONTROL

The fuzzy logic controller is proposed for the DC link voltage control to reduce the DC voltage ripples. Rule based fuzzy logic controllers are useful when the system dynamics are not well known or when they contain significant non-linearities, such as the un-steady wind contains large turbulence. Fuzzy logic controllers apply reasoning, similar to how human beings make decisions, and thus the controller rules contain expert knowledge of the system. The design process for a fuzzy logic controller consists of (i) determining the inputs, (ii) setting up the rules and (iii) designing a method to convert the fuzzy result of the rules into output signal, known as defuzzification. The developed fuzzy logic control system is shown in Fig. 4. The inputs (Error & Dot Error) and output (Angle) of the Fuzzy Block are shown in Fig. 5, Fig. 6 and Fig. 7 respectively. Triangular symmetrical membership functions are suitable for the input and output, which give more sensitivity especially as variables approach to zero value. The width of variation can be adjusted according to the system parameters.

In the proposed fuzzy System, seven fuzzy sets have been considered for variables: Large Negative (LN), Medium Negative (MN),Small Negative(SN),Very Small (VS), Small Positive(SP), Medium Positive (MP) and Large Positive(LP).

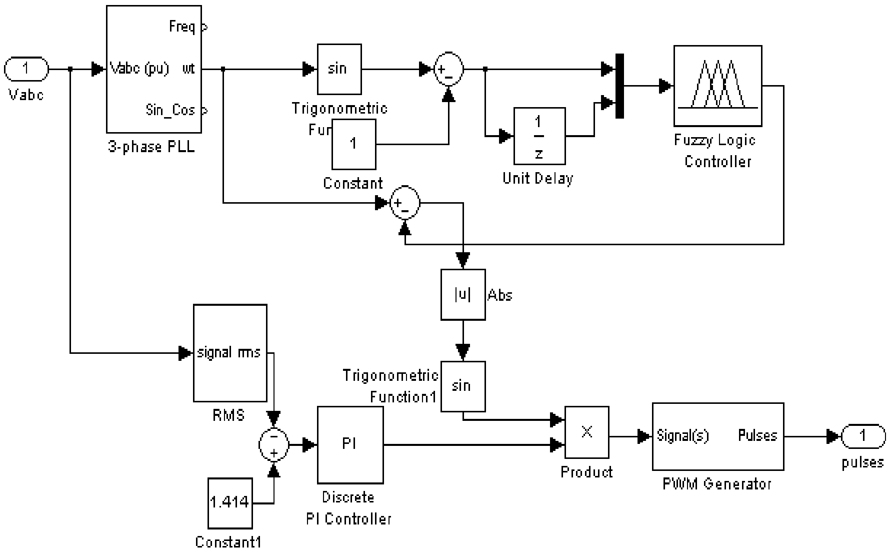

Fig 4. *Developed fuzzy logic control system*

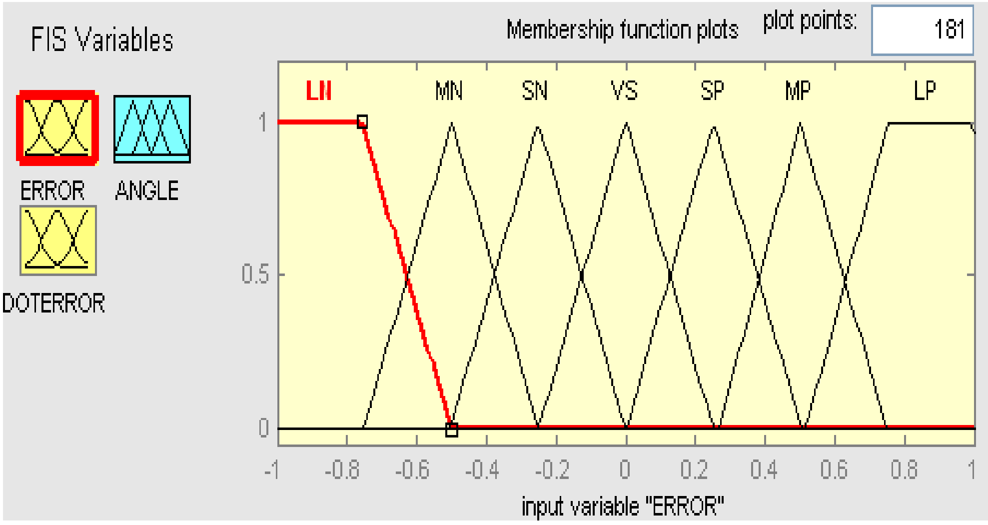

Fig5: *Membership functions of Error Input*

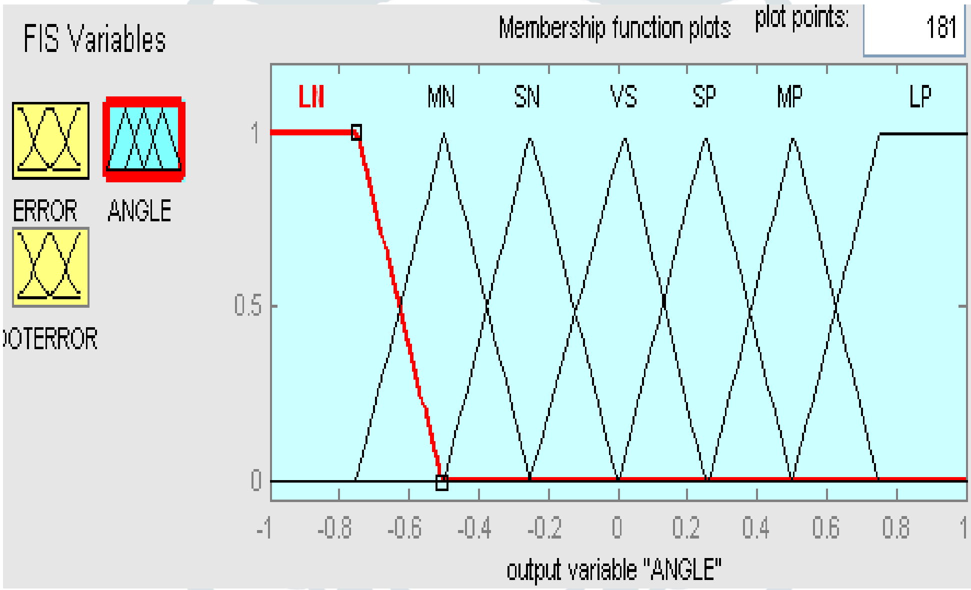

Fig 6: *Membership functions of Dot Error Input*

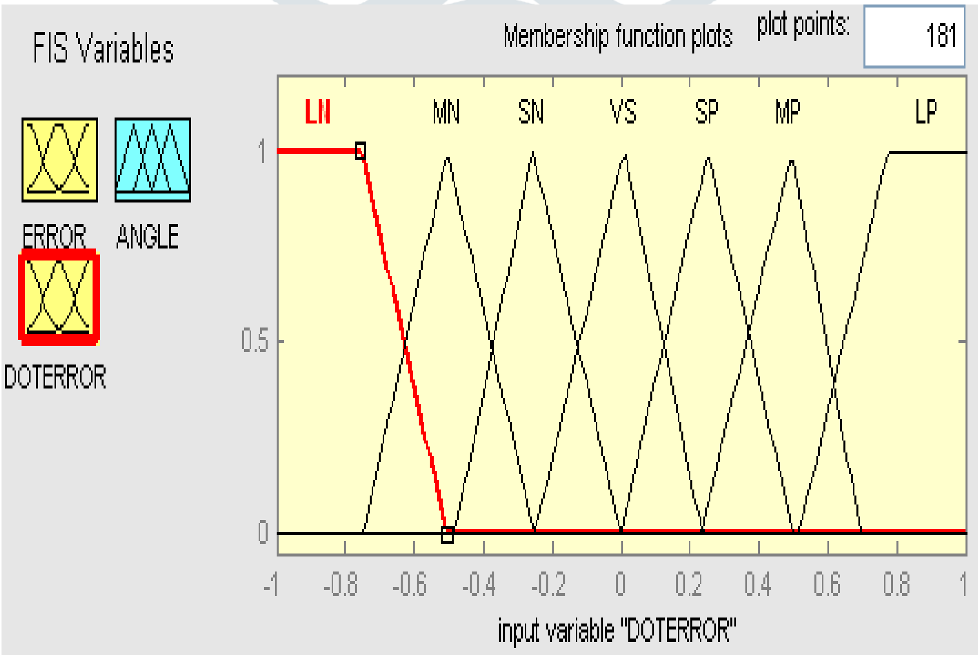

Fig 7: *Membership functions of Angle output*

V. SIMULATION RESULTS

The block diagram of Control of DC Link Voltage in Grid-Connected Wind Energy Conversion System is developed in MATLAB-SIMULINK. The Sending end Active and Reactive Powers are shown in Figure 8.

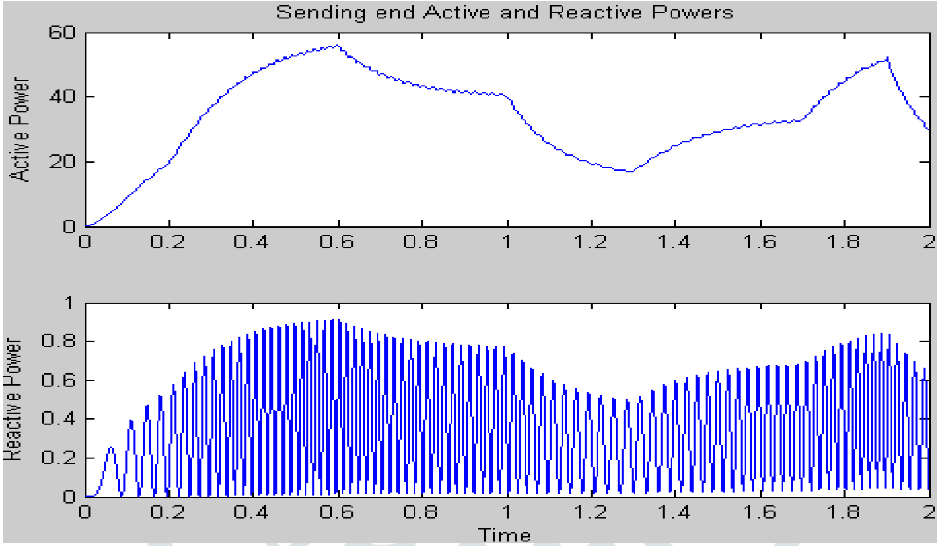

Fig 8: *Sending end Active and Reactive Powers*

Sending end Voltages and Currents are shown in Figure 9.

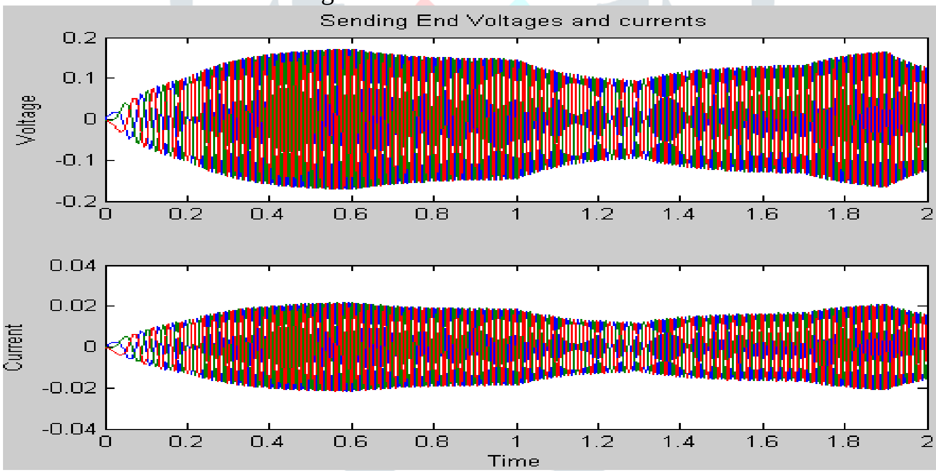

Fig 9: *Sending end Voltages and Currents*

Receiving end Active and Reactive Powers are shown in Figure10

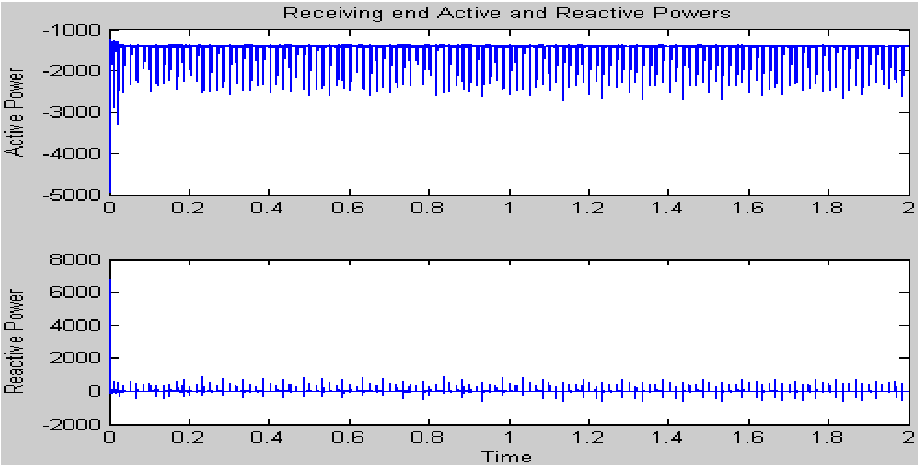

Fig10: Receiving end Active and Reactive Powers

Receiving end Voltages and Currents are shown in figure11.

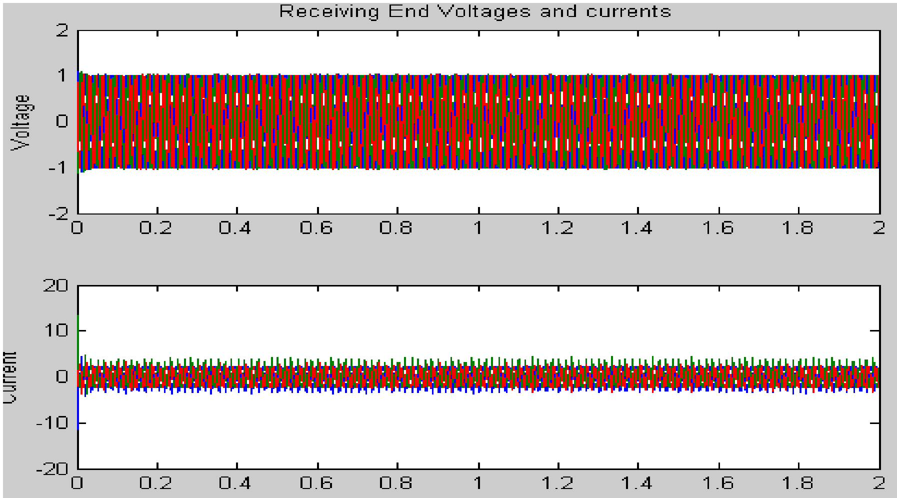

Fig11: Receiving end Voltages and Currents

The output characteristics of PMSM i.e. Stator Phase Current, Rotor Speed, Electromagnetic Torque is sown in Figure12.

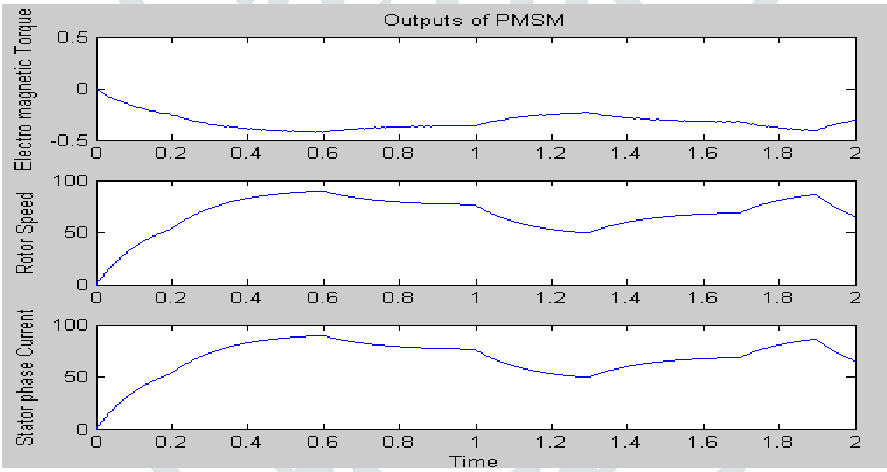

Fig12*: The output characteristics of PMSM*

The Series of pulse applied to the converter is shown in Figure 13.

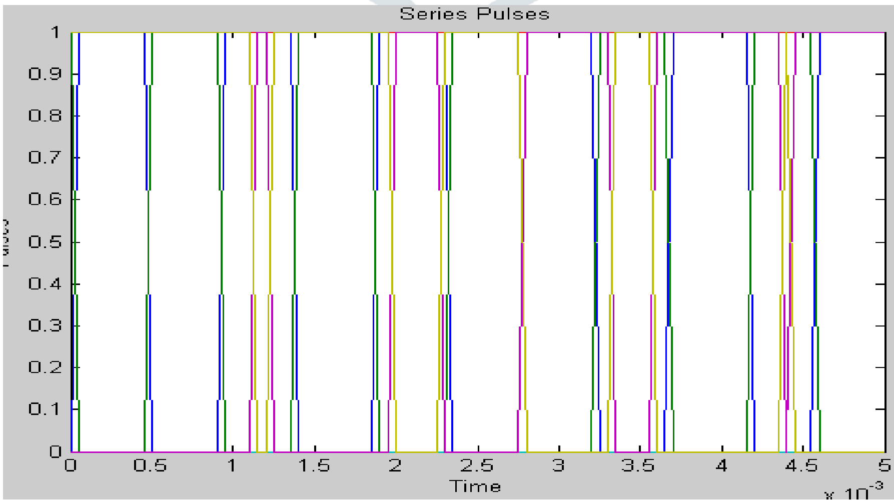

Fig 13*: pulses applied to the Converter.*

VI . ACKNOWLEDGMENT

This paper proposes a fuzzy logic control strategy for the DC link voltage control. The simulations of the fuzzy logic controller and PI controller are carried out. It is shown that the fuzzy logic controller can reduce the ripples of the DC link voltage significantly. In this case smaller **capacitance** may be selected for DC link capacitor and the size of the wind power generation system may be reduced. The power quality of the wind power generation system can also be improved by using the fuzzy logic controller due to the lower DC voltage fluctuation.

VII .REFERENCES

[1]Chen Z, Gomez S A, McCormick M, "A fuzzy logic controlled power electronic system for variable speed wind energy conversion systems," *Eighth International Conference on Power Electronics and Variable Speed Drives*, London, UK, 2000, pp. 114-119.

[2]M. Chinchilla, S. Arnaltes, J. C. Burgos, "Control of permanent-magnet generators applied to variable-speed wind-energy systems connected to the grid,"
IEEE Transactions on Energy Conversion, 2006, vol. 21, no. 1, pp. 130-135.

[3]J. Zhang, M. Cheng, Z. Chen, 'Nonlinear control for variable-speed wind turbines with permanent magnet generators," *Proceedings of International Conference on Electrical Machines and Systems*, Seoul, Korea, 2007, pp. 324-329.

[4] E. Muljadi, K. Pierce, P. Migliore, "Control strategy for variable-speed stall-regulated wind turbines," *American Controls Conference*, Philadelphia, USA, 1998, pp. 1-5.

[5] A. G. Abo-Khalil, D. Lee, J. Seok, "Variable speed wind power generation system based on fuzzy logia control for maximum output power tracking," *35th Annual IEEE Power Electronics Specialists Conference*, Achen, Germany, 2004.

[6] Y. M. Chen, C. S. Cheng, H. C. Wu, Grid-connected hybrid PV/wind power generation system with improved DC bus voltage regulation strategy," *APEC* 2006, Dallas Texas, 2006, pp. 1088-1094.

[7] N. Silva, A. Martins, A. Carvalho, "Design and evaluation of a PWM rectifier control system for testing renewable DC sources connected to the grid," *Inter. SPEEDAM* 2006, Taormina, Italy, 2006, pp. 32-37.

[8] J. Sastry, O. Ojo, Z. Wu, "High-performance control of a boost AC-DC PWM rectifier/induction generation system," *IEEE Trans. on Ind. Appli.*, vol. 42, no. 5, 2006, pp. 1146-1154.

[9] J. Yao, H. Li, Y. Liao, Z. Chen, "An improved control strategy of limiting the DC-link voltage fluctuation for a doubly fed induction wind generator," *IEEE Trans. on Power Electronics*, vol. 23, no. 3, 2008, pp. 1205-1213.

[10] S. B. Skretas, D. P. Papadopoulos, "Enhance design and performance of WECS with PMSG connected to MV grid using intelligent control methods," *Proc. of the 2008 International Conference on Electrical Machines*, Vilamoura, Portugal

[11] Joris Soens, Vu Van Thong, Johan Driesen, Ronnie Belmans, "Modeling wind turbine generators for

[12] power system simulations," European Wind Energy Conference EWEC, Madrid, 16 – 19 June 2003

[13] Branislav Dosijanoski, "Simulation of Doubly-Fed Induction generator in a Wind Turbine," XI International PhD Workshop OWD 2009, 17–20 October 2009

[14] Yi Goo, John N. Jiang, and Choon Yik Tang, "Nonlinear Control of Wind Power Generation Systems," 2009 IEEE explores.

AUTHORS:

[1]**B.V. Sai Thrinath** was born in Krishna District, Andhra Pradesh, on 16-07-1991. He completed his B.Tech. (EEE) from SSIET, NUZVID in 2012, M.Tech. **(ELECTRICAL MACHINES & DRIVES)** from JNTU Kakinada, Andhra Pradesh in 2014. His research interests are Renewable Energy Sources, New technology in electrical machines & drives, Distributed Generation, FACTS Controllers , Power Systems and Power Electronics .

[2] **P.Narendra** was born in prakasam District, Andhra Pradesh, on 15-04-1986. He completed his B.Tech. (EEE) from SSIET, NUZVID in 2008, M.Tech. **(POWER ELECTRONICS & DRIVES)** from VIGNAN UNIVERSITY, Andhra Pradesh in 2011. His research interests are Renewable Energy Sources, New technology in FACTS Controllers , Power Systems and Power Electronics .