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Development of Doubly fed Induction Generator Wind Power System with Fuzzy Controller

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Abstract: Power generation from the non-conventional sources is the need of the day. Wind energy is one of the major fields, where various conversion topologies have been proposed in order to produce electric power. Squirrel cage induction generator (SCIG), permanent magnet synchronous generator and doubly fed induction generator (DFIG) are mainly used in wind power generation. The DFIG is a variable speed generator where active and reactive power control is done by power converters. While in SCIG, reactive power requirement is fulfill by compensating device like STATCOM. In this paper we have done mathematical modeling of DFIG generator and matlab simulation is done for grid connected system. Fuzzy controller is implemented in stator side controlling and system is simulated in matlab environment and finally comparison is done with PI controller.

Index Terms: doubly fed induction generator, fuzzy-PI controller, power stability, wind energy.

I. INTRODUCTION

Power is the life blood of a developing economy. The modern day power system is undergoing rapid and dynamic metamorphosis from the legacy system, in the direction of an intelligent power system. The use of renewable energy resources at the distribution level is on the rise alongside advances in the efficiency of associated technologies and automation of the power sector. Renewable energy resources (RERs) such as wind and photovoltaic (PV) technologies that are time variant are planned for meeting variation of loads. PV and wind technologies are two technologies that have seen
the most significant growth for use and distributed sources. In the past 30 years, the size of wind turbines and the size of wind power plants have increased significantly. Applications such as reactive power compensation, static transfer switches,
energy storage, and variable speed generations are commonly found in modern wind power plants. DFIG behaves superior to Synchronous generator as it allows the maximum power point tracking, higher efficiency of the turbine, capable to control at unity power factor and finally the improved amount of power quality achieved. [1] [2].

The DFIG system having AC/DC/AC converter normally consists of a rotor-side converter and a grid-side converter. By means of the bi-directional converter in the rotor circuit, the DFIG is able to work as a generator in both sub-synchronous and over synchronous operating area. Depending on the operating condition of the drive, the power Is fed in or out of the rotor. Different types of wind turbine systems have quite different performances and controllability.
Variable speed operation in DFIG used widely due the fact that only the power generated in the generator rotor has to be fed through a power electronic converter system (25%-30%) [3] Rotor side and grid side converter controlling consist of current regulation part and cross coupling part [4].

Modelling of double fed induction generator is done to transform the actual variables into dq variables so that number of variables are reduced and is easy to simulate. Generally, the FOC has been presented based on DFIG mathematical equations only. However, a three-phase choke is commonly used to couple the stator-side converter into the grid [4]. Various control techniques are used for improvement in performance of DFIG system during normal and transient operation [5]. In this paper fuzzy logic controller is used in stator side controlling scheme. The paper is organised as follow: the modelling of DFIG wind power system is described in section II. In section III controlling schemes are presented. The proposed fuzzy-PI controller is described in section IV. Section V gives the simulation result including an improved performance with fuzzy controller. Finally, the conclusion is presented in section VI.

II. MODELING OF DFIG WIND POWER SYSTEM

Wind turbine cannot extract the power completely from the wind. Only a section of its kinetic energy is transformed to the rotor, while the remaining air leaving the wind turbine is carried away. A controller continuously monitors and regulates the functions of the wind turbine. This is done in order to achieve the maximum amount of efficiency [1]. Pitch angle control and maximum power point tracking are used to extract highest amount of available energy from the wind, while it is operating over a large range of wind speed. According to maximum power point tracking the generator speed is adjusted according to the variations of wind speed Modelling of double fed induction generator is done to transform the actual variables into dq variables so that number
of variables are reduced and is easy to simulate. The converter
of double fed induction generator functions in a bidirectional power mode; either in sub-synchronous or in super synchronous mode. In case of under synchronous operation active power is fed to the rotor from the supply. While active power is produced by the rotor and fed to the supply when operating over synchronous speed.

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Among the two convertersa dc link capacitor is placed, in order to keep the dc link constant and also to make the voltage variations ripple free. Modelling of dc link capacitor is done to make the voltage constant irrespective of grid faults.

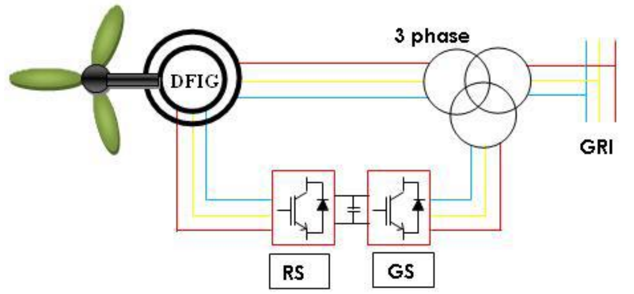

Fig. 1. DFIG wind power system

A. DFIG Model

The resistance and leakage reactance per phase of the stator windings are represented as r_s and $j\omega_s L_s$ while r_r and $j\omega_s L_r$ in the figure notify the resistance and leakage reactance per phase of the rotor winding on the rotor side. The DFIG circuit starts to operate as an ordinary squirrel cage induction type generator if in case the rotor voltage V_r is short circuited. Mutual reactance is given by $j\omega_s L_m$. When the rotor starts rotating at the angular velocity of ω_r rad/sec, the rotor resistance is transformed to r_r/s, where s is the slip. The function of the rotor side converter is to induce three phase voltages at slip frequency.

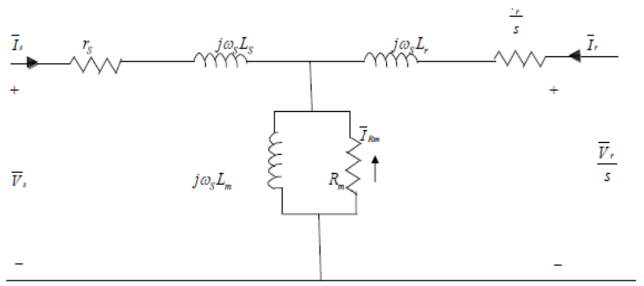

Fig 2. Circuit diagram of DFIG

The three phase induction machine possesses three phases in stator and three phases in rotor. Over here the three phase actual variables namely the abc (stationary) variables are transformed into two phase variables, that are the direct axes(d) and quadrature axes(q). The two axes, d and q axes are in a position of perpendicular to each other. The position of dq axes rotating at an angle ɵ are placed in an arbitrary position with respect to the stationary abc reference frame. Equation of mmf in d-axis is given by:-

$$N_s i_{ds} = N_s(i_a + i b \cos 1200 + i_c \cos 240^0) \quad (1)$$

$_s i_{ds}$ is the d axis mmf produced by the dq winding in stator. The mmf produced by d axis stator will be same as the mmf produced by the abc stator in d axis.So by projecting the phase b, phase c and phase a mmf all along the d axis, which is aligned along the phase a of the stator, we equalize the mmf of the dq machine and the abc machine in the stator. Similarly we equalize the mmf in q-axis by $N_s i_{qs.}$ Therefore, finally the transformation of the current is done from the actual variables to the dq variables. In additional to the dq component, zero sequence components do also exist. The equation of the zero sequence components is given

$$I_{0s} = 1/3(i_{as} + i_{bs} + i_{cs}) \quad (2)$$

Since stator is stationary, hence the stator does not have any rotationally induced emf and the flux linkage can therefore be expressed in terms of inductance and current.

$$V_{ds} = r_s\, i_{ds} + p\psi_{ds} = r_s\, i_{ds} + L_s p i_{ds} + L_m p i_{dr} \quad (3)$$

$$V_{qs} = r_s\, i_{qs} + p\psi_{ds} = r_s\, i_{qs} + L_s p i_{qs} + L_m p i_{qr} \quad (4)$$

Where i_{dr} is the current referred from primary side. Over here the zero sequence components is not considered because the zero sequence equation does not take part in torque production. Similarly the equations for d and q axis voltage of the rotor are given by:-

$$V_{dr} = r_r\, i_{dr} + p\psi_{dr} + \omega_r\psi_{qr} \quad (5)$$

$$V_{qr} = r_r\, i_{qr} + p\psi_{qr} - \omega_r\psi_{dr} \quad (6)$$

Where V_{dr} and V_{qr} represents the d-axis and q axis voltage and ψ_{dr} represents the rotationally induced emf which is a function of speed of the rotor. Rotor possesses the rotationally induced emf and also is a function of speed[4]. The Fig (3.4, 3.5) represent the equivalent circuit of double fed induction machine in the dq reference frame. In the figure $s\omega_s$ denotes the divergence between the synchronous speed and rotor speed. The mutual inductance is represented by L_m The subscripts r, s, d and q represent the rotor, stator, d-axis and q-axis.

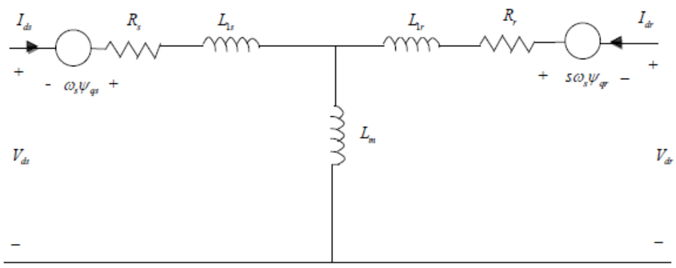

Fig. 1.Model of d-axis

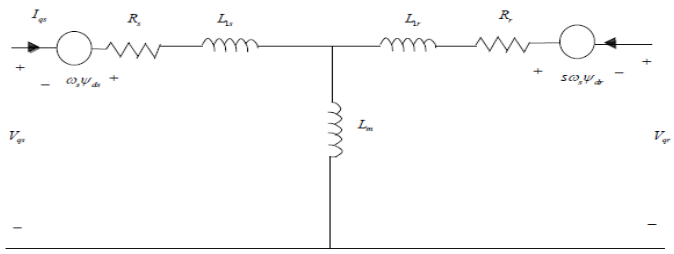

Fig. 2.Model of q-axis

nominal wind speed. Beyond this speed, the pitch angle system will prevent the output power from exceeding the nominal value. That is, when the wind speed is below nominal value, the power capture can vary with the change of wind speed; and when the wind speed is above nominal value, the pitch angle control system will limit the generated power by changing the pitch angle. In such way, the output power will be stabilized at nominal value where the wind speed is always above nominal speed.

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The pitch angle is determined by an openloop control of regulated output active power.

B. Rotor side control

For the rotor-side controller the d-axis of the rotating reference frame used for d-q transformation is aligned with air-gap flux. The actual electrical output power, measured at the grid terminals of the wind turbine, is added to the total power losses (mechanical and electrical) and is compared with the reference power obtained from the tracking characteristic. A Proportional-Integral (PI) regulator is used to reduce the power error to zero. The output of this regulator is the reference rotor current Iqr_ref that must be injected in the rotor by converter rotor [7]. This is the current component that produces the electromagnetic torque Tem. The actual Iqr component is compared to Iqr_ref and the error is reduced to zero by a current regulator (PI). The output of this current controller is the voltage Vqr generated by rotor. The current regulator is assisted by feed forward terms which predict Vqr. The voltage at grid terminals is controlled by the reactive power generated or absorbed by the converter rotor. The reactive power is exchanged between rotor and the grid, through the generator. In the exchange process the generator absorbs reactive power to supply its mutual and leakage inductances. The excess of reactive power is sent to the grid or to rotor.

C. Stator side controller

Stator side controller uses vector control method to maintain V_{dc} –dc link voltage constant. Mainly, dc voltage is held constant by d-axis current vector, while q- axis current is responsible for maintaining reactive power flow between the grid. For designing stator side converter we use same principle as that of rotor side converter i.e. current regulation and cross coupling part. Current loop is used as inner loop while outer loop is composed of voltage loop. Here , we used PI controller in a voltage loop which is responsible for maintaining the V_{dc} under normal and fault operation. The value for dc link capacitor $V_{dc\text{-}ref}$ is held 1200 volts constant and measured value V_{dc} is continouosly monitor by PI controller. The error value gives $i_{ds\text{-}ref}$ value which is added to i_{ds} and again input to PI controller of current loop. Hence, smaller difference in V_{dc} measured and constant value gives the value which is closed to $V_{dc.}$ Volage loop PI controller has gains, Kp=0.3 and Ki=8. Firstly we modelled system using PI controller and and simulation readings are taken for different wind speeds. Secondly, we replace PI controller by Fuzzy controller and simulation readings are taken.

III. FUZZY CONTROLLER

The fuzzy logic controller system is shown in figure. In the figure Vdc is measured dc link voltage which is compared with the grid voltage. Grid voltage value is to be kept constant. The difference value is taken as error value and change in error are the inputs of fuzzy controller.

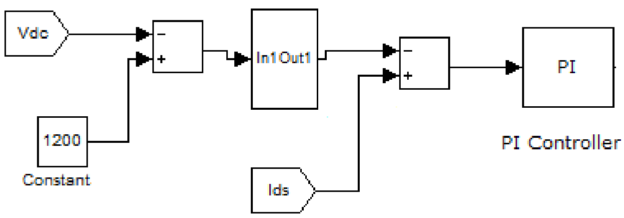

Fig. 3.Fuzzy-PI controller

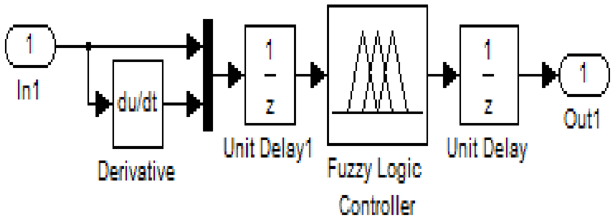

Fig. 4.Structure of fuzzy logic controller

The mechanism of the fuzzy controller is shown in Fig. The fuzzy controller consists of four parts: fuzzification, fuzzy rule base, inference engine and defuzzification [6]. The actual value of the error e, the change of the error e˙ and the output are all fuzzily partitioned into fuzzy sets in

TABLE 1.

e	e˙	δu
NB	NB	NB
NM	NM	NM
NS	NS	NS
ZE	ZE	ZE
PS	PS	PS
PM	PM	PM
PB	PB	PB

which the linguistic terms ‘‘NB’’, ‘‘NM’’, ‘‘NS’’, ‘‘PS’’, ‘‘PM’’, ‘‘NB’’ mean ‘‘negative big’’, ‘‘negative medium’’, ‘‘negative small’’,‘‘positive small’’, ‘‘positive medium’’, ‘‘positive big’’, respectively. The universes of discourse of the error e, the change of the error e˙ and the output are firstly determined by the range of predicted actual values.

The FIS Editor displays general information about a fuzzy inference system. Input and output variables membership functions are displayed in a box. Here in our project we use two inputs and one output. The first input variable is error value which is obtained for V_{dc} and second input is change in error. Output value is maximum peak current value. We can assign number of membership functions for each variable, and can have number of set rules, but the complexity is arises and in evaluating the system time is increases.

Membership Function editor is used to edit membership functions for each input and output variable value. Here. We assign the membership functions range -1 to 1 for input and output variable. There are various types of membership functions such as- trapezoidal, triangular, Gaussian, sigmoid, and piecewise linear. In our project we use triangular type membership functions for each input and output value. We assign 7 membership functions for each input value. Finally, the defuzzification is done by centroid method..Following figure shows the output maximum peak current.

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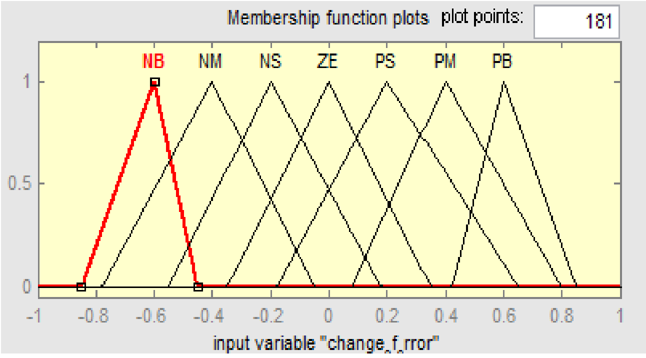

Fig. 5.Output membership function plot

IV. SIMULATION RESULT

The proposed system is simulated in matlab/simulink environment and also conventional system results of PI controller are compared.The dynamic response of wind step response is simulated and corresponding results of rotor speed, active power, reactive power and grid voltage respectively are shown in figures. Here, the system inertia coefficient value is to be kept small in order to reach steady state quiker. The system grid voltage is mainted at 1200 Vdc and the converter switch frequencyis set to be 27 times the grid frequency *f*.

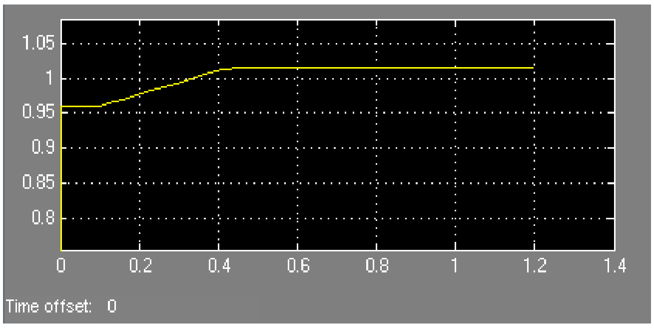

Fig. 6.Rotor speed ω_r

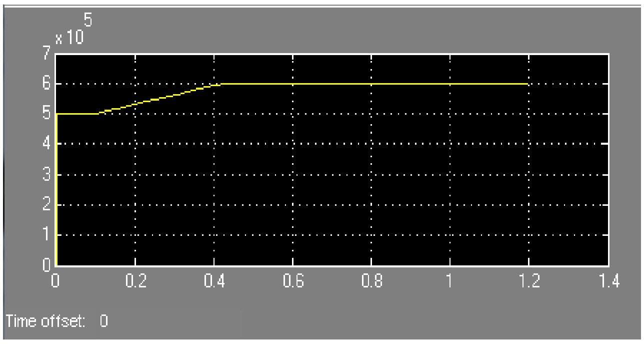

Fig. 7. Active power P

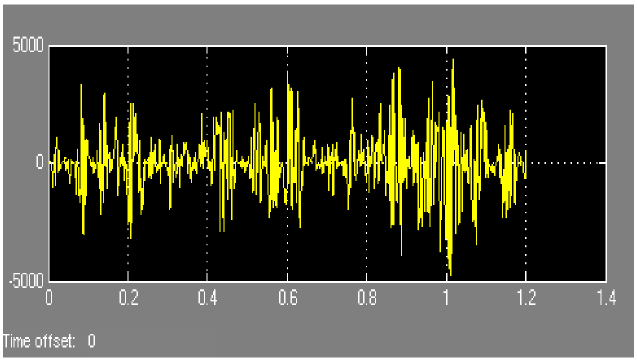

Fig. 8.Reactive power Q.

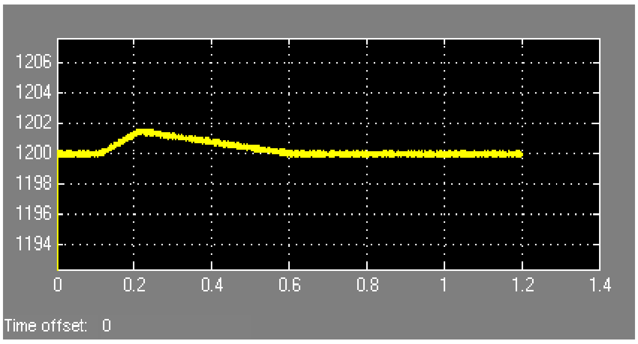

Fig. 9.DC link voltage Vdc with fuzzy-PI controller

The characteristic plot is obtained by simulating the supply side converter with the help of fuzzy PI controllers. With the use of fuzzy PI controllers the fluctuations in the curve are greatly reduced. Therefore a faster and dynamic response is achieved with almost no overshoot and faster settling time. By comparing both the results regarding the control of DC link voltage variation, an observation is made, proving that the response of the system can be greatly improved by more precised use of fuzzy PI controllers

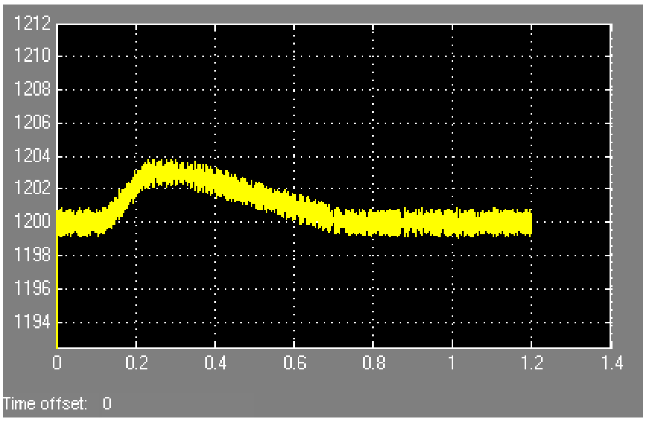

Fig. 10. DC link voltage Vdc with PI controller

V. CONCLUSION

The modeling of the Double fed induction generator is done from the abc variables to the dq axis variables, so as to reduce the number of variables and also to reduce the complexity of the model. The vector control strategy that is implemented for the grid side control ensures a decoupling strategy of the stator side. The dc link voltage is maintained constant using a PI controller. In the traditional PI control, two loops namely; current control and voltage control loop have been implemented. However, a new improved and a convenient strategy, fuzzy PI technique has been further developed to control the dc link voltage. In the case of fuzzy PI control error has been taken as the input value. A comparison graph has been done between the simple use of PI and fuzzy PI, to ensure the best among the controller. The result showed the fuzzy controller was superior in performance as compared to the traditional PI controller.

In future scope we can model system with MPPT algorithm for maximum power extraction or to implement fuzzy PI concept in the machine side converter to achieve better performance results.

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REFERENCES

1. Jianxing liu, Yabin Gao, Sijia Geng2, Ligang Wug, “Nonlinear control of variable speed wind turbines via fuzzy techniques,” in IEEE access digial library, p. 11,2016.
2. M. Molinas, J. A. Suul, and T. Undeland, “Low voltage ride through of wind farms with cage generators: STATCOM versus SVC,” IEEE Power Electron., vol. 23, no. 3, pp. 1104–1117, May 2008Power Electron., vol. 23, no. 3, pp. 1104–1117, May 2008.
3. R. Ganon, G. Sybille, and S. Bernard, “ Modeling and real time simulation of a doubly fed induction genratordriven by a wind turbine,” presented at the Int. Conf Power system transient,CanadaM. Young, The Technical Writer’s Handbook. Mill Valley, CA: University Science, 1989.
4. Yu Zou, Malik E. Elbuluk, Y. Sozer, “Simulationa comparison and implementation of induction generator wind power system”, in IEEE transaction on industrial applications Vol 49, no 3, May 2013.
5. Z. Chen, J. M. Guerrero, and F. Blaabjerg, “A review of the state of the art of power electronics for wind turbines,” IEEE Trans. Power Electron., vol. 24, no. 8, pp. 1859–1875, Aug. 2009.
6. Sabah Louarem, Saad Belkhiat , Djamel Eddine Chouaib Belkhiat “A control method using PI/fuzzy controllers based DFIG in wind energy conversion system”, IEEE grenoble conference, p.p. June 2013.
7. R. Pena, J. C. Clare, and G. M. Asher, “Doubly fed induction generator using back-to-back PWM converters and its application to variable-speed wind-energy generation,” Proc. Inst. Elect. Eng.—Elect. Power Appl.,vol. 143, no. 3, pp. 231–241, May 1996.

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