Fuzzy Logic Improved Static Synchronous Compensator to Control Voltage of a Grid-connected Squirrel Cage Induction Generator

Reza Sharifian Dastjerdi [1], Ehsan Jafari [2], Farshad Kabiri [3], Payam Ghaebi Panah [4]

[1,2,3,4] Department of Electrical Engineering, Lenjan Branch, Islamic Azad University, Isfahan, Iran
sharifian@iauln.ac.ir

Abstract: In this paper a new model for a wind generation system is introduced which includes induction machine, static synchronous compensator, excitation and load capacitors. Moreover, a new method is proposed for voltage control of a grid-connected squirrel cage induction generator. Unfortunately, induction generators require a flexible reactive power source beside them since under variable load conditions the output voltage cannot remain constant autonomously. In this paper, a compensator is used to control the reactive power and stabilize voltage fluctuations during a three-phase fault and generator isolation. Furthermore, a fuzzy controller is developed to ameliorate compensator's performance. Accordingly, simulations are carried out in MATLAB/Simulink environment to confirm the abilities of new control scheme.

[Reza Sharifian Dastjerdi, Ehsan Jafari, Farshad Kabiri, Payam Ghaebi Panah**. Fuzzy Logic Improved Static Synchronous Compensator to Control Voltage of a Grid-connected Squirrel Cage Induction Generator.** *Life Sci J* 2012;9(4):2955-2960]. (ISSN: 1097-8135). http://www.lifesciencesite.com. 432

Keywords: Fuzzy Logic, Squirrel Cage Induction Generator, Static Synchronous Compensator, Three-phase Fault.

1. Introduction

Renewable energy has been developed greatly during recent years especially when the price of oil and subsequently relevant productions increased. Obviously, among different sources, wind power grabbed a huge attention. Hence, induction generators got a dominant role in the wind power generation. Apparently, salient features of induction generators are small size, separate dc excitation and brush omission, and low maintenance cost [1-2]. On the other hand, analyses of generator's voltage and frequency are easier when the machine is connected to the grid in comparison with the isolated situation [3-4]. The two main drawbacks of induction generators are weak voltage regulation and reactive power requirement. The needed reactive power is provided without any parallel capacitor and just from the DC link capacitor when it is charged. Generally, both generator and load are reactive power consumers. However, unbalanced reactive power causes voltage fluctuation. Therefore, a good choice for capacitance would be when the minimum required reactive power is proportional to inverse of squared speed and maximum amount is equal to the magnetizing reactance [5]. Logically, constant capacitors could not provide the appropriate reactive power. Therefore, a combined set of capacitors is installed which includes constant and switching types.

Fuzzy sets can be very helpful in making decision during different situations and thereupon the performance of compensator is improved. Off-grid generators sometimes suffer from excess or lack of active and reactive produced powers which can cause frequency deregulation. An effective solution is to change the blades angle [7]. Blades angle is similar to steam turbine's valves through which the speed is controlled. Note that vividly the response time in wind turbines is very faster than steam types [8]. On the other hand, in a squirrel cage induction generator, the magnetizing reactive power in terminals is undesirable. Hence, capacitors are installed to obviate the problem. They can provide the magnetizing current and even load reactive power as well. Besides, a power electronic based compensator such as SVC, STATCOM, etc. is installed in parallel with the machine to make the response better during a fault. Numerous publications are dedicated to this issue. Some researchers focused on modeling of an induction machine and a capacitor next to [9]. This technique is useful in sliding mode control, state feedback, output feedback, etc. [1, 2, and 10].

2. Distribution System Model

A single line diagram is illustrated in Fig. 1 which represents the wind energy conversion system. This local system is fed by a generator which is connected to a 132kv infinite bus [1]. A 133/33kv transformer is a medium between local grid and infinite bus and similarly, a 33/0.6kv transformer connects the induction generator to the local grid.

Induction generator is driven by a wind turbine which is controlled via rotation angle (β). In order to control β, a reference value is compared with the generator's injected power (p *). Afterwards, the resulted error is passed through a proportional-integral controller and therefore, an acceptable value for β is estimated. The capacitor provides the required reactive power for the magnetizing current. The system's specifications are given in the appendix.

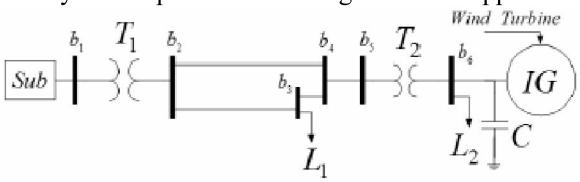


Figure 1. System model

3. System Elements

3.1. Wind Turbine

The output power of the induction generator is obtained as follows [1, 2, 3]:

$$P_m = \frac{1}{2}\rho\pi R^2 cp(\lambda, B)V_w^2 \qquad (1)$$

where ρ is air density, V_w is wind speed, R is blade length, and C_p indicates the fraction of aerodynamic wind power extracted from the turbine. Note that Cp varies with wind speed and can be defined as Equation (2).

$$C_p = 0.00051\lambda^5 - 0.001539\lambda^3 - 0.03892\lambda^2 - 0.0462\lambda - 0.000006 \qquad (2)$$

λ is the Blade tip speed and can be calculated using Equation (3).

$$\lambda = \frac{\omega_m R}{V_w} \qquad (3)$$

where ω_m is angular rotating velocity of turbine.

3.2. Induction Generator

Equation (4) presents model of induction generators in an optional reference frame [2-3]. In this equation, the rotor's residual flux is essential for generator to make the initial voltage. The upper case indices are related to rotor and conversely, the lower case ones are corresponding to stator values.

$$\begin{bmatrix} i_{qx} \\ i_{dx} \\ \lambda_{qr} \\ \lambda_{dr} \end{bmatrix} = \begin{bmatrix} r_s + \delta L_s\rho & \delta L_s\omega & \frac{L_{rs}}{L_r}\rho & \frac{L_{rs}}{L_r}\omega \\ -\delta L_s\omega & r_s + \delta L_s\rho & -\frac{L_{rs}}{L_r}\omega & \frac{L_{rs}}{L_r}\rho \\ -r_r\frac{L_{rs}}{L_r} & 0 & \frac{r_r}{L_r} + \rho & \omega_s - \omega_r \\ 0 & -r_r\frac{L_{rs}}{L_r} & -\omega_r & \frac{r_r}{L_r} + \rho \end{bmatrix} = \begin{bmatrix} v_{qs} \\ v_{ds} \\ 0 \\ 0 \end{bmatrix} \qquad (4)$$

where R_r and R_s are equivalent rotor and stator resistances respectively L_{Ls} and L_{Lr} are stator and rotor leakage inductances respectively, L_m magnetizing is inductance, L_s and L_r are stator and rotor inductances respectively.

(The (3), δ and ρ values as relations (5) are defined).

$$\omega_r = \frac{P}{2}\omega_m, \rho = \frac{d}{dt}, \delta = 1 - \frac{L_m}{L_s L_r} \qquad (5)$$

where w is an optional speed and ω_r is the rotor speed in rad/s.

Figure (2) depicts the model of an asynchronous machine in which R_d is the resistance that indicates the absorbed power from the input. ($R_d = (1-s)R_r / s$).

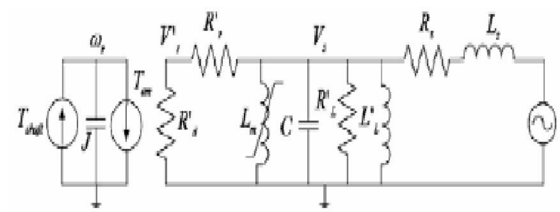


Figure 2. Induction generator model and the mechanical parts

C is the field capacitor which provides the magnetizing current flown through L_m . R_1 and L_1 are loads. In generation mode, the rotor moves faster than the synchronous speed; therefore, slip value is negative (s<0). The capacitance can be calculated using produced reactive power and voltage.

3.3. STATCOM

Figure (3) shows a device which can compensate and control the voltage or power factor in the d-q coordinate [3-4]. V_{abc} are generator terminal voltage, I_{abc} are three-phase currents injected by the compensator to grid, V_{rms} is the effective voltage, and V_{dc} is the dc voltage of capacitor. The controller consists of a phase locked loop in order to synchronize the three-phase voltage in the output of converter according to zero crossing point. Thus PLL creates θ which is used in d-q conversion. (4)

Figure (3), This figure includes four PI controllers. The first block tunes terminal voltage with respect to the reference current i_q . Next PI has the role of keeping dc voltage constant via active power exchange with grid. In other words, the reference current i_d is determined by the second controller. The next two blocks produce base voltages v_q and v_d which after conversion into three-phase system, the base voltage V_{abc} is formed and applied to inverter switches according to PWM scheme.

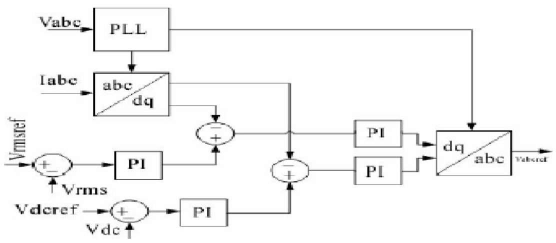


Figure 3. compensator control diagram

The STATCOM which should control power factor operates like the block responsible for voltage control but the only difference is that reactive power is tuned with regard to demand. Therefore, $V_{rms-ref}$ should be replaced with Q_{ref} in Figure (3). This value is usually assumed zero to regulate the measured reactive power in the consumer's place.

4. Fuzzy Control

Den and en are fuzzy block inputs and zetan is the output signal. K_{de} , K_e , and K_{zn} are values which can vary and have an important role in fuzzy controller performance in both transient and steady states.

In this research, the latter values are assumed constant and equal to 0.2, 500, and 0.05 respectively for simplification and easier implementation. As it is shown in Figure (4), triangular membership functions with overlap are used in both input and output of fuzzy block.

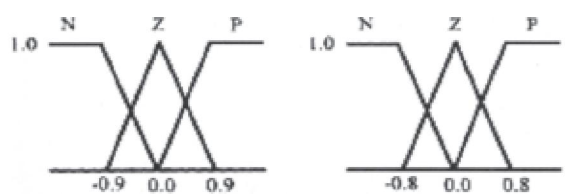


Fig. 4. compensator control diagram

Fuzzy rules are defined using linguistic variables listed in Table (1) which include N (Negative), Z (Zero), and P (Positive). Mamdani max-min technique is adopted to produce outputs from the fuzzy variables. Figure (5) depicts complete fuzzy system through which the reference voltage is obtained [6].

5. System Modeling

In this section, a new analytical model is presented for the system's behavior [2-3]. For simplicity, let's assume:

1) iron loss is negligible
2) All parameters are constant except the magnetic inductance.
3) All parts have three-phase star connected configuration.

Table 1: Fuzzy linguistic variables

den	en	zeta n
N	N	P
Z	N	P
P	N	Z
N	Z	P
Z	Z	Z
P	Z	N
N	P	Z
Z	P	N
P	P	N

In order to elevate modeling, the mechanical parts are taken into account and modeled in Figure (2). In this model, the applied torque to the shaft (τ_{shaft}) is modeled by a current source. Similarly, the electromechanical torque (τ_{em}) is shown as a current source. Finally, the inertia of rotor is modeled as a capacitor.

It should be noted that the mechanical model (ω_r and τ_{em}) are DC variables whereas elecric parts (V_r and V_s) includes ac variables in 50 or 60 Hz. R_d is a negative resistance in generation mode which produces mechanical power (P_{em}) and represents the converted power from mechanical to electrical form.

R_s and L_s are equivalent resistance and inductance of transmission lines. In order to control the voltage, a current controlled voltage source is used in the model as shown in Figure (6 - a). In this model, another scheme (6 - b) is employed to tune the voltage source.

In this method, bus voltage is compared with a refrence value and the subsequent error passes through a PI block to produce the required current for reactive power generation. This current affects voltage according to equation (6).

$$KV_s-V_s=L_dI_d \quad (6)$$

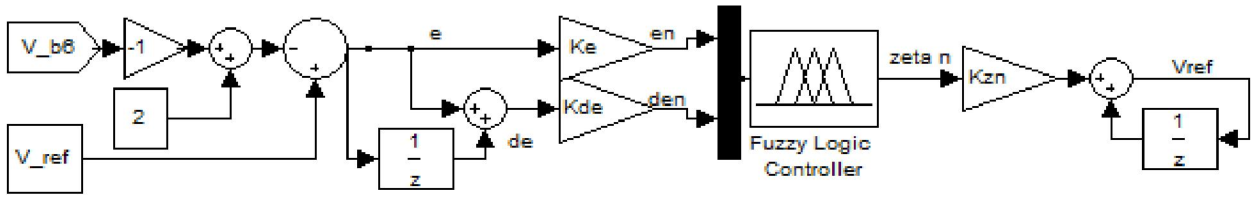
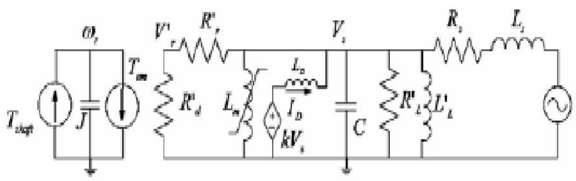
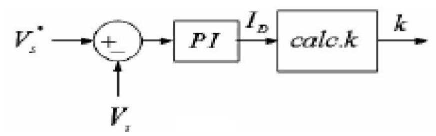


Figure 5. Fuzzy system diagram



(a)



(b)

Figure 6. a) expanded model for voltage control
b) control diagram

6. Simulations

Energy conversion system consists of a 9 MW wind turbine connected to a 33 kV distribution system. This source feeds a 133 kV load through a 25 Km transmission line. Stator of the squirrel cage induction generator is directly connected to a 60 Hz grid and the rotor moves by a turbine with a variable angle pitch.)**.**

Angle pitch is useful for the output power restriction when the speed is higher than normal (9 m/s). The output power can be extracted just when the speed is higher than the synchronous value. The speed usually changes from 1 pu in no-load and 1.005 pu in full-load conditions. Moreover, the generator has error monitoring equipments for current, voltage, and speed from which if a fault report received, the generator goes off. Besides, a group of capacitors, installed in the low voltage terminal bus, supply the required reactive power of generator, equal to 400kVar. The required reactive power for voltage stabilization is provided by a 3MVar compensator in the one per unit voltage (33kV).

The turbine delivers rated power (3 MW) at the rated speed (9 m/s). If wind speed changes, the output power alters with regard to the speed-power curve.

Here, wind speed at t=2s is set to 8 m/s and increases to 11 m/s in one second.

At t=15s a temporary fault occurs in the bus b_6. Subsequently, both active and reactive powers of bus b_6 are given in Figures (7) and (8). The corresponding dc voltage is illustrated in Figure (9). When simulation starts active power ascends gradually until nominal point in 5 seconds. During this period, the generator speed increases from 1.0028 to 1.0047pu. The resulted voltage without fuzzy controller in b_6 is sketched in Figure (10).

The terminal voltage drops to around 0.97 due to wind speed change. If a fault is occurred, voltage variations are severe and perhaps the steady-state error would be remarkable. Figure (11) illustrates the bus voltage when fuzzy controller is running. Not only voltage variations in transient condition (due to wind speed alteration and errors) are improved but also in steady state mode the reference voltage is traced well. Furthermore, the generator's absorbed reactive power increases with the produced active power growth.

The generator demands reactive power of 1.47 MVar in the nominal state. The output power is 9 MVar in 11 m/s wind while the compensator keeps terminal voltage constant, equal to 0.984, via reactive power injection of 1.62 MVar. At t=15 a phase to phase fault occurs at b_6 and it is obviated at t=15.11. The power injected by compensator is depicted in Figure (12).

The bus connected to generator is encountered with reactive power shortage; therefore, voltage drop is inevitable. At first, turbine's angle pitch is zero; however, when the output power exceeds 3 MW, the angle pitch expands to eight degrees for the output power compensation equal to the nominal value as it is shown in Figure (13). The parameters values employed in the simulation process are listed in Table 2.

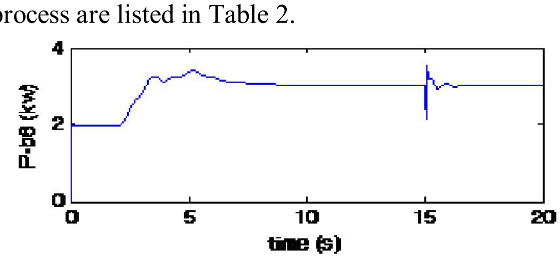


Figure 7. Active power of b_6 bus

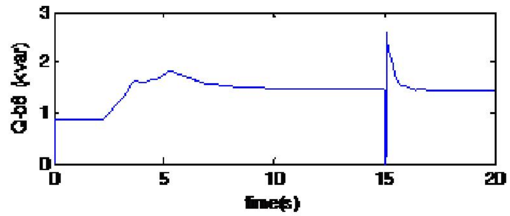


Figure 8. Ractive power of $b_6$bus

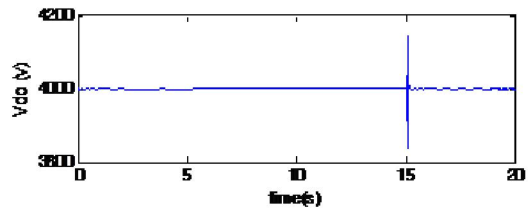


Figure 9. variation of DC link voltage

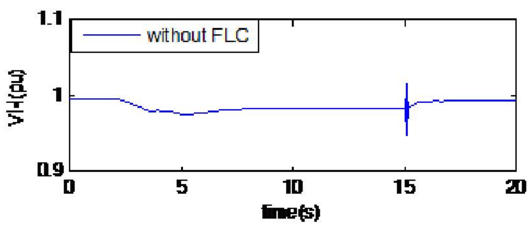


Figure 10. Line to line voltage without FLC

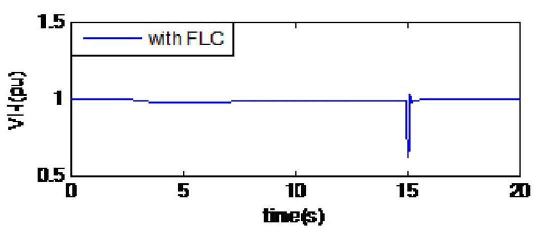


Figure 11. Line to line voltage with FLC

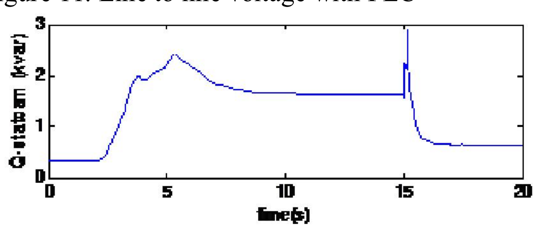


Figure 12. Reactive power injecting by STATCOM

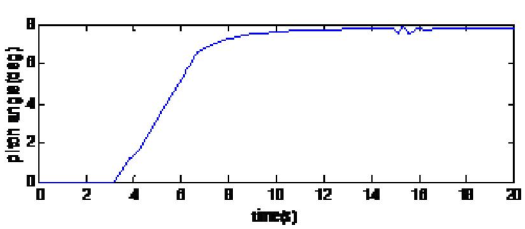


Figure 13. Pitch angle

Conclusions

In this paper a new model and a control diagram for a wind energy conversion system composed of load, exciting capacitor, and induction generator are introduced. The equivalent circuit makes a complete connection between electrical and mechanical parts. As a result, a deep insight into the behavior of both systems is achieved. Such these illustrated knowledge could be extremely worthwhile for controller design and voltage regulation.

The model aims to control the bus voltage via a compensator in an induction generator connected to the grid. To excel the compensation policy, a fuzzy controller is designed to determine the reference voltage. Considering simulation results, fuzzy controller ameliorates both transient and steady states voltage waveforms.

Corresponding Author:
Reza Sharifian
Department of Electrical Engineering,
Lenjan Branch, Islamic Azad University,
Isfahan, Iran.
E-mail: sharifian@iauln.ac.ir

Appendix

Table 2. Parameter of simulation

parameter	value
L_m	650mH
L_{lr}	30mH
L_{ls}	30mH
R_S	5.67Ω
R_r	3.64Ω
P	2
F	60Hz
P_N	440Kw
V_N	460V
RPM	1450rpm

References

1. Moren J, Haan S, Kling W, Ferreira JA, Wind turbine emulating inertia and supporting primary frequency control, IEEE Trans. on Power Systems, vol. 21, No. 1, 2009.
2. Chen W, Hsu Y, Controller design for an induction generator driven by a variable speed wind turbine, IEEE Trans. on Energy Conversion, vol. 21, No. 3, pp. 625-635, September 2006.
3. Freitas W, Morelatto A, Xu W, Sato F, Impacts of ac generators and D-Statcom devices on the dynamic performance of distribution systems, IEEE Trans. on Power Delivery, vol. 20, No. 2, pp. 1493-1500, April 2008.
4. Kumarasen N, Subiah M, Analysis and control of wind driven self-excited induction generators with load matching, in Proc. 11th National Power System Conf,. Bangalore, India, Dec. 20–22, 2000, pp.21–26.
5. Tiwari HP, Diwedi JK, Minimum capacitance requirement for self-excited induction generator, in Proc. 12th Nat. Power System Conf., Kharagpur, India, 2002, pp. 5–10.
6. Driankov D, Hellendoorn H, Reinfrank M, An Introduction to Fuzzy Control. Springer-Verlag, 1993.
7. Chanand TF, Loi LL, induction generators elf-excited with a single capacitance and supplying a single-phase load, IEEE Trans. Energy Convers., vol.17, pp.90–94, Mar.20 2002.
8. Bhatti TS, Bansal RC, Kothari DP, Reactive power control of isolated hybrid power systems , in Proc. Int. Conf. Computer Aplacation Electrical Engineering Recent Advances, Roorkee, India, Feb.21–23, 2002, pp.626–632.
9. Wekhande S, Agarwal V, A new variable speed constant voltage controller for self-excited induction generator ,Electr Power Syst. Res., vol.59, no.3, pp.157–164, 2001.
10. Charles Smith J, Winds of change: issues in utility wind integration, IEEE Power and energy magazine, November/December 2005.

11/12/2012