Control of DC link Voltage Unit with Fuzzy Logic Controller in the Wind Farm

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Abstract

In this study, the analysis of wind farm that has Double Feed Induction Generator (DFIG) with Fuzzy Logic Controller (FLC) in its operation connected to the grid is realized. In wind farm, DC voltage control is modeled with FLC. Bus voltages that are connected to grid, load bus voltage, DC link voltage, active and reactive power variations of wind farm are examined. Simulation results are demonstrated with figures by Fuzzy Logic Controller (FLC)-Proportion Integrate (PI) comparison. As a result of the studies, it is observed that FLC makes the system stable in a shorter time than PI.

1. Introduction

Wind power may be considered as one of the most promising renewable energy sources after its progress during the last three decades. However, its integration into power systems has a number of technical challenges concerning security of supply, in terms of reliability, availability and power quality. Wind power impact mainly depends on its penetration level, but depends also on the power system size, the mix of generation capacity, the degree of interconnections to other systems and load variations. Since the penetration of wind power generation is growing, system operators have an increasing interest in analyzing the impact of wind power on the connected power system. For this reason, grid connection requirements are established. In the last few years, the connection requirements have incorporated, in addition to steady state problems, dynamic requirements, like voltage dip ride-through capability (1). In the solution of these problems, time response is very important. In terms of time response FLC is one of the controllers that are used in wind farm. If we are to examine the studies that are carried out in wind farms with FLC; it is observed that FLC is efficient in the problems that occur during the getting in and out of the variable speed wind farm (2). It is examined that FLC effect is used in variations of torque and flux in wind farm different wind speed (3). Energy Storage Systems that are used as expand wind farm on the voltage and frequency with FLC are examined (4). During the adaptation of wind farm in HVDC systems, input power and output power variations with FLC are examined. Also analyses of steady-state and transient state are observed (5). Primarily frequency controller is done in wind farm power and frequency variations with FLC are observed (6). Analysis of symmetric and asymmetric fault in wind farm is examined. To achieve maximum energy, FLC is used (7). It is clear in the examinations carried out that FLC is efficient in active and reactive control in wind farm (8-9). With the help of the modeling of buck-boost converter with FLC, effects of fault have been focused on (10-11).

In the pitch angle control, FLC has been efficient and the systems has soon been stable (12-13). In the examination that has been carried out, steady-state analysis approach in wind farm in comparison with FLC-PI has been demonstrated. Effects of voltages and powers have been examined by ensuring of DC link voltage with FLC modeling. It is seen that FLC makes the system stable in a shorter time than the Proportion-Integrate (PI).

2. Wind Turbine Modeling

Output mechanical power and torque of wind turbine is explained as:

$$P_m = \frac{\rho}{2} A C_p(\lambda, \theta) V^3 \tag{1}$$

$$T = \frac{P_m}{w} = \frac{\rho}{2} A C_p(\lambda, \theta) R V^2 \tag{2}$$

Where, ρ is the air density, A is the blade sweep area, V is wind speed. R is the rotor radius of wind turbine, Cp is the power coefficient of the blade which is a function of the blade pith angle θ, and the tip speed ratio λ as;

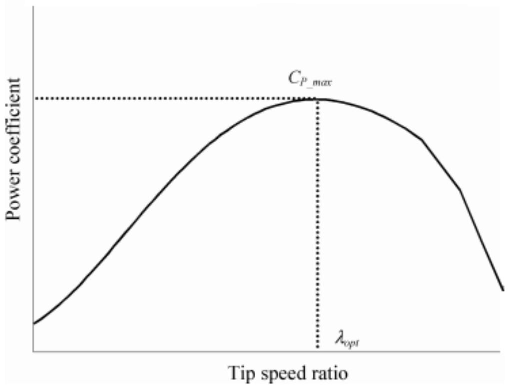

Fig. 1. Power coefficient versus tip speed ratio

Example of power coefficient versus tip speed ratio is shown in Fig. 1: the maximum power coefficient Cp_max corresponds to the optimal tip speed ratio λ_{opt}. Clearly, the turbine speed should be changed with wind speed so that optimum tip speed ratio is maintained (7-14).

3. Double Feed Induction Generator (DFIG)

Circuit model of DFIG is demonstrated in Fig. 2.

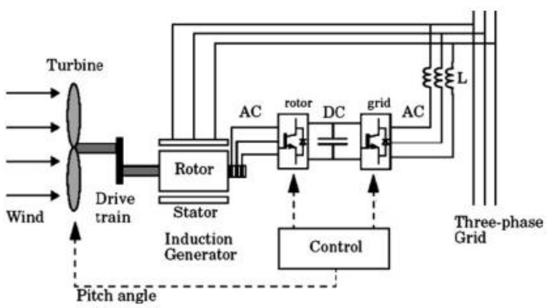

Fig. 2. DFIG circuit model

DFIG wind turbine includes a wound rotor induction generator connected to the wind turbine rotor through a drive train. This generator presents the stator winding directly grid-coupled and a bidirectional power converter feeding the rotor winding, made up two back-to-back IGBT bridges based voltage source converters linked by a DC bus. This power converter decouples the electrical grid frequency and the mechanical rotor frequency, thus enabling variable speed wind turbine generation (15). The dynamic equation of a three-phase DFIG can be written in a synchronously rotating d-q reference frame as.

$$u_{ds} = r_s i_{ds} - w_s \psi_{qs} + \frac{d\psi_{ds}}{dt} \tag{3}$$

$$u_{qs} = r_s i_{qs} - w_s \psi_{ds} + \frac{d\psi_{qs}}{dt} \tag{4}$$

$$u_{dr} = r_r i_{dr} - Sw_s \psi_{qr} + \frac{d\psi_{dr}}{dt} \tag{5}$$

$$u_{qr} = r_r i_{qr} - Sw_s \psi_{dr} + \frac{d\psi_{qr}}{dt} \tag{6}$$

Where w_s is the rotational speed of the synchronous reference frame, $Sw_s = w_s - w_r$ the slip frequency and S is the slip, w_r is the generator rotor speed and the flux linkages are given by:

$$\psi_{ds} = L_s i_{ds} + L_m i_{dr} \tag{7}$$

$$\psi_{qs} = L_s i_{qs} + L_m i_{qr} \tag{8}$$

$$\psi_{dr} = L_r i_{dr} + L_m i_{ds} \tag{9}$$

$$\psi_{qr} = L_r i_{qr} + L_m i_{qs} \tag{10}$$

Where, L_s, L_r and L_m are the stator inductance, rotor inductance and mutual inductances, respectively. The active and reactive stator powers and rotor powers are:

$$P_s = \frac{3}{2}(u_{ds} i_{ds} + u_{qs} i_{qs}) \tag{11}$$

$$Q_s = \frac{3}{2}(u_{qs} i_{ds} - u_{ds} i_{qs}) \tag{12}$$

$$P_r = \frac{3}{2}(u_{dr} i_{dr} + u_{qr} i_{qr}) \tag{13}$$

$$Q_r = \frac{3}{2}(u_{qr} i_{dr} - u_{dr} i_{qr}) \tag{14}$$

Where, P_s and P_r, stator, rotor active power, Q_s and Q_r, stator and rotor reactive power (16).

4. Wind Farm Controller Unit

The control of wind farm DC voltage is done with PI controllers. The circuit of wind farm DC voltage control is given Fig. 3.

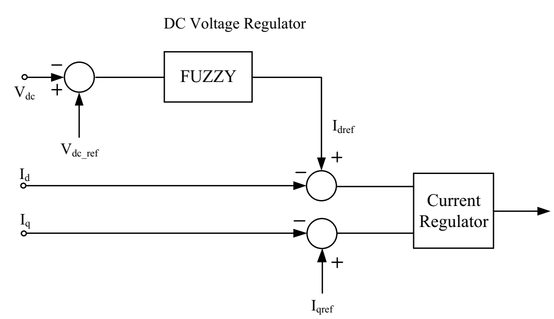

Fig. 3. Wind farm dc voltage controller

DC voltage goes through PI controller by comparing with reference voltage. DC voltage value is classified as PI controller with the signal that is accepted as a reference. Converter trigger angles are produced the rates that capacitor voltage is minimum and maximum the part in which PI controller is done is converted into FLC to ensure the control of thyristors with triggering angle FLC.

5. Fuzz Logic Controller (FLC)

A FLC comprises of three basic blocks, namely, Fuzzification, Inference system and Defuzzification as shown in Fig. 4.

Membership functions are applied as a means of controller tuning and range between 0 and 1. Membership functions are chosen in such a way that these reflect the characteristics of the input variables and meet the requirements of the controller. The fuzzy inference includes the process of fuzzy logic operation, fuzzy rule implication and aggregation. In the fuzzy inference system, the fuzzified input variables are processed with 'AND' fuzzy operators and the IF-THEN rule implementation, which are based on expert knowledge of the control problem to be dealt with. These rules are fact, the control strategy of the system and describe the actions that are required for all conceivable combinations of memberships. Fuzzy sets representing the outputs of each rule are then combined into a single fuzzy set, known as aggregation. The desired output signal of the FLS is then transformed into a crisp value. But at any time several rules will fire, each of them makes a suggestion as to how the output signal should be changed. Hence the defuzzification combines the results of all the rules and finds a crisp value. The Centre of Gravity method is used for defuzzification, which returns the center of the area under the curve representing the aggregated output fuzzy set (12).

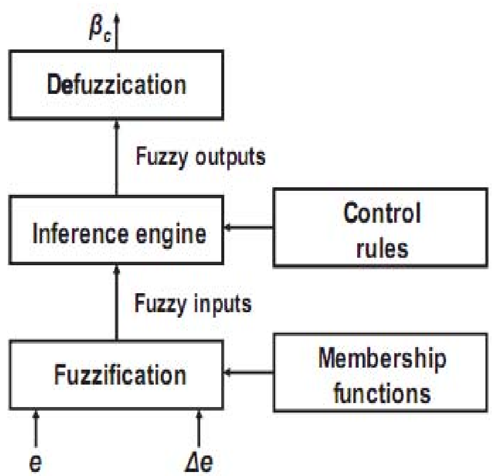

Fig. 4. FLC blok diagram

6. System Analysis

In the study, analysis of three bus system is carried out. Model of the applied system is demonstrated in Fig. 5.

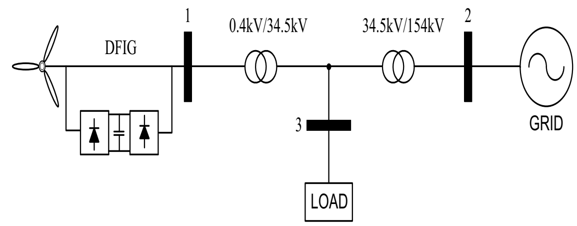

Fig. 5. Simulation system modeling

There is a wind farm that is 6MW DFIG in bus 1. While modeling of bus 2 with grid that has 154 kV is done, bus 3 is modeled as load bus. 2 transformers are used in the system. A transformer decreases the voltage that is 154 kV to 34.5 kV. . A transformer increases the voltage that is 34.5 kV to 0.4 kV. Grid short circuit powers are regulated as 100 MVA. Also the circuit X/R rate is determined as 7. Bus 3 a 4-3 MW-2.3 MVAr RL load is used. FLC model is applied to the part of wind farm where DC voltage control is done. In DC control unit of wind farm, Comparison PI, FLC models are done. In the FLC occurred 5×5 rule tables.

7. Simulation Result

Wind Farm is connected bus voltage, grid is connected to bus voltage, middle bus voltage, given in Fig. 6-8.

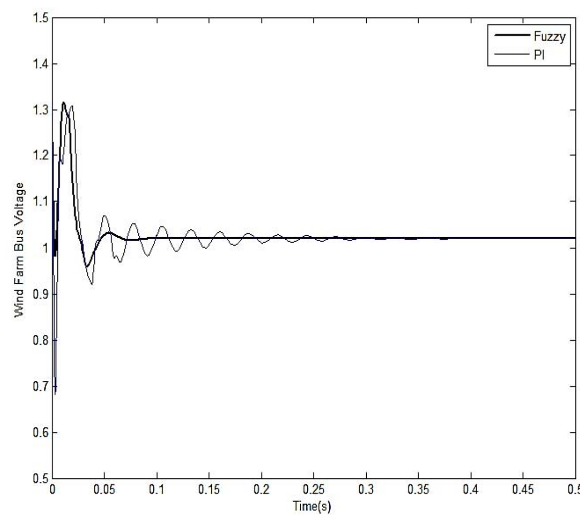

Fig. 6. Wind farm voltage variations

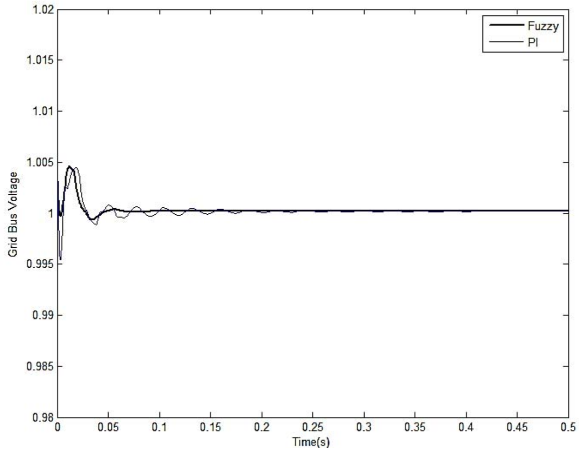

Fig. 7. Grid voltage variations

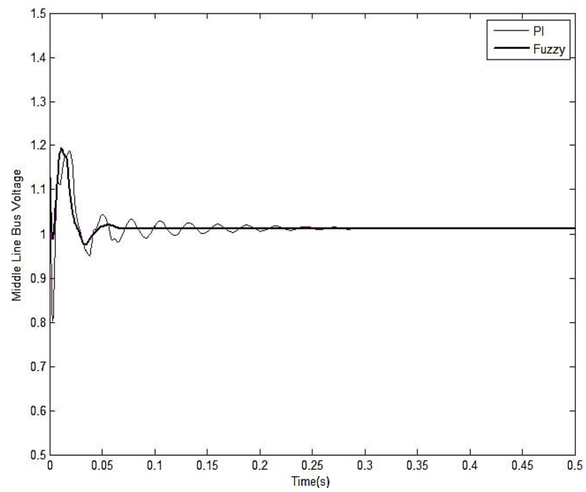

Fig. 8. Load bus voltage variations

When the system study is 0.05 seconds, wind farm bus voltage and bus voltage has risen to 1.3 p.u. values, middle line bus voltage has risen to 1.2 p.u. value and grid bus voltage has risen to 1.005 p.u. value. DFIG DC link voltage, DFIG active-reactive power variations have been shown in between Fig. 9 and Fig. 11.

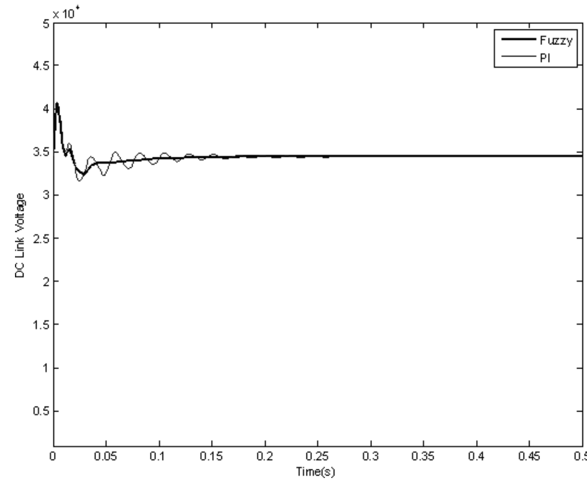

Fig. 9. DC link voltage variations

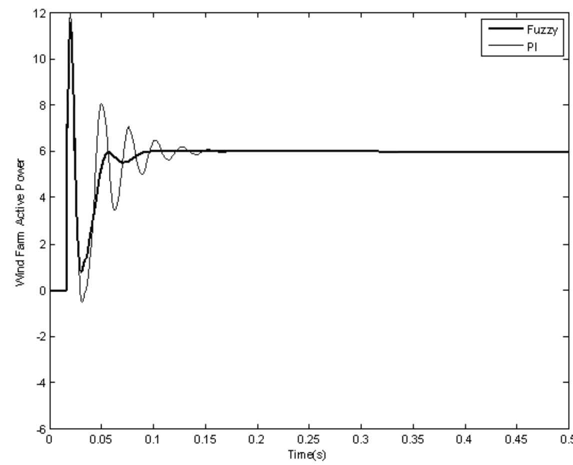

Fig. 10. Wind farm active power

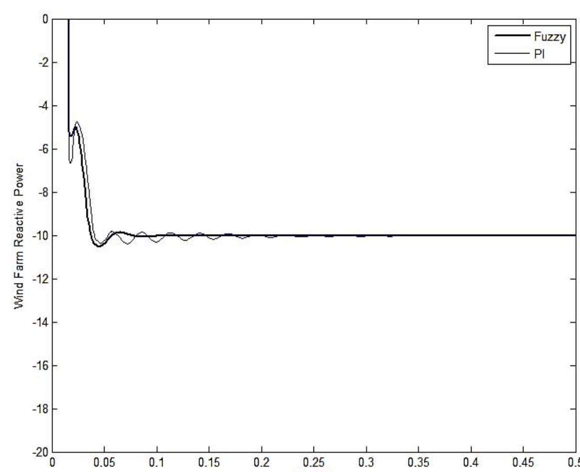

Fig. 11. Wind farm reactive power

While PI study, the DC link voltage, active-reactive power increasing oscillations, FLC study less oscillations.

Wind farm bus voltage, Grid connect bus voltage, load bus voltage, DC link voltage, active and reactive power in wind farm time responses are given in table 1, during the period wind farm is connected to the system.

Table 1. Variable time responses

Variables	**PI**	**FLC**
Wind farm bus voltage	0.25s	0.07s
Grid bus voltage	0.18s	0.05s
Load bus voltage	0.18s	0.05s
DC link voltage	0.25s	0.1s
Wind farm active power	0.2s	0.06s
Wind farm reactive power	0.2s	0.06s

8. Conclusions

It has been observed that system becomes stable in a shorter time as opposed to PI controller in wind farm by carrying out conventionally with FLC. It is also seen that control of circuit and load Busses achieve stability very quickly with FLC in terms of time response. It occurred that bus voltage that is connected to wind farm and DC link voltage becomes stable in longer time than other variables. It has become clear that bus which is connected to wind farm and load bus voltages are affected as soon as wind farm is connected to the system whereas grid side isn't affected by this situation at all in terms of oscillation.

9. References

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