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Power Control using Fuzzy Logic Controller in DFIG Wind Farm

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Abstract:
This paper presents the control of fuzzy based controller for the wind form represented with equivalent double fed induction generator of power system. Voltage swags and dips can be damped out with off-line and on-line simulation. Fuzzy logic rule base is tuned input parameters of turbine blades. Fuzzy logic controller is fine tuned to obtain better performance, power control and stability criteria. Proposed work describes fuzzy logic control of induction generator speed in wind turbine application. Fuzzy controller is to used found the maximum power delivery to the infinite bus. Fully-controlled wind turbine which consists of induction generator and back-to-back converter is under estimate. Design has full control over the electrical torque, reactive power compensation, control of the speed under grid disturbances.

Keywords*: Wind form, Doubly fed Induction Generator, Fuzzy logic controller*

1. Introduction

There many forms resources to generate electrical power and wind-energy technology has progressed significantly over the last two decades. Wind energy is one of the imported sources of renewable energy due to its clean character and availability.

It must be stressed that wind energy involves no combustion or nuclear reaction, so it is pollution free. It is renewable and plentiful and free, and what is more it is available everywhere, especially in remote areas and often it is windier in mountains and near costal areas. There are significant environmental benefits obtained from using renewable energy device attributed to preventing the release of green house gases associated with fossil fuels.

As energy sources are depleting due to the energy needs of the world, alternative energy sources are being sought after. The search for clean and low cost energy alternatives has yielded wind energy as an excellent candidate against conventional fossil fuel based power generation.

Moreover, because of reducing the cost and improving techniques, the growth of wind energy in Distributed Generation units has developed rapidly In terms of wind power generation technology, because of numerous technical benefits (higher energy yield, reducing power fluctuations and improving var supply) the modern MW-size wind turbines always use variable speed operation which is achieved by a converter system.

2. Wind Energy

A wind turbine is characterized by its power-speed characteristics. The power extracted from a wind turbine is a function of the wind power available, the power curve of the machine and the ability of the machine to react to wind variations. The power extracted from the wind can be expressed as given by.

$$Pm = \frac{1}{2} C_p \, \rho \, A V_w^3$$

ρ - air density,
A - area covered by turbine blades
Vw - wind speed.
C_p – turbine power coefficient.

The power coefficient is the ratio of the mechanical power at the turbine shaft to the power available in the wind, given as a function of tip speed- ratio λ as given in

$$\lambda = \frac{\text{tip speed of rotor blades}}{\text{wind speed}} = \frac{\omega_m R}{v_w}$$

3. Model of Studied System

Studied configuration of double fed induction generator (DFIG) based wind firm is shown in figure.1. The 50-MW wind firm is represented by a large equivalent aggregated DFIG driven by an equivalent aggregated variable-speed WT through an equivalent aggregated gearbox. The Wind firm, and a local load are connected to an AC bus that is fed to the onshore power grid through an offshore step-up transformer and undersea cables. The employed mathematical models of the studied system are described as below.

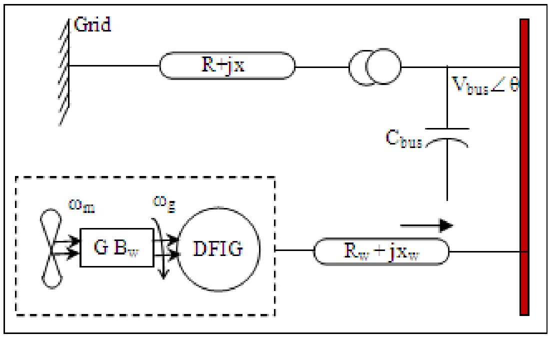


Figure 1: Wind firm with DFIG connected to Grid

Parameter	Range of parameter
Base MVA, S_{base}	2MW
Base voltage, V_{base}	690 V
Base frequency, f_{base}	60Hz
Base angular frequency, ω_{base}	2π rad /sec
Stator resistance, r_s	0.018p.u.
Rotor resistance, r_r	0.021p.u.
Rated Voltage	0.69kV
Rated Power	2MW
Stator/Rotor ratio	0.43
Angular Moment of Ineteria, J	1.6p.u.
Mechanical damping	0.02
Stator leakage inductance	0.23
Rotor leakage inductance	0.36
Mutual inductance	4.4

Table 1

4. Fuzzy Rule-Base for PWM Signal

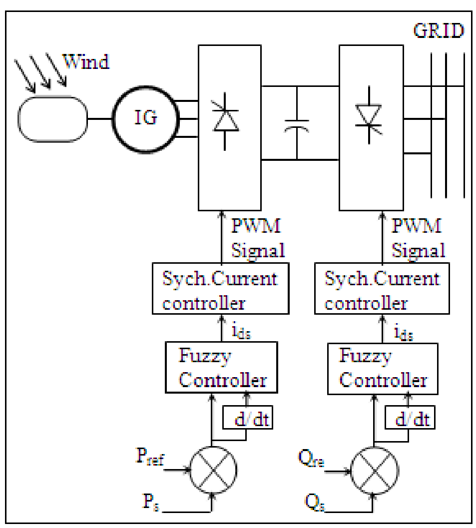


Figure 2: Wind turbine control block diagram

Control block diagram of wind turbine is shown in Fig. 2. The system consists of squirrel-cage induction generator and back-to-back PWM converter connected to the grid through the coupling inductances. The voltage equations which describe the behavior of induction machine contain

time-varying coefficients in real domain, due to the fact that some of the machine inductances are functions of the rotor displacement. A change of variables suggested by reference-frame theory is often used to reduce the complexity of these differential voltage equations. It could be shown that in synchronously rotating reference frame a constant amplitude balanced 3-phase set of variables will appear as constants. This enables, among reduction of complexity of induction machine voltage equations and their analysis, also simplify in controlling the alternating systems because *ac* quantities became constants in steadystates. In system analysis it is also often convenient to express machine parameters and variables as per unit quantities. Base power and base voltage are selected, and all parameters and variables are normalized using these base quantities.

5. Fuzzy Logic Implimentation

The structure of a complete fuzzy control system is composed from the following blocks:

- Fuzzification,
- Knowledge base,
- Inference engine and
- Defuzzification.

Advantages of fuzzy logic controllers are mainly solves the non linear problems with vague inputs, not needed an accurate mathematical model, handling nonlinearity. For controlling such a complicated system, fuzzy logic controllers gives very good results like this application. The inputs to a fuzzy logic controller are usually an error 'e' and a change of error '∆e'.

Actual values that indicates input variables, here change of output power, and last change of generator speed, are initially converted into the correspondent fuzzy sets with human linguistic and perceptive values such are terms VERY BIG, BIG, MEDIUM, SMALL, ZERO. This is done in the "fuzzification block", where the variables error and change in error accordance with variation of output power, variation of generator speed are described by membership functions given in Figure 3, Figure 4, Figure 5. Afterwards, it is possible to apply descriptive rules of reasoning like "if the last change of output power during maximum power searching was POSITIVE and BIG and the last change of desired generator speed was POSITIVE then keep tracking the maximum power in the same POSITIVE direction with BIG increment". Rules like this are involved in block "rules table", and they are given in Table 2. Finally, the fuzzy set of output reference change of generator speed is back "deffuzified" to convert it to the actual value. That means the output values such are VERY BIG, BIG, MEDIUM, SMALL are translated to numbers which indicates a measurable (but normalized) value of the generator speed. It could be also noticed the output of controller is added by some amount of in order to avoid local minima in characteristics due to the changes of wind speed. value. That means the output values such are BIG, MEDIUM, SMALL are translated to numbers which indicates a measurable (but normalized) value of the generator speed. It could be also noticed the output of controller is added by some amount of in order to avoid local minima in characteristics due to the changes of wind speed.

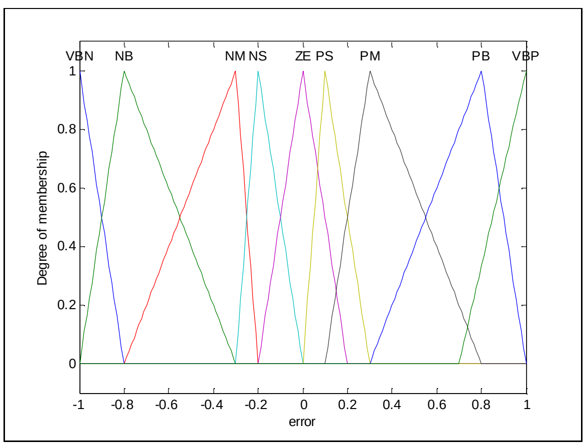


Figure 3: Membership value of power, P

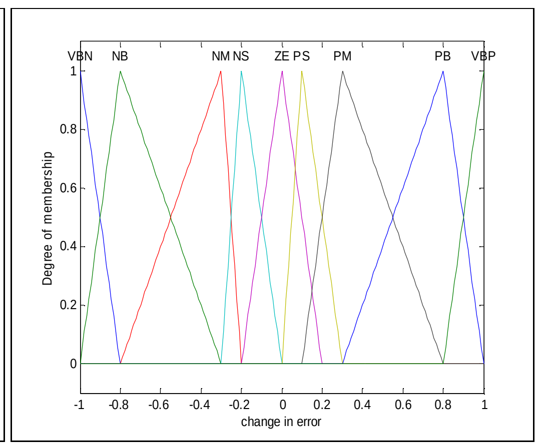


Figure 4: Membership value of change in power, ∆P

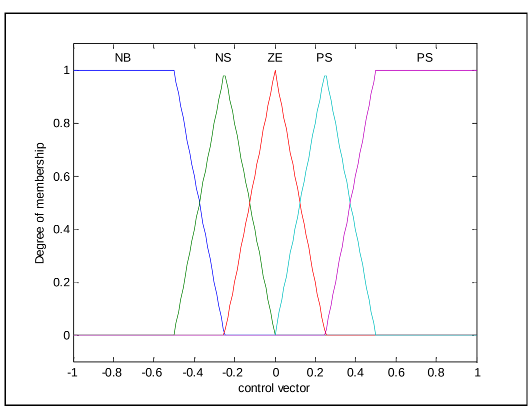


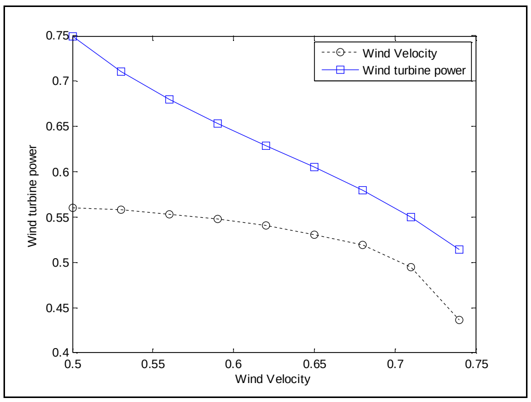
Figure 5: Membership value of control vector, u

e /Δe	VBN	NM	ZE	PM	VBP
VBN	VBP	VBP	VBP	PM	PM
NM	VBP	VBP	PM	PM	ZE
ZE	VBP	PM	PM	ZE	ZE
PM	PM	PM	ZE	ZE	NM
VBP	PM	ZE	ZE	NM	NM

Table 2: Sample rule base table of 9×9

6. Simulation Results

Figure 6 shows the static characteristics of the wind turbine at different wind velocities. Figure.7 shows the static characteristics of the wind turbine at different wind torques. Nature of curves for turbine output power, turbine torque, and line-side output power with respect to wind speed and sets of generator speed. For constant generator speed and the wind velocity increases, the turbine power, turbine torque, and line power will increase and then will tend to saturate. The slope of increase is higher with higher generator speed. At particular fixed wind velocity, as the generator speed increases, firstly torque and power outputs increase and then decrease.



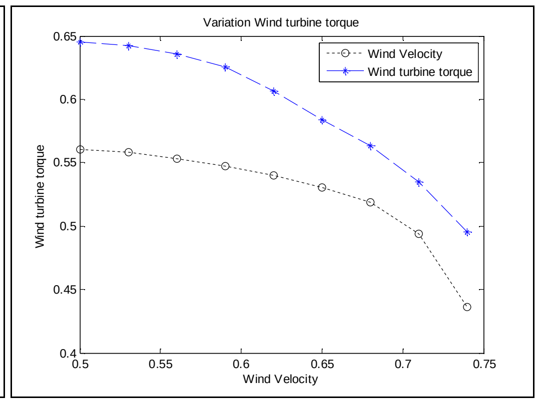


Figure 6: Characteristics of the wind turbine at different wind velocities
Figure 7: Characteristics of the wind turbine at different torques

Test cases for different operating points also simulated. Efficiency of wind turbine plant with fuzzy logic controller for different cases i.e. operating points observed with simulation of power system. Operating points of low power case with 0.10+j0.03 p.u., medium power case with 0.45+j0.31 p.u., normal power case with 0.85+j0.98 p.u. and high power case with 1.8+j2.5 p.u. are considered for testing. In every study case the fuzzy logic exhibits its better performance to improve efficiency.

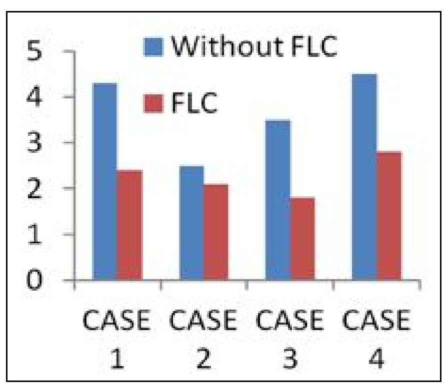


Figure 8: Performance of the wind turbine at different test cases

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