

A Fuzzy Controller for Optimum Power Flow in Doubly Fed Induction Generator Based Wind Energy Conversion Systems

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Abstract: The control of a doubly fed induction generator by fuzzy is described. The active and reactive power can be controlled by rotor and grid side converters with fuzzy controller. The main objective is to maintain constant voltage and frequency at the output of the generator. However the Line Side Converter (LSC) can be controlled to supply up to 50% of the required reactive current. When the crowbar is not activated the DFIG can supply reactive power from the rotor side through the machine as well as through the LSC.

Keywords: Doubly fed induction generator (DFIG); Rotor side converter (RSC); Grid side converter (GSC); Wind energy conversion systems (WECS).

1. Introduction

Due to increase in demand, the growths of renewable energies are used to produce electric power also increasing. Wind plays a major role to generate maximum power.

- DC machines, synchronous machines and induction machines are used in wind power generation. Nowadays, the use of DFIG is widespread. Induction generators are operated either at fixed speed or variable speed.
- If fixed speed turbines are used, then the generators can be directly connected to the grid. If a variable speed is employed, it is necessary to have power electronic converter interface before connected to the grid.
- However, this type of generation have high energy capture, feasible, cost effective than fixed speed power generation.

The main objective to have power electronic interface is to convert variable amplitude variable frequency to constant voltage constant frequency, to overcome power factor problem. In case of induction generator the capacitor banks and FACTS devices are employed for power factor correction.

Variable speed wind turbines are equipped with a pitch change mechanism to adjust the blade pitch angle and to obtain a better power co-efficient profile. For grid connected wind turbines with three rotor blades the optimal tip speed ratio is 7, the value is in between 6-8. If the tip speed ratio is high, it causes vibration, noises, reduced rotor efficiency and difficulties in the shaft to rotate.

2. DFIG Based Standalone Generator

When the windmill is started, the brake pad gets released from brake disc and the rotor rotates in a free wheel. When the rotor speed reaches close to the synchronous frequency, the generation starts and the synchronization speed takes place which is calculated by

$$N_s = 120 * f/p$$

Where,

f is the nominal frequency,

p is the number of poles.

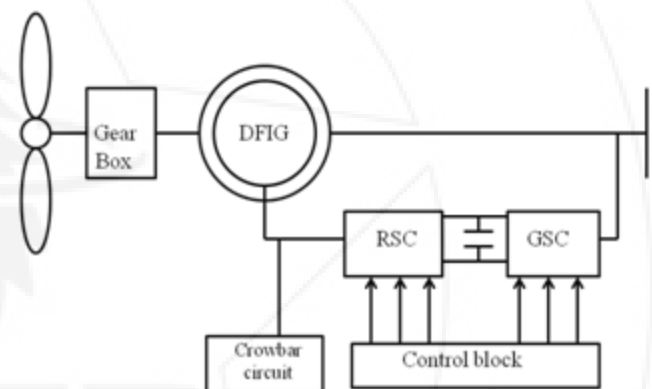


Figure 1: Schematic Diagram for DFIG based WECS

This speed should match the generation speed for parallelization. When the DFIG can be operated above synchronous speed or above its saturation level then the machine act as the generator and if it operated below synchronous speed or below its saturation level then the machine act as the motor.

The schematic diagram for the DFIG based grid connected generator as shown in the fig(1). Converter 1 is called rotor side converter and converter 2 is called grid side converter. The rotor side converter is responsible for control the flux and grid side converter is to maintain DC link voltage as constant and to control active and reactive power transfer to the grid. The three main transformations for designing control in DFIG has to perform both stator and rotor quantities. It includes stationary reference frame, synchronous reference frame and rotor reference frame.

3. Rotor Side Converter

In stator flux oriented reference frame , reactive power can be controlled by varying the d-axis rotor current. In rotor the transformations are taken as follows:

TRANSFORMATION OF 3 PHASE STATIONARY TO 2 PHASE SYNCHRONOUS

$$\begin{bmatrix} i_{qr}^s \\ i_{dr}^s \\ i_{0r}^s \end{bmatrix} = \frac{2}{3} * \begin{bmatrix} \cos\theta & \cos(\theta - 2\pi/3) & \cos(\theta + 2\pi/3) \\ \sin\theta & \sin(\theta - 2\pi/3) & \sin(\theta + 2\pi/3) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} I_{a_r} \\ I_{b_r} \\ I_{c_r} \end{bmatrix}$$

After controlling by fuzzy controller, the controlled voltage has undergone two transformations.

TRANSFORMATION OF SYNCHRONOUS TO ROTOR CURRENT REFERENCE FRAME

$$\begin{bmatrix} v_{qr}^{*s} \\ v_{dr}^{*s} \end{bmatrix} = \begin{bmatrix} \cos\theta_{rr} & -\sin\theta_{rr} \\ \sin\theta_{rr} & \cos\theta_{rr} \end{bmatrix} \begin{bmatrix} v_{qr}^* \\ v_{dr}^* \end{bmatrix}$$

TRANSFORMATION OF ROTOR CURRENT ORIENTED REFERENCE FRAME TO ROTOR REFERENCE FRAME

$$\begin{bmatrix} v_{qr}^{**s} \\ v_{dr}^{**s} \end{bmatrix} = \begin{bmatrix} \cos\theta_{rr} & \sin\theta_{rr} \\ -\sin\theta_{rr} & \cos\theta_{rr} \end{bmatrix} \begin{bmatrix} v_{qr}^{*s} \\ v_{dr}^{*s} \end{bmatrix}$$

Finally inverse park transformation is used to convert 2 phase to 3 phase quantities.

4. Grid Side Converter

The objective of grid side converter is to maintain DC link voltage as constant. Decoupled control of real and reactive power flowing to the grid by using flux oriented control.

TRANSFORMATION FROM 3 PHASE STATIONARY TO 2 PHASE STATIONARY FRAME

$$\begin{bmatrix} v_{dq}^s \\ v_{0s}^s \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -0.5 & -0.5 \\ 0 & 0.866 & -0.866 \\ 0.5 & 0.5 & 0.5 \end{bmatrix} \begin{bmatrix} v_{a_s} \\ v_{b_s} \\ v_{c_s} \end{bmatrix}$$

Under balanced condition, $v_{0s}^s = 0$.

TRANSFORMATION OF 2 PHASE STATIONARY TO SYNCHRONOUS 2 PHASE ROTATING AXES

$$\begin{bmatrix} v_{dq}^s \\ v_{0s}^s \end{bmatrix} = \begin{bmatrix} \cos\theta_s & -\sin\theta_s \\ \sin\theta_s & \cos\theta_s \end{bmatrix} \begin{bmatrix} v_{qs}^s \\ v_{ds}^s \end{bmatrix}$$

After controlling the stator voltages it convert to 2 phase stationary reference frame and finally convert to 3 phase quantities by inverse park transformation.

5. Fuzzy Controller

Fuzzy controller outputs are more reliable because the effect of other parameters such as noise and events due to wind range of control area can be considered. Mamdani fuzzy model was developed.

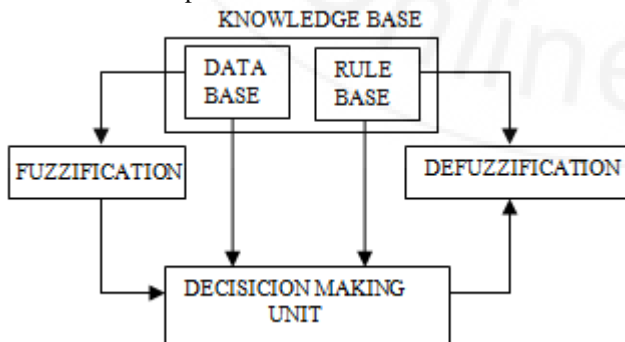


Figure 2: Fuzzy Inference System

To avoid miscalculations due to fluctuations in wind speed and the effects of noise on data, trapezoidal membership functions are chosen to have smooth and constant region in the mesh points. In order to construct the fuzzy controller the procedure are as follows,

1. create the membership values,
2. specify the rule table,
3. select the procedure for defuzzifying the obtained result.

CREATE THE MEMBERSHIP VALUE

The fuzzy controller here used has two input and one output. The change in direct axis rotor current and the change in voltage are the two inputs and controlled direct axis voltage is the output. While in other the change in quadrature axis rotor current and the change in voltage are the two inputs and controlled quadrature axis axis voltage is the output. The ranges determine for each set of data can dramatically determine how well the controller works.

Specify the Rule Table

The rule table must be created to determine which output ranges are used. The table is an intersection of two inputs.

Table 1: Rule Base Table

Δv	NB	N	ZE	P	PB
NB	NB	NB	N	N	ZE
N	NB	N	N	ZE	P
ZE	N	N	ZE	P	P
P	N	ZE	P	P	PB
PB	ZE	P	P	PB	PB

Table 2: Rule Base Table

Δv	NB	N	ZE	P	PB
Δi_{qr}	NB	NB	N	N	ZE
N	NB	N	N	ZE	P
ZE	N	N	ZE	P	P
P	N	ZE	P	P	PB
PB	ZE	P	P	PB	PB

LIST OF RULES

- If Δi_{dr} is NB and Δv is NB then output is NB.
- If Δi_{dr} is N and Δv is NB then output is NB.
- If Δi_{dr} is P and Δv is PB then output is PB.
- If Δi_{dr} is ZE and Δv is N then output is N.
- If Δi_{qr} is NB and Δv is NB then output is NB.
- If Δi_{qr} is N and Δv is NB then output is NB.
- If Δi_{qr} is P and Δv is PB then output is PB.
- If Δi_{qr} is ZE and Δv is N then output is N.

DEFUZZIFY THE RESULT

The typical way is used to defuzzify using Mamdani's centre of gravity method. In this method, it takes the input values and find where they intersect their sets. This intersection creates a cut-off line known as the alpha-cut. The rule is then cut-off by the alpha-cut, to give trapezoidal shapes. These shapes are added together to find their total centre of gravity.

$$X_{COG} = \frac{\int_a^b x(f)dx}{\int_a^b f(x)dx}$$

6. Conclusion

This paper has proposed a new control strategy of DFIG based wind turbine system to enhance its operation. RSC of the DFIG system was controlled to eliminate the electromagnetic torque and stator power oscillations. The control of the machine converter is to regulate the control of real and reactive power exchanged between the machine and grid

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