A Novel Method to Improve the Stability of Doubly Fed Induction Generator Under Grid Disturbances using Fuzzy Controller

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Abstract: This paper proposes a new technique called fuzzy logic to improve the behavior of stability of DFIGs during grid faults, to ability of wind generators to stay connected to the grid during grid fault occurrence.. The controller is designed in order to compensate the voltage in the faulty lines without disturbing voltage at healthy lines at the point of common coupling by controlling the active and reactive power generated by DFIG. The Simulation results are carried out on faulty system. So the proposed controller can improve stability of DFIG

***Index Terms — Doubly Fed Induction Generator (DFIG), Faulty networks, Stability*, Fuzzy control.**

1. Introduction

Wind power plays important role on performance of power system during abnormal situations. Due to recent developments in modern power electronics, the doubly fed induction generator (DFIG) play very important role in wind power generation. In DFIG the AC/DC/AC converter consists of a rotor-side converter (RSC) and a grid-side converter (GSC) connected back-to-back by a dc-link capacitor. The AC/DC/AC converter handle a full control of the generator and control of active and reactive power, faster dynamic response with low harmonic distortion, and so forth, handling only a very small fraction (30–40%) of the total power. DFIG wind turbine also improves system efficiency, reduces noise and mechanical stresses, and improves power quality. In this paper the rotor circuit is first short-circuited by a crowbar circuit, the generator starts to absorb VAR power as it acts as a conventional induction generator. The operation of the DFIG in producing active power continues and, to have a control over there active power and voltage, the GSC can be set. The interface of DFIG with the grid becomes extremely critical, unlike conventional power plants, during and immediately following a grid failure. Like conventional power plants, these renewable energy generators should be able to with standard supply active and reactive power support immediately after the fault has been cleared to control and stabilize the power system. One of the most common control techniques is decoupled PI control of output active and reactive power to improve dynamic behavior of DFIG. The fuzzy control technique can produce controller outputs more consistent, for the reason that the effect of other parameters such as noise and events due to wide range of control and online changing of the controller parameters can be considered. Moreover without the need of a detailed mathematical model of the system and just using the information of the total operation and behavior of system, alteration of parameters can be done more simply.

2. DFIG Wind Turbine Model:

Dynamic model of a DFIG can be represented in terms of the equations of each of the subsystems, mainly the turbine, the drive train, the generator, converter system and the control system. The detailed description of the dynamic modeling of DFIG is out of the scope of the this paper .Detailed information regarding this can be found I the block diagram shows in figure

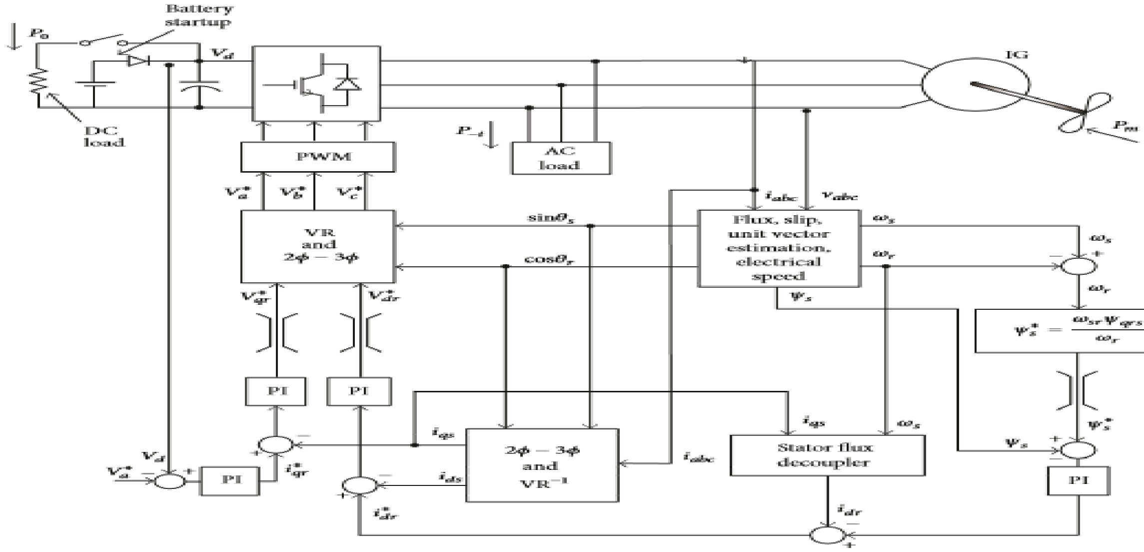
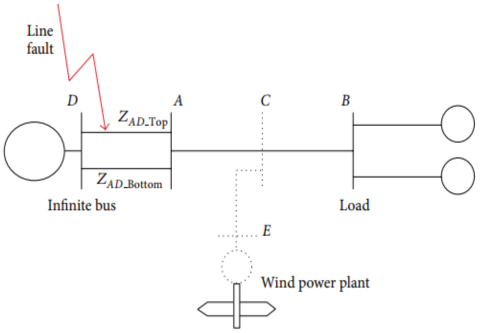


Figure 1: Grid connected DFIG wind turbine model

3. Assessment of System Transient Stability

Power system transient stability is the ability of a power system to return to a stable operating state after the occurrence of an interruption that changes its topology. The changes of the topology of a power system includes tripping of a generator or a line, sudden change of a load, including a load trip, occurrence of a fault, that is, a short circuit the voltage reduction in the healthy line if fault occur in one of the parallel line.



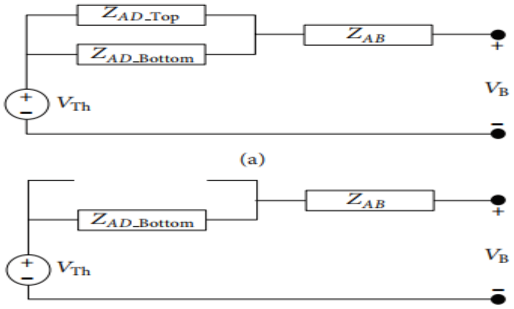


Figure: 2 A test system suffering a short circuit Figure: 3 Thevenin equivalent circuit

Illustrating the fault process:

(a) prefault operation and

(b) postfault operation.

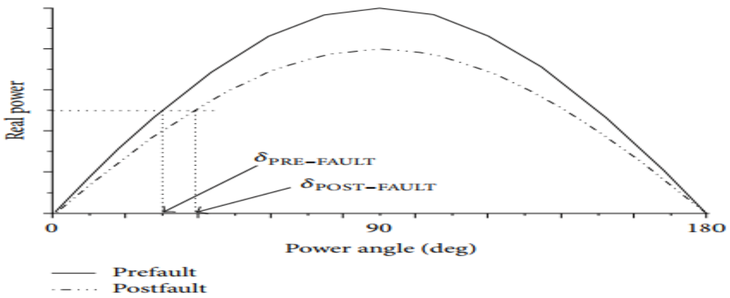


Figure 4 : Power transfer between two buses

To analysis the DFIG connected system transient stability under grid disturbances, a short circuit fault and its simplest Thevenin equivalent circuit is simulated with bus impedances at fault existence and after fault clearance time on one of the lines between Bus *A* and Bus *D* in (Figures 2 & Figure 3).. This is generally called the driving point impedance at Bus *B* of the power system network. The Thevenin impedance before the fault

$Z_{\text{Th before}}{}^{F} = (Z_{AD\text{Top}} \parallel Z_{AD\text{Bottom}}) + Z_{AB}$,

Where $Z_{\text{Th before}F}$ is Thevenin impedance between Bus-*D* and Bus-*B* before the fault, $Z_{AD\text{Top}}$

and $Z_{AD\text{ Bottom}}$ are the impedance of the top and bottom lines between Buses *A* and *D* respectively, and $Z_{AB}=Z_{AC}+Z_{BC}$ is the impedance between Bus *A* and Bus *B*.

The Thevenin impedance after the fault cleared

$Z_{\text{Th after}}{}^{F} = Z_{AD\text{ Bottom}} + Z_{AB}$

Where $Z_{\text{Th after}F}$ is Thevenin impedance between Bus-*D* and Bus-*B* after the removal of the fault line. It is clear that $Z_{\text{Th before}F}$ is less than $Z_{\text{Th after}F}$, which weakens the system after fault. The weaker system can have two types of impact:

(1) The voltage drop across the Thevenin impedance is more and

(2) The power transfer capability will be minimized.

(3) $P = \left(\frac{V_1 V_2}{X}\right) \sin\delta$

Where V_1 and V_2 are the sending end voltage magnitude at bus-1 and receiving end voltage magnitude at bus-2 respectively, X is the reactance between Buses 1 and 2, and δ is the phase angle between Bus-1 and Bus-2. When the voltage is recovering right after the fault, the power transfer capability is reduced proportionally to the amount of voltage reduced at Bus 1 or Bus 2 or both. If the network configuration changes after the fault the reactance X of the system increases significantly, thus changing the power transfer capability. The changes in the power-angle characteristic, indicates the power transfer between the two buses, are represented in Figure 4. Due to the constant load transfer from the source to the sink, the power angle δ increase as the grid weakens ($\delta_{\text{POST-FAULT}} > \delta_{\text{PRE-FAULT}}$). The operating δ is small at the pre fault condition. During the post fault condition, the operating δ angle improves closer to 90∘, making the power system more prone to instability.

4. Transient Phenomena with Double Fed Induction Generator (DFIG)

This section emphasizes the transient phenomena with grid connected DFIG wind turbines.

4.1 During the Fault.

At the instant of fault occur, due to short circuit, the voltage in one of the parallel line and the DFIG generator terminal drops. This leads the several effects in the DFIG system.

a) Generator rotor and stator flux reduces resulting in generator demagnetizing process. The consequent result is the reduction in the electromagnetic torque and active power of the generator. Mechanical torque becomes higher as compared to the electromagnetic torque and therefore the generator starts to accelerate

b) Over current transients come into view in the stator and rotor windings. Crowbar is triggered to bypass this over current away from the RSC to protect the converters from any kind of destructions.

c) The GSC is do not transfer the total power from the rotor through the converter further in to the grid. As a result, the additional energy charges the dc-bus capacitor rapidly.

d) Due to decouple control of mechanical rotor frequency from the grid frequency by of power electronic converters ,is a part of the potential energy stored in the rotating mass of the shaft of DFIG wind turbine cannot be supplied to the system, so the DFIG wind turbine resist from restoration of grid frequency

e) It causes exciting oscillations in the rotating mass of the shaft as well, which is severe with higher time constant and higher damping time due to manufacturing DFIG with softer shaft

4.2: After Clearance of the Fault.

When the fault is cleared, the voltage cannot recover completely restored, because RSC cannot provide sufficient reactive power to the generator for its magnetization process, because it is blocked with crowbar. So the generator absorbs reactive power from the grid, at the same time GSC successfully controls the dc-voltage back to its nominal value. When the grid voltage recovers to its nominal value, the crowbar is removed, and the generator currents and voltages become to their pre fault values, and the RSC retain sits control over the active and reactive power.

4.3 Factors affecting the transient stability.

At fault duration, the strength of grid coupling, or other mechanical properties play minor role on the transient stability. At the reconnection time damping time are very high, so the generated electrical power in the system is lower than the extracted mechanical power and an unbalance between mechanical and electrical torque results takes place.

4.4 Indirect Current Mode Control

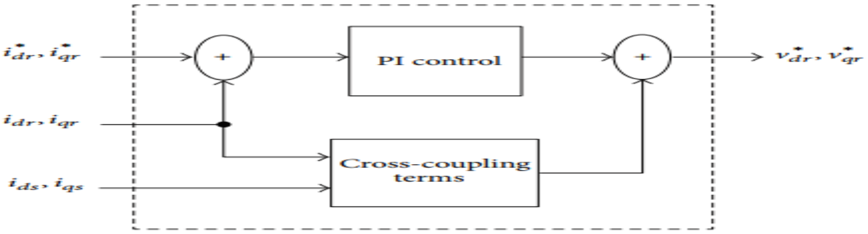


Figure 5: Conventional (indirect) current regulator

This section the closed-loop behavior of the DFIG system is analysis using indirect CMC methods. Two current regulators for the rotor-side converter are considered: the conventional regulator and a regulator deliberate for unbalanced grid faults. In this the open-loop system the DFIG system model and current regulator model is analyses by combining them..

4.5 Conventional Current Regulator.

The open-loop model of the DFIG system is represented, on $d–q$ reference frame. Asynchronously rotating reference frame is used with the direct axis orientation along the stator flux position. Thus, the stator and rotor voltages can be given as follows:

$$V_{ds} = R_s I_{ds} + \frac{d\psi_{ds}}{dt} - j\omega\psi_{ds}$$

$$V_{qs} = R_s I_{qs} + \frac{d\psi_{qs}}{dt} - j\omega\psi_{qs}$$

$$V_{dr} = R_r I_{dr} + \frac{d\psi_{dr}}{dt} + j(\omega - \omega_r)\psi_{qr}$$

$$V_{qr} = R_r I_{qr} + \frac{d\psi_{qr}}{dt} + j(\omega - \omega_r)\psi_{dr}$$

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

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

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

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

We consider the voltages and angular frequencies as inputs, and the currents as output for the open loop model. The stator voltage is supplied by the grid voltage, while the rotor voltage is supplied by the rotor-side converter. It is assumed in this study that the converters are adequately fast, so that they can accurately track the reference voltage.

$V_{dr} = V_{dr}^*$

$V_{qr} = V_{qr}^*$

The figure 5 shows the conventional current regulator for the rotor side converter. The regulator model combines a proportional- integral (PI) controller with cross-coupling.

$V_{dr}^* = R_r i_{dr} + V_{dr}^{Pi} - (\omega_s - \omega_r)\psi_{qr}$

$V_{qr}^* = R_r i_{qr} + V_{qr}^{Pi} - (\omega_s - \omega_r)\psi_{dr}$

5. DESCRIPTION OF FUZZY CONTROLLER

The control system is based on fuzzy logic. This type of control, approaching the human reasoning that makes use of the tolerance, uncertainty, imprecision, and fuzziness in the decision-making process, manages to offer a very acceptable performance, without detailed mathematical model of the system. In addition, it has inherent abilities to deal with imprecise or noisy data; thus, it is able to extend its control capability even to those operating conditions where linear control techniques fail (i.e., large parameter variations).

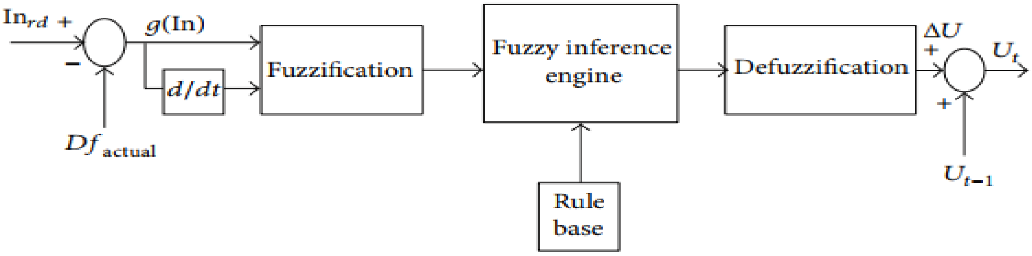


Figure 6: Block diagram of fuzzy controller

This system has four main stages. At initial stage the inputs are fuzzified using input membership functions, and then based on rule bases and inference system outputs are generated, and finally the fuzzy outputs are defuzzified and applied to the main control system. The error of inputs from their references and error deviations in any time interval are chosen as inputs. By using the fuzzy controller it is easy obtaining variable gains depending on the error and it is simple solving problems affected by uncertain models compared to conventional PI controller. The proposed controller is designed in order to compensate the voltage at the PCC by injecting/absorbing the reactive power generated by both of GSC and RSC as well as by regulating the pitch angle in case of voltage sag or voltage swell. When the injected reactive power reaches its maximum value, the voltage in the system reaches to its nominal value, at this pitch angle can be regulated by the fuzzy controller in order to limit the generated active power. Additionally, it is used in combination with a protection system for disconnecting the DFIGs from the grid when the controller is unable to compensate the voltage variations.

In this paper the MATLAB software is used for simulation. The fuzzy logic Control units available in the MATLAB are linked with main system in EMTDC software. Therefore, both softwares work simultaneously in any simulation time. The inputs are sent to MATLAB and they sent to EMTDC software for the main system. The outputs of the fuzzy controller should be added to the prior output to produce new reference output. The main aim of this part is to control active power and voltage regulation of DFIG system using reactive power control. In this system the rotor-side converter manages the reference input of active (P_{ref}) power and reference input of voltage (V_{ref}) separately using fuzzy controllers. Based on inputs of fuzzy controller the errors are estimated in active and reactive powers are produce at any time interval. After the production of d-axis and q-axis rotor currents, they converted to a-b-c reference frame using flux angle, rotor angle, and finally slip angle calculation and Concordia and Park transformation matrix has done. Then they are applied to a hysteresis current controller, they can be compared with actual currents and produce switching time intervals of converter. Controllers in distinction to the conventional PI controllers can take care of the nonlinearity under variable operating conditions. Furthermore, the TS-fuzzy is better than the mamdani type fuzzy controller, because it takes less number of fuzzy sets and rule sets for the input fuzzification.

The proposed fuzzy controller has seven linguistic variables: "NVB"= Negative-Very-Big, "NB"= Negative-Big, "NM" = Negative-Medium, "NS" = Negative-Small, "ZE" = Zero, and so forth.

The Fig. 3.a and Fig. 3.b show respectively the rule bases of voltage and reactive power and membership functions of the inputs (error, error variation)/output (command) variables and the generated surface of the fuzzy controller

6. Rules bases of both voltage and power of Fuzzy controller

6.1 Rules bases of Voltage Fuzzy Controller

			ΔV(volts)			
ΔIDR		NB	N	ZE	P	PB
V(volts)	NB	NB	NB	N	N	ZE
	NB	NB	N	N	ZE	P
	ZE	N	N	ZE	P	P

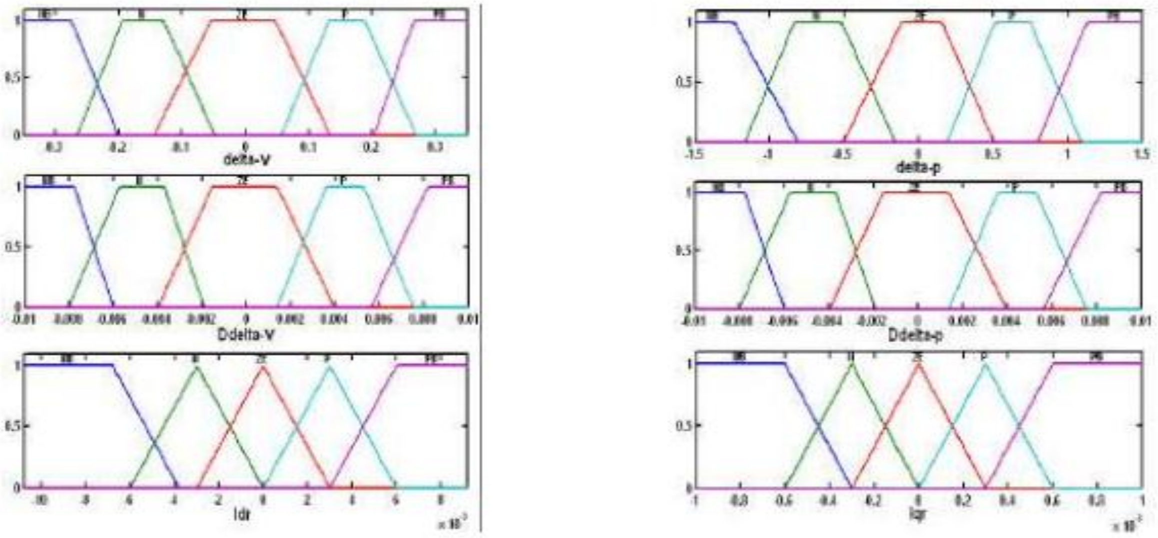
P	N	ZE	P	P	PB
PB	ZE	P	P	PB	PB

6.2 Rules bases of Active Power Fuzzy Controller

		ΔV(Power)				
ΔIqR		NB	N	ZE	P	PB
V(Power)	NB	NB	NB	N	N	ZE
	NB	NB	N	N	ZE	P
	ZE	N	N	ZE	P	P
	P	N	ZE	P	P	PB
	PB	ZE	P	P	PB	PB

7. Member ship functions of Fuzzy controller

Rotor side converter fuzzy controller unit structure



Input and output membership functions of voltage controller

Input and output membership functions of active power controller

Figure: 7

8. MATLAB Simulation Diagrams

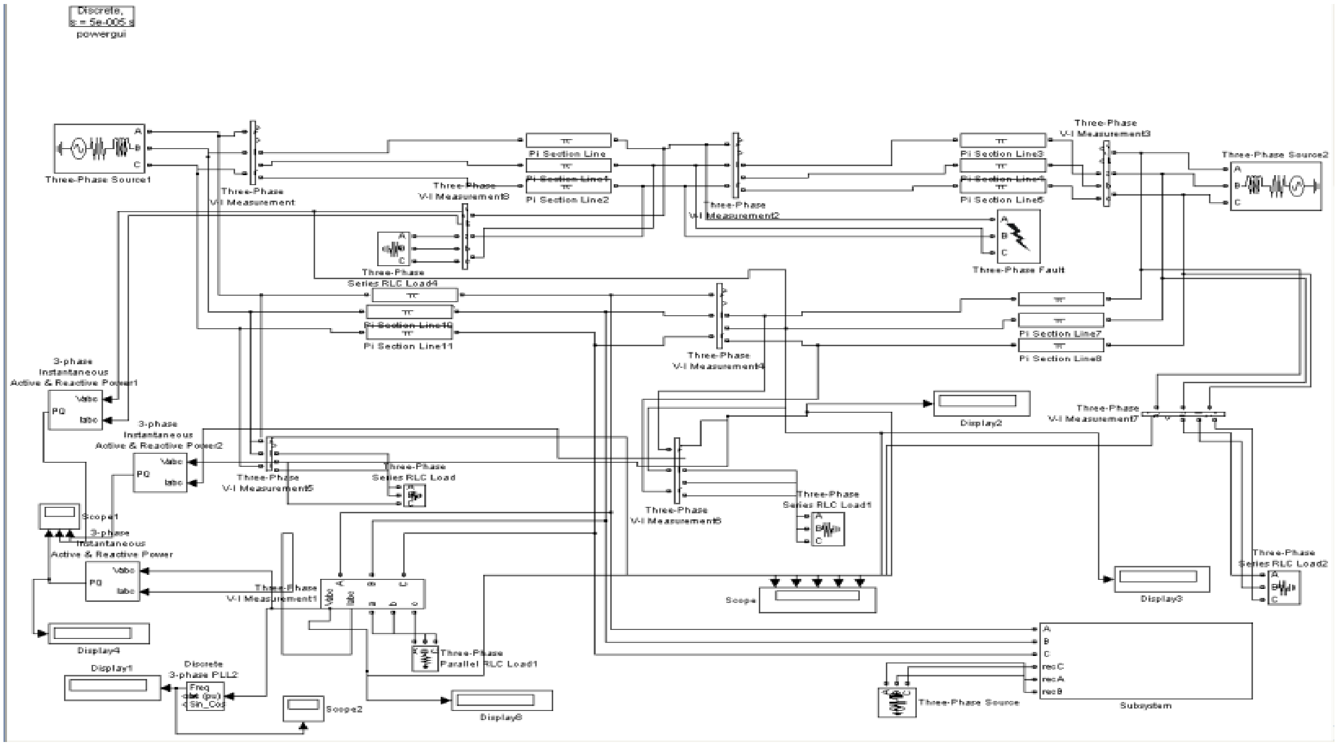


Figure 8: Transmission line of grid connected DFIG model

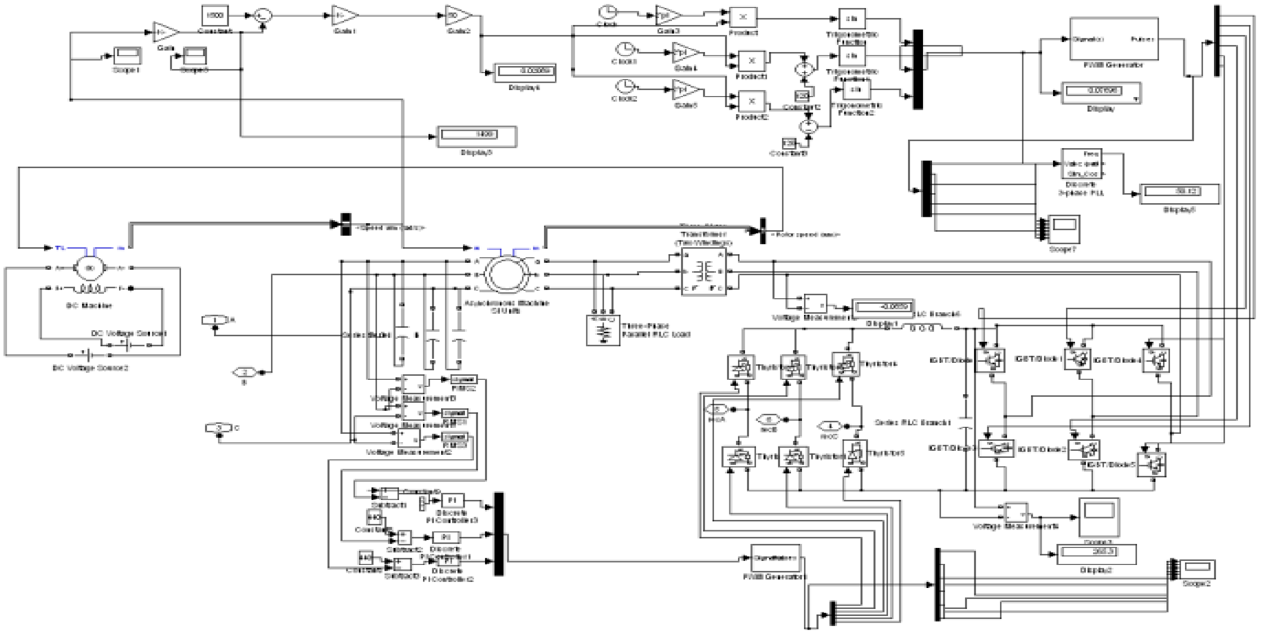


Figure 9DFIG with Fuzzy controllers

Simulation and Discussion

Effect on voltages and power using fuzzy controller

To analyze the effectiveness of fuzzy controller, we will set a MATLAB simulation block diagram shown in figure 8 and figure 9. In this methodology first concerns the extraction of the voltage outages and then the active and reactive power control in faulty phases of double fed induction generator connected grid system using fuzzy controllers. In below figure.5.1 and figure 5.2 shows that voltage recovery and active reactive power improvement in faulted transmission line and healthy transmission lines respectively.

From the figure 10 and figure 11, it is observed that the fault occurred on one of the line, there is an effect that can reduce the voltages and power on other line which are connected to same bus also. After the application of fuzzy controllers guarantees a fast response time and a quick disturbance rejection and improves the voltage and power to great extent.

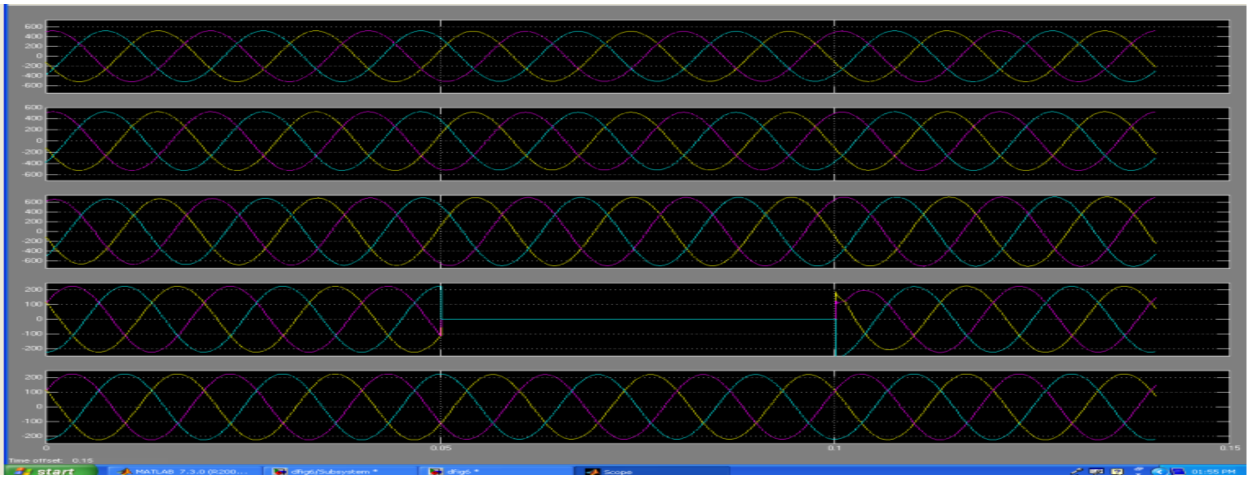


Figure 10: Output voltage status in grid connected DFIG with Fuzzy controller

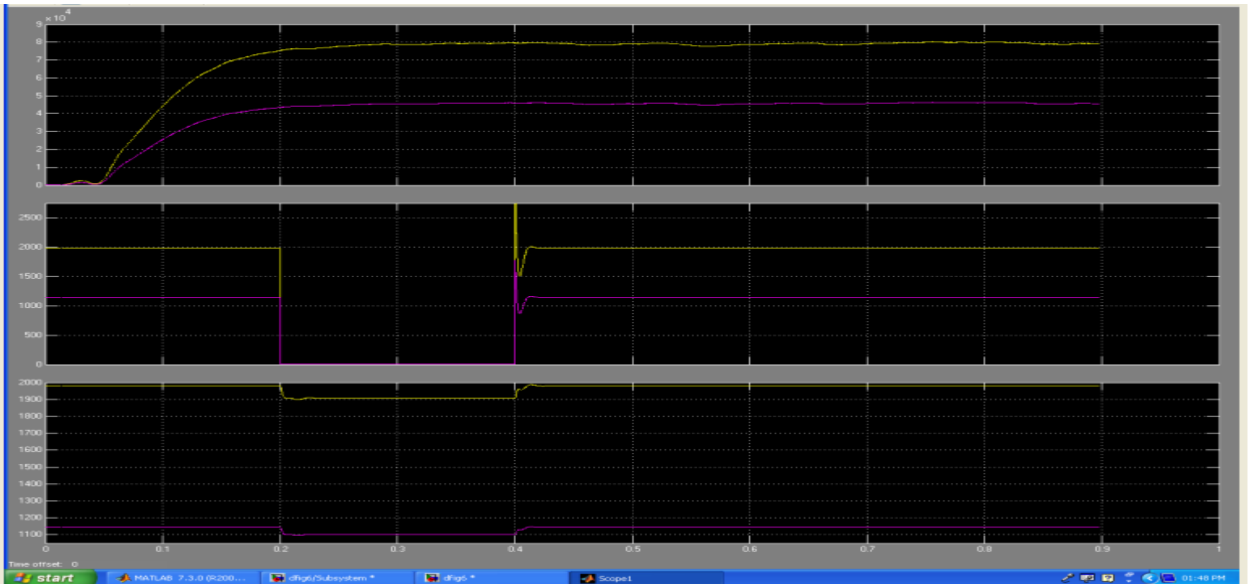


Figure 11: Output Power status in grid connected DFIG with Fuzzy controller

9. CONCLUSION

This paper investigates a fuzzy controller for improving the FRT capability of variable speed Double Fed Induction generator. The controller is designed in order to compensate the voltage sags and swells by controlling the reactive power generated by wind turbines. Simulations carried out on MATLAB based weak transmission; network demonstrated that the proposed method can improve FRT capability in several cases.

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