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Efficacy of Controller Speed on Inertia Response of DFIG

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ABSTRACT

In this paper we studied the effect of the operation speed of the doubly fed induction generator controller on its inertia response. Doubly fed induction generators (DFIG) are commonly used wind turbine generators (WTG) in electricity network. The inertia response of a generator is influenced by the sensitivity of the generator's electromagnetic torque to changes in the power system frequency. DFIG has low inertia response because it's controller takes the slip of machine within fix range. When a dip in grid frequency occurred it couldn't help the system to return back to its optimal value. So, firstly we improved the inertia response of DFIG by adding feedback parameter as a function of the rate of the change of the grid frequency to reference electromagnetic torque and then considered the effect of controller speed. By this, in that condition DFIG released energy in order to reach the frequency to the first value.

KEYWORDS: Wind turbine, Time constant, Inertia response, Electromagnetic Torque, Doubly fed induction generator.

1. INTRODUCTION

With increased production capacity in wind farms, their role in power system stability has become important. The doubly fed induction generator construction caused a good performance when the voltage reduction occurs. In these conditions, without losing any dynamic balance, it will remain connected to the power system. DFIGs are variable speed generators with advantages than others.they are used more in wind turbine because its control is easier and energy efficiency is higher than other generators and power quality is improved in this type of generator [1]. controlled power electronics converters are used for improving the efficiency.

Voltage source inverters are used to convert the voltage magnitude and frequency to adapt the grid values. Stator windings are connected to the grid directly and rotor windings are connected through a back-to-back voltage source converter as shown in Fig. 1[1].

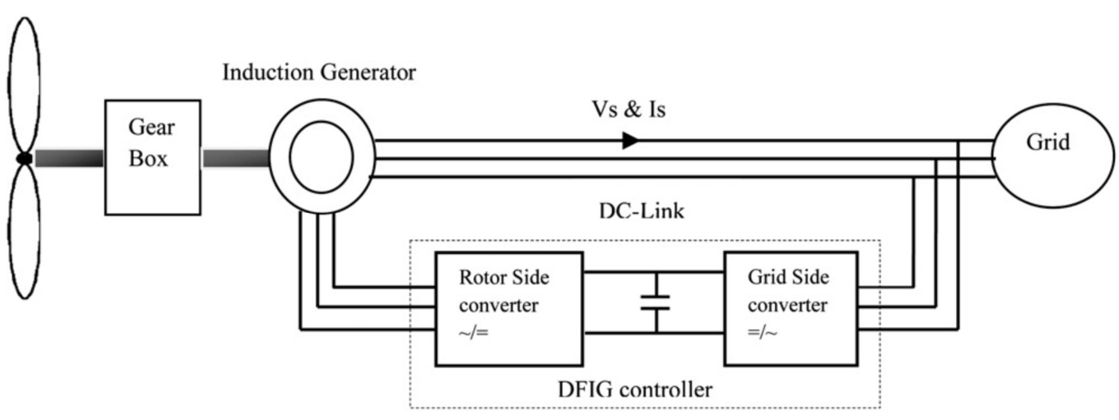

Fig. 1. wind turbine with DFIG

In DFIGs Power converters are used in rotor, so the nominal power that they should have is lower than situation in which the converters are put in the stator circuit(20-25% of the total generator power). This is due

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to the fact that the rotor voltage is lower than the stator voltage. This makes the system more economical [2], [3], [4], [5]. Although all stated advantages, DFIG has a very low inertia response. In conventional synchronous generators when system frequency decreases because of sudden connecting a big load or sudden disconnecting of a big generator in power system, stator rotational field speed will decrease (according to (1)). Considering the existence of coupling between rotational fields of the stator and rotor, speed of the rotational field of the rotor will decrease by decreasing the speed of the rotational field of the stator. By knowing that every rotational mass has stored kinetic energy that is given by (2), released energy by dropping in rotor speed will be calculated by (3) [6,7]. Therefore kinetic energy will release in this situation. Based upon above descriptions conventional synchronous generators will have very good inertia response.

$$n_s = \frac{120f}{p} \tag{1}$$

$$E = \frac{1}{2} j\omega^2 \tag{2}$$

$$\Delta E = \frac{1}{2} j({\omega_2}^2 - {\omega_1}^2) \tag{3}$$

Where n_s, f, p, E, j,w are speed of the rotational field of the stator, system frequency, number of poles, kinetic energy, moment of inertia and angular speed respectively.

In the usual induction generator same as SCIG (squirrel cage induction generator) when system frequency decreases, stator rotational field speed and slip will decrease. By decreasing slip, the electromagnetic torque will increase and rotor speed will decrease, so SCIG has good inertia response [8].

This paper indicates that DFIG has low inertia response. We add some parameters to reference electromagnetic torque and after that we considered different time constant. Simulation results prove that this method improved the inertia response of DFIG and if time constant is reduced the inertia response is increased. In the later studies, they just investigate the inertia response of DFIG without improving it or without consideration the effect of controller speed on inertia response. Section 2 describes the model of DFIG. in section 3 the inertia response of DFIG is investigated and the problem is shown, we improved the inertia response of DFIG by feedback controller in section 4 and in section 5 different time constant for controller is considered. Finally, section 6 presents the conclusion.

2. Mathematical model of DFIG

A model of DFIG for the purpose of analysis, simulation and control is in terms of direct(d) and quadrature (q) axis. The relationship between the stator voltage, the rotor voltage and the fluxes are given by the following equations, where rotor variables and parameters are referred to the stator.

$$\upsilon_{qs} = R_s i_{qs} + \frac{d}{dt}\psi_{qs} + \omega_s \psi_{ds} \tag{4}$$

$$\upsilon_{ds} = R_s i_{ds} + \frac{d}{dt}\psi_{ds} - \omega_s \psi_{qs} \tag{5}$$

$$\upsilon_{qr} = R_r i_{qr} + \frac{d}{dt}\psi_{qr} + (\omega_s - \omega_r)\psi_{dr} \tag{6}$$

$$\upsilon_{dr} = R_r i_{dr} + \frac{d}{dt}\psi_{dr} - (\omega_s - \omega_r)\psi_{qr} \tag{7}$$

The stator and rotor fluxes are given by:

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

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

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

$$\psi_{dr} = L_s i_{dr} + L_m i_{ds} \quad (11)$$

Where

$$L_s = L_{ls} + L_m \quad (12)$$

$$L_r = L_{lr} + L_m \quad (13)$$

The electromagnetic torque is calculated using

$$T_e = \frac{3}{2} p(\psi_{ds} i_{qs} - \psi_{qs} i_{ds}) \quad (14)$$

Finally, if T_{mech} is the mechanical torque, dependent on the local wind speed, the mechanical equation can be written as:

$$\frac{d}{dt}\omega_r = \frac{1}{j}(T_e - T_{mech}) \quad (15)$$

3. PROPOSED PRIMARY CONTROLLER

In the usual DFIG, inertia response is very low. controllers try to keep the turbine at its optimal speed and This causes the slip to be constant hence the output electromagnetic torque becomes constant. In the simulation, fault is take effect as a dip in grid frequency which was shown in Fig. 2. Till 70^{th} second, grid frequency was 50 Hz and the generator has a rotor speed 100 rad/s while give 2MV active power to the infinite bus that were shown in Fig. 3 and Fig. 4 [9].

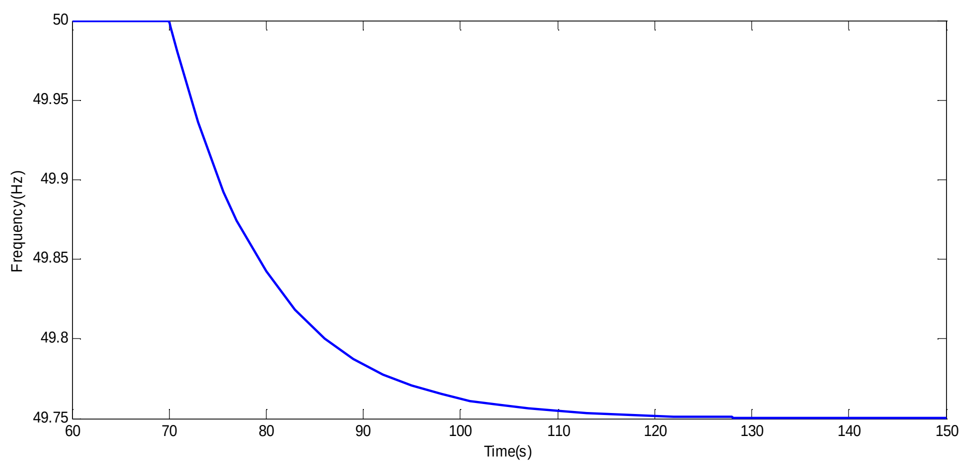

Fig. 2. Grid frequency

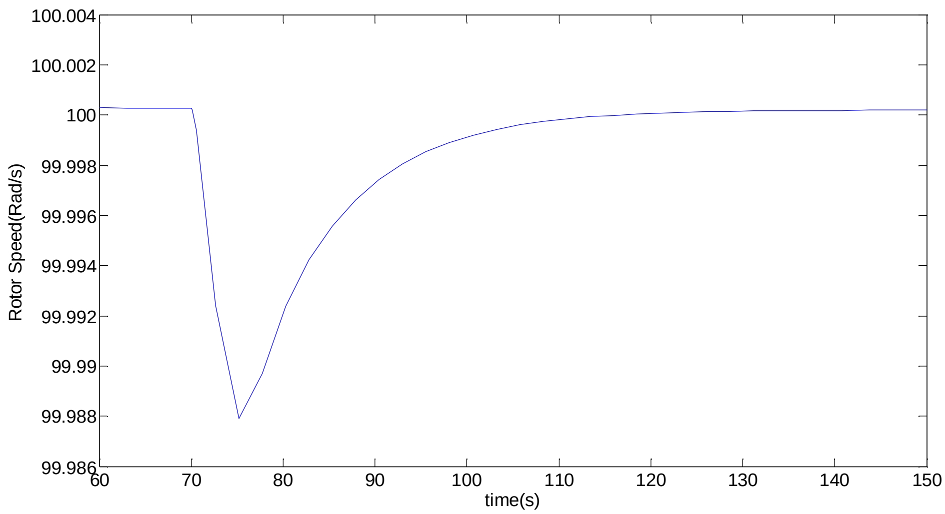

Fig. 3. Rotor speed of DFIG

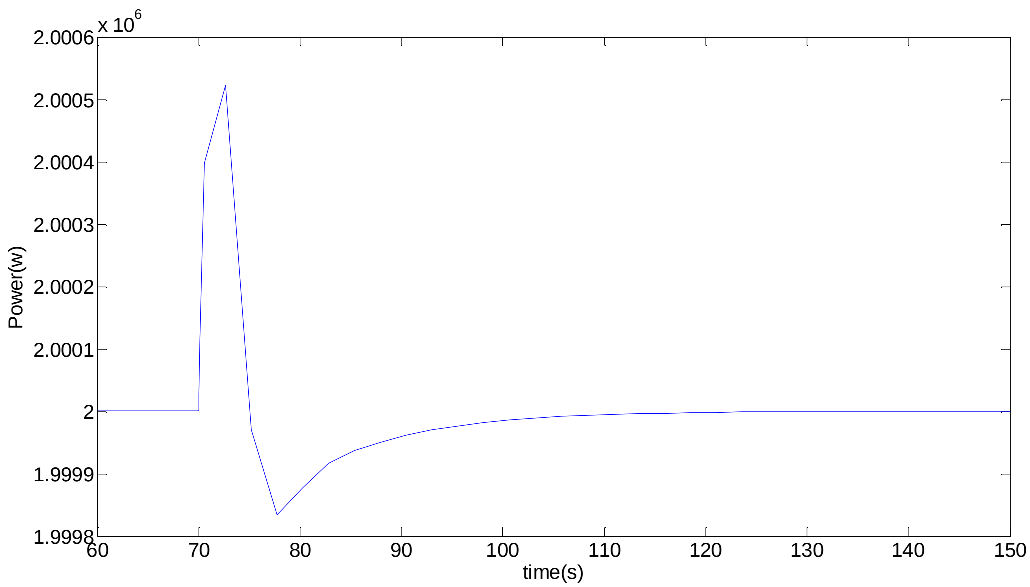

Fig. 4. Output power of DFIG

To improve that, additional parameters should be added to reference electromagnetic torque. The proposed method equations are given by:

$$E = \frac{1}{2} j\omega_r^{\ 2} \tag{17}$$

$$P = \frac{dE}{dt} \tag{18}$$

$$P = j\omega_r \frac{d\omega_r}{dt} \tag{19}$$

$$T = \frac{P}{\omega_r} = j\frac{d\omega_r}{dt} \tag{20}$$

Variations in system frequency have no effect on angular speed of the rotor, therefore this additional parameter is added as a function of the rate of the change of the grid frequency [10]. it is indicated in Fig. 5.
In simulations, reference torque is implemented by below equation:

$$T_e^* = k_1\omega_r^{\,2} + k_2\frac{df_s}{dt} \tag{21}$$

Inertia response is proportional to the controller constant k_2 and deviation of the grid frequency and rotor speed.

Because of feedback in the controller, the rotor speed after 1 second delay, return to its previous speed so during this returning period, kinetic energy and output power of the generator decrease for a moment.

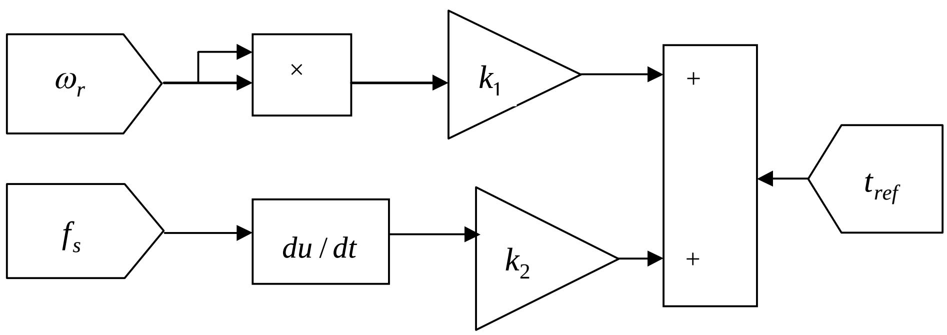

Fig. 5. Primary controller

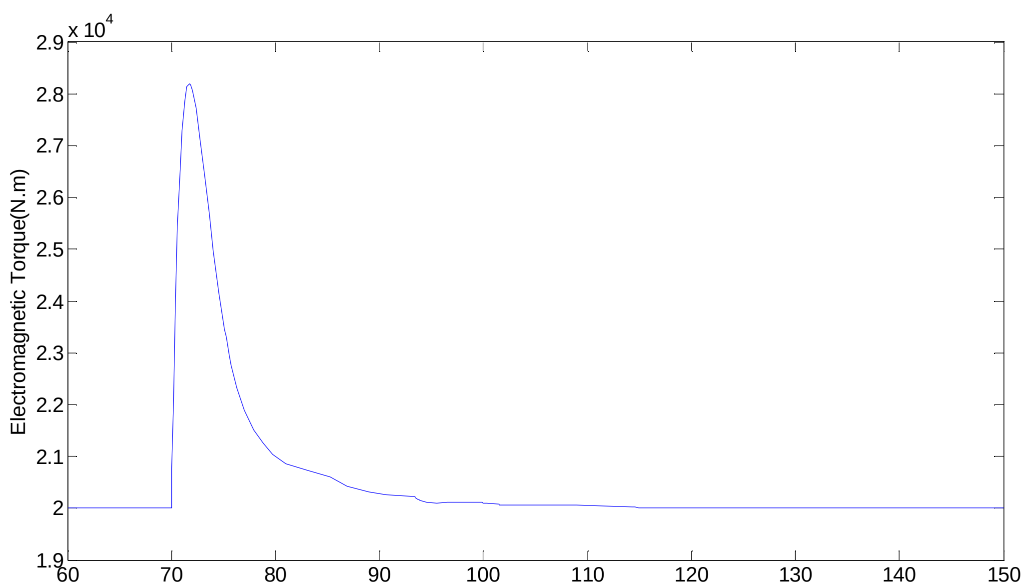

Fig. 6. Electromagnetic Torque of DFIG

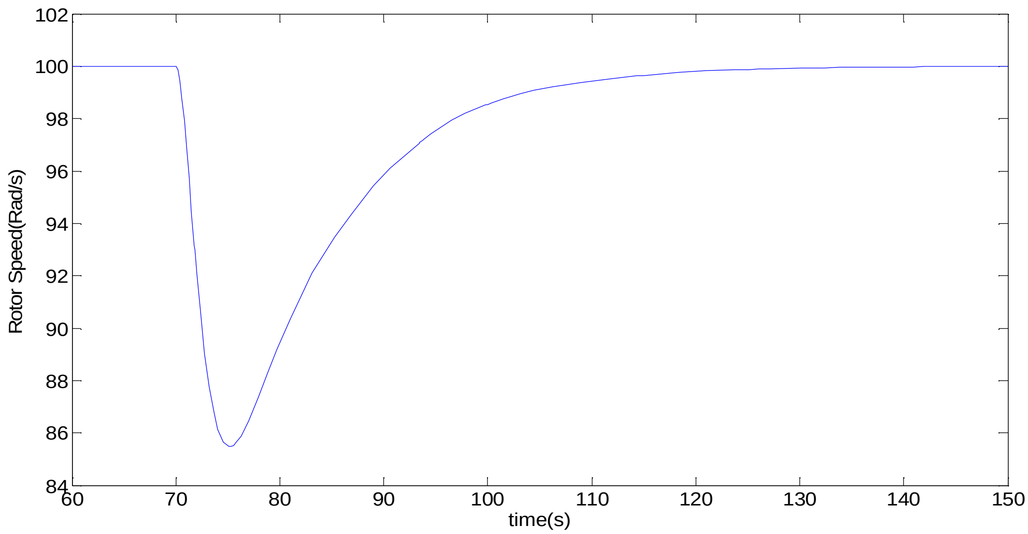

Fig. 7. Rotor speed of DFIG

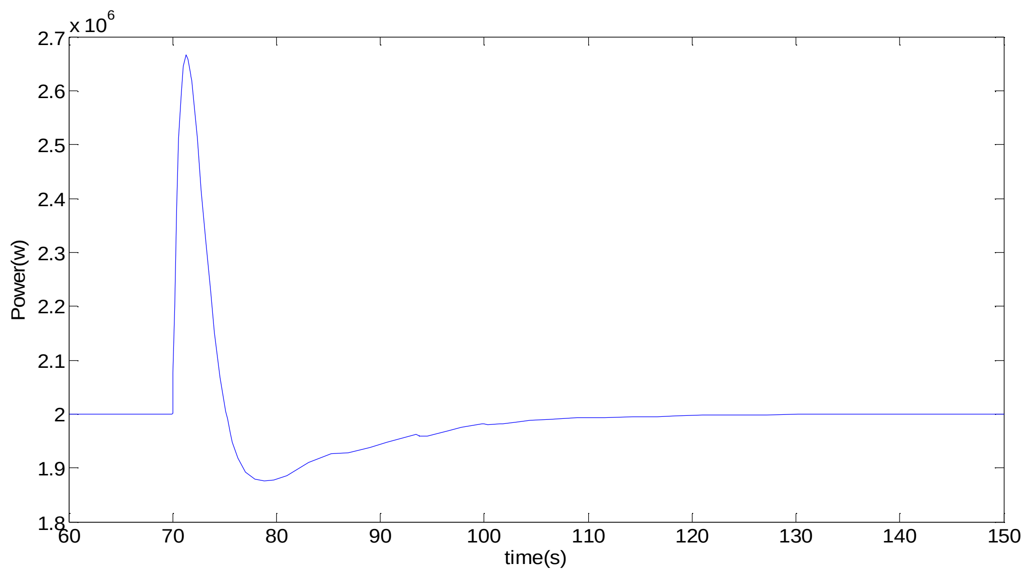

Fig. 8. Output Power of DFIG

It can be seen from figures when the controller is added the inertia response is improved. By taking 1 second for delay time of controller, rotor speed decreased from 100 to 85.5 rad/s. in this decrease of rotor speed as shown in Fig. 7, electromagnetic torque and output power increased up to 28 KN.m and 2.66 MW, respectively. As a result, its inertia response is better than situation without additional controller.

4. INERTIA RESPONSE OF DFIG IN DIFFERENT TIME OF CONTROLLER SPEED

In this section we compare inertia response of DFIG in different delay time of system. We consider 3 time constant as 0.1, 1 and 2 sec. It can be seen from figure that if time constant is reduced the inertia response is increased. When time constant is equal to 0.1sec, the inertia response increases more. So the reaction speed of control system becomes very important.

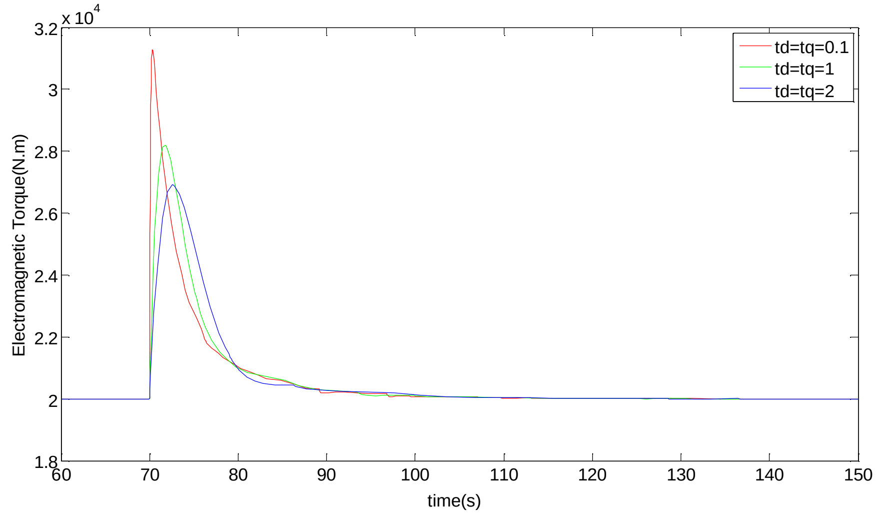

Fig. 9. Electromagnetic torque of DFIG in different time of controller speed

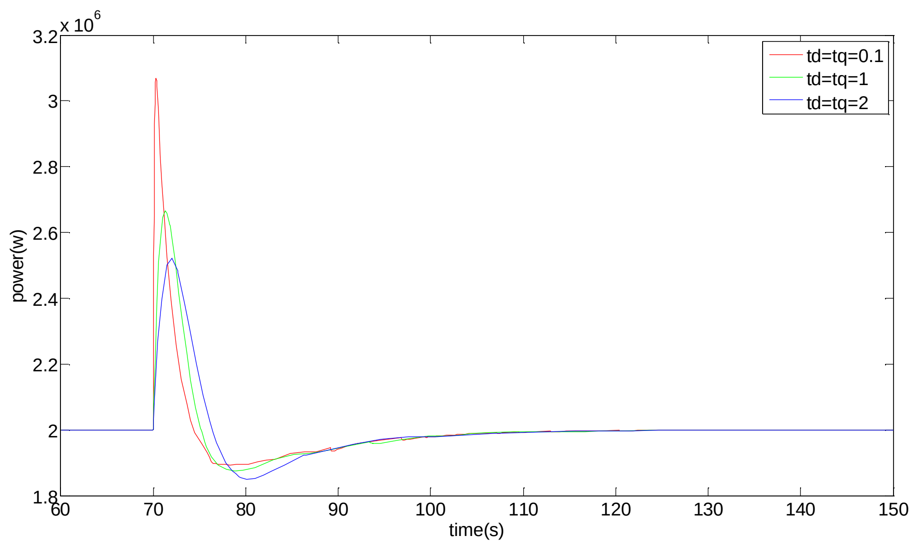

Fig. 10. Output power of DFIG in different time of controller speed

Figure 10 show that when time constant is 0.1 sec inertia response increases about 1 MW, whereas increase for 1sec is about 0.66 MW and for 2 sec is 0.55 MW. So, in the presence of feedback for improving inertia response if the time constant is decreased the inertia response is increased.

5. CONCOLUSION

In this paper, inertia response of doubly fed induction generator was studied. we add controller to its reference electromagnetic torque. The proposed DFIG was compared with DFIG without feedback controller. It showed that after adding controller when a dip in grid frequency occurred, the rotor speed is reduced, kinetic energy is released and output power is increased and inertia response improved. Also, we consider three time constant that show the speed of control system. When we have reduction in time constant, more energy released and output power increases more. So, we see that if time constant is reduced the inertia response is increased. therefore, the reaction speed of control system becomes very important.

APPENDIX

TABLE I: PARAMETERS OF SIMULATED DFIG

Components	Part name/ Manufacturer	Rating values
P_{out}	Rated power	2×10^{6}W
R_S	Stator resistance	$1.748\times10^{-3}\Omega$
Rr	Rotor resistance	$3.253\times10^{-3}\Omega$
Ls	Stator inductance	2.589×10^{-3}H
Lr	Rotor inductance	2.604×10^{-3}H
Lm	Mutual inductance	2.492×10^{-3}H
Vs	Generator output voltage	690V
J	Moment of inertia	1.39×10^{3}Kg/m
T_{in}	Input mechanical torque	2×10^{4}N.m
P	Number of pole	6
fs	frequency	50Hz

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