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Keywords: Inertia response, DFIG, DFIG controller.

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EFFECTS OF THE CONTROLLER PERFORMANCE OF DFIG ON ITS INERTIA RESPONSE

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Effects of the Controller Performance of DFIG on its Inertia Response

Ramin Tayebi Derazkolaie[α], Heidar Ali Shayanfar[Ω], Babak Mozafari[β]

Abstract-Inertia response is the first reaction of the generator to the frequency disturbance in power system that is so important for the grid. Conventional synchronous generators have a high inertia response inherently and therefore the power system by these generators has a high Inertia response. Recently, using the wind turbines by DFIG generators are become popular, consequently, investigation the Inertia response of DFIG is important. At this work the inertia response of a DFIG that is connected to an infinite bus investigated and it is observed that DFIG has a very low inertia response, because its controller takes the slip of machine within fix range. In this paper for studying on effect of the operation speed of the DFIG controller on its inertia response, several different times took for its controller speed.

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I. Introduction

Frequency of power system increases by adding a big load or by disconnecting a big generator. When frequency is proportional by rotor speed of generator and they are electrically couple, by dropping of power system frequency, rotor speed will decrease (from ω_1 to ω_2). By knowing that every rotational mass has stored kinetic energy that is given by (1), released energy by dropping in rotor speed will calculate by equation (2) [1], [2].

$$E = \frac{1}{2} j\omega^2 \qquad (1)$$

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

Where, E, j and ω are kinetic energy, moment of inertia and angular speed respectively. In generators, this released energy will inject in the power system and it will be cause of sudden increasing in output power of generator that is named inertia response [2, 3]. Importance of this increasing in output power is that additional power in all generators of power system in dropping frequency supply some of demand of system and therefore frequency will drop smoother. Having good inertia response in power system, cause that system has not sudden change in frequency in misbalance of supply and demand.

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 the equation (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 of speed of the rotational field of the stator. Therefore kinetic energy will release in this situation. Based upon above descriptions conventional synchronous generators will have very good inertia response.

$$f_s \quad \frac{n_s p}{120} \qquad (3)$$

In which, f_s, n_s and p are system frequency, speed of the rotational field of the stator and number of poles respectively.

Usual induction generator same as SCIG (squirrel cage induction generator) has good inertia response. Therefore increasing of these generators in power system doesn't change inertia response of power system out of normal range. Nowadays DFIG uses in wind power systems. Therefore by increasing of this generator in power system, investigation of its inertia response is important [4].

In this paper inertia response of a DFIG that is connected to an infinite bus investigated. Then by forcing different times for operation speed of the DFIG controller and comparison their result to each other, it is concluded that increasing in speed of the DFIG controller cause to decrease in inertia response of DFIG.

II. Inertia response of DFIG

In DFIG, the rotor winding is connected to the controller through slip rings that control the voltage amplitude and rotor frequency due to demanded applications.

Hence the appropriate performance of the machine is obtained for specific and constant slip and electromagnetic torque with respect to change in wind speeds, the controller injects specific voltage to change the electrical speed of rotor field to prohibit effect of change in mechanical speed of rotor (change of wind

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speed). Therefore it makes constant total rotational speed of rotor field (n_r) through the equation (4).

$$n_r = n_{re} + n_{rmech} \tag{4}$$

Where, n_{re} is electrical and n_{rmech} is mechanical rotational speed of rotor.

This causes the slip to be constant hence the output electromagnetic torque become constant approximately. On the other hand, with this type of control, when the grid frequency decrease and therefore n_s decrease, the controller makes the slip and electromagnetic torque constant by changing the rotor field speed.

According to equation (7), rotor speed is not change and Kinetic energy is not release. So during changes in grid frequency, generator doesn't sense any of that and the inertia response of the machine doesn't change. Of course because of the delay in controlling system, generator has a small inertia response with respect to the delay time. In this interval (delay time), DFIG behave like as a SCIG. So DFIG in the time of grid frequency changes has a small inertia response that is undesirable [5].

Table I: parameters of simulated DFIG

parameter	Value	Unit
P_{out}(rated power)	2×10^{6}	W
R_S(stator resistance)	1.748×10^{-3}	Ω
R_r(rotor resistance)	3.253×10^{-3}	Ω
L_s(stator inductance)	2.589×10^{-3}	H
L_r(rotor inductance)	2.604×10^{-3}	H
L_m(mutual inductance)	2.492×10^{-3}	H
V_s(generator output voltage)	690	V
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	----
f_s(frequency)	50	Hz

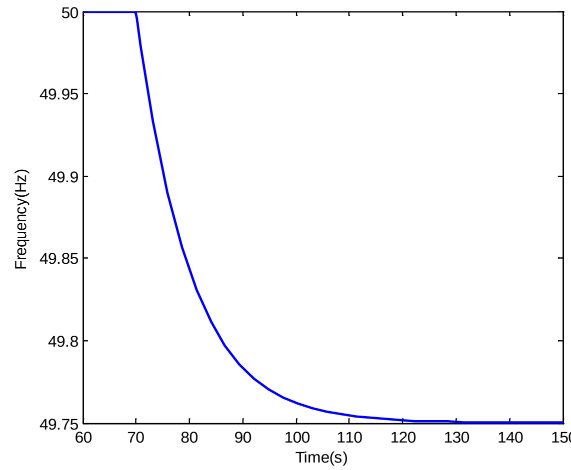

Fig.1. grid frequency

In the simulation according the tabulated parameters values in table I, fault is take effect as a dip in grid frequency which was shown is figure 1. Till 70th 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.

By taking 1 second for delay time of controller, rotor speed decreased from 100 to 99.988 rad/s. in this decrease of rotor speed as shown in figure 2, kinetic energy of rotor decreased from 6950 to 6948.332 KJ. Therefore only 1.6 KJ kinetic energy released. Because of releasing this energy, output power of DFIG as shown in figure 3, increased from 2 to 2.0005 MW that its change is too small.

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.

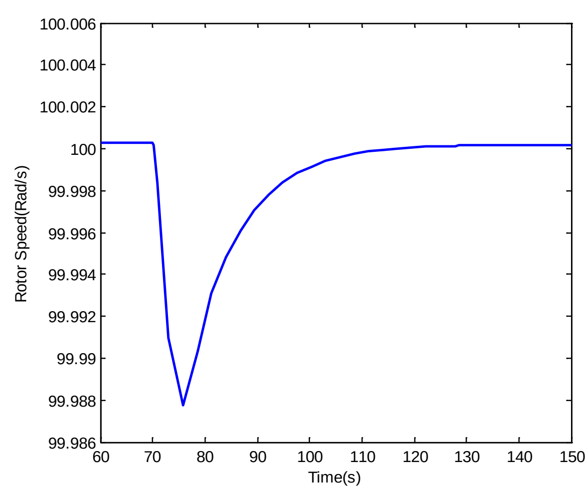

Fig.2. rotor speed of DFIG

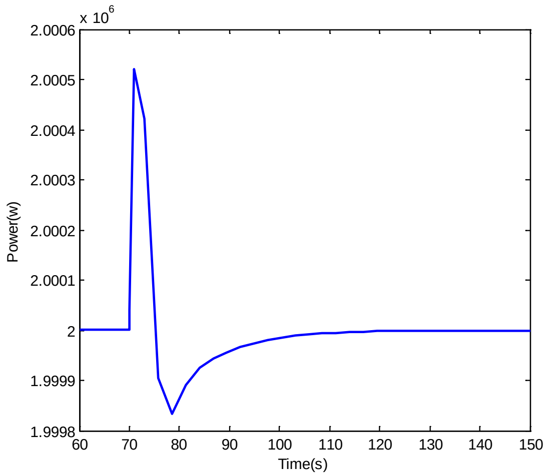

Fig.3. Output power of DFIG

III. Inertia Response of DFIG in Different Times for Controller Speed

Till the controlling system has delay, the DFIG acts as a usual induction generator like a SCIG. In SCIG by decrease in grid frequency, n_s decreases too. So slip that calculates by equation (5) decreases. Since the case study in this paper is in steady state situation, slip is very small and the approximate electromagnetic torque equation for DFIG is given in (6).

As it was mentioned in the last section the value of the delay in controlling system of DFIG has an influence in inertia response of it. In this section, the comparison is made between the different delay times.

It is clear that increasing the slip cause the electromagnetic torque increases. According to equation (6), in normal situation when output electromagnetic torque is equal by input mechanical torque, $d\omega_r/dt$ is zero so the generator works at a constant speed. But if the torque increases for any reason, $d\omega_r/dt$ becomes negative and therefore the rotor speed decreases which cause releasing the kinetic energy from rotor and therefore increasing in output of generator.

So the faster the DFIG controller acts the faster it prevents changes in slip and because of it, the inertia response will decrease [7, 8].

$$S = \frac{n_r - n_s}{n_s} \qquad (5)$$

$$Te = \frac{3SV_{th}^{2}}{R_r \omega_S} \qquad (6)$$

$$\frac{P_{mech}}{\omega_r} - T_e = j\frac{d\omega_r}{dt} \qquad (7)$$

In above equations, S, T_e, V_{th}, P_{mech}, ω_s and ω_r are slip, electromagnetic torque, equal voltage, input mechanical power, stator electrical angular velocity, rotor electrical angular velocity respectively.

In the DFIG that simulated, in order to show the effects of the speed performance of the control system on inertia response, different times took for control system performance speed that the results of it will explain.

Figure 4 shows electromagnetic torque difference with delay times of 0.1, 1, and 2 seconds respectively in performance speed of controller system of DFIG. Note that, in these figures, td and tq are time constants of DFIG controller in Direct and quadrature axis component [1].

It can be seen that electromagnetic torque decreases in the fault by increasing the speed of the controller.

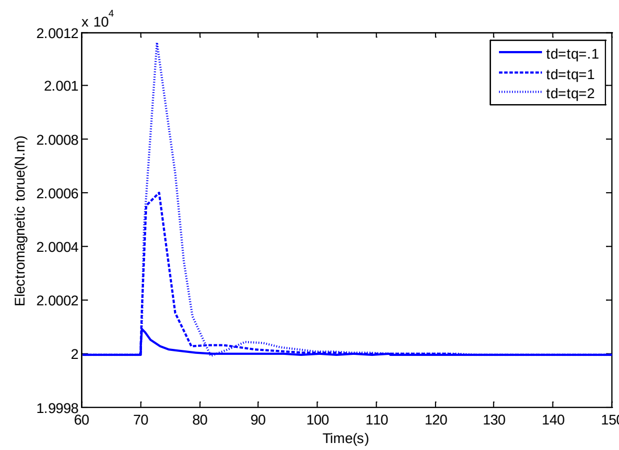

Fig.4. electromagnetic torque of DFIG in different time of controller speed

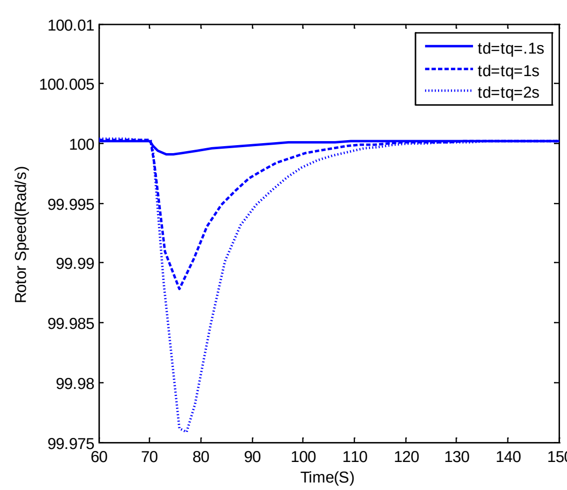

Fig.5. rotor speed of DFIG in different time of controller speed

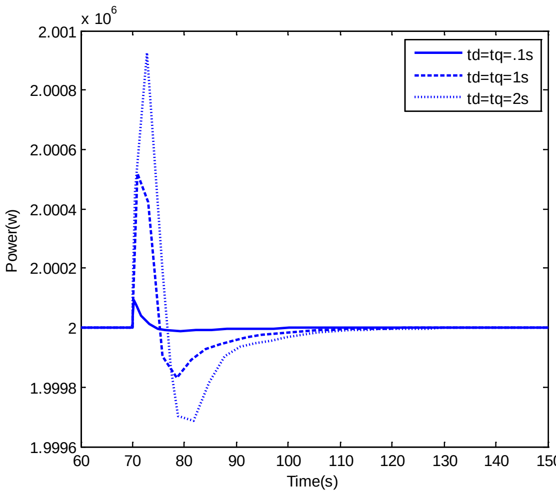

Fig.6. Output power of DFIG in different time of controller speed

Also, Figure 5 shows the rotor speed difference with mentioned delay times. It can be seen that for 2 seconds delay time in comparison to the 1 second delay time, the rotor decreases 2 times more. But for the 0.1 second delay time, the rotor speed is approximately not change. So by decreasing the delay time dip in the rotor speed during grid frequency changes will be less. As it can be seen in figure 6 at this point rotor provides less kinetic energy that causes the active power of the generator to increase less than other situations.

IV. Conclusion

Conventional synchronous generator has appropriate inertia response due to the coupling with grid frequency. So in the grid that most of its generator is synchronous, frequency change doesn't cause any perturbation. Recently contribution of the wind turbines in power generation has been increased and in some case situated for the thermal power plants.

SCIG was the first popular generator used in wind turbines that almost has the same inertia response like synchronous generators.

Nowadays DFIG become the most popular generators used in wind turbines. But this generator doesn't take affect from the grid frequency (because its control system) and it hasn't an appropriate inertia response. Due to delay time till since the control system doesn't work operation of these generators are like Conventional induction machine and has inertia response. By increasing in speed of control system, generator changes in slip modifies sooner which cause the inertia response to decrease.

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