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Investigation of the Inertia Response of the SCIG

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Abstract: Inertia response is so important for the grid because it is the first reaction of the generator to the frequency disturbance in power system. Conventional synchronous generators have a high inertia response inherently. But, nowadays using wind power plants in power system has increased so that in some countries thermal generation stations are exchanged with the wind power plants. Squirrel Cage Induction Generator (SCIG) is popular to use in power plants in location by fix speed wind. Because, it is cheap and does not need any extra maintenance. Consequently, investigation of the inertia response of the SCIG is important. In this study, the SCIG and a week grid are simulated in MATLAB Simulink. At first, inertia response of the grid investigated without connecting the SCIG. Then, by adding the SCIG to this grid, inertia response of the SCIG and grid by taking rotor speed, electromagnetic torque, output power of the SCIG and grid frequency when fault has occurred, are being investigated.

Keywords: Inertia response, SCIG, wind power

INTRODUCTION

Nowadays, renewable energy is popular to use and therefore, wind power plants are being used to generate electrical energy in most countries. Two conventional generators that are used in power plants are SCIG and DFIG. SCIG generator works in location by fix speed wind but, DFIG generator can work in location by variable speed wind (Tayebi-Derazkolaie *et al*., 2011a). By considering the performance in wind speed, DFIG generator is so better than the SCIG generator. But, because of having wounded rotor, back to back system in rotor feed and brush to connect rotor winding to back to back system, DFIG generator is so expensive and needs to extra maintenance (Tayebi-Derazkolaie *et al*., 2011b). SCIG has a simple structure because, it has not back to back system and its rotor is bars that are connected to each others. Therefore, SCIG is so cheaper than DFIG and in location by fix speed wind, using SCIG generator in wind power plants is better and more economic than using DFIG. By considering to use SCIG in power plants, investigation of the inertia response of it, is so important.

Power system frequency increases by adding a big load or by disconnecting a big generator to grid suddenly. 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 Eq. (1), released kinetic energy by dropping in rotor speed will calculate by Eq. (2) (Morren *et al*., 2006; Chowdhury and Ma, 2008).

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

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

where, E, j and ω are kinetic energy, moment of inertia and angular speed, respectively.

In generators, this released energy will inject in the grid and it will be the cause of sudden increasing in the output power of generator that is named inertia response (Chowdhury and Ma, 2008; Mullane *et al*., 2005).

Importance of this increasing in output power is that, additional power in all generators of the grid in dropping frequency supply some of demand of the system and therefore, frequency will drop smoother. Therefore, when power system has good inertia response, frequency of it will not change suddenly in misbalance of supply and demand (Mullane and Malley, 2005).

In conventional synchronous generators when system frequency decreases because of sudden connection to a big load or sudden disconnection from a big generator in power system, rotational field speed of the stator will

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decrease Eq. (1). By considering the existence of coupling between rotational fields of the stator and rotor, by decreasing of speed of the stator rotational field, the speed of the rotor rotational field will decrease. Therefore, kinetic energy will be released in this situation. Based upon the above descriptions, conventional synchronous generators have very good inertia response and therefore, a grid that most generator of it, is conventional synchronous generator, has good inertia response (Holdsworth *et al*., 2003; Mullane and Malley, 2005).

$$f_s = \frac{n_s p}{120} \tag{3}$$

In which, f_s, n_s and P are grid frequency, speed of the stator rotational field and number of poles, respectively. In this work, a SCIG and a week grid are simulated in MATLAB Simulink. At first, inertia response of grid is investigated without connecting SCIG. Then, by adding the SCIG to this grid which 13.3% of the all generation is produced by this generator, the inertia response of the SCIG and grid by taking rotor speed, electromagnetic torque, output power of the SCIG and grid frequency when fault has occurred, are being investigated.

Details of simulated SCIG: Main relations of induction machines has used for the simulation of the SCIG generator.

These equations are formulated in (4)-(7):

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

$$v_{qs} = R_s i_{qs} + \omega\psi_{ds} + \frac{d\psi_{qs}}{dt} \tag{5}$$

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

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

where, V_{ds}, V_{qs}, V_{dr}, V_{qr}, R_s, R_r, L_m, Ψ_{ds}, Ψ_{qs}, i_{ds}, i_{qs}, i_{dr}, i_{qr}, ω and ω_r are stator voltage in direct axis, stator voltage in quadrature axis, rotor voltage in direct axis, rotor voltage in quadrature axis, stator resistance, rotor resistance, mutual inductance, stator flux linkage in direct axis, stator flux linkage in quadrature axis, stator current in direct axis, stator current in quadrature axis, rotor current in direct axis, rotor current in quadrature axis, reference frame angular velocity and rotor electrical angular velocity, respectively.

The stator and rotor currents can be expressed in terms of the dq flux linkages as Eq. (8).

$$\begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ i_{qr} \end{bmatrix} = \begin{bmatrix} -\frac{l_r}{l_\alpha} & 0 & \frac{l_m}{l_\alpha} & 0 \\ 0 & -\frac{l_r}{l_\alpha} & 0 & \frac{l_m}{l_\alpha} \\ -\frac{l_m}{l_\alpha} & 0 & -\frac{l_s}{l_\alpha} & 0 \\ 0 & -\frac{l_m}{l_\alpha} & 0 & -\frac{l_s}{l_\alpha} \end{bmatrix} \begin{bmatrix} \psi_{ds} \\ \psi_{qs} \\ \psi_{dr} \\ \psi_{qr} \end{bmatrix} \tag{8}$$

$$l_\alpha = l_m^2 - l_r . l_m \tag{9}$$

where, L_s and L_r are stator inductance and rotor inductance, respectively.

By locating relations (8) and (9) to (4)-(7), Eq. (10)-(13) are given as:

$$v_{ds} = [\frac{d}{dt} + \frac{R_s}{l_s}]\psi_{ds} - \omega.\psi_{qs} - \frac{R_s l_m}{l_s}.i_{dr} \tag{10}$$

$$v_{qs} = \omega.\psi_{ds} + [\frac{d}{dt} + \frac{R_s}{l_s}]\psi_{qs} - \frac{R_s l_m}{l_s} i_{qr} \tag{11}$$

$$\begin{aligned} v_{dr} &= \frac{l_m}{l_s}\frac{d}{dt}\psi_{ds} = (\omega - \omega_r)\frac{l_m}{l_s}\psi ds \\ &+ (R_r - \frac{l_\alpha}{l_s}\frac{d}{dt})i_{dr} + (\omega - \omega_r)\frac{l_\alpha}{l_s} i_{qr} \end{aligned} \tag{12}$$

Table 1: Parameters of SCIG

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)	H2.604×10^{-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

$$v_{qr} = (\omega - \omega_r)\frac{l_m}{l_s}\psi_{ds} - \frac{l_m}{l_s}\frac{d}{dt}\psi_{qs} - (\omega - \omega_r)\frac{l_\alpha}{l_s}i_{dr} + (R_r - \frac{l_\alpha}{l_s}\frac{d}{dt})i_{qr} \tag{13}$$

Of course, in SCIG, rotor voltages in direct and quadrature axis are zero.

Simulated SCIG in its original value of rotor resistance delivers 2 MW to the grid. Wind speed and therefore, aerodynamic input torque are assumed constant (Holdsworth *et al*., 2003; Mullane and Malley, 2005). Grid frequency is assumed constant in 50 HZ. Values of other parameters have shown in Table 1.

Inertia response of SCIG: In SCIG generator, by decreasing the system frequency, speed of the rotational field of the stator will decrease. By decreasing speed of rotational field of the stator, slip that can be resulted by Eq. (14) will decrease. This investigation is in the steady state situation. Therefore the slip is too low and relation of electromagnetic torque of this generator will be as equation that is given in (15). It is clear by this equation that by increasing and decreasing the slip, the electromagnetic torque will increase and decrease, respectively (Lalor *et al*., 2005)

In the steady state and normal situation, mechanical torque of the input and electromagnetic torque of generator are equal and by attention to Eq. (16), ($d\omega_r/dt$) will be zero. Therefore, generator works without changing in the rotor speed. But, when electromagnetic torque increases by any reason, ($d\omega_r/dt$) will be negative and consequently, the rotor speed will decrease. By this decrease in the rotor speed, kinetic energy releases that cause to the momentary increase in output power of the generator. This process proves that SCIG has rather good inertia response (Holdsworth *et al*., 2004; Sumper *et al*., 2009).

$$S = \frac{n_r - n_s}{n_s} \tag{14}$$

$$Te = \frac{3SV_{th}^2}{R_r\omega_s} \tag{15}$$

$$\frac{P_{mech}}{\omega_r} - T_e = j\frac{d\omega_r}{dt} \tag{16}$$

$$P_{out} = T_e.\omega_r \tag{17}$$

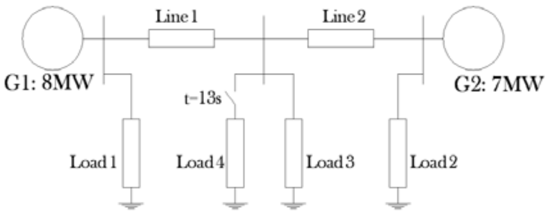

Fig. 1: Grid without SCIG

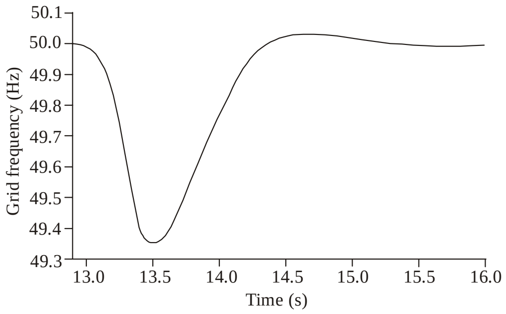

Fig. 2: Grid frequency

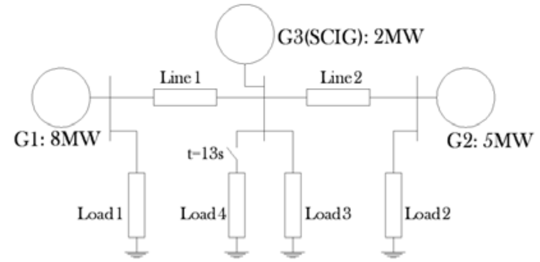

Fig. 3: Grid with SCIG

where, S, n_r, n_s, T_e, V_{th}, R_r, ω_s, ω_r, P_{mech} and P_{out} are slip, rotational field speed of rotor, rotational field speed of stator, electromagnetic torque, thevenin equivalent voltage, rotor resistance, stator electrical angular velocity, rotor electrical angular velocity, mechanical input power and output power of generator, respectively.

RESULTS OF SIMULATION AND DISCUSSION

By considering the fact that the synchronous generators have good inertia response inherently and comparing the inertia response of SCIG with synchronous generator, it can be understand that the rate of inertia response of SCIG is so good.

Therefore, in this section, for more investigation of the inertia response of SCIG and comparing with inertia response of synchronous generator, a week grid that has two synchronous generators (Fig. 1) simulated and at first, fault (fault assumed connecting a 5.5 MW load to system at 13th second) occurs when SCIG that simulated according the tabulated parameters values in Table 1, is

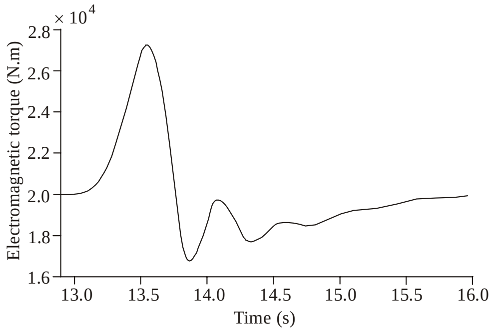

Fig. 4: Electromagnetic torque of SCIG

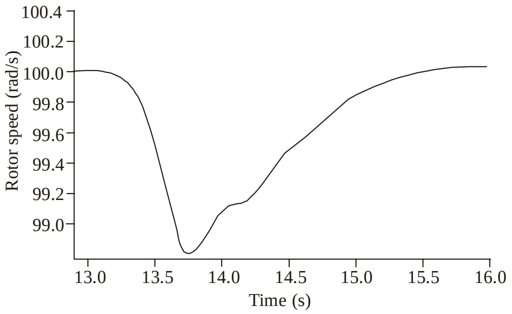

Fig. 5: Rotor speed of SCIG

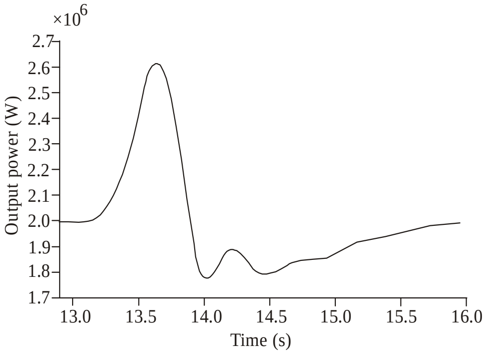

Fig. 6: Output power of SCIG

disconnected and grid contains a 7 MW and a 8 MW synchronous generator. By forcing fault to this grid, frequency decreased from 50 to 49.355 Hz (Fig. 2).

Then, by decreasing 2 MW of generation from 7 MW synchronous generator, SCIG has connected to system Fig. 3. Therefore, in this situation, 13.3% of grid generation, produces by SCIG.

By forcing same fault to this grid during of decrement in grid frequency, electromagnetic torque of SCIG Fig. 4, increased from 20 to 27.44 kN.m. cause of this increase, according to Eq. (16), rotor speed of SCIG, Fig. 5, decreased from 100 to 98.82 rad/s.

Consequently, kinetic energy of rotor that its relation is given in Eq. (1), decreased from 6950 to 6786.948 kJ and therefore, 163.02 kJ energy released. Because of releasing this amount of kinetic energy, output power of SCIG Fig. 6, increased from 2 to 2.618 MW. By considering the increase output power of SCIG when this generator produces 13.3% of grid generation, frequency of grid Fig. 7, decreased from 50 to 49.315 Hz.

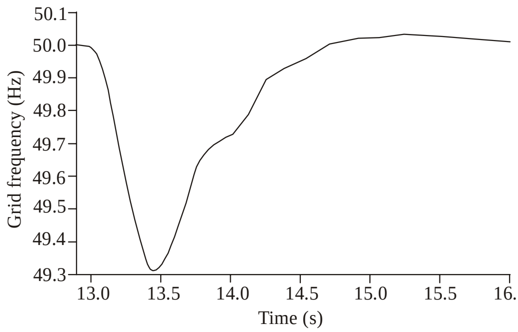

Fig. 7: Grid frequency

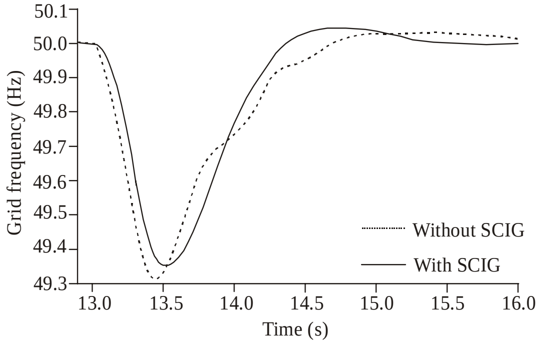

Fig. 8: Grid frequency

In Fig. 8, decreasing the grid frequency when 100% of the generation produces by the synchronous generator and when SCIG contributes in 13.3% of grid generation, can be seen together. It can be understood from this Figure that the inertia response of SCIG is almost as good as the inertia response of the synchronous generator. Consequently, SCIG has rather good inertia response.

CONCLUSION

Conventional synchronous generator has appropriate inertia response due to the coupling with the grid frequency. Thus, in the grid that most of its generators are synchronous, change of frequency doesn't cause any perturbation. Recently, contribution of the wind turbines in power generation has been increased. Therefore, wind power plants are being used to generate electrical energy in most countries. SCIG generator is popular in power plants. Because, it is cheap and does not need any extra maintenance. Consequently, investigation of its inertia response is important. In this study, inertia response of a grid that was feed only by the synchronous generator is investigated. Then, simulated SCIG contributed to 13.3% grid generation and when fault occurred, the rate of change in frequency and inertia response of SCIG is measured. By this study, it can be seen that when system frequency drops, SCIG releases some kinetic energy and its output power increases momentary in a way that the rate of frequency decrease is almost the same as frequency decrease when conventional synchronous generator released kinetic energy. Consequently, it can be concluded that the SCIG has inertia response almost as good as the inertia response of the conventional synchronous generators and this is a good characteristic for the SCIG.

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REFERENCES

Chowdhury, B.H. and H.T. Ma, 2008. Frequency Regulation with Wind Power Plants. Power and Energy Society General Meeting-Conversion and Delivery of Electrical Energy in the 21st Century, Pittsburgh, PA, pp: 1-5.

Holdsworth, L., J.B. Ekanayake and N. Jenkins, 2003. Comparison of Fixed Speed and Doubly-fed Induction Wind Turbines during Power System Disturbances. IEE P-Gener., Transm. D., 150(3): 343-352.

Holdsworth, L., J.B. Ekanayake and N. Jenkins, 2004. Power system frequency response from fixed speed and doubly fed induction generator-based wind turbines. Wind Energy, 7(1): 21-35.

Lalor, G., A. Mullane and M. O'Malley, 2005. Frequency control and wind turbine technologies. IEEE T. Power Syst., 20(4): 1905-1913.

Morren, J., S.W.H. De Haan, W.L. Kling and J.A. Ferreira, 2006. Wind turbines emulating inertia and supporting primary frequency control. IEEE T. Power Syst., 21(1): 433-434.

Mullane, A., A. Bryanst and M. O'Malley, 2005. Kinetic Energy and Frequency Response Comparisons for Renewable Generation Systems. International Conference on Future Power Systems, Amsterdam, pp: 6-11.

Mullane, A. and M. Malley, 2005. The inertial response of induction-machine-based wind turbines. IEEE T. Power Syst., 20(3): 1496-1503.

Sumper, A., O. Gomis, A. Sudria, R. Villafafila and J. Rull, 2009. Response of fixed speed wind turbines to system frequency disturbances. IEEE T. Power Syst., 24(1): 181-192.

Tayebi-Derazkolaie, R., H.A. Shayanfar and B. Mozafari, 2011a. Effects of the controller performance of DFIG on its inertia response. Global J. Res. Eng., 11(3): 21-24.

Tayebi-Derazkolaie, R., H.A. Shayanfar and B. Mozafari, 2011b. Effects of rotor resistance value of SCIG on its output power and efficiency. Int. J. Pure Appl. Sci. Technol., 4(1): 41-48.