Comparison of Squirrel Cage Induction Generator (SCIG) and Doubly Fed Induction Generator (DFIG) Based on Wind Farm Transient Stability Analyses

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Abstract— **There are various wind turbines that are connected to power systems. Investigation of transient stability is very important during connection of wind turbines to power systems. In this study, behaviors of Squirrel Cage Induction Generator (SCIG) and Doubly Fed Induction Generator (DFIG) that were connected to IEEE 14 bus power system were examined during the breakers short-term on-off. In the solution of the problems, Power Systems Analysis Toolbox (PSAT) software was used. SCIG and DFIG connected to the IEEE 14 bus power system. Transient stability effects of SCIG and DFIG were compared. In the IEEE 14 bus test system, angular speed of generator, some generator buses voltage changes, angular speed and angle of asynchronous generators. As a result of the study, we were observed that DFIG becomes stable in a shorter time than SCIG during line break. Thanks to DFIG had been seen that the oscillations disappear.**

***Keywords*— SCIG, DFIG, Wind farm, Transient stability, Generator modeling**

I. INTRODUCTION

Renewable energy sources studies began due to the rising cost of fossil fuels. The most important of these is wind energy. Wind energy power plants that connect to grid are generate electrical energy from wind energy. They have led to positive results for voltage stability due to these plants work together with other different plants in the same power system. However, there is a need to examine instability analysis of wind power plants that work connected to the power systems There are too many studies about the transient stability of wind power plants in the literature analytical calculation of symmetric and asymmetric fault currents were achieved by a method during SCIG and DFIG run on the grid[1]. Three-phase fault analysis and analysis of different critical clearing time were examined by the development of various control models in the wind power plants. Analysis were performed take into account faults were been at different times, and comparisons were made thanks to the developed models [2-3]. Analysis studies were made to work of SCIG and DFIG in the multi-bus power system, against this situation, short-circuit current calculation method is developed. Effects of different buses faults on the system were examined [4-6]. Small signal stability, local effects, inter-area oscillations, synchronous and sub synchronous analysis were examined when various wind turbines worked in the power systems [7-8]. Another one of the analysis of transient stability studies of wind power plants is examined to effects on the static and dynamic load models [9]. Variable speed wind turbine pitch control models that depending on the speed of the wind have been developed. Through this control models SCIG and DFIG have been used more effectively and efficiently [10]. One of the major issues in the study of transient stability is the capacity of active power. Comparisons were made to analysis of different power rates of SCIG and DFIG [11]. Active and reactive power control of SCIG and DFIG were achieved under continuous operation conditions. Power controls were studied depending on the torque-slip characteristics [12]. In this study, the effects of SCIG and DFIG on the system focused when they have operated with power systems as a result of the improper coordination of breakers in the case of the wrong opening and closing. Responses of generator buses, SCIG and DFIG in the IEEE 14 bus test system were given by figures and interpreted.

II. SYNCHRONOUS GENERATOR MODELLING

For the stability analysis, in synchronous generator the sixth order model is used. The equations can be written as,

$$\dot{\delta} = f_b(w-1) \tag{1}$$

$$\dot{w} = \frac{(P_m - P_e - D(w-1))}{M} \tag{2}$$

$$\dot{e}_q' = (-e_q' - (x_d - x_d' - \frac{i_{d0}}{\tau_{d0}}\frac{\dot{x}_d}{x_d'}(x_d - x_d'))i_d + (1 - \frac{\tau_{AA}}{\tau_{d0}'})v_f)/T_{d0}' \tag{3}$$

$$\dot{e}'_d = (-f_s(e'_d) + (x_q - x'_q - \frac{i_{q0}}{\tau_{q0}}\frac{\dot{x}_q}{x'_q}(x_q - x'_q))i_q / T'_{d0} \tag{4}$$

$$\begin{aligned}\dot{e}''_q = (&-e''_q + e'_q - (x'_d - x''_d + \frac{i_{d0}}{\tau_{d0}}\frac{\dot{x}_d}{x'_d}(x_d - x'_d)i_d \\ &+ (\frac{\tau_{AA}}{\tau'_{d0}})v_f) / T''_{d0}\end{aligned} \tag{5}$$

$$\dot{e}''_d = (-e''_d + e'_d - (x'_q - x''_q + \frac{i_{q0}}{\tau_{q0}}\frac{\dot{x}_q}{x'_q}(x_q - x'_q)i_q) / T''_{d0} \tag{6}$$

Where f_b is the fundamental frequency base, P_m the mechanical power, M the mechanical starting time, D the damping coefficient, x_d and x_q the d-q axes synchronous reactance, x'_d and x'_q the d-q axes transient reactance, x_d'' and x_q'' the d-q axes sub transient reactance, T'_{d0} and T'_{q0} the *d*-q axes open circuit transient time constant, T''_{d0} and T''_{q0} *d*-q axes open circuit sub transient time constant, T_{AA} d-axis additional leakage time constant, i_d and i_q d-q axes current, δ the rotor angle, w the rotor speed, v_f the field voltage, e'_d and e'_q d-q axes transient voltage, e''_d and e''_q *d*-q axes sub transient voltage [13-15].

III. SQUIRREL CAGE INDUCTION GENERATOR (SCIG) AND DOUBLY FED INDUCTION GENERATOR (DFIG) MODELING

The schematic representation of the SCIG is shown in Fig. 1.

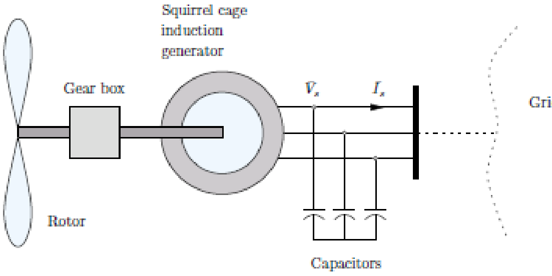

Fig. 1 Schematic representation of the SCIG

Squirrel Cage Induction Generator (SCIG) is connected directly to the distribution grid through winding transformers. There is a gear box which regulates the generator’s speed to the frequency of the grid. During high wind speeds, the power extracted from the wind is limited by the stall effect of the generator. This prevents the mechanical power extracted from the wind from becoming too large. In most cases, a capacitor bank is connected to the fixed-speed wind generator for reactive power compensation purposes. The capacitor bank minimizes the amount of reactive power that the generator draws from the grid. The schematic representation of the DFIG is shown below in Fig. 2.

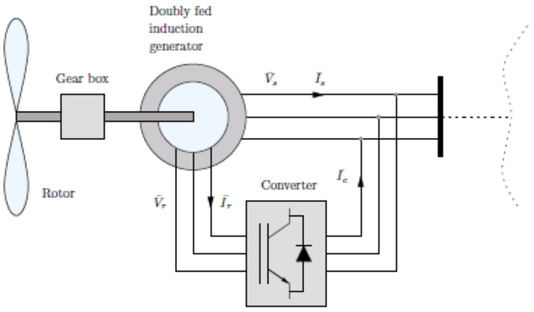

Fig. 2 Schematic representation of the DFIG

Doubly Fed Induction Generator (DFIG) has a gear box, but it is much more complex than the fixed speed generator. The generator is connected to the grid through winding transformers as opposed to a two winding transformer of the fixed speed wind generator. The stator is directly connected to the grid through a pulse width modulated converter. This converter connects to the generator from the grid and therefore allows variable speed operation. In high wind speeds, and fluctuating wind, the output power is kept relatively constant, but close to the rated power of the generator [16-18]. SCIG and DFIG model is represented equations, considering the generator’s variables in the d-q synchronous reference frame. The equations for the stator and rotor windings with the torque equations can be given as follows:

$$v_{ds} = R_s i_{ds} + w_s \lambda_{qs} + \frac{d}{dt}\lambda_{ds} \tag{7}$$

$$v_{qs} = R_s i_{qs} - w_s \lambda_{ds} + \frac{d}{dt}\lambda_{qs} \tag{8}$$

$$v_{dr} = R_r i_{dr} - s w_s \lambda_{qr} + \frac{d}{dt}\lambda_{dr} \tag{9}$$

$$v_{qr} = R_r i_{qr} + s w_s \lambda_{dr} + \frac{d}{dt}\lambda_{qr} \tag{10}$$

$$M = \lambda_{ds} i_{qs} - \lambda_{qs} i_{ds} \tag{11}$$

Flux-inductance equations can be expressed in d-q coordinates as follows:

$$\lambda_{ds} = (L_s + L_m) i_{ds} + L_m i_{dr} \tag{12}$$

$$\lambda_{qs} = (L_s + L_m) i_{qs} + L_m i_{qr} \tag{13}$$

$$\lambda_{dr} = (L_r + L_m) i_{dr} + L_m i_{ds} \tag{14}$$

$$\lambda_{qr} = (L_r + L_m) i_{qr} + L_m i_{qs} \tag{15}$$

In these equations; v_{ds}, v_{dr}, v_{qs}, v_{qr} ,d and q axis voltages of stator and rotor, i_{ds}, i_{dr}, i_{qs}, i_{qr}, d and q axis of currents of stator and rotor, λ_{ds}, λ_{dr}, λ_{qs}, λ_{qr}, d and q axis magnetic fluxes of stator and rotor, w_s angular speed of stator, s slip, R_s and R_r, resistance of stator and rotor, L_s and L_r , inductance of stator and rotor, L_m, magnetic inductance and M :torque [19].

IV. SIMULATION STUDY

Studies have been tested on IEEE 14 bus test system. Tests Power Systems Analysis Program (PSAT) were made. Circuit model in the IEEE 14 bus system shown in Fig. 3.

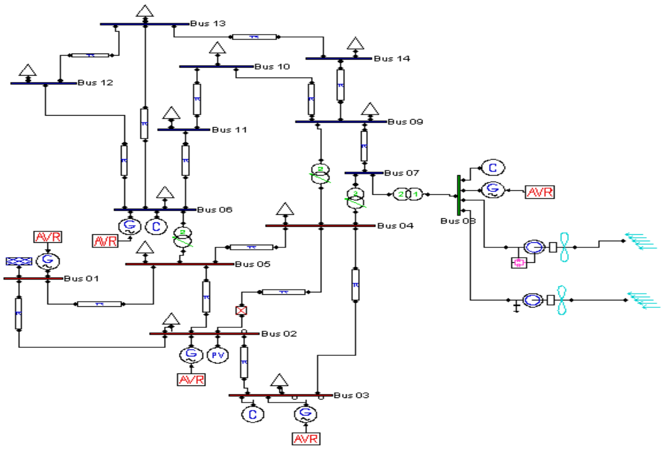

Fig. 3 14 buses system modeling

Bus number 1 in the IEEE 14 bus test system was used as infinite, number 2, 3, 6, and 8 buses were used as generator bus.

Other remaining nine bus were used as the load buses. Reduce voltage transformers were used in 4-7, 4-8 and 4-9 transmission lines. Transformers that located the transmission lines 4-7 and 4-9, performed tap-change and phase shifting operations. Automatic voltage regulator was used to control of power in the generator buses 0.5 MW SCIG and DFIG were connected to generator bus number 8. Switching phenomenon was investigated as a result of the improper coordination breaker that used between the bus number 2 and bus number 4. Breaker was opened and closed between 1 second and 1.5 seconds. SCIG and DFIG analysis in simulation studies were examined separately. The wind speeds of wind turbine that given Fig. 2 for number bus 8 were selected as weibull distribution

V. SIMULATION STUDY RESULTS

Breakers responses were examined against opening and closing when 0.5 MW SCIG and DFIG connected to the IEEE 14 bus power system. Angular speed of synchronous generator, generator buses voltages, SCIG and DFIG angular speed, angle changes were investigated The analysis results of SCIG that is connected to bus number 2 and bus number 8 was shown in Fig. 4-7.

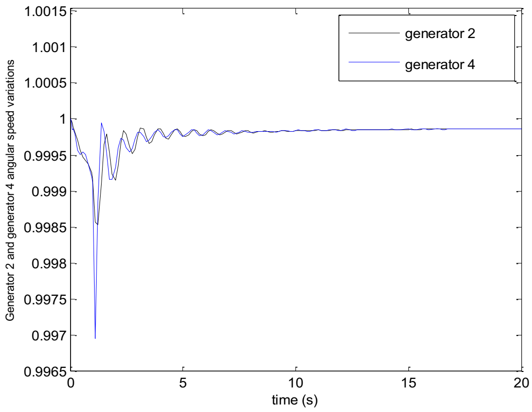

Fig. 4 Generator 2 and generator 4 angular speed variations (with SCIG)

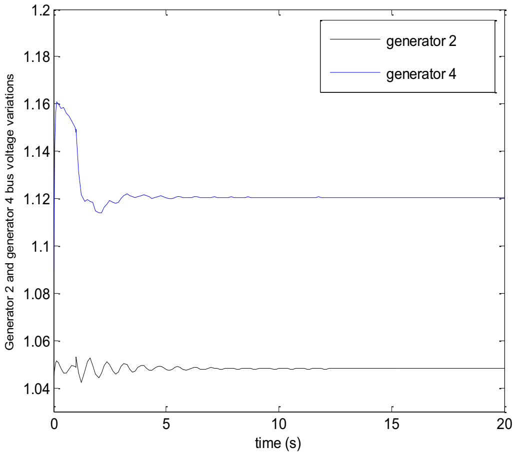

Fig. 5 Generator 2 and generator 4 connected bus voltage variations (with SCIG)

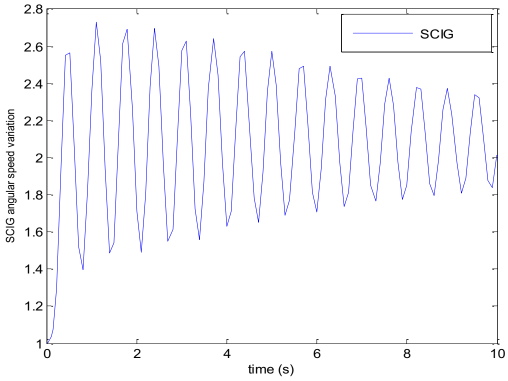

Fig. 6 SCIG angular speed variation

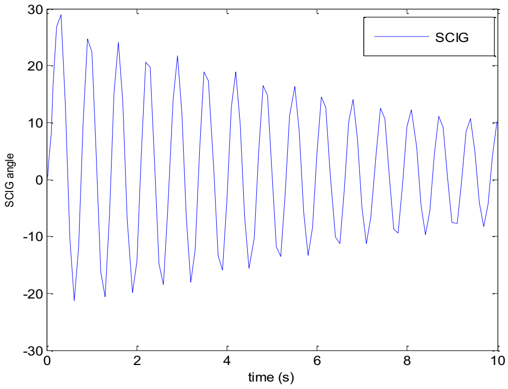

Fig. 7 SCIG angle variation

Synchronous generator angular speed, bus voltage of bus number 2 and bus number 8, were found to had stabilized after a certain time at the 1 second to 1.3 seconds in the process of opening and closing of circuit breakers with SCIG connect to the bus number 8. But the angular speed of SCIG later become stable over time was observed. According to DFIG connect to the bus number 8 that is connect it to the IEEE 14 buses system, the angular speed of synchronous generator, bus voltage, SCIG and DFIG angular velocity, angle changes were shown in Fig. 8-11.

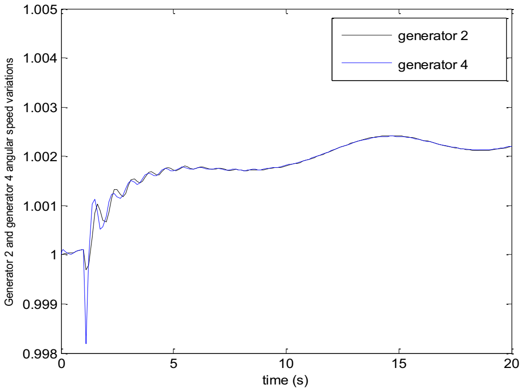

Fig. 8 Generator 2 and generator 4 angular speed variations (with DFIG)

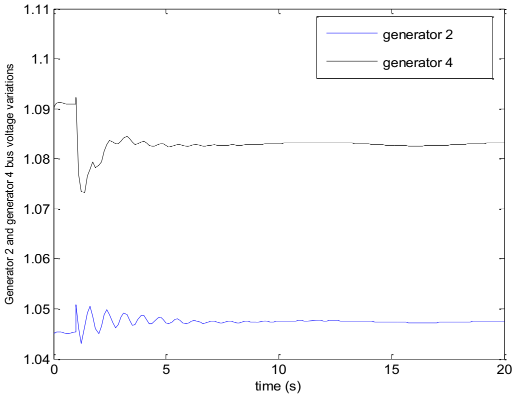

Fig. 9 Generator 2 and generator 4 connected bus voltage variations (with DFIG)

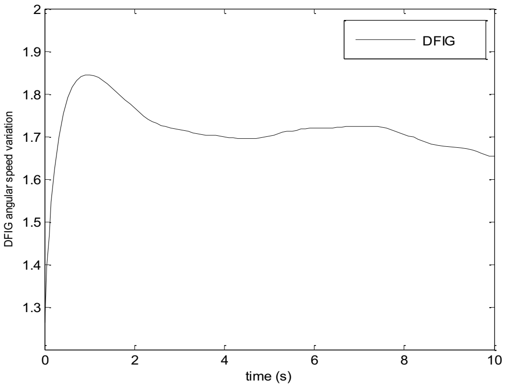

Fig. 10 DFIG angular speed variation

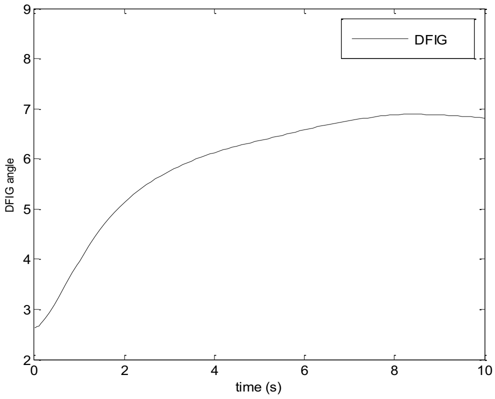

Fig. 11 DFIG angle variation

Synchronous generator angular speed, bus voltage of bus number 2 and bus number 8 were found to had stabilized after a certain time at the 1 second to 1.3 seconds in the process of opening and closing of circuit breakers with DFIG connect to the bus number 8.

VI. CONCLUSIONS

In these studies, effects of SCIG and DFIG on the multi bus power system were investigated under transient stability conditions as a result of line break. In use of both induction generator, their effects on angular speed and angle changes were observed. When used SCIG, synchronous generator of oscillation was found to be a bit more compared to the use DFIG. When used DFIG bus voltage was found to give better results. In line break conditions, the angular speed and angle changes of DFIG and SCIG were examined. It is observed that, oscillations of SCIG increased and system to became stable in a long time. In case of using DFIG instead of SCIG, oscillations of DFIG decreased and system to became stable in a short time.

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