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Transient Simulation of a Self-Excited Induction Generator during Grid Faults

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ABSTRACT

This paper deals with the transient performance of an induction generator in a wind power plant. An induction generator and grid equipment may be damaged when a sudden disturbance occurs, for example, a sudden disconnection from the utility grid. The reasons for this are over-voltage and over speed. This paper analyzes this phenomena using PSCAD/EMTDC and coincides with its corresponding mathematical equation.

Keywords: SEIG(Self-Excited Induction Generator), Wind Power, PSCAD/EMTDC

1. Introduction

It is well known that a three-phase induction machine can be made to work as a self-excited induction generator. When capacitors are connected across the stator terminals of an induction machine, driven by an external prime mover, voltage will be induced at its terminals.

In a small wind power plant or hydro power plant, the use of a three-phase self-excited induction generator (SEIG) is essential. An SEIG provides capacitor banks to compensate for the power factor, and the active power controller and the reactive power controller are coupled, unlike a synchronous machine. This means that the control of an SEIG is complex; an SEIG can be damaged by over-voltage due to capacitors.

In this paper, several phenomena that can be generated in an SEIG are analyzed. The main objectives of this study were:

- To investigate the influence of different capacitors on over-voltage, resulting from fault or AC network disconnection.
- To derive the planning guidelines for operation of an induction generator.

A three-axes to two-axes transformation is used in the calculation of the dynamic frequency value. Here, the transformation is used to simplify the calculation. The dynamic currents, active power, speed, and voltage generated by the SEIG are also given in this paper. To demonstrate several phenomena of induction generators, PSCAD/EMTDC was used.

2. Mathematical Modelling of an Induction Generator

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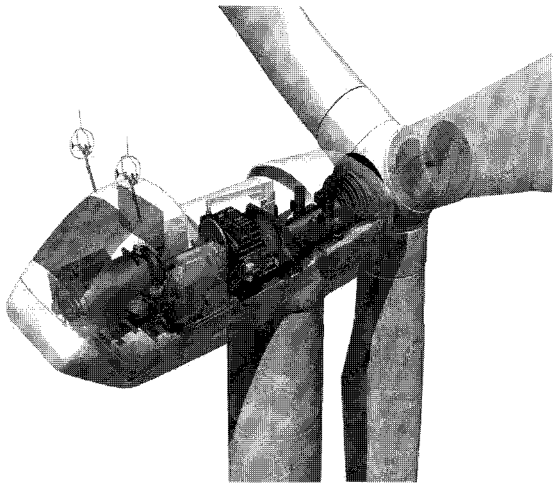
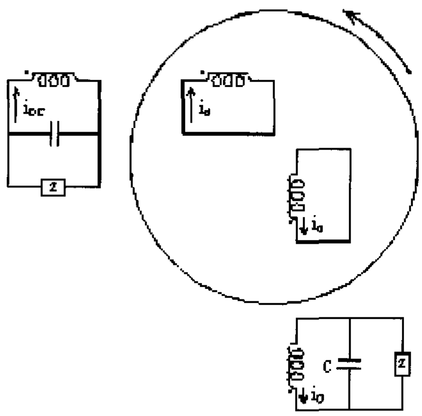
The stator equivalent circuit is compared to an RLC circuit; the term $K_1 e^{m_i t}$ of the transient current flow in both the RLC circuit and the stator equivalent circuit will determine the excitation point. If the real part of m_i is positive, the self-excitation process will start in the air gap of the self-excited induction generator. The process of air-gap voltage build-up will continue until the iron circuit of the machine saturates. Hence, the air-gap voltage stabilizes and the current reaches its steady state, and maintains continuous self-excitation. However, a continuously increasing transient current in the stator circuit is assured if the coefficient K_i has a nonzero value. For an induction generator, this is assured by the presence of sufficient initial residual magnetism in the air gap of the machine.

The initiation of the self-excitation process is a transient phenomenon and is better understood if the process is analyzed using instantaneous values of current and voltage. Thus, a stationary reference frame will be used to represent the transient analysis of the self-excited induction generator. The stationary reference frame representation of a loaded self-excited symmetrically connected induction generator is shown in Fig. 1 where Z can be one of the following cases:

(a) $Z = R + pL$ (inductive load)
(b) $Z = R$ (pure resistive load)
(c) $Z = \infty$ (no load)
(d) $Z = R + 1 + pC_l$ (capacitive load)



(a) Actual Induction Generator



(b) D-Q Model of Induction Generator

Fig. 1 Three-Phase Induction Generator

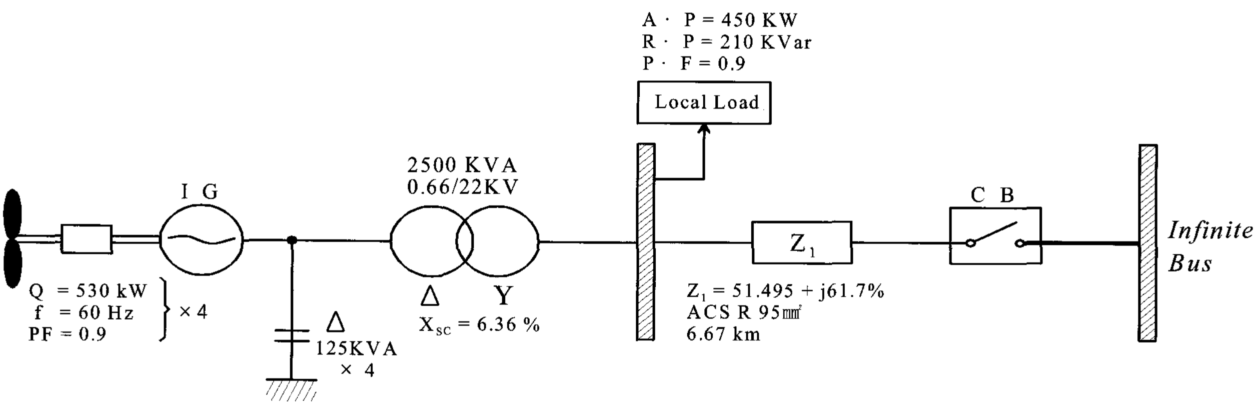


Fig. 2 System Model for Study

For a representative impedance Z, the voltage equations may be expressed as:

$$\begin{bmatrix} v_D \\ v_Q \\ v_d \\ v_q \end{bmatrix} = \begin{bmatrix} R_1 + L_s p + \frac{Z}{1+Z_p C} & 0 & M_P & 0 \\ 0 & R_1 + L_s p + \frac{Z}{1+Z_p C} & 0 & M_P \\ M_P & -\omega_\gamma M & R_2 + L_\gamma p & -\omega_\gamma L_\gamma \\ \omega_\gamma M & M_P & \omega_\gamma L_\gamma & R_2 + L_\gamma p \end{bmatrix} \begin{bmatrix} i_D \\ i_Q \\ i_d \\ i_q \end{bmatrix} \tag{1}$$

Where, $L_s = \frac{X_1 + X_m}{2\pi f}$, $L_\gamma = \frac{X_2 + X_m}{2\pi f}$ and $M = \frac{X_m}{2\pi f}$

The mechanical equation that relates the wind turbine output torque with the induced electromagnetic torque in the induction generator is given by

$$T_t = J\frac{d\omega_m}{dt} + D\omega_m + T_e \tag{2}$$

Where, T_t : Output torque of the wind turbine,

ω_m : Angular mechanical speed,

T_e : Electromagnetic torque in the induction,

D : Friction coefficient,

J : Effective inertia

Since no external voltage is applied and the rotor is short-circuited, the direct-axis stator current will be

$$i_D = \frac{0}{\left(R_1 + L_s p + \frac{Z}{1+ZpC} - \frac{M^2 \delta p}{\Delta}\right)^2 + \left(\frac{M^2 \omega R_2 p}{\Delta}\right)^2} \tag{3}$$

Where, $\delta = L_\gamma p^2 + R_2 p + \omega^2 L_\gamma$, $\Delta = (R_2 + L_\gamma p)^2 + (\omega L_\gamma)^2$

The characteristic equation which represents the self-excitation process of an induction generator and which satisfies all types of loads, is obtained from equation 2 as

$$0 = \{A_5 p^5 + A_4 p^4 + A_3 p^3 + A_2 p^2 + A_1 p + A_1 p + A_0\}^2 + \{B_3 p^3 + B_2 p^2 + B_1 p\}^2 \tag{4}$$

From equation (1), the self-excitation process will start when the polynomial presented in equation (4) has one root having a positive real part.

Assuming a root is obtained in the form $\alpha_i + j\beta_i$, as the capacitance C is increased, α_i will change its sign from negative to positive passing through a zero value. The corresponding value of capacitance C, at α_i=0, is the minimum value C_{min} required to start the process of self excitation. As the capacitance C is increased further, the sign of α_i changes from positive to negative passing through another zero value. At this new zero value of α_i, the corresponding capacitance is the maximum capacitance C_{max}. Fig. 3 shows the capacitance range to generate the self excitation. Fig. 4 shows the variations of the capacitor versus the variation of the generator speed to generate the self-excitation. Fig. 5 shows the variations of the capacitor versus the variations of local resistive load to generate the self-excitation. From Fig. 6, the range of the capacitor of the induction generator to generate the self-excitation is wider than in Fig. 3 in the case with the capacitive local load.

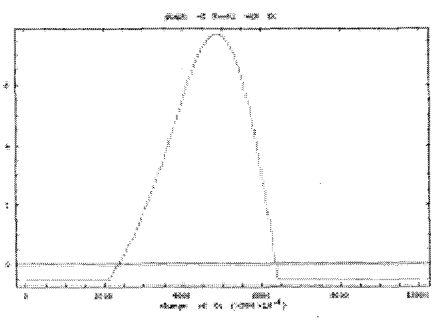


Fig. 3 Capacitor range to generate self-excitation of the induction generator (local load: inductive and resistive load)

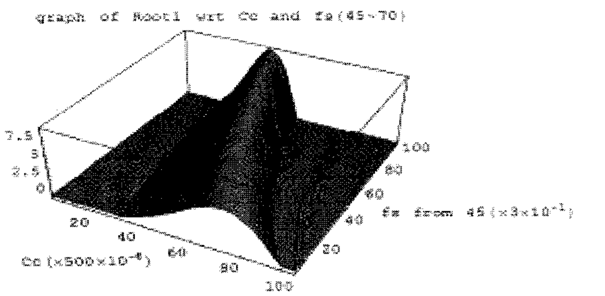


Fig. 4 Capacitor range to generate self-excitation of the induction generator according to frequency variation

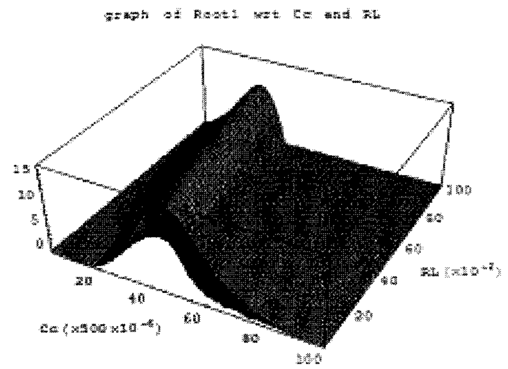


Fig. 5 Capacitor range to generate self-excitation of the induction generator according to local resistive load variation

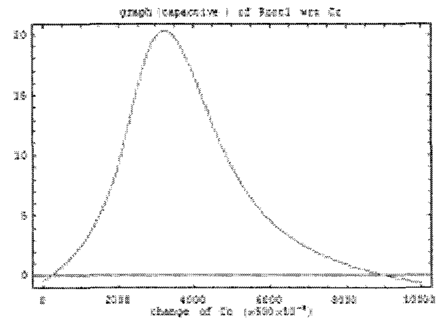


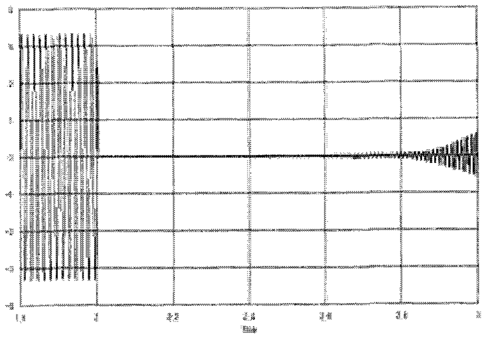
Fig. 6 Capacitor range to generate self-excitation of the induction generator (local load: capacitive and resistive load)

3. System Description and Simulation

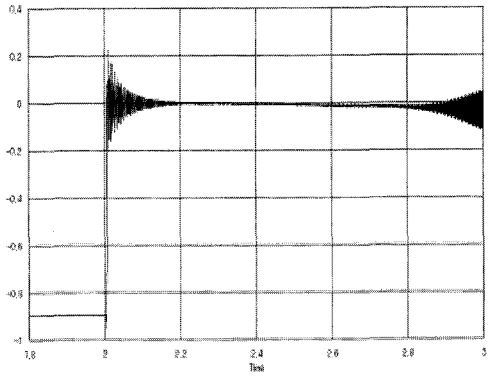
Fig. 2 shows the system studied. The simulation cases were:

1) The influence of the CB disconnection
2) The influence of the capacitor
3) The influence of the load rate of the induction generator
4) The influence of the induction generator according to fault kinds

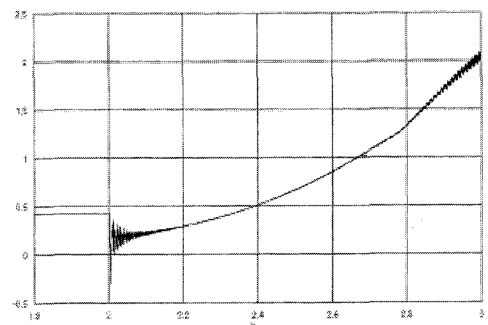
Fig. 7 shows the results of the simulation of the CB disconnection for wind power. In Fig. 7, (a) is the stator current of the induction generator, (b) is the real power of the induction generator , (c) is the reactive power of the induction generator and (d) is the speed of the induction generator , (e) is the voltage of the induction generator.



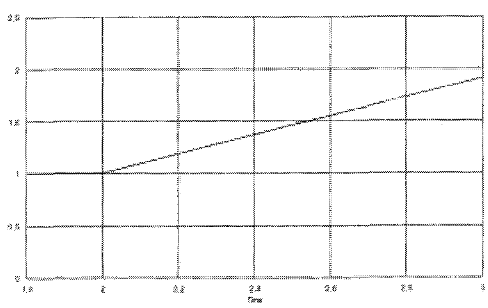
(a) Stator Current



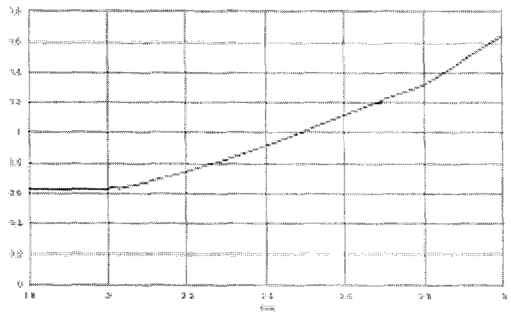
(b) Real Power



(c) Reactive Power

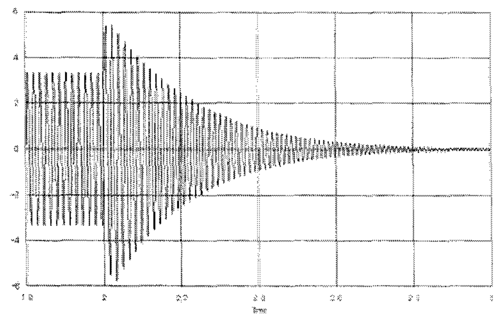


(d) Speed

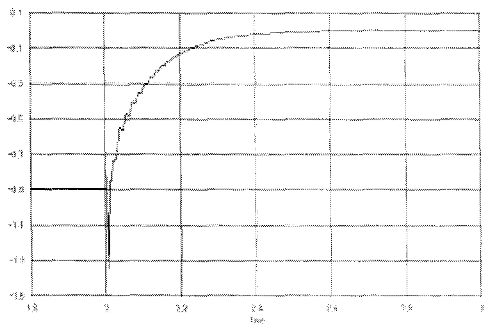


(e) Voltage

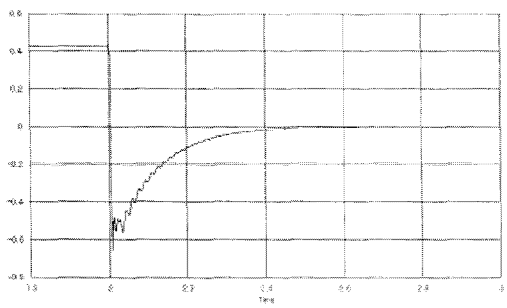
Fig. 7 Simulation Results of the Induction Generator (Break Open)



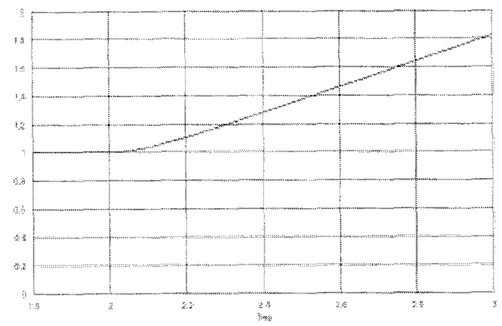
(a) Stator Current



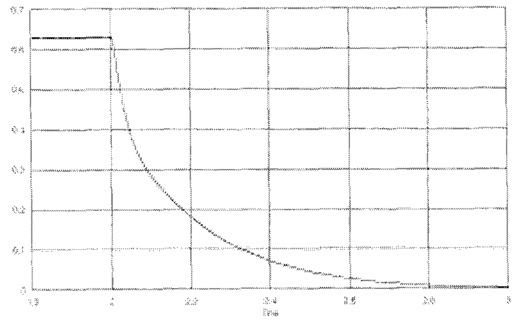
(b) Real Power



(c) Reactive Power

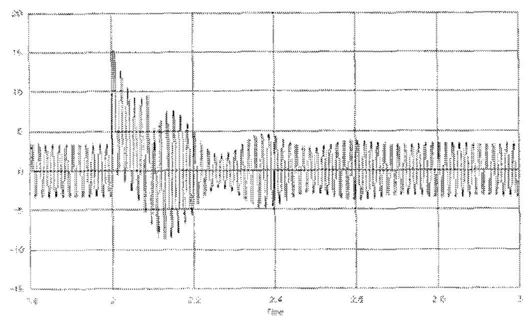


(d) Speed

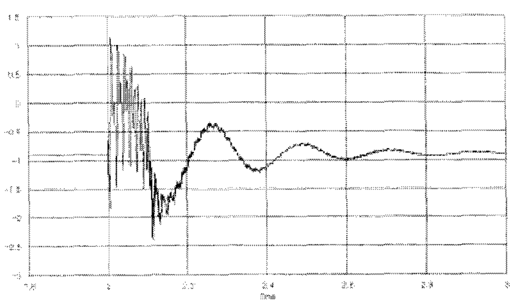


(e) Voltage

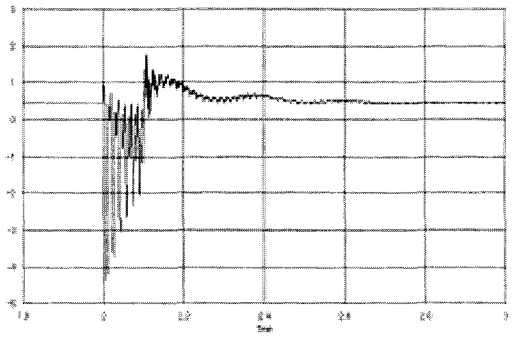
Fig. 8 Simulation Results of the Induction Generator (Break Open –on Load)



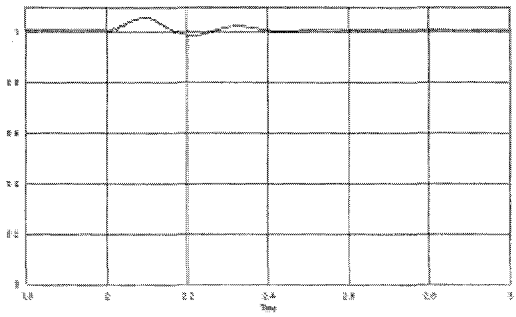
(a) Stator Current



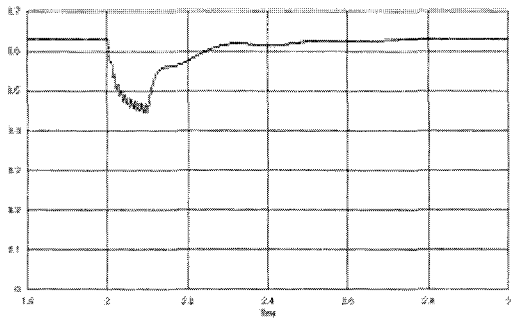
(b) Real Power



(c) Reactive Power

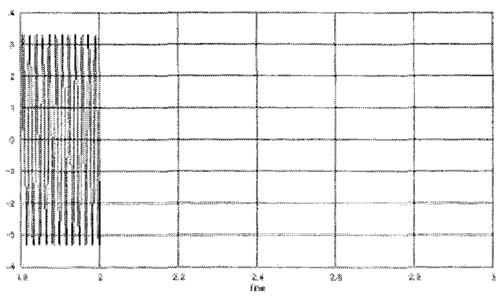


(d) Speed

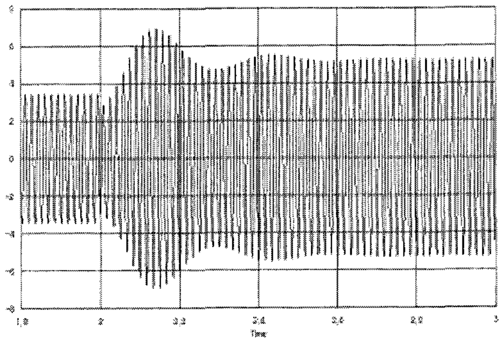


(e) Voltage

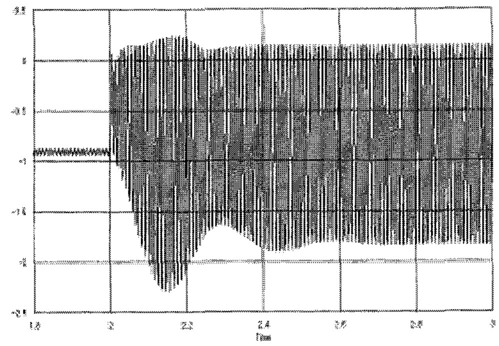
Fig. 9 Simulation Results of the Induction Generator (One Phase Fault)



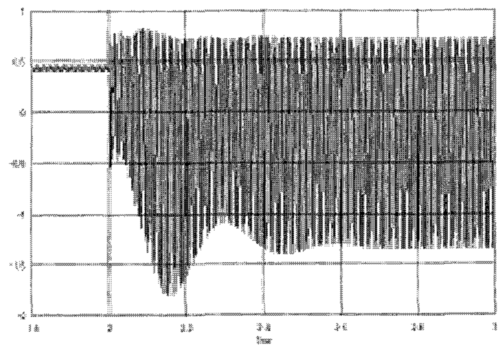
(a) Stator Current (A-Phase)



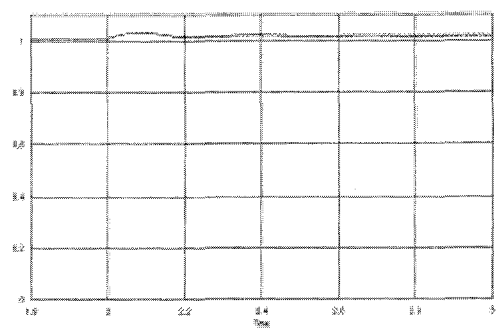
(b) Stator Current (B-Phase)



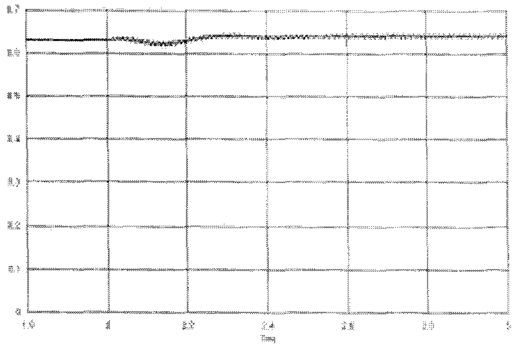
(c) Real Power



(d) Reactive Power



(e) Speed



(f) Voltage

Fig. 10 Simulation Results of the Induction Generator (A-Phase Capacitor Disconnection)

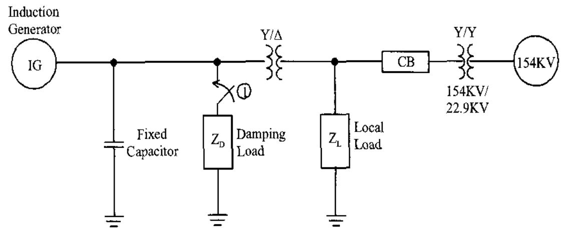
Fig. 8 shows the results of the simulation of the CB disconnection considering the local load. In Fig. 8, (a) is the stator current of the induction generator, (b) is the real power of the induction generator, (c) is the reactive power of the induction generator, (d) is the speed of the induction generator, and (e) is the voltage of the induction generator.

Fig. 9 shows the results of the simulation for the condition of one phase fault. In Fig. 9, (a) is the stator current of the induction generator, (b) is the real power of the induction generator, (c) is the reactive power of the induction generator, (d) is the speed of the induction generator, and (e) is the voltage of the induction generator.

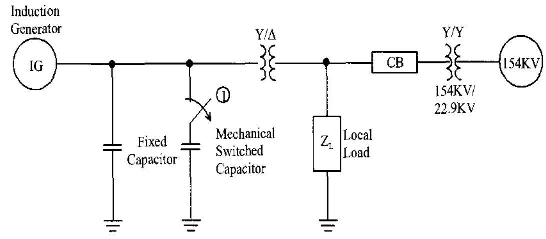
Fig. 10 shows the results of the simulation for the condition of one capacitor fault. In Fig. 6, (a) and (b) is the stator current of the induction generator, (c) is the real power of the induction generator, (d) is the reactive power of the induction generator, (e) is the speed of the induction generator, and (f) is the voltage of the induction generator.

4. Solution

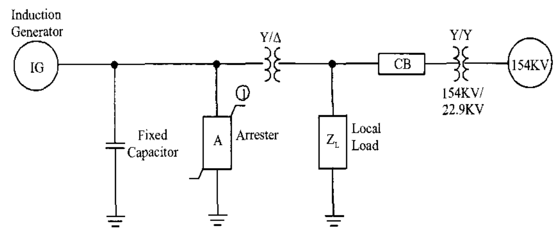
Several methods are presented to avoid the over-voltage from the simulation results as shown in Figure 11(a)~(c). If we consider the factors as unbalanced fault, unbalanced load, unbalanced capacitor, harmonic current and power factor, the best solution is shown in Figure 11 (d).



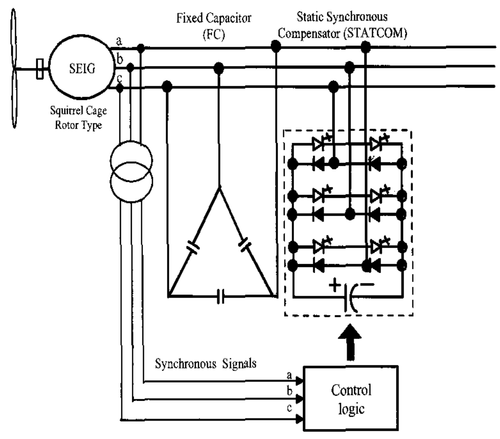
(a) SEIG with Damping Load



(b) SEIG with Double-Separated-Capacitor



(c) SEIG with Arrester



(d) SEIG with STATCOM

Fig. 11 Simulation Results of the Induction Generator

5. Conclusions

The dynamic performance of the machine we studied was analyzed to determine the effects of various conditions on the SEIG. The specific conclusions of this paper are as follows.

• When the CB is suddenly disconnected from the machine's terminals under a no-load condition, causing the self-excitation, over-voltage and over-speed of the machine, then the local loads of the SEIG terminal enhance the system stability.

• When the capacitance for self excitation is suddenly switched off, the machine's voltage quickly reaches steady-state zero. The capacitive load has an effect similar to an excitation capacitance and it will cause the generated voltage to delay a moment to reach its steady-state value.

• When one-phase fault is suddenly generated from the machine's terminals, the machine's phenomena are similar to a synchronous machine.

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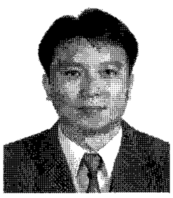

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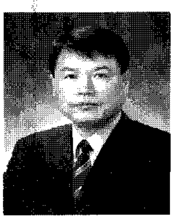

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