SELF –EXCITATION OF THREE PHASE INDUCTION GENERATOR (SEIG) ANALYSIS OF TRANSIENT WITH MATLAB/SIMULINK APPLICATION

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Abstract
Self – Excitation is a common attribute of Induction generators, whenever capacitors are being arrange in such a way that they are in series with the terminals of the stator, and externally driven by the prime mover. Self – excited generators are often associated with the attendant problem of Poor voltage regulation as well as overload strength which suffers from problems of excitation losses, short-circuit and re-excitation. This can be easily experienced when the generator is used in wind power generation. In situations where carried loads experiences short circuit, excitation is being sustain by the machine but the voltage drops as the fault is sustained. These short comings of the associated with the induction generators with self- excitations (SEIG) are investigated and performance at transient level of a self -excited induction generator under fault conditions is analyzed. The SEIG model equations are first developed and simulation carried out using MATLAB/SIMULINK on the models under different operating conditions. The effect of faults conditions of such a machine is determined through its transient evaluation. From which it could be observed that excitation is lost due to short –circuit experienced at the machine terminals, the machine rebuilt voltage is removed at fault condition and momentarily, the buildup process is faster. Transient quick response of the induction generator under self-excitation makes it most suitable for a self-regulated, rugged and simple generating system.

Keywords: Machine transients, faults conditions, SEIG, Machine stability MATLAB/SIMULINK.

1.0 INTRODUCTION

Induction machines (IMs) with three phase configurations can be used as generators in electric power systems, apart from their general use as motors. The induction generator is advantageous mostly in hydro and wind power and plays a major role in the renewable energy industry. However, the induction generator is limited in terms of excitation. This means that it is difficult to employ induction generators in remote areas where there is no electrical power supply network. Off grid excitation can be achieved by connecting a three-phase capacitor bank shunted at the terminals of the stator to supply the reactive power requirement, [1, 2].

Once the power source is externally engaged to drive such machines, electromagnetic force EMF is produced by the residual magnetism emanating from the rotor as a result of the windings in the stator. The current flow in the stator at this point is as a result of the EMF generated and establishing a magnetizing flux in the machine. Real power supply induction generator is achieved if the connections are done this way and it could serve as a standalone generating plant or generator. This is capable of carrying reactive loads.

However, induction generators that are self-excited have a certain setback which is that system frequency and voltage produced by the system is highly dynamic under various fault conditions. Many findings have been made in the quest to effectively regulate the speed and voltages of induction generators that are self-excited under variable loads conditions yet the outcomes of these have not satisfactorily ascertain the its level of performance as a result of its non-linear behavior of the machine in question [2,3]. In an attempt to better understand the above problem, this work is focused on studying the transient behavior of the induction generator with self-excitation (SEIG) system under fault condition.

II. Self-Excitation Process and Voltage Buildup SEIG

Self-Excitation Process and Voltage Buildup in induction generators that are always self-excited is a common and quick process as compared to the non-self-excited ones. Self-excited induction generator works just like an induction machine in the saturation region except that it has excitation capacitors connected across its stator terminals. In the absence of power supply from the national grid, these machines are the best available alternative stand-alone energy producing sources to meet the teeming demand for electricity in that region. The rotor here must have an accurate and adequate capacitive power attached to it externally as a backup for the magnetic field. To obtain affected output parameters such as frequency, voltage, torque, speed etc. The induction generator must be in the excited mode with capacitance, [7].

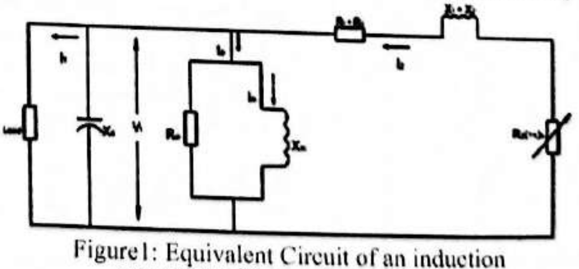

Figure1: Equivalent Circuit of an induction generator with per-phase variables

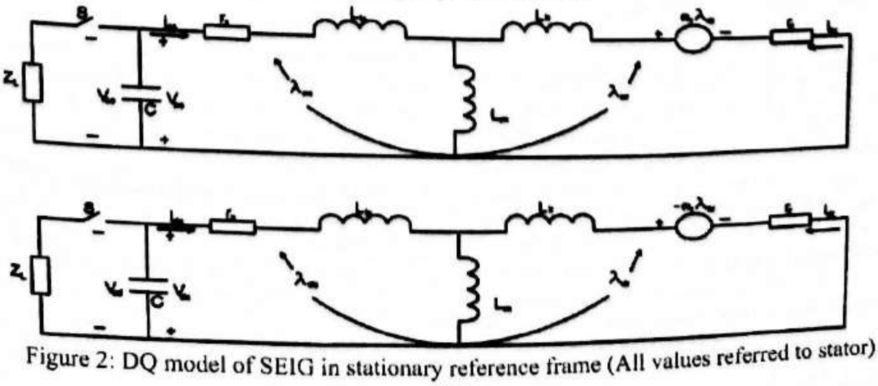

Figure 2: DQ model of SEIG in stationary reference frame (All values referred to stator)

So it is possible to obtain and maintain residual magnetism at its highest level, as it does ease the process of machine excitation [5]-[7]. T. Ahmed [5] present a paper for variable speed prime mover for infinitesimal capacitive effect required for self-excitation, he used a nodal admittance approach to find it. DecioBispo [6] takes the magnetic saturation effects and third harmonics which are generated due to this magnetic effect in analysis for self-excitation process. The minimum terminal capacitor required for induction generator to build up is the main concern. Eltamaly [7] proposed technique, which use nodal analysis instead of loop analysis to obtain just one formula for the infinitesimal capacitive effect required for induction generator operation at different load and speed conditions. In this technique, the operating frequency can be obtained directly from equating the real part of admittance with zero where the real part dose not function in Xc, then use the imaginary part to calculate the value of Xc. D-q transformation with reference frames either in state space, steady state or stationary used for modeling of induction generators that are self-excited is a major computational approach used here for the machine model.

I. Modeling of Induction Generator with Self-excitation

That is, d-q axis model based on the generalized machine theory employed to analyze the machine's transient. Three-axes to two-axes transformation is used in the calculation. Figure2: DQ model of SEIG in stationary reference frame (All values referred to stator). From figure 2, representing its equivalent circuit, the stator parameters are unaffected or unaltered but the rotor parameters are greatly altered, this expresses the dynamic nature of the capacitor storage bank shunted at the terminals of the induction generator.
The equivalent circuit of Figure 2, clearly shows that the rotor side state space equations are not changed, whereas the stator voltage equations need to be changed to represent the dynamics of the capacitor bank connected to the stator terminals.

This equation can be written in matrix form as in equation (1)
Where the symbol ρ is used to denote differentiation with respect to time.

$$\rho = \frac{d}{dt} \tag{3}$$

The machine equation becomes as follows

$$[V] = [R][I] + [L]\rho[I] + \omega r[G][I] \tag{4}$$

$$\rho[I] = [L]^{-1}\{[V][R][I] - \omega r[G][I]\} \tag{5}$$

where $[V] = [V_{sd}\ V_{sq}\ V_{rd}\ V_{rq}]^T$, $[I] = [i_{sd}\ i_{sq}\ i_{rd}\ i_{rq}]^T$

$$R = \begin{bmatrix} R_s & 0 & 0 & 0 \\ 0 & R_s & 0 & 0 \\ 0 & 0 & R_r & 0 \\ 0 & 0 & 0 & R_r \end{bmatrix}$$

$$L = \begin{bmatrix} L_s & 0 & L_m & 0 \\ 0 & L_s & 0 & L_m \\ L_m & 0 & L_r & 0 \\ 0 & L_m & 0 & L_r \end{bmatrix}$$

$$G = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & L_m & 0 & L_r \\ -L_m & 0 & -L_r & 0 \end{bmatrix} \tag{6}$$

Torque Equation

The electrical torque expression can be expressed as

$$T_e = \frac{3p}{4} L_m\left(i_{sq}\, i_{rd} - i_{sd}\, i_{rq}\right) \tag{7}$$

$$T_{sh} = T_e + J\left(\frac{2}{p}\right) * \rho\omega r \tag{8}$$

Thus $\rho\omega r = \left(\frac{p}{2J}\right) * (T_{sh} - T_e)$ (9)

Magnetizing Current

Magnetizing current I_m is determined from i_{sd}, i_{sq}, i_{rd} and i_{rq} using the expression

$$I_m = \sqrt{(i_{rq} + i_{sq})^2 + (i_{rd} + i_{sd})^2} \tag{10}$$

Load Side Equations

$$[v_s] = R_l\rho[v_e] + \frac{1}{C}(v_e) \tag{11}$$

$$\rho[v_e] = \frac{1}{R_l}[v_s - \frac{1}{C}(v_e)] \tag{12}$$

Where $[v_s] = [v_{sd}\ v_{sq}]^T$

Table 1. Machine Parameters Specification

MACHINE PARAMETERS	RATED VALUE
POWER, (P)	3.5kW
PHASE - PHASE VOLTAGE, (Vph)	415V
CURRENT, (I)	7.5A
FREQUENCY, (F)	50Hz
POLES PAIR, (P)	4
SYNCHRONOUS SPEED, (Ns)	1500 r.p.m
STATOR RESISTANCE, (Rs)	0.435
ROTOR RESISTANCE, (Rr)	0.816
STATOR INDUCTANCE, (Ls)	0.1292H
ROTOR INDUCTANCE, (Lr)	0.1292H
MUTUAL INDUCTANCE, (Lm)	69.31e-3H
CAPACITANCE, (C)	58Uf

The measured machine parameters were:
R_s=0.435Ω; R_r=0.816Ω;L _s=L_ R=0.1292H. Lm=69.31e-3H and capacitance C=58μF.

IV. Results and Discussion

A. Transient analysis under Different Unbalanced Conditions

Transient analysis of the induction generator at different conditions produces different responses as well. Transient responses are presented using MATLAB/SIMULINK under fault conditions. For validation of results obtained, more than one computer programs is enhanced to carry out separate performance simulations and the results being compared with respect presents of the capacitor bank connected at the generator's terminals and when absent. Fault conditions responses are shown as: Three capacitors are selected to be C1= C2 = C3 =58μF.

B. The Self-excitation Induction Machine

Transient analysis of the induction generator at different conditions produces different responses as well. Transient responses are presented using MATLAB/SIMULINK under fault conditions. For validation of results obtained, more than one computer programs is enhanced to carry out separate performance simulations and the results being compared with respect presents of the capacitor bank connected at the generator's terminals and when absent. Fault conditions responses are shown as: Three capacitors are selected to be C1= C2 = C3 =58μF.

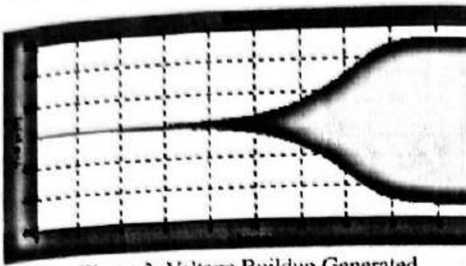

Figure 3: Voltage Buildup Generated

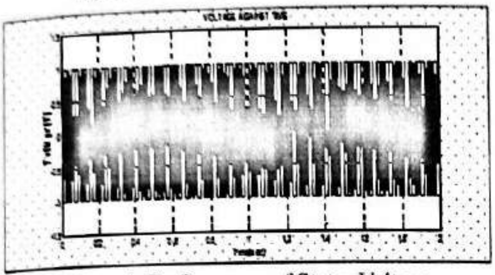

Figure 4: Performance of Stator Voltage during normal operating conditions

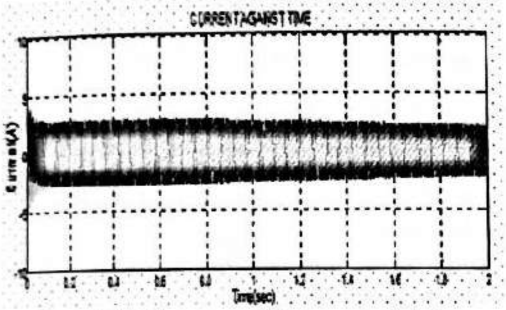

Figure 5: Performance of Stator current during normal operating conditions

C. Sudden Short Circuit At Machine Terminals

Immediately the machine de excites, the voltage collapses, as seen from figure 6. The voltage output at this point of induction generator performance is expressed technically. Figure 7, is the line current of the induction generator. The short circuit is applied at t=0.1sec and reaches to zero voltage at t=0.1sec. From these figures we can clearly find out that the responses of SEIG in case of abrupt voltage surges at machine terminals, voltage quickly reach zero value at about t =0.01sec to when the fault is remove at t=0.2sec.

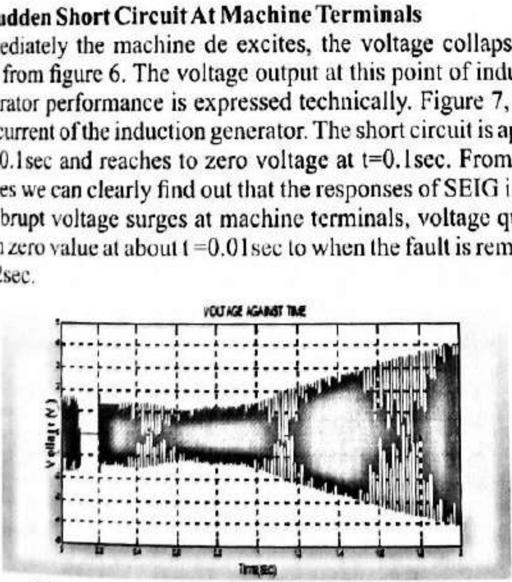

Figure 6: Performance of SEIG during sudden voltage short circuit occurrence

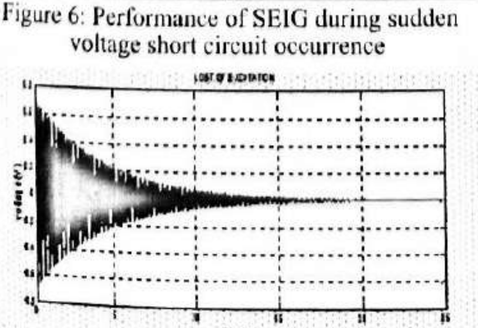

Figure 7: Performance of SEIG during short circuit sudden application

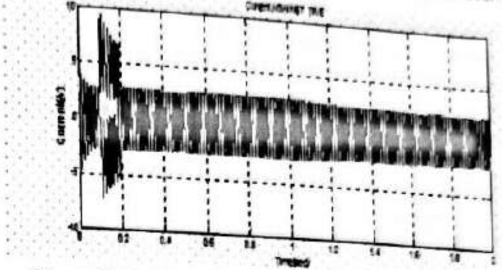

Figure 8: Performance of SEIG during disconnection of self-exciting capacitance

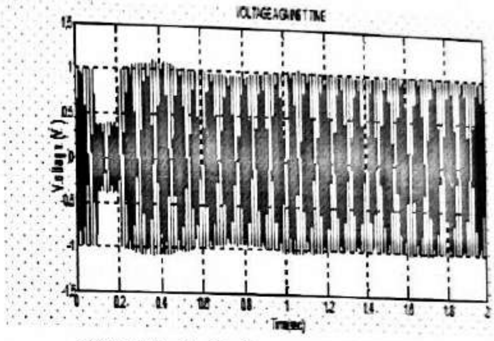

FIGURE 9: Performance of SEIG during normal operating conditions

D. Sudden Disconnection Of Excitation Capacitance

Re-excitation takes place again when the fault was removed. Figure 6: performance of the induction generator during sudden voltage surges Figure 7: performance of the induction generator during sudden current surges. Figure 8: performance of the induction generator during sudden disconnection from self-excitation capacitance / FIGURE 9: performance of the induction generator during normal operating condition and the transient responses simulated and their results for the loaded SEIG subjected sudden Switching on and off the self-excited capacitor under the loading conditions. The capacitance of self-excitation is isolated from the machine once steady state condition is reached. By disconnecting the excitation capacitance, the machine lost its generating mode. Parameters such as speed is decreased, voltage generated mode is lost, the line current tends to zero as well as its torque. Figure 8 gives this curve response illustration. Response time t=0.03sec.

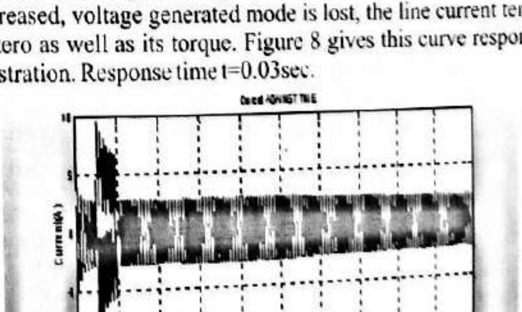

Figure 10: Performance of stator current under sudden fault application for SEIG

E. Short Circuit At Load Terminal

This transient performance of the system is shown in figure 9. In (SEIG), it can be predicted easily that self-excitation cannot be sustained on a load at short circuit response. There is a sudden rush of current of very short duration, magnitude of which depends upon the voltage existing at the capacitor terminals at the instant of short circuit as shown in figure 4. During de-excitation, infinitesimal amount of surges are experienced and they collapses instantaneously in some cases which it may be due to overload or surges. This experience could be advantageous and very harmful for air craft power supplies.

Current protective devices are non-applicable in this kind of condition as a result of the fast dis- appearance of the de-excitation process. Thus, for most critical applications certain excitations are required for the use of self-excited generator. Let the process encourage deduction in the voltages and currents.

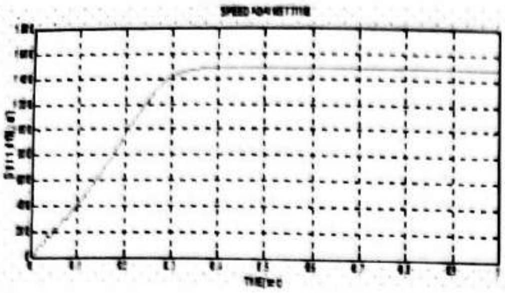

Figure 11: Speed Performance of SEIG

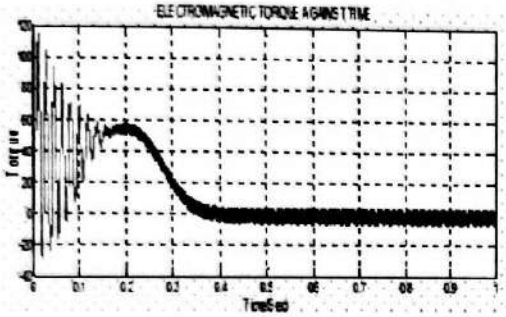

Figure 12: Electromagnetic Torque performance of SEIG

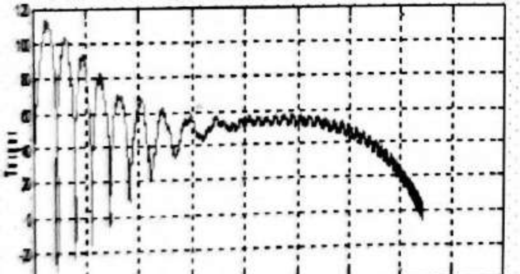

Figure 13: Performance of Torque, Speed under normal operating conditions for SEIG

A. CONCLUSION

The transient analysis of the machine studied was analyzed to determine the effects of fault conditions on the SEIG. Loss of excitation, de-excitation, poor voltage regulations and low overload capabilities are the common challenges faced by the three phase induction generator under self-excitation. Serious voltage drop is observed as a result of the fault. The generator has the inherent capability to rebuild its loss voltage, hence it is unnecessary to source for an auxiliary or external excitation at all conditions under operation. Voltage build up process is faster if the load is momentarily shortened. Self-excitation occurs always when capacitive power is unaltered at the terminal of the generator, after its separation from the grid, provided a torque is conveyed to the shaft. If the system is to be connected to grid, then the expected voltage at the RMS value has to depend on the loading condition. Other factors such as the feeders, power factors, capacitance of the system has to establish excellent conformability of the induction generator that is self-excited with a simple, rugged and self-regulated attributes.

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