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THE EFFECT OF EXCITATION ON THE STABILITY OF ELECTRICAL MACHINE

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ABSTRACT:

Electrical generator are device that convert mechanical power to electrical power. The conversion depends on types of generator and its parameters.it stability depends on the loads connected and the frequency of the system. When a system excited, some amount of energy is being generated thereby causing the rotation on the system. The excitations on this machine is examine in this work. The Matlab Simulink has been use to ascertain the effect of excitation on the machine. The excitation affect the system depending on its types. The analysis on this paper has been done for the different types of excitation mode such as normal, under, over and critical excitation and their effects on the machine. This effect causing the system in stability especially on critically excited mode which causes the system to stabilized at a higher time than every others. This in stability effect can causes a damage to the system and the loads on which it is feeding. The results from the simulations revealed that the critical excitation can affect both the machine and the loads connected to it.

KEY WORDS: **Excitation, Stability, Electric Machine, Effects and Generator**.

1.0 INTRODUCTION

Power system networks including generators are susceptible to disturbances occurring internally and externally. Severe range of damages may result due to mix-operation in control and protective functions. The idea is to ensure that each power system equipment failure does not affect other neighboring equipment. A part of ensuring the network's safety, stability and reliability is by ensuring that the stability control and protection of the system is adequate. With appropriate operation of power system controls such as circuit breakers, generator excitation controls; the power can regain stability before any damage to the system. Generator protection services employed in many utilities allows [13], Sufficient sensitivity and the timely tripping of the faulted portions of the network under fault conditions, Prevention of tripping under no fault conditions, Discrimination and grading for backup functions during fault conditions [12]. The protection functions are not only limited to the above mentioned but also include generator capability control. Within the scope of generator excitation control and protection, it is very important that these two be coordinated adequately to provide full protection. Detailed real-time models are developed to carry out hardware-in-loop studies for particular generator protection elements related to the studies conducted. The phase-domain synchronous machine model is utilized for the simulation studies. The validity of testing a commercial generator and its protection relay using the phase-domain synchronous machine model is established. With the major focus on coordination of generator protective functions with respect to excitation limiters in the under excitation and over excitation region. These coordination studies particularly help to provide generators with excitation control; capability limits control, primary and backup protection enhancing the stability of the power system. To capture the behavior of synchronous machine accurately in power system stability studies, it is essential that their excitation systems are modeled in sufficient detail. The models has to be suitable in representing the actual excitation appliance performance for a big, severe interruption as well as for small perturbations. [8] Based on excitation power source, excitation systems are categorized into three groups showing as follows, Type DC Excitation Systems which utilized a direct current generator with a commutator as the source of excitation system power. [9]. Excitation control is of great importance in terms of controlling generator excitation system parameters and with proper coordination with protection relays, overall system protection is adequate. The idea behind coordination of controls with protection is to allow time between operation of excitation limiters and protection. The governor main purpose is to control the speed of the generator. When a generator is connected to an interconnected system, the governor plays an important role in controlling the synchronous speed of the network. When generators are interconnected they rotate at a synchronous speed. Initially the power demand is distributed between the generators by the economic dispatch. The additional power needed for each generator is controlled by the governor system of the generator. If a load is lost from a system the generator will accelerate to a new steady state determined by all the steady state gain of the governor [8, 9, 10, 11,15].

2.0 MATHEMATICAL MODEL OF EXCITATION SYSTEMS

A modeling of a synchronous generator can be written by mathematical model of second, third, fifth, or seventh order. Seventh-order model describes synchronous generators most accurately and is the most complex [14]. It is used for analysis of dynamic behaviors in normal conditions and in conditions of generator failure. Third-order model is crucial to studying the control systems of synchronous generators as well as their synthesis. It neglects frequency deviations, high-order harmonics, and behavior in damped windings. Used for its simplicity and good dynamic reversing process has the higher usage for analysis and its complex of control system. The simplest model of synchronous generators is second-order model; it describes only the dynamics of a moving rotor [16,17]. Mathematically describing for an excitation system. An exciter's equations can be written as follows

$$\tilde{v}_{ed} = -R_{es}\tilde{i}_{ed} + w_e(L_{eis} + L_{emq})\tilde{i}_{eq} - (L_{eis} + L_{emd})\frac{d\tilde{i}_{ed}}{dt} + L_{emq}\frac{d\tilde{i}_{efd}}{dt} \quad (1)$$

$$\tilde{v}_{eq} = -R_{es}\tilde{i}_{eq} + w_e(L_{eis} + L_{emd})\tilde{i}_{ed} + w_e L_{emd}\tilde{i}_{ed} - (L_{eis} + L_{emq})\frac{d\tilde{i}_{eq}}{dt} \quad (2)$$

$$\tilde{v}_{efd} = R_{efd}\tilde{i}_{efd} - L_{emd}\frac{d\tilde{i}_{ed}}{dt} + (L_{eifd} + L_{emd})\frac{d\tilde{i}_{efd}}{dt} \quad (3)$$

When combining linearized model of the generator/rectifier with the exciter's DC load model will get:

$$\tilde{v}_{edc} = K_{138}\tilde{v}_{ed} + K_{239}\tilde{v}_{eq} \quad (4)$$

$$\tilde{i}_{ed} = K_4\tilde{i}_{edc} + K_5K_8\tilde{v}_{ed} + K_5K_9\tilde{v}_{eq} \quad (5)$$

$$\tilde{i}_{eq} = K_6\tilde{i}_{edc} + K_7K_8\tilde{v}_{ed} + K_7K_9\tilde{v}_{eq} \quad (6)$$

$$K_{138} = K_1 + K_3K_8 \quad (7)$$

$$K_{239} = K_2 + K_3K_9 \quad (8)$$

Now, the voltage equation of the main generator's field can be written as:

$$\tilde{v}_{afd} = R_{afd}\tilde{i}_{afd} - L_{amd}\frac{d\tilde{i}_{ad}}{dt} + (L_{aifd} + L_{amd})\frac{d\tilde{i}_{afd}}{dt} + L_{amd}\frac{d\tilde{i}_{akd}}{dt} \quad (9)$$

Now, the voltage equation of the main generator's field can be written as:

$$\tilde{v}_{afd} = t_a\tilde{v}_{edc} \quad (10)$$

Similarly, for currents

$$\tilde{i}_{afd} = \frac{1}{t_a}\tilde{i}_{edc} \quad (11)$$

Combining (9), (10), and (11) produces the following exciter load equation:

$$\tilde{v}_{edc} = \frac{R_{afd}}{t_a^2}\tilde{i}_{edc} - \frac{L_{amd}}{t_a}\frac{d\tilde{i}_{ad}}{dt} + \frac{(L_{aifd}+L_{amd})}{t_a^2}\frac{d\tilde{i}_{afd}}{dt} + \frac{L_{amd}}{t_a}\frac{d\tilde{i}_{akd}}{dt} \quad (12)$$

The mathematical expressions for $\tilde{v}ed$ and $\tilde{v}eq$ can be written by eliminating $\tilde{v}edc$ as

$$\tilde{v}_{ed} = r_{edd}\tilde{i}_{ed} + l_{edd}\frac{d\tilde{i}_{ed}}{dt} + r_{edq}\tilde{i}_{eq} + l_{edq}\frac{d\tilde{i}_{eq}}{dt} - K_9 l_{ae}\frac{d\tilde{i}_{ed}}{dt} + K_9 l_{ae}\frac{d\tilde{i}_{akd}}{dt} \quad (13)$$

$$\tilde{v}_{eq} = r_{eqd}\tilde{i}_{ed} + l_{eqd}\frac{d\tilde{i}_{ed}}{dt} + r_{eqq}\tilde{i}_{eq} + l_{eqq}\frac{d\tilde{i}_{eq}}{dt} - K_8 l_{ae}\frac{d\tilde{i}_{ad}}{dt} + K_8 l_{ae}\frac{d\tilde{i}_{akd}}{dt} \quad (14)$$

Where:

$$K_{det} = K_4K_7(K_9K_{138} - K_8K_{239}) + K_5K_6(K_8K_{239} - K_9K_{138}) \quad (15)$$

$$r_{edd} = \frac{K_6 K_{239} + K_7 K_9 \frac{R_{afd}}{t_a^2}}{K_{det}} \quad (16)$$

$$l_{edd} = \frac{K_7 K_9 (L_{alfd} + L_{amd})}{t_a^2 K_{det}} \quad (17)$$

$$l_{edq} = \frac{K_5 K_9 (L_{alfd} + L_{amd})}{t_a^2 K_{det}} \quad (18)$$

$$r_{edq} = \frac{K_6 K_{138} + K_7 K_8 \frac{R_{afd}}{t_a^2}}{K_{det}} \quad (19)$$

$$r_{edq} = \frac{K_4 K_{138} + K_5 K_8 \frac{R_{afd}}{t_a^2}}{K_{det}} \quad (20)$$

$$l_{eqd} = \frac{K_7 K_8 (L_{alfd} + L_{amd})}{t_a^2 K_{det}} \quad (21)$$

$$l_{eqq} = \frac{K_5 K_8 (L_{alfd} + L_{amd})}{t_a^2 K_{det}} \quad (22)$$

$$l_{ae} = \frac{K_4 K_7 - K_5 K_6}{t_a K_{det}} L_{amd} \quad (23)$$

Similarity with the main generator's field current [4]

$$\tilde{i}_{afd} = h_{aed} \tilde{i}_{ed} + h_{aed} \tilde{i}_{eq} \quad (24)$$

Where;

$$h_{aed} = \frac{K_{138} K_7 K_9 - K_{239} K_7 K_8}{t_a K_{det}} \quad (25)$$

$$h_{aeq} = \frac{K_{239} K_5 K_8 - K_{138} K_5 K_9}{t_a K_{det}} \quad (26)$$

Linear state-space representation can be get by substituted equations (14) and (15) with (1) and (2). The final description of the model can be done by reduce the system order by one. [5]

MODELING OF SYNCHRONOUS MACHINE

Voltage Equations

The stator and rotor voltages can be expressed in vector-matrix form as: $V_{abcs} = r_s I_{abcs} + P\lambda_{abcs}$ (in the stator frame) (27)

$V_{dqfr} = r_s I_{dqfr} + p\lambda_{dqfr}$ (In the rotor frame). (28)

In these equations the operator p = d/dt and

$$V_{abcs} = \begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} \text{ While } V_{dqfr} = \begin{bmatrix} V_{dr} \\ V_{qr} \\ V_{fr} \end{bmatrix} \quad (29)$$

Similar definitions apply for current vectors I_{abcs}, I_{dqfr}, and the flux linkages λ_{abcs}, and λ_{dqfr}. The resistance matrix appearing in (1) and (2) may be defines as:

$$= \begin{bmatrix} r_{as} & 0 & 0 \\ 0 & r_{bs} & 0 \\ 0 & 0 & r_{cs} \end{bmatrix} \quad (30)$$

However, since each of the resistances of the three phase stator windings is equal we may then say that, $r_s = diag[r_s r_s r_s]$.
In general, the rotor is unsymmetrical so that the rotor resistances must now be defined by a matrix r_r, where:

$$r_r = \begin{bmatrix} r_{qr} & 0 & 0 \\ 0 & r_{dr} & 0 \\ 0 & 0 & r_{fr} \end{bmatrix} \quad (31)$$

Solving the first order differential equation (3.1), now we may rewrite as:

$$V = IR + \frac{d}{dt}(LI) \quad (32)$$

L is a function of rotor position θ_r which is also a function of time and I is only a time varying function so we may write:

$$V = IR + \frac{dL(\theta_r)}{dt} + L(\theta_r)\frac{dI}{dt} \quad (33)$$

This now implies a differential equation with time varying coefficient. But equation (33)can be rewritten as:

$$V = IR + I\frac{dL(\theta_r)}{d\theta_r} \text{x} \frac{d\theta_r}{dt} + L(\theta_r)\frac{dI}{dt} \quad (34)$$

But we know that $\frac{d\theta_r}{dt}$ is the derivative of position which means "speed", or $\omega_r$so (c) now becomes:

$$V = IR + \omega_r \text{x}\, I\frac{dL(\theta_R)}{d\theta_r} + L(\theta_r)\frac{dI}{dt} \quad (35)$$

Equation (3.9) may finally be written as:

$$\frac{dI}{dt} = \left[V - I\left(R + \omega_r \text{x} \frac{dL(\theta_r)}{d\theta_r}\right)\right] \text{x}\, (\text{L}(\theta_r))^{-1} \quad (36)$$

Equation (36) shows that the solution of current at every time step involves the computation of the derivative of the inductance matrix, $\frac{dL(\theta_r)}{d\theta_r}$ for the particular rotor position and the computation of the inverse of the inductance matrix, $(L(\theta_r))^{-1}$.

3.0 MODELLING IN TERMS OF THE MACHINE PARTS

Electrical part

(37)

$$E'_d = \frac{x'_d - x_q}{1 + sT'_{q0}} I_q \quad (38)$$

Mechanical part

$$\Delta\omega = \frac{1}{D + sM}(P_m - P_e) \quad (39)$$

$$\delta = \omega_0 \frac{\Delta\omega}{s}$$

(40)

Turbine and Governor System Model

$$\Delta P_m = \frac{sK_{RH}T_{RH}}{1 + sT_{RH}} \Delta P_c \quad (41)$$

EXCITER MODEL

$$E_{fd} = \frac{K_E}{1 + sT_E}(V_{tr} - V_t - V_s) \quad (42)$$

TERMINAL EQUATIONS

$$V_{td} = E'_d - R_e I_d - x'_q I_q = -V_0 \sin\delta + R_e I_d + x_e I_q \qquad (42)$$

$$V_{tq} = E'_q - R_e I_q + x'_d I_d = V_0 \cos\delta + R_e I_q - x_e I_d \qquad (43)$$

$$P_e = E'_d I_d + E'_q I_q \qquad (44)$$

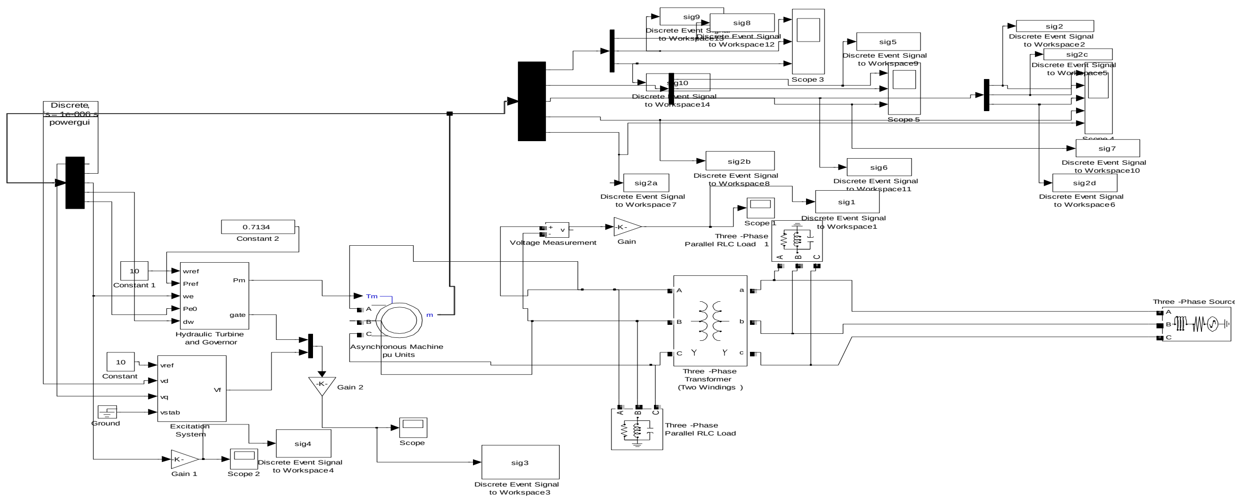

Fig.1.0 Simulink Model of the System

4.0 RESULT PRESENTATION/DISCUSSION

The simulation was done in four stages, these normal excitation, under excitation, over excitation and critical excitation. The simulation emphasize on the current as shown in the results figures.

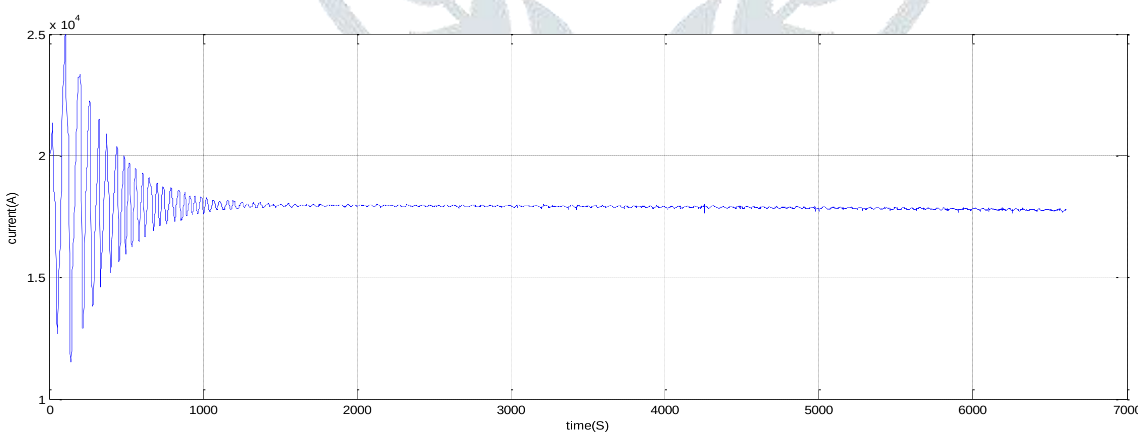

Fig.2: Graph of currents /time normal Excitation

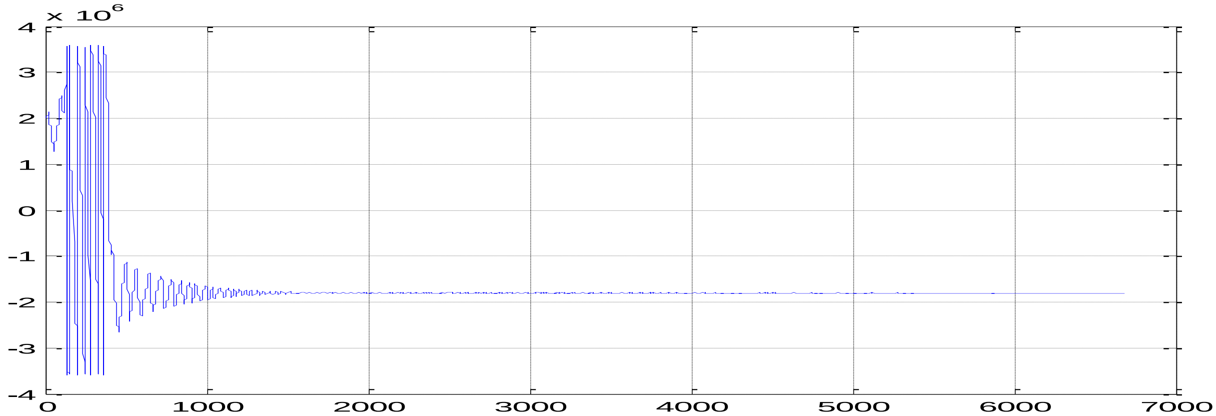

Fig.3: Graph of currents /time under Excitation

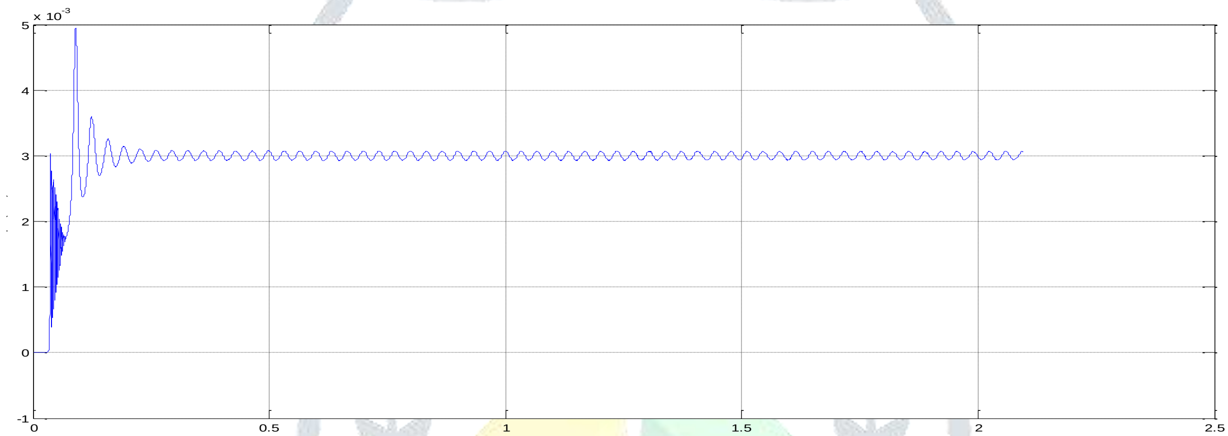

Fig.4: Graph of currents /time over Excitation

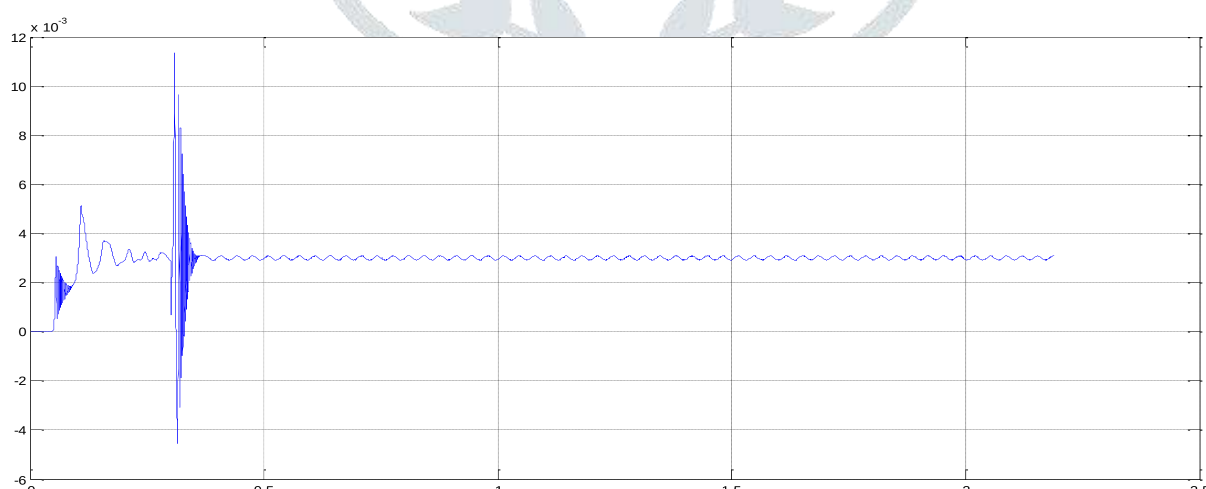

Fig. 5: Graph of currents /time critical Excitation

DISCUSSION

Figure 2, 3,4, and 5 shows the machine outputs at normal, under, over and critically excitation at a constant load. At normal excitation the machine operate at a standard rated parameters.(i.e current, voltage and speed). At this point the induce EMF is equal to the applied voltage. But for the case of under excitation the EMF is lesser than the applied voltage as shown in figure 3. Over excitation shown in figure 4 reveals that the back EMF is higher than the applied voltage thus making the system stability very high in values. In figure 5 it was discover that, the system stability takes more time to build up itself before it finally stabilizes and it stability is at a time higher which can cause a damages to the load on the system.

5.0 CONCLUSION

The excitation effect on electric machine may be directly or indirectly depending the types of excitation. It affect the system in some cases or it affect the loads connected to the machine. In this work it is revealed that the critical excitation can affect both the machine and the loads connected to it. Although the effect might not be much when comparing it to the others effects of faults on the system stability.

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