TRANSIENT ANALYSIS OF SELF-EXCITED INDUCTION GENERATOR UNDER BALANCED AND UNBALANCED OPERATING CONDITIONS

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ABSTRACT:

In this paper, a generalized dynamic d-q axis model based upon stationary reference frame with cubical curve fitting for open circuit characteristic curve is proposed to analyse the behaviour of a three phase self-excited asynchronous generator. The model is found to be suitable to handle both symmetrical and unsymmetrical load and capacitor configurations. A close agreement between the simulated results and test results on a test machine confirms the validity of proposed model. Further simulated results as obtained are used to analyse the behaviour of machine handles symmetrical and unsymmetrical operating conditions.

Keywords: - *Three Phase Induction Machine, Capacitor Bank, Self-Excitation, Matlab*

INTRODUCTION

The asynchronous generators ability to generate power at varying speed facilitates its application in various modes over the traditionally used generators, normally synchronous generators. The asynchronous generators are increasingly being used due to the combined pressures of the inherent low cost of asynchronous generators and the relatively high unit cost of small scale generation. It is true that induction generator offers a lot of distinct technical advantages over the synchronous generators. These include simpler excitation, simple starting and control requirements, robust construction to fault levels. However their selection must be carefully considered, particularly to avoid potential problems with self excitation. The disadvantages of self excited asynchronous generator are: Reactive power consumption and poor voltage regulation, but these issues can be overcome by developing static power converters. Both transient analysis and steady state analysis of a system are essential to determine its complete behaviour. The steady state behaviour is important for ensuring good quality power and assessing the suitability of configuration for a particular application. Transient behaviour is helpful in determining: Insulation strength, suitability of winding, shaft strength, value of capacitor, the devising protection strategy.

II. Transient Modelling

Induction machine modelling

The schematic diagram of a delta-connected SEIG is observed in Fig. 1. The Mathematical model required for analysing the transient performance of an induction machine referred to the d-q axis stationary frame is shown in equation(1).

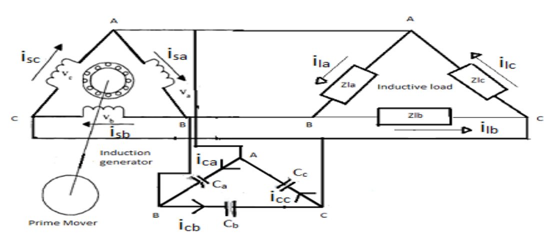


Fig 1.Schematic of delta connected self-excited asynchronous generator

$$[v] = [R][i] + [L]p[i] + w_r [G][i] \quad (1)$$

Where [v], [i], [R], [L], and [G] are matrices of voltage, current, resistance, transformer inductance, and rotational inductance, respectively, and are described in Appendix.

Capacitor and load Model [9]

An induction machine needs reactive power for continuous Excitation process. Based on reactive power source, asynchronous generators are of two types: 1.Grid connected induction generator 2.Self-Excited asynchronous generator. In grid connected asynchronous generator machine will draw reactive power from grid, where as in self-excited induction generator capacitor bank is required for supplying required amount of reactive power. For continuous excitation process sufficient value of capacitor bank is required. The capacitor current equations in terms of phase voltages are written as below.

$$i_{ca}=C_a p v_{sa}$$
$$i_{cb}= C_b p v_{sb} \qquad (2)$$
$$i_{cc}=C_c\, p v_{sc}$$

From equation (2) load voltage equations interms of d-q axis can be expressed by using transformation matrix.

The load current equations for an unbalanced resistive load are expressed as below

$$i_{la}=v_{sa}/R_a$$
$$i_{lb}=v_{sb}/R_b \qquad (3)$$
$$i_{lc}=v_{sc}/R_c$$

d-q axis load current equations for an unbalanced resistive load are shown as equation (A).

For balanced resistive load Ra=Rb=R

The load current equations for an unbalanced inductive load are expressed as below

$$V_{sa} = i_{la} R_a + L_a p i_{la}$$
$$V_{sb} = i_{lb} R_b + L_b p i_{lb} \qquad (4)$$
$$V_{sc} = i_{lc} R_c + L_c p i_{lc}$$

d-q axis load current equations for an unbalanced inductive load are shown as equation (B).

$$P\begin{bmatrix} i_{ld} \\ i_{lq} \end{bmatrix} = \begin{pmatrix} 0 & 0 & 0 & 0 & \frac{1}{Ra} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{\sqrt{3}}\left(\frac{1}{Ra}-\frac{1}{Rb}\right) & \frac{1}{Rb} & 0 & 0 \end{pmatrix} \begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ i_{qr} \\ v_{ld} \\ v_{lq} \\ i_{ld} \\ i_{lq} \end{bmatrix} + \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} v_{ds} \\ v_{qs} \\ v_{dr} \\ v_{qr} \end{pmatrix}$$

For balanced resistive load Ra=Rb=R (A)

$$P\begin{bmatrix} i_{ld} \\ i_{lq} \end{bmatrix} = \begin{pmatrix} 0 & 0 & 0 & 0 & -\frac{1}{La} & 0 & -\frac{Ra}{La} & 0 \\ 0 & 0 & 0 & 0 & \frac{2}{(\sqrt{3})}\left(\frac{-1}{La}+\frac{1}{Lb}\right) & \frac{1}{Lb} & \frac{2}{\sqrt{3}}\left(-\frac{Ra}{La}+\frac{Rb}{Lb}\right) & \frac{-Rb}{Lb} \end{pmatrix} \begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ i_{qr} \\ v_{ld} \\ v_{lq} \\ i_{ld} \\ i_{lq} \end{bmatrix} + \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} v_{ds} \\ v_{qs} \\ v_{dr} \\ v_{qr} \end{pmatrix}$$

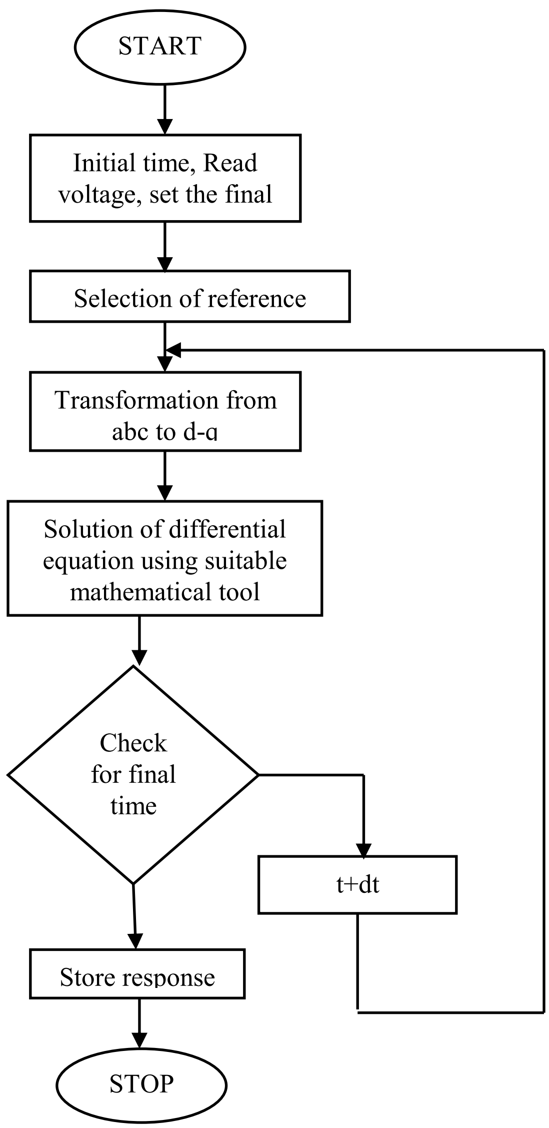
The load current equations for an unbalanced inductive load are expressed as below

(B)

Magnetization Curve Model [10]

The variation of the magnetizing inductance with magnetizing current is the main factor in the dynamics of the voltage build up and stabilization in self-excited induction generator. The relationship between magnetizing inductance (Lm) and magnetizing current (Im) is expressed as non-linear polynomial equation. For finding numerical relation between Lm and Im excitation voltage and excitation current data under no load condition are required.

Flow chart for transient analysis



RESULTS & DISCUSSIONS

The study is carried out on a 3 H.P. squirrel cage induction machine driven by a d.c. motor. The machine parameters and open circuit characteristics are detailed in Appendix.

Experimental verification:

For C=51μF, R=160Ω

Serial no	Speed (R.P.M.)	Generated Voltage (Volts)	
		Practical Value	Simulation value
1	1280	166	164.3
2	1321	187	179.6
3	1353	201	190.1
4	1390	215	201
5	1440	232	214

For C=51μF, R=220Ω

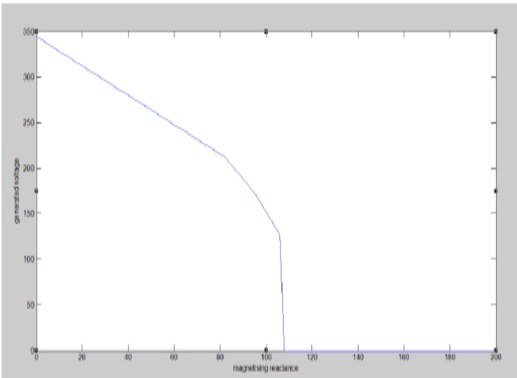
Serial No	Speed (R.P.M.)	Generated Voltage (Volts)	
		Practical Voltage	Programming Voltage
1	1285	174	166.6
2	1315	187	177.3
3	1350	202	190
4	1386	216	200
5	1430	237	212

For C=36μF, R=160Ω

Serial no	Speed (R.P.M.)	Generated Voltage (Volts)	
		Practical Voltage	Programming Voltage
1	1433	134	149
2	1467	158	168
3	1498	176	183

Simulation of SEIG:

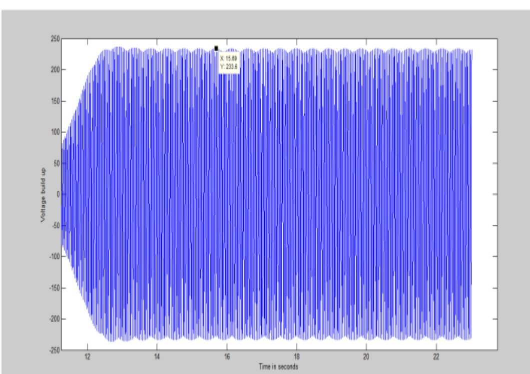
The following simulation results are obtained by using MATLAB programming. In order to initiate the excitation process, the residual magnetism is included in simulation process, without which voltage build up process fails.



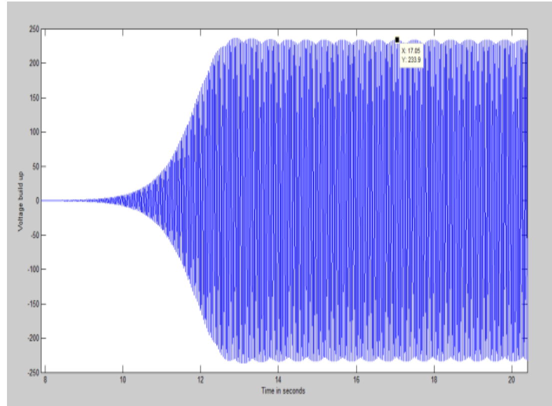
Magnetization Characteristic Curve

Voltage build up under no load:

When Generator is excited with balanced excitation capacitance value of C=60 µF and rotor speed is set to 1550 r.p.m., generated voltage attains its steady state value of 238 V in 13 seconds.

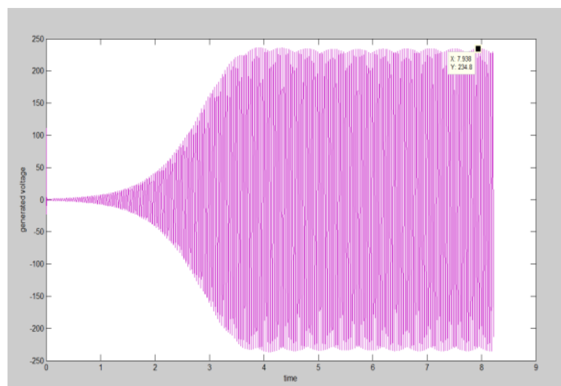


Voltage build up under load condition: When Generator is started with some balanced resistive load of value R=75Ω, generated voltage attains its steady state value of 230 V in 15 seconds. It is observed that under loading condition transient time increases.

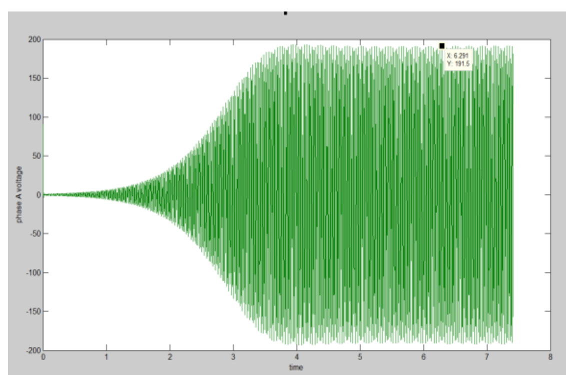


Effect of unbalanced load:

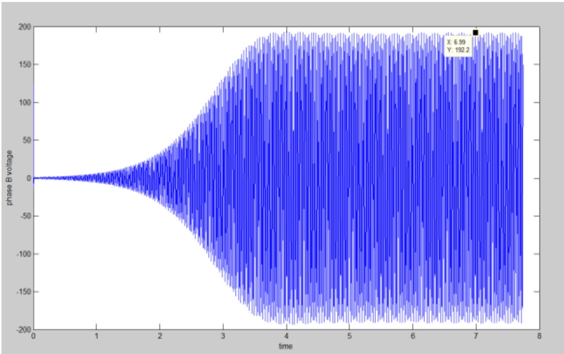
When Generator is started with some unbalanced resistive load of R1=75;R2=10; R3=75; with balanced excitation (c1=60*10^-6; c2=60*10^-6; c3=60*10^-6) ,it is observed that there is no effect on the three phase voltage build up but there is effect on individual phase voltage build up.



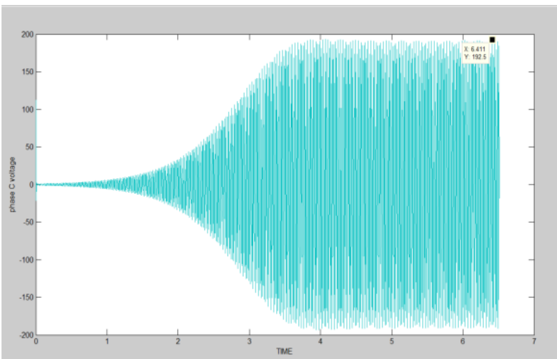
Three phase voltage build up



Phase-a voltage build up



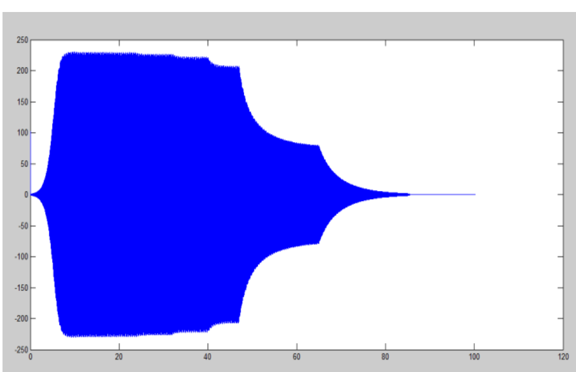
Phase-b voltage build up



Phase-c voltage build up

Under unbalancing load condition, the steady state value of individual phase voltage is depending upon the load impedance value.

Voltage Collapse: During step increment in load it is found that up to R=2Ω load can be impressed on the machine without excitation failure.



Voltage collapse during step increment in load

CONCLUSION:

The developed dynamic model can handle both balanced and unbalanced loads with both balance and unbalance in excitation. It is observed that with the help of transient analysis how much load can be impressed on the machine without excitation failure can be found.

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Appendix:

Test machine details: 3 H.P. (2.2 Kw), delta connected, 230 V, 4-pole, 50 Hz, 8.6 A; Stator Resistance - 3.35Ω; Stator Leakage reactance: 4.85Ω; Rotor Resistance: 1.76Ω; Rotor Leakage reactance : 1.76Ω

Magnetization curve modelling equation of test machine is given below:

$$L_m = 1.734-0.673i_m+0.089i_m^2-0.004\ i_m^3$$

The matrices [v], [i], [R], [L], and [G] shown in equation (1) are described as

$$[v] = [V_{sd} V_{sq} V_{rd} V_{rq}]\ [i] = [i_{sd} i_{sq} i_{rd} i_{rq}]^T$$

$$[R] = \begin{pmatrix} Rs & 0 & 0 & 0 \\ 0 & Rs & 0 & 0 \\ 0 & 0 & Rr & 0 \\ 0 & 0 & 0 & Rr \end{pmatrix}$$

$$[L] = \begin{pmatrix} L_{sd} & L_{dq} & L_{md} & L_{dq} \\ L_{dq} & L_{sq} & L_{dq} & L_{mq} \\ L_{md} & L_{dq} & L_{rd} & L_{dq} \\ L_{dq} & L_{mq} & L_{dq} & L_{rq} \end{pmatrix}$$

$$[G] = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & L_m & 0 & -L_r \\ -L_m & 0 & -L_r & 0 \end{pmatrix}$$