Capacitance Required for Self-Excited Induction Generator as an Isolated Power Source for Wind Mill

[1]Saroja Kumar Dash,[2]Surendra Pattanaik, [3]SahasranshuDas, [4]Rabinarayan Rout, [5]Amit Kumar Pattanaik, [6]Monalisha Sahoo

[1,2,3,4,5,6]Department of Electrical Engineering, GITA, Bhubaneswar, Odisha, India

Abstract : The major obstacle of self-excited induction generator (SEIG) as an isolated power source is its capacitance requirement for building up terminal potential difference .Basically the reactive power support is developed out of the proper capacitance value of the capacitor .This enables the SEIG to operate in its self-excited mode .This paper presents an analysis based on Kirchhoff's laws and current division to estimate the capacitance requirement for a three phase,3kW self-excited induction motor as an induction generator.

Keywords: Self -excited induction generator (SEIG), revolution per minute (rpm), Steady state analysis (SSA)

I. INTRODUCTION

The widespread popularity of induction generator is due to its ability to generate the power from variable speed as well as constant speed prime movers, low unit cost, very simple and ruggedness etc. It produces high power per unit mass of materials and needs very little maintenance.

In an induction generator the only problem is that of guaranteeing self- excitation. Self -excitation of an induction machine and its perpetuity depends on the combination of speed, load and terminal capacitance in relation to the magnetic non-linearity of the machine. This in turn causes certain limitations on the performance of the machine. Looking at these aspects, studies on the criteria for self- excitation of an induction generator are relevance in the field of nonconventional generation. The excitation requirements, of an induction generator have been dealt with in details in[4]-[7].For self -excitation to occur, the following two conditions must be satisfied:

i. The rotor should have sufficient residual magnetism.

ii. The three capacitor bank should be of sufficient value.

If an appropriate capacitor bank is connected across the terminals of an externally driven induction machine and if the rotor has sufficient residual magnetism an EMF is induced in the machine windings due to the excitation provided by the capacitor. The EMF if sufficient would circulate leading currents in the capacitors. The flux produced due to these currents would assist the residual magnetism. This would increase the machine flux and larger EMF will be induced. This in turn enhances the current and the flux. The induced voltage and the current will continue to rise until the VAR supplied by the capacitor is balanced by the VAR demanded by the machine, a condition which is essentially decided by the saturation of the magnetic circuit. This process is thus cumulative and the induced voltage keeps on rising until saturation is reached. To start with transient analysis the dynamic modelling of induction motor has been used which further converted into induction generator [8]-[10]. Magnetizing inductance is the main factor for voltage build up and stabilization of generated voltage for unloaded and loaded conditions. The dynamic Model of SEIG is helpful to analyse all characteristic especially dynamic characteristics. For the past few years the researchers developed positively steady state models of (SEIG) [11] and proposed the steady state equivalent circuit that represents the SEIG. The critical capacitance requirement and excitation balancing has been proposed through [11] -[7]. Accordingly the better applicability of induction motor as a generator for isolated applications has been proposed in [7]. The model was found suitable for steady state analysis. Thus for analysing the transient characteristics, dynamic model of SEIG has been developed [8] which analysed the dynamic characteristics for various transient conditions and stability.

In this context, this work presents generalized state-space dynamic model of a three phase SEIG using d-q variables in stationary reference frame for transient analysis and a method to find the value of terminal capacitance required for self-excitation incorporating the rotor speed and load impedance vide a computer program. The proposed model for induction generator, load and excitation using state space approach driven by wind turbine coupled to a centrifugal pump is used to optimize the performances.

Section two gives the system modelling in static and a dynamic state. In this section, a simple method is also presented and analysed to find the minimum value of required capacitance for self-excitation. Simulation results are discussed in section three. Finally a conclusion describes the proposed work and its features.

II. ANALYSIS

2.1 Proposed system:

In the proposed system (Figure 1), a power generation system consisting of a wind turbine[2] with SEIG as an isolated power source has been focussed.

The produced power is used to supply an induction motor coupled to a centrifugal pump. As the SEIG requires reactive power for its excitation, a three phase capacitor bank is connected across its stator terminals.

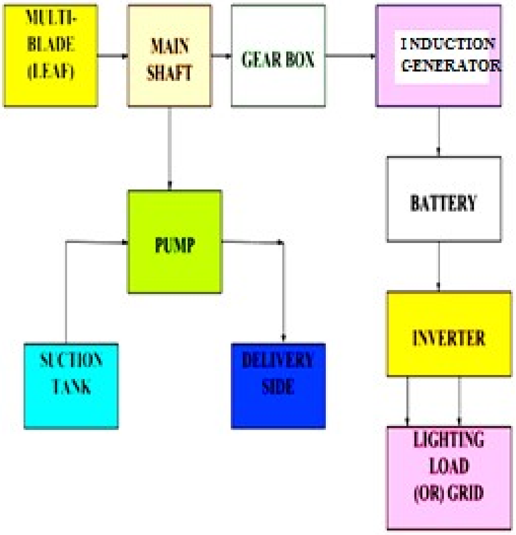

Fig.1 Wind Electric Pumping System

The Induction Motor cannot be supplied unless the SEIG stator voltage build up process occurs. For this reason an operating mode switch selects first the no load condition until the voltage build up process is accomplished. Subsequently the switch is turned on so as to connect the Induction Motor to the SEIG.

In order to analyse the performances of self-excited induction generator which supplies an induction motor driving pump, a system modelling is required. Steady state and dynamic models have been used in this paper.

2.2 Steady state Analysis of SEIG:

Figure 2 shows the per-phase equivalent circuit commonly used for SEIG [1]feeding an induction motor. A three phase induction machine can be operated as a SEIG if its rotor is externally driven at a suitable speed and a three-phase capacitor bank of a sufficient value is connected across its stator terminals. When the induction machine is driven at the required speed, the residual magnetic flux in the rotor will induce a small electromotive force in the stator winding. The appropriate capacitor bank causes this induced voltage to continue to increase until an equilibrium state is attained due to magnetic saturation of the machine.

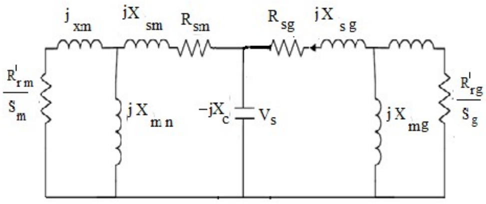

Fig.2 Per phase equivalent circuit of self-excited Induction generator feeding an induction pump motor

We note: Index g for Induction Generator Index m for Induction Motor

All circuital parameters except the magnetizing inductance Lmg are assumed to be constant and insensitive to saturation.

From Figure 2, the total current at node a may be given by:

$$Vs.(Yg+Yc+Ym)=0 \tag{1}$$

$$Yc=j\frac{a}{Xc} \tag{2}$$

$$Yg=\frac{Yg_1(Yg_2+Yg_3)}{Yg_1+Yg_2+Yg_3} \tag{3}$$

$$Yg_1=\frac{1}{R_{sg}+jaX_{sg}}$$

$$Yg_2=\frac{1}{jaX_{mg}}$$

$$Yg_3=\frac{1}{\frac{aR'_{rg}}{a-b}+jaX'_{rg}} \tag{4}$$

$$Vs\neq 0 \quad \text{So} \quad (Yg+Yc+Ym)=0 \tag{5}$$

$$\Re(Yg+Yc+Ym)=0 \tag{6}$$

$$\Im(Yg+Yc+Ym)=0 \tag{7}$$

$$Yg=\frac{1}{R_G+jX_G}=\frac{R_G}{R_G^2+(X_G)^2}-j\frac{X_G}{R_G^2+(X_G)^2} \tag{8}$$

$$R_G=R_{sg}+\frac{a(a-b)R'_{rg}X_{mg}^2}{(a-b)^2(X'_{rg}+X_{mg})^2+R'^{\,2}_{rg}} \tag{9}$$

$$X_G=aX_{sg}+\frac{aX_{mg}((a-b)^2X'_{rg}(X_{mg}+X'_{rg})+R'^{\,2}_{rg})}{(a-b)^2(X'_{rg}+X_{mg})^2+R'^{\,2}_{rg}} \tag{10}$$

$$Ym=\frac{1}{R_M+jX_M}=\frac{R_M}{R_M^2+(X_M)^2}-j\frac{X_M}{R_M^2+(X_M)^2} \tag{11}$$

$$\frac{R_G}{R_G^{\,2}+(X_G)^2}+\frac{R_M}{R_M^{\,2}+(X_M)^2}=0 \tag{12}$$

$$\frac{a}{Xc}-\frac{X_G}{R_G^{\,2}+(X_G)^2}-\frac{X_M}{R_M^{\,2}+(X_M)^2}=0 \tag{13}$$

$$R_{sg}+\frac{a(a-b)R'_{rg}X_{mg}^2}{R'^{\,2}_{rg}+(a-b)^2(X'_{rg}+X_{mg})^2}=0 \tag{14}$$

$$a_{\max}=b-\frac{b}{2}\left[\frac{1-\sqrt{1-(\frac{b_c}{b})^2}}{1+\frac{R_{sg}}{R'_{rg}}(1+\frac{X^i_{rg}}{X_{mg}})^2}\right] \tag{15}$$

$$b_c=\frac{2R_{sg}}{X_{ms}}\sqrt{\frac{R'_{rg}}{R_{sg}}+(1+\frac{X'_{rg}}{X_{mg}})^2} \tag{16}$$

$$Xc=a_{\max}^2[X_{sg}+\frac{aX_{mg}((a-b)^2X'_{rg}(X_{mg}+X'_{rg})+R'^{\,2}_{rg})}{(a-b)^2(X'_{rg}+X_{mg})^2+R'^{\,2}_{rg}}] \tag{17}$$

$$C_{\min}=\frac{1}{2\pi 50.a_{\max}^2(X_{sg}+\frac{aX_{mg}((a-b)^2X'_{rg}(X_{mg}+X'_{rg})+R'^{\,2}_{rg})}{(a-b)^2(X'_{rg}+X_{mg})^2+R'^{\,2}_{rg}})} \tag{18}$$

2.3 **Method of solution:**

Equation (12), (13) and (18) represent the conditions that must be satisfied for the self-excitation of the induction machine corresponding to various generator and load configurations as discussed above. Each of these equations is complex and non-linear which can be expressed as two simultaneous real, nonlinear equations with two unknowns. Such equations can be solved using any suitable technique (Program computer). If the values of the machine parameters, its speed (or frequency), excitation capacitance as well as load impedances are given, the two equations can be solved for the magnetizing reactance and frequency (or speed). On the other hand, if the interest is to find the range of terminal capacitances to sustain self- excitation, the two equations can be solved for the frequency (or speed) and these capacitances by specifying the machine parameters, its speed (or frequency), load impedances and the maximummagnetizing reactance Xmgas function of speed and load impedance.

2.4 SEIG Modelling:

The model for the SEIG is similar to that of theinduction motor. To model the SEIG effectively,the parameters should be measured accurately. The parameters used in the SEIG can be obtained by conducting tests on the induction generator when it is used as a motor. The traditional tests used to determine the parameters are the open circuit (no load) test and the short circuit (locked rotor) test.

In this paper the d-q model is used because it is easier to get the complete solution, transient and steady state, of the self –excitation[3]. The parameters given in the d-q equivalent circuit shown in Figure 3are obtained by conducting parameter determination tests on the above mentioned induction machine. As it is a wound rotor induction machine there is no variation of rotor parameters with speed.

The parameters obtained from the test at rated values of voltage and frequency are

L_{sg}=L'$_{rg}$=227mH, L_{mg}=215mH, ,

R'$_{rg}$=2.66Ω. For motoring application these parameters can be used directly. However, for SEIG application the variation of L_{mg} with voltage should be taken into consideration.

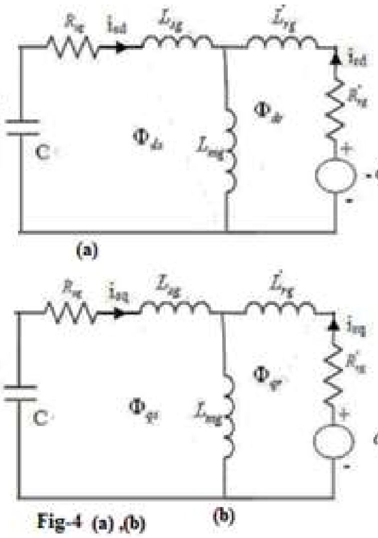

Fig.3 D-Q Model Of SEIG at No Load a) d-axis b) q-axis

$$\begin{bmatrix} R_{sg}+pL_{sg}+\frac{1}{pC} & 0 & pL_{mg} & 0 \\ 0 & R_{sg}+pL_{sg}+\frac{1}{pC} & 0 & pL_{mg} \\ pL_{mg} & -\omega_r L_{mg} & R'_{rg}+pL'_{rg} & -\omega_r L'_{rg} \\ \omega_r L_{mg} & pL_{mg} & \omega_r L'_{rg} & R'_{rg}+pL'_{rg} \end{bmatrix}\begin{bmatrix} i_{sq} \\ i_{sd} \\ i_{rq} \\ i_{rd} \end{bmatrix}=\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \tag{19}$$

Where $pI = AI + B$

$$I=\begin{bmatrix} i_{sq} \\ i_{sd} \\ i_{rq} \\ i_{rd} \end{bmatrix} \qquad B=\frac{1}{L}\begin{bmatrix} L_{mg}K_q - L'_{rg}V_{cq} \\ L_{mg}K_d - L'_{rg}V_{cd} \\ L_{mg}V_{cq} - L_{sg}K_q \\ L_{mg}V_{cd} - L_{sg}K_d \end{bmatrix}$$

$$A=\frac{1}{L}\begin{bmatrix} -L'_{rg}R_{sg} & -L^2_{mg}\omega_r & L_{mg}R'_{rg} & -L_{mg}L'_{rg}\omega_r \\ L^2_{mg}\omega_r & -L'_{rg}R_{sg} & L_{mg}L'_{rg}\omega_r & L_{mg}R'_{rg} \\ L_{mg}R_{sg} & L_{sg}L_{mg}\omega_r & -L_{sg}R'_{rg} & L_{sg}L'_{rg}\omega_r \\ -L_{sg}L_{mg}\omega_r & L_{mg}R_{sg} & -L_{sg}L'_{rg}\omega_r & -L_{sg}R'_{rg} \end{bmatrix} \tag{20}$$

III. RESULTS AND DISCUSSION

Table I: Variation Of Frequency With Speed

Base Speed= 1500rpm SPEED (PU)	FREQUENCY (PU)	SPEED (PU)	FREQUENCY (PU)
1	0.9987	0.6	0.5978
0.9	0.8986	0.5	0.4974
0.8	0.7984	0.4	0.3967
0.7	0.6982	0.3	0.2955

TABLE II

INDUCTIONGENERATOR PARAMETERS	
Rated power	3 KW
Voltage	380V Y
Frequency	50 Hz
Pair of pole	2
Rated speed	1400 rpm
Stator resistance	2.2 Ω
Rotor resistance	2.68 Ω
Inductance of stator	229 mH
Inductance of rotor	229 mH
Mutual inductance	217 mH

Table III:

Induction Motor Parameters	
Rated power	1.5 KW
Voltage	380V Y
Frequency	50 Hz
Pair of poles	02
Rated speed	1440 rpm
Torque	0.164NM

The variation of capacitance with resistive load for different values of speed taking into account magnetising reactance and neglecting the same as well has been reflected vide Fig-5(b) and 5(a) respectively. It is quite conspicuous from Fig-5(b) that capacitance requirement become less when magnetising reactance enhances.Fig-5(a) suggests that exclusion of core loss demands higher capacitance requirement adding to cost of the system which becomes a challenging optimization problem.

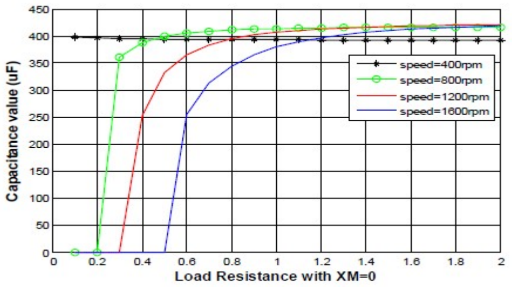

Fig-5(a)

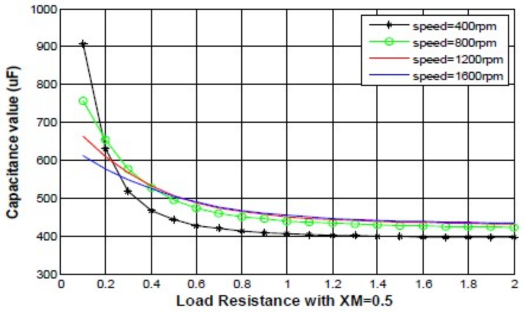

Fig-5(b)

IV. CONCLUSION

Self- excitation in induction machine depends on particular combination of speed, load and excitation capacitance. In this paper we have shown the relationship between the required capacitance, the rotor speed and the nature of load impedance using a computer program. This program gives typical results without any iteration or divergence problem.In this dissertation we studied the effect of capacitance[3] requirement for an induction generator with and without magnetising reactance subjected to resistive load.

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