Effect of the Inductive Load on the Capacitance Requirement of Self-Excited Induction Generator

Ashraf Mohamed
Electricl Engineering Department,Tobruk University
oasnaini@yahoo.com

Ahmed Abdolkhalig
Electricl Engineering Department,Tobruk University
almsraty@hotmail.com

Fatihe R.Abusief
Electricl Engineering Department,Tobruk University
f.r.abusief@eng.tu.edu.ly

Abstract— **In this paper, a simple and direct analytical method is proposed to analyze the effect of the load inductance to obtain the minimum requirement of the capacitance for self-excited induction generator for different speeds. A computer software has been developed to compute the minimum capacitance requirement at different load conditions for excitation of the machine for wide range of speeds. Results are compared and discussed in detail..**

Index Terms: **Self excited, induction generator, Capacitance, inductive Load.**

I. INTRODUCTION

Due to increasing price and depletion of conventional energy sources, interest in renewable energy resources such as wind, solar, tidal, micro-hydel has intensified. The three common electric generators are the dc generator, alternator (field wound/permanent magnet) and capacitor excited induction generator. The d.c. generator a nd field wound alternator have maintenance problem associated with commentator and brush-gear. Induction generators are receiving close attention because of the quantities such as small size, low weight, robust construction, low unit cost, manufacturing simplicity, absence of separate source for excitation, better stability, self-protection under fault conditions and low maintenance requirements [1,2]. In late 1970s, the efforts concentrated on wider applicability of self-excited induction generator {SEIG) due to oil crisis in early seventies, made exploitation of non-conventional sources inevitable for generating electricity. Wind has been identified as one of the most viable sources for converting its energy into electricity [3,6].The Application of SCRs in SEIG-Systems has ledto an upsurge in the use of electronic controller and regulators in wind energy based schemes[3].The SEIG-schemes have been used to generate d.c. to a.c. power in isolation for feeding a.c. power to grid through a dc link, by using variety of control strategies [7].

Received 25 Feb, 2019; revised 7 March, 2019; accepted 30 March, 2019.

Available online March 31, 2019.

II. SELF EXCITED INDUCTION GENERATOR

In isolated applications, an induction generator operates under self-excited mode[4,5]. If an appropriate capacitor bank is connected across the terminals of an externally driven induction machine, an EMF is induced in the machine windings due to the excitation provided by the capacitor. The magnitude and frequency of this EMF depends upon the prime mover speed, value of capacitance and load impedance. Further, owing to the saturation, the magnetizing reactance varies with the operating point. The induced voltage and 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. The machine now operates as a self-excited induction generator (SEIG) and can feed a load, at a voltage and frequency dictated by the value of the capacitor. It is known that in the operation of self-excited induction generators, for a given capacitance value and load, there is a minimum speed below which the excitation cannot be sustained. To extend the speed range, the practice has been to increase the capacitance value particularly for wind driven applications where there is a wide variation in speed. As soon as induction motor speed exceed its synchronous speed, it starts delivering active power to the three-phase line. However for creating its own magnetic field it absorb reactive power from the line to which it is connected. Reactive power flows in the opposite direction to active power. The active power is directly proportional to the slip above the synchronous speed. The reactive power required can also supplied by a group of capacitors connected across machine terminals. This arrangement can be used to supply a three phase load without using an external source. The frequency generated is slightly less than that load without using an external source. The frequency generated it slightly less than that corresponding to speed of rotation. The terminal voltage increases with capacitance. If capacitance is insufficient, the generator voltage will not build up. Hence capacitor bank must be large enough to supply the reactive power.

Figure.1 shows the capacitor connected to the machine are in delta for economic reasons. If these are connected in star connection, voltage across and reactive power supplied by each capacitor will be 0.588 and 1/3 times that in delta connection. For the same reactive power, three times as much capacitance is required in star connection which increases the system size and cost. These capacitances have been used to self-excite the generator.

A single phase equivalent circuit of SEIG as shown in Figure.2 is called a negative resistance oscillator. The oscillations occurs at a particular frequency where the capacitive reactance equals the inductive reactance of the generator. The oscillations are more pronounced if the R-L load is disconnected at the time of start and is switched in after normal voltage build up. The induction generator produces as small voltage due to residual magnetism which initiates oscillations. Change in capacitance will

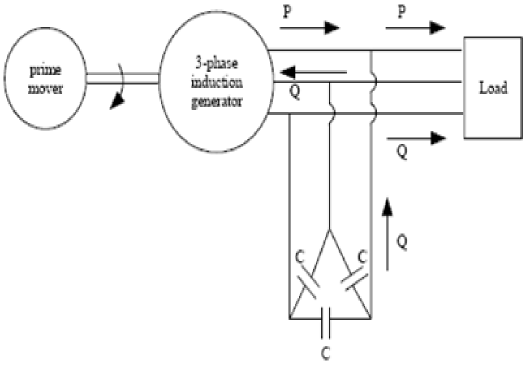

Figure1.Self-Excited Induction Generator.

Change the frequency of oscillation therefore the machine speed. It is found that at a particular shaft power input, decrease in capacitance causes the speed to increase. The change is more for heavy load than for light loads.

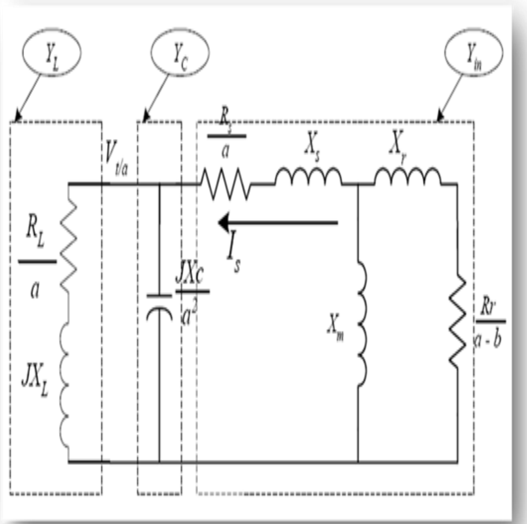

Figure 2. Single-Phase Equivalent Circuit of Self-Excited Induction Generator.

Figure.3 shows both the magnetizing curve of an unloaded SEIG and the voltage–current characteristic of a capacitor bank plotted on the same set of axes. The intersection of the two curves is the point at which the capacitor bank exactly supplies the reactive power demanded by the generator. As shown in the figure the no-load terminal voltage of the generator may be determined from this point .When a SEIG is loaded, both the magnitude and frequency of the induced e.m.f. are affected by the prime mover speed, the capacitance of the capacitor bank and the load impedance.

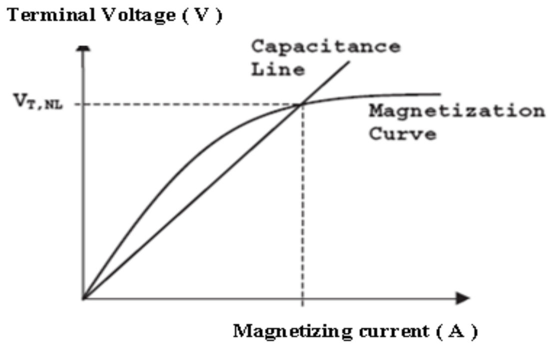

Figure3. No-load Magnetization Characteristics and Capacitive Impedance Line.

III. MODELING & SIMULATION TEST

The circuit shown in Figure.1is used to analysis theinduction generator under steady-state operation. However, as the operating frequency of the generator varies with the driving speed and the load. The mathematical models representing the SEIG could be simulated using conventional MatLab language MatLab Released 2008 (MATLAB R2008a) is used to simulate the performance of SEIG.

It is to be noted that the circuit has been transformed to the base frequency by introducing the parameters a and b, which are defined as :

$$a = \frac{f_g}{f_b}$$

Where f_g is the generated frequency, and f_b is the base frequency.

$$b = \frac{\omega}{\omega_b}$$

Where(ω) is the actual rotor speed, and (ω_b) is the synchronous speed corresponding to base frequency.

Then the slip under operating conditions is giving by:

$$S = \frac{\omega_s - \omega}{\omega_s} = \frac{a-b}{a}$$

Applying Nodal analysis at the terminal of the load then:

$$\frac{V_t}{a} \cdot Y_t = 0$$

Where:

$Y_t = Y_{in} + Y_c + Y_L$

For successful voltage build-up, , hence

$Y_t = 0$ (1)

This implies that both real and imaginary parts of Eq.(1) would be zero. Upon equating the imaginary part of the Eq.(1) to zero, the following non-linear equation is obtained :

$$C_4 a^4 + C_3 a^3 + C_2 a^2 + C_1 a + C_0 = 0 \qquad (2)$$

The coefficients of Eq. (2) are given by:

$$C_4 = X_L^2 R_r (L_2 L_3 - L_1) + X_L^2 R_s L_2^2 + R_L L_1^2$$

$$C_3 = X_L^2 R_r b(L_1 - L_2 L_3) - 2b(X_L^2 R_s L_2^2 + R_L L_1^2)$$

$$C_1 = R_L^2 R_r b(L_1 - L_2 L_3) - 2b R_L R_s L_2^2 (R_s + R_L)$$

$$C_0 = (R_r^2 + L_2^2 b^2) R_L R_s (R_L + R_s)$$

Where:

$$L_1 = X_s(X_r + X_m) + X_r X_m$$

$$L_2 = X_r + X_m$$

$$L_3 = X_s + X_m$$

In Eq.(2) there are four roots; the positive real roots only have the physical meaning. If there is no any positive real root, then there is no self-excitation. By solving Eq.(2) the p. u. frequency and then the operating frequency can be obtained.

The minimum value of terminal excitation capacitor (Cmin) for induction generator to build up can be obtained from the following formula:

$$C_{min} = \frac{1}{2\pi}\left(\frac{X_L a^2}{M_3} + \frac{M_4}{M_1^2 + M_2^2}\right)$$

Where:

$$M_1 = R_s R_r - a(a-b)L_1$$

$$M_2 = R_r a L_3 + R_s(a-b)L_2$$

$$M_3 = R_L^2 + X_L^2 a^2$$

$$M_4 = R_r * M_2 - L_2 a(a-b)M_1$$

After a successful self-excitation process and voltage build-up of the SEIG the machine magnetic circuits becomes saturated. Therefore, the saturated value of the magnetizing inductance must be used in the steady state computations.

The mathematical models representing the SEIG could be simulated using conventional MatLab language. A MatLab Released 2008 (MATLAB R2008a) is used to simulate the performance of SEIG.The parameters of the per-phase equivalent circuit of the SEIG in PU are as follows:

Rs =0.071 pu, Rr =0.0881 pu, Xs = Xr =0.1813 pu,
Xm =3.23 pu , Z_b=43.3 N=1800 rev/min, fb =50Hz,
b = 1 pu.

Figure. 4 and Figure.5 show the requirement of minimum capacitance of SEIG under different values of load resistance for different set of speed.

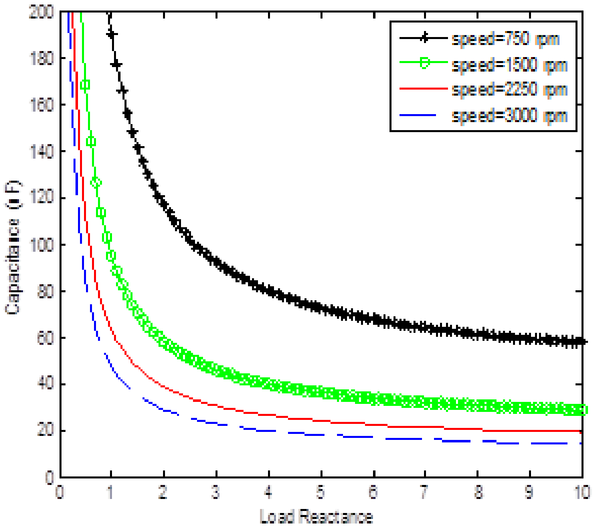

Figure4. The Relationship Between Capacitance and Load Reactance when RL=0pu.

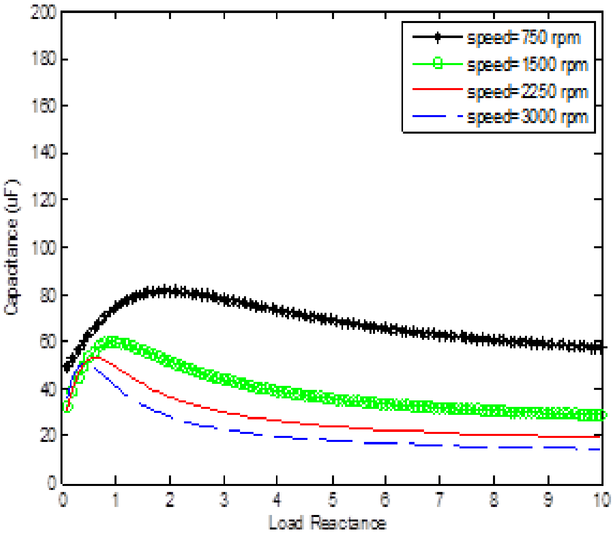

Figure5. The Relationship Between Capacitance and Load Resistance when RL=1pu.

These curves show that:

(i) Minimum capacitance requirement for load is more than no load condition.

(ii) There exit a trend between capacitance requirement at a given speed and the nature of load

(iii) Results also show the requirement of capacitance is minimum for inductive load than resistive load.

(iv) The larger the value of impedance, smaller the value of minimum capacitance required.

IV. CONCLUSIONS

The analysis used to determine the minimum value of capacitance has been found equally suitable for different load conditions. This fact can be utilized for making a Sel-Excited Induction Generator of smaller size and an economical one for isolated purpose. An automatic switching scheme using power electronic devices can be incorporated to make suitable isolated self-excited induction generator for different load requirements.

REFERENCES

[1] J.M. Elder, J. T. Boys, J.L. Woodward, "*Self-excited Induction Machine as a Small Low-cost Generator*" Lee Proceedings Vol.131, No 2, pp. 33-40, March 1984.

[2] Edward L. Owen, Glenn R. Griffith "*Induction Generator Applications for Petroleum and Chemical Plants*" IEEE Transactions on Industry Applications, Vol. IA-19, No 6 ,pp.1003- 1011, November/ December 1983.

[3] G. Raina. O.P. MalIk "*Wind Energy Conversion Using a Self Excited Induction Generator*" IEEE Transactions on Power Apparatus and Systems, Vol. PAS 102, No.12, pp. 3933-3936, December 1983.

[4] C. V. Nayar, "*Small Scale Wind Electricity Generator-Design Criteria*" TIDE-3(2), June 1993.

[5] S.P. Singh, Bhim Singh, M.P. Jain "*Simplified Approach for Analyisis of Self-Excited Induction Generator*" Journal of The Institution of Engineers (India) Vol. 76, pp.15-17, May 1995.

[6] S.C. Agrawal, M. Singh, D.P. Kothari, "*Analysis Of Induction Generator for Wind Energy Conversion System at Constant Output Voltages*" Journal of The Institution of Engineers (India) Vol. 77, pp.182-185, Feb 1997.

[7] . S.P. Singh, M.P. Jain, Bhim Singh "Steady State Analysis of a Self Excited Induction Generator with an AC-DC Conversion Scheme for Small Scale Generator" Electric Power System Research Vol.20, pp.95-104,1991.