



AN EFFICIENT APPROACH FOR ANALYSIS OF ISOLATED SELF –EXCITED INDUCTION GENERATOR

Deepika¹, Pankaj Mehara²

Assistant Professor, Dept. of EE, DCRUST, Murthal, India¹

PG Student, Dept. of EE, DCRUST, Murthal, India²

ABSTRACT: An efficient analytical technique using Secant method is used to describe the generated frequency and saturated magnetizing reactance of self-excited induction generator for a given capacitance, speed, and load. The nodal technique is used on the single phase equivalent circuit of SEIG. The nodal analysis provides two non-linear equations. One equation contains only generated frequency term solve by Secant method using initial values calculation by real power balance equivalent circuit. This proposed technique is simple and used for any kind of balanced load.

Keywords: Self-excited induction generator, Secant method, Non-linear equations.

I.INTRODUCTION

The increasing concern to the environment and fast depleting conventional resources have caused the researchers towards rationalizing the use of conventional energy resources and motivating the non-conventional energy resources to meet the energy demand. A number of renewable energy sources like small hydro, wind, solar, industrial waste, geothermal, etc. are explored. Since small hydro and wind energy sources are available in plenty, their utilization is felt quite promising to accomplish the future energy requirements. Harnessing mini-hydro and wind energy for electric power generation is an area of research interest and at present, the emphasis is being given to the cost-effective utilization of these energy resources for quality and reliable power supply. Induction generators are often used in wind turbines and some micro hydro installations due to their capability to produce useful power at varying speeds [1].

If an appropriate three phase capacitor bank is connected across the induction machine driven by external source, the EMF is induced in the machine winding due to excitation provided by the capacitor bank. This phenomenon is known as capacitor excitation which is an important thing to operate the induction machine as a generator. An induced voltage and current will be continuously rise and finally reached at steady state due to magnetic saturation in the machine.

The induction machine having the following advantages over synchronous machine as a source of isolated power supply. Operated as a varying speed, reduced unit cost, brushless rotor construction (squirrel cage rotor), no separate DC source is required for excitation and ease of maintenance is the following advantages.

The steady state analysis is very important for design as well as operational point of view. If the machine is connected to infinite bus bar, the terminal voltage and frequency are known, the prediction of the performance of the machine is straightforward. But in case of self-excited induction generator used as a stand-alone purpose, both the terminal voltage and generated frequency are unknown, to determine the performance of machine the unknowns have to be computed for given speed, capacitance and load [2]-[9]. The calculation is complicated due to magnetic saturation, so a suitable parameter is used to calculate the performance in the saturated condition. The Secant method is used in this paper to identify the steady state performance using the single phase equivalent circuit of the self-excited induction generator. In the Secant method the initial values of generated frequency are determined by using real power balance equivalent circuit. The result is discussed and presented graphically to guidelines for designers.

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 8, August 2013

II. THEORY

For steady state analysis the following assumption are taken

- Only the magnetizing reactance is assumed to be changes by magnetic saturation, and all the other parameters remains constant.
- Stator and rotor leakage reactance are assume equal.
- Core losses in the machine are neglected.
- MMF space harmonics and time harmonics in the induced voltage and current waveforms are ignored. These all assumptions are valid for well design machine.

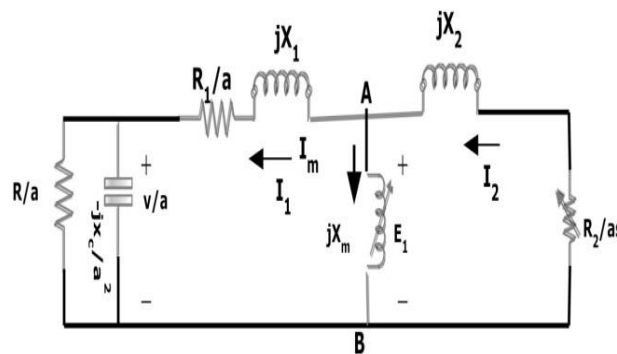


Fig. 1 Equivalent per phase circuit of the SEIG

The steady state equivalent circuit of capacitor self-excited induction generator with resistive load connected to its terminal as shown in fig. 1 where :

- R_1, R_2 = per phase stator and rotor resistance. (referred to stator)
 R = load resistance per phase
 X_1, X_2 = per phase stator and rotor (referred to stator) reactance.
 X_c, X_m = per phase capacitive and magnetizing reactance at rated frequency.
 ω_b, ω_s = rated frequency and stator frequency
 ω_r = rotor speed
 $a = \omega_s / \omega_b$ = per unit frequency
 b = per unit speed
 I_1, I_2, I_L = stator, rotor (referred to stator) and load current per phase
 V, E_1 = terminal voltage and air gap voltage

The equivalent per phase circuit of SEIG as shown by fig.1 which is only valid for generated frequency. Here use nodal analysis technique to determine generated frequency and magnetizing reactance at node M. This analysis considers the admittances connected across the nodes which define the air gap. By equating the sum of real parts to zero (which is equivalent to active power balance), a polynomial in 'a' is obtained. 'Xm' can be determined upon equating the sum of imaginary parts to zero, using the value of 'a' obtained after solving the polynomial by any method among various methods as iterative method, secant method etc.

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 8, August 2013

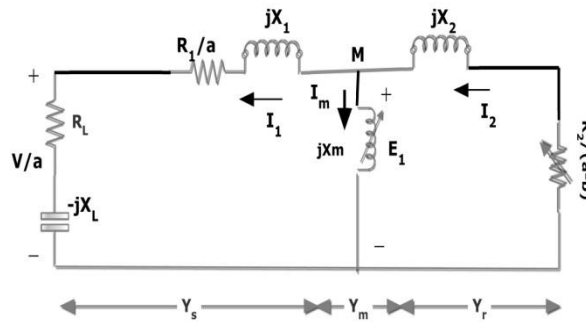


Fig.2 Simplified equivalent circuit of fig. 1

$$E_1(Y_s + Y_m + Y_r) = 0$$

$$Y_s = \frac{1}{(R_L + R_1/a) + j(X_1 - X_L)}$$

$$Y_m = \frac{1}{jX_m}$$

$$Y_r = \frac{1}{\frac{R_2}{a-b} + jX_2}$$

Hence for voltage build-up $E_1 \neq 0$ so

$$(Y_s + Y_m + Y_r) = 0$$

Separating the real and imaginary term

$$\text{real}(Y_s + Y_m + Y_r) = 0$$

$$P_5 a^5 + P_4 a^4 + P_3 a^3 + P_2 a^2 + P a + P_0 = 0 \tag{1}$$

$P_5, P_4, P_3, P_2, P_1, P_0$ Are the coefficients does not contain X_m . As described in appendix A.

$$\text{imag}(Y_s + Y_m + Y_r) = 0$$

$$X_m = \frac{1}{-\frac{X_2}{\left(\frac{R_2}{a-b}\right)^2 + X_2^2} - \frac{(X_1 - X_L)}{\left(\frac{R_1}{a} + R_L\right)^2 + (X_1 - X_L)^2}} \tag{2}$$

Since the equation (1) contain frequency term and this polynomial equation can be solved by secant method using initial values calculation then compute the value of frequency in equation (2) to calculate the value of X_m .

III. INITIAL VALUES CALCULATION TECHNIQUE

The Secant method requires two initial values for solving a polynomial equation. Here the two initial values can be calculated by real power balance equivalent circuit.

The equation (1) can be rewritten as a function of a

$$f(a) = 0$$

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 8, August 2013

If a_0 and a_1 are two initial values for a . Then the next value for a will be:

$$a_{i+1} = a_i - f(a_i)(a_i - a_0)/(f(a_i) - f(a_0))$$

$i = 1, 2, 3 \dots$

The iterations stop with an accuracy of 0.000001.

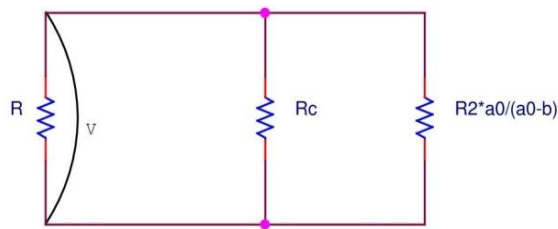


Fig. 3 Real power balance circuit

The desired value of a lies between upper initial value (a_0) and lower initial value (a_1)

The upper initial value (a_0)

The real power balance equation according to the fig. 3

$$V^2 \left[\frac{1}{R} + \frac{1}{R_c} + \frac{a_0 - b}{a_0 R_2} \right] = 0 \quad (3)$$

Since V^2 cannot be zero, solve the equation (3) for a_0

$$a_0 = \frac{b}{\left(1 + R_2 \left(\frac{1}{R} + \frac{1}{R_c} \right) \right)} \quad (4)$$

Lower initial value (a_1)

Lower initial value can be found out by assuming a very close value at which maximum torque occur.

$$s_{\max} = R_2/(X_1 + X_2) \quad (5)$$

The induction motor run as generator then the slip will be negative and the s_{\max} depends upon the overloading factor. Assuming an overloading factor is 2 and the rated torque occurs at a_1

$$a_1 = b/(1 + 0.5(R_2/(X_1 + X_2))) \quad \left(\frac{1}{2} \right) s_{\max} = -(a_1 - b)/a_1 \quad (6)$$

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 8, August 2013

IV. SYNCHRONOUS SPEED TEST

After solving the value of a, X_m the next step is to calculate the airgap voltage E_1 and the terminal voltage V . The synchronous speed provide the information about the variation of X_m with respect to E_1/a which relate to the air gap flux. These information require to be obtained experimentally by driving the induction machine at synchronous speed corresponding to line frequency, i.e. $a=1$ and measuring the magnetizing reactance with increase the line voltage at line frequency according the fig.4. When the induction machine rotated at synchronous speed the slip will become zero and rotor resistance become very high and behave as an open circuit on rotor side. A curve fitted of E_1/a against X_m by the experimental result.

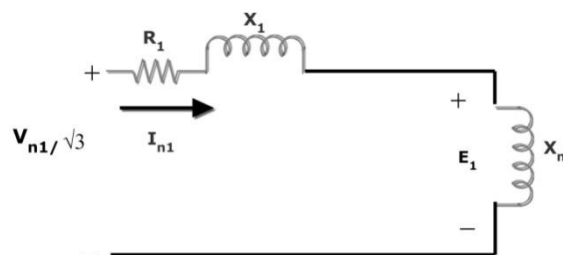


Fig. 4 Synchronous speed test circuit

The R.M.S. voltage of magnetising branch is

$$E_1 = X_m I_{n1}$$

$$I_m = I_{n1}$$

The no load current is equal to

$$I_{n1} = (V_{n1}/\sqrt{3})/Z_0$$

Z_0 Is the absolute value of total impedance of circuit

$$Z_0 = R_1 + j(X_1 + X_m)$$

The magnetising reactance is

$$X_m = (Z_0^2 - R_1^2)^{1/2} - X_1$$

For computer simulation a curve, which will gives the variation of E_1/a with a

$$E_1/a = k_1 - k_2 X_m \quad (7)$$

The values of k_1, k_2 for test machine are given in appendix A.

V. PERFORMANCE CALCULATION OF THE MACHINE

Performance of machine is computed as follows:

$$I_1 = (E_1/a)/((R_1/a) + jX_1 - (X_c R)/(a^2 R - aX_c)) \quad (8)$$

$$I_2 = -(E_1/a)/(R_2/(a-b) + X_2) \quad (9)$$

$$I_L = -X_c I_1/(Ra - X_c) \quad (10)$$

$$V = I_L R \quad (11)$$

$$P_{in} = -q I_2^2 a R_2/(a-b) \quad (12)$$

$$P_{out} = q I_L^2 R \quad (13)$$

VI. RESULT AND DISCUSSION

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 8, August 2013

Here the effective secant method is used to find generated frequency and magnetizing reactance and a terminal voltage is computed at resistive loads and at constant speed and with fixed capacitor value. Further check the performance of machine at different values of capacitance. And provide a table to require the value of capacitance which remains constant the terminal voltage at different load condition.

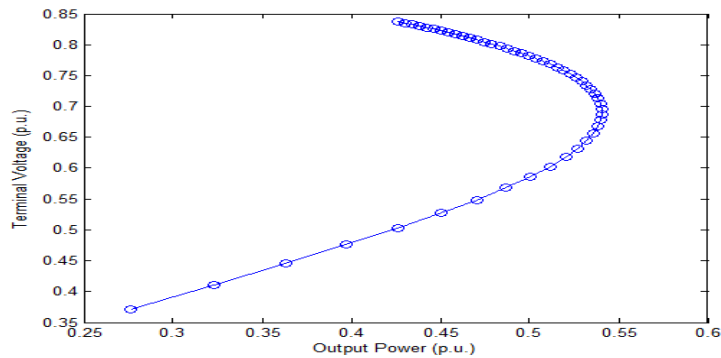


Fig. 5 Terminal voltage (V) v/s output power at $41\mu\text{F}$, $b=1\text{p.u.}$

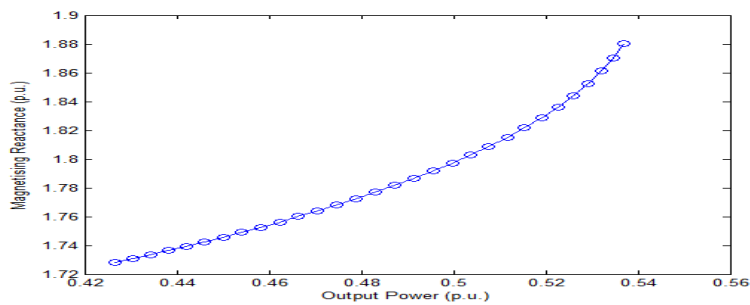


Fig. 6.2: Magnetizing Reactance (X_m) v/s output power at $41\mu\text{F}$, $b=1\text{p.u.}$

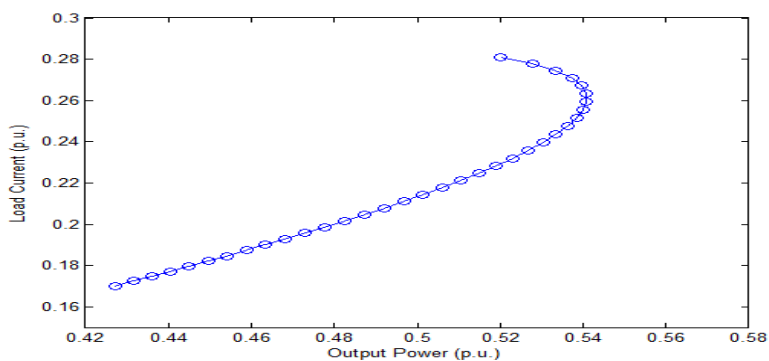


Fig. 6.3 Shows the simulated results for load current v/s output power. For the resistive load,

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 8, August 2013

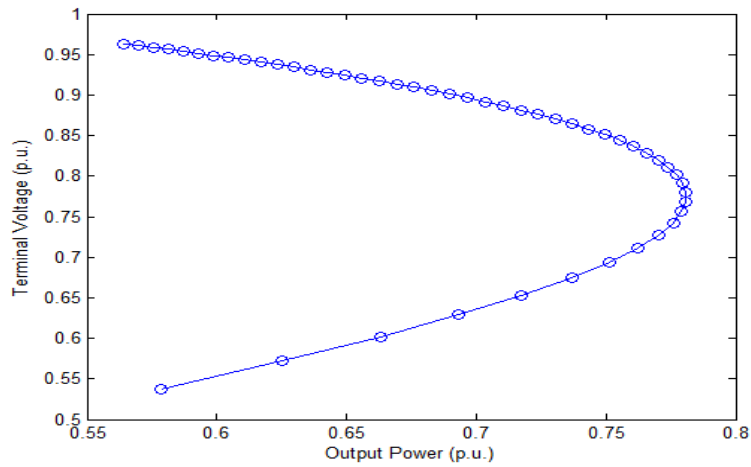


Fig. 6.4: Terminal voltage (V) v/s output power at 46µF, b=1p.u.

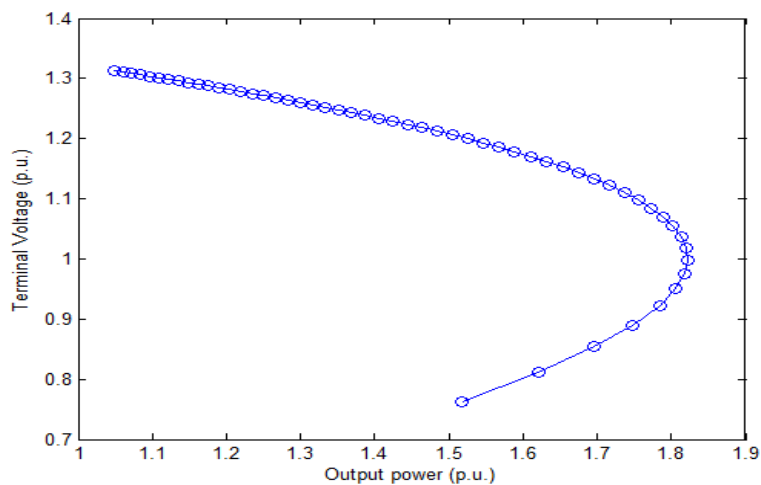


Fig. 6.9: Terminal voltage (V) v/s output power at 66µF, b=1p.u.

LOAD RESISTANCE (R) p.u.	CAPACITANCE (C) uf	TERMINAL VOLTAGE (V) p.u
15	43.4520	1.0010
14	43.5860	1.0010
13	43.7420	1.0010
12	43.9250	1.0010
11	44.1440	1.0010
10	44.4110	1.0010



International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 8, August 2013

9	44.7420	1.0010
8	45.1650	1.0010
7	45.7210	1.0010
6	46.4880	1.0010
5	47.6080	1.0010
4	49.3920	1.0010
3	52.5450	0.9990
2	60.1670	0.9990
1	93.6750	0.9990

Table 6.1 Shows the value of capacitance required to constant terminal voltage

VII.CONCLUSION

This paper introduced the efficient approach to calculate initial values of generated frequency with the help of real power balanced circuit. This technique is simple in nature and very effective to analyse the SEIG. This technique is suitable for any kind of balance load. The paper describes the value of capacitance required to maintain the specific terminal voltage across the load which is varying in nature.

Appendix 1

Machine specification: (parameters are given in per unit)

3-phase, 4 poles, 50Hz, 230V, 8.6A, 2.2KW delta-connected squirrel cage induction machine

$$R_1 = 0.076$$

$$R_2 = 0.076$$

$$X_1 = 0.112$$

$$X_2 = 0.112$$

$$b = 1$$

$$Z_{base} = 46.32 \text{ ohm}$$

$$P_{base} = 1.190 \text{ KW}$$

Synchronous speed curve fitting equation

$$E_1/a = k_1 - k_2 X_m$$

The value of k1, k2

$$k_1 = 1.726$$

$$k_2 = .54$$

Coefficient of polynomial equation

$$P_5 = R_2 R^2 X_1^2 + R^2 R_1 X_1^2$$

$$P_4 = -b(R_2 R^2 X_1^2 + 2X_2^2 R_1 R^2)$$

$$P_3 = R_2 R^2 R_1^2 + R_2 X_1^2 X_c + b^2 X_2^2 R^2 R_1 + R^2 R_1 R_2^2 + R_3 X_c^2 X_2^2 - 2R_2 X_1 X_c R^2$$

$$P_2 = -bR_2 R_1^2 R^2 - bR_2 X_1^2 X_c^2 + 2bR_2 X_1 X_c R^2 - 2bR_3 X_c^2 X_2^2$$



International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 8, August 2013

$$P_1 = R_2 R_3^2 X_c^2 + b^2 R_3 X_c^2 X_2 + R_3 X_c^2 R_2^2$$

$$P_0 = -b R_2 R_3^2 X_c^2$$

Coefficient of polynomial equation

$$P_5 = R_2 R^2 X_1^2 + R^2 R_1 X_1^2$$

$$P_4 = -b(R_2 R^2 X_1^2 + 2X_2^2 R_1 R^2)$$

$$P_3 = R_2 R^2 R_1^2 + R_2 X_1^2 X_c + b^2 X_2^2 R^2 R_1 + R^2 R_1 R_2^2 + R_3 X_c^2 X_2^2 - 2R_2 X_1 X_c R^2$$

$$P_2 = -b R_2 R_1^2 R^2 - b R_2 X_1^2 X_c^2 + 2b R_2 X_1 X_c R^2 - 2b R_3 X_c^2 X_2^2$$

$$P_1 = R_2 R_3^2 X_c^2 + b^2 R_3 X_c^2 X_2 + R_3 X_c^2 R_2^2$$

$$P_0 = -b R_2 R_3^2 X_c^2$$

REFERENCES

- [1] M. Godoy Simoes and F. A. Farret, "Renewable Energy Systems: Design and Analysis with Induction generators", CRC Press, Boca Raton, FL, 2004.
- [2] T. F. Chan, "Steady-state analysis of self-excited induction generators", IEEE Trans. Energy Conversion, Vol. 9, no. 2, pp. 288-296, June 1994.
- [3] S. S. Murthy, "A novel self-excited self-regulated single-phase induction generator, part-I: basic system and theory", IEEE Trans. Energy Conversion, vol. 8, pp. 377-382, Sept. 1993.
- [4] S. P. Singh, B. Singh, and M. P. Jain, "Simplified approach for the analysis of self-excited induction generator", J. Inst. Eng. (India), vol. 76, no. 2, pp. 14-17, 1995.
- [5] L. Quazene and G. McPherson Jr., "Analysis of an isolated induction generator", IEEE Trans. Power App. Syst., vol. 102, no. PAS-8, pp. 2793-2798, Aug. 1983.
- [6] D. K. Jain, A. P. Mittal, and B. Singh, "An efficient iterative technique for the analysis of self-excited induction generator", J. Inst. Eng. (India), vol. 79, no.1, pp. 172-177, 1999.
- [7] D. W. Novotny, D. J. Gritter and G. H. Studtmann, "Self-excitation in Inverter Driven Induction Machines," IEEE Transactions on Power Apparatus and Systems, vol. 96, no. 4, pp. 1117 - 1125 , July 1977.
- [8] S. Rajakaruna, R. Bonert, "A technique for the steady-state analysis of a self-excited induction generator with variable speed", IEEE Trans. Energy Conversion, Vol. 8, no. 4, pp. 757-761, Dec. 1993.
N. H. Malik and S. E. Haque, "Steady state analysis and performance of an isolated self-excited induction generator", IEEE Trans., 1986, EC-1, (3), pp. 134-139.

BIOGRAPHY

Deepika obtained B.Tech in electrical engineering from VCE, Rohtak (Haryana), India and M.Tech in power system and electric drives from YMCAUST, Faridabad, India, in 2007 and 2011, respectively. Since April-2012 she has been with Department of Electrical Engineering, Faculty of Engineering and Technology, DeenBandhuChhotu Ram University of Science & Technology, Murthal (Sonapat)-Haryana, India, where she is currently Assistant Professor. Her research interests include Induction Machine, Renewable Energy resources etc.

Pankaj Mehara obtained B.Tech in Electrical Engineering from YMCAIE Faridabad, affiliated to MDURohtak, Haryana, India and pursuing his M.Tech in Electrical Engineering (Power System) from DeenBandhuChhotu Ram University of Science and Technology, Murthal (Sonapat) – Haryana, India. His research interests include Induction Machine, Renewable Energy Sources, and Smart Grid Technology etc.