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Steady State Analysis of Self-Excited Induction Generator

Harish Kumar, Neel Kamal

***Abstract:** The paper deals with the steady state analysis of self-excited induction generator using Genetic Algorithm, Pattern Search and Quasi-Newton optimization techniques. The performance of an induction generator, maintaining a constant terminal voltage is analyzed under resistive loads. Further the paper deals with effects of various system parameters on the steady state performance of an induction generator. Simulated results obtained from various optimization techniques are compared graphically. The comparison of results, had lead to their comparative importance.*

***Key Words:** Induction Generator, Optimization Techniques, steady state analysis*

I. INTRODUCTION

Presently, most of the electricity generated comes from fossil fuels (coal, oil and natural gas). These fossil fuels have finite reserves and will run out in the future. The negative effect of these fossil fuels is that they produce pollutant gases when they are burned in the process to generate electricity. Fossil fuels are a non-renewable energy source. However, renewable energy resources (wind, hydro, solar, biomass, geothermal and ocean) are believed not to run out, and are environmental friendly. In renewable energy resources wind energy is the dominating source. It is a clean and abundant resource that can produce electricity with no pollutant gas emission. Induction generators are widely used for wind powered electric generation, especially in remote areas, because they do not need an external power supply to produce the excitation magnetic field. An induction generator offers various advantages over the conventional synchronous generators such as reduced unit cost, easy maintenance, rugged and simple construction, brushless rotor (squirrel cage) and so on [1].

It is well known that a three-phase induction machine can be made to work as a self-excited induction generator (SEIG) [2]. In an isolated application an induction generator operates in the self-excited mode by connecting the capacitors to the stator terminals. In a grid connected induction generator the magnetic field is produced by excitation current drawn from the grid. In this paper the steady state performance of an isolated induction generator excited by the capacitors is analyzed with different optimization techniques. The effects of various system parameters on the steady state performance have been studied.

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II. ANALYSIS

A. Nomenclatures

R_S, R_R Per phase stator and rotor resistance respectively

X_S, X_R Per phase stator and rotor leakage reactance respectively

X_M Magnetizing reactance

X_C Per phase capacitive reactance of the terminal capacitance C

R_L Per phase load resistance

F,ν Per unit frequency and speed respectively

I_S, I_R, I_L Per phase stator, rotor and load current respectively

V_T, V_G Terminal and air gap voltage respectively

VAR Per phase volts ampere reactive

Pin & Pout Per phase input and output power respectively

(All these quantities are referred to the stator and at base frequency)

In the present paper, the standard steady state equivalent circuit of a SEIG with the usual assumptions [3], considering the variation of magnetizing reactance with saturation as the basis for calculation. The equivalent circuit is normalized to the base frequency by dividing all the parameters by the p.u. frequency as shown in Fig. 1.

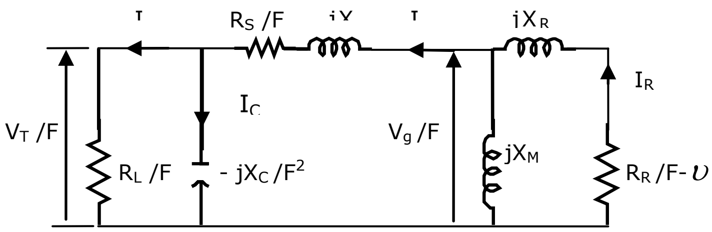

Fig. 1 Per-phase equivalent circuit of SEIG

For the purpose of obtaining required lagging reactive power to maintain desired voltage at machine terminals, X_C and F are only unknown parameters for a given speed and load.

From the Fig. 1 the loop equation for stator current is given by:

$$Z_S I_S = 0 \quad (1)$$

Where

$$Z_S = Z_1 + Z_2 + Z_3 \quad (2)$$

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$$Z_1 = \frac{-jX_C R_L}{\left(R_L F^2 - jX_C F\right)} \quad (3)$$

$$Z_2 = R_S/F + jX_S \quad (4)$$

$$Z_3 = \frac{jX_M\left[R_R + j\left(F - \upsilon\right)X_R\right]}{R_R + j\left(F - \upsilon\right)\left(X_M - X_R\right)} \quad (5)$$

Since under steady state operation of SEIG, I_S can not be equal to zero, therefore:

$$Z_S = 0 \quad (6)$$

This equation after separation into real and imaginary parts, can be rearranged into two nonlinear equations which are solved using different optimization techniques to obtain value of X_C and F after substituting

$X_S = X_R = X_L$ [4].

An objective function is given by equation

$$Z = \left(f^2 + g^2\right)^2 \quad (7)$$

(Where f & g are given in Appendix-I)

The relation between X_M and Vg/F is given by equation

$$X_M = \frac{\left(K_1 - \frac{V_g}{F}\right)}{K_2} \quad (8)$$

Where K_1 and K_2 are depends on the design of the machine.

$$V_g = V_T\left(\frac{Z_1 + Z_2}{Z_1}\right) \quad (9)$$

Thus for a given value of R_L and V_T, the value of V_g can be determined from equation (9). With the known values of V_g, F, X_C, υ , R_L and the generator's equivalent circuit parameters, the following relations can be used for the computation of the machine performance [5].

$$I_S = \frac{\left(V_g/F\right)}{\left(Z_1 + Z_2\right)} \quad (10)$$

$$I_R = \frac{\left(-V_g/F\right)}{\left[R_R/\left(F - \upsilon\right) + jX_R\right]} \quad (11)$$

$$I_L = \frac{-jX_C I_S}{R_L F - jX_C} \quad (12)$$

$$V_T = I_L R_L \quad (13)$$

$$VAR = V_T^2\left(F/X_C\right) \quad (14)$$

$$P_{in} = -\frac{\left|I_R\right|^2 R_R F}{\left(F - \upsilon\right)} \quad (15)$$

$$P_{out} = \left|I_L\right|^2 R_L \quad (16)$$

III. OPTIMIZATION TECHNIQUES

This paper deals with the implementation of different optimization techniques such as Genetic Algorithm (GA), Pattern Search (PS) and Quasi-Newton (QN) which are based on the software of MATLAB. The above optimization techniques used the same equations to solve irrespective of the unknown parameter which is not possible in other conventional methods of analysis. The equations can be solved for capacitive reactance and frequency, magnetizing reactance and frequency of the generator.

A. Genetic Algorithm

The GA is a method for solving optimization problems that are based on natural selection, as process is derived from biological evolution. The genetic algorithm repeatedly modifies a population of individual solutions. At each step, the GA selects individuals at random from the current population to be parents and uses them to produce the children for the next generation. Over successive generations, the population evolves toward an optimal solution. The GA has several advantages over other optimization methods. It is robust, able to find global minimum and does not require accurate initial estimates [7] [8]. The flowchart describing the GA optimization technique implemented in this paper is shown in Fig. 2. The two unknowns X_C and F are determined by optimizing the fitness function.

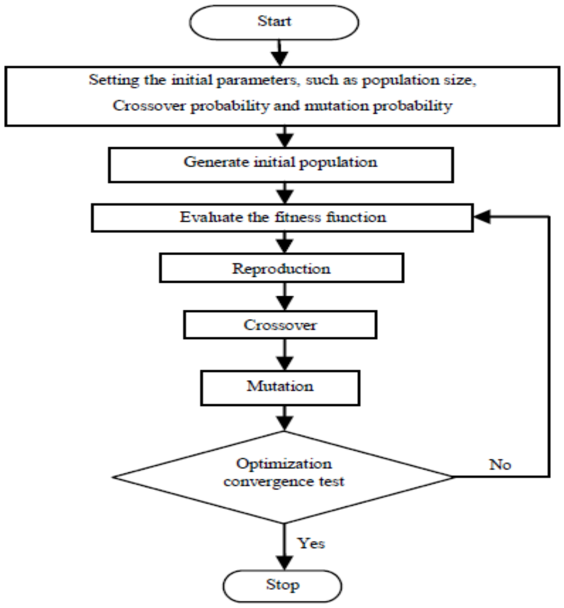

Fig. 2 Flow chart of genetic algorithm

B. Pattern Search

PS is a subclass of direct search algorithms, which involve the direct comparison of objective function values and do not require the use of explicit or approximate derivatives. Direct search is a method for solving optimization problems that does not require any information about the gradient of the objective function. As opposed to more traditional optimization methods that use information about the gradient or higher derivative to search for an optimal point, a direct search algorithm searches a set of points around the current point, looking for one where the value of the objective function is lower than the value at the current point. Direct search can be used to solve problems for which the objective function is not differential, or even continuous [9].

The flowchart describing the PS optimization technique implemented in this paper is shown in Fig. 3

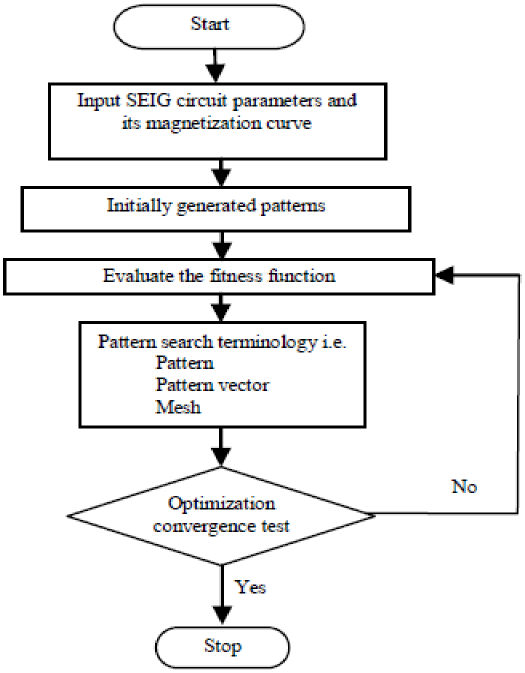

Fig. 3 Flow chart of pattern search

C. Quasi-Newton

QN methods, are currently the most robust and effective algorithms for unconstrained optimization [10]. General QN optimization algorithm flow chart as shown in Fig. 4

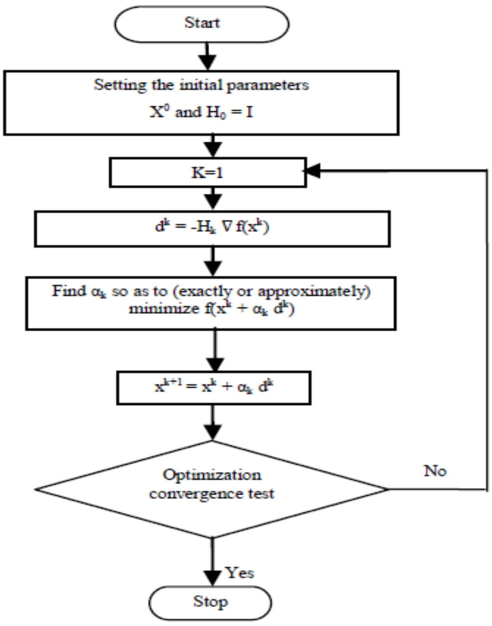

Fig. 4 Flow chart of Quasi-Newton

IV. RESULTS AND OBSERVATIONS

The performance characteristics of capacitor excited, 3.7 KW, cage generator (specification of machine in Appendix-II) has been obtained by using different optimization techniques. To avoid repetition Fig. 5 to Fig. 11 represent the performance characteristics of SEIG obtained only by GA. The performance characteristics shown from Fig. 5 to Fig. 9 are obtained at constant terminal voltage and rated speed and Fig. 12 to Fig. 15 shows combined results obtained from the GA, PS and QN optimization techniques for constant terminal voltage and constant speed.

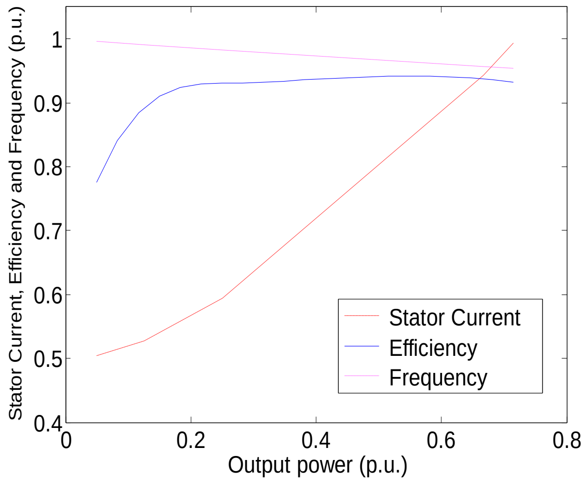

Fig. 5 Variations of stator current, efficiency and frequency with output power.

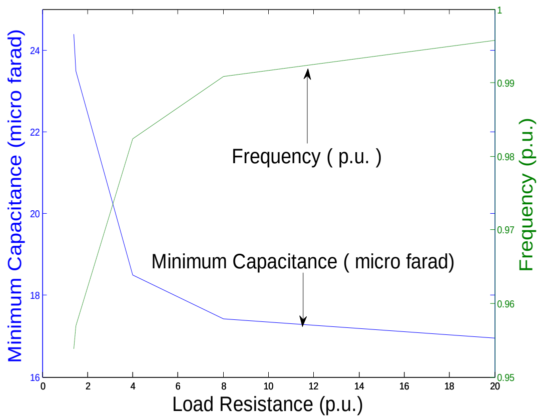

Fig. 6 Variations of minimum capacitance and frequency with load resistance.

From Fig. 5 it can be observed that at constant terminal voltage the frequency variation is negligible. Whereas the efficiency is good throughout the power range and the stator current increases with increase in output power.
Fig. 6 results show that the exciting capacitance decreases as load resistance increases, whereas the frequency increases with increase in load resistance.

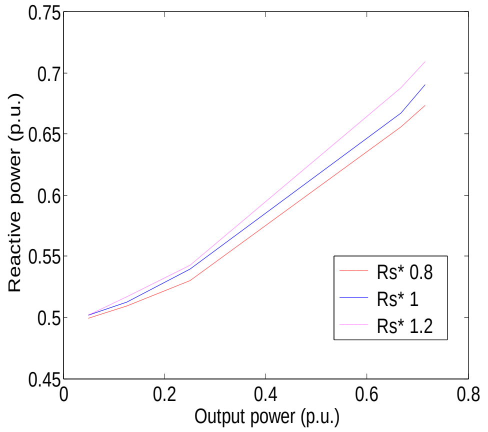

Fig. 7 Variations of Reactive power with output power for different values of stator resistance.

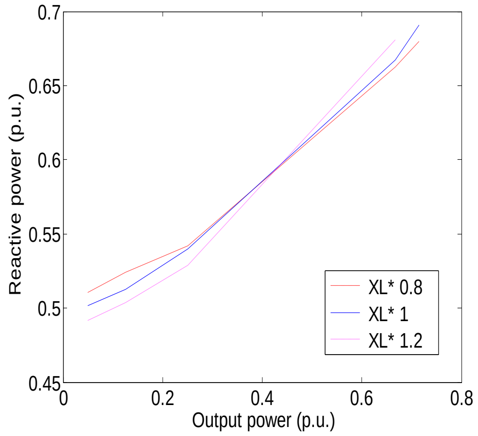

Fig. 8 Variation of Reactive power with output power for different values of leakage reactance.

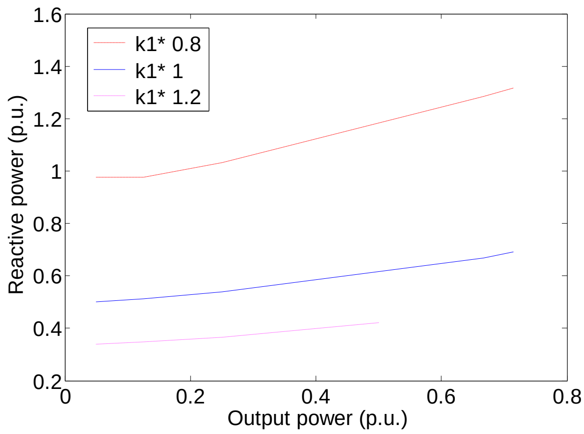

Fig. 9 Variations of Reactive power with output power for different values of K1.

It is seen from Fig. 7 that there is marginal reduction in reactive power requirement when stator resistances is decreased. The same stands true for rotor resistance as well.

From Fig. 8 it is seen that effect of leakage reactance on reactive power requirements at lower and higher loads is reverse, however the crossover takes place around the full load.

Fig. 9 shows that a small reduction in magnetizing reactance causes a significant increase in reactive power requirement for various constant terminal voltages and at rated speed.

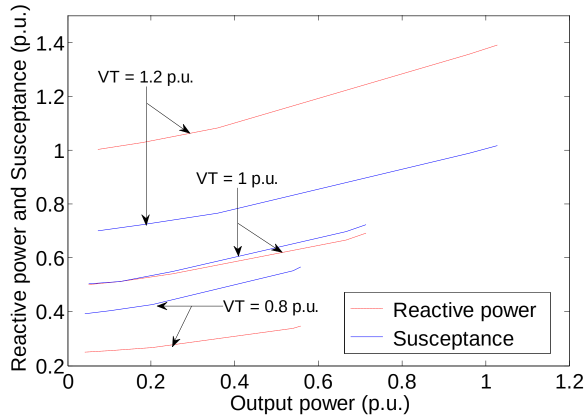

Fig. 10 Variations of reactive power and capacitancein terms of susceptance with output power

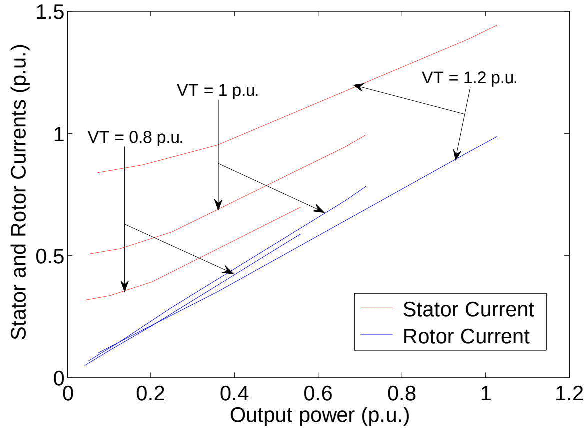

Fig. 11 Variations of stator and rotor currents with output power for various constant terminal voltages and rated speed.

From Fig. 10 it can be seen that at constant terminal voltage, the susceptance and reactive power increases with output power. With increase or decrease in the terminal voltage, the reactive power requirements increases or decreases accordingly.

It can be observed from Fig. 11 that the magnitude of the rotor current is always less than the stator current. This is because the rotor current is approximately in quadrature with the magnetizing current in both the motoring and generating modes

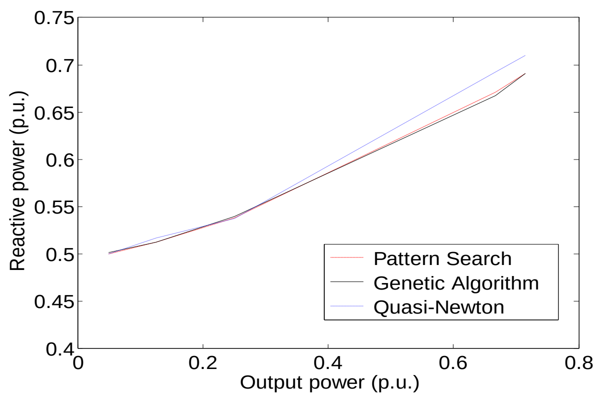

Fig. 12 Variation of reactive power with output power.

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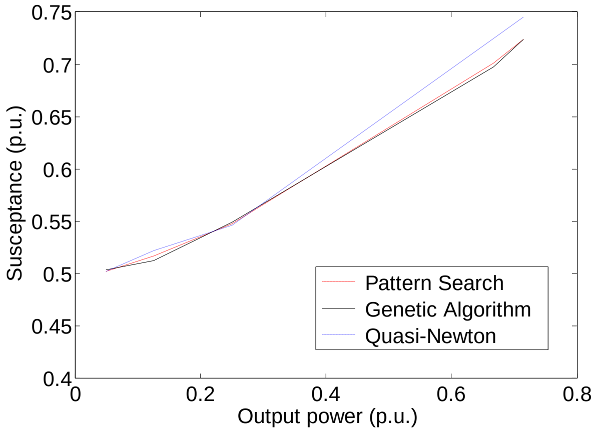

Fig. 13 Variations of suspetance with output power

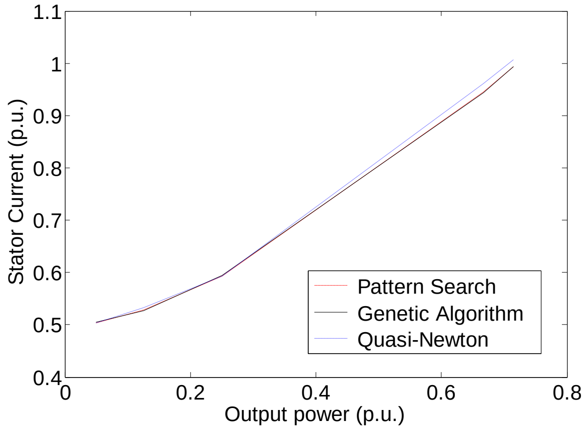

Fig. 14 Variations of stator current with output power.

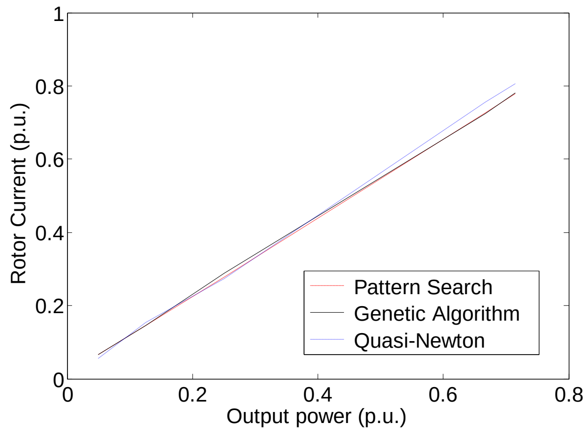

Fig. 15 Variations of rotor current with output power.

V. CONCLUSIONS

This paper presents the steady state performance of SEIG with different optimization techniques. At given load, speed and terminal voltage two unknowns i.e., p.u. capacitive reactance and frequency are determined. The steady state equivalent circuit is used to compute the performance of SEIG after determining the unknowns. The effects of various system parameters are presented. It has been observed that the value of capacitance varies over a vide range in order to maintain the terminal voltage constant. The small change in stator resistance and leakage reactance do not affect the performance. Where as the magnetizing reactance is found to be very sensitive parameters.

REFERENCES

1. D. Seyoum, C. Grantham & F. Rahman, "The dynamic analysis and control of a self-excited induction generator driven by a wind turbine", Proceedings IEEE-IAS, USA, Oct. 2002.
2. S.S Murthy, B.P. Singh, C. Nagamani & K.V.V. atyanarayana, "Studies on the use of conventional induction motor as self- excited induction generators", IEEE Trans. EC, Vol. 3, No. 4, pp 842-848, Dec. 1988.
3. A.K. Tandon, S.S. Murthy & G.J. Berg, "Steady state analysis of capacitor self-excited induction generator", IEEE Trans. On PAS, Vol. PAS-103, No. 3, March 1984.
4. L. Shridhar, Bhim Singh & C.S. Jha, "A step towards improvements in the characteristics of self excited induction generator", IEEE Trans. EC, Vol. 8, No. 1, pp 40-46, March 1993.
5. S.P. Singh, Bhim Singh & M.P. Jain, "Performance characteristics and optimum utilization of a cage machine as capacitor excited induction generator", IEEE Trans. EC, Vol. 5, No. 4, pp 679-684, Dec. 1990.
6. S.S. Murthy, O.P. Malik & A.K. Tandon, "Analysis of self- excited induction generators", Proc. IEE, Vol. 129, Pt. C., No. 6, pp 260-265, Nov. 1982.
7. Y.N. Anagreh & I.S. Al-Kofahi, "Genetic algorithm-based performance analysis of self-excited induction generator", International Journal of Modeling and Simulation, Vol. 26, No. 2, pp 175-179, 2006.
8. Genetic Algorithm Manual.
9. Pattern Search Manual.
10. Quasi-Newton Manual
11. A.K. Al Jabri & A.L. Alolah, "Capacitance requirement for isolated self-excited induction generator", IEE proceedings, Vol. 137, Pt. B, No. 3, pp 154-159, May 1990. induction generator", IEEE Trans. EC, Vol. 10, No. 3, pp 516-523, Sept. 1995.
12. Dheeraj Joshi, K.S. Sandhu & M.K. Soni, "Constant voltage constant frequency operation for a self-excited induction generator", IEEE Trans. EC, Vol. 21, No. 1, March 2006.
13. R. Bansal, T. Bhatti, & D. Kothari, "Bibliography on the application of induction generators in non-conventional energy systems", IEEE Trans. EC, 18(3), pp 433-439, 2003.

APPENDIX-I

$$f\left(X_C, F\right) = A_1 F^3 + A_2 F^2 + \left(A_3 X_C + A_4\right) F + A_5 X_C = 0$$

$$g\left(X_C, F\right) = \left(B_1 X_C + B_2\right) F^2 + \left(B_3 X_C + B_4\right) F + B_5 X_C = 0$$

Where the constants are defined as,

$$A_1 = -\left(2\ X_L X_M R_L + X_L^2 R_L\right)$$

$$A_2 = -A_1 \times \upsilon$$

$$A_3 = \left(X_M + X_L\right)\left(R_L + R_S + R_R\right)$$

$$A_4 = R_S R_L R_R$$

$$A_5 = -\left(X_M + X_L\right)\left(R_L + R_S\right) \times \upsilon$$

$$B_1 = 2\ X_L X_M + X_L^2$$

$$B_2 = R_L\left(R_S + R_R\right)\left(X_L + X_M\right)$$

$$B_3 = -B_1 \times \upsilon$$

$$B_4 = -R_S R_L\left(X_M + X_L\right) \times \upsilon$$

$$B_5 = -R_R\left(R_L + R_S\right)$$

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APPENDIX-II

Rating of Machine

3.7KW/5HP 3-phase, 415 Volts, 7.6 Amp, 4 poles, 50 Hz, delta connected cage induction motor

Base Quantitative

Voltage/phase – 415 Volts, Currents/phase – 4.39 Amp, Impedance/phase – 94.53 ohms, Power – 1820 Watts, Frequency – 50 Hz, Speed – 1500 r.p.m.

Equivalent Circuit Parameters

R_S = 0.053 p.u., R_R = 0.061 p.u., $X_S = X_R = X_L$ = 0.087 p.u., X_M (unsaturated) = 2.35 p.u., K_1 = 1.6275, K_2 = 0.3418, Air gap voltage Vg/F = $K_1 - K_2 X_M$

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Neel Kamal received his B.Tech degree in Electrical Engineering from G.B.P.U.A.&T. U.S. Nagar U.P. INDIA . His M.Tech. degree is in Power Electronics from L.I.M.A.T.-M.D.U. Rohtak Haryana India. He is Associate member of the Institution of Engineers (India). He has more than 10 international journals and proceedings of various conferences. Presently he is working as Head of E.E.E Department of V.I.T.S. Ghaziabad U.P. India. His area of interest includes Power Electronics, Electric Drive and renewable energy etc.

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