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Steady State Analysis of Self-Excited Induction Generator using THREE Optimization Techniques

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ABSTARCT

It is well known that a three-phase induction machine can be made to work as a self-excited induction generator. In an isolated application a three-phase induction generator operates in the self-excited mode by connecting three AC 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 dissertation the steady state performance of an isolated induction generator excited by three AC capacitor is analyzed with the different optimization techniques. The effects of various system parameters on the steady state performance have been studied.

Keywords:- Artificial Neural Network, Induction Generator, Genetic Algorithm

1.1 INTRODUCTION

An induction generator is a type of electrical generator that is mechanically and electrically similar to a poly-phase induction motor. Induction generators produce electrical power when their shaft is rotated faster than the synchronous frequency of the equivalent induction motor. Induction generators are often used in wind turbines and some micro hydro installations due to their ability to produce useful power at varying rotor speeds.

Induction generators are not self-exciting, meaning they require an external supply to produce a rotating magnetic flux. The external supply can be supplied from the electrical grid or from the generator itself, once it starts producing power. The rotating magnetic flux from the stator induces currents in the rotor, which also produces a magnetic field. If the rotor turns slower than the rate of the rotating flux, the machine acts like an induction motor. If the rotor is turned faster, it acts like a generator, producing power at the synchronous frequency. In induction generators the magnetising flux is established by a capacitor bank connected to the machine in case of stand alone system and in case of grid connection it draws magnetising current from the grid. It is mostly suitable for wind generating stations as in this case speed is always a variable factor.

A self-excited induction generator systems are shown in figure 1.1 consists of an induction machine driven by a prime mover. A three-phase capacitor bank provides for self-excitation and load VARs requirements. As the load varies randomly the capacitor has to be varied to obtain the desire voltage.

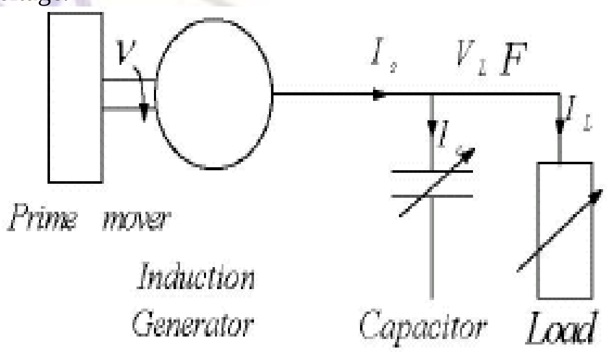


Figure 1.1 Self-excited induction generator systems

ANALYSIS OF SELF-EXCITED INDUCTION GENERATOR

In the present dissertation, the standard steady state equivalent circuit of a self-excited induction generator with the usual assumptions, considering the variation of magnetizing reactance with saturation as the basis for calculation. The equivalent circuit is nomalised to the base frequency by dividing all the parameters by the p.u. frequency as shown in figure 1.2.

For the purpose of obtaining required lagging reactive power to maintain desir ge machine terminals, XC and F are only unknown parameters for a given speed and load.

Where

$$Z_S = Z_1 + Z_2 + Z_3 \tag{2}$$

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

$$Z_2 = R_S / F + jX_S \tag{4}$$

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

Since under steady state operation of SEIG IS 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 XC and F after substituting $X_S = X_R = X_L$.

$$f(X_C, F) = A_1F^3 + A_2F^2 + (A_3X_C + A_4)F + A_5X_C = 0 \quad (7)$$

$$g(X_C, F) = (B_1X_C + B_2)F^2 + (B_3X_C + B_4)F + B_5X_C = 0 \quad (8)$$

Where the constants are defined as,

$$A_1 = -(2X_LX_MR_L + X_L^2R_L)$$

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

$$A_3 = (X_M + X_L)(R_L + R_S + R_R)$$

$$A_4 = R_SR_LR_R$$

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

$$B_1 = 2X_LX_M + X_L^2$$

$$B_2 = R_L(R_S + R_R)(X_L + X_M)$$

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

$$B_4 = -R_SR_L(X_M + X_L) \times \upsilon$$

$$B_5 = -R_R(R_L + R_S)$$

Objective function

$$Z = \left(f^2 + g^2\right)^2 \quad (9)$$

The relation between XM and Vg/F are given by:

$$X_M = \frac{\left(K_1 - \frac{V_g}{F}\right)}{K_2} \quad (10)$$

Where K1 and K2 are depends on the design of the machine.

$$V_g = V_T\left(\frac{Z_1 + Z_2}{Z_1}\right) \quad (11)$$

Thus for a given value of RL and VT, the value of Vg can be determined. With the known values of Vg, F, XC, υ, RL and the generator's equivalent circuit parameters, the following relations can be used for the computation of the machine performance.

$$I_S = \frac{(V_g/F)}{(Z_1 + Z_2)} \quad (12)$$

$$I_R = \frac{(-V_g/F)}{[R_R/(F - \upsilon) + jX_R]} \quad (13)$$

$$I_L = \frac{-jX_CI_S}{R_LF - jX_C} \quad (14)$$

$$V_T = I_LR_L \quad (15)$$

$$VAR = V_T^2(F/X_C) \quad (16)$$

$$P_{in} = -\frac{|I_R|^2R_RF}{(F - \upsilon)} \quad (17)$$

$$P_{out} = |I_L|^2R_L \quad (18)$$

To obtain the performance of self-excited induction generator for the given value of capacitance and speed, the unknown parameters are the XM and F. The two non-linear equations after substitution XS= XR= XL is given by:

$$f(X_M, F) = (C_1X_M + C_2)F^3 + (C_3X_M + C_4)F^2 + (C_5X_M + C_6)F + (C_7X_M + C_8) = 0 \quad (19)$$

$$g(X_M, F) = (D_1X_M + D_2)F^2 + (D_3D_M + D_4)F + D_5 = 0 \quad (20)$$

Where

$$C_1 = -2X_LR_L$$

$$C_2 = -X_L^2R_L$$

$$C_3 = -C_1 \times \upsilon$$

$$C_4 = -C_2 \times \upsilon$$

$$C_5 = X_C(R_L + R_S + R_R)$$

$$C_6 = X_CX_L(R_S + R_L + R_R) + R_SR_LR_R$$

$$C_7 = -X_C(R_S + R_L) \times \upsilon$$

$$C_8 = -X_LX_C(R_S + R_L) \times \upsilon$$

$$D_1 = 2X_LX_C + R_L(R_S + R_R)$$

$$D_2 = R_L X_L (R_S + R_R) + X_L^2 X_C$$
$$D_3 = -(R_S R_L + 2\ X_C X_L) \times \upsilon$$
$$D_4 = -(X_L R_S R_L + X_C X_L^2) \times \upsilon$$
$$D_5 = -X_C R_R (R_L + R_S)$$

Objective function

$$Z = \left(f^2 + g^2\right)^2 \qquad (21)$$

By Finding these unknown parameters using different optimization techniques and after that performance of SEIG has been evaluated.

3.0 DIFFERENTOPTIMIZATION TECHNIQUES FOR STEADY STATE ANALYSIS OF SEIG GENETIC ALGORITHM

The genetic algorithm is a method for solving optimization problems that is based on natural selection, the process that drives biological evolution. The genetic algorithm repeatedly modifies a population of individual solutions. At each step, the genetic algorithm selects individuals at random from the current population to be parents and uses them 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.

The genetic algorithm uses three main types of rules at each step to create the next generation from the current population:

Selection rules select the individuals, called parents that contribute to the population at the next generation.

Crossover rules combine two parents to form children for the next generation.

Mutation rules apply random changes to individual parents to form children.

3.2 PATTERN SEARCH

Pattern search 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.

Pattern search over continuous variables is defined via a finite set of directions used at each search iteration. The direction set and a step length parameter define a conceptual mesh centered about the current iterate. Trial points are selected from the mesh, evaluated, and compared to the current iteration in order to select the next iterate. If an improvement is found among the trial points, the iteration is declared successful and the mesh is retained; otherwise, the mesh is refined and a new set of trial points is constructed. The key to generating the mesh is the definition of the direction set. This set must be sufficiently rich to ensure that at least one of the directions is one of descent.

3.3 QUASI-NEWTON

Quasi-Newton methods, which are currently the most robust and effective algorithms for unconstrained optimization, are based on the following set of ideas.

If Bk (definite matrix) is positive definite, the direction –Bk-1 ∇f (xk) is always a descent direction at xk, and we can perhaps get global convergence (i.e. convergence starting anywhere) by searching in those directions.

As long as Bk approximates the second derivative matrix at least asymptotically, the method is likely to work well locally (i.e. fast convergence).

For a quadratic function, a set of conjugate directions, when searched sequentially, gives the optimum solution in at most n iterations.

In terms of numerical computations for the inverse of a matrix, the following formula is used for a low rank update to a matrix

[A + uvT]-1 = A-1+(1/1+k) A-1 uvT A-1, where k = vTA-1u Note that if A-1 is known, this is much faster than computing [A + uvT]-1 directly. This is a rank one update (uvT is a rank one matrix) of the original matrix A. In particular, A + uuT is a symmetric rank one update.

If Bk is updated by a small rank correction to get Bk+1 then Bk+1-1 can be computed easily by the above argument.

Quasi-Newton methods put all these ideas together to construct approximations Bk to the Hessian matrix at each stage. Note that some updates work on Bk and update Bk and then find its inverse, whereas some work directly on the inverse of the second derivative approximation (Hk).

3.31 General Quasi-Newton Algorithm for Minimizing a Function f

Start with x0 and H0 = I (approximation to the inverse of the Hessian)

At step k,

dk = -Hk ∇f(xk)

Find αk so as to (exactly or approximately) minimize f(xk + αk dk)
xk+1 = xk + αk dk
Update Hk+1
Continue until a termination condition is satisfied.

EFFECTS OF VARIOUS SYSTEM PARAMETERS BY PATTERN SEARCH

The performance characteristics of capacitor excited, 3.7 KW, cage generator (detailed data given in Appendix A) has been verified [4], [7] using pattern search.

4.1Effects of Terminal Voltage on VAR Requirements

The computed results for the given machine are presented in figures 4.1 - 4.8. From these results, the following salient features are observed.

Figure 4.1 shows the variations of frequency, efficiency and stator current with output power at constant terminal voltage and rated speed.

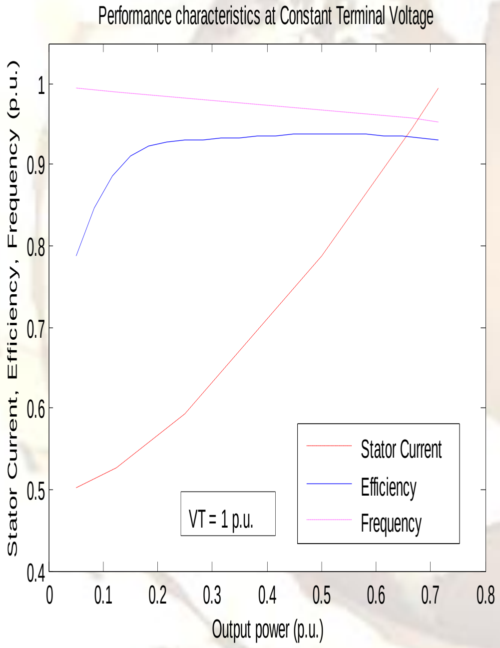


Figure 4.1

At constant terminal voltage the frequency variation is negligible. The efficiency is good throughout the power range and the stator current increases with output power.
Figure 4.2 shows the variations of reactive power in terms of reactive VAR and capacitance in terms of susceptance with output power for various constant terminal voltages and rated speed.

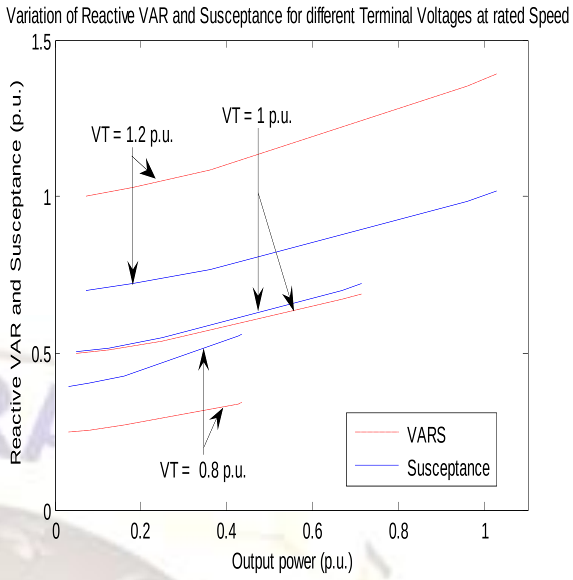


Figure 4.2

For constant terminal voltage, the susceptance and VARs increases with output power. With increase or decrease in the terminal voltage, the VARs requirements increase or decrease accordingly.

Figure 4.3 shows the variations of stator and rotor currents with output power for various constant terminal voltages and rated speed.
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.

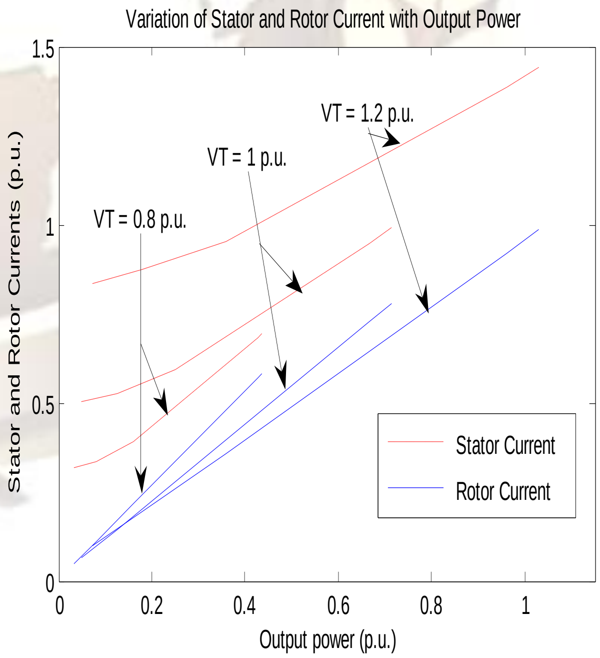


Figure 4.3

Figure 4.4 shows the variations of Cmin and frequency with load resistance at constant terminal voltage and rated speed.

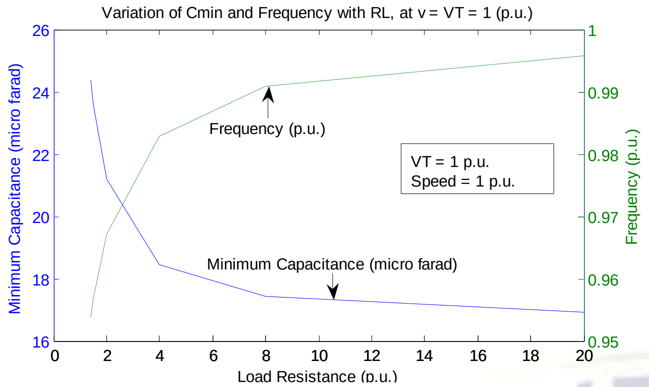


Figure 4.4

As shown in figure the exciting capacitance decreases as load resistance increases, whereas the frequency increases.

Figure 4.5 and 4.6 shows the variations of VARs with output power for different values of stator and rotor resistance at constant terminal voltage and rated speed.

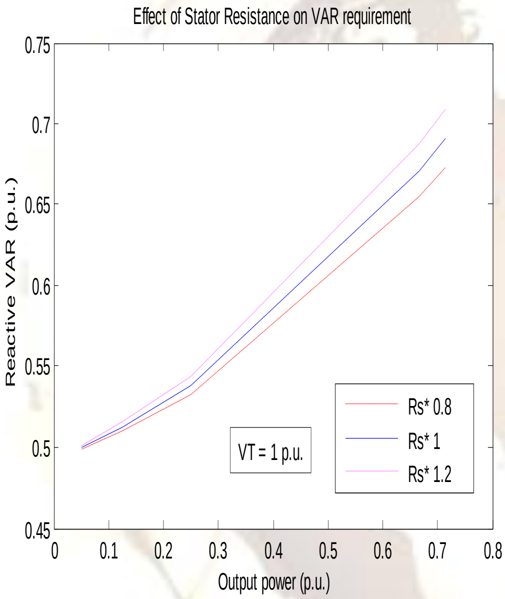


Figure 4.5

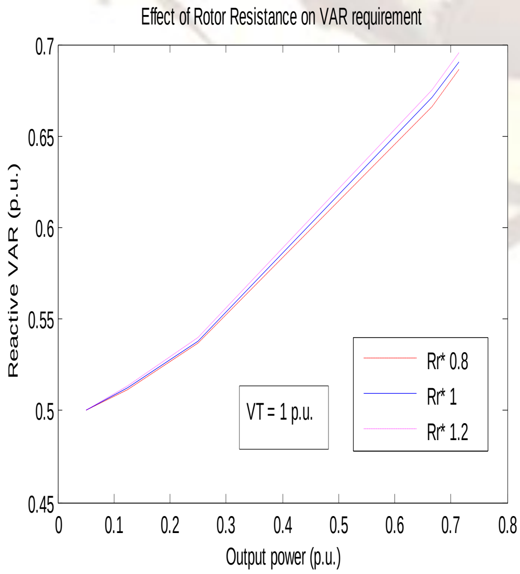


Figure 4.6

It is seen from figures that a marginal reduction in VAR requirement when stator and rotor resistance are decrease.

Figure 4.7 shows the variation of VAR with output power for different value of leakage reactance at constant terminal voltage and rated sp

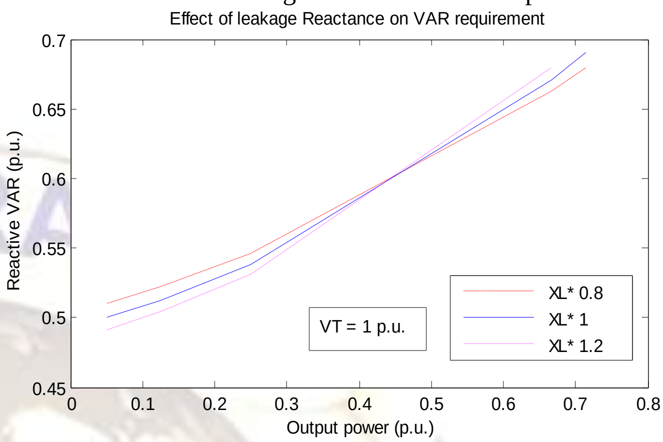


Figure 4.7

From figure the effect of leakage reactance on VAR requirement at lower and higher loads are reverse, the crossover taking place around the full load.

Figure 4.8 shows the variations of VAR with output power for different values of K1 at constant voltage and rated speed.

As shown in figure a small reduction in K1 there is significant increase in VAR requirements.

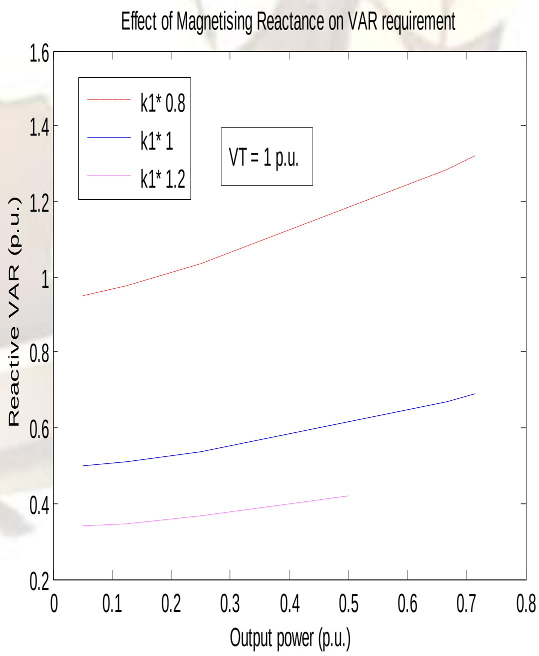


Figure 4.8

4.1.1Effects of Capacitance on Terminal Voltage

The computed results for the given machine are presented in figures 4.9 - 4.16. From these results, the following salient features are observed.

Figure 4.9 shows the variation of terminal voltage, frequency and efficiency with output power at fixed capacitance and constant speed.

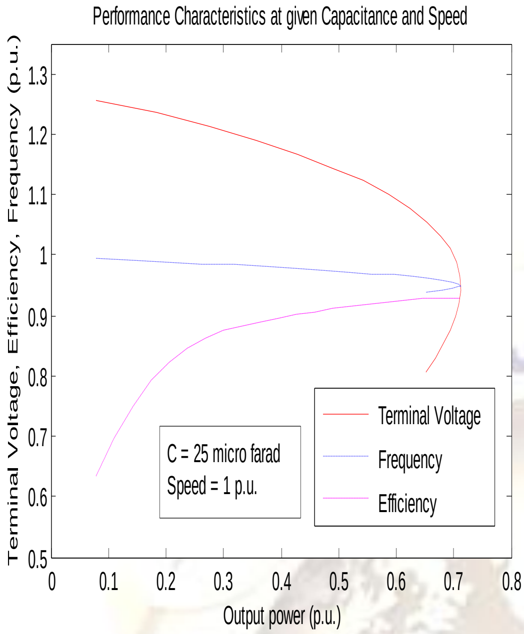


Figure 4.9

It can be noted that the terminal voltage and frequency decreases with output power, and generator efficiency improves with load.

Figure 4.10 shows the variation of terminal voltage and frequency with output power for different values of capacitance and constant speed.

It can be seen that the terminal voltage are almost parallel, indicating the proportional increase of VT with capacitance. The frequency drop with output power was not very much affected by the capacitance.

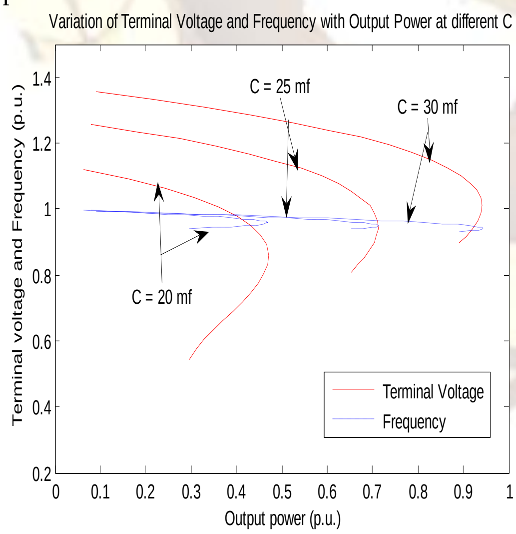


Figure 4.10

Figure 4.11 and 4.12 shows the variations of terminal voltage with output power for different values of stator and rotor resistance at fixed capacitance and constant speed.

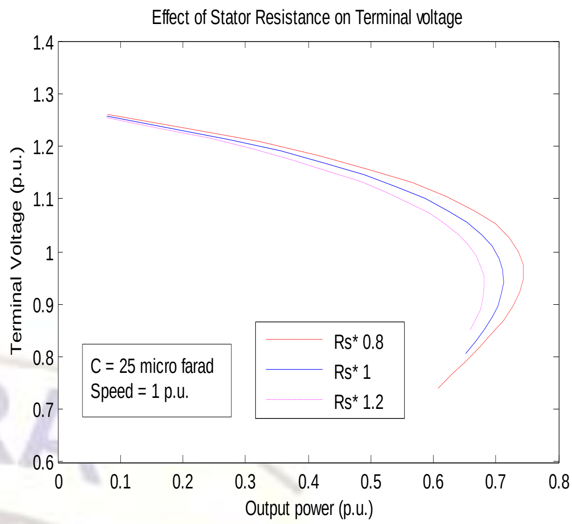


Figure 4.11

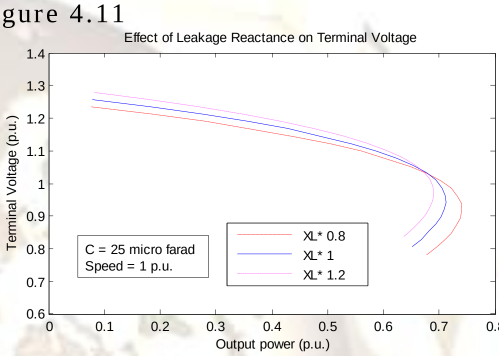


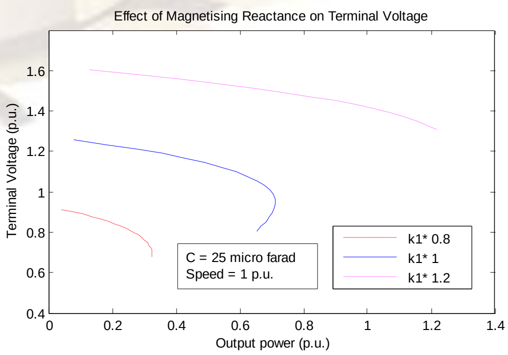
Figure 4.12

From figure it can be shown that at increased value of stator and rotor resistance causes more drooping the characteristics and decrease the maximum output power.

Figure 4.13 shows the variation of terminal voltage with output power for different values of leakage reactance at fixed capacitance and constant speed.

Figure 4.13

From figure it can be seen that for a given value of capacitance and speed there is one value of output power for which VT is independent of leakage reactance. While lower value of leaka



ge reactance the terminal voltage improves.

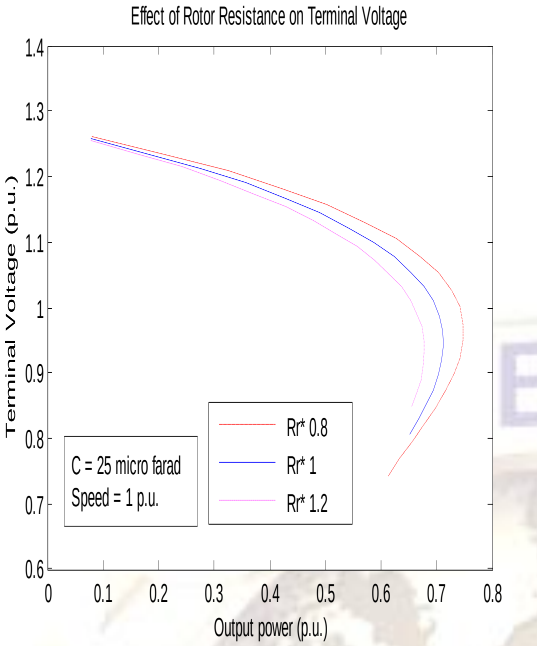
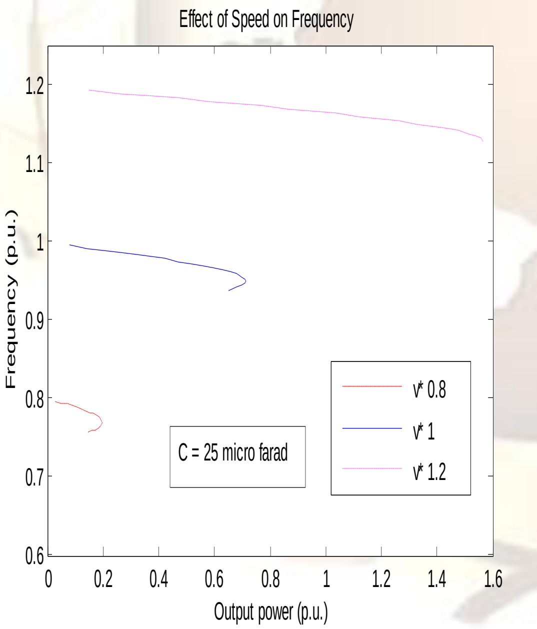


Figure 4.14 shows the variation of terminal voltage with output power for different values of K1 at fixed value of capacitance and constant speed.
Figure 4.14
From figure it can be seen that at increase value of K1 causes increased terminal voltage and maximum output



power. These changes are quite significant.
Figure 4.15 and 4.16 shows the variation of terminal voltage and frequency with output power for different values of speed at fixed capacitance.

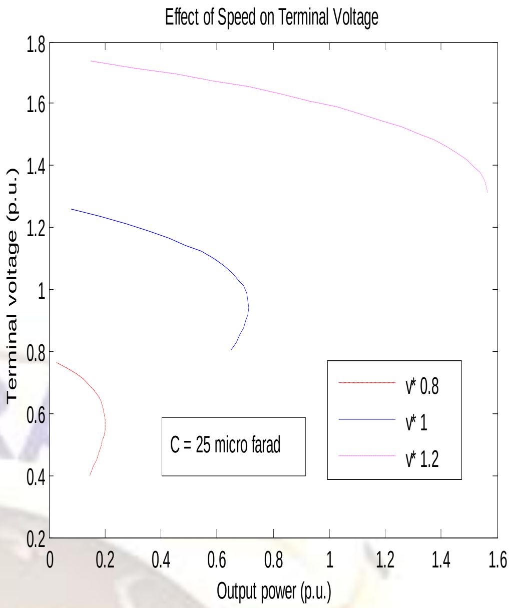


Figure 4.15

Figure 4.16
From figure it can be seen that the terminal voltage and frequency for the same output power increases with speed. It is shown that both VT and frequency are almost the same at all speed.
Effects of Various System Parameters by Genetic Algorithm
The performance characteristics of capacitor excited, 3.7 KW, cage generator (detailed data given in Appendix A) has been verified [4], [7] using genetic algorithm.
Effects of Terminal Voltage on VAR Requirements
The computed results for the given machine are presented in figures 4.17 - 4.24.
Figure 4.17 shows the variations of frequency, efficiency and stator current with output power at constant terminal voltage and rated speed.

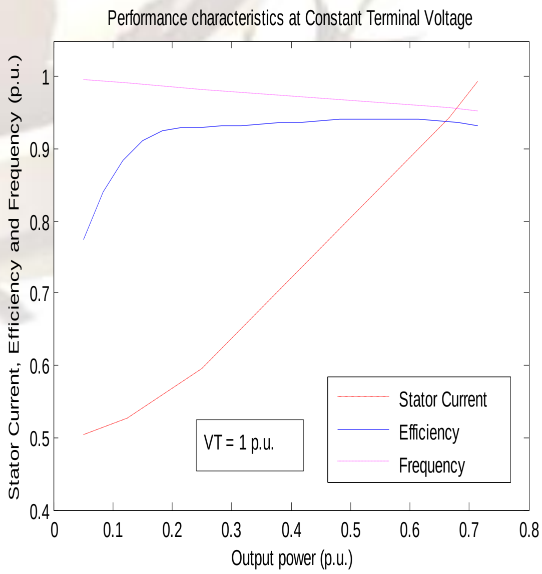


Figure 4.17

Figure 4.19 shows the variations of stator and rotor currents with output power for various constant terminal voltages and rated speed.

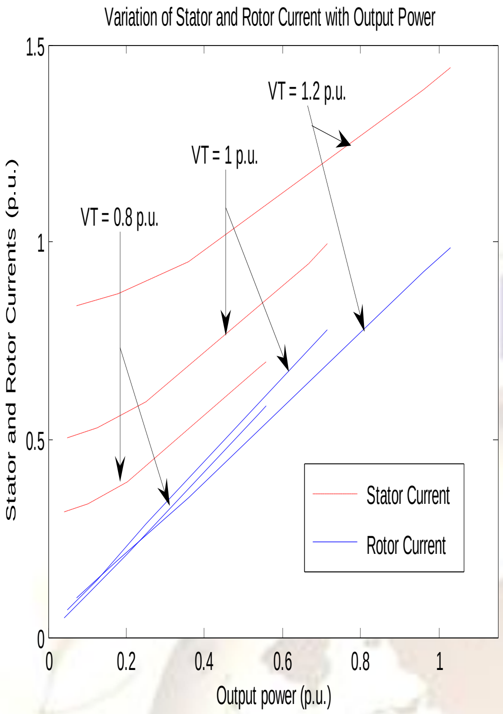


Figure 4.19

Figure 4.20 shows the variations of Cmin and frequency with load resistance at constant terminal voltage and rated speed.

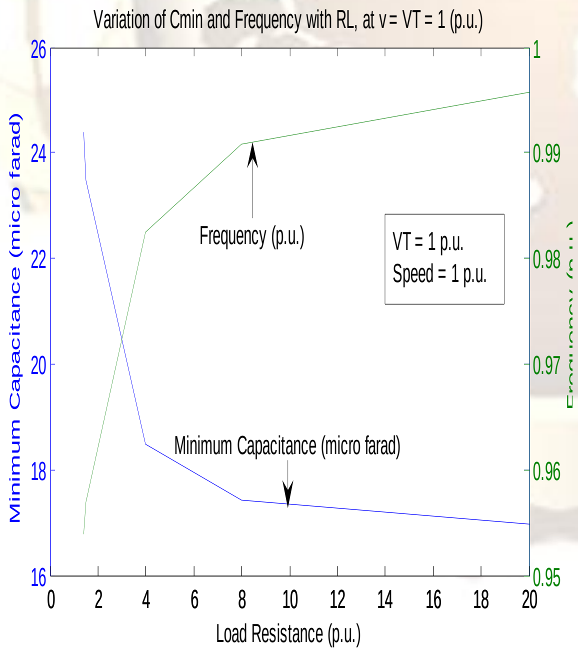


Figure 4.20

Figure 4.21 and 4.22 shows the variations of VARs with output power for different values of stator and rotor resistance at constant voltage and rated speed.

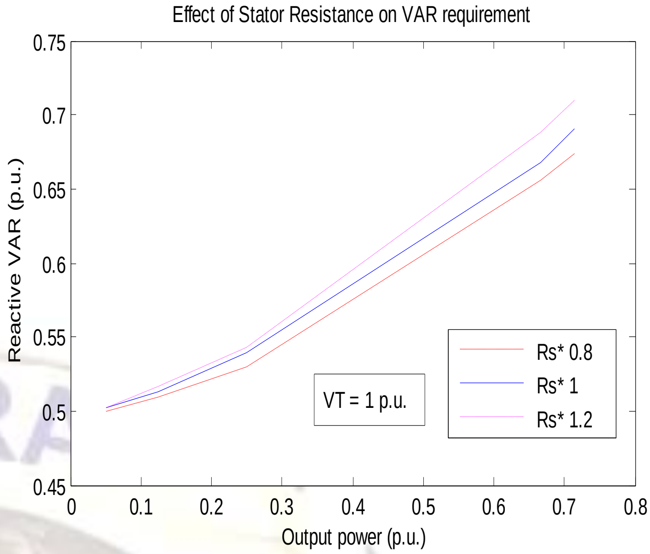


Figure 4.21

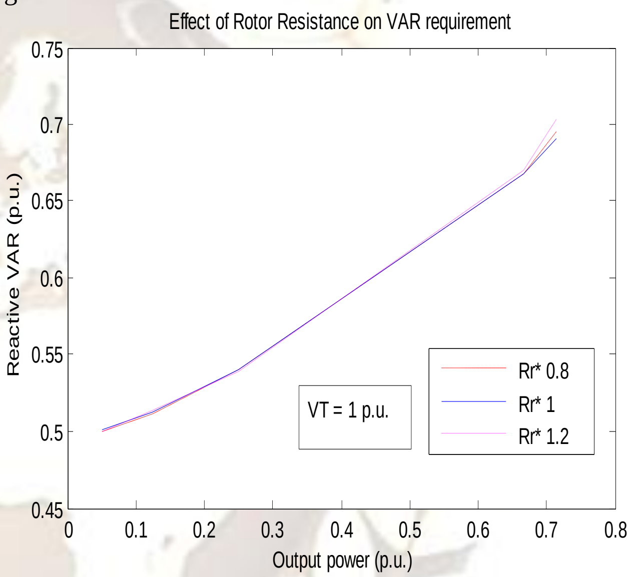


Figure 4.22

Figure 4.23 shows the variation of VAR with output power for different values of leakage reactance at constant terminal voltage and rated speed.

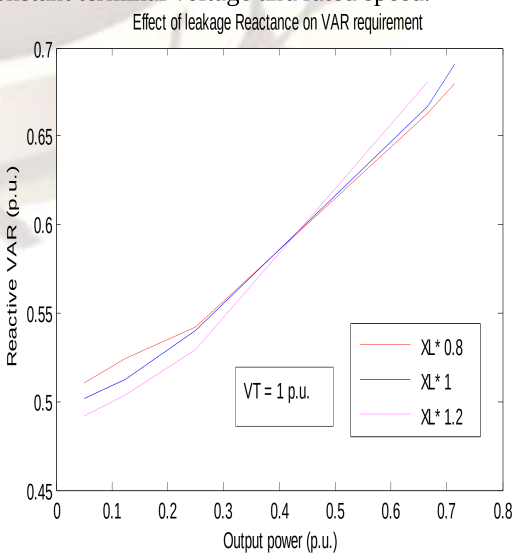


Figure 4.23

Figure 4.24 shows the variations of VAR with output power for different values of K1 at constant terminal voltage and rated speed.

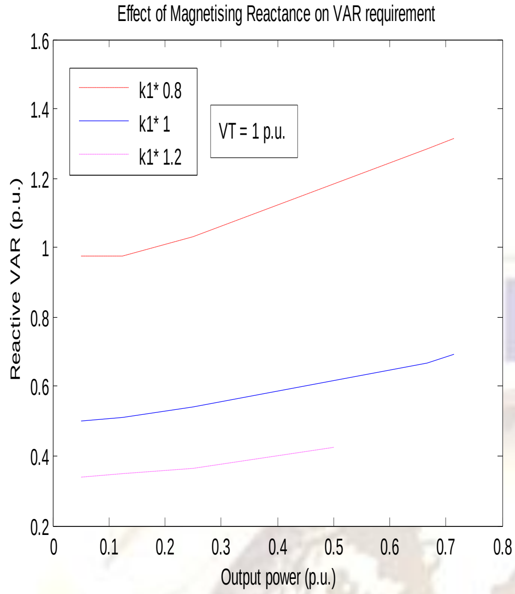


Figure 4.24

Observations

There are close relation between the two results. The genetic algorithm optimization technique gives almost same results which we getting from the pattern search optimization technique.

4.2.2 Effects of Capacitance on Terminal Voltage

The computed results for the given machine are presented in figures 4.25 - 4.32.

In this case also the values which are obtained from genetic algorithm optimization technique are much closed with the values of the pattern search optimization technique the figures are shown below.

Figure 4.25 shows the variation of terminal voltage, frequency and efficiency with output power at fixed capacitance and constant speed.

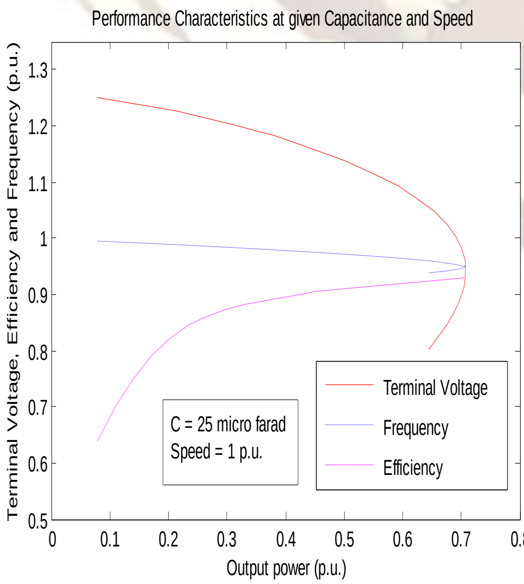


Figure 4.25

Figure 4.26 shows the variation of terminal voltage and frequency with output power for different values of capacitance and constant speed.

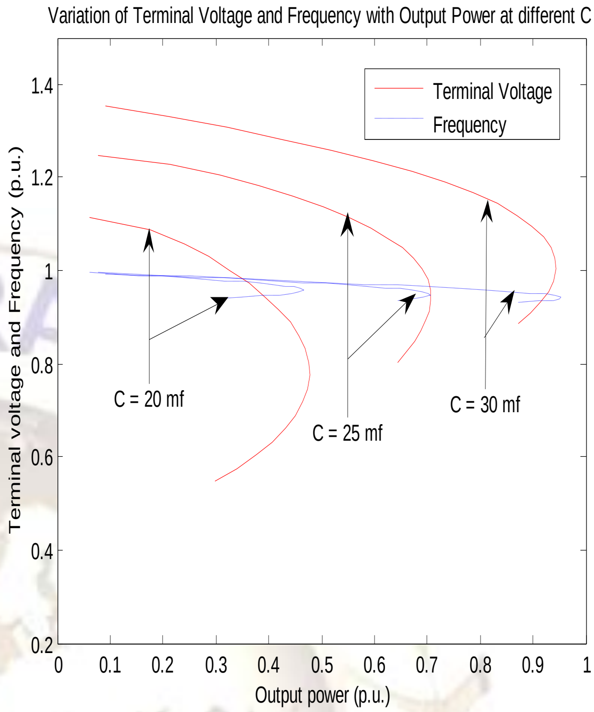


Figure 4.26

Figure 4.27 and 4.28 shows the variations of terminal voltage with output power for different values of stator and rotor resistance at fixed capacitance and constant speed.

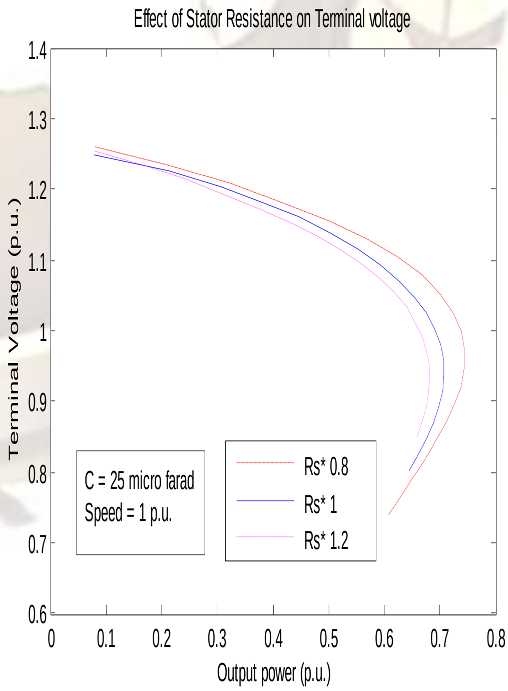


Figure 4.27

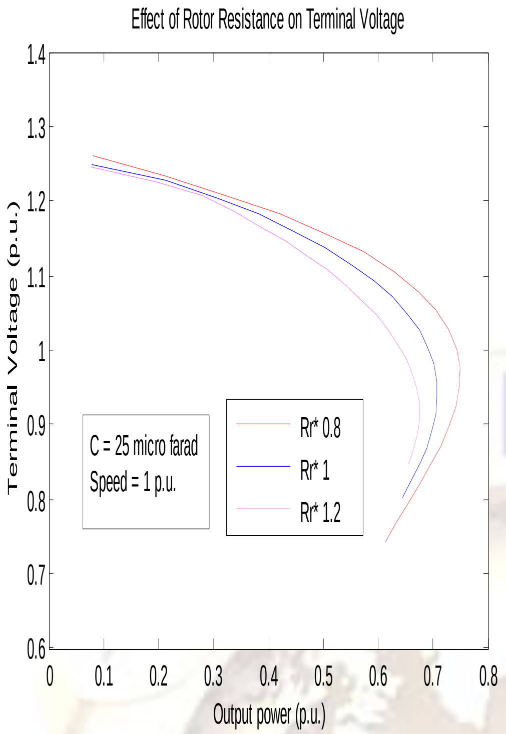


Figure 4.28

Figure 4.29 shows the variation of terminal voltage with output power for different values of leakage reactance at fixed capacitance and constant speed.

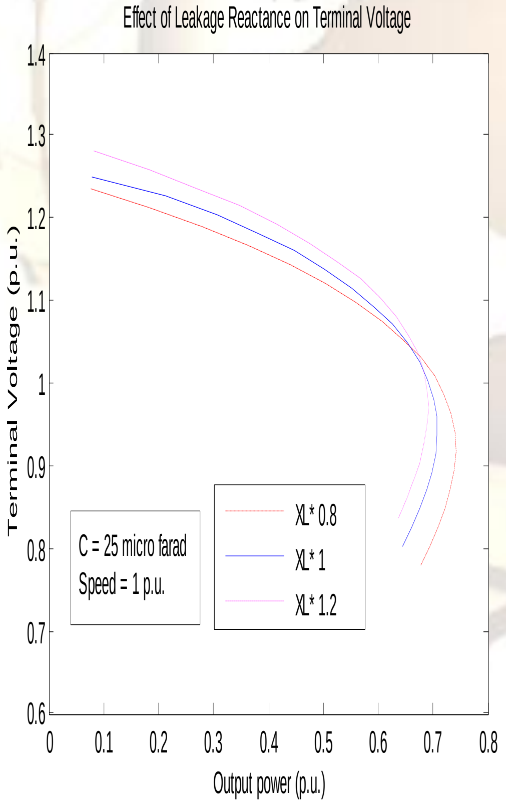


Figure 4.29

Figure 4.30 shows the variation of terminal voltage with output power for different values of K1 at fixed value of capacitance and constant speed.

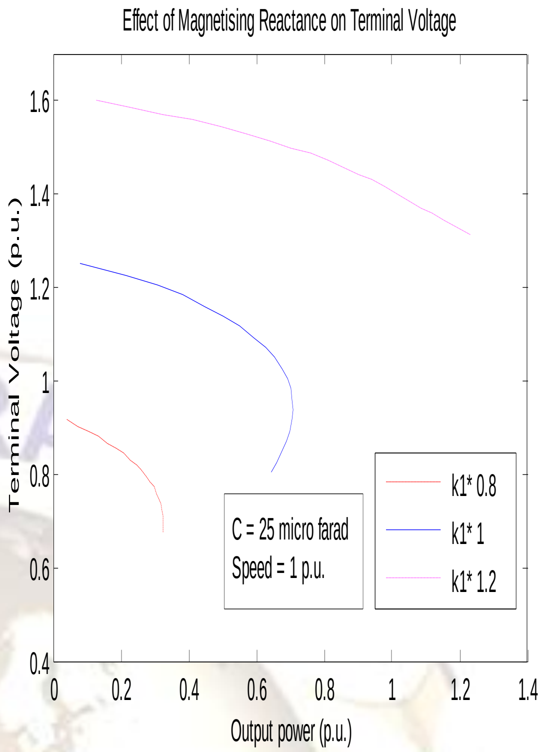


Figure 4.30

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