Particle Swarm Optimization Based Performance Investigation of Self-Excited Induction Generator

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Article Info
Article history:
Received 8 January 2015
Received in revised form
15 January 2015
Accepted 22 January 2015
Available online 31 January 2015

Keywords
Steady-State Analysis,
Self-Excited Induction Generator,
Particle Swarm Optimization

Abstract

In this paper the steady state performance of self excited induction generators is determined using particle swarm optimization(PSO) technique. The analysis is carried for R-L load. Simulated results obtained using the particle swarm optimization technique via Matlab facilitate in exploring the performance of self-excited induction generator.

List of symbols

ω	angular frequency
F	per unit generated frequency
I_L	per unit load current
I_S	per unit stator current
R_S	per unit stator resistance
R_R	per unit rotor resistance
R_L	per unit load resistance
v	per unit speed
V_g	per unit air gap voltage
V_L	per unit load voltage
V_t	per unit terminal voltage
V_S	per unit stator voltage
X_S	per unit stator reactance
X_R	per unit rotor reactance
X_L	per unit load reactance
X_m	per unit magnetizing reactance
X_C	per unit shunt capacitance
j	per unit imaginary operator

1. Introduction

Induction generators were used from the beginning of the 20th century until they were abandoned and almost disappeared in the 1960s. With the dramatic increase in petroleum prices in the 1970s, the induction generator returned to the scene. With such high-energy costs, rational use and conservation implemented by many process of heat recovery and other similar forms became important goals. By the end of the 1980s, wider distribution of population over the planet, as improved transportation and communication enabled people to move away from large urban concentration, and growing concerns with the environment led to demand by many isolated communities for their own power plants. In the 1990s, ideas such as distributed generation began to be discussed in the media and in research centers [1].

Traditionally, synchronous generators have been used for power generation but induction generators are increasingly being used these days because of their relative advantageous features over conventional synchronous generators. These features are brush less and rugged construction, low cost, maintenance and operational simplicity, self-protection against faults, good dynamic response, and capability to generate power at varying speed. For its simplicity, robustness, and small size per generated kW, the induction generator is favored for small hydro and wind power plants.

The need of external reactive power, to produce a rotating flux wave limits the application of an induction generator as a stand-alone generator. However, it is possible for an induction machine to operate as a self-excited induction generator (SEIG) if capacitors are connected to the stator terminals to supply sufficient reactive power.

The analysis of steady state performance is important for ensuring good quality power and assessing the suitability of the configuration for a particular application. In an isolated power system, both the terminal voltage and frequency are unknown and have to be computed for a given speed, capacitance, and load impedance. A large number of articles have appeared on the steady state analysis of SEIG [2], [3] - [5]. T. F. Chan [4] has proposed solution technique for the steady state analysis of self-excited induction generator. He proposed an iterative technique by assuming some initial value for frequency and magnetizing reactance and then solving for a new value considering a small increment until the result converges.

S. S. Murthy [6] et al. presents a Matlab based generalized algorithm to predict the dynamic and steady state performance of self-excited induction generators (SEIG) under any combination of speed, excitation capacitor and loading. Three different methods, operational equivalent circuit, Newton-Raphson and equivalent impedance method are used for analyzing under any given situation.

Abdulrahman L. Alolah [7] has proposed an optimization based approach for steady state analysis of SEIG; the problem is formulated as a multidimensional optimization problem. A constrained optimizer is used to minimize a cost function of the total impedance or admittance of the circuit of the generator to obtain the

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frequency and other performance of the machine. Hassan E.A. Ibrahim [8] et al has compared the results obtained by the conventional mathematical methods and particle swarm optimization. Dheeraj Joshi [9] et al have used the Genetic Algorithm Approach for the solution of problems related to the operation of a number of self-excited induction generators(SEIGs) running in parallel.

Yaser N. Anagreh [10] has further proposed an another optimization technique for steady state analysis; the method is based on the implementation of a constrained optimizer "finicon" which is built in MATLAB, to minimize the total impedance equation of the generator and then determining the required unknown parameters. The main advantage of this technique, compared with other methods of analysis, is its simplicity since no lengthy algebraic derivations are required.

Lu Xiaomin [14] et al has presented a analysis of commercially available copper-rotor and aluminium-rotor induction motors which are to be used as induction as induction generators in the voltage regulation scheme for a distributed wind power generation.

A.Domiroren [15] et al has presented a method based on particle swarm optimization for tuning of static synchronous compensator (STATCOM) parameters. The results which were simulated proved the capability of PSO technique in optimal tuning of STATCOM for voltage control in a wind farm integrated system.

2. Steady-State Analysis of Three-Phase SEIG

Steady state analysis of SEIG is of interest, both from the design and operational points of view. In isolated power system both terminal voltage and frequency are unknown and have to be computed for a given speed, capacitance and load impedance.

2.1 Mathematical Modeling of SEIG

An equivalent circuit of the induction machine, also known as the per-phase equivalent model is represented in Fig.1 which will be used further for steady state analysis of SEIG. In this figure R1 and X1 the resistance and leakage reactance respectively of the stator, Rm and Xm are the loss resistance and the magnetizing reactance, and R2 and X2 the resistance and reactance of the rotor. I1 and Ir are the stator current and rotor current respectively.

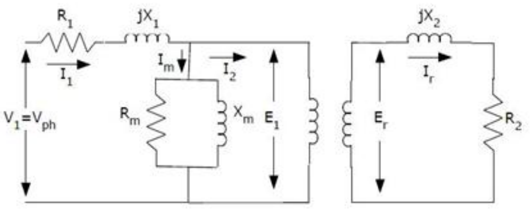


Fig: 1. Equivalent Model of Induction Machine

The equivalent circuit of the induction generator and of the transformer differ fundamentally in that in the induction generator, the rotor voltage is subject to a variable frequency making Er, R2 and Xr also variable. Here Xr=X2 (rotor side reactance).

$$E_r = sE_{r0} \tag{1}$$

$$X_r=sX_{r0} \tag{2}$$

Where Xr0 is the blocked rotor reactance.

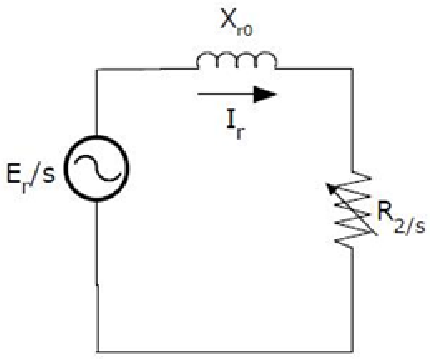


Fig: 2. Rotor Side Equivalent Model of Induction Machine

Fig. 2 displays the equivalent circuit of the rotor impedance Zr0=Rr0+jXr0 as a function of slip factor given by

$$I_r = \frac{E_r}{Z_2} = \frac{sE_{r0}}{R_2 + jsX_{20}} = \frac{E_{r0}}{\frac{R_2}{s} + jX_{20}} \quad \text{or}$$

$$Z_2 = \frac{E_{r0}}{I_r} = \frac{R_2}{s} + jX_{r0} \tag{3}$$

3. Particle Swarm Technique

Particle swarm optimization technique was first proposed by Kennedy and Eberhart in 1995 [12]. PSO is motivated from the simulation of the behavior of social systems such as fish schooling and birds flocking. The PSO has been found to be fast in solving nonlinear, non-differentiable, multimodal optimization problems. Comparing with genetic algorithm, PSO's advantages lie on its easy implementation and few parameters to adjust, also the PSO algorithm requires less computation time and less memory. Particle swarm optimization technique has been successfully used in many research area such as function optimization, fuzzy system control, ANN training etc and has become a new and hot spot of research in the world. The following is a brief introduction to the operation of the PSO algorithm. Consider a swarm of particles. Each particle represents a potential solution and has a position in the problem space represented by a position vector *xi*. A swarm of particles moves through the problem space with the moving velocity of each particle represented by a velocity vector *vi*. At each time step, a fitness function f representing a quality measure is calculated by using *xi* as input. Each particle keeps track of its individual best position, *xpbest*, which is associated with the best fitness it has achieved so far. Furthermore, the best position among all the particles obtained so far in the swarm is kept track of as *xgbest*. This information is shared by all particles. The PSO algorithm is implemented in the following iterative procedure to search for the optimal solution.

(i) Initialize a population of particles with random positions and velocities of N dimensions in the problem space.
(ii) Define a fitness measure function to evaluate the performance of each particle.

(iii) Compare each particle's present position *xi* with its *xpbest* based on the fitness evaluation. If the current position *xi* is better than *xpbest*, then set *xpbest = xi*.

(iv) If *xpbest* is updated, then compare each particle's *xpbest* with the swarm best position *xgbest* based on the fitness evaluation. If *xpbest* is better than *xgbest*, then set *xgbest = xpbest*.

(v) At iteration *k*, a new velocity for each particle is updated by

$$vi(k+1)=wvi(k)+c1r1(xpbest(k)-xi(k))+c2r2(xgbest(k)-xi(k)) \quad (4)$$

(vi) For each particle, change its position according to the following equation.

$$xi(k+1)=xi(k)+vi(k+1) \quad (5)$$

(vii)Repeat steps (iii)-(vi) until a criterion, usually a sufficiently good fitness or a maximum number of iterations is achieved. The final value of *xgbest* is regarded as the optimal solution of the problem.

In (4), *c1* and *c2* are positive constants representing the weighting of the acceleration terms that guide each particle towards the *individual best* and the *swarm best* positions *xpbest* and *xgbest*, respectively, *r1* and *r2* are uniformly distributed random numbers in [0, 1]; *w* is a positive inertia weight developed to provide better control between exploration and exploitation; *N* is the number of particles in the swarm. The velocity *vi* is limited to the range [-*vmax*, *vmax*]. If the velocity violates this limit, it is set to the relevant upper or low-bound value.

3.1 Problem Formulation

The machine specifications and parameters for which the steady state analysis was done using the Particle Swarm Optimization method on Matlab is given in the Appendix.

Following are the various methods to calculate the steady state performance of SEIGs:

- Loop impedance method
- Nodal admittance method

The steady state model based on nodal admittance method is presented here.8 in the analysis that follows, the following assumptions are made:

(i) The core loss in the machine is neglected.

(ii) All the machine parameters in the equivalent circuit are assumed to be constant except the magnetizing reactance which is assumed to be affected by the magnetic saturation.

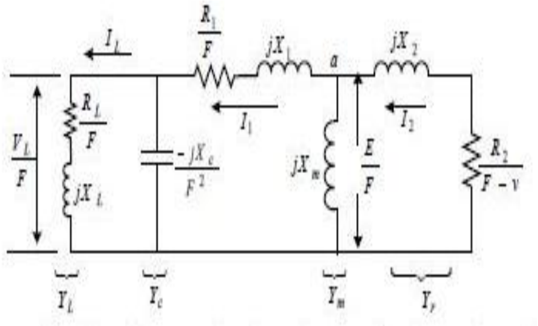


Fig: 3. Per-Phase Equivalent Circuit of a Three-Phase SEIG

The per-phase equivalent circuit of a three-phase SEIG with a R-L load and excitation capacitor is shown in Fig. 3 above, where R1, X1, R2, X 2 and Xm represent the stator resistance, stator leakage reactance, rotor resistance, rotor leakage reactance, and magnetizing reactance respectively, RL, XL, and Xc represent the load resistance, load reactance, and excitation capacitor reactance, respectively and F and v represent the per unit (p. u.) frequency and speed, respectively. The reactance's are specified at a base or rated frequency. The circuit is normalized to the p.u. frequency by dividing all parameters and voltages by the p.u. frequency F. Using nodal analysis, the circuit can be represented by three parallel admittances Y1, Ym and Yr,

$$Y_1=\frac{(Y_c+Y_L)Y_s}{Y_c+Y_L+Y_s} \qquad Y_s=\frac{1}{R_1/F+jX_1} \qquad Y_L=\frac{1}{R_L/F+jX_L}$$

$$Y_c=\frac{jF^2}{X_c} \qquad Y_m=\frac{1}{jX_m} \qquad Y_r=\frac{1}{(R_2/F-v)+jX_2}$$

Where

The nodal equation for node "a" is found to be

$$E_1(Y_1+Ym+Yr)=0 \quad (6)$$

Under normal operating condition, the self-excitation, E1 is not equal to zero. Thus

$$(Y_1+Y_m+Y_r)=0 \quad (7)$$

4. Results and Discussions

Using the particle swarm optimization technique on Matlab the objective function

$Y_1+Y_m+Y_R=0$

Was optimized to find the values of Xm and F which were found to be as follows:-

Xm=0.7462 pu

F=0.9459 pu

Fig. 4 shows the variation of the terminal voltage with the power output. It is shown that the terminal voltage decreases with an increase in the output power. This curve suggests the voltage range for realizing output power and also indicates the terminal voltage corresponding to the maximum output power.

Fig. 5 shows the variation of magnetizing reactance with excitation capacitance. Increasing the excitation capacitance reduces the magnetizing reactance which saturates at high values of excitation.

Fig. 6 depicts the variation of per unit frequency with excitation capacitance of induction generator. It decreases as excitation is increased.

Fig. 7 represents the Matlab animation plot of the particle swarm optimization.

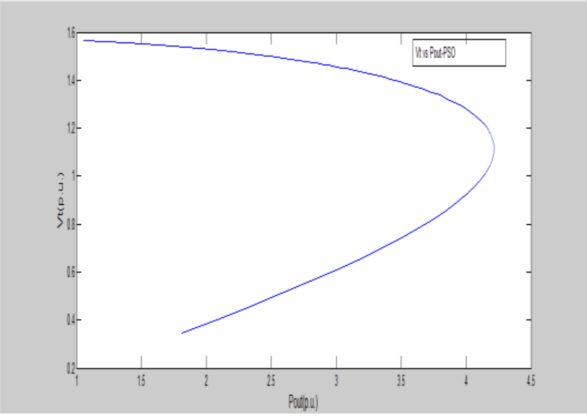


Fig: 4. Variation of Terminal Voltage with Output Power

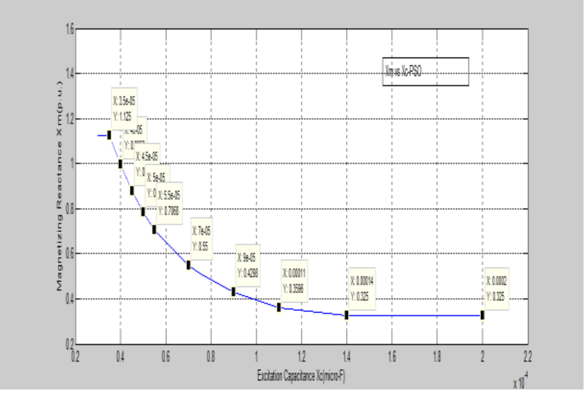


Fig: 5. Variation of Magnetizing Reactance with Excitation Capacitance

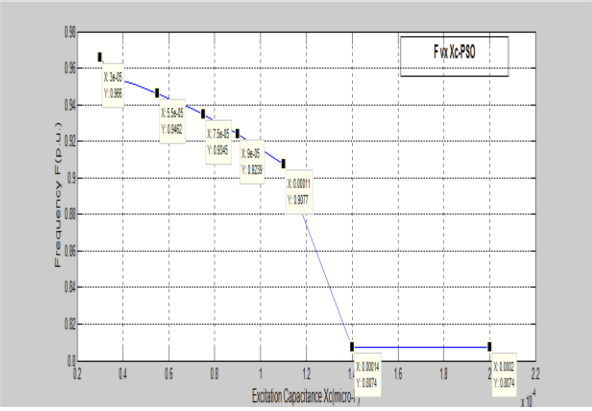
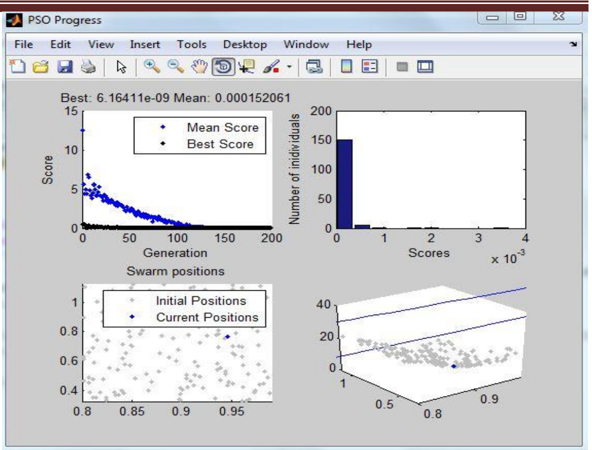


Fig: 6. Variation of Frequency with Excitation Capacitance of Induction Generator



Best: 6.16411e-09 Mean: 0.000152061

Fig: 7. Implementation of Particle Swarm Optimization (Animation Plot)

5. Conclusion

In this paper, the particle swarm optimization procedure has been implemented successfully for steady state analysis of self-excited induction generators under different, capacitance and resistive load conditions. The suite of functions and programs included with the Particle Swarm Optimization Toolbox are useful in applying PSO to real world optimization and computational intelligence problems. The proposed technique has shown that, it is reliable, accurate and simple compared to the conventional methods.

References

[1] R.C. Bansal, Three phase self excited induction generators: an overview, IEEE Trans. Energy Conversion, 20, 2005, 292-299

[2] M. Godoy Simoes, F. A. Farret, Renewable Energy Systems: Design and Analysis with Induction generators, CRC Press, Boca Raton, FL, 2004

[3] T. F. Chan, Analysis of self-excited induction generators using an iterative method," IEEE Trans. Energy Conv., 10, 1995, 502-507

[4] T. F. Chan, Steady state analysis of self-excited induction generators, IEEE Trans.on Energy Conversion, 9, 1994, 288-296

[5] Y. Cao, Q. Wu, Teaching Genetic Algorithm Using Matlab, International Journal of Electrical Engineering Education, 36(2), 1999, 139-153

[6] S. S. Murthy, S. Acharya, MATLAB based steady state analysis of self excited induction generator, IEEE CNF on Power Electronics and Drive Systems, 1, 2003, 749-753

[7] A. L. Alolah, M. A. Alkanhal, Optimization-based steady state analysis of three phase self-excited induction generator, IEEE Transaction on Energy Conv., 15, 2000, 61-65

[8] Hassan E. A. I brahim, Mohamed F. Serag, Analysis of self-excited induction generator using particle swarm optimization, World Academy of Science, Engineering and Technology, 5, 2011, 224-228

[9] D. Joshi, K. Sandhu, R C Bansal, Steady state analysis of Self-Excited Induction Generator Using Genetic Algorithm approach under different operating modes, International Journal of Sustainable energy (Taylor and Francis group), 32(4), 2013, 244-258

[10] Y N Anagreh, A new approach for steady state analysis of single phase self excited induction generator, IEEE CNF , 2, 2004, 509-512

[11] C. Wagner, Self-excitation of induction motors," AIEE Trans., 58, 1939, 47–51

[12] J. Kennedy, R. Eberhart, Particle Swarm Optimization", Proceedings of the IEEE International Conference on Neural Networks, IEEE Service Center, Piscataway, NJ, IV: 1995, 1941-1948.

[13] K. Deb, Optimization for Engineering Design, PHI, India, 2005.

[14] Lu Xiamon, K. L. V. Iyer, K. Mukherjee, N. C. Kar, A Wavelet/PSO based Voltage Regulation scheme and suitability analysis of copper and aluminium rotor induction machines for Distributed Wind Power Generation, IEEE Transactions on Smart Grid, 3(4), 2012, 1923-1934

[15] A. Demiroren, M. Guleryuz, PSO Algorithm-based optimal tuning of STATCOM for voltage control in a Wind farm integrated system, 7th International Conference on Electrical and Electronics Engineering, 2011, I-367 – I-370