Estimation of Excitation Capacitance Requirement of an Isolated Multi-phase Induction Generator for Power Generation

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ABSTRACT

Self Excited induction generators are used in remote places for electrical power generation from both conventional as well as non-conventional sources. An Induction generator can operate as a capacitor excited machine provided the machine is driven beyond synchronous speed and a suitable capacitor is connected across its terminals. In this paper a technique has been proposed to estimate the values of excitation capacitances to maintain desired terminal voltages in a multi-phase induction generator. A mathematical model using nodal admittance technique of a six-phase induction generator has been analyzed. Genetic algorithm technique is applied here to obtain the unknown parameters and the capacitance requirements to obtain desired terminal voltages under various operating conditions.

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1. INTRODUCTION

The depletion of conventional sources, has led the experts to explore the possibility of using non-conventional energy sources. The increasing concern towards the environment has motivated the researchers towards rationalizing the use of conventional energy sources. Induction generator are suitable for power generation particularly in remote areas due to certain advantages such as brush less rotor construction, easy maintenance and less unit cost [1-4]. Even though three-phase induction generators are used for this purpose but due to certain advantages possessed by multi-phase (more than three phase) induction machines such as higher power rating and improved reliability they are now-a-days becoming popular. As an induction generator suffers from inherent poor voltage regulation, voltage regulation is to be taken in to account when using the multi-phase induction generators.

In this paper mathematical modeling of multi-phase induction generator employing graph theory was proposed in [5]. In this paper a simplified model based on nodal admittance technique is proposed and the matrix equations developed are being solved by GA technique to obtain the desired capacitance values to maintain desired terminal voltage and the variation of other system parameters are presented.

2. MULTI-PHASE INDUCTION GENERATOR

Machines having phases more than three phases as in a conventional machine are referred to as a high phase order machine or multiphase machines [6]. Multiphase machines have certain advantages over the conventional three phase machines such as capability to start and run even one or two of its stator phase open or short circuited, lower current per phase without increasing voltage per phase, increased power in the same frame, for a given machine output power utilization of more than three phase enables splitting of power across larger number of inverter legs [7, 8].

Additional number of phase added to the machine also brings additional freedom for improvements in the system. Basically a multiphase induction machine can have two different types of configurations.

2.1 Split Phase Electrical Machines

Split phase electrical machines consist of two similar stator windings sharing the same magnetic circuit. Such a construction has made it possible to extend the power range by sharing the total power into two parts. Usually a split phase machine is built by splitting the phase belt of a conventional three phase machine into two equal parts with phase separation of 30^o electrical. By using this arrangement for the same air gap flux, the inverter voltage can be reduced by half as compared to the three phase machines since the number of turns is reduced.

2.2 Dual Stator Electrical Machines

This type of electrical machines consists of two separate independent stator windings sharing the same magnetic circuit. Six different voltage magnitudes could be used for each winding group [9]. One set of the stator winding is used for electromechanical power conversion while the second set of stator winding can be used for excitation purpose. In dual stator electrical machines, the power can be extended without the need to use multilevel converters

In a conventional three phase machine ,the conductors are distributed in slots symmetrically for each phase group and the conductors belonging to each phase group are series whereas in a multiphase induction machine we subdivide each phase group of a usual three phase machine into equal subgroups by disconnecting the series connection of the conductors. More number of three phase groups can be obtained from the same machine. In this way multiphase machine such as six phases [6-8], nine phases, twelve phases, fifteen phases, and eighteen phases can be produced from a three phase machine by subdividing the phase groups into two, three, four subgroups respectively.

The diagrammatic Representation of Multi-Phase (Six-phase) self-excited induction generator is shown in Figure 1.

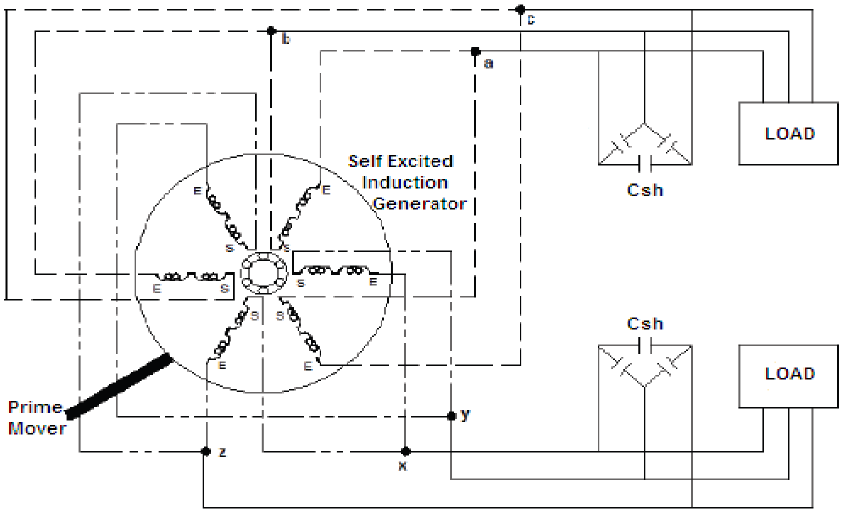

Figure 1. Diagrammatic Representation of Multi-Phase (Six-phase) self-excited induction generator

3. MATHEMATICAL ANALYSIS OF A MULTI-PHASE INDUCTION GENERATOR

A mathematical model of a six-phase self excited induction generator as shown in Figure 2 is developed from the equivalent circuit of the machine [10-12]. The model results in a matrix form that makes the analysis of the machine simpler and easier. The equivalent circuit representation consist of four nodes and the equivalent admittances are represented by admittances Y1,Y2,Y3,Y4,Y5,Y6,Y7,Y8 and Y9 respectively.

$$1/[R_r/(F-v)+jX_r]=Y_1 \quad (1)$$

$$1/[jX_M]=Y_2 \quad (2)$$

$$1/[jX_{lm}]=Y_3 \quad (3)$$

$$1/[R_{s2}/F+jX_{s2}]=Y_4 \quad (4)$$

$$1/[R_{s1}/F+jX_{s1}]=Y_5 \quad (5)$$

$$1/[-jX_{c2}/F^2]=Y_6 \quad (6)$$

$$1/[R_{L2}/F+jX_{L2}]=Y_7 \quad (7)$$

$$1/[-jX_{c1}/F^2] = Y_8 \quad (8)$$

$$1/[R_{L1}/F + jX_{L1}] = Y_9 \quad (9)$$

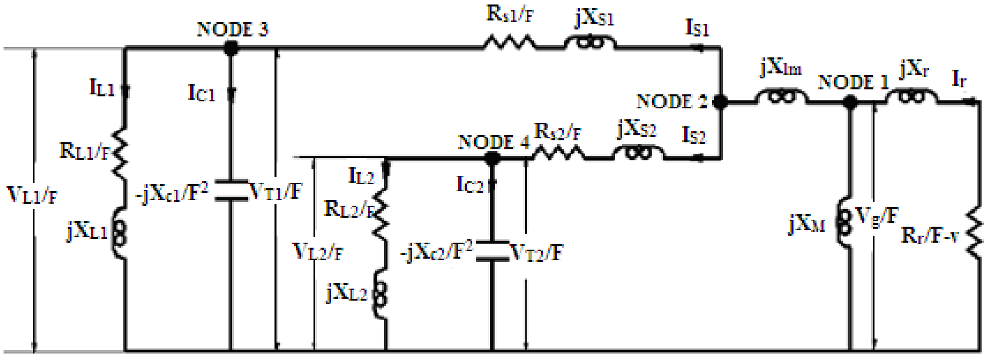

Figure 2. Equivalent circuit representation of a six-phase self-excited induction generator.

The resultant equation based on nodal admittance approach of circuit is expressed as

$$[Y][V] = [I_s]$$

Where $[V]$ is matrix of voltage, $[I_s]$ is the matrix of current, and $[Y]$ is the admittance matrix.

$$[Y] = \begin{bmatrix} Y_1+Y_2+Y_3 & -Y_3 & 0 & 0 \\ -Y_3 & Y_3+Y_4+Y_5 & -Y_5 & -Y_4 \\ 0 & -Y_5 & Y_5+Y_8+Y_9 & 0 \\ 0 & -Y_4 & 0 & Y_4+Y_6+Y_7 \end{bmatrix} \quad (10)$$

Where Y_{ii} is the summation of admittances of all the branches connected to the i^{th} node and Y_{ij} is the summation of admittances of all the branches connected in between i^{th} node and j^{th} node. As the admittance matrix [Y] is symmetric in nature therefore

$Y_{ji}= Y_{ij}$. When there exists no branches between two nodes then the matrix value is zero. As the equivalent circuit as shown in the figure does not contain any current or voltage sources therefore [Is] =0 and [Vs] =0. Hence the equation

$[Y]\ [V] = [I_S]$

gets reduced to [Y] [V] =0

In an induction generator for proper voltage build up [V] should never be equal to zero hence the admittance matrix determinant becomes equal to zero [13, 14]. Hence the real and imaginary part of the admittance matrix should be zero. To find out the certain parameters which make the determinant of admittance matrix equal to zero an algorithm has been proposed.

4. EVALUATION OF EXCITATION CAPACITANCE REQUIREMENTS

To determine the magnitude of excitation capacitance many methods have been proposed which are time consuming and are also subjected to human errors while performing the necessary manipulations and determination of unknown variables. A Genetic algorithm is a technique for determining true or approximate values to optimization or search problems [15, 16].GA are classified as global search heuristics. GA is a particular class of evolutionary algorithms that use techniques inspired by evolutionary biology such as inheritance, mutation, selection, and crossover. The evolution of GA starts from a population of randomly generated individuals and happens in generations. In each generation, the fitness of every individual in the population is evaluated multiple individuals are selected from the current population and modified to form a new population. The new population is used in the next iteration of the algorithm. The algorithm stops when highest number of generations has been produced [16].

In the proposed method GA technique is used to determine the determinant matrix [Y] =0 which is used to determine the unknown parameters. The objective function to be minimized for obtaining frequency and magnetizing reactance must be equal to the summation of absolute values of real and imaginary parts of determinant of admittance matrix. In addition to determination of F and Xm the other unknown such as excitation capacitance, rotor speed and load impedance can be found out in the algorithm. The constraints involved in the analysis are

$X_m^{min} \leq X_m \leq X_m^{max}$

$F^{min} \leq F \leq F^{max}$

$C^{min} \leq C \leq C^{max}$

The flow chart for the genetic algorithm is shown in Figure 3. The GA parameters used for the evaluation is given in Table 1.

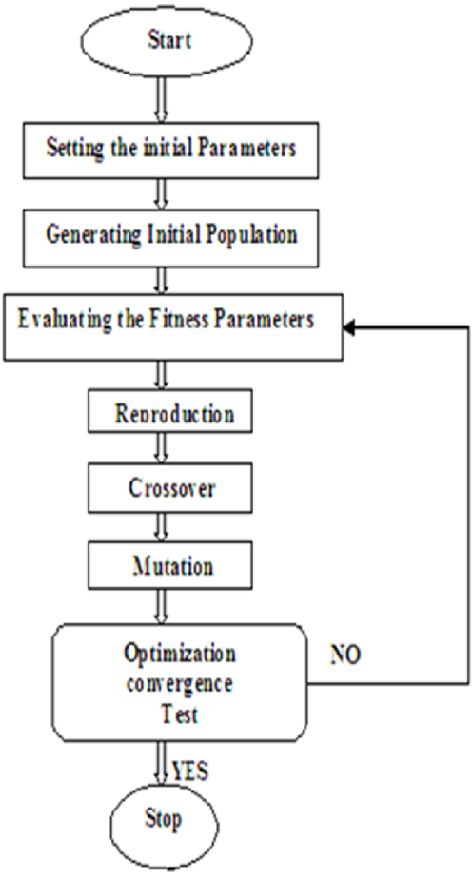

Figure 3. Flow chart of Genetic Algorithm

Table 1. GA parameters

Parameters	Value
Generation	100
Population	20
Initial population	Feasible population
Scaling function	Top, Quantity: 0.4
Selection	Tournament, Tournament K: 4
Crossover	Heuristic, Ratio: 1.2
Mutation	Adaptive feasible
Ending conditions	Max generation: 100

5. RESULTS AND DISCUSSIONS

5.1 Excitation capacitance requirements to maintain desired terminal voltage

In a self excited induction generator when the active power demand of the load is higher than the input rotor mechanical power, the load voltage collapses. These performance constraints of capacitive compensated induction generator limit their wide spread application, especially in areas where regulated load voltage and frequency are required. Multi-Phase induction generator is identified as an isolated power sources whose terminal voltage and frequency are controlled by varying speed, excitation capacitance and load impedance. An isolated induction generator operating in six-phase mode is able to excite only when proper values of capacitance are connected to either the three phase winding sets or one of the two three phase winding sets respectively.GA technique is used to evaluate the capacitive requirements by solving the admittance matrix to determine the unknown parameters.

The variation of the terminal voltage expressed in per unit with the shunt capacitances connected across both the three phase winding sets is shown in Figure 4 .It is observed under no load terminal voltage increases with the increase in shunt capacitance values. It is found that the shunt excitation value that corresponds to terminal voltage of 1 per unit under no load condition is 35µF. The variation of no load terminal voltage when capacitance connected to one of the three phase winding sets is shown in Figure 5. The magnitude of capacitance value corresponding to terminal voltage 1 per unit if found to be 65 µF.

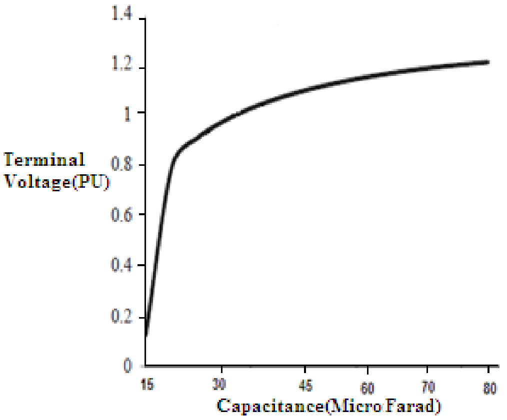

Figure 4.Variation of terminal voltage when six-phase induction generator subjected to no-load and the capacitance connected to both the three phase winding sets

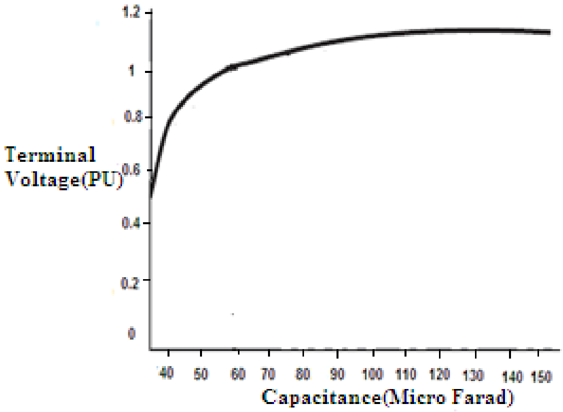

Figure 5.Variation of terminal voltage when six-phase induction generator subjected to no-load and the capacitance connected to one of the three phase winding sets

5.2 Variation of speed of the prime mover with terminal voltage

During this analysis the shunt capacitance value is kept constant and the speed is varied subjected to the condition that the machine is under no load. Figure 6 shows the variation of terminal voltage in per unit with the prime mover speed. The slope 1 in Figure 6 corresponds to capacitance value of 48 µF whereas slope 2 corresponds to capacitance value of 28 µF. The terminal voltage is assumed to be constant in both the three phase winding sets.

5.3 Variation of power output with stator current

The variation of the power output with the stator current expressed both in per units when the shunt excitation capacitances being connected to both the three phase winding sets is shown in Fig.ure 7. The slope 1 corresponds to when speed is 0.95per unit while slope 2 corresponds to speed 1 per unit respectively. It is seen that when the speed is varied from 0.95 per unit to 1 per unit, the stator currents are below the rated value.

The range of capacitance that can be used for excitation six-phase self excited induction generator under the conditions when capacitance connected to both the three phase winding sets, capacitance connected to one of the three phase winding sets and when both sets of three phase winding equally loaded is depicted in Table 2.

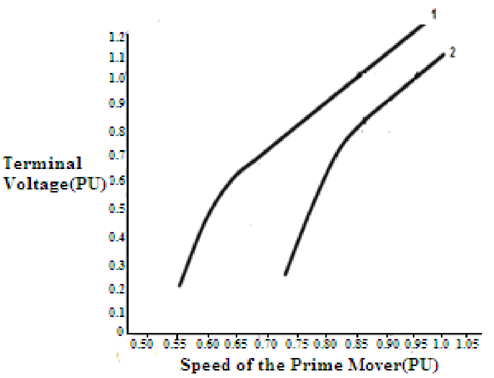

Figure 6.Variation of terminal voltage in per unit with the prime mover speed

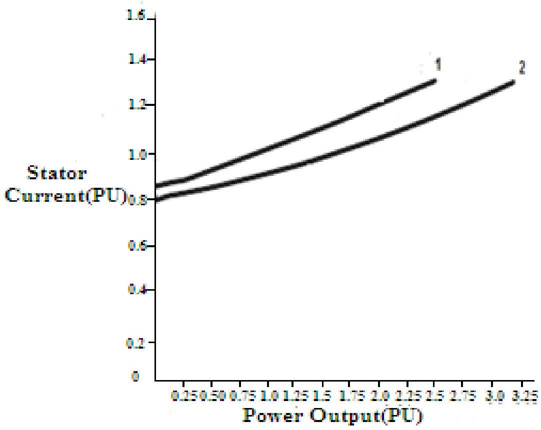

Figure 7.Variation of power output with stator current

Table 2. The range of capacitance

Capacitance	Load	Speed in per unit	Capacitance in μF
Capacitance in both the three phase sets	Both sets are equally loaded	0.95 1	38-50 34-46
Capacitance in one of the three phase sets	Both sets are equally loaded	0.95 1	66-82 58-76

6. CONCLUSION

In this paper a mathematical model using nodal admittance technique has been analyzed and genetic algorithm technique has been proposed to determine required capacitance value to maintain terminal voltage constant at different speeds. From the range of capacitance obtained the capacitance value is chosen to obtain rated value of terminal voltage .It is observed that the machine is self excited when correct value of shunt excited capacitor is connected to both of the three phase winding sets or any one of the three phase winding sets.

APPENDIX

The machine parameters are as follows:

Magnetization characteristics

$V_g/F=1.2-0.2X_M$ for $X_M<1.8$

$V_g/F=2.6-0.9X_M$ for $X_M\geq1.8$

$R_{S1}=6.9\Omega$

$R_{S2}=6.9\Omega$

$X_{S1}=3.5\Omega$

$X_{S2}=3.5\Omega$

$R_r=1\Omega$

V=230v

N=1500

F=50

LIST OF SYMBOLS

R_{s1}, R_{s2}	stator resistance per phase of two stator winding sets
R_s, R_r	stator and rotor resistances per phase
R_M	stator resistance per phase
R_{1M}, R_{1A}	main winding and auxiliary winding per phase (referred to stator) resistance
R_{L1}, R_{L2}	Load resistance per phase for two winding sets
R_L, X_L	Load resistance and reactance per phase
X_{S1}, X_{S2}	Leakage reactance per phase of two stator winding sets
X_{ls}, X_{1r}	Leakage reactance per phase of stator and rotor as referred to stator
X_r	Leakage reactance per phase of rotor as referred to stator
X_{lm}	Common mutual Leakage reactance between two sets of stator winding sets
X_{c1}, X_{c2}	Capacitive reactance of capacitors of two stator winding sets
X_{csh1}, X_{csh2}	Series capacitive reactance of two capacitance sets
X_{L1}, X_{L2}	Leakage reactance per phase of stator and rotor as referred to stator
X_{L1}, X_{L2}	load inductive reactance per phase of two winding set
I_{S1}, I_{S2}	stator current per phase of winding set
I_M, I_A	main winding and auxiliary winding per phase current
I_{C1}, I_{C2}	shunt capacitive per phase current of winding
I_{L1}, I_{L2}	load current per phase of two winding sets
I_S, I_r, I_L	stator, rotor and load current per phase
V_{T1}, V_{T2}	terminal voltage per phase of two winding set
V_L, I_L	load voltage and load current per phase

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