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Performance Analysis of SEIG under Unbalanced Load Conditions using Particle Swarm Optimization

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ABSTRACT: These are the induction generators operated in isolated mode (SEIG) are serving appreciably so as to supply the three-phase load connected in remote areas where it is quite unfeasible for the extension of the grids. Generally the three phase load connected to such induction machines is unbalanced and sometimes the value of required excitation capacitance at stator terminals may also differ in various phases. These unbalanced conditions will certainly cause to over voltage and over current in various phases of the SEIG. The research work as described in the paper targets toward behavior of induction machines of various ratings that will be helpful to decide the suitable machine suited for unbalanced load operation. The model as presented consequences an multivariable objective function which includes four variables voltage unbalanced factor, generated frequency, magnetizing reactance of positive sequence and negative sequence networks. All the variables associated in objective function have been solved through particle swarm optimization.

KEYWORDS: Self-excited induction generator, Voltage unbalanced factor, Unbalanced operations, Renewable energy

I.INTRODUCTION

Today renewable energy is being considered on large scale for electric power generation. Continuous increasing demand of electric supply is encouraging the minds of research persons so as to utilize these renewable resources to mitigate the gap between demand and supply. Wind power which is absolutely a clean renewable energy source and is available in abundance of quantity are forced to rotate the wind turbines. Self-excited induction generators (SEIG) connected to wind turbines are being utilized for the production of electric power. It is the superiority of induction generators over other electrical generators to utilize these in the area of power invention through wind energy. These induction generators in self excited mode are generally used in isolated areas where the grid extension is quite unfeasible. In these isolated modes a three phase capacitor bank is connected to stator terminals so as to supply the required reactive power to load and the generator as well.

Loop impedance and nodal admittance are the two famous well known methodologies generally used to predict the behaviour of self-excited induction generator. These two well famous approaches results in to two simultaneous equations that are non linear. Nodal admittance approach in the equivalent circuit of SEIG leads to a mathematical expression [1] that contains real as well as imaginary parts. The electrical equivalent of induction generator [2] supplying a balanced resistive-inductive load with core loss branch may be used for obtaining generated voltage and generated frequency of SEIG. Same is also applicable to find the minimum excitation capacitor required so as to maintain the constant voltage across the machine terminals. Research persons [3] analyze the performance of various capacitor connected self-excited induction generator. A new iterative technique [4] for SEIG with less computational efforts was developed and the same was considered also for study of such generators that includes core loss in the short-shunt & long-shunt compensation of induction generators. A model of self-excited induction generator that contains a quadratic expression with other machine parameters was presented by [5]. It is found that speed of the machine, load resistance and excitation capacitance affect the machine performance quite more in comparison to other parameters. Right handling of these key parameters may lead to the performance as per the desire. An implementation of genetic algorithm optimization [6-7] was considered in SEIG for finding of known variables associated in it also to maintain the constant voltage & constant frequency in SEIG.

The process of self-excited induction generator in isolated mode generally suffers with the unbalanced loading in various phases of the generator which leads the generators in to unbalanced mode. Some times the value of required excitation capacitance across the stator terminals also differs that also results it to unbalanced operation of the generator. A thought of excitation balancing [8] was offered using symmetrical component theory. A focus on mathematical models was offered for many generator-load combinations [9] in order to find performance characteristics of isolated three-phase self-excited induction generators with balanced and unbalanced loading as well. Comparative appearance of many theory of voltage unbalancing was given by [10]. Unbalanced operation of such machines generally leads to complexity due to many variables. The efforts in computation of these variables were reduced [11] by taken the positive sequence network and negative sequence network as well. Here the generated frequency (p.u) was taken equal to speed of the machine (p.u) where as source branch in negative sequence network was removed. A model based on two port network [12] also be considered for such analysis under unbalanced conditions. Many optimization techniques have been implemented under balanced conditions of SEIG. The comparison among them suggests to adopt these optimization techniques in unbalanced operation of SEIG as well [13]-[16].

Main contribution of the paper:

- A multivariable objective function has been made from the model which has been solved for its variables using particle swarm optimization.
- Analysis has been made on different induction generators under unbalanced operations to find the suitable induction machine.

II.MODELING OF SEIG

Delta connected three-phase load which is supposed to supplied by a three phase self-excited induction generator are shown in figure.1. The notation for voltages and currents in various phases of the machine is V_a, V_b, V_c & I_a, I_b, I_c respectively. Admittances of combination of load resistance and excitation capacitance across each phases are Y_{al}, Y_{bl}, Y_{cl} respectively.

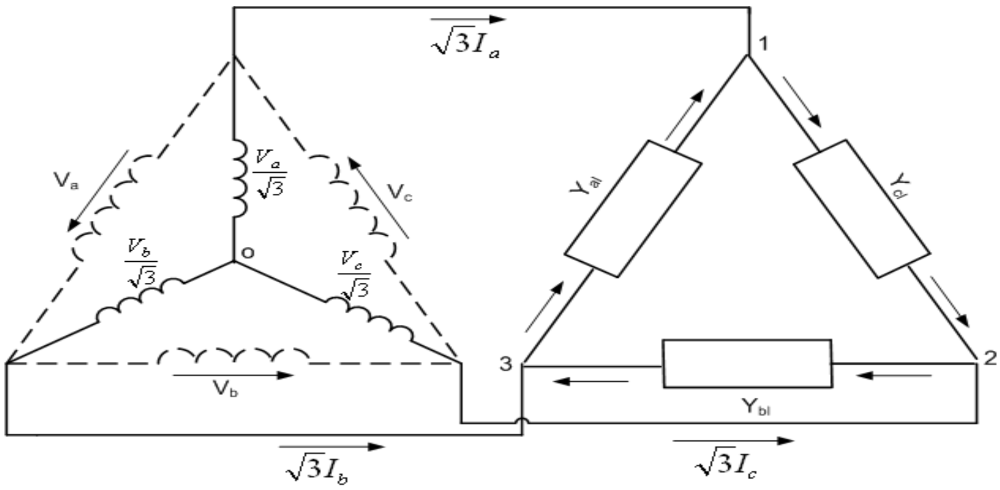

Fig1 : Three phase circuit of SEIG

Application of KCL at all the three nodes of SEIG and the use of symmetrical component theory results in to ratio of negative to positive sequence circuit may be written as:

$$\frac{I_n}{I_p} = \frac{Y_3 + KY_1}{Y_1 + KY_2} \quad (1)$$

Where V_p & V_n are the voltage components of positive & negative sequence and Y_1, Y_2, Y_3 are represented as:

$$\begin{bmatrix} Y_1 \\ Y_2 \\ Y_3 \end{bmatrix} = -\frac{1}{3}\begin{bmatrix} -1 & -1 & -1 \\ a & 1 & a^2 \\ a^2 & 1 & a \end{bmatrix}\begin{bmatrix} Y_{al} \\ Y_{bl} \\ Y_{cl} \end{bmatrix} \quad (2)$$

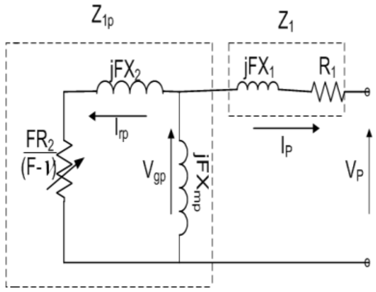

Fig2 : Positive sequence circuit of SEIG

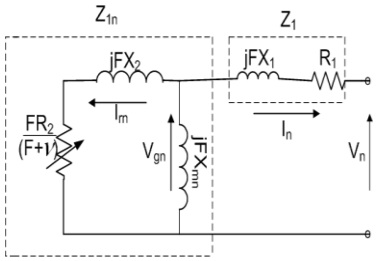

Fig3 :Negative sequence circuit of SEIG

From the positive sequence circuit of SEIG and negative sequence circuit of SEIG as well, following equation may be formed:

$$\frac{I_n}{I_p} = \left(\frac{Z_1 + Z_{1p}}{Z_1 + Z_{1n}}\right)K \tag{3}$$

Equating (1) & (3) results in to following quadratic expression in K :

$$min\left|f\left(K, F, X_{mp,}X_{mn}\right)\right| = \min\left(f\left(K^2 Y_2 (Z_1 + Z_{1n}) + K\left[Y_1\left(Z_{1p} - Z_{1n}\right)\right] - Z1 + Z1nY3\right.\right. \tag{4}$$

For the induction generator having certain values of load and excitation running at a particular speed, equation (4) may be solved for its variable by adopting algorithm based on Particle swarm optimization.

III.ROLL OF PARTICLE SWARM OPTIMIZATION (PSO) TO COMPUTE VARIABLES OF SEIG

The burly capabilities of PSO to crack the problems based on non linear optimization are attracting to compute control variables in many engineering field. The line of attack is focused on bird's flock motion whereas the swarms move in a cluster [18] for searching their food. Every character solution of these swarms is nominated as a particle and its possible solutions are termed as swarms. Each and every particle moves with its own velocity in the group having a certain positions. The route of penetrating the food depends on the particle owns skill and other member's as well. The best position occupied by particle is represented as P_{best}, while best position occupied by swarms is represented as G_{best}. Equation 5 and 6 shows the velocity and the position of swarm given as:-

$$V_{id} = V_{id} + c_1 r_1 (P_{id} - X_{id}) + c_2 r_2 \left(P_{gd} - X_{id}\right) \tag{5}$$

$$X_{id} = X_{id} + V_{id} \tag{6}$$

Here $d = 1, 2... n$ represents dimension of the problem and $i = 1, 2... S$, represents the size of swarm of the problem. The constants c_1 and c_2 are represented as scaling and learning parameters as shown in table-1.

Table-1: PSO parameters and their values

PSO Parameters	Values of Parameters
C_1 & C_2	2.2
R_1 & R_2	[0 1]

In the paper as presented, PSO algorithm has been adopted in order to compute the four variables generated frequency, speed of machine, reactance of source branch in positive and negative circuits as well. Initially Frequency and speed has taken 0.97 p.u while magnetizing reactance is taken as their unsaturated value.

IV.RESULTS AND DISCUSSION

The circuit analysis of self-excited induction generator as offered in the paper has been implemented to calculate the performance of three phase self-excited induction generators of three different ratings [14-15] under unbalanced conditions. At opening these generators are bound to run at rated values of voltage and current at balanced loading. After it the unbalancing has been shaped in load resistance of one phase of the generators. Operating speed of all generators was maintained at 1.027p.u.throughout the operation. Figure 4 to Figure 9 shows the simulation results on three generators under testing.

4.1 Unbalancing due to load variation of one phase of SEIG

Unbalancing in the load has been set up by creating variation in the load resistance of phase-a only while load resistance of other two phases remains the same. Simulation results over generators of different ratings for phase voltages are shown in figure 4 to 6 whereas simulation results for phase currents are shown in figure 7 to 9. The operating speed of generators was maintained at 1.027 p.u throughout the operation.

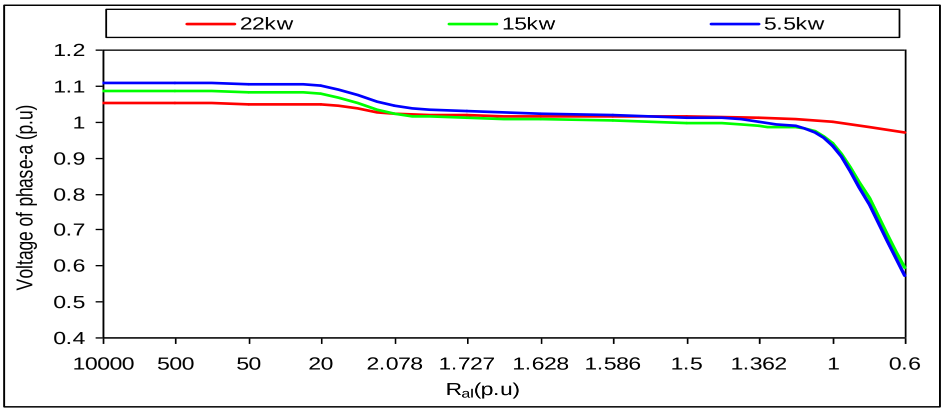

Fig 4: Variation in voltage of phase-a due to load resistance of one phase

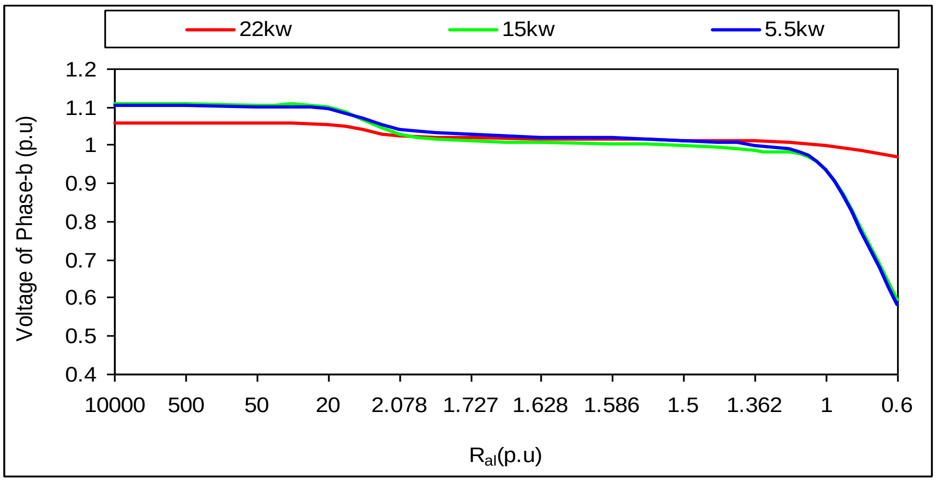

Fig 5: Variation in voltage of phase-b due to load resistance of one phase

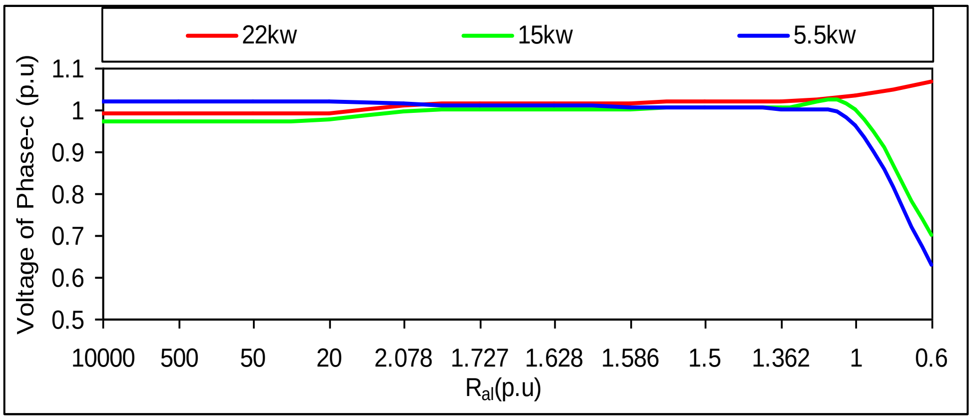

Fig 6: Variation in voltage of phase-c due to load resistance of one phase

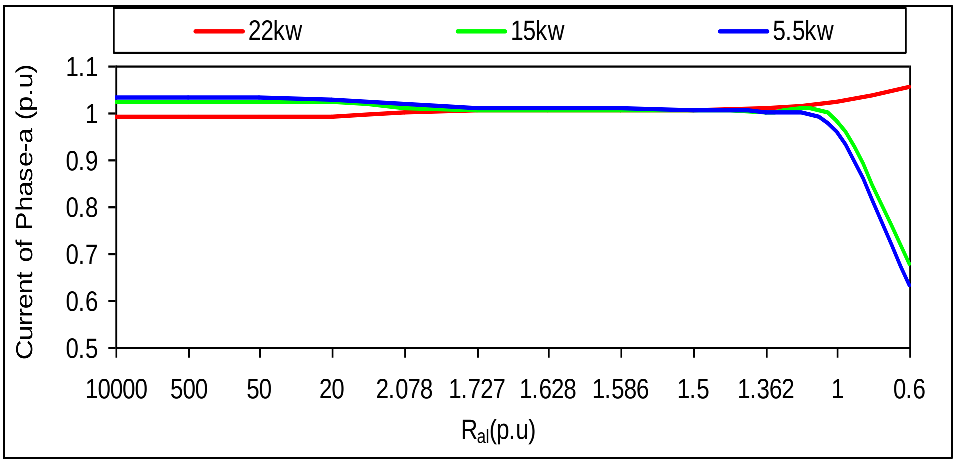

Fig 7: Variation in current of phase-a due to load resistance of one phase

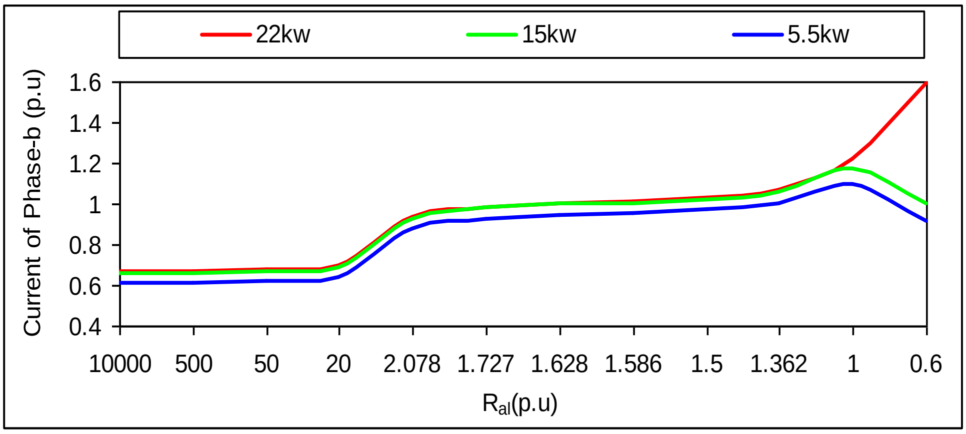

Fig 8: Variation in current of phase-b due to load resistance of one phase

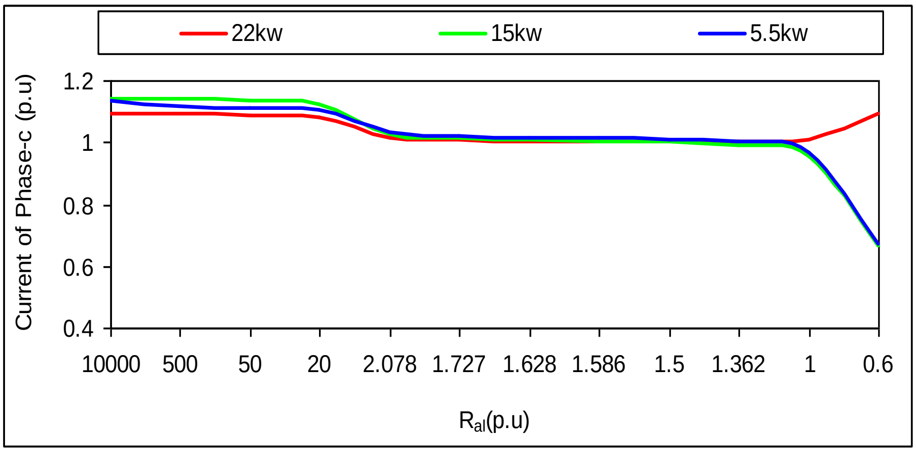

Fig 9: Variation in current of phase-c due to load resistance of one phase

The results as obtained from simulation shows the variations in voltages and currents of various phases of the generators due to load resistance of one phase only. During analysis it was found that function of these generators towards larger values of load resistance of phase-a produces the values of voltages and currents in various phases which are moderately high from their rated values. Under such high voltages and currents, generators may function for a short duration only but its operation is limited for longer periods due to damage of the insulation, burning of windings etc. Further it has been observed that due to lessening in load resistance, such generators might be collapsed as the voltage across the phases approaches to very low from its rated values and machines will not be able to generate the power.

V. CONCLUSION

The research work as presented in the paper is based on the assessment of performance analysis of three different rating induction machines. In order to trim down the control variables, generally the source branch accountable for generation in the negative sequence network of SEIG has been removed by the scientists. But in this work the same branch has been included and with use of symmetrical component theory it results in to a new multivariable objective function. It is the PSO which is well known for simplicity and for fast convergence rate as well has been considered for obtaining the appropriate values of the variables associated with the objective function. The finding of results from the algorithm as presented in the paper will decides the suitable machine considered for unbalanced load operation.

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