Performance evaluation of three-phase SEIG with unbalanced loading using Particle swarm optimization

Yatender Chaturvedi

Abstract— **These are the Self-excited induction generators (SEIG) which are serving significantly so as to power the three-phase load connected at remote places where it is quite impractical for the extension of the grids. The three phase load connected to these machines is generally unbalanced and sometimes the required excitation to these machines may also differ in various phases. Such unbalancing will certainly arise over voltage and over current in various phases of the SEIG. The work presented in the paper shows performance of different induction machines which will decides the suitable machine considered for unbalanced load operation. The circuit as presented results an objective function which includes its variables voltage unbalanced factor, generated frequency, magnetizing reactance of positive sequence and negative sequence networks. These associated variables have been solved through particle swarm optimization.**

Key words: Self-excited induction generator, unbalanced voltage, voltage unbalanced factor, renewable energy

I. Introduction

Renewable energy resources are being considered on large scale in the area of electric power generation. Day by day increasing demand of electric power is forcing our minds to utilize these renewable resources to mitigate the gap between demand and supply. Wind which is a clean renewable energy source and available in plenty of quantity are forced to rotate the wind turbines. Self-excited induction generator (SEIG) connected to wind turbines is utilized for the production of electric supply. It is the dominance of induction generators over other generators to use it in the area of power production through wind energy. These induction generators in self excited mode are generally used in isolated mode where the grid extension is quite impractical. In such mode a capacitor bank is adopted to supply the reactive power to load and the machine as well.

Loop impedance and nodal admittance are the two well known approaches generally used to analyze the SEIG. These two well known approaches come to two simultaneous equations that are non linear. Nodal admittance method in the circuit of SEIG earns 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 operation of self-excited induction generator in isolated mode generally suffers with the unbalanced loading in different phases of the generator which leads the generators 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 concept of excitation balancing [8] was presented using symmetrical component theory. A focus on mathematical models was presented for many generator-load combinations [9] in order to obtain performance characteristics of isolated three-phase self-excited induction generators with balanced and unbalanced loading as well. Comparative presentation 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].

II. Modeling of Machine

Circuit as shown in figure-1 represents a delta connected three-phase load which is suppose feeded by a three phase self-excited induction generator. The 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.

Yatender Chaturvedi, Department of Electrical & Electronics Engineering, KIET Group of Institutions, Ghaziabad, India, 6397488715.

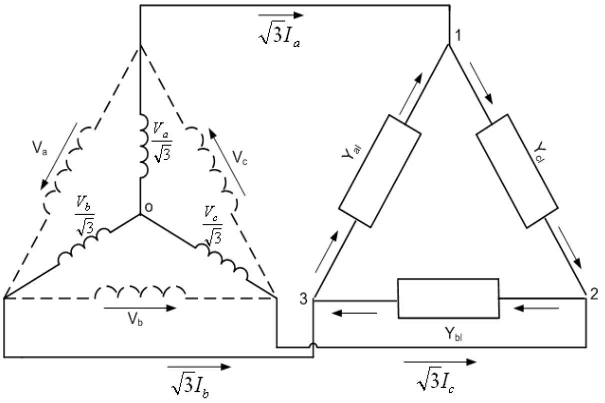

Fig. 1 Delta connected three-phase SEIG

Application of KCL at all three nodes of SEIG [13] and the use of symmetrical component theory results in to ratio of negative to positive sequence circuit may be written as:

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

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

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

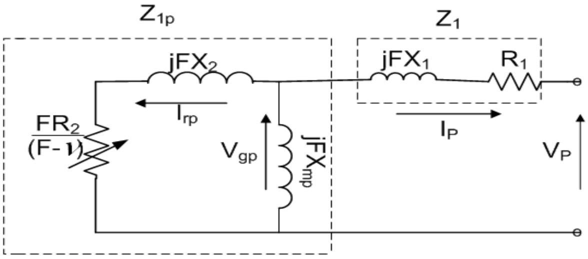

Fig.2 Positive sequence circuit of SEIG

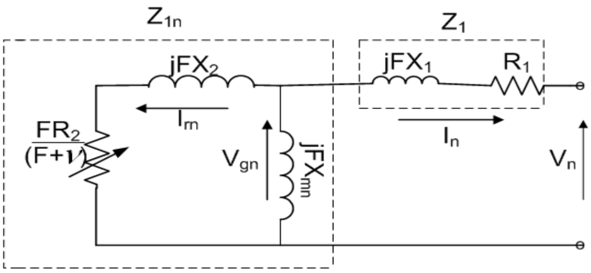

Fig.3 Negative sequence circuit of SEIG

Following equation may be formed from positive sequence circuit of SEIG and negative sequence circuit of SEIG as well:

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

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

$$\min\left|f(K,F,X_{mp},X_{mn})\right| = \min\Big(f\big(K^2Y_2(Z_1+Z_{1n}) + K[Y_1(Z_{1p}-Z_{1n})] - (Z_1+Z_{1n})Y_3\big)\Big) \qquad (4)$$

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. PSO TO COMPUTE SEIG VARIABLES

The strong capabilities of PSO to solve the problems based on non linear optimization are attracting to compute control variables in the engineering field. The methodology is focused on bird's flock motion whereas the swarms move in a group [18] for searching their food. Every individual solution of these swarms is nominated as a particle and its possible solutions are termed as swarms. Every particle moves with its velocity in the group having a certain positions. The process of searching 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:-

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

$$X_{id} = X_{id} + V_{id} \qquad (6)$$

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. Here values of parameters C_1 & C_2 may be takes as 2.2 and R_1 & R_2 in range of [0,1].

In this research work, PSO algorithm has been adopted in order to compute the variables generated frequency, speed of machine, reactance of source branch in positive and negative circuits as well. Initially Frequency and speed has taken 0.95 p.u while magnetizing reactance is taken as their unsaturated value.

IV. RESULTS AND DISCUSSION

The modeling of SEIG as presented in the paper has been implemented to forecast the performance of three SEIG,s of different ratings [14-15] under unbalanced conditions. At starting these generators are bound to operate at rated values of voltage and current at balanced loading. After it the unbalancing has been created in load resistance and capacitance of various phases 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.

(a) Unbalancing due to load variation of one phase of SEIG

In this section, 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 where as figure 10 show the variations in degree of unbalance. The operating speed of generators was kept fixed (1.027 p.u) throughout the operation.

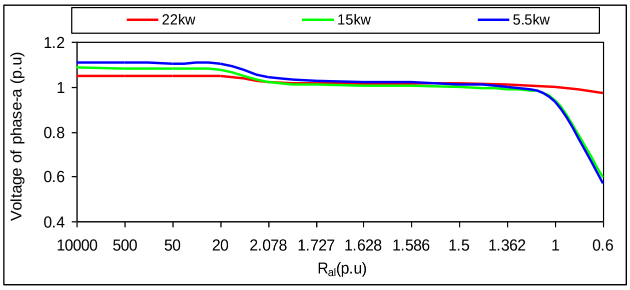

Fig 4: Variation in voltage of phase-a due to load resistance of one phase

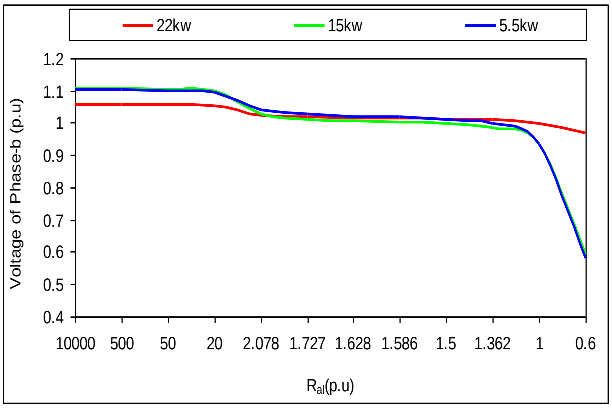

Fig 5: Variation in voltage of phase-b due to load resistance of one phase

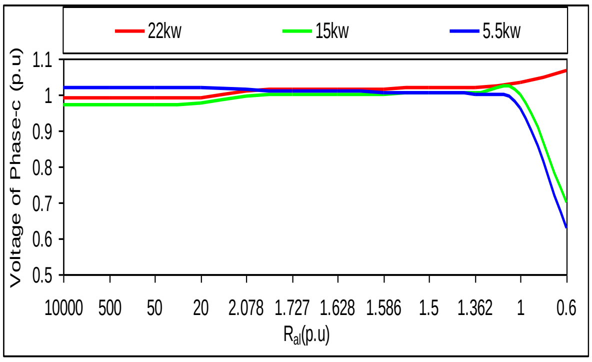

Fig 6: Variation in voltage of phase-c due to load resistance of one phase

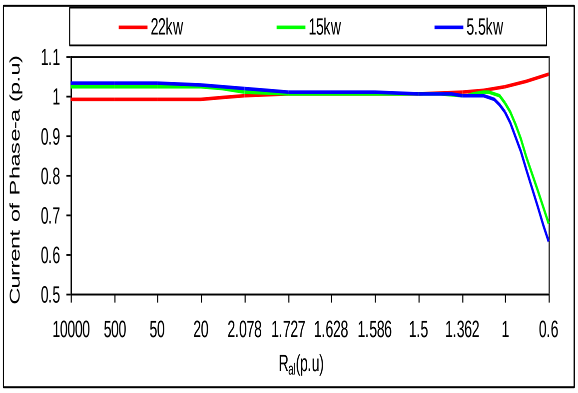

Fig 7: Variation in current of phase-a due to load resistance of one phase

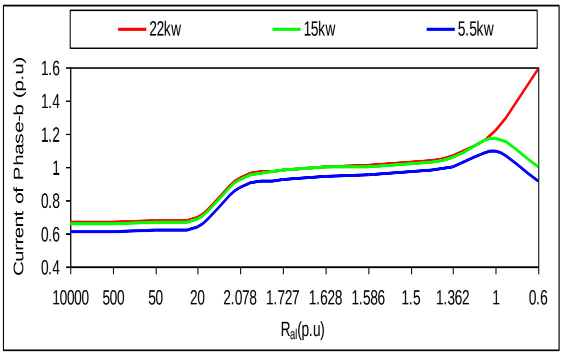

Fig 8: Variation in current of phase-b due to load resistance of one phase

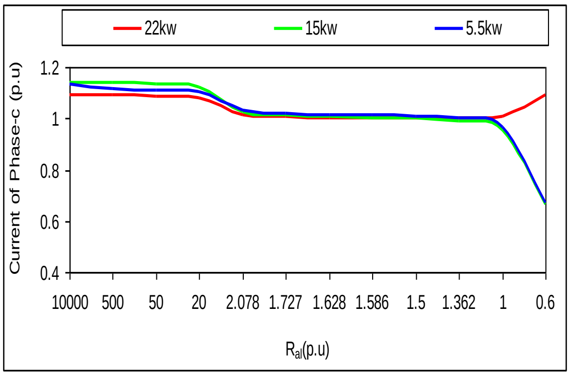

Fig 9: Variation in current of phase-c due to load resistance of one phase

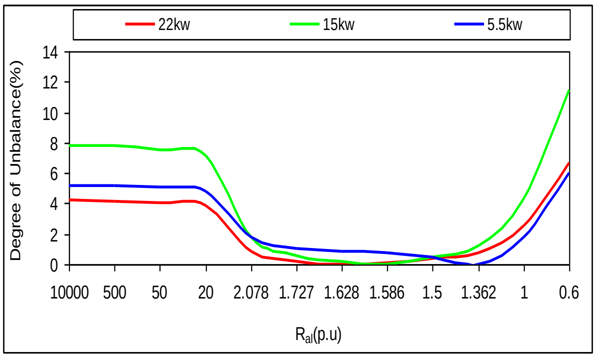

Fig 10: Variation in Degree of Unbalance due to load resistance of one phase

(b) Unbalancing due to load variation of two phases of SEIG

In this section, unbalancing in the load has been set up by creating variation in the load resistance of phase-a and phase-b while load resistance of third phase remains the same.

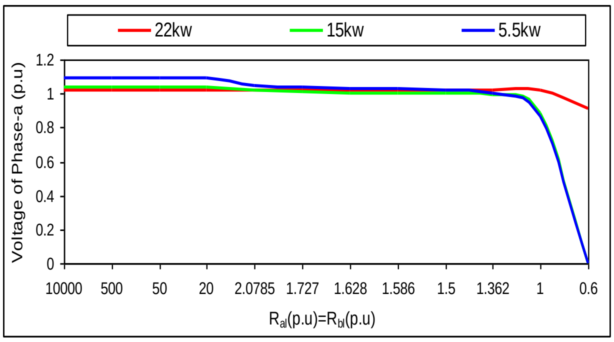

Fig 11: Variation in voltage of phase-a due to load resistance of two phases

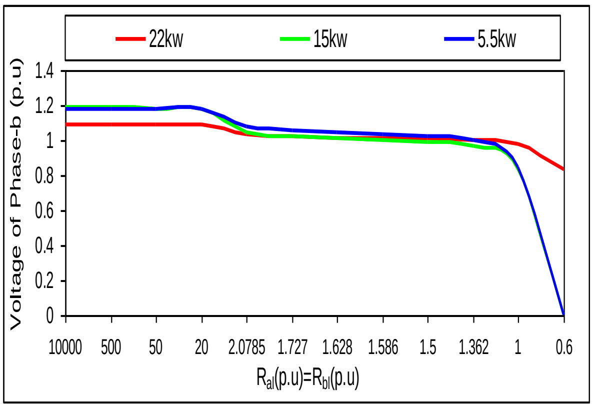

Fig 12: Variation in voltage of phase-b due to load resistance of two phases

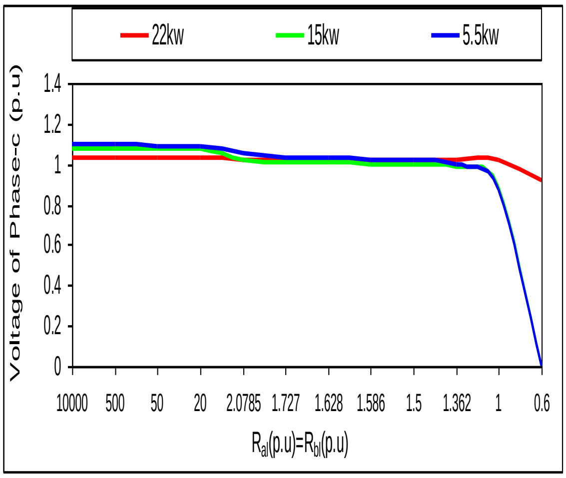

Fig 13: Variation in voltage of phase-c due to load resistance of two phases

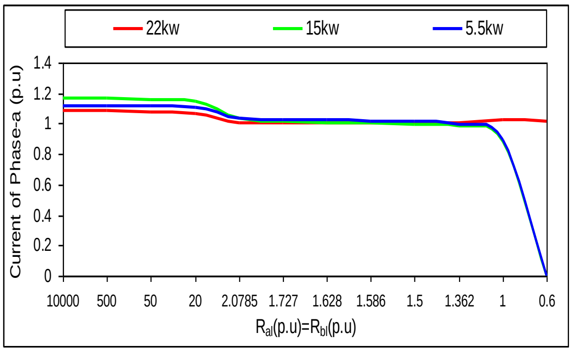

Fig 14: Variation in current of phase-a due to load resistance of two phases

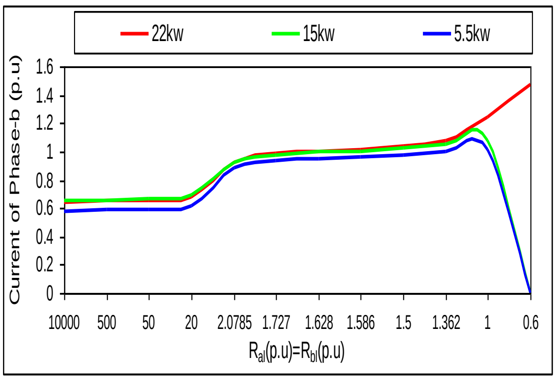

Fig 15: Variation in current of phase-b due to load resistance of two phases

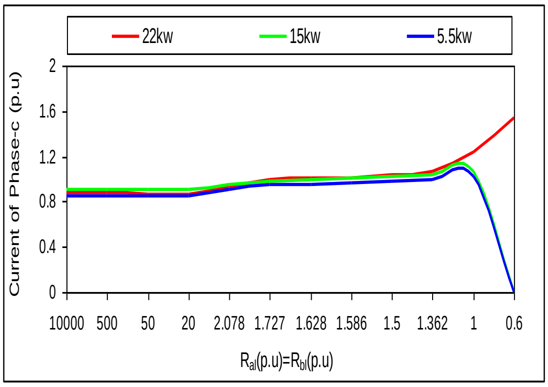

Fig 16: Variation in current of phase-c due to load resistance of two phases

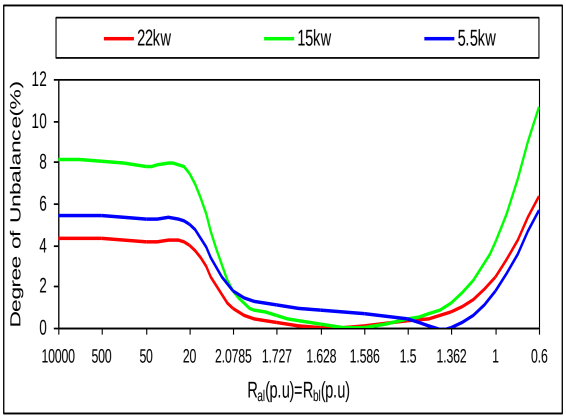

Fig 17: Variation in degree of unbalance due to load resistance of two phases

Table 1: Safe operation of machines with load variation in one phase

Rating of machines	**Value of R_{al} (p.u) from balanced operation**		**Degree of unbalance (%)**	
	Higher side	Lower side	Higher side	Lower side
22KW	18.35	1.4	10000	0.5
15 KW	12.48	1.362	10.12	1.0
5.5 KW	15.69	1.23	50	0.5

Table 2: Safe operation of machines with load variation in two phases

Rating of machines	**Value of ($R_{al} = R_{bl}$) from balanced operation**		**Degree of unbalance (%)**	
	Higher side	Lower side	Higher side	Lower side
22KW	15.88	1.4	10000	0.45
15 KW	12.11	1.362	10.02	0.9
5.5 KW	2.078	1.0	20	0.5

Simulation results over generators of different ratings for phase voltages are shown in figure 11 to 13 whereas simulation results for phase currents are shown in figure 14 to 16 where as figure 17 show the variations in degree of unbalance. The operating speed of generators was kept fixed (1.027 p.u) throughout the operation.

The simulated result shows the variations in voltages and currents in various phases of the generators due to load resistance of one phase only. During simulation it is found that function of these generators towards higher values of load resistance of phase-a produces the values of voltages and currents in various phases which are quite high from their rated values. Under such high voltages and currents, generators may operate for a short duration only but its operation is restricted for longer periods due to damage of the insulation, burning of windings etc. Further it has been observed that due to reduction 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 offered is based on the examination of performance analysis of different rating induction machines. In order to reduce the control variables, generally the source branch responsible for generation in the negative sequence network of SEIG has been cut off by the scientists. But in this work the same branch has been incorporated 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.

REFERENCES

[1] L.Quazene and G.McPherson "Analysis of the isolated induction generator", *IEEE Trans. on Power Apparatus System*, Vol. 8, No. 102, 1983, pp. 2793-2798.

[2] N.H Malik and S.E. Haque "Steady state analysis and performance of an isolated self-excited induction generator", *IEEE Trans. on Energy Conversion*, Vol. 3, No. 1, 1986, pp.134-140.

[3] S.P. Singh, B. Singh and M.P. Jain " Comparative study on the performance of a commercially designed induction generator with induction motors operating as self- excited induction generators*", IEE Proc.*, Vol. 140, No. 5, 1993, pp. 374-380.

[4] T.F. Chan "Analysis of Self-excited induction generators using an iterative method", *IEEE Trans. on Energy conversion*, Vol. 10, No. 3, 1995, pp. 502- 507.

[5] K. S. Sandhu and S. K. Jain "Operational aspects of self- excited induction generator using a new model", *Electric Power Components and Systems*, Vol. 27, No. 2, 1999, pp. 169–180.

[6] D. Joshi, K. S .Sandhu. and M.K. Soni "Constant voltage constant frequency operation for a self-excited induction generator", *IEEE Trans. on Energy Conversion*, Vol. 21, No. 1, 2006, pp. 228-234.

[7] Dheeraj Joshi, K.S Sandhu and M.K. Soni "Performance analysis of three-phase self-excited induction generator using genetic algorithm", *Electric Power Components and System*s, Vol. 34, No. 4, 2006, pp. 461-470.

[8] J.L. Bhattacharya and J.L. Woodward "Excitation balancing of a self-excited induction generator for minimum power output", *IEE Proc*., Vol. 135, No. 2, 1998, pp. 88-97.

[9] A.H. AL.-Bahrani "Analysis of self-excited induction generators under unbalanced conditions", *Electric Machines and Power Systems*., Vol. 24, 1996, pp. 117-129.

[10] J. Faiz, H. Ebrahimpour and P. Pillay " Influence of unbalanced voltage on the steady-state performance of a three-phase squirrel-cage induction motor*", IEEE Trans. on Energy Conversion*, Vol. 19, No. 4, 2004, pp. 657-662.

[11] S.S. Murthy, B. Singh, S. Gupta and B.M. Gulati "General steady-state analysis of three-phase self-excited induction generator feeding three-phase unbalanced load/ single-phase load for stand-alone applications", *IEE Proc*., Vol. 150, No. 1, 2003, pp. 49-55.

[12] Wang, Y.J., and Huang, Y.S "Analysis of a stand-alone three-phase self-excited induction generator with unbalanced loads using a two-port network model", *IET Electric Power Applications*, Vol. 3, No. 5, 2009, pp. 445-452.

[13] Yatender Chaturvedi, Sumit Kumar, Priti Bansal and Sushil Yadav "Comparison of APSO, PSO, & GA for performance investigation of SEIG with balanced loading*", 9th International Conference on Cloud Computing Data Science & Engineering (Confluence), 2019,* pp. 459-463.

[14] Yatender Chaturvedi and Kanwarjit Singh Sandhu "Analysis of three-phase self-excited induction generator under unbalanced operations", *International Journal of Energy Engineering*, Vol. 3, No. 3, 2013, pp. 200-207.

[15] Yatender Chaturvedi , Sumit Kumar and Vishal Gupta "Capacitance requirement for rated current and rated voltage operation of SEIG using whale optimization algorithm", *Procedia Computer Science* 167, 2020, pp. 2581-2589.

[16] Yatender Chaturvedi and Sumit Kumar "Selection of stand-alone self-excited induction generator parameters to obtain maximum allowable operating range under unbalanced operations using particle swarm optimization", *International Journal of System Assurance Engineering and Management*, Vol. 11, No. 3,2020, pp. 677-689.

[17] A.H. Bonnet and G.C. Soukup "Understanding the NEMA motor-generator standards of section MG-1-1993, revision, three- phase induction motors", *Copyright Material IEEE Paper*. 97-24, 1993, pp. 225-238.

[18] R.C. Eberhart and Y. Shi "Tracking and optimizing dynamic systems with particle swarms", In Evolutionary Computation. *Proceedings of the 2001 Congress*. 1, 2002, pp. 94–100.

Yatender Chaturvedi has completed his B.E from Agra University in 2002, M.Tech & Ph.D from NIT Kurukshetra in 2006 & 2015 respectively. He has published more than 30 research papers in various international journal and conferences as well. His current research area belongs to renewable energy, power system, and electric drives. Currently he is working as Professor (Research) in KIET Group of institutions, Ghaziabad.