Available online at www.worldscientificnews.com

World Scientific News

An International Scientific Journal

WSN 121 (2019) 90-100 EISSN 2392-2192

Wind Powered Electricity Generation Through Self Excited Induction Generator

Yatender Chaturvedi[1], **Ankit Goel**[2]

KIET Group of Institutions, Ghaziabad, India

[1,2]E-mail address: yatendra.chaturvedi@kiet.edu , ankit.goel@kiet.edu

ABSTRACT

An iterative method is used to identify the saturated magnetizing reactance and the frequency of a self-excited induction generator for given capacitance, speed, and load in a systematic way. Under steady state, this procedure is effective in analyzing such systems. A correlation has been observed between the computational algorithm results & experimental outcomes. Under steady state condition, changes in various variables have been studies and the determination of the feasibility of such system is done.

***Keywords*:** Magnetic saturation, Newton-Raphson method, Magnetizing reactance

1. INTRODUCTION

It has become very challenging to meet the power demand for increasing population from the conventional energy resources, such as coal, gas etc. To overcome these challenges power industries have now shifted their attention over to non-conventional sources of energy like wind, sun, biogas etc. as they are available in abundance, renewable and environment-friendly. Development of economic & efficient power generators is the main target.

Due to the low price, robust structure and ease of maintenance the squirrel cage induction generator may be preferred over the synchronous generator for such applications [1-15]. Feasibility of these machines depends upon the controllability of their voltage and frequency

(Received 02 February 2019; Accepted 16 February 2019; Date of Publication 19 February 2019)

(at all loads). To regulate the required voltage and frequency at preferred levels, power converters [1, 5-8] are used. By connecting a suitable capacitor bank across induction machine & rotating its rotor at a speed higher than its synchronous speed it can be used as an induction generator. At the generator terminals, a small EMF has induced due to the presence of residual magnetism in the rotor. Because of the speed increases, the capacitor impedance decreases, the excitation increases, and which means terminal voltage on the equipment increases. But this rise of voltage is limited because magnetic characteristics of the machine have been saturated. The values of capacitor, speed, and load affect the terminal voltage of the generator.

The efficiency of the induction machine is generally poor when operating as an induction generator because of system variables. The performance of an induction machine with low winding resistances and leakage reactance should have a much better efficiency when operated as an induction generator.

In this paper, a method is represented to identify generated frequency and saturated parameters for a given load using the Newton- Raphson technique. With the help of obtained value & the equivalent circuit the steady-state performance can be analyzed. The technique is very simple. At the end, experimental values & simulated results are compared. On the bases of which, various system parameters & their effects are studied on the steady-state characteristics. Outcomes are discussed and plotted in tabular form & graphically which are helpful for the designing of machine.

2. THEORY

The following assumptions are made to complete this analysis:

1) Magnetic saturation affects only magnetizing reactance while other parameters of the circuit are kept constant. Main field flux saturates due to self-excitation. It is important to study the variation of magnetizing reactance Xm with the saturation level of main flux because the value of Xm reflects the magnitude of main flux. Generally, the path of leakage flux occurs in the air, thus leakage flux does not affect saturation of main flux.
2) In the induction machine, the leakage reactance of stator and rotor are equal [17].
3) Core losses are neglected.
4) In the voltage and current waveform MMF based harmonic and time-harmonic are ignored. But this assumption is valid only on a well-designed machine.

Table 1. Symbolic representation of various machine components.

R1, R2	stator and rotor (referred to stator) resistance per phase in p.u
X1, X2	stator and rotor (referred to stator) leakage reactance Per phase in p.u
Xm	magnetizing reactance
Xc	capacitive reactance of the terminal capacitor C per phase in p.u
R_L	load resistance per phase

a, b	frequency and speed, respectively
Is, Ir, I_L	stator, rotor (referred to stator) and load
Vt, Vg	terminal and airgap voltage, respectively

Equivalent circuit of a standalone self- excited induction generator operating a resistive load in Figure 1, where:

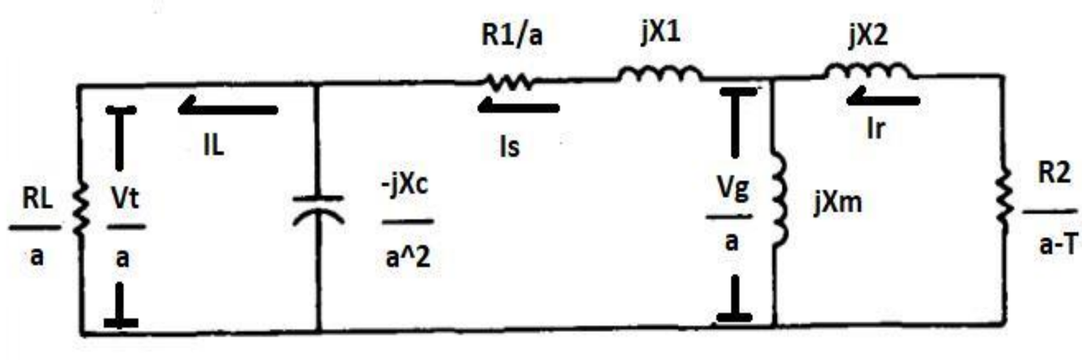

Figure 1. Equivalent circuit of the induction generator with load

Operation equivalent circuit is helpful to study transient and steady state voltage build-up process [16-17], this equivalent circuit results in the time derivative of characteristics. For a particular machine, self-excitation would occur if at least one roots of characteristics polynomial, have a positive realpart. As soon as voltage build-up, the machinecomes into saturation because of resultant air gap flux, which results ina decrease in value of saturated magnetizing reactance Xm and positive real part reduced to zero. For steady-state analysis, we use above a saturated value of Xm.

To calculate the steady-state response of the equivalent circuit, it is essential to calculate steady-state values of Xm & F for a particular machine.

On applying KVL on the equivalent circuit, following equation is obtained.

$$Is*Zs = 0 \quad \ldots\ldots \quad (1)$$

where $Zs = (Z_1 + Zc*RL)/(Zc + RL) + (Z_2*Zm)/(Z_2 + Zm)$

In steady state, $Is \neq 0$, Therefore from the equation Is*Zs = 0, Both Real & Imaginary part of Zs will be zero separately.

$$f = (Re3/Re4) + (Re1/Re2) + R1/a \quad \ldots\ldots \quad (2)$$

$$g = (Xe5/Re4) + ((Xe1 + Xe2)/Re2) + X1 \quad \ldots\ldots \quad (3)$$

where,

$Re1 = R2*Xm^2/(a-b)$, $Re2 = (R2^2/(a-b)^2) + (X2 + Xm)^2$, $Re3 = RL*Xsh^2/a^5$

$Re4 = (RL^2/a^2) + ((Xsh/a^2) - XL)^2$, $Xe1 = R_2{}^2*Xm/(a-b)^2$, $Xe2 = X2*Xm*(X2 + Xm)$

$Xe3 = (R2^2/(a-b)^2) + (X2 + Xm)^2$, $Xe4 = Re4$,

$Xe5 = ((XL*Xsh\text{^}2/a^4) - (Xsh*RL^2/a^4) - (XL^2*Xsh/a^2))$

The above non-linear equations (2) & (3) are not easily solvable, so we use special numerical technique wiz. Newton-Raphson method, to find the value of magnetizing reactance Xm & the output frequency ‗a' for a given machine parameter.

For computation of NR Method, we need to find out jacobian of the two non-linear equations, which is obtained as:

J11 = diff (f,a), J12 = diff (f,Xm), J21 = diff (g,a), J22 = diff (g,Xm)

where J11 implies the differentiation of equation (2) with respect to frequency ―a‖

The initial guess in this method for unknown Xm_o and a_o = will be chosen as: $Xm_o = Xm$ $a_o = a$

Now $f_o = f(Xm_o, a_o) = 0$ and $g_o = g(Xm_o, a_o) = 0$

Next iteration will take $Xm_o + h$, $a_o + k$ as the initial guess, h & k are increments.

This iteration process will continue until the desired accuracy is obtained.

After determining the values a & Xm, calculation of air gap voltage (Vg) & terminal voltage (Vt), For this purpose, we need to have the relation between Xm & Vg/a which relates to air gap flux. With Vg, Xm, a, Xc, a-T and machine parameters are known, calculation of the terminal voltage Vg and the load current is done using the equivalent circuit of Fig. 1.

Expressions for the respective variables are summarized below:

E1 = (1.4974-(0.32424*Xm)), N7 = ((-E1/a)*N5), N8 = ((-E1/a)*N6), IL = sqrt(N7^2+N8^2)

V1 = IL*(sqrt(RL^2 + (a*XL)^2)), Pout = 3*V1*IL, Pout1 = 3*IL^2*RL

where,IL = Output Current, V1 = Output Voltage, Pout = Output Power

These relations are made into a matlab program. Based on the technique mentioned above, the program has been developed which calculates the steady-state performance of the unit for given values of speed, terminal capacitance and load resistance. The program may be used to determine the steady-state operating characteristics of the generator.

With the help of this analytic technique, various system parameters & their effects are studied under the steady-state characteristics. Observed variation has been collected in tabular form, plotted graphically and analyzed

3. EXPERIMENTAL SETUP AND MACHINEPARAMETERS

We have considered three self-excited induction generators and analyze their performance on the basis of different parameters. Consider machine 1, machine 2, and machine 3 respectively.

A. Machine 1:

3-phase, 15KW, 4-pole, 50 Hz, 415V, 30A, Delta connected squirrel cage induction machine with per-phase equivalent circuit parameters in per unit are:

$$R1 = 0.0288,\ R2 = 0.03088,\ X1 = X2 = 0.1456,\ Xc = 1.2898,\ b = 1.0286$$

The representation of magnetizing curve in per units is:

$$Vg/a = 0.49 + 0.813Xm - 0.30225Xm^2$$

B. Machine 2:

3-phase, 5.5KW, 4-pole, 50 Hz, 415V, 11A, Delta connected squirrel cage induction machine with per-phase equivalent circuit parameters in per unit are:

$$R1 = 0.0525,\ R2 = 0.05417,\ X1 = X2 = 0.09,\ Xc = 1.2898,\ b = 1.0286$$

The representation of magnetizing curve in per units is:

$$Vg/a = 0.21235 + 1.248Xm - 0.4373\,Xm^2$$

C. Machine 3:

3-phase, 2.2KW, 4-pole, 50Hz, squirrel cage induction machine with 230V, 8.6A, Delta connected squirrel cage induction machine per-phase equivalent circuit parameters in per unit are:

$$R1 = 0.07232,\ R2 = 0.038,\ X1 = X2 = 0.01047,\ Xc = 1.2898,\ b = 1.0286$$

The piecewise representation of magnetizing curvein per units is as

$$Vg/a = \begin{cases} 1.4974 + 0.3242\ Xm & \text{for } 1.776\ Xm < 1.776 \\ 2.022 - 0.6197\ Xm & \text{for } 1.776 < Xm < 2.0632 \\ 2.5213 - 0.8615\ Xm & \text{for } 2.0632 < Xm < 2.3316 \\ 0 & \text{for } Xm > 2.3316 \end{cases}$$

Table 2. Base values of machine parameter

Vbase = rated phase voltage	230 V
Ibase = rated phase current	4.74 A
Zbase	48.52 ohm
Ybase	0.0206 S
Base power Pbase = VbaseIbase	1.09kW
Base speed Nbase	1500 rev/min
Base frequency fbase	50 Hz

4. RESULTS AND DISCUSSION

A. *Effects on Machine parameters with load variation*

Table 3. Effects on machine 1 parameters with load variation.

RL	a	Xm	IL	V1	Pout
.986	.9902	2.5729	.5691	.5611	.9580
1.086	.9934	2.1574	.7396	.8032	1.7822
1.186	.9961	1.9131	0.7587	0.8998	2.0482
1.286	.9984	1.7532	.7366	.9473	2.0933
1.386	1.004	1.6408	.7033	.9747	2.0566
1.486	1.0021	1.5580	0.6683	0.9930	1.9908
1.586	1.0037	1.4946	0.6347	1.0066	1.9167
1.686	1.0050	1.4446	0.6035	1.0176	1.8424
1.786	1.0062	1.4044	.5749	1.0268	1.7711
1.886	1.0075	1.3641	.5490	1.0355	1.7055

Table 3(continue). Effects on machine 1 parameters with load variation.

RL	a	Xm	IL	V1	Pout
.986	.9863	2.2067	.5756	.5676	.9801
1.086	.9895	1.9837	.6713	.7291	1.4683
1.186	.9923	1.8339	.6909	.8195	1.6986
1.286	.9947	1.7266	.6793	.8735	1.7801
1.386	.9967	1.6463	.6524	.9043	1.7700
1.486	.9986	1.5840	.6258	.9299	1.7458
1.586	1.002	1.5343	.6002	.9518	1.7137
1.686	1.0016	1.4939	.5759	.9709	1.6774
1.786	1.0029	1.4604	.5530	.9877	1.6388
1.886	1.0040	1.4322	.5317	1.0027	1.5993

B. *Effects of load variation on magnetizing reactance (Xm)*

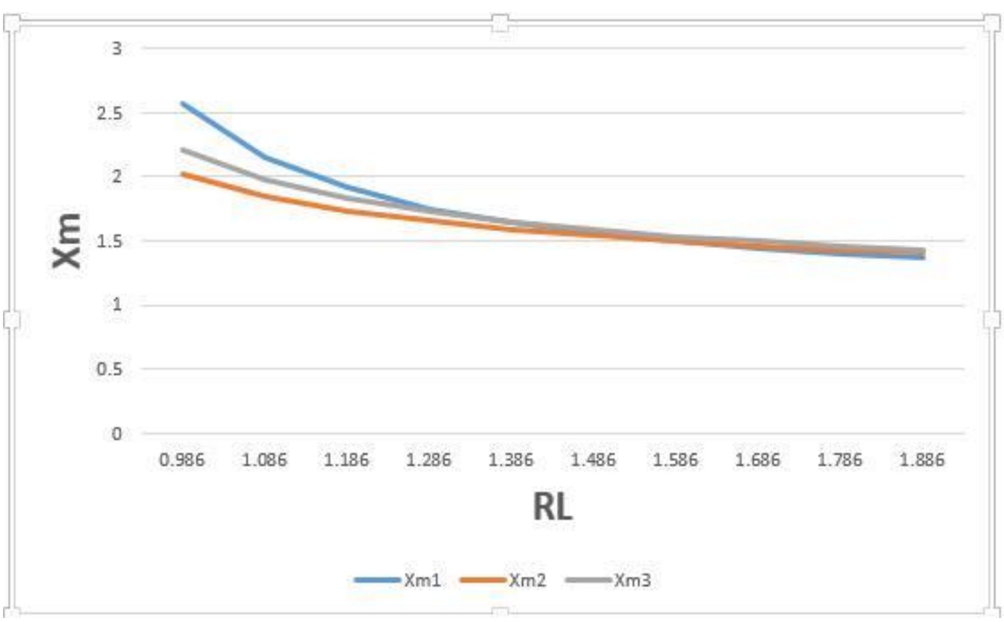

Figure 2. Effects of load variation on magnetizing reactance (Xm)

The value of magnetizing reactance is low if load is high and the value of magnetizing reactance is high if the load is low. Hence increment in R_{L}, reduces the value of magnetizing reactance of all the machines.

C. *Effects of load variation on load current (IL)*

The Load current attains a peak value at a particular value of load resistance. In the increasing value of load, load current first increase then it would be decrease further more. Increment in the values of load resistance reduces the load current I_L.

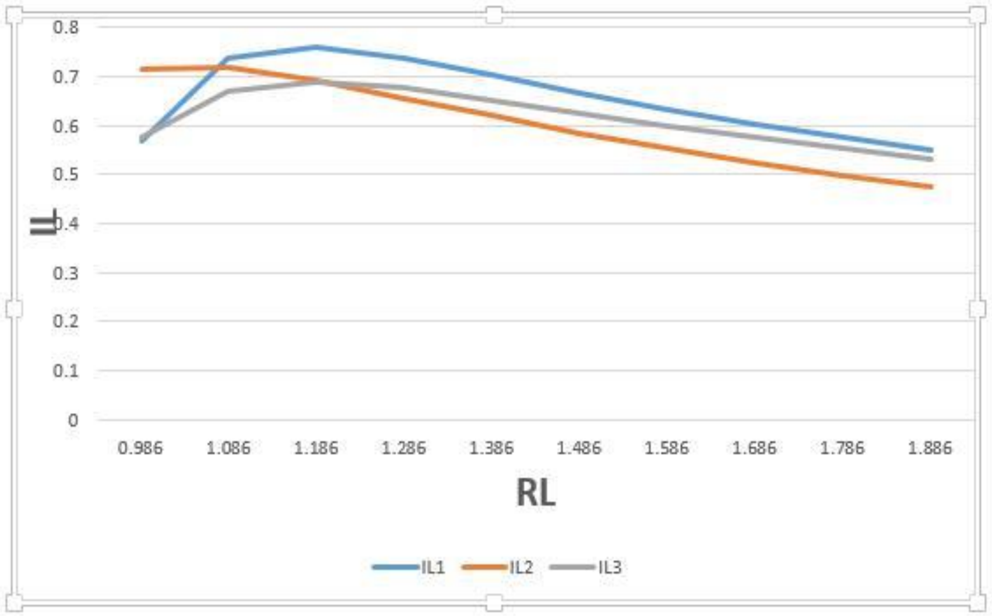

Figure 3. Effects of load variation on load current (IL)

D. *Effects of load variation on load voltage (V1)*

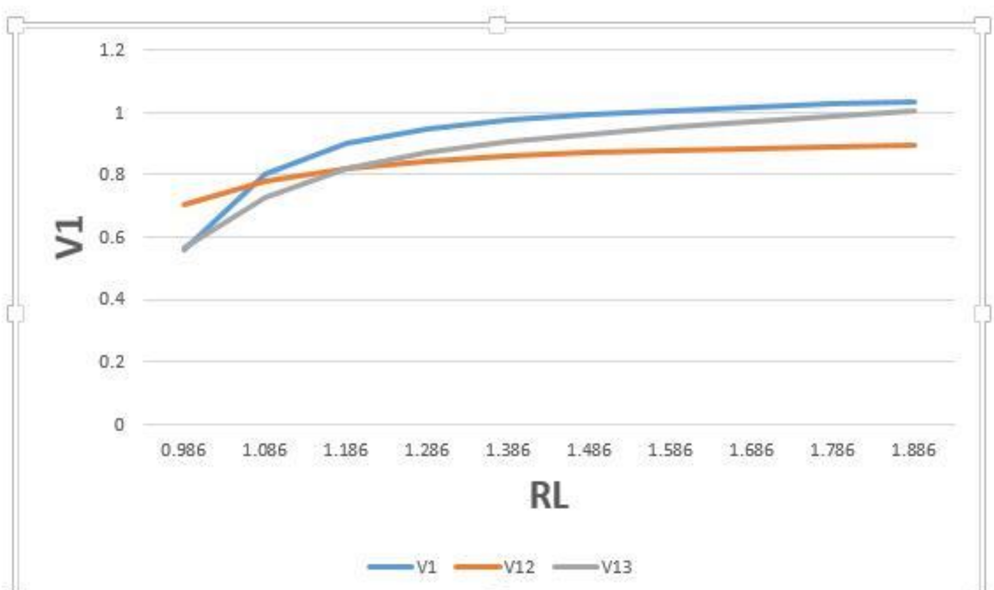

Figure 4. Effects of load variation on load voltage (V1)

If the load on the system increase then V1 will increase further and if the load increase furthermore then it will attains constant value. With the Increment in the values of load resistance the output voltage (V1) increases

E. ***Effects of load variation on output power (Pout)***

At a particular value of load resistance we get the maximum output power. If nature of the load is increasing then output power will first increase then it would decrease. From the result, we observe that as we increase the load resistance RL, POUT of each machine increases up to values of RL and after it the value of POUT reduces.

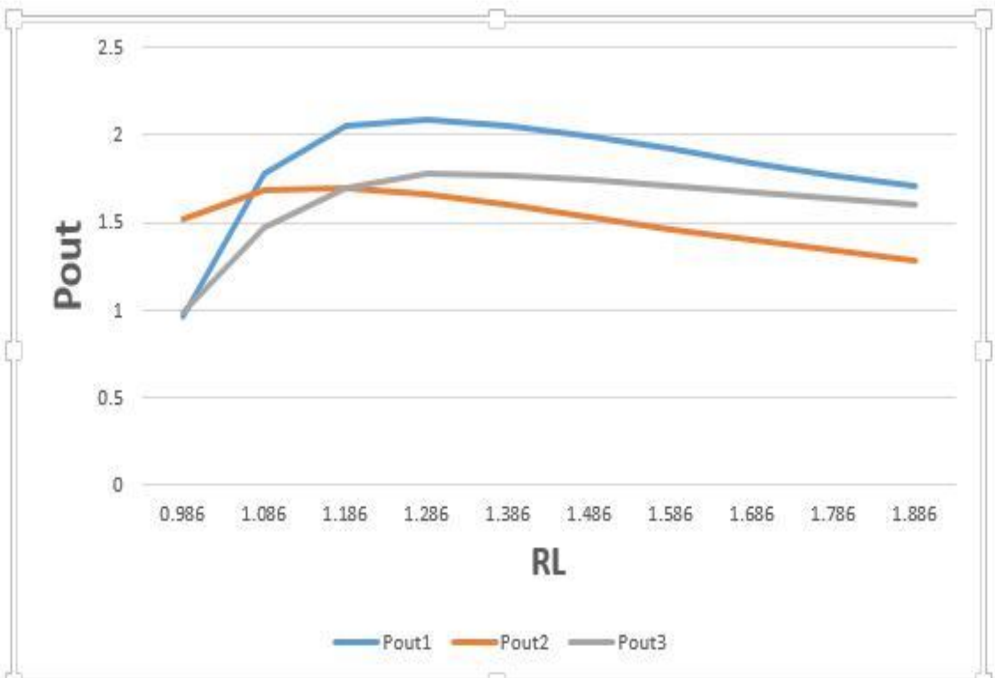

Figure 5. Effects of load variation on output power (Pout)

5. CONCLUSION

In this analysis it is observed that the variation of load changes the different parameters value accordingly and hence SEIG performance is analyzed and the result is obtained accordingly. In the analysis of SEIG, We have picked induction machines of different rating. We conclude that every machine is designed for a particular load will gives it‘s better performance when it‘s system parameters would be lies in certain limits. Out of all three machine we observe that machine-2 undergoes higher values of Pout & voltage across load terminal. This is perhaps due to the lower value of magnetizing reactance or higher value of air gap voltages.

References

[1] Novotny, D.W., Critter, D.J. & Studtmann, G.H.: Self excitation in inverter driven induction machines. *IEEE Trans. Power Appar. & Syst.* 1977, 4, pp. 1117-1 125.

[2] Ammasaigounden, N., Subbiah, M., and Krishnamurthy, M.R.: Wind driven self-excited pole-changing induction generators, *IEE Proc. B*, 1986, 133, (5), pp. 315-321.

[3] Quazene, L., and McPherson, G., Jr.: Analysis of isolated induction generators. *IEEE Trans. Power Appar. & Sysr.* 1983, PAS-102. (S), pp. 2793-2798.

[4] Elder, J.M., Boys, J.T., and Woodward, J.L.: Self-excited induction machine as a low-cost generator. *IEE Proc C*, 1984, 131, (2), pp. 33-45

[5] Arrillage, J., and Watson, D.B.: Static power conversion from self excited induction generators. *Proc. IEE*, 1978, 125, (8). pp. 743-746

[6] Watson, D.B., Arrillage, J., and Densem, T. Controllable DC power supply from wind driven self exnted induction machines. *Proc. IEE*, 1979, 126, (12), pp. 1245-1248

[7] Brennen, M.B., and Abbondati, A.: Static exciters for induction generators. *IEEE Trans. Ind. Appl.* 1977, IA-13, (5), pp. 422-428

[8] Raina, G., and Malik, O.P.: Wind energy conversion using a self excited induction generator. *IEEE Trans. Power Appar. & Syst.* 1983, PAS-102, (12), pp. 3933-3936

[9] Murthy, S.S., Malik, O.P., and Tandon, A.K. Analysis of self excited induction generators. *Proc. IEEE C.* 1982, 129, (6), pp. 264-265 .

[10] Tandon, A.K., Murthy, S.S., and Berg, G.J.: Steady state analysis of capacitor self excited induction generators. *IEEE Trans. Power Appar. & Syst.* 1984, PAS-103, (3). pp. 612-618

[11] Watson, D.B., and Milner, I.P.: Autonomous and parallel operation of self excited induction generators. *Inc. J. Elerrr. Eng. Educ.* 1985, 22, (4), pp. 365-374

[12] Melkbeek, J.A.A., and Novotny, D.W.: Small signal dynamic analysis of regeneration and self excitation in induction machines. *Electric Mach. Power Syst.* 1983, 8, 4-9, pp. 259 -280

[13] Melkbeek, J.A.A.: Magnetising field saturation and dynamic behaviour of induction machines. Part 2: stability limits of a voltage-fed induction motor and of a self-excited induction generator. *Proc. IEE B*, 1983, 130, (I), pp. 10-17

[14] Murthy, S.S., Singh, B.P., Nagamani, C. and Satya Narayana K.V.V.: Studies on the use of conventional induction motor as self excited induction generators. *IEEE Trans. Energy Conuers.* 1988, 3, (4), pp. 842-848

[15] Murthym, S.S., Nagraj, H.S., and Kuriyan, A.: Design based computational procedure for perormance prediction and analysis of self excited induction generator using motor design packages. *Proc. IEE B*, 1988, 135, pp. 8-16

[16] Yatender Chaturvedi and Kanwarjit Singh Sandhu, Analysis of three-phase self-excited induction generator under unbalanced operations. *International Journal of Energy Engineering*, 3(3), pp. 200-207, 2013.

[17] Yatender Chaturvedi and Kanwarjit Singh Sandhu. Design parameters of three-phase self-excited induction generator for desired performance under unbalanced operations. *Journal of Power Electronics & Power Systems*, Vol. 4, Issue 1, pp. 1-12, 2014.