MATHEMATICAL MODELLING OF SELF EXCITED INDUCTION GENERATOR SUPPLYING SINGLE PHASE LOAD USING MATLAB SIMULINK

Yogesh Kumar[1], Varun Kumar[2], Abhishek Gandhar[3], Dr. Balwinder Singh[4]
1,2 Asstt Proffesors, Department of Electrical Engineering
Manav Bharti University, Solan H.P INDIA-173229
3 Associate Proffesor, EEE Deptt, BVCOE,New Delhi
4 Head Electrical Engineering Department, PEC University of Technology, Chandigarh

Abstract

This paper presents a transient analysis of a self-excited induction generator (SEIG) supplying single phase load used in stand-alone micro-hydro power generation employing uncontrolled turbines. In view of the need to feed static loads from such systems, the transient behavior due to switching in of such loads is of interest and is carried out here. A composite mathematical model of the total system has been developed by combining the modeling of prime mover, SEIG and load. Simulated results are compared with the experimental ones, obtained on a developed prototype of a self excited induction generator system for the starting of an IM and switching in a resistive load. For the starting of an IM, a star/delta starter is used to avoid inrush current. Harmonic analysis is carried out to find total harmonic distortion of the terminal voltage and current to assess its power quality.

Keywords: *SG ,SEIG,DC Separately Exited Motor*

I. INTRODUCTION

In present scenario due to increased power demand, limited fuel supply, emission of green house gases and increase in the complexity of system need for a stand -alone non-conventional renewable source based generating system has increased. These generating units are helpful in lighting remote areas where transmission is not only difficult but also not cost effective. Among distinct stand alone generation alternative, small hydro power station using synchronous generator (SG) can be considered the most efficient one. However, SG has many technical advantage such as good voltage control, stability, frequency control it's complexity and it's demand of skilled labor force for maintenance and operation make it sometime, economical unviable [6]. Thus, self excited induction generator (SEIG) comes into picture. SEIG use induction machine that are low cost, robust, easily available in market and also needs low skilled labour force for its maintenance and operation[1-2].

As for as operation of SEIG is considered it is an induction generator that is governed by self excitation phenomenon to generate a steady voltage across its terminal. The initiation of the self-excitation process is a transient phenomenon and is better understood if the process is analyzed using the transient model for both the voltages and currents. Granthum et al. have demonstrated the initiation of the voltage build-up process by discussing the transient phenomenon in the RLC circuits. In this case the stator of the self-excited induction generator may be represented by an RLC circuit in which the transient voltage and current have terms of the form k*exp(st). The root s is often a complex quantity and its real part, which is adjusted by the saturation of the magnetic circuit. In this paper the simulink model, to simulate the SEIG, is developed [3].

II. MODELING OF SELF EXCITED INDUCTION GENERATOR

For the modeling of the self-excited induction generators, the main flux path saturation is accounted for while the saturation in the leakage flux path, the iron and rotational losses are neglected [3]. Therefore in the following analysis the parameters of the induction generator are assumed constant except the magnetizing inductance which varies with saturation [3]. In the proposed simulink d-q model current of rotor and stator are taken as state variable Fig(1.2) shows the dq axes equivalent circuit of a Self Excited Induction Generator(SEIG) figure (1.2) is a classical matrix using dq axes modeling is used to represent the dynamics of conventional induction machine operating as a generator. The representation includes the self and mutual inductances as coefficients widely used in machine theory. Using such a matrix representation, one can obtain the instantaneous voltages and currents during the self-excitation process, as well as during load vi) Current i)

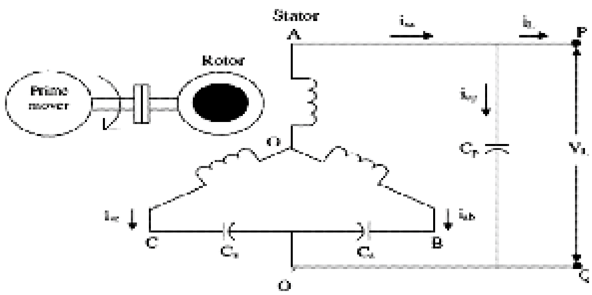

Fig. 1 Block Diagram of SEIG

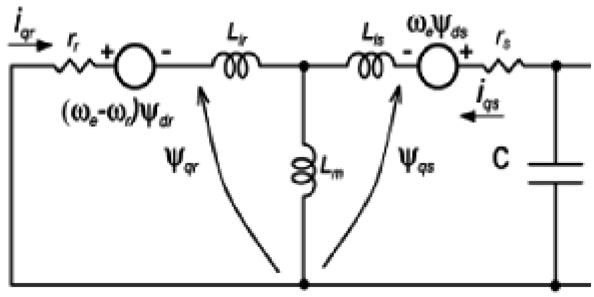

Fig. 1.2 d-q axes equivalent circuit of SEIG

Current equations: the expressions for other current components are obtained and the SEIG can be represented in a matrix form as:

$$pI = AI + B \tag{1.0}$$

$$A=1/L \begin{bmatrix} -L_r r_s & -L^2 m & Lmrr & -L_m w_r L_r \\ L^2_m & -L_s r_s & L_m w_r L_r\, r & L_m r \\ L_m r_s & L_s w_r L_m & -L_s r_r & L_s w_r L_r \\ -L_s w_r L_m & L_m r_s & -L_s w_r L_r & -L_s r_r \end{bmatrix} \tag{1.2}$$

$$B=1/L \begin{bmatrix} LmKq & -LrVcq \\ LmKd & -LrVcd \\ LmVcq & -LsKq \\ LmVcd & -LsKd \end{bmatrix} \tag{1.3}$$

pIqs =a1Iqs + a2Ids + a3Iqr + a4Idra + 5Kq + a6Vcq (1.4)

pIds = b1Iqs + b2Ids + b3Iqr + b4Idr + b5Kd + b6Vcd (1.5)

pIqr = c1Iqs +c2Ids +c3Iqr +c4Idr +c5Kq + c6Vcq (1.6)

pIdr = d1Iqs +d2Ids +d3Iqr +d4Idr +d5Kd + d6Vcd (1.7)

Where a1, a2, a3, a4…. are variables and there values are given in appendix 1. Here, Kq and Vcq0 are initial voltage across q-axis rotor winding and stator winding respectively and Kd and Vcd0 are initial voltage across d-axis rotor winding and stator winding respectively.

.

ii) - Voltage across the terminal of the SEIG are given by

Vcq= (1/C)*[]Iqs dt +Vcq0 (1.8)

Vcd= (1/C)*[]Ids dt +Vcd0 (1.9)

iii)The equation of motion at the SEIG mechanical shaft or the mechanical torque supplied by the prime mover at the generator shaft is:

Tsh =Te + J(2 / P) pωr (1.10)

Therefore the derivative of the shaft speed is given as:

Pωr = (P/2J)*(Tsh-Te) (1.11)

the electromagnetic torque Te. is given by the following relation.

Te = (3/2)*(P/2)*Lm*(Ids*Iqr –Iqs*Idr) (1.12)

The relationship between the mechanical torque
of the prime mover and the shaft speed is, represented by the following formula

$\omega = \omega 0 - K\omega Tsh$ (1.13)

Where: ω is the ideal no load angular speed of the prime mover (DC separately excited motor) and K is constant and Tsh is shaft torque.
Since the operation of the SEIG takes place in the nonlinear region of the magnetization characteristics, therefore the magnetization current should be calculated in each step of integration in terms of both stator and rotor currents using the following formula.

$$Im = \sqrt{(I_{qr} + I_{qs})^2 + (I_{dr} + I_{ds})^2} \quad (1.14)$$

where Imq= Iqr + Iqs (1.15)
Imd= Idr + Ids (1.16)

The relationship between magnetizing inductance (Lm)and magnetizing current (Im) for induction machine was obtained experimentally taken from reference[14]. The non linear relationship between
magnetizing inductance and magnetizing current is given as

Lm = a + bIm + cI2m + dI3m (1.17)
Where a,b,c,d are the constants.

Three phase generator currents are obtained from d-q axes components using the relation

$$\begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} ids \\ iqs \end{bmatrix} \quad (1.18)$$

for the delta connection of the SEIG shown in fig 1, line currents of the SEIG (iga , igb, igc)
can be expressed in terms of phase currents as

iga = ic - ia (1.19)
igb= ia - ib (1.20)
igc= ib - ic (1.21)

further
Va + Vb+ Vc = 0 (1.22)
applying Kirchhoff's current law(KCL) to the circuit comprising excitation capacitor and consumer load , node current equations are obtained as
Capva - Ccpvc = ipca - ipcc = ica = iga-(iaL+ iDa) (1.23)

Cbpvb – Capva = ipcb - ipca = ica = igb-(ibL+ iDb) (1.24)

Ccpvc – Cbpvb = ipcc - ipcb = icc = igc-(icL+ iDc) (1.25)

The currents iaL , ibL and icL are line currents of the load and iDa , iDb and iDc are the ac currents of the ELC which are defined in the modeling of the ELC.
Substitution of results in two equations in derivative of ac voltages (pva and pvb) as

(Ca + Cc)pva + Cc pvb = ica (1.26)
-Ca pva + Cc pvb = icb (1.27)
solving , the voltage derivatives are

$$pv_a = \frac{\{C_b i_{ca} - C_c i_{cb}\}}{K_{eq}} \quad (1.28)$$

$$pv_b = \frac{\{C_b i_{ca} + (C_a + C_c) i_{cb}\}}{K_{eq}} \quad (1.29)$$

where
Keq=CaCb+CbCc+CcCa (1.30)

for balanced excitation with equal excitation capacitors Ca=Cb=Cc=Cx for example, Keq=3Cx2
the d and q axes voltages in the stationary reference frame as follows

$$V_{ds} = \frac{2}{3}\{(v_a - \left(\frac{v_b}{2}\right) - \left(\frac{v_c}{2}\right)\} \quad (1.31)$$

$$V_{qs} = \frac{2}{3}\{\left(\frac{\sqrt{3}v_b}{2}\right) - \left(\frac{\sqrt{3}v_c}{2}\right)\} \quad (1.32)$$

these voltages Vds and Vqs are the forcing functions of the SEIG

Modeling of single phase consumer load

$$Ilqs = Vqs/R \qquad (1.33)$$

$$Ilds = Vds/R \qquad (1.34)$$

Ilqs is the stator quadrature axis load current and Ilds is the stator direct axis load current which is abtaine after the load connected to the system which is shown in Fig 1.3 [11-15]

With the help of equations (1.1)to(1.17) the model develop is shown blow.

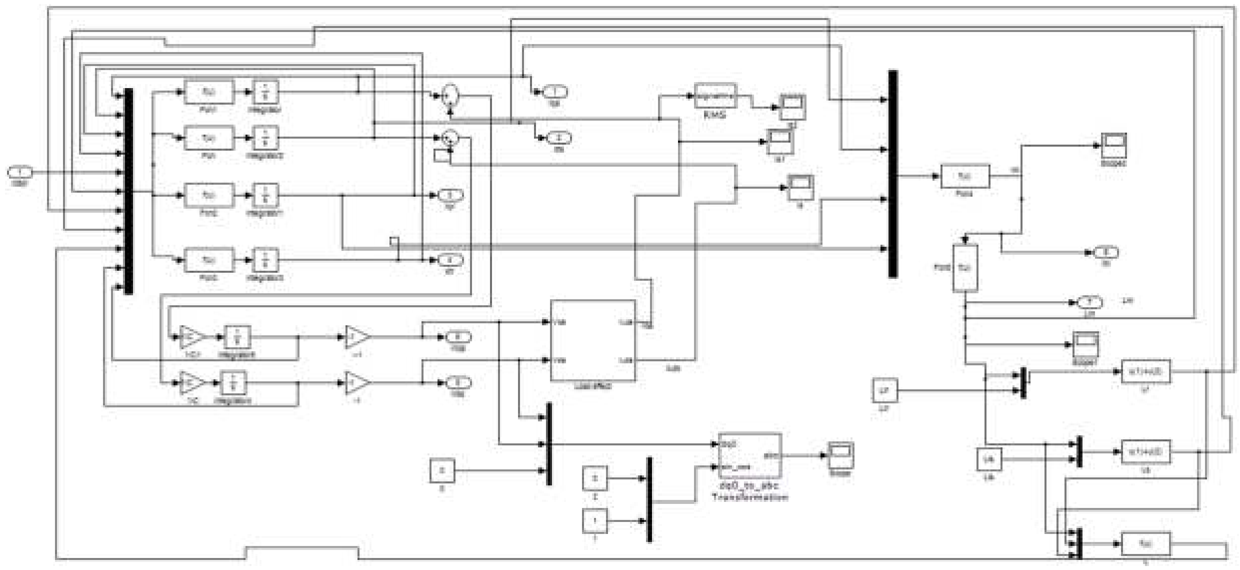

Fig. 2 Simulation Model Of Self Excited Induction Generator Defining Vds and Vqs

With the helf of equations (1.33)to(1.34) the model develop is shown blow.

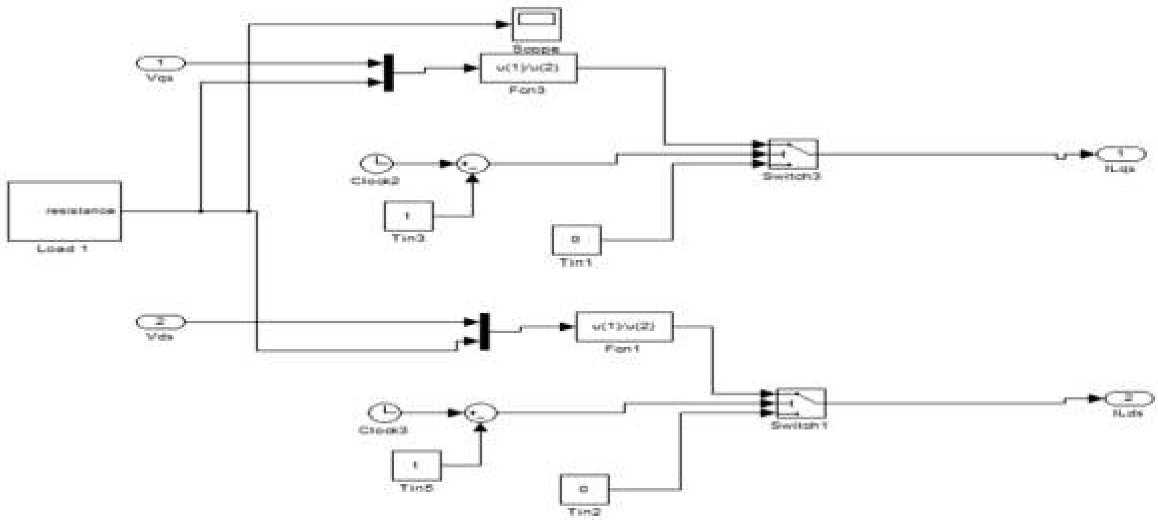

Fig. 3 Subsystem block diagram of quadrature axis load current(ILqs)

With the helf of equations (1.17)to(1.32) the model develop is shown blow

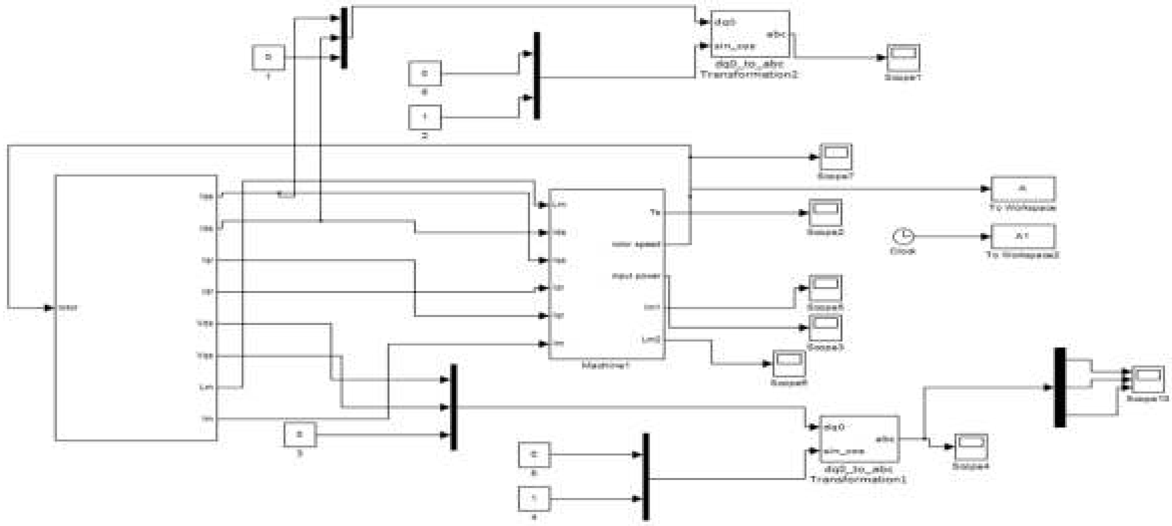

Fig. 4 Complete Simulation Model Of Self Excited Induction Generator shows, power(p), rotor speed (wr), torque(

III Simulink results of SEIG

When machine is loaded (R=90Ω) and excited with the capacitance value of C=300 μF current is gradually increase from 2.2(sec) to 5(sec) and reaches its steady state value. The current increase reaches to its constant value 12(amp) is which is shown in fig. 4.3

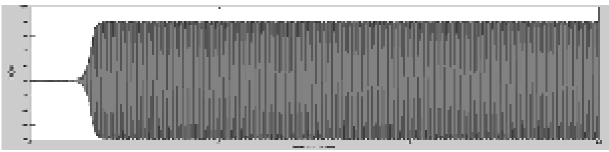

Fig.5.1 Simulation response of stator output current(is in amp)vs time(t in sec) without load

When machine is loaded (R=90Ω) and excited with the capacitance value of C=300 μF current is gradually increase from 2.2(sec) to 5(sec) and reaches its steady state value. When the self excited induction generator loaded at 5sec steady state current 12 Amp which is reduce to 9 amp

And then current again increase reaches to its constant value which is shown in fig. 4.4

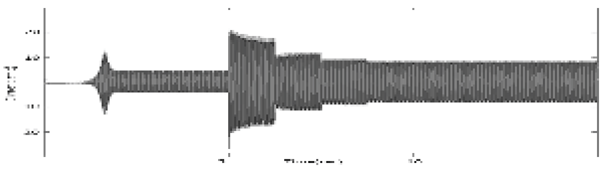

Fig.5.2 Simulation response of stator output current (is in amp) vs time(t in sec) with load

When generator is excited with capacitance value C=280μF and rotor speed increased from zero to 185 rmp in 0.8 sec, still not connected load after conneted load at t=4sec self excited induction generator speed decrease to 175rpm and after some time it also constant.

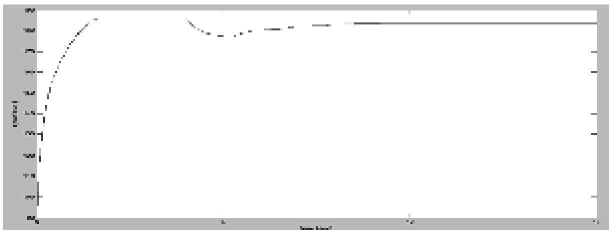

Fig.5.3 Simulation responce of rotor speed (in rpm) and time(in sec)with load

When generator is excited with capacitance value C=280μF initially torque is zero and it build up 1(nm) and then constant. After applying a load at t=4(sec) torque increase to 6 (nm) and then again constant.

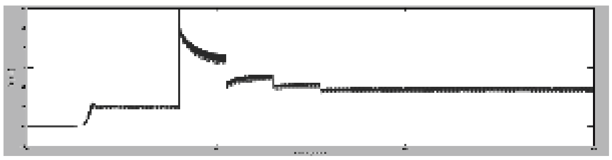

Fig.5.4 Simulation responce of Torque(nm) and time(in sec) with load

When machine is loaded (R=90) and excited with the capacitance value of C=280 F . The Fig1 shows the output voltage of induction generator without load in this diagram voltage initially zero and than increase constant at t=(1.4sec) and Fig. 2 shows the output voltage with load applied at t=4(sec) voltage slightly decreases and then agin constant.

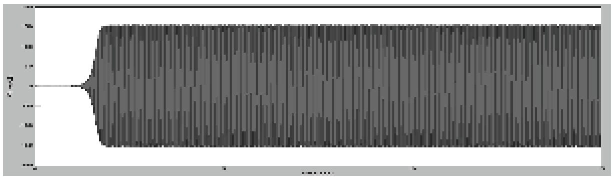

Fig. 5.5 Simulation response of output voltage (volt) and time(sec)without load

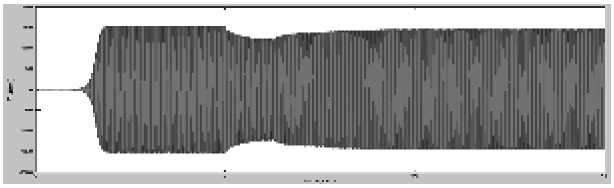

Fig. 5.6 Simulation response of rotor speed (in rpm) and time (in sec)with load

In the analysis of self excited induction generator, power is also a useful factor when machine is loaded (R=90) and excited with the capacitance value of C=280µF. Power at the time of starting decreases which is shown in fig 4.7 after 2 (sec) power is constant . when we applied load at t=4 (sec) power increase and then constant.

Fig.5.7 Simulation response of power (in watt) and time(in sec)with load

In the given fig 4.10 shows the magnetizing inductance of self excited induction generator with load . when we applied load at t=2(sec) magnetizing induction incease and then decrease after 8(sec) it is constant.

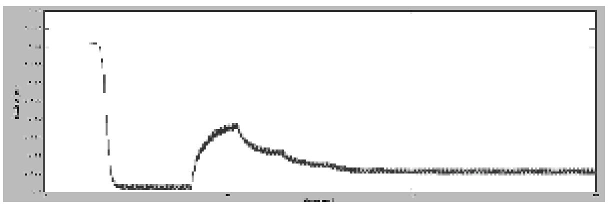

Fig.5.8 Simulation response of magnetizing inductance (in Henry) and time(in sec)with load

IV CONCLUSION

At first simulation of SEIG has been done using MATLAB/SIMULINK block sets. In that output current, output voltage has been determined and we have seen that some voltage dip occurs at the starting and then it can be recovered soon by the generator. Output power, torque and speed has also been determined and shown by the waveforms after that we have developed mathematical model of the SEIG supplying a resistive load has been found suitable for the transient analysis and to assess the rating of the motor, which can be safely started on the SEIG system. The simulation has been carried out in MATLAB/SIMULINK environment. With the application of load at certain instant how the voltage is soon recovered has been shown. The dynamic behavior of the SEIG supplying a resistive load reveals that this system can be used satisfactorily in constant power applications such as micro-hydro with uncontrolled turbines. Based on this study, the developed SEIG supplying a resistive load can be installed in the field to feed static loads

APPENDIX

Parameters of SEIG (7.5 kW)—A 230-V 26.2-A 50-Hz four pole three-phase squirrel-cage induction machine is used as the SEIG. The parameters of the SEIG are as follows:

Magnetizing inductance.

Lm = a + bIm + cI2m + dI3m

Rs = 1 Ω

Rr = .77Ω

Xls = 1Ω

Xlr = 1Ω

J = .1384kg/m2

a = .1407

b = .0014

c = -.0012

d = .0005

REFRENCES

[1] N. P. A. Smith, “Induction generators for stand-alone micro-hydro systems,” in Proc. IEEE Int. Conf. Power Electronics Drives and Energy Systems, New Delhi, India, Jan. 1996, pp. 669–673.

[2] L. Wang and C. H. Lee, “Dynamic analysis of parallel operated self excited induction generators feeding an induction motor load,” IEEE Trans. Energy Convers., vol. 14, no. 3, pp. 479–485, Sep. 1999.

[3] R. Bonert and G. Hoops, “Stand-alone induction generator with terminal impedance controller and no turbine controls,” IEEE Trans. Energy Convers., vol. 5, no. 2, pp. 28–3, Mar. 1990. Convers., vol. 15, no. 1, pp. 1–7, Mar. 2000

[4] R. C. Bansal, “Three-Phase Self-Excited Induction Generators: An Overview,” in Proc. IEEE transactions on energy conversion, vol. 20, no. 2, june 2005

[5] L. Quazene and G. McPherson Jr., “Analysis of an isolated induction generator,” IEEE Trans. Power App. Syst., vol. 102, no. PAS-8, pp. 2793–2798, Aug. 1983.

[6] B. Singh, “Induction generator-A prospective,” Elect. Mach. Power Systems, vol. 23, pp. 163–177, 1995.

[7] Bhim Singh, S. S. Murthy, and Sushma Gupta, "Transient analysis of self-excited induction generator with electronic load controller (ELC) supplying static and dynamic loads", IEEE Trans. on Industry Applications, vol. 41, no. 5, September 2005.

[8] S. Mbabazi and J. Leary, “Analysis and Design of Electronic Load Controllers for Micro-hydro Systems in the Developing World University of Sheffield, E-Futures March 2010.

[9] Bhim Singh, S. S. Murthy, and Sushma Gupta “Analysis and Design of Electronic Load Controllerfor Self-Excited Induction Generators,” IEEE transactions on energy conversion, vol. 21, no. 1, march 2006.

[10] L. Shridhar, B. Singh, C. S. Jha, and B. P. Singh, “Analysis of self-excited induction generator feeding induction motor,” IEEE Trans. Energy Convers., vol. 9, no. 2, pp. 390–396, Jun. 1994.

[11] S. S. Murthy, O. P. Malik, and A. K. Tandon, “Analysis of self-excited induction generator,” Proc. Inst. Elect. Eng., pt. C., vol. 129, no. 6, pp. 260–265, Nov. 1982.

[12] C. Grantham, D. Sutanto, and B. Mismail, “Steady-state and transient analysis of self-excited induction generators,” Proc. Inst. Eect. Eng., pt. B, vol. 136, no. 2, pp. 61–68, Mar. 1989.

[13] K. E. Hallenius, P. Vas, and J. E. Brown, “The analysis of a saturated self-excited asynchronous generator,” IEEE Trans. Energy Convers., vol. 6, no. 2, pp. 336–345, Jun. 1991.

[14] S. S. Murthy, R. Jose, and B. Singh, “Experience in the development of microhydel grid independent power generation scheme using induction generators for Indian conditions,” in Proc. IEEE Int. Conf. Global Connectivity in Energy, Computer, Communication and Control, vol. 2, 1998, pp. 461–465.

[15] Tadashi Fukami,Yuichi Kaburaki, Satoru Kawahara, and Toshio Miyamoto “Performance Analysis of a Self-Regulated Self-Excited Single-phase Induction Generator Using a Three-phase Machine”, IEEE Transactions on Energy Conversion, Vol. 14, No. 3, September 1999.