Applications of a Dummy Load for Output Voltage Regulation of a Self-Excited Induction Generator for Hydroelectric Power Generation

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ABSTRACT

This research paper presents a technique to regulate the output voltage of self-excited induction generators. The self-excited induction generators output terminals are normally equipped with parallel connected excitation capacitors. A mismatch occurs when the load on the SEIG changes and thereby creating voltage deregulation. This research paper presents the connection of a three-phase dummy load for voltage regulation purposes. The dummy loads are equipped with IGBT based switching for becoming on-load or off-load. Simulation of SEIG with the dummy load is presented.

Keywords- Self-excited induction generators, Hydroelectric Power Generation, variable load.

I. INTRODUCTION

Although the self-excited induction generators (SEIG) were invented many decades ago. However, in recent times the use of SEIG systems for producing electric energy from non-traditional sources, has gained considerable strength [1]-[3]. Nevertheless, SEIG systems have unstable frequency, output power, and output voltage problems. On the centenary, synchronous generators are mostly successful in producing electricity in large bulk due to the volume and cost.

The scope of this paper is to show a method to regulate SEIG output voltage. The technique presented is based on the fact that SEIG output voltage remains stable as long as the load remains same. A change in the load will shift the operating properties of the SEIG and the voltage will deregulate. If a dummy load is connected along with the actual load, then by adjusting the dummy load counter to the load changes, the voltage can be regulated [3].

In our work, a SEIG is coupled with a hydroelectric turbine. Hydroelectric power is the source of generation of electricity in this case. It is assumed that the hydroelectric turbine provides constant amount of power. The primary objective is to solve for SEIG output voltage regulation.

TABLE 4. Parameter Definitions

Parameter	Definition
R_s	Stator resistance
$L_s=L_m + L_{lr}$	Stator inductance
R_r	Rotor resistance
$L_r=L_m+L_{lr}$	Rotor inductance
C	Excitation Capacitance
ω_r	Rotor speed
L_m	Magnetizing inductance
i_{ds}	d-axis stator current
i_{qs}	q-axis stator current
i_{dr}	d-axis rotor current
i_{qr}	q-axis rotor current
R	Load resistance

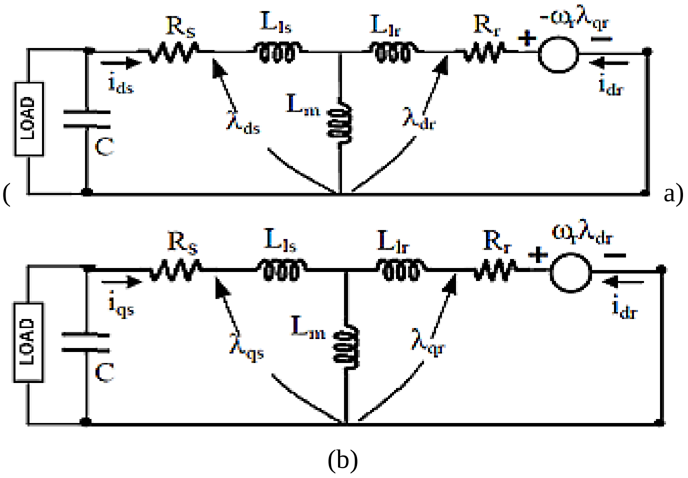


Fig. 1 The SEIG machine stationary reference frame models (a) d-axis model. (b) q-axis model.[1-4]

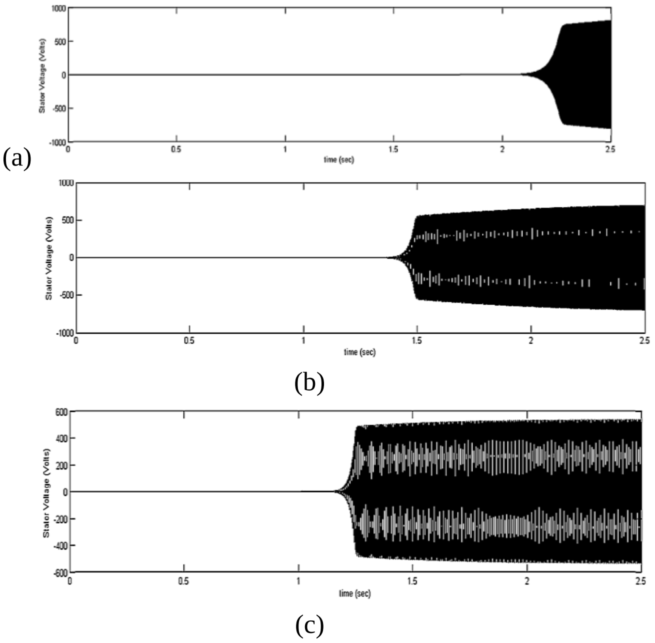


Fig.2 Shows the voltage generation process with respect to time for (a) C=10µF (b) C=30µF, and (c) C=50µF.

II. THE TRADITIONAL SEIG MODEL

The traditional d-q model of a SEIG machine in the stationary reference frame is shown in fig. 1 [4]-[6]. Such a model will be used during the simulation stage of the proposed system. Various parameters of the d-q model are defined in Table-I. The external capacitance C connected across the load is used to voltage generation and will be dealt in a preceding section.

The d-q model of the SEIG can be expressed mathematically by the following matrix [3],[4],[5],[6], i.e.,

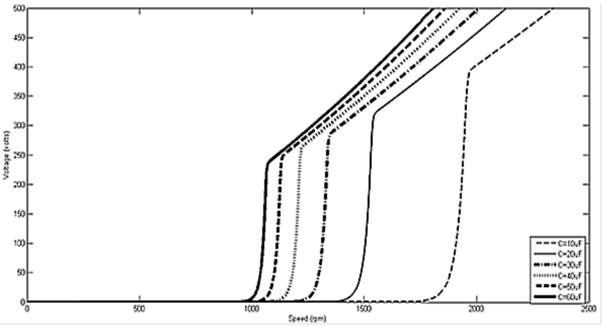


Fig. 3 SEIG output voltage as a function of rotor speed for changing values of excitation capacitance C.

$$\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_s + sL_s + \dfrac{1}{sC} & 0 & sL_m & 0 \\ 0 & R_s + sL_s + \dfrac{1}{sC} & 0 & sL_m \\ sL_m & -\omega_r L_m & R_r + sL_r & -\omega_r L_r \\ \omega_r L_m & sL_m & \omega_r L_r & R_s + sL_s \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix} \tag{1}$$

The expansion of (1) leads to an eighth order differential equation, shown as follows, i.e.,

$$\left[As^4 + Bs^3 + Cs^2 + Ds + E \right]^2 + \left[Gs^2 \right]^2 = 0 \tag{2}$$

Where,

$$A = L_r^2 L_s C - L_m^2 C L_r \tag{3}$$

$$B = L_r^2 R_s C + 2R_r L_r L_s C - L_m^2 C R_r \tag{4}$$

$$C = L_r^2 + 2R_s R_r L_r C + (R_r^2 + \omega^2 L_r^2) L_s C \\ - L_m^2 C \omega^2 L_r \tag{5}$$

$$D = 2RrLr + (R_r^2 \omega^2 L_r^2) R_s C \tag{6}$$

$$E = R_r^2 + \omega^2 L_r^2 \tag{7}$$

$$G = L_m^2 C \omega R_r \tag{8}$$

III. SEIG VOLTAGE GENERATION PROCESS

The rotors of most SEIG are permanent magnetics (residual flux) in addition to rotor windings. The residual flux aids in inducing an EMF(electro-motive force) on the stator windings. The induced EMF is feedback to the rotor windings, thus creating a positive feedback and the stator voltages tends to increase. The external capacitance C connected across the load plays vital role during the build-up process of the output voltage. However, when the lagging VARs required by the SEIG machines is equal to the VAR of the external capacitor C, the stator voltage will be saturated. At this point the system has reached to equilibrium. Such a voltage generation process is unique to SEIG machines and it is the reason why SEIG machines are used in remote small scale electrical generation units.

Since the early invention of the SEIG machines, it is a known fact that larger the value of the excitation capacitance C, the larger the generation of SEIG output voltage will be obtained at a lower rotor speed [3] and [7]. Similar results were obtained when the above mentioned system was simulated in MATLAB computer simulation software.

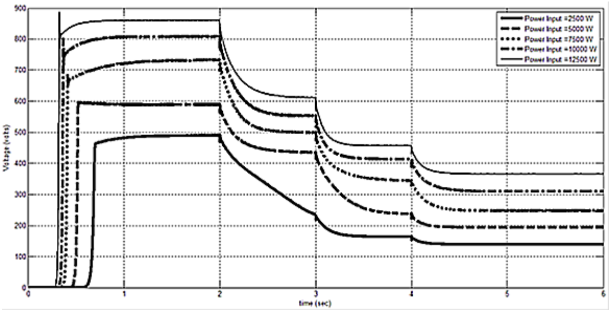


Fig. 4. SEIG output voltage for changing load and changing values of input power.

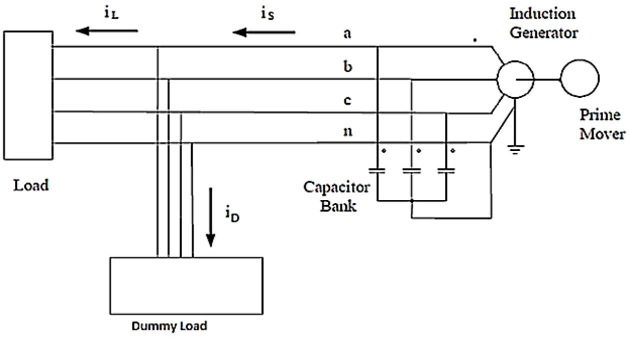


Fig. 5. Connection scheme of the dummy load to the SEIG system.

TABLE 2. Parameter Values

Parameter	Values
Number of poles	= 4
Rated voltage	= 230V
Rated frequency	= 50Hz
Stator resistance R_s	= 0.44Ω
Rotor resistance R_r	= 0.82
Stator Inductance L_S	= 73mH
Rotor inductance L_r	= 73mH
Magnetizing inductance L_m	= 80mH

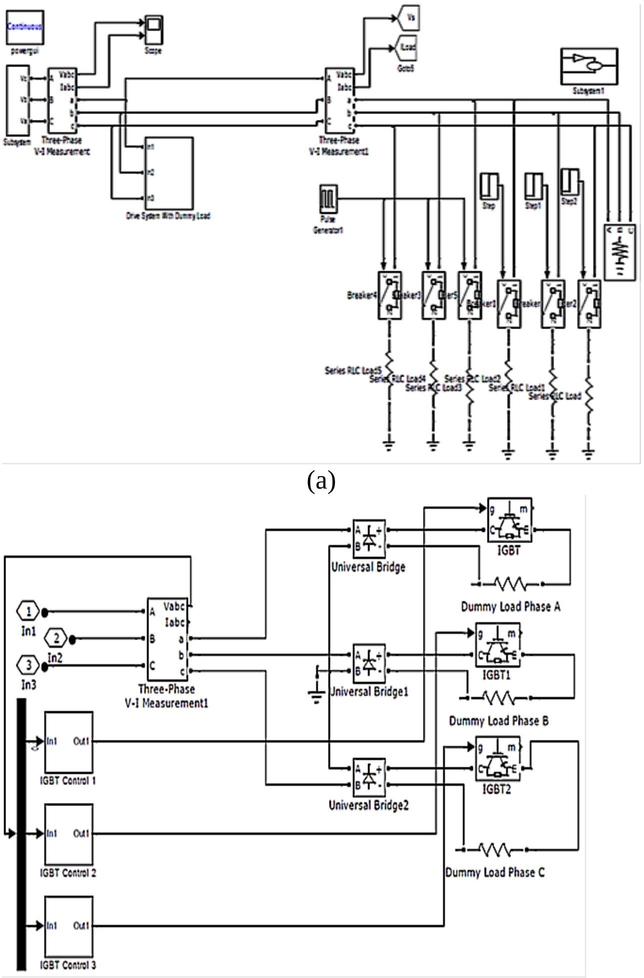
Capacitance values selected for the simulations were as, 10μF, 30μF, and 50μF. Table-II presents the values of parameters of the SEIG to be simulated.

In all simulation test, the initial speed of the SEIG was set to zero and the machine was run with a constant power. Fig. 1 displays the electrical voltage generation process for C= 10 μF is shown in Fig.2(a) , for C=30μF is shown in fig. 2(b) , and for C=50μF is shown in fig.2(c) .

In addition, fig. 3 shows the simulation results of the SEIG output voltage as a function of rotor speed. Here again the external excitation capacitance C was varied from 10μF to 60μF, in equal steps.

Furthermore, to observe how SEIG output voltage changes as the output load changes, three different loads were applied to the machine after equal intervals. As shown in fig. 4, for a varying output power, the loads were applied in such a way that initially the machine was energized (machine starts at time *t = 0s*) at no load condition. After 2 seconds from start a load of 300W per phase was applied, at time *t = 3s* a load of 500W was added per phase, and finally at time *t = 4s* a load of

500W was added. It was observed that the SEIG output voltage does not remain constant for varying load.



(a)

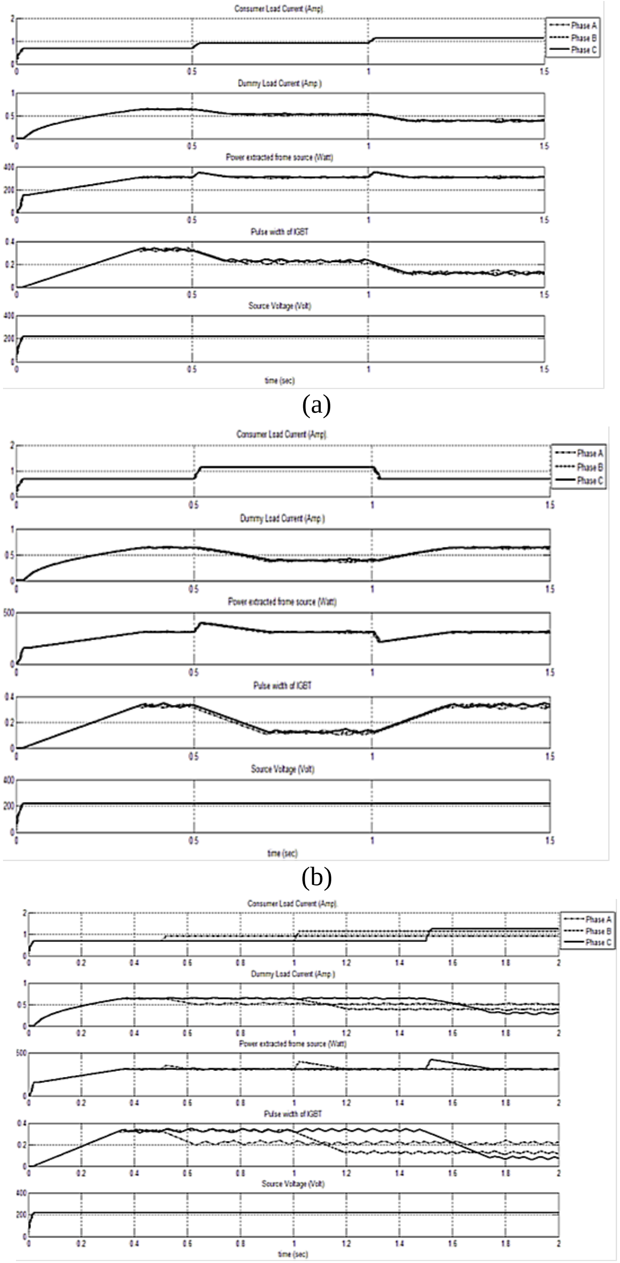
(b)

Fig. 6 (a) SEIG system configuration for constant output voltage (b) Dummy load controller using IGBTs.

A careful inspection of fig. 1, 2, 3 shows an interesting problem associated with SEIG when used as generators. It is observed that the SEIG output voltage changes with external capacitance C, rotor speed, and output load. The above mentioned results indicate that the SEIG cannot be used in the present form because for example if the consumer loads changes, then the output voltage may also change. Hence for SEIG output voltage regulation additional circuits will be required.

IV. DEPLOYMENT OF A DUMMY LOAD FOR VOLTAGE REGULATION

An inspection of fig. 4, shows that the SEIG output voltage remains almost same for a fixed load. Therefore, if a dummy load could be connect across the actual load. This dummy may be brought into the circuit or be removed from the circuit with help of power semiconductor IGBT switches. The dummy load will compensate the changes in the actual load in such a way that as the actual load decreases the dummy load may be increased and similarly as the actual increases the dummy load value may be decreased. By this way the load as seen by the SEIG machine would remain constant. Fig. 5 presents the circuit scheme to deploying the dummy load.



(a)

(b)

(c)

Fig. 7. Result of the SEIG system deploying IGBT based dummy load controller (a) for increasing consumer loads (b) for increasing and decreasing consumer load (c) for asymmetric consumer loads.

Fig. 6(a) SEIG simulation system implemented in MATLAB software with the dummy load, whereas fig.6(b) shows the details of the IGBT based dummy load controller. The constant voltage is achieved from the information of the output voltage.

V. RESULTS

The SEIG output voltage variation using the actual load along with the dummy load was studied in three different cases. In the first case, the actual load was increased by adding 50W per phase after equal time intervals of 0.5s. The results were studied in terms of load consumed, current consumed by the dummy load, power extracted from the load, pulse width of the IGBT (i.e., the amount of time the dummy load is put in the circuit), and the

SEIG output voltage. Fig. 7(a) shows the observation for increasing loads.

In the second case, the initial load presented on the SEIG system, equal loads on all phases, from time t=0s to 0.5s was 150W, from time t=0.5s to 1s an additional load of 100W was added, and from time t=1s to 1.5s the presented load was again 150W. Fig. 7(b) shows the observations for increasing and decreasing loads.

In the third case, the load presented on the SEIG system was 150W per phase. However, at time t=0.5s a load of 50W was added to phase A. At time t=1s a load of 100W was added to phase B and at time t=1.5s a load of 125W was added to load phase C. Fig. 7(c) shows the observations for varying loads on different phases. In all cases, the dummy load proves to aid to keep the SEIG output voltage regulated.

VI. DISCUSSION

Careful observation of Fig. 6 shows that the proposed dummy load scheme has effectively regulated SEIG output voltage. The IGBT dummy load controller is robust with simple operation. However, one drawback of the dummy load is the constant loss of power dissipated through it when it is in use. Extension of the work includes regulation of the SEIG output frequency and delivery of constant power. Future work may include inductive resistive e.g., an induction motor as the load. In such case the nature of dummy load may have to changed i.e., the RLC circuit.

This system has shown the successful working of a simple IGBT controlled resistive dummy load. However improvements could be made to increase the response time and settling times by the use of PID controller for tracking faster load changes. Furthermore use of IGBTs will add a number of higher order unwanted harmonics which could be eliminated by LC or LCCL filters.

VII. CONCLUSIONS

This research paper has presented the simulations of regulating the output voltage of a SEIG system using three-phase dummy loads. At first the results of SEIG system without a three-phase dummy load were presented followed by the application of three-phase dummy load. The results were encouraging. Despite the fact that three-phase dummy load introduced heat losses, however, the requirement of voltage regulation was achieved with less number of circuit component. The overall system was robust.

VIII. ACKNOWLEDGMENTS

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IX. REFERENCES

[1] R. C. Bansal, T. S. Bhatti, and D. P. Kothari, “A bibliographical survey on induction generators for application of nonconventional energy systems,” IEEE Trans. Energy Convers., **18(**3): 433-439, 2003.

[2] M. G. Simões and F. A. Farret, “Alternative Energy Systems: Design and Analysis with Induction Generators, Taylor & Francis, December 2007.

[3] Shariq Riaz , “Design and Implementation of Low Cost and Minimum Maintenance Micro Hydel Power Generation System” Master of Science Thesis, Electrical Engg. Dept., U.E.T., Lahore, 2012.

[4] K. S. Sandhu, “Steady State Modeling of Isolated Induction Generators,” WSEAS Transactions on Environment and Development, **4**(1): 66-77, 2008.

[5] D. Seyoum, C. Grantham, and F. Rahman. "Analysis of an isolated self-excited induction generator driven by a variable speed prime mover," Proc. AUPEC, **1**: 49-54, 2001.

[6] A. Kishore, R. C. Prasad, and B. M. Karan. "Matlab simulink based DQ modeling and dynamic characteristics of three phase self excited induction generator." In Proceedings of the Progress in Electromagnetics Research Symposium, Cambridge (USA), 312-316, 2006.

[7] E. Levy and Y. W. Liao, “An Experimental Investigation of Self-excitation in Capacitor Excited Induction Generators,” Electric Power System Research, 53(1): 59-65, 2000.

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