Voltage Controller of a Single Phase Self-Excited Induction Generator

R. Ahshan[*] and M.T. Iqbal

Faculty of Engineering and Applied Science, Memorial University of Newfoundland, St. John's, NL, Canada A1B 3X5.

Abstract: This paper presents the design of a low cost voltage controller of a single phase Self-Excited Induction Generator (SEIG). The control scheme is based on the measurement of users load voltage and controlling the dump load power using an Analogue Input Power Controller (AIPC). The controller output varies from 2 -10V and it controls the output AC power going to a resistive dump load. A PI type controller is designed to adjust the dump load as the users load varies to maintain a constant voltage across the load. The system voltage regulation is tested by sudden change in the users load. This paper presents the system description, controller design, and test results.

INTRODUCTION

Induction generators are widely used to extract energy from renewable energy resources because they have rugged construction; these generators are simple, reliable, cost effective, and require little maintenance [1-4]. It also has the self protection feature against overload [5], and does not require a DC exciter like synchronous generator [2]. However, poor voltage regulation is a great disadvantage of self-excited induction generators. Therefore, a control system is required to regulate the voltage to meet the constant voltage demand.

This issue has been addressed by several researchers. A DSP based voltage regulator is presented by Dheeraj and Singh [5], where the amount of power required dumping in the dump load is decided by the controller. Self regulation using series capacitor or short-shunt and long-shunt connections have been reported in literature [6-11]. Murthy *et al.* [7] also proposed a saturable core reactor, and a constant voltage transformer based voltage regulation scheme. The performance of a series capacitor based voltage regulation scheme is not satisfactory because of a limited percentage of voltage regulation. The saturable core reactor based scheme introduces harmonic in the terminal voltage at no load, which vanishes as the load is applied. The constant voltage transformer based voltage regulation scheme provides better result than series capacitor and saturable core reactor based schemes, however, a constant voltage transformer is costly. Optimized utilization of single phase SEIG, system performance, and its transient analysis have been reported by Murthy and Bhim Singh [12, 13]. Ojo *et al.* [14] have presented an inverter assisted single phase induction generator for voltage and frequency control. Bhim Singh [15] has presented the design and implementation of an analog based electronic

load controller to regulate voltage and frequency of SEIG for constant power applications. Bhim Singh and Gaurav [16] also proposed a voltage frequency controller using an IGBT based current controlled voltage source inverter and a high frequency DC chopper at its DC bus. A pulse width modulated voltage source inverter based voltage controller of an induction generator for stand-alone application is also presented by Jayaramaiah and Fernandes [17]. The control system proposed by Bhim Singh and Jayaramaiah [16, 17] requires high cost power electronics, which is a major issue for small scale power generation systems. A rectifier chopper feeding a fixed resistive dump load is discussed by Ammasaigounden [18], where dump power is controlled by varying the duty cycle of the chopper. As choppers receive power from a fixed voltage DC source using a rectifier, this arrangement can not be recommended for AC primary load. Ahmed *et al.* [19] proposed a static VAR compensator, which consists of thyristor switched shunt capacitor and saturable core reactor which has already been approached by Murthy [7]. The approach by Ahmed *et al.* [19] differs from the approach by Murthy [7] in terms of a switched capacitor and reactor instead of a fixed value of them.

Our proposed control scheme is based on an analogue input power controller which is the only power electronic module used in the system. A simple operational amplifier based proportional-integral controller is designed to control the input voltage of the analogue input power controller. The control system determines the power to be dumped in the dump load according to the user load variations, and maintains the constant voltage at the users load terminal. The proposed control scheme is very cost effective and simple which is important for a micro power generation unit. The control scheme can be used in micro-hydro and small fixed speed wind turbine in stand-alone applications.

SYSTEM DESCRIPTION

The proposed system shown in Fig. (**1**) consists of a prime mover and a two winding single phase induction generator with self-excitation capacitors. User load is connected

*Address correspondence to this author at the Faculty of Engineering and Applied Science, Memorial University of Newfoundland, St. John's, NL, Canada A1B 3X5, Canada; E-mail: rahshan@mun.ca
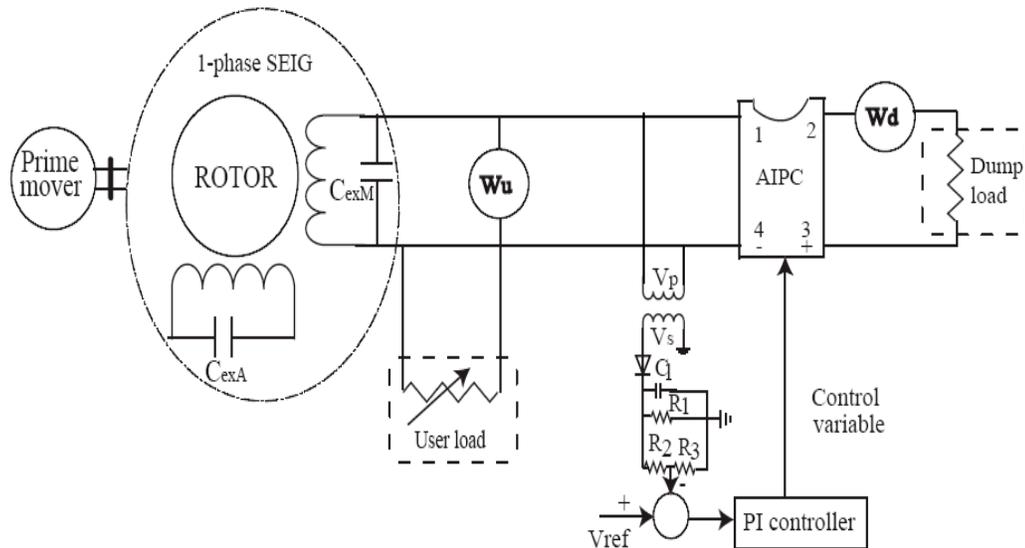
Fig. (1). Block diagram of the proposed system.
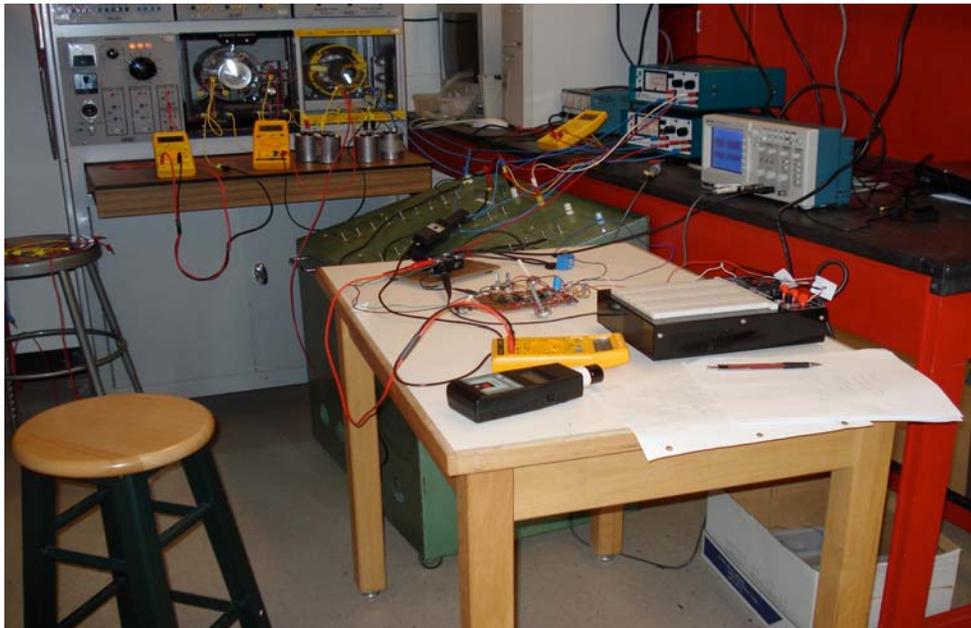
Fig. (2). A photo of the experimental setup.

directly to the main winding of the generator and dump load is connected through AIPC. Two watt meters are used to measure user load and dump load. A 120V, 2.8A, 175W, 1800 rpm shunt type DC motor is used as a prime mover, which is coupled with the rotor of the induction generator. The prime mover can be replaced by a renewable energy converter such as a micro-hydro or a small wind turbine. A 0.25HP, 120V, 60Hz, 1715 rpm single phase induction motor is used as a single phase induction generator using self-excitation capacitors. The excitation capacitors are connected both across the main and auxiliary winding. The excitation capacitors at the main winding C_{exM}, and auxiliary winding C_{exA}, are selected to provide the generator rated terminal voltage at no load condition. In this case, the selected capacitors are at the main winding, C_{exM} = 100uF, 370V AC, and at the auxiliary winding, C_{exA} = 100uF, 370V AC.

The user and the dump loads are considered as the multiple switched resistive loads. The watt meters W_u and W_d are used to observe the power flow through the user load and the dump load, respectively. The control scheme of the system consists of a voltage sensor, a peak detector circuit, operational amplifier based proportional-integral controller, and an analogue input power controller. A photo of the experimental setup is shown in Fig. (**2**).

CONTROL SYSTEM DESIGN AND IMPLEMENTATION

The AIPC is a four terminal device (10PCV25) which has a self-contained power control module integrating with a phase fired logic control system and a solid state relay. The AIPC takes 2-10V DC input, and provides variable output, which is rated at 120/240V AC, 25A. The operating charac-
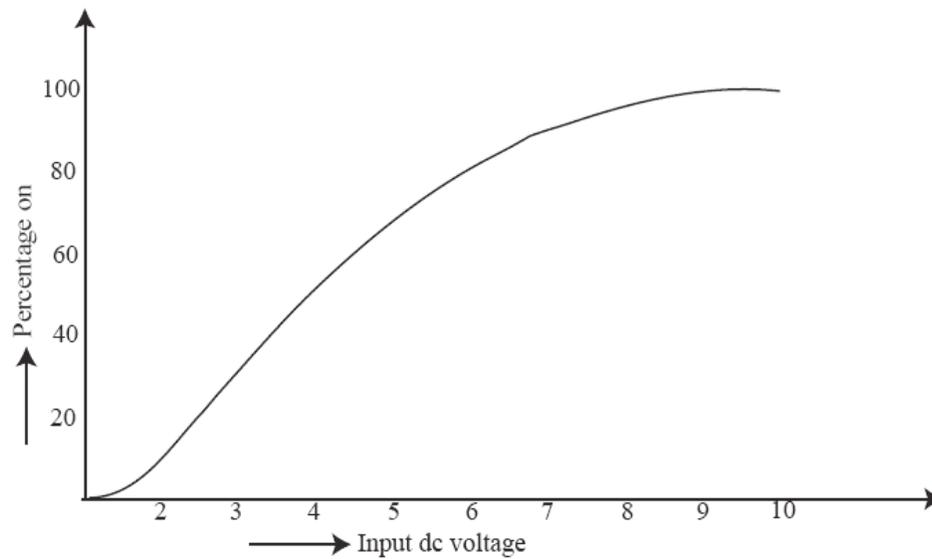
Fig. (3). Operating characteristic of the AIPC.
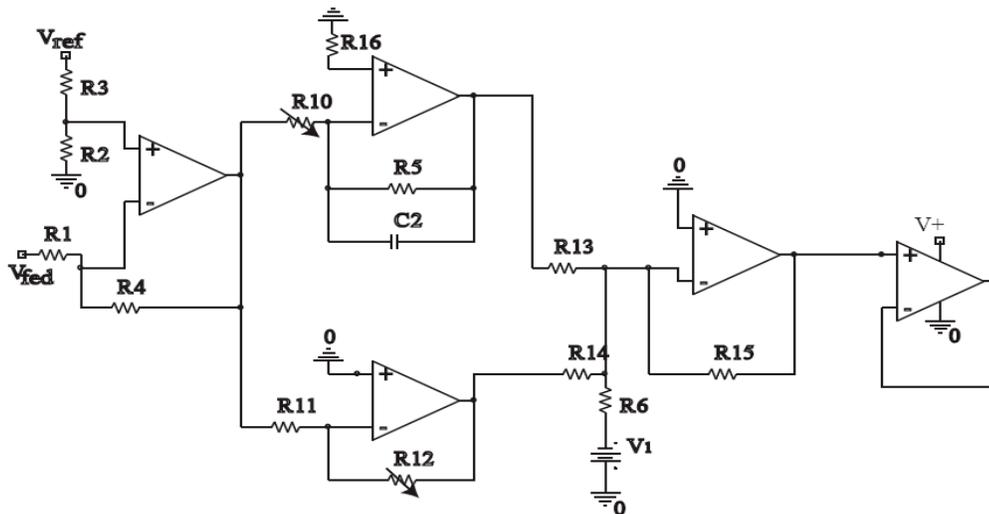
Fig. (4). Operational amplifier based PI controller.

teristic of the AIPC is shown in Fig. (**3**). It shows that the percentage on-time of the AIPC depends on the input DC voltage; that means the output of the AIPC is controllable and the control variable is input voltage which varies from 2-10V. Therefore, the objective of the PI regulator is to control the AIPC output according to the terminal voltage by controlling the analogue input voltage of the AIPC. In other words, the dump power is controlled by controlling the output of the AIPC. The control system is designed to vary the percentage on-time in case of user load increase or decrease to maintain the voltage constant at the user load terminal. The system non-linearity and the non-linear operating characteristic of the AIPC limit the controller performance within a certain range.

A voltage transformer is used to obtain the user load terminal voltage under various load conditions. The voltage output of the secondary terminal is passed through a voltage averaging circuit to obtain a DC value, which is used as the feedback signal for the PI regulator. The feedback voltage is compared with a reference signal, which generates an error signal. A simple operational amplifier based PI controller is shown in Fig. (**4**). The best controller parameter value for the proposed scheme was found to be $K_p = 1.475$ and $K_i = 0.0718$. A single supply voltage follower is used at the controller output to obtain only positive control voltage for the AIPC.

TEST RESULTS

The voltage controller test results of a single phase SEIG are shown in the Figs. (**5-10**) in terms of the voltage and current response both at the user and the dump load terminal. Figs. (**5-7**) show the dump load terminal voltage and current at different user loads. The user load variation is shown in Fig. (**8**). The voltage and current at the user load terminal under user load variations are shown in Figs. (**9** and **10**). The
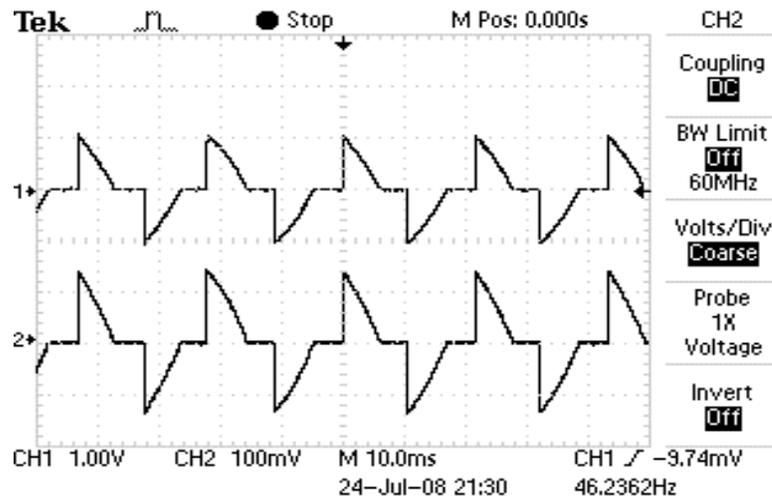
Fig. (5). Voltage and current at the dump load terminal when user load at 70 ohm.
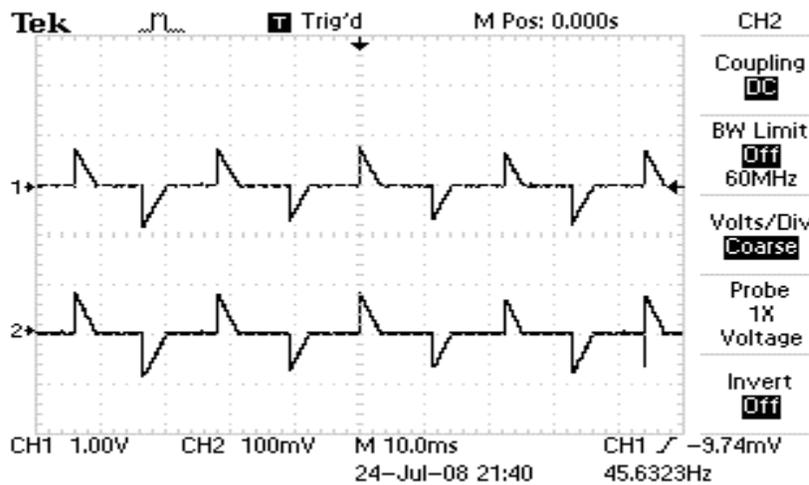
Fig. (6). Voltage and current at the dump load terminal when user load at 46 ohm.
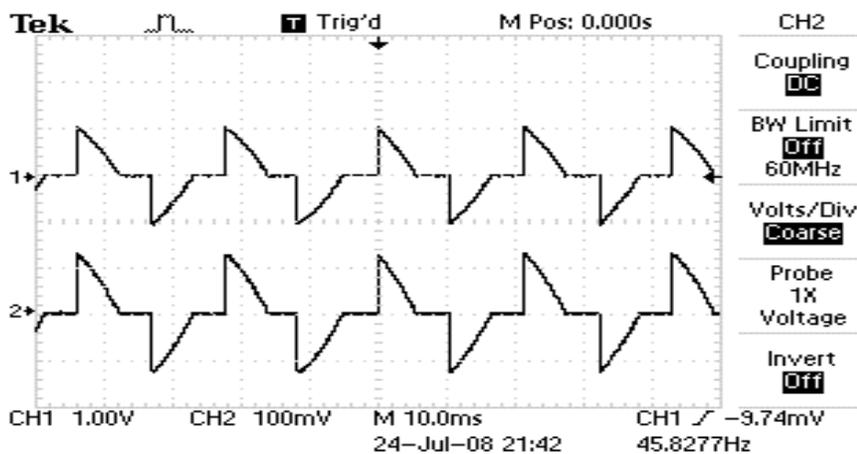
Fig. (7). Voltage and current at the dump load terminal when user load back at 70 ohm.

upper and lower traces of Figs. (**5-10**) represent the voltage and the current, respectively. The voltages are measured using a 100X probe, and the currents are measured using a current probe, which was set at 100mV/A.
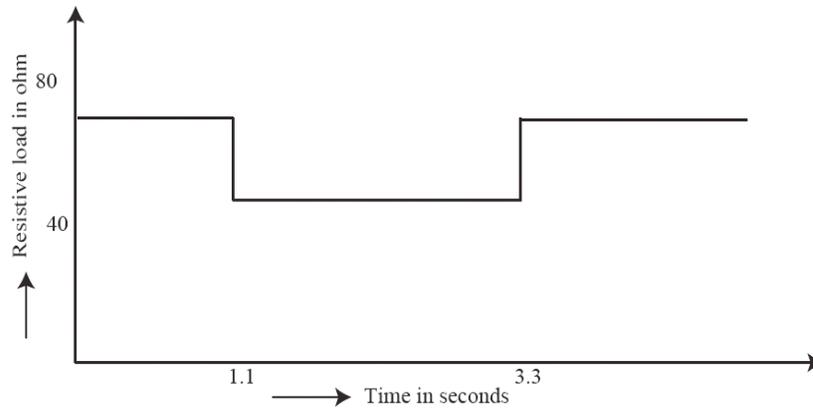
Fig. (8). User load variations.
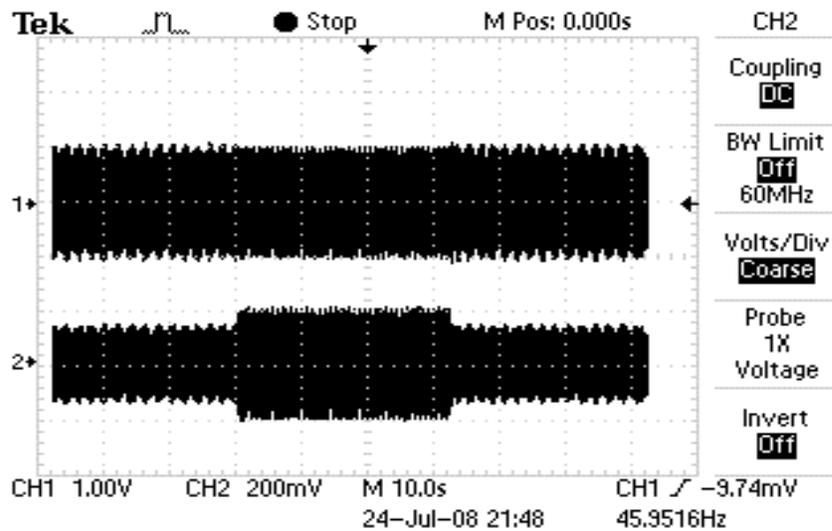
Fig. (9). Voltage and current at the user load terminal under a load disturbance.
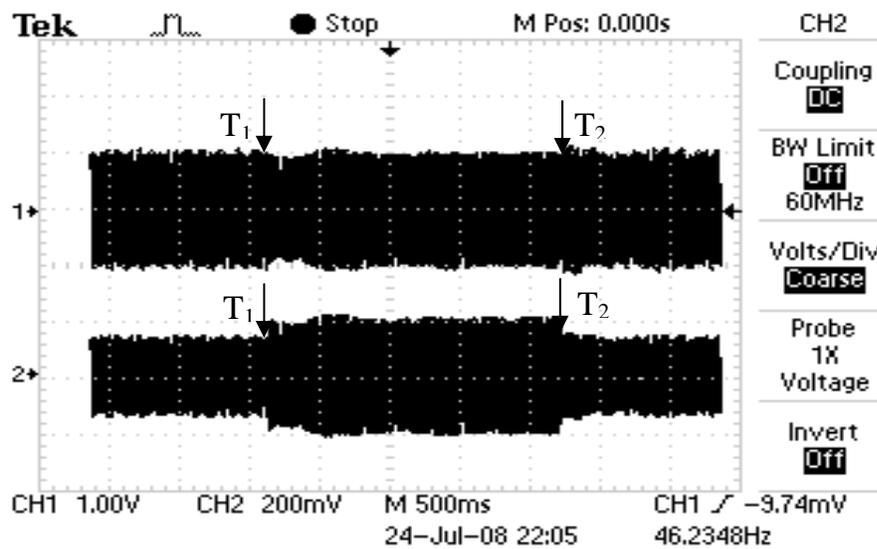
Fig. (10). Voltage and current at the user load terminal under load disturbance at T_1 and T_2.

Fig. (**5**) shows the voltage and the current at the dump load terminal when the user load is at 70 ohm. When the user load is increased by changing resistance from 70 ohm to 46 ohm as shown in Fig. (**8**), the voltage and the current at the

dump load terminal are reduced, which is shown in Fig. (**6**). The current going to the dump load is reduced by the controller to allow more current flow to the user load as the output power of the generator is required to be constant for a constant mechanical input. When the user load is again reduced by increasing the resistance to 70 ohm, the voltage and the current at the dump load terminal reach their previous value which means the dump power is increased as user load demand is reduced.

Figs. (**9**) and (**10**) show the user load terminal voltage and current response while the change in the user load was 34 percent. Fig. (**9**) shows the result for longer time period, whereas Fig. (**10**) shows the result for only 4.5 seconds, and shows the transient in voltage and current during the user load change. Until time T_1 the user load is 70 ohm. At T_1 the load is increased, which causes the increase in user load current. The voltage at T_1 decreases briefly, due to increase in the user load; however, the voltage becomes its previous value within 0.3 seconds, due to a proper control action. The voltage and the current remain unchanged until the next change in the user load. Fig. (**10**) also shows the voltage and the current transient, due to the next change in the user load at T_2. At T_2, the user load is again reduced to value as it was before time T_1. As a consequence, the voltage at T_2 first increases briefly but it comes back to its previous value within 0.25 seconds.

CONCLUSIONS

A simple cost effective power electronics based load controller is developed and tested for a single phase self-excited induction generator. The designed controller performs as a voltage regulator for the SEIG. A 34 percent change in the user load results an 11.8 percent voltage change in the test system while there was no control action. However, with the proposed control scheme, test results show that the load voltage change is negligible, due to the same percentage change in the user load. The designed controller achieves the required voltage with a transient time of less than 0.5 seconds. The proposed voltage controller can be used in micro-hydro and other renewable energy installations.

NOMENCLATURE

AIPC	=	Analogue input power controller
AC	=	Alternating current
C_{exM}	=	Main winding excitation capacitor
C_{exA}	=	Auxiliary winding excitation capacitor
DSP	=	Digital signal processing
DC	=	Direct current
HP	=	Horse power
IGBT	=	Insulated gate bi-polar transistor
SEIG	=	Self-excited induction generator
T_1	=	Time at which user load is increased
T_2	=	Time at which user load is decreased
V_p	=	Primary voltage of the voltage sensor
V_{ref}	=	Reference voltage for the controller
V_s	=	Secondary voltage of the voltage sensor
W_u	=	User load power observation meter
W_d	=	Dump load power observation meter

REFERENCES

[1] Singh, S.P.; Jain M.P.; Bhim Singh, A. New technique for analysis of self-excited induction generator. *Electric Mach. Power Syst.*, **1995**, *23*, 647-656.

[2] Ermis, M.; Ertan H.B.; Demirekler, M.; Saribatir, B.M.; Uctug Y.; Sezer, M.E.; Cadirci, I. Various induction generator schemes for wind-electricity generation. *Electric. Power Syst. Res.*, **1992**, *23*, 71-83.

[3] Shridhar, L.; Singh, B.P.; Jha, C.S. A step towards improvements in the characteristics of self-excited induction generator. *IEEE Trans. Energy Convers.,* **1993**, *8* (1), 40-46.

[4] Orabi, M.; Youssef, M.Z.; Jain, P.K. *Investigation of Self-excited Induction Generators for Wind Turbine Applications*. Proceedings of the Canadian Conference on Electrical and Computer Engineering, Niagara Falls, Canada, May **2004**, vol. *4*, pp. 1853-1856.

[5] Dheeraj, K.P.; Singh, S.P. DSP based induction generator controller for single phase self- excited induction generator. *Int. J. Emerg. Electric. Power Syst.*, **2008**, *9* (1), 1-9.

[6] Murthy, S.S. A novel self-excited self-regulated single phase induction generator Part 1: basic system and theory. *IEEE Trans. Energy Convers.*, **1993**, *8* (3), 377-382.

[7] Murthy, S.S.; Rai, H.C.; Tandon, A.K. A novel self-excited self-regulated single-phase induction generator Part I1: Experimental investigation. *IEEE Trans. Energy Convers.*, **1993**, *8* (3), 383-388.

[8] Rahim, Y.H.A.; Alolah, A.; Al-Mudaiheem, R.I. Performance of single phase induction generator. *IEEE Trans. Energy Convers.*, **1993**, *8* (3), 389-395.

[9] Ojo, O. The transient and qualitative performance of a self excited single phase induction generator. *IEEE Trans. Energy Convers.*, **1995**, *10* (3), 493-501.

[10] Ojo O. Performance of self excited, single phase induction generators with shunt, short-shunt and long shunt excitation connections. *IEEE Trans. Energy Convers.*, **1996**, *11* (3), 477-482,

[11] Murthy, S.S.; Rai, H.C.; Bhim, S.; Singh, B.P.; Goyal, N.K.; Vaishya, M.O. *New Experimental Finding on a Novel Two Winding Single Phase Self Excited Induction Generator for Standby Power Generation*. Proceedings of the International Conference on Power Electronics, Drives and Energy Systems for Industrial Growth, New Delhi, India, January, **1996**, vol. *2*, pp. 674-678.

[12] Bhim Singh. Optimum utilization of single phase induction machine as a capacitor self excited induction generator. *Electric. Mach. Power Syst.*, **1987**, *13* (2), 73-85.

[13] Salama, M.H.; Holmes, P.G. Transient and steady state load performance of a stand alone self excited induction generator. *IEE Proc. Electric Power Appl.,* **1996**, *143*, 50-58.

[14] Ojo, O.; Omozusi, O.; Jimoh, A.A. The operation of an inverter assisted single phase induction generator. *IEEE Trans. Indian. Electron.*, **2000**, *47* (3), 632-640.

[15] Bhim Singh; Murthy S.S.; Shushma G. *An electronic Voltage And Frequency Controller For Single Phase Self-Excited Induction Generators For Pico-Hydro Applications*. Proceedings of the International Conference on Power Electronics, Drives and Energy Systems for Industrial Growth, **2005**, vol. *1*, pp. 240-245.

[16] Bhim Singh; Kasal, G.K. *Voltage and Frequency Controller for Isolated Asynchronous Generators Feeding 3-phase 4-Wire Loads*. IEEE International Conference on Industrial Technology, December **2006**, pp. 2773-2778.

[17] Jayaramaiah, G.V.; Fernandes, B.G. *Novel Voltage Controller for Stand-alone Induction Generator using PWM-VSI*. IEEE Industry Application Conference, October **2006**, vol. *1*, pp. 204-208.

[18] Ammasaigounden N.; Subbiah, M. Chopper-controlled wind-driven self-excited induction generators. *IEEE Trans Aerosp Electron. Syst.*, **1989**, *25* (2), 268-276.

[19]   Ahmed, T.; Ogura, K.; Soshin, K.; Hiraki, E.; Nakaoka, M. *Small-Scale Wind Turbine Coupled Single Phase Self-Excited Induction Generator with svc for Isolated Renewable Energy Utilization.* Proceedings of the 5th International Conference on Power Electronics and Drive System, November **2003**, vol. *1*, pp. 781-786.