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SIMULINK BASED MODELING, ANALYSIS AND SIMULATION OF SELF EXCITED INDUCTION GENERATOR FOR USE IN REMOTE AREAS

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Abstract— **In remote location/ far off areas where transmission cost is very high, harnessing of electrical energy from local resources are very much in use. In this paper modeling, analysis and simulation of Self Excited induction generator at variable loads with Electronic Load Controller is discussed. The modeling and simulation has been done in simpowersystem block set of MATLAB/ SIMULINK environment. The power in surplus of the consumer load is dumped in a resistance through an ELC. The excess power dumped in resistance can be used for heating purposes.**

Keywords — **Self Excited induction generator, MATLAB/ SIMULINK, Simpowersystem, Electronic Load Controller, Capacitor , Consumer Loads .**

I. INTRODUCTION

Due to an increase in greenhouse gas emissions more attention is being given now to renewable energy and moreover rapid depletion of conventional fossil fuels and environmental concern have resulted in extensive use of renewable energy sources for electrical power generation. The inability of the power utilities to supply isolated users has resulted in the development of stand-alone power generation systems. Distributed & stand-alone power generation are receiving greater attention due to the cost and complexity of grid systems with related to transmission losses [1]. With increased emphasis on renewable energy technologies hydro, wind and biomass is being explored out of which small hydro and wind remain the most competitive. Since the location of these systems are in remote areas these systems must be reliable, robust , economical and manageable by the local people [2]. For the above requirements the induction generators IG is the most suitable. It has several advantages over the synchronous machines. The development in power electronics and control devices has also removed the drawbacks of induction generators regarding Voltage and frequency control [3].

Two main problems arise in stand-alone systems based on micro-hydro and wind concerning frequency regulation. First, the mechanical power delivered by the turbines can vary, especially in wind farms. Second, the loads supplied are variable by nature, so an active power balance should be achieved rapidly. From the efficiency point of view turbine governor seems an appropriate solution because by maintaining the produced power in range with the demanded one eliminates the need for an additional circuit in the system. But, such a configuration is expensive and inefficient for low-power applications (few tens of kW) [3]. As the mechanical constants are high, the regulating process is slow and the overall cost is significant. Also, the system’s response under suddenly load switching is poor, resulting in voltage sags and frequency deviations. Using a load controller is a better option, which feeds a dump load, enabling the total power supplied by the generator to match the sum between the consumer’s loads and dump load. As the active power balance is achieved, the frequency is satisfactory regulated [4].

In the literature, starting in the early nineteenth century, it is well known that a three-phase induction machine can be made to work as a self-excited induction generator (SEIG) [5, 6]. In an isolated application a three-phase induction generator operates in the self-excited mode by connecting three AC capacitors to the stator terminals [5-7] or using a converter and a single DC link capacitor [8]. The normal connection of a SEIG is that the three exciting capacitors are connected across the stator terminals and there is no electrical connection between the stator an rotor windings. However, in the literature a SEIG with electrical connection between rotor and stator windings is also reported [9]

A three-phase SEIG can be used as a single-phase generator with excitation capacitors connected in C-2C mode where capacitors C and 2C connected across two phases respectively and nil across the third phase [10].The steady state performance of an isolated SEIG when a single capacitor is connected across one phase or between two lines supplying one or two loads is presented in [11]. However in these applications the capacity of the three-phase induction generator cannot be fully used. In the calculation of capacitance required for

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self-[...]d technically, it is not advi[...]m value [...] This [...]e same vol[...] high[...]st more. the higher capacitance value is chosen then there is a [...]ility that the current flowing in the capacitor might [...]d the rated current of the stator due to the fact that

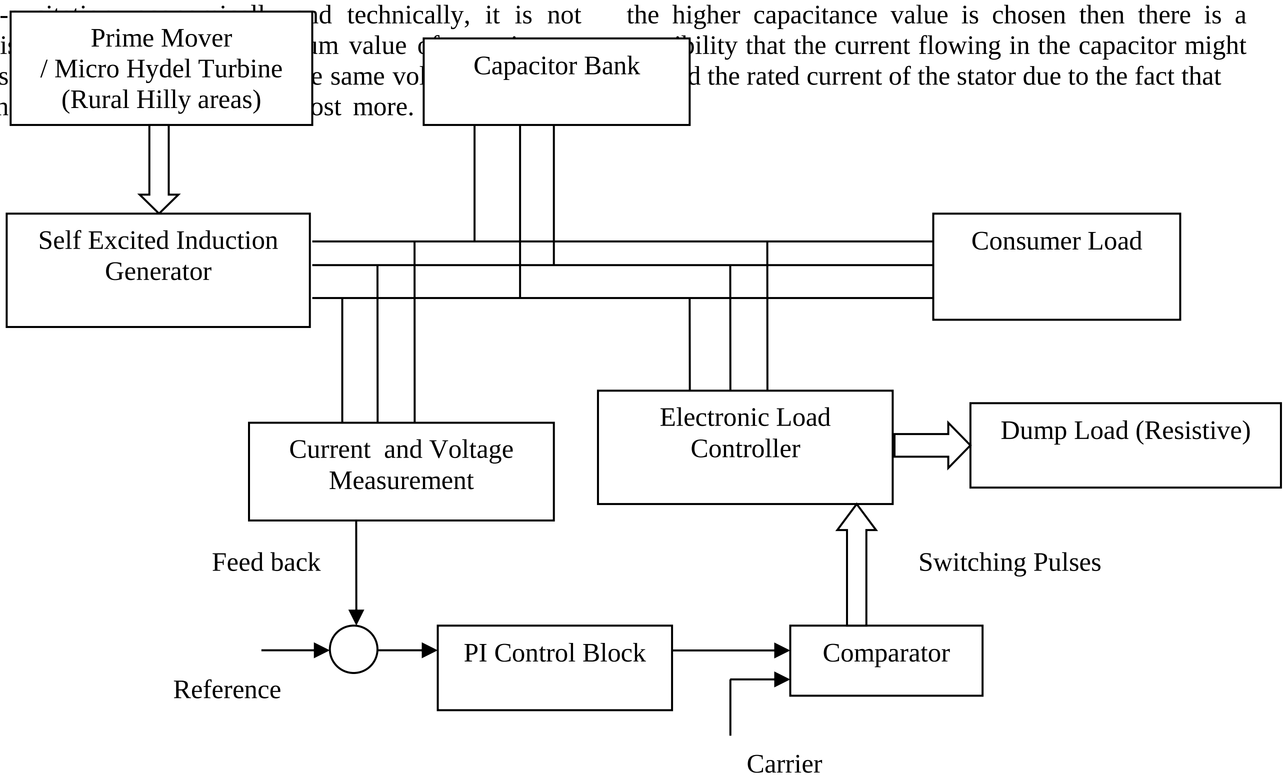

Figure 1: Block diagram of the proposed SEIG system for rural (Hilly) areas.

the capacitive reactance reduces as the capacitance value increases.

The main problem in using a SEIG is the control of the generated voltage because the voltage amplitude and frequency drops with loading as well as with a decrease in the generator rotor speed

In the SEIG, the frequency of the generated voltage depends on the speed of the prime mover as well as the condition of the load. With the speed of the prime mover of an isolated SEIG constant, an increased load causes the magnitude of the generated voltage and frequency to decrease. This is due to a drop in the speed of the rotating magnetic field. When the speed of the prime mover drops with load then the decrease in voltage and frequency will be greater than for the case where the speed is held constant.

In this paper modeling and analysis of Self Excited Induction Generator with Electronic Load Controller (ELC) with varying loads has been done. Modeling and simulation was done in simpowersystem block set of MATLAB/SIMULINK environment.

II. PROPOSED SYSTEM DESCRIPTION

A structure diagram of the proposed system for rural area is shown in Fig. 1. It consists of a three-phase delta-connected induction generator driven by an uncontrolled micro hydel turbine which is easily available in rural hilly areas. The induction generator is connected to three phase consumer load which is controlled by ELC. A fixed terminal capacitor is connected of such a value as to result in rated terminal voltage at full load. The connection of capacitor across the terminal make the generator to operate as an SEIG .The output power of the SEIG must be held constant at all consumer loads as any decrease in load may accelerate the machine and raise the voltage and frequency levels to prohibitively high values, resulting in large stresses on other connected loads. The power in surplus of the consumer load is dumped in a resistance through an ELC [12]. Thus, SEIG sees two balanced three-phase loads in parallel such that the total power is constant, thus:

$$Pc = P_x + Py \qquad (1)$$

where Pc is the generated constant power of the generator , P_x is the consumer power and Py is the dump load power . This dump power (Py) may be used for space heating, water heating, battery charging, cooking, baking etc. but the relevant hardware needs to be developed. [13]

The voltage was measured from the terminals of the SEIG and was compared with a reference voltage to produce an error. The error voltage was then fed to the PI Controller, and its output was compared with the carrier signal to produce pulses for Gating Signals. These pulses will make the ELC to Switch On and the extra power will get dissipated in the Dump load. This extra power can be used for space heating, water heating, battery charging, cooking, baking etc.

III. MODELING OF THE SYSTEM

The proposed SEIG-ELC system consists of an induction generator, capacitor bank, consumer load, and ELC. A dynamic model of the SEIG-ELC system with load (static) consists of modeling of the above subsystems as explained below.

Modeling of SEIG

The dynamic model of the three-phase squirrel-cage induction generator was developed by using the relevant volt-current equations given here and the Simulink model is given in Figure 2

$$v = R.i + L\frac{di}{dt} + \omega k_b.i \qquad (2)$$

The developed electromagnetic torque of the SEIG is:

$$Te = (\frac{3}{2}).(\frac{P}{2}).L_m.(i_{qs}.i_{dr} - i_{ds}i_{qr}) \qquad (3)$$

The torque balance equation is:

$$T_{sh} = T_e + J.(\frac{2}{P})\frac{d\omega}{dt} \qquad (4)$$

Here, T_{sh} is the input torque to the shaft of the SEIG from the constant power prime mover (micro-hydro turbine), J is the moment of inertia, P is the number of poles and T_e is the electromagnetic torque.

Three-phase currents and voltages are obtained by converting d–q axes components into a, b and c phase currents and voltages as follows:

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{ds} \\ i_{qs} \end{bmatrix} \qquad (5)$$

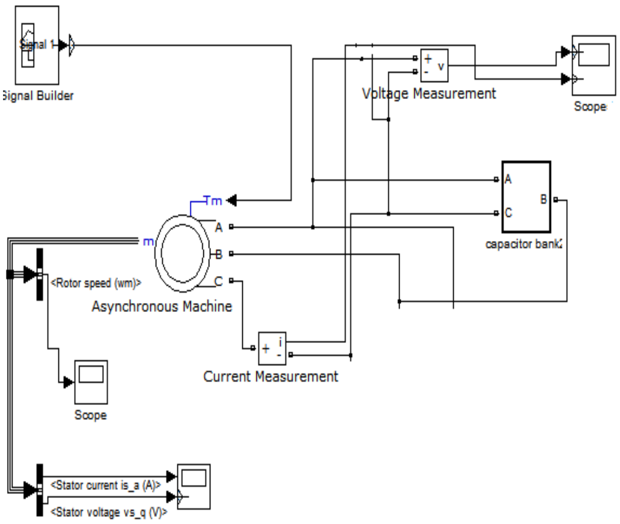

Figure 2. MATLAB/SIMULINK model of Self Excited Induction Generator (SEIG)

Modeling of Consumer Loads (Static and Variable)

Practical consumer loads consisting of resistive and inductive load (static load), shown in Fig. 3, and are modeled as follows.

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} R_a + La\frac{d}{dt} & 0 & 0 \\ 0 & R_b + Lb\frac{d}{dt} & 0 \\ 0 & 0 & R_c + Lc\frac{d}{dt} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \qquad (6)$$

Here R_a ,R_b and R_c & L_a , L_b and L_c are the resistance and inductance of the respective phases of the three phase network.

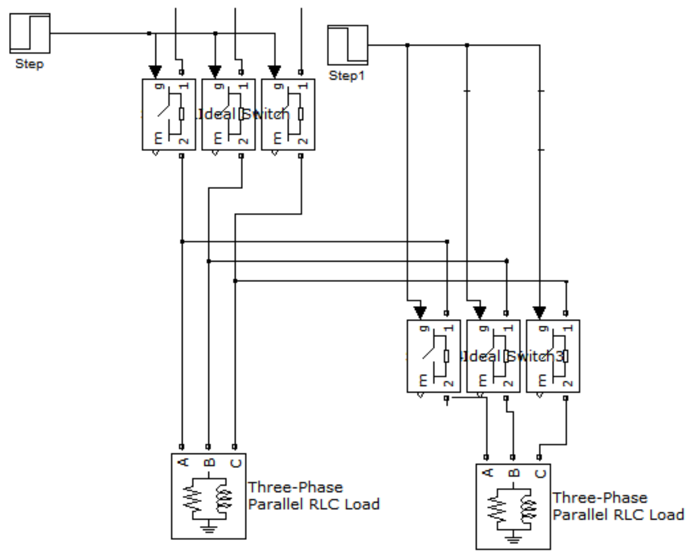

Figure 3. MATLAB/SIMULINK model of Consumer loads (Variable).

Modeling of Electronic Load Controller (ELC)

The simulink model of ELC is shown in Fig. 4. It consists of an uncontrolled diode rectifier bridge, control circuit, and IGBT based chopper. The stator voltage is fed to the ELC circuit consisting of diode rectifier [13]. To filter out the ripples of the dc voltage a filtering capacitor is connected across the rectifier output. The volt–current relation defining the complete load controller system is

$$pv_d = \frac{i_d - i_l}{C} \tag{7}$$

Where i_L is

$$i_L = [\{{}^{v_d}/_{R_{d1}}\} + D\{{}^{v_d}/_{R_{d2}}\}] \tag{8}$$

Where, D is the switching function indicating the switching status of the IGBT switch. When the switch is closed then D = 1and when the switch is opened then D =0. The output voltage of the PI voltage controller is compared with the saw tooth carrier wave which results in PWM output of the varying duty

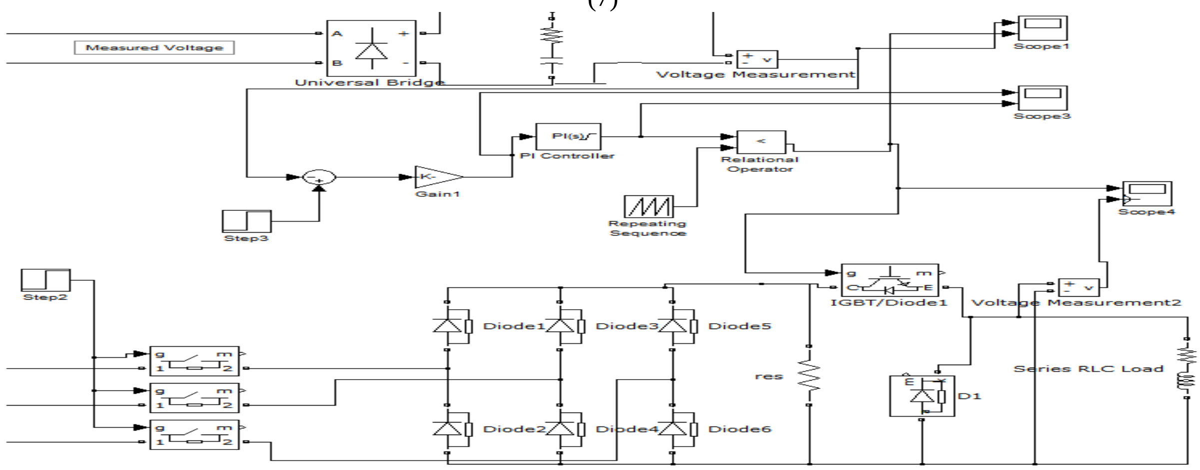

Figure 4. MATLAB/SIMULINK model of Electronic Load Controller.

cycle to generate the switching states of the IGBT chopper (1 or 0)

IV. RESULTS AND DISCUSSIONS

The proposed system was validated in Matlab/Simulink Environment. The Simulation was performed to observe the starting transients and load dynamics of the proposed system. The simulation was performed for the parameters given in Table 1.

Table 1, Parameters of SEIG

Parameters	Value
Power	4 kW
Voltage	400 V l-l
Frequency	50 Hz
Stator- Resistance	1.40 Ω
Stator- Inductance	5 mH
Stator- Resistance	1.39 Ω
Stator- Inductance	5 mH
Mutual Inductance	172 mH
J (Moment of Inertia)	0.0131 kgm^2

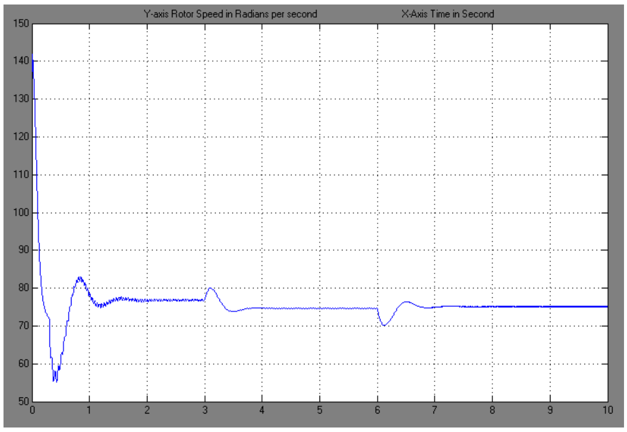

Figure 5: Rotor Speed in Radians per Second

Fig 5 shows the rotor speed in radians per second for SEIG. It can be observed that at 3 seconds when the load was decreased the speed of the motor got increased but due to the presence of ELC it settles to its steady state speed.

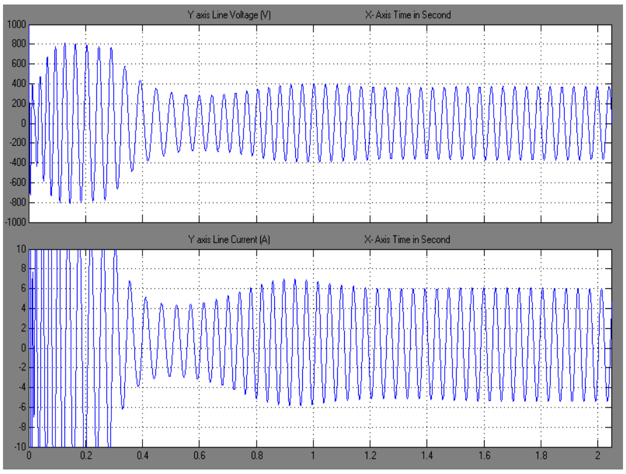

Figure 6: Starting Transients of SEIG

As one can see from Fig. 6 the Induction generator terminal voltage has reached steady state after 1 second. The capacitor bank of 100 μF was used to make the Induction generator function as SEIG.

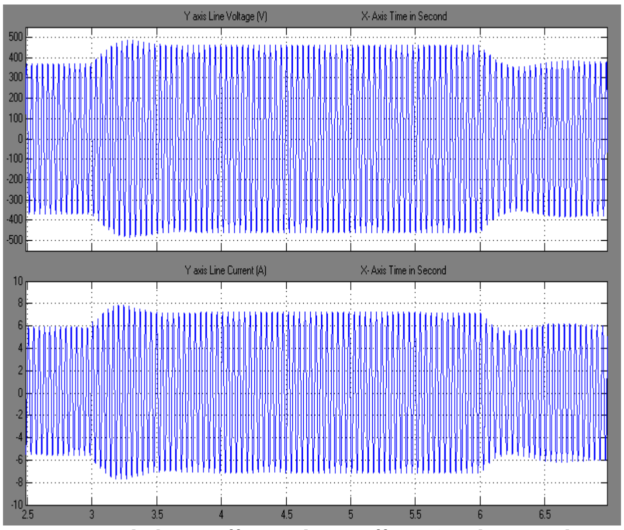

Figure 7: Load Change Effects and ELC Effects- (Load Removed at 3 seconds & ELC Introduced at 6 seconds)

The SEIG was run with constant load till 3 seconds. Then load is decreased by 50% without switching ON the ELC. Hence the voltage shoots up as can be observed from Fig 7. At 6 seconds the ELC was introduced and hence it retained the same desired terminal voltage within few cycles. This can be observed from the Fig 7.

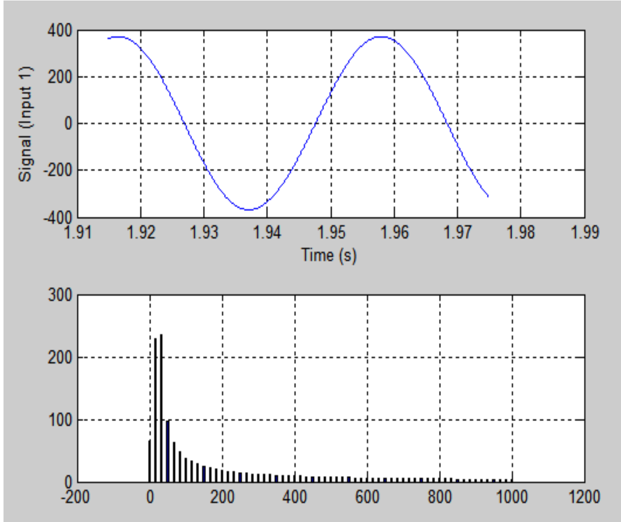

Figure 8 THD of Line Voltage

THD of Line voltage from Fig.8 is as follows:-
Fundamental: **220.6%**
Highest harmonics: Orders= [55]
THD = **25.75%** of the fundamental
WTHD = **15.43%** of the fundamental

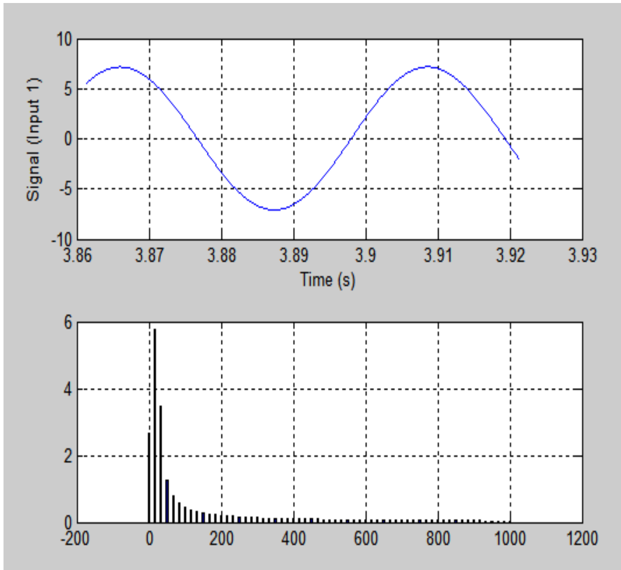

Figure 9 THD of Line Current

THD of Line Current from Fig.9 is as follows:-
Fundamental: **76.2%**
Highest harmonics: Orders= [55]
THD = **16.32%** of the fundamental
WTHD = **10.28%** of the fundamental

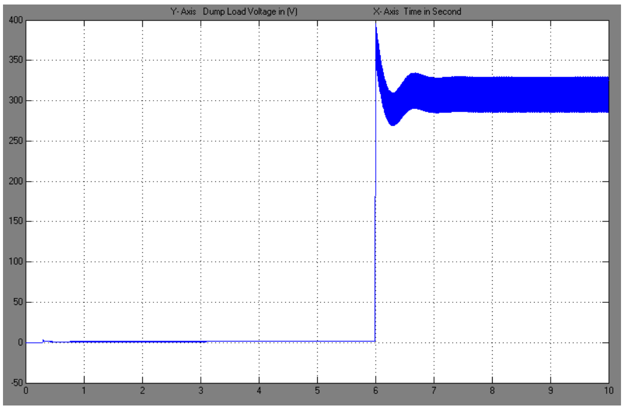

Figure 8: Dump Load Voltage

Figure 8 shows the Switching ON of ELC at 6 seconds and the surplus power was dissipated in Dump Load.

V. Conclusion

The transient and dynamic analysis of the three-phase SEIG with Electronic load controller shows that the discussed system can be used in micro-hydro applications. A micro-hydro system can be installed easily and economically in remote locations/ rural areas/ hilly regions. The ELC discussed in the paper exhibits high performance and low cost to be implemented. It is reliable, simple, and an excellent option to be employed in micro-hydro applications. Many countries have enormous hydroelectric potential in isolated and remote locations/ rural areas/ hilly regions, hence the presented research is very significant.

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Author’s Biographies

Mohd. Tariq was born in Mau (A district in Eastern U.P. in India) in 1989. He completed his formal education from Allahabad before joining Aligarh Muslim University in 2007 for B.Tech in Electrical Engineering. He qualified GATE-2011 with 99.7 percentile.

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Yuvarajan S was born in 1985 in Tindivanam (A District in Tamilnadu, India). He completed his BE Electrical & Electronics Engineering in 2006 from Pallavan College of Engineering, Kanchipuram. He worked in Bharat Electronics and Rane madras Limited during 2006 to 2010 in the research field.

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