Research Article

Experimental and simulation testing of an EGLC controller for an IAG-EGLC system for electrifying off-grid rural sites

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Abstract
The voltage support at consumer terminals is required in remote areas. This voltage support should be provided economically. In the manuscript, the study carried out emphasis on the designing methodology and hardware implementation of an electronic generator load controller (EGLC) for an isolated asynchronous generator (IAG) feeding single-phase loads. The EGLC is build using the uncontrolled rectifier bridge, an IGBT based chopper switch with series connected dump load. The driving signals for the IGBT based chopper switch is generated using Pule Width Modulation PWM IC. The generator is providing power to the two loads connected in shunt across each other. The objective of the controller is to maintain constant load on the generator during the entire operation of the generator. The expected simulated outcomes are verified using a hardware model of the EGLC prototype developed for an IAG in the laboratory. The closeness of both the simulated and experimental results justified its application for the electrification of various off grid remote sites available in hilly areas.

Article Highlights

- An EGLC Controller is designed, fabricated and tested in the laboratory for an IAG for voltage and frequency support.
- The proposed controller maintains constant load on the generator irrespective of nature of varying load.
- The prototype developed for an IAG-EGLC proves to be cost effective and can be proposed for electrification of off grid sites.

Keywords Design of ELC · Isolated asynchronous generator (IAG) · PWM · Controller · Electrification of rural sites · Renewable energy technologies

Abbreviations

EGLC	Electronic generator load controller
ELC	Electronic load Controller
IAG	Isolated Asynchronous Generator
SEIG	Self-Excited Induction Generator
IGBT	Insulated Gate Bipolar Transister
PWM	Pulse Wdth Modulation
V_{dco}	The average value of dc voltage
V_{cl}	R.m.s value of the input voltage of the uncontrolled rectifier of an EGLC
V_{Pk}	Peak value of r.m.s ac input voltage
I_{aca}	Active current of an IAG
P_{cl}	Power rating of single-phase load.
I_{aca}	Active current of an IAG

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$I_{dac(peak)}$ Input ac current (peak value) of EGLC
R_{dld} Rating of the dump load resistance R_{dld}
C_{dcl} Filtering capacitance
THD Total harmonic Distortion

1 Introduction

Energy is the basic need for the social and economic development of a country. Energy consumption of a nation is the direct way of accessing the index of development and it is only 500 W for India which is lower than the developed countries like America, U.S etc. In developing countries like India around 1/3 of the country population resides in villages or rural areas and they even do not have any access to electricity. In such areas, grid extension may not be possible and feasible due to some technical constraints, financial constraints and cost effectiveness. India is glorified with plenty of sustainable renewable energy sources in such off-grid areas. Due to continuous degradation, depletion and cost hike of conventional energy sources in early 1970's, researchers promoted the renewable energy technologies for electrical power generation (EPG) using isolated asynchronous generators (IAG). The IAG driven by these renewable energy sources (RES) is emerged as a viable and cost effective alternative. Using such systems, power generation capacity can be raised and can efficiently meet the increased energy needs in future. It is a well-known fact that more power generation leads to more power consumption and cost per kWh decreases and hence the people residing in remote areas can access the electricity at the lowest possible rates. Now a day, microgeneration technologies are preferred for low power generation. It includes wind turbine, solar power photovoltaic or a combination of these technologies. It is promoted as an alternative source of renewable energy technology. India is the first country in the world to establish a Ministry of non-conventional energy resources called MNRE (Ministry of new renewable energy). India set a target of accomplishing 40% of its total power generation from non-fossil fuel by 2030.

Therefore, the concept of distributed generation using RES to cater the single-phase load requirements in rural off grid areas has proved a viable and cost effective option. The installed units of such generating systems are usually handled by local communities or by village panchayats. These generating systems are simple, robust, maintenance free operation, no operating personnel. So, the unskilled people can handle the plant. This paper is organized as follows: Sect. II presents the Literature Survey. The constant load based control and PWM generation of IAG using EGLC is detailed in Sect. III. The Design methodology for 1-phase EGLC is described in Sect. IV. Section V covers the hardware implementation and testing of 1-ϕ EGLC for 3-phase IAG The experimental and simulated outcomes of the results are illustrated in Sect. VI. Some deduced conclusions from results are discussed in Sect. VII.

2 Litreture survey

The steady state and transient state performance analysis of 3-phase IAG feeding balanced and unbalanced is discussed in several papers. Various phase balancing schemes are discussed and implemented to obtain balanced sinusoidal voltages under unbalanced conditions.

S. S Murthy et.al [1] discussed the theory of symmetrical components for the performance analysis of 3-phase SEIG furnishing three-phase unbalanced and 1-phase load. The analysis was little bit complicated due to effect of unbalance in operating conditions and magnetic saturation. T. F Chan et.al [2] focused on the analysis of a single-phase SRSEIG based on symmetrical component theory. A pattern search optimization method is used to evaluate the performance. S.N Mahto et.al [3] discussed the way of evaluating the optimal value of excitation capacitance required for obtaining maximum power output of three-phase SEIG using Sequential Unconstrained Minimization Technique (SUMT). T. F Chan et.al [4, 5] revealed the symmetrical component theory based steady state performance analysis of 1-phase SRSEIG using a 3-phase asynchronous machine. For performance assessment, the values of F and X_m are evaluated using Hooke's and Jeeve's method (Pattern search method). The Steinmetz connection is used in single phase SRSEIG. This generator improved the voltage regulation, increased power output and provided better phase balance. It is observed that IAG is subjected to poor voltage and frequency regulation under varying load situation. So, there is felt a need of some controller which can provide voltage and frequency support under varying loads condition.

A numerous number of papers are covering the analysis; design and implementation of three-phase EGLC or ELC for three-phase IAG or SEIG feeding single phase load.

J. M Elder et.al [6] recommended the integral cycle control scheme for micro-hydro based power generation (upto 100 kW) for stand-alone. The proposed scheme proves cost effective for small scale power generation schemes. Results are demonstrated to testify and validate the proposed scheme for micro-hydro based power generation.

D. Henderson [7] explored the research part related with the the evolution of microprocessor operated binary weighted Electronic load governer, ELG. A hardware prototype of the proposed microprocessor operated ELG is developed, tested and verified in hydraulic laboratory of Napier University. The enhanced performance is accomplished using advanced algorithm rather than the original ELG.

E. Suarez et.al [8] explored and focussed a new strategy of Variable Structure Control Criteria for regulating SEIG voltage and its associated frequency. The dynamic model of the SEIG is recommended for carrying out its analysis under transient state under varying load situation. The dynamic model also provide guidelines for designing of the controller.

B. Singh et.al [9] provided an insight into the detailed modelling of isolated asynchronous generator (IAG) and single-phase ELC delivering single-phase load. The composite modelling of the IAG, ELC and load are tested and validated using both hardware and software.

B. Singh et.al [10] discussed the d-q modelling of SEIG, modelling of ac capacitor, modelling of induction motor as a dynamic load, unity p.f. load, modelling of 3-Φ ELC and its control scheme, modelling of prime mover in stationary reference frame. A SEIG-ELC system hardware set-up is constructed to validate the system and its outcomes. The THD based analysis is done to check the power quality of SEIG voltage and it's current.

B. Singh et.al [11] explored the stationary reference frame based dynamic d-q modelling of the SEIG with an improved version of ELC. The dynamic response of SEIG-IELC system is tested under the situation of balanced/ unbalanced type consumer load. The proposed IELC controller is tested and simulated outcomes show that the IELC is efficiently act as voltage and frequency supporter and THD minimizer.

S. S Murthy et.al [12] shared an experience of installing standalone generating systems in the field using SEIG spinned by hydro turbines. The back to back thyristor based ELC and uncontrolled rectifier based ELC are also explored. These properly designed ELC's maintain power balance even under varying nature load. Field data of generator alongwith both types of ELC is mentioned to test the feasibility and viability of the proposed scheme.

T. S Chandra et.al [13] discussed how a three-phase induction machine operated as an induction generator with the aid of ac capacitor bank connected across the machine terminals. It also discussed about the details related with different types of power electronics based controllers: thyristor switched capacitor bank, thyristor controlled inductors with fixed capacitor bank, AC/DC converters, ELC, STATCOM and magnetic amplifier. This paper also introduced new voltage regulation schemes based on Magnetic amplifier, ELC and STATCOM or SEIG.

B. Singh et.al [14] explained the stationary reference frame based modelling of IAG or SEIG, ELC modelling and its control strategy, load. The non-linear differential equations obtained after modelling are solved using of numerical integration based Runga Kutta method.

B. Singh et.al [15] elaborated the designing aspects of three-phase and single-phase electronic load controller (ELC) for a 7.5 kW three-phase SEIG. The outcomes attained during steady state and transient conditions proved that the recommended ELC can support the voltage constant under the situation of varying load.

B. Singh et.al [16] described the control technique, designing and implementation of an EVFC for a 1-phase IAG. The dynamic response of IAG-EVFC is examined experimentally to discuss the effectiveness of the proposed designed EVFC.

S. S Murthy et.al [17] discussed the complete performance of SEIG with digitally controlled ELC feeding both three-phase type and single-phase type loads. It covered in detail the complete mathematical modelling of various parts: (1) d-q modelling of SEIG including saturation effect, (2) excitation capacitor modelling, (3) load modelling, (4) ELC modelling. The suggested controller is then tested for field based applications for voltage regulation aspect of SEIG.

I. Serban et.al [18] elaborated completely the analysis aspect of an ELC. The dump load is considered as ELC here. The feasibility and validity of the proposed ELC is extensively tested by performing simulations and experiments.

J. M. Ramirez [19] detailed about the designing of a dump load resistance of a three-phase ELC-SEIG system for feeding a three-phase load. The proposed system performance is tested and analyzed under different types of loads. It is noticed that the suggested controller maintains the SEIG voltage and its frequency when operated under varying load.

B. Singh et.al [20] focussed on the implementation of six-pulse ELC and 24-pulse ELC for power quality improvement in voltage and current of an IAG. A polygon connected autotransformer design criteria is discussed in detail. Both ELCs are tested experimentally and analytically using MATLAB software. It is concluded that 24-pulse ELC provided better performance. But the autotransformer based ELC increases the cost of the whole generating system and makes the system expensive.

S. N Mahato et.al [21] evaluated and assessed the performance analysis of three-phase SEIG feeding lagging power factor loads under transient conditions. The complete system is modelled using d-q modelling. To validate modelling based results, a hardware set-up of SEIG-ELC is developed. Finally, a comparison is made between the results obtained from modelling and experimental, both results are closely related. Hence, such systems can be adopted for micro-hydro based generation.

E. Torres et.al [22] highlighted the designing of an improved version of an ELC for an SEIG for micro-hydro based applications. A dump load is maintaining constant power at consumer terminals under varying load. It is observed that the proposed controller provided better voltage and frequency regulation under balanced/unbalanced conditions. A THD analysis is performed to evaluate the harmonic content in the generated voltage and consumer load current.

E. G Marra et.al [23] proposed a PWM base inverter for the performance improvement of IG. This paper discussed in detail two schemes. In one scheme, generator speed is controlled and the other scheme does not have any speed governor (cogenerator scheme). In both schemes the voltage and frequency regulation is provided by PWM based inverter. The obtained result outcomes show that the system is robust, stable and can act as a regulated 3-phase power source.

S. Mbabazi [24] provided an overview of already existing literature, technology and various aspects related to ELC for micro-hydro based power generation in detail. It covered the working principle of micro-hydro, components related with micro-hydro system, different load regulation techniques etc.

S.Gao et.al [25] discussed about the designing aspects of PIC18F252 microcontroller based ELC for SEIG for feeding single-phase load for pico hydro based generation. The proposed is tested both experimentally and through simulation study to demonstrate its feasibility and effectiveness.

D. K Palwalia et.al [26, 27] proposed a DSP based VFC for a 3-phase SEIG rotated by an unregulated micro-hydro turbine and feeding 1-phase load. The DSP based controller helps in retaning the generator load constant. A laboratory hardware set-up of the proposed controller is developed to testify its effectiveness and feasibility. Moreover the DSP operated controller proves to be reliable and cost effective option for micro-hydro based power generation.

V. Verma et.al [28] analyzed the performance of the SEIG subjected to various critical operating conditions of load i.e. full application and full removal of load. This paper recommended a VSC for providing support to SEIG voltage and its frequency under varying load. The voltage and frequency regulation is achieved by controlling active and reactive power through VSC. The control algorithm of SEIG voltage and its frequency regulation by VSC is operated on indirect current control strategy modeled in d-q reference frame.

S. S Murthy et.al [29] proposed a digitally controlled ELC for accessing the complete performance of the IAG under transient and steady state condition. The compete modelling of the generating system is accomplished by combining the d-q model of SEIG (considering saturation effect), ac excitation capacitor model, 1-phase load model, electronic load controller (ELC) model. This controller provides better voltage support and proves to be more reliable, economical and compact for practical applications.

R.Raja Singh et.al [30] elaborated the various review aspects of the developments done in the field of Micro-hydro based generation using reduced dump load based ELC.It also proposed a new technique to increase generator efficiency and its life span.

S. Gao et.al [31] proposed a microcontroller based ELC for supporting voltage of three-phase SEIG furnishing single-phase load. The proposed controller keeps fixed load on the generator and hence the SEIG voltage remains constant when subjected to variable load. A hardware model is developed to verify and validate the simulated outcomes. Such microcontroller based system proves cost effective and viable solution for electrical power generation in grid isolated remote areas.

In this manuscript, the study carried out is based on the analysis, design and the practical implementation of a very cost effective voltage and frequency controller for a three-phase IAG feeding 1-phase load as compared to the various existing microcontroller and DSP based ELC's. The proposed controller can be recommended as a cost effective voltage regulator for micro hydro systems in rural sites.

3 Constant load based control and PWM generation of an IAG using EGLC

A three-phase delta connected Asynchronous machine (AM) is used as an asynchronous generator. The asynchronous machine is driven mechanically above synchronous speed with the help of dc machine [32].

A C-2C capacitor configuration is opted here to obtain single-phase supply for supplying single-phase loads. An autotransformer is used here to step-down the ac voltage

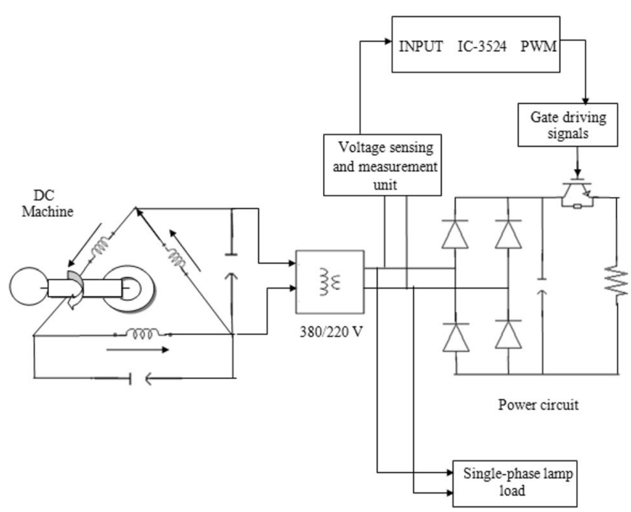


Fig.1 Schematic diagram of three-phase IAG feeding single-phase load along with EGLC

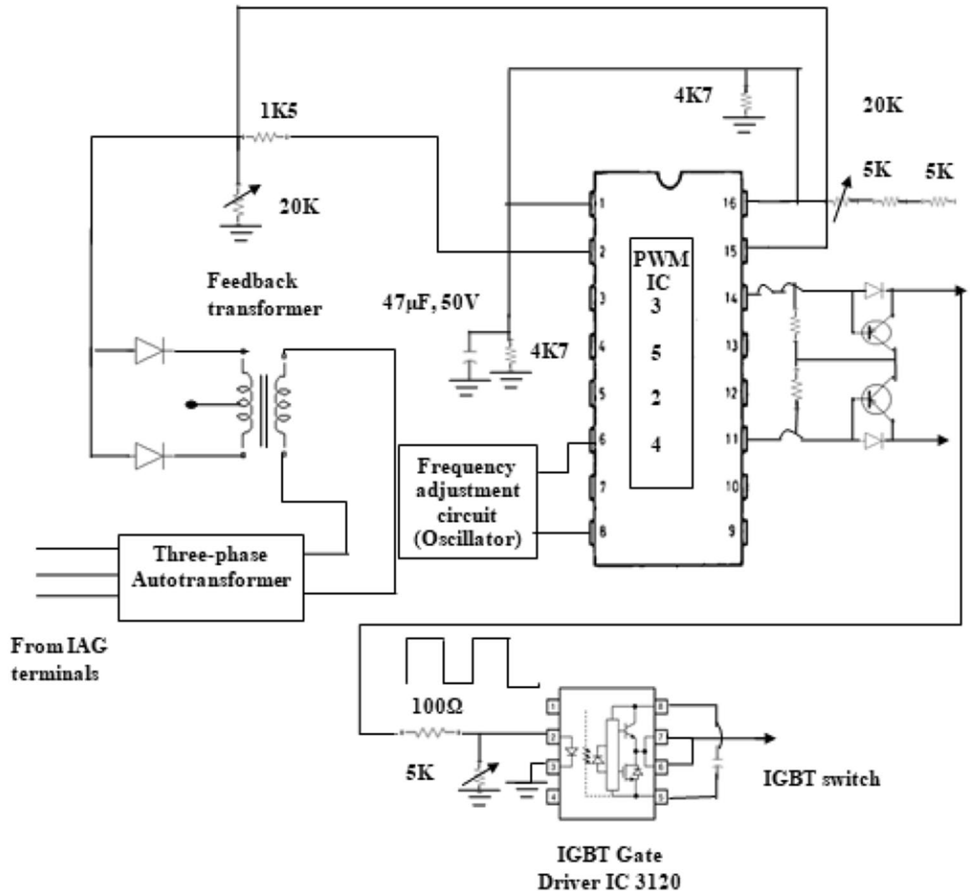


Fig. 2 Hardware diagram of the control circuit

from a level of 380 V to 230 V as depicted in Fig. 1. This 230 V acts as an input to both the consumer load (lamp load) and dump load. The designed PWM IC-3524 based controller is fabricated using Protel System Design Software (Fig. 2). The electronic components used are uncontrolled diode rectifier, chopper (IGBT type) switch, optocoupler, IC-3524, transistors. The PWM based IC-3524 operates at a frequency determined by resistance and capacitance R and C. The inbuilt 5 V regulator acts as a reference voltage inside the IC. This 5 V voltage is divided outside the IC using resistor divider circuit and this voltage is treated as a reference input voltage to inbuilt error amplifier. The output voltage is first sensed and then compared with the reference voltage. This error in voltage is first amplified and then compared with the ramp voltage for generating the PWM signal or driving signal. This PWM signal is then fed to transistor T_1 and transistor T_2 through flip-flops.The oscillator output pulse also acts as an inhibiting pulse i.e. both the transistors T_1 and T_2 are never in ON state simultaneously. The duration of this pulse is controlled by the value of C. Pin no. 11 and 14 are connected to the transistors T_1 and T_2 for driving 12–0-12 V primary and 220 V secondary. When pin no. 14 is high, upper transistor is ON and positive train of pulses is obtained. When pin no. 11 is high, lower transistor is ON and negative train of pulses is obtained. The gate pulses thus obtained are fed to the IGBT Gate driver IC 3120 and are then fed to the IGBT switch of the EGLC.

The IAG is supplying current to the two loads (consumer load and dump load) in parallel. When the consumer is requiring more load current, then the current in the dump load decreases to maintain constant load on the IAG. When the consumer current decreases, then the current in the dump load increases to maintain constant load on the IAG. Thus EGLC maintains constant load on the IAG throughout the continuous operation of the IAG. The dump load power is further utilized for various practical applications in remote ares i.e. heating, water pumping, cooking, fireworks, battery charging etc. Thus makes the IAG-EGLC system more efficient for electrification of off-grid sites.

4 Design methodology of 1-Φ EGLC

The voltage rating of the uncontrolled rectifier and IGBT type chopper switch will be the same and dependent on the r.m.s ac input voltage and average value of the output dc voltage [15]. The average value of dc voltage is calculated as

$$V_{dco} = \frac{\left(2\sqrt{2}\,V_{cl}\right)}{\pi} = (0.9)V_{cl}$$

where V_{cl} is the r.m.s value of the input voltage of the uncontrolled rectifier of an EGLC. For the 1.2 kW rating load, the average value of dc voltage

$$V_{dco} = (0.9)*240 = 216V$$

An overvoltage of 10% of the rated voltage is considered for the transient condition and hence, the r.m.s ac input voltage will be (264 V) with a peak value of

$$V_{Pk} = \sqrt{2}*264 = 373.296V$$

This peak voltage will appear across the components of EGLC. The current rating of the uncontrolled rectifier and chopper is decided by the active component of input ac current and is calculated as

$$I_{aca} = \frac{P_{cl}}{V_{cl}}$$

where P_{cl} is the power rating of single-phase load. The active current of an IAG may be calculated as

$$I_{aca} = \frac{1200}{240} = 5\text{ A}$$

The single-phase uncontrolled rectifier current waveform has a distortion factor of 0.9; the input ac current (peak value) of EGLC may be obtained as

$$I_{dac(peak)} = \frac{I_{aca}*2}{0.9} = \frac{5*2}{0.9} = 11.11\text{ A}$$

So, for the uncontrolled rectifier, the maximum voltage may be 373.296 V and peak current may be 11.11 A. The commercial available rating of an uncontrolled rectifier and chopper switch is 600 V and 30 A. Therefore, rating of the uncontrolled rectifier and chopper switch has been decided to be 600 V and 30 A.

The rating of the dump load resistance R_{dld} is calculated by

$$R_{dld} = \frac{\left(V_{dco}\right)^2}{P_{rated}} = \frac{(216)^2}{1200} = 38.88\Omega$$

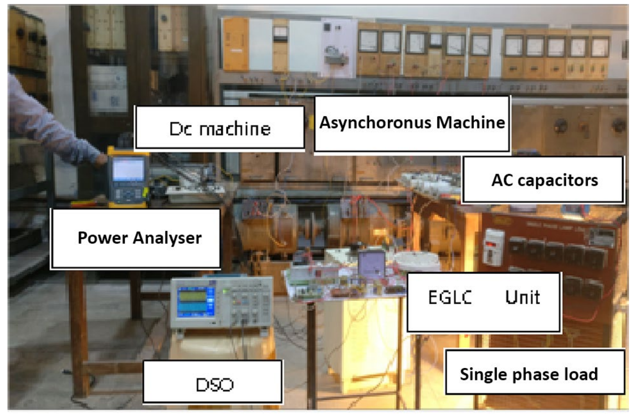


Fig. 3 Photograph of the complete generating unit along with EGLC unit

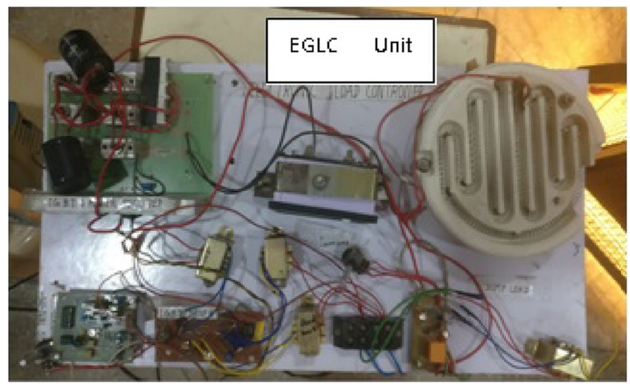


Fig. 4 Photograph of the Electronic Generator Load Controller (EGLC)

The value of the dc-link capacitance of the EGLC varies with the ripple factor (RF). The relation between the value of the dc link capacitance and ripple factor for a single-phase uncontrolled rectifier is

$$C_{dcl} = \left\{\frac{1}{(4fR_D)}\right\}\left\{1 + \frac{1}{\left(\sqrt{2}RF\right)}\right\}$$

If 20% ripple factor is permitted in the average value dc-link voltage then the filtering capacitance is calculated as

Table 1 Rating of various components

Power of motor (W)	Voltage of the uncontrolled bridge rectifier (V)	Current of the uncontrolled bridge rectifier (I)	Voltage of the chopper switch (V)	Current of the chopper switch (I)	Dump load resistance (Ω)	Filtering capacitor (µF)
3730 W	600 V	30A	600 V	30A	38.88	583

$$C_{dcl} = \left\{ \frac{1}{(4 * 50 * 38.88)} \right\} \left\{ 1 + \frac{1}{\left(\sqrt{2} * 0.2\right)} \right\} = 583\mu\,F$$

The rating of various components of 1-phase EGLC based on designed methodology is tabulated in Table 1.

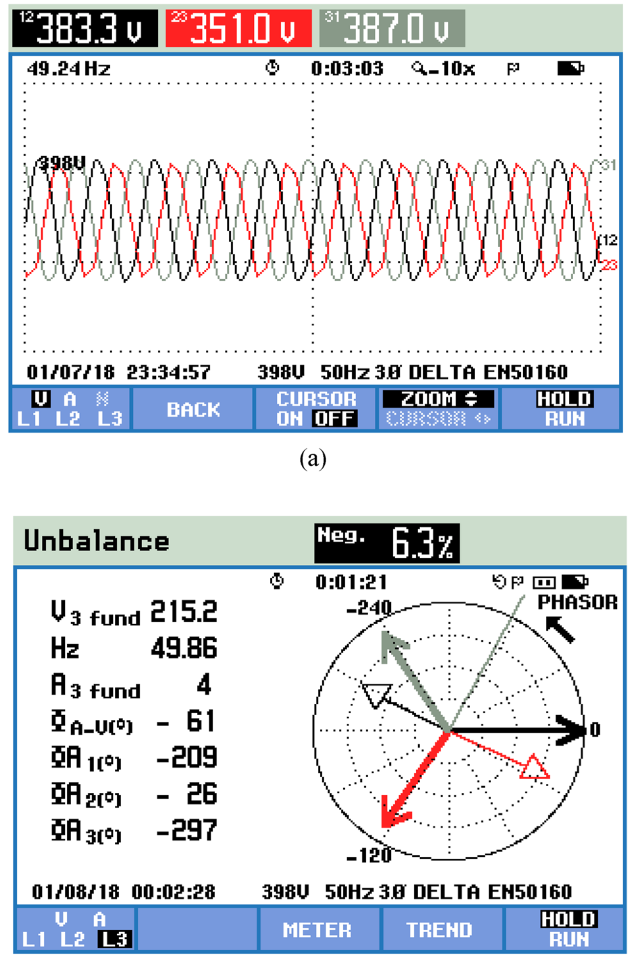
5 Hardware implementation and testing of 1-Φ EGLC for 3-phase IAG

The hardware part of the whole generating system integrated with the EGLC unit consists of a three-phase asynchronous machine, a dc machine acting as a prime-mover, set of three-phase capacitor banks, a single phase resistive load, voltmeters, ammeters, wattmeters, mulltimeters, tachometer, power analyzer, Digital Storage Oscilloscope (DSO), 10:1 attenuator probe, frequency meter, EGLC unit (Fig. 3). The hardware part of the EGLC is depicted in Fig. 4.

6 Experimental and simulated outcomes

6.1 Transient result outcomes of three-phase IAG feeding single-phase load

When a three phase IAG is feeding single-phase load, an unbalance occurs in three-phase generated voltages and currents of the IAG. To avoid or minimize this unbalance a C-2C capacitor connection is suggested [1–5]. A voltage of 380 V is generated with the help of a delta-connected IAG at no load first. Then to feed single-phase load a capacitor connection of type C-2C is used here. The voltage across capacitor C is first fed to autotransformer for stepping



(a)

(b)

Fig. 6 **a** Waveform of three-phase generator voltages **b** voltage unbalance on single-phase side under no-load conditions

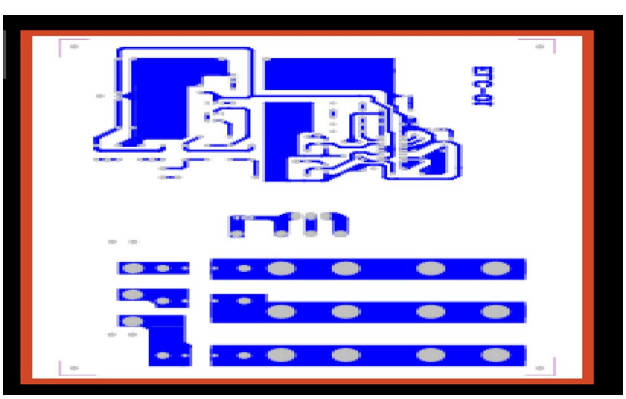


Fig. 5 PCB layout of the EGLC Controller

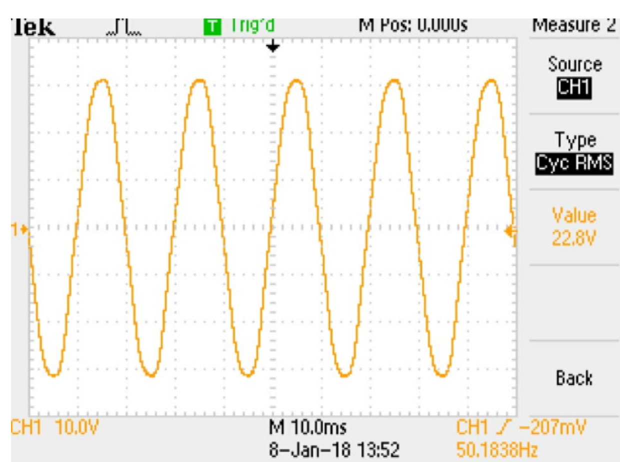


Fig. 7 Single-phase voltage (228 V) fed to EGLC

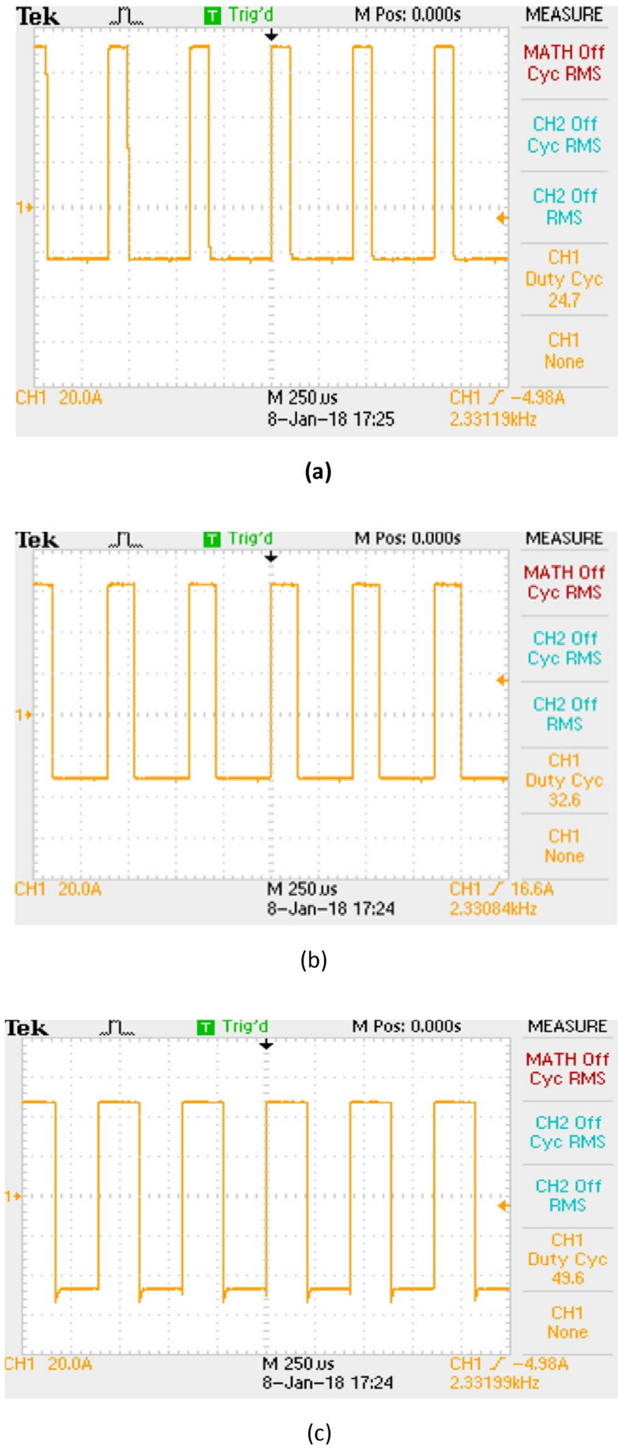


Fig. 8 PWM generation of different duty cycle **a** at duty cycle 24.7 **b** at duty cycle 32.6 (2.33 kHz)

down to 230 V for single-phase load. The PCB layout of the EGLC controller is illustrated in Fig. 5.

Figure 6a and b depicts the simulated outcomes for three-phase generated voltage and capacitor current and the unbalance in both voltage and current. An unbalance

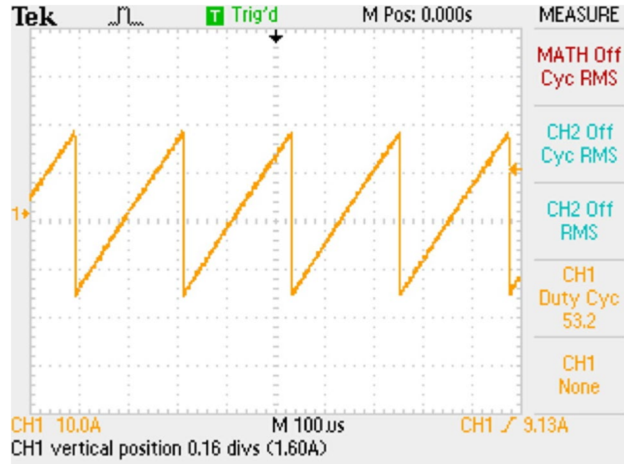


Fig. 9 Sawtooth waveform

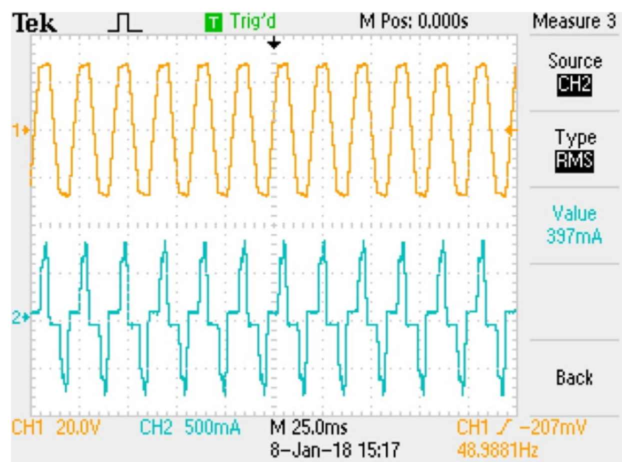


Fig. 10 Top: Single-phase voltage fed to EGLC (228 V) at zero consumer loads, Bottom: Current flowing through EGLC at zero consumer loads

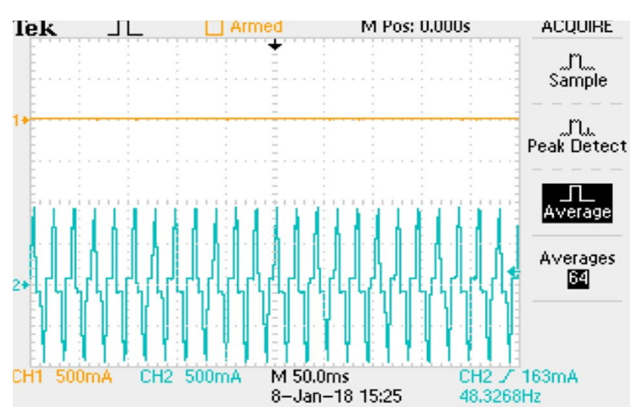


Fig. 11 EGLC current under zero consumer loads

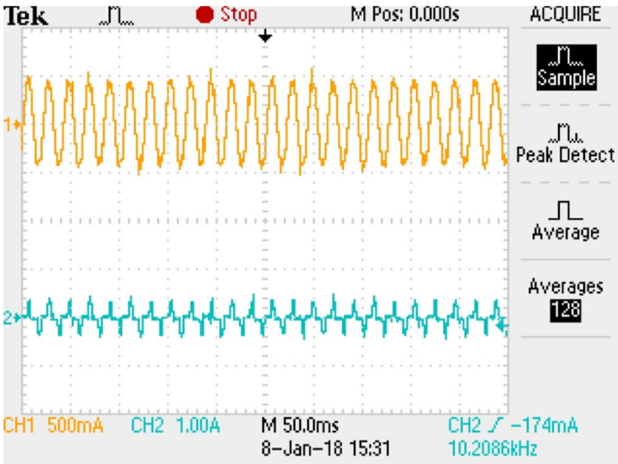


Fig. 12 Consumer current under varying consumer load under zero EGLC current

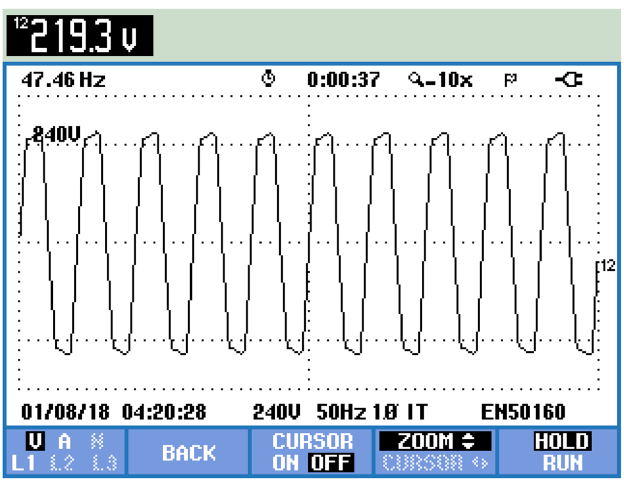


Fig. 13 Single-phase load voltage of IAG with controller EGLC

of 6.3% is observed in generated voltage and current as depicted in Fig. 6c.

Figure 7 depicts the simulated outcomes for single-phase ac voltage fed to the single-phase uncontrolled rectifier under no load situation. A voltage of 228 V and frequency 50 Hz is applied to the uncontrolled rectifier.

Figure 8 depicts the simulated outcomes related to PWM generation at different duty cycles (24.7, 32.6 and 49.6) for driving the IGBT type chopper switch so that the dump load is connected in the circuit and current starts flowing through the dump load.

Figure 9 depicts the simulated outcomes for saw tooth waveform required for modulation purpose for attaining PWM pulses for driving the IGBT type chopper switch.

Figure 10 depicts the simulated outcomes related to single-phase voltage fed to the single phase rectifier and

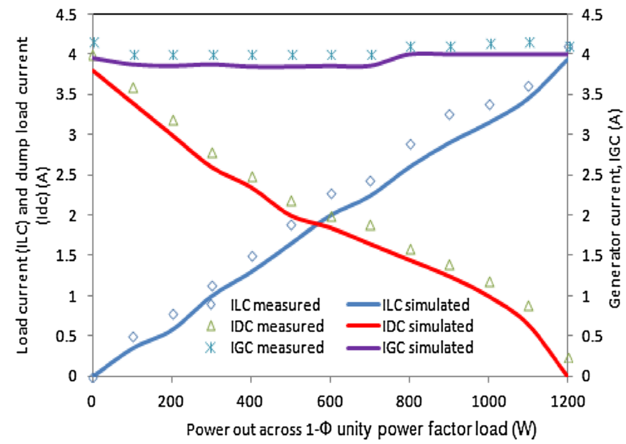


Fig. 14 Variation pattern of load current, dump load current and generator current with power output

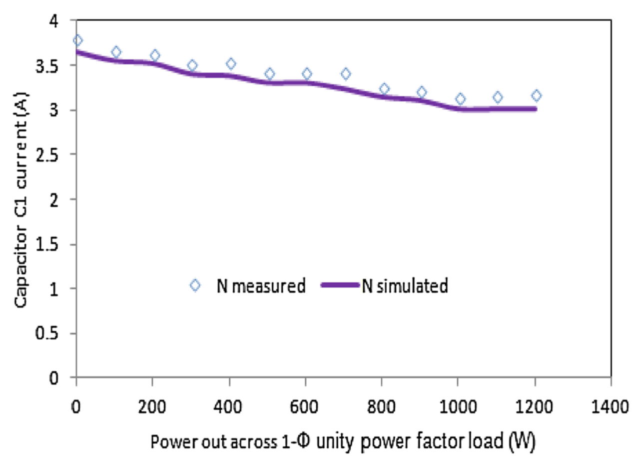


Fig. 15 Variation pattern of capacitor current with power output

the driving signals are fed to the controller with zero consumer load. Now the whole of the generated current is passing through the EGLC. This situation is depicted in Fig. 11. Now the consumer load is switched on in steps from zero to full load. As the consumer load is inserted into the circuit and is increased, the current in the controller starts decaying. It means when the consumer load current is increasing, then the current in the controller starts decaying so that the total load on the generator is held constant (Fig. 12) This constant load attributes to the constant load voltage (Fig. 13) and frequency operation of the IAG when administered to varying load.

6.2 Steady state result outcomes interpretation on single-phase load side with EGLC controller

Figure 14 depicts the analytical and experimental variation of load current, dump load current and the generator

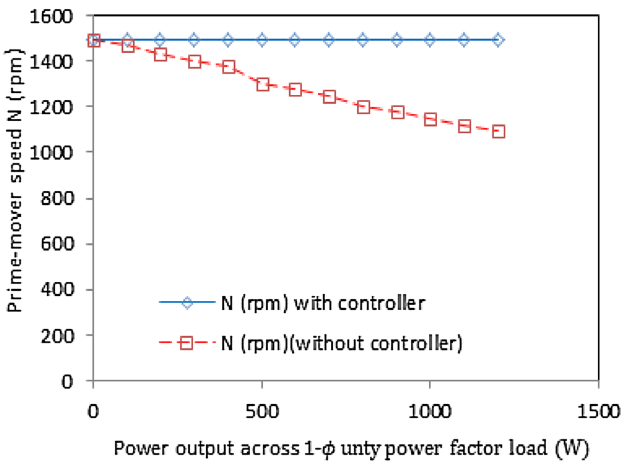


Fig. 16 Comparison of outcomes attained for prime-mover speed with and without EGLC controller

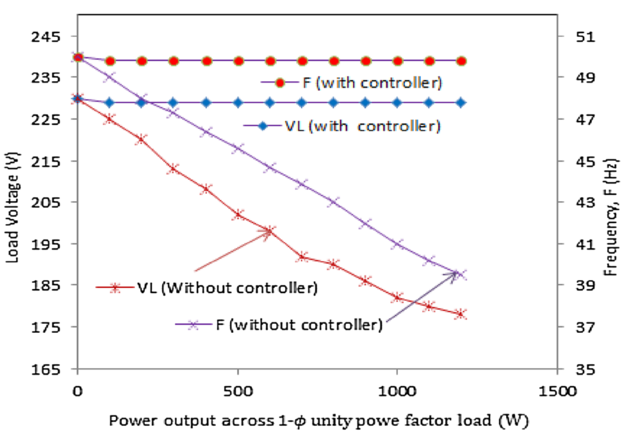


Fig. 17 Comparison of outcomes attained for load voltage and frequency with and without EGLC controller

current with the power out across 1-phase unity power factor load. The load current rises as the load is increased and the dump load current decays and decays to almost zero at a maximum load. There is good resemblance between the analytical and experimental obtained results which validates the practical implementation of the proposed controller. There is slight decrease in capacitor current with increase in load as expected and is depicted in Fig. 15. This controller current is complementary type and helps in retaining constant load on the generator. As expected without controller, with increase in load on the generator the prime-mover speed decreases. The speed regulation is 26.3% But the controller maintains constant load on the generator under varying load situation so the prime-mover speed is maintained constant. On the contrary with controller, the speed regulation is 0.66%.The prime-mover speed is constant throughout the operation under varying load conditions as illustrated in Fig. 16. As expected without any controller, with increase in load on the generator, the voltage across it decreases and hence frequency also decreases (Fig. 17). This decrease in voltage is attained due to the armature reaction phenomenon, drop in resistance and leakage reactance. But due to the controller action the load on the generator is maintained constant throughout the operation of the generator. Hence due to the controller action voltage and frequency of the IAG is maintained constant as depicted in Fig. 17. The analytical and experimental results are closely related. The closeness between the analytical and experimental outcomes proves the validation of the proposed controller as voltage and frequency regulator (Table 2).

7 Conclusions

A practical PWM based EGLC controller is designed, fabricated and implemented for an IAG for electrifying the rural sites. From Table 2 it is observed that the superior voltage and speed regulation of 0.86% and 0.66% is attained with the aid of the proposed controller. Moreover, the voltage and frequency are also maintained at desired level as per the limits mentioned in the IEEE-519 std [33]. The controller cost is approximately less than 5000 Rupees which is very-very less as compared to the various existing microcontroller and DSP based ELC's. A single IC operation proves sufficient for voltage and frequency support of IAG. Thus an IAG with this IC based EGLC can electrify the rural communities with desirable voltage and frequency support with minimum cost of generation and electrification. The degree of closeness of experimental and simulated result proves its effectiveness as a cost effective controller for the electrification of off-grid rural sites.

In future work, the hardware implementation of the control circuit of the controller can be realized using

Table 2 Comparison of outcomes with and without EGLC controller

Isolated Asynchronous Generator (IAG)	V_L(Load Voltage) % Regulation	Prime-mover speed N (rpm)
Without controller	22.6% Poor voltage regulation	26.3% Poor speed regulation
With EGLC controller	0.86% Superior voltage regulation	0.66% Superior speed regulation

DSPACE and Controller HIL (C-HIL) Typhoon HIL. The Controller HIL (C-HIL) testing can be performed using Typhoon ultra high fidelity Typhoon HIL Simulator.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no confict of interest.

Consent for publication On behalf of all authors, the corresponding author states that all authors have consented to publish this work in the SN journal of Applied.

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