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An efficient and novel technique for electronic load controller to compensate the current and voltage harmonics

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ABSTRACT

This paper presents an efficient technique to switch on and off the dummy loads in an electronic load controller effectively. The electronic load controller is an essential part of pico and micro hydro-power generating units that provide stable and high quality electric power to consumers. The magnitude and frequency of the output voltage is kept stable by keeping the power consumption equal to the generated power; this is achieved by turning on and off multiple dummy loads through electronic switches. In the current scenario, the loads are switched on and off at random time intervals that produces a huge noise, harmonics and transients in sinusoidal current and voltage. Random switching of dummy loads looses a significant amount of energy in switching and damages electronic switches along with non-linear loads connected to the system. To tackle this problem, we have investigated different scenarios and reached to the conclusion that, if the zero-crossing technique is deployed for this purpose, the quality of the generated power will be enhanced. The proposed system is simulated in MATLAB/Simulink as well as Proteus. Based on Proteus software model a hardware is made and validated by comparing its frequency graph with results obtained from MATLAB/Simulink model.

1. Introduction

The rapid reduction of fossil fuels and high cost of production of conventional energy have given push to utilize non-conventional energy sources [1]. All renewable energy resources are cheaper and better to produce electricity, but small hydro power plants, particularly micro hydro power plants (MHPP), are best to provide electricity. With MHPPs, less civil work is required than that of big dams, and efficiency is also high [2]. The voltage and frequency of these power plants does not remains constant because of variation in water flow into turbines and the changes in consumer load connected to generator [3]. This variation in generated voltage and frequency damages consumers' electrical appliances connected to the generator [4]. Electronic load controller (ELC) is a special circuit designed to keep MHPP and isolated wind turbine voltage and frequency constant by converting surplus power of the generator to dummy loads through electronic switches [5–7]. Mechanical hydraulic governor (MHG) used in conventional power plants for voltage and frequency control is not used in MHPP because of its high cost, bulkiness and technical expertise requirement [8].

The turbine rotational speed depends on the mechanical power of the water flow, and the generator speed depends upon the load connected to the generator [9]. If the water flow into turbine changes or the consumer load connected to generator changes, this causes an equivalent decrease or increase in the generator output voltage and frequency [10]. ELC, also known as a solid-state electronic device, is intended to control output power of the generator used in the MHPP [6]. In case of constant water flow into turbines, ELC keeps almost constant load on the generator by switching on and off dummy loads if consumer loads connected to generator decrease or increase. Hence, on a given constant water input, the generator generates a stable voltage and frequency. The reaction time of ELC is very fast, because it switches on and off dummy loads through electronic switches [11]. ELC keeps frequency and voltage at agreed value devoid of the need of an operator intrusions. Switching of dummy loads at peaks of sine waves can produces high sparks that damage electronic switches and consumer loads connected to the generator [12]. Also, the output of

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the generator will no more remains a pure sine wave [13]. This paper presents an effective technique through which switching of dummy loads at zero crossing will reduces sparks in switching and minimize damage of electric appliances [14]. The results show a pure sine wave in dummy loads and consumer loads connected to the generator in case the zero crossing switching technique is used. Fig. 1, shows a schematic diagram of a powerhouse with an ELC that keeps generator at full load. In this Fig. 1, Q shows the water discharge, H shows head. The turbine produces mechanical energy and the generator converts this mechanical energy into electrical power shown by P_G.

2. Mathematical calculation

The mechanical power (P_{mech}) available from a micro-hydro power turbine is equal to the product of effective head (H) and flow rate of water (Q), but practically, the turbine is not 100% efficient, so the turbine power (P_{mech}) is reduced by an efficiency factor (η_{turb}) [15].

$$P_{mech} = \eta_{turb}\rho gHQ \tag{1}$$

(P_{mech}) is the hydraulic power at the input of the turbine, which is used to drive generator. Typically, a synchronous generator has a rotary electro-magnet called the rotor, which rotates within a stationary set of conductors wound in coils on an iron core known as stator. Alternating current (AC) induced in stator winding, when the field provided by electro-magnet cuts across the conductors due to the mechanical input power from turbine causes the turning of the rotor. The electrical power (P_{elec}) produced by synchronous generator, is mathematically expressed in terms of mechanical power from turbine as [16]

$$P_{elec} = \eta_{gen}P_{mech} \tag{2}$$

Where η_{gen} shows efficiency of the generator

Generated frequency (f) depends upon the synchronous speed (N_s) and number of poles (p).

$$f = \frac{N_s p}{120} \tag{3}$$

Because of an ELC the power generated (P_{elec}) is always equal to power consumed in load connected to generator (P_{cl}) and dummy load power (P_{dl}) as shown in Fig. 2.

$$P_{elec} = P_{cl} + P_{dl} \tag{4}$$

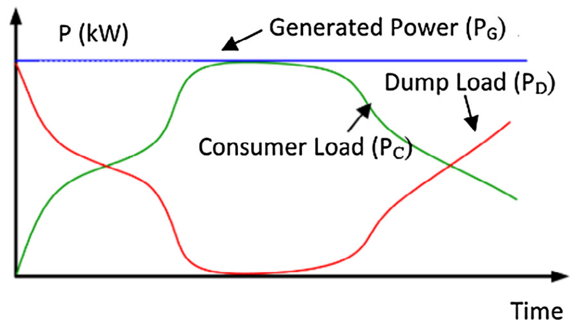

Fig. 2. ELC graph.

3. Simulink model of proposed system

Simulink model of the proposed system contains a 100 kW synchronous generator (SG) connected to 60 kW main load and two variable domestic loads as shown in Fig. 3. A 10 kW consumer load_1 is turned on at 1sec and turned off at 2sec through 3-phase breaker1. Similarly, 20 kW domestic load_2 turned on from 3sec to 4sec using 3-phase breaker2. The SG run at persistent input mechanical power, but switching of domestic loads causes fluctuations in frequency from set value. The ELC sense this fluctuation in frequency and turn on or off dummy loads connected to it. The generator output frequency, voltage, consumer load currents, and ballast load currents are shown by scope 1. The scope 2 shows generated power, consumer required power and dummy load power. The generator outputs are used as input for ELC and ELC give its output to ballast loads. The power line diagram of the proposed ELC design is shown in Fig. 4.

3.1. Switches and dummy loads

Dummy load block of simulink model contains switches and resistive loads as shown in Fig. 5. The switches block acquired signal from ELC and, according to a received signal, a dummy load is turned on or off. A total of eight switches, with three phase supply, switch on and off eight three phase dummy loads. The dummy loads are of various power. The low power dummy load is 2 kW and others are multiples of it. The low power dummy load is turned on when the difference in measured frequency and reference frequency is slight. In case of high difference, a heavy dummy

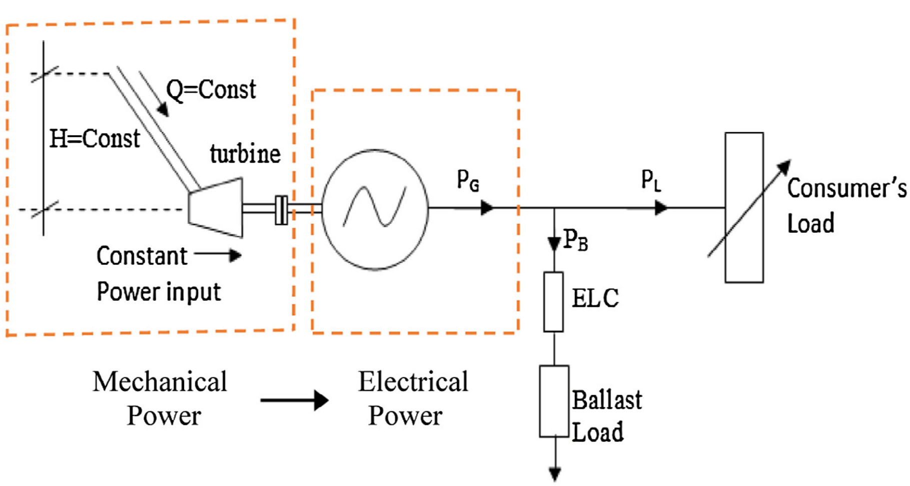

Fig. 1. Power house with an ELC.

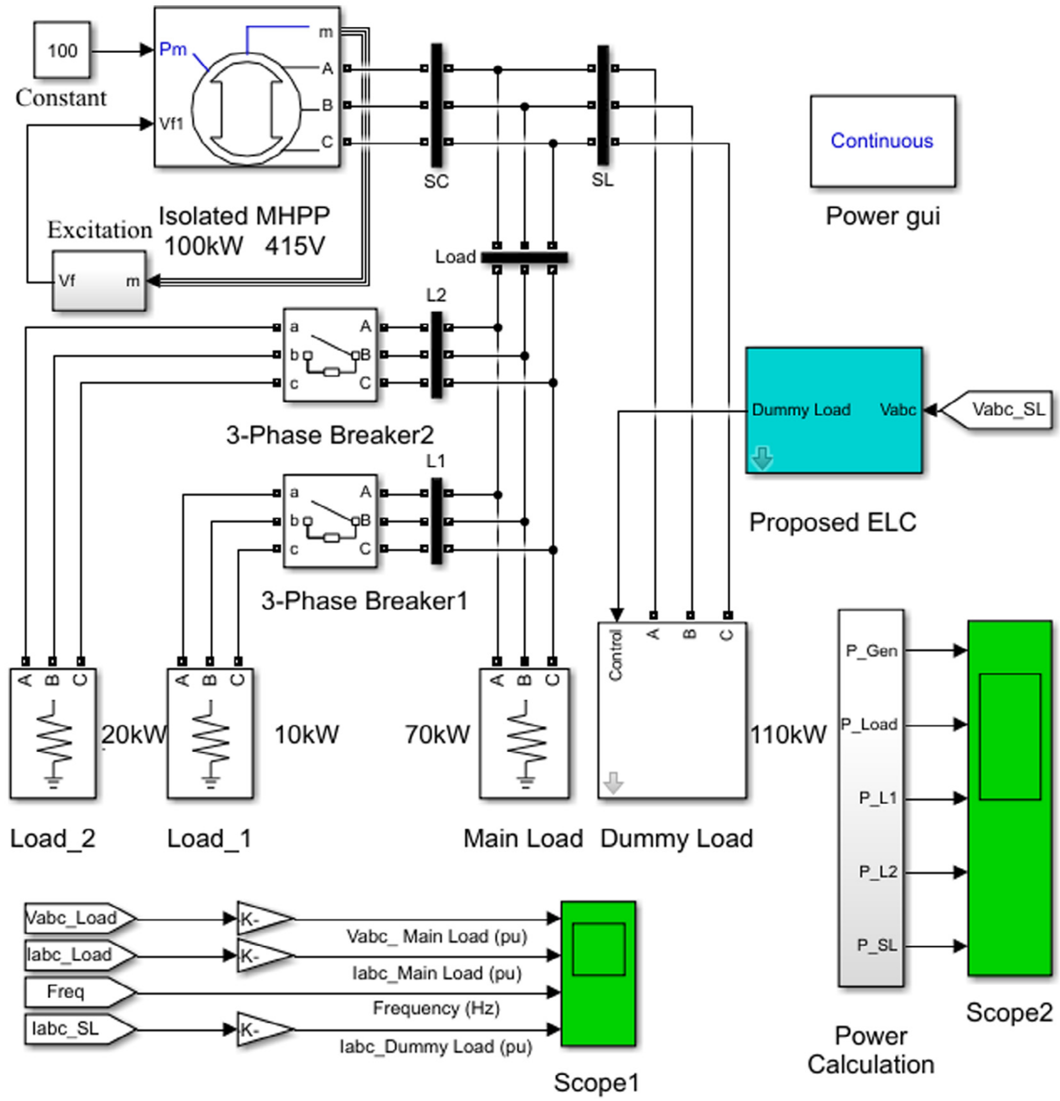

Fig. 3. Simulink diagram of proposed ELC design.

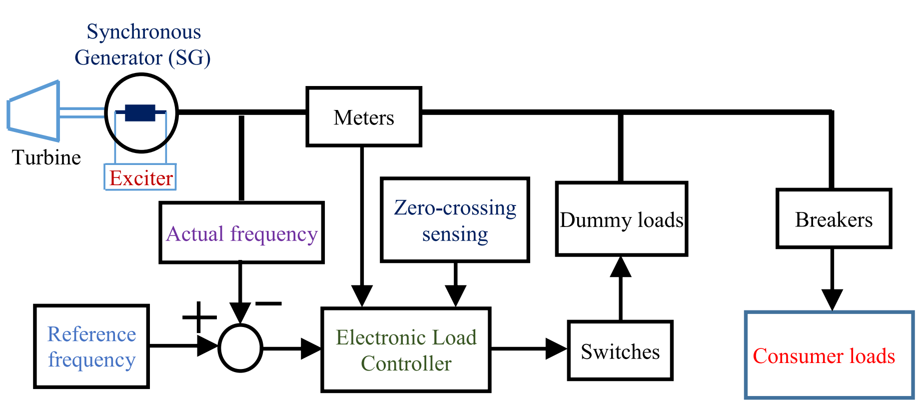

Fig. 4. Power line circuit diagram of proposed system.

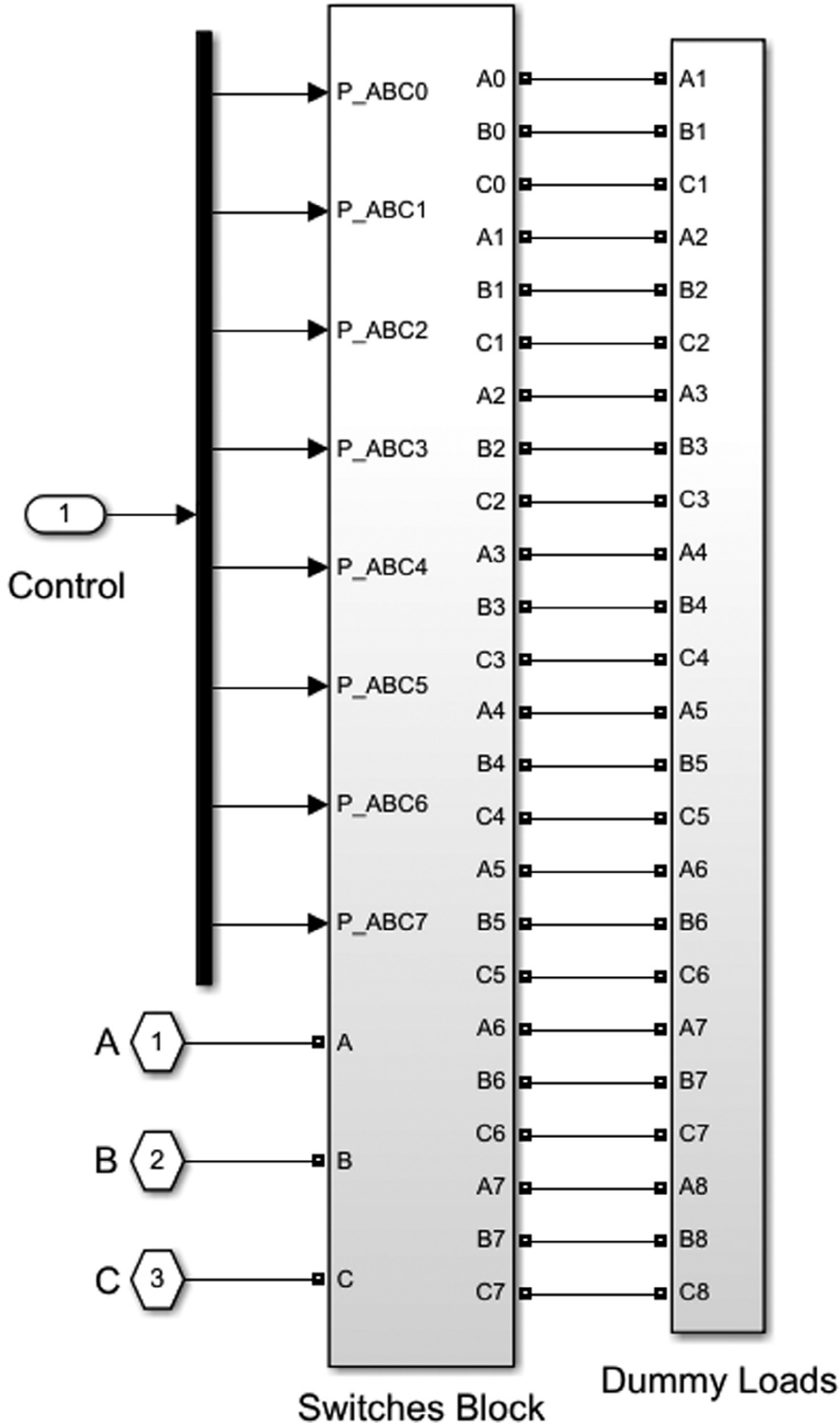

Fig. 5. Switches and dummy loads.

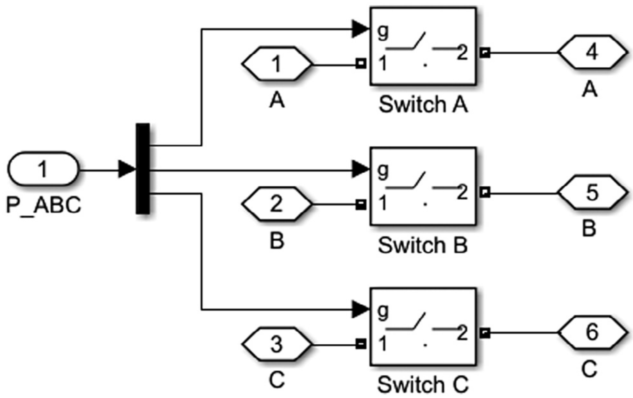

Fig. 6. Switches.

load is turned on through ELC. The switches are given in Fig. 6 and dummy loads are shown in Fig. 7.

3.2. Electronic load controller

ELC block of the proposed simulink model calculate generator output frequency and compare it with reference frequency. In case of difference in generated frequency and reference frequency, dummy loads are tuned on and off at the zero junctions of current and voltage in sinusoidal waveform. ELC consist of phase looked loop (PLL), proportional integral derivative (PID) controller block, code pulses block, and sampling system block as shown in Fig. 8. The PLL block compute generated voltage frequency and match with 50 Hz reference value. PLL block output is given to PID block. The proportional part of PID controller increase sensitivity, integrative measure helps in stability and derivative controller increase response of the controller. Pulse decoder block receive signal from PID controller and converts the PID analogue graph into digital pulses. These pulses are in the form of binary numbers. A small binary number is produced when the difference in measured frequency and reference frequency is low. But in case of high difference, a large binary is produced and heavy dummy load is switched on. The sampling block get a signal from pulse decoder block. Sampling block contain zero crossing section, logic switches, selector element as shown in Fig. 9. The zero crossing element detects when the sinusoidal wave AC waveform hit the zero offset value it produces 1 output. The logic switch passes input 1 when control input 2 is higher than threshold value; otherwise passes through input 3. The input 1 and input 3 are data ports and input 2 is control port. The selector specifies order of multidimensional input signal. Multiple dummy loads are turned on and off at the zero crossing of sine waveform with the help of sampling block.

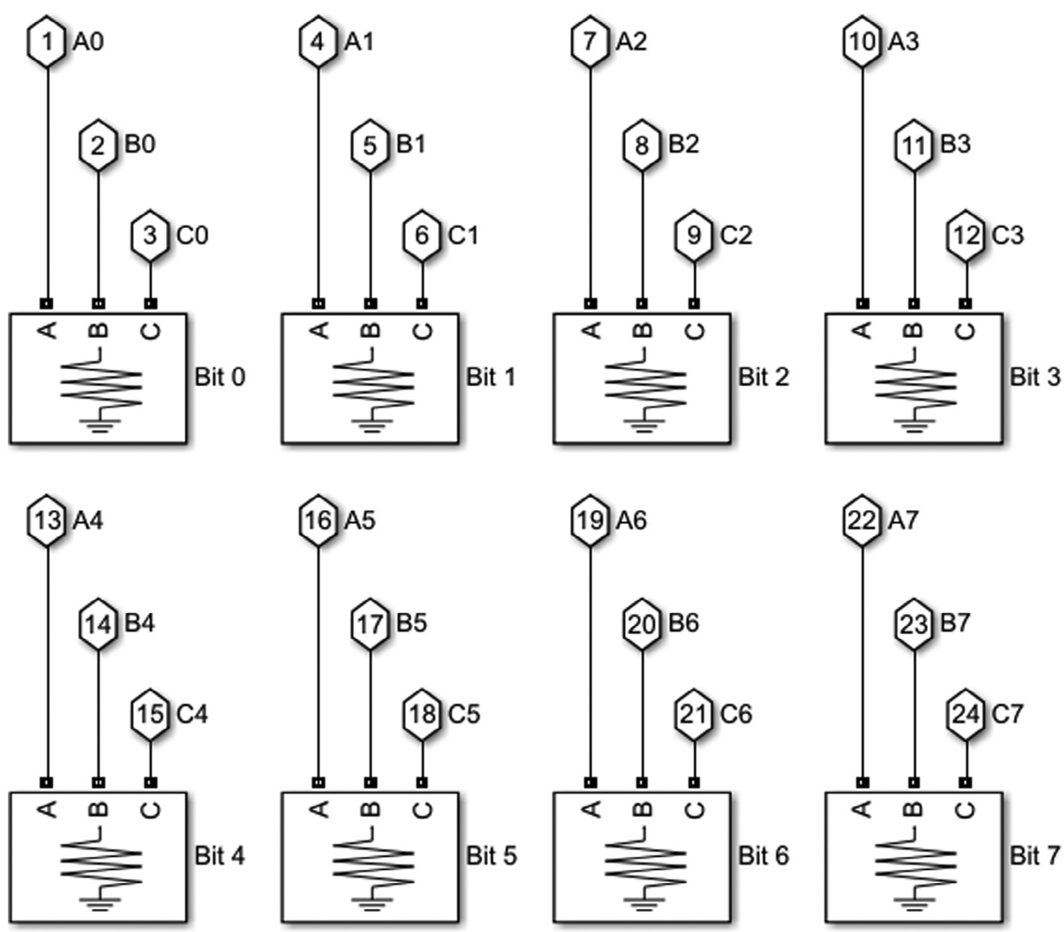

Fig. 7. Dummy loads.

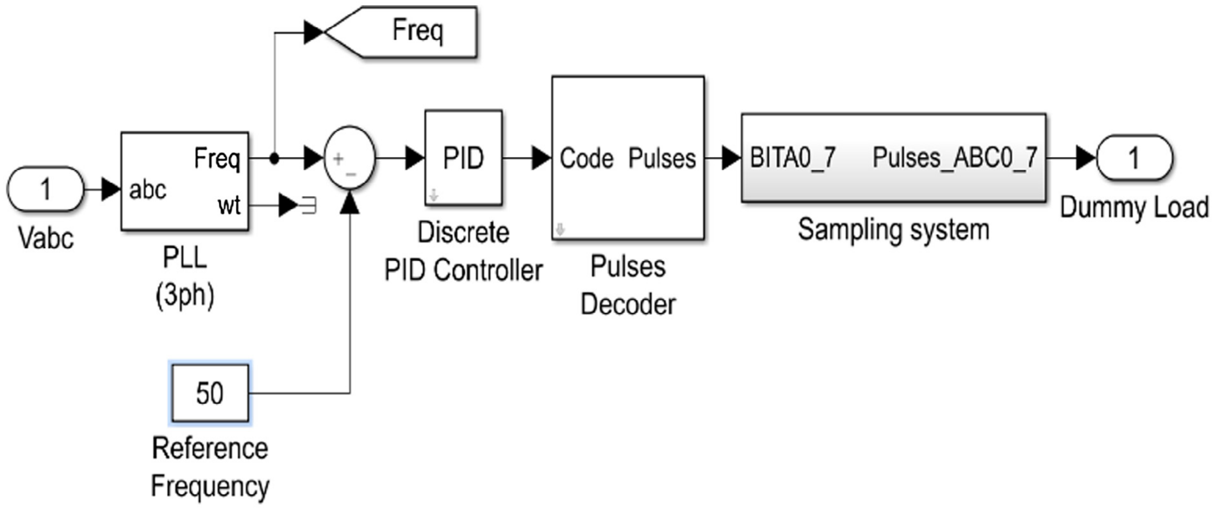

Fig. 8. Electronic load controller.

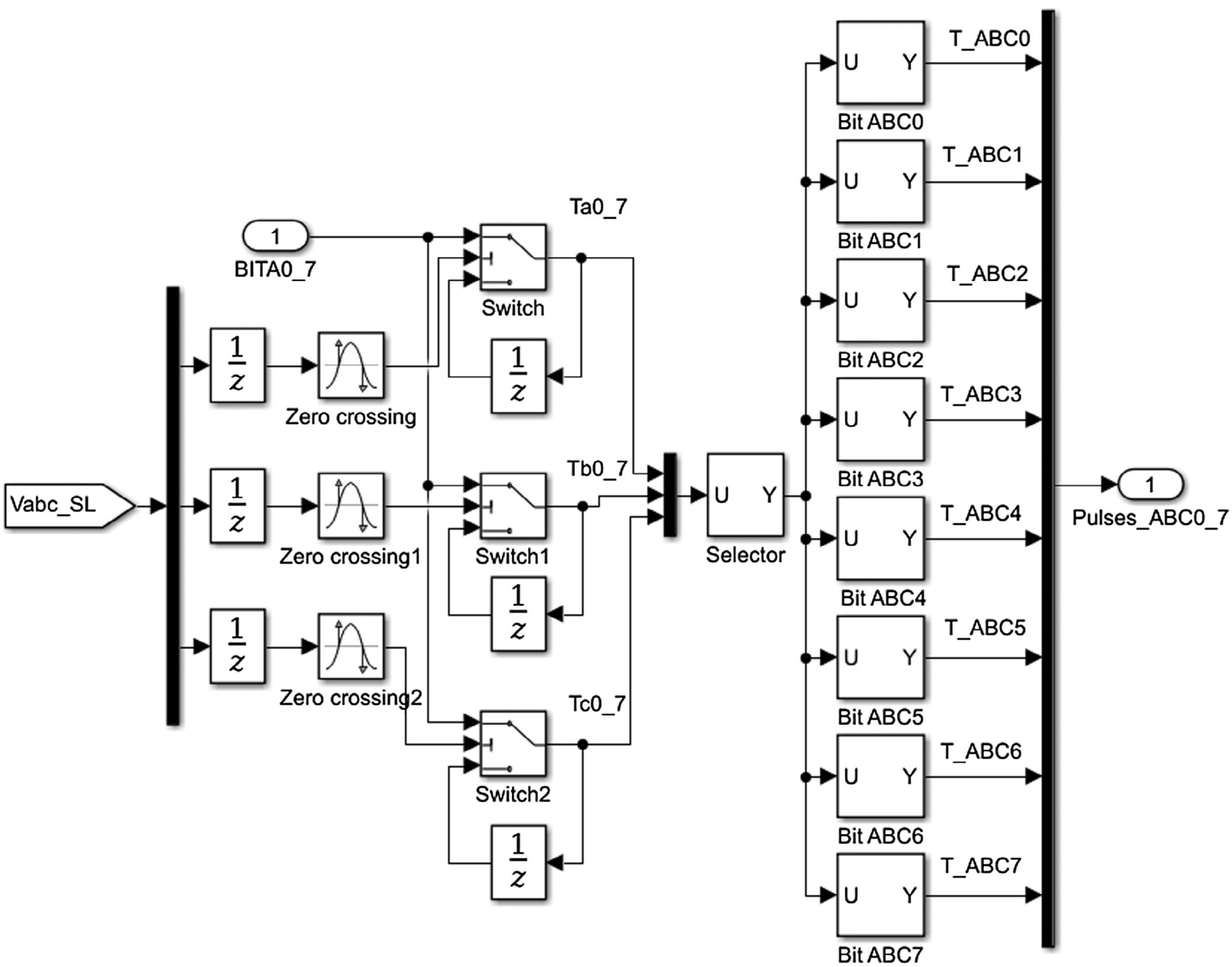

Fig. 9. Sampling block.

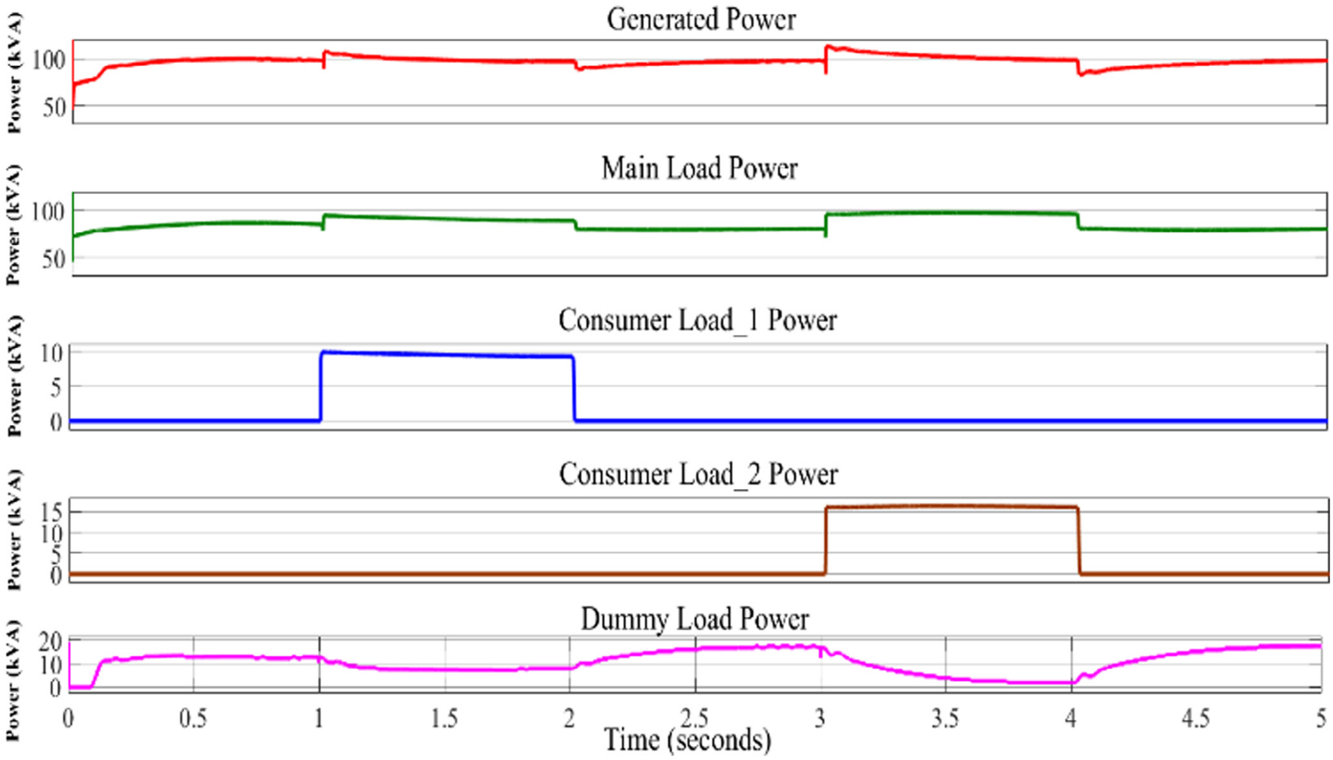

Fig. 10. Power graph at zero crossing switching.

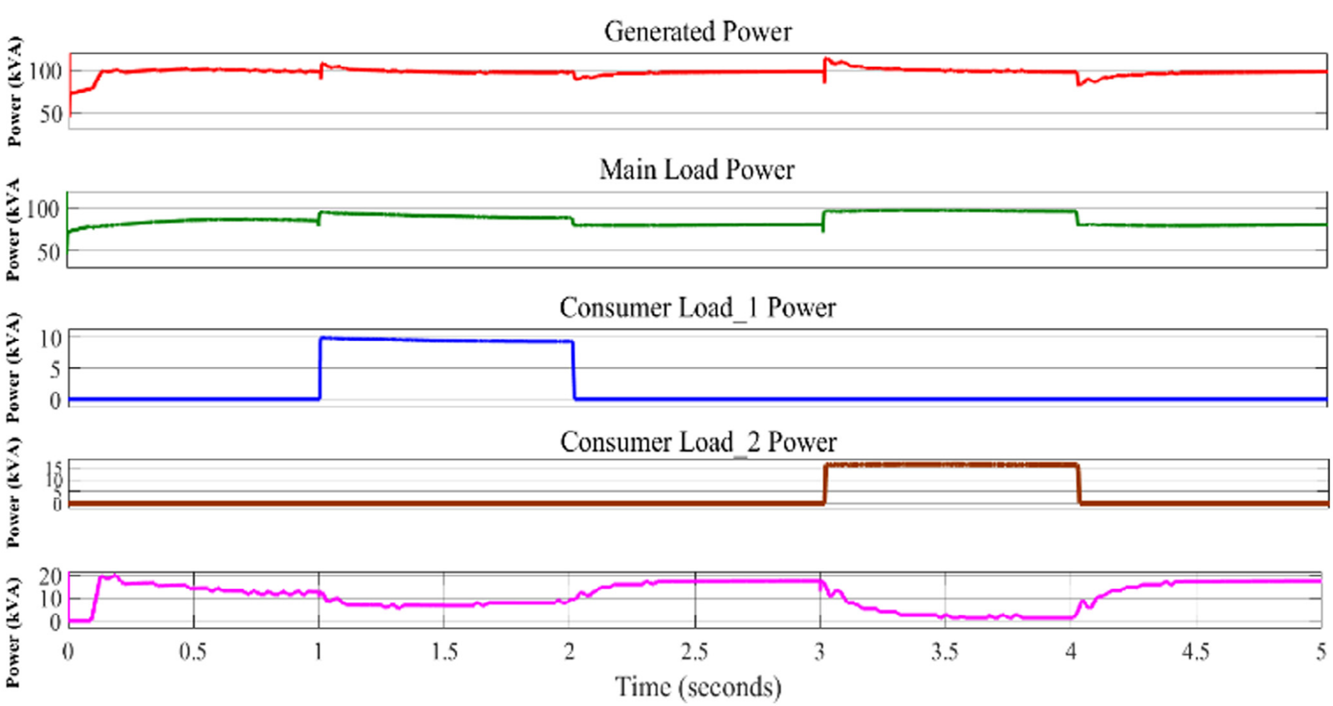

Fig. 11. Random switching power graph.

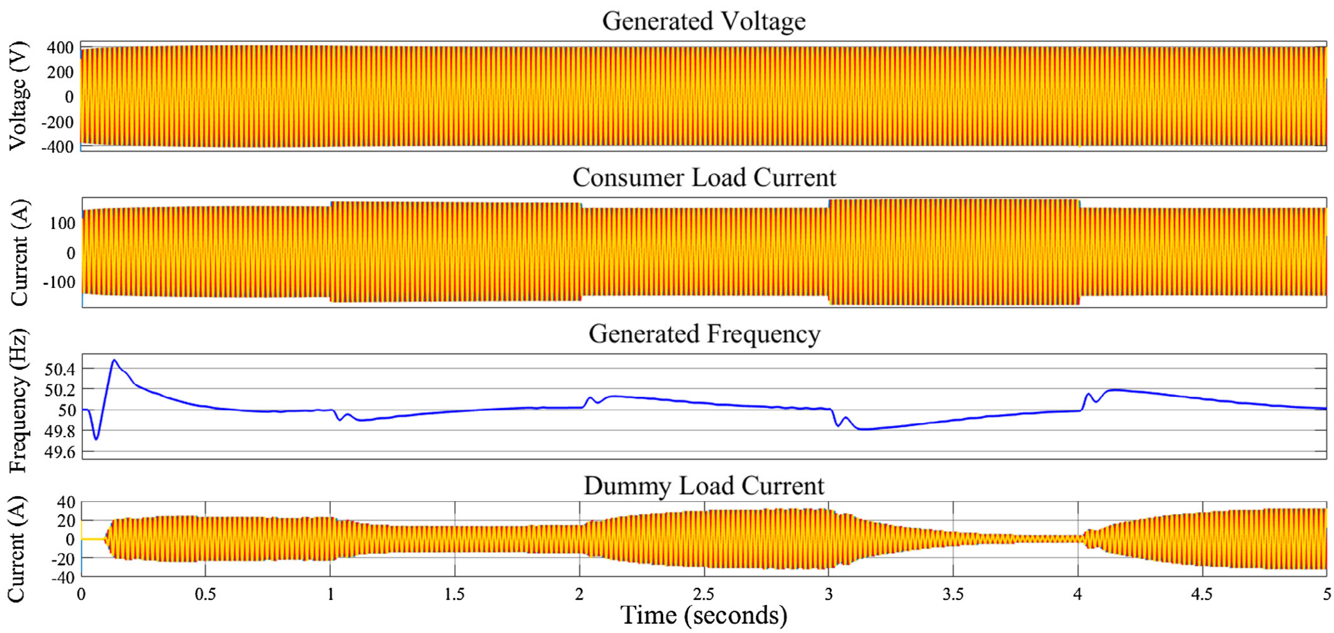

Fig. 12. Voltage, frequency and current graphs with zero crossing ELC.

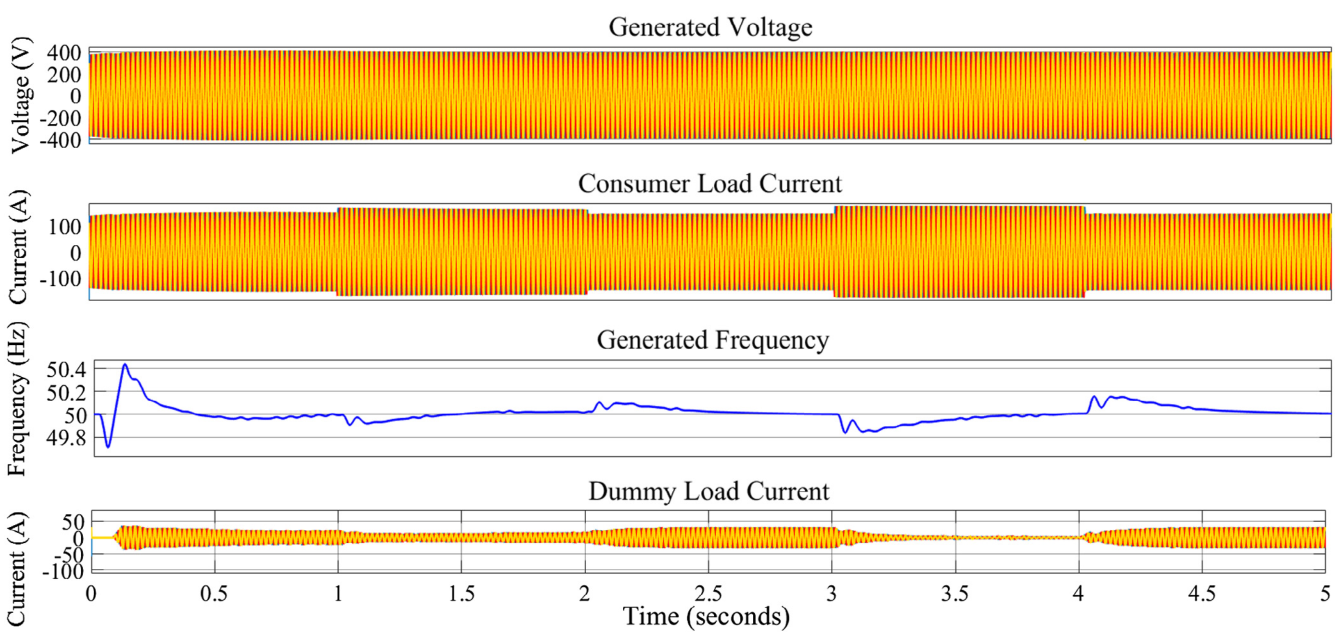

Fig. 13. Voltage, frequency and current graph.

4. Results

Simulation results of the proposed system in simulink cover random switching and zero crossing switching graphs. The zero crossing switching graphs are compared with random switching graphs and determined that zero crossing switching eliminates spikes, transients and harmonics in AC sinusoidal waveform. The scope2 results at zero crossing are shown in Fig. 10 and the random switching power graph is shown in Fig. 11. It comprises of generated power, consumer load power and dummy load power. Generated power is displayed on the top that is approximately 100kVA. Consumer load power is after that and is about 70kVA. 10 kW load1 is turned on from 1 s to 2 s for one second duration that causes an increase in consumer total load power. Similarly, load2 (i.e.20kVA) is switched on at 3sec and switched off at 4sec, due to which consumer total power increase and dummy load power decrease. The switching of these loads causes variation in speed and frequency of the generator, which needs to switch on and off dummy loads through robust ELC circuit. The dummy loads power is less when load1 or load2 is on but increases in case of load1 or load2 is off.

Voltage, current and frequency graphs at the zero crossing technique is shown in Fig. 12, while the random switching graphs are shown in Fig. 13. The generator output voltage is about 415 V

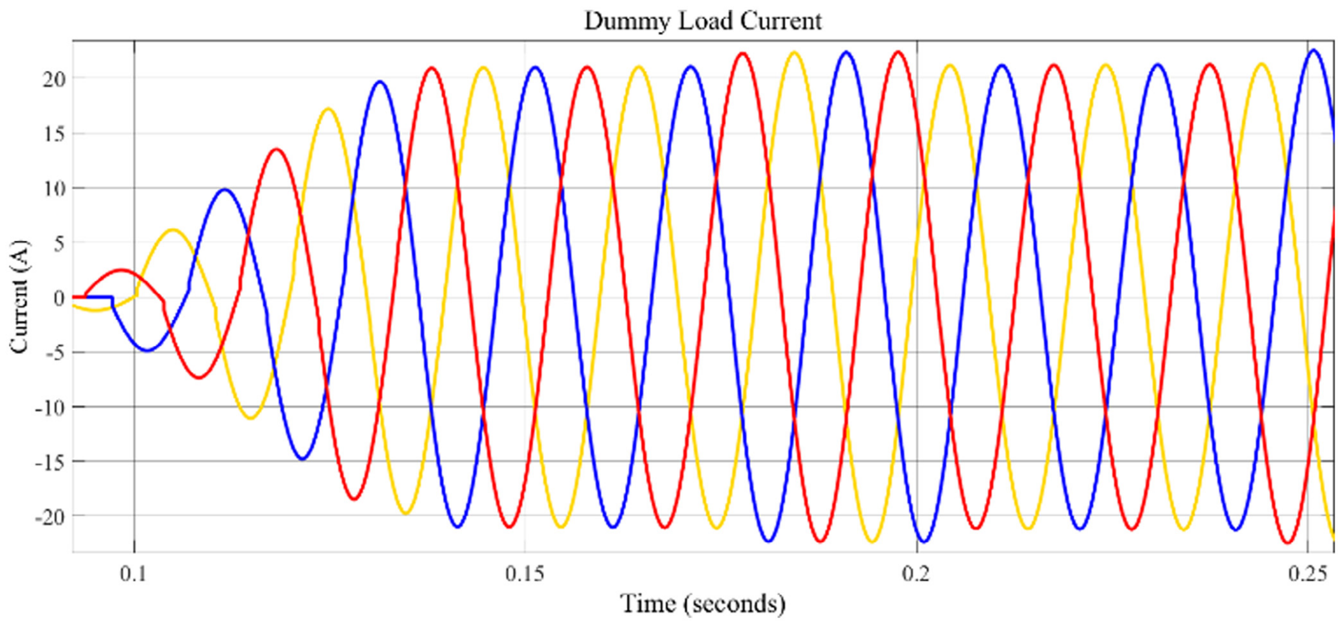

Fig. 14. Dummy load current zero crossing switching zoom-in graph.

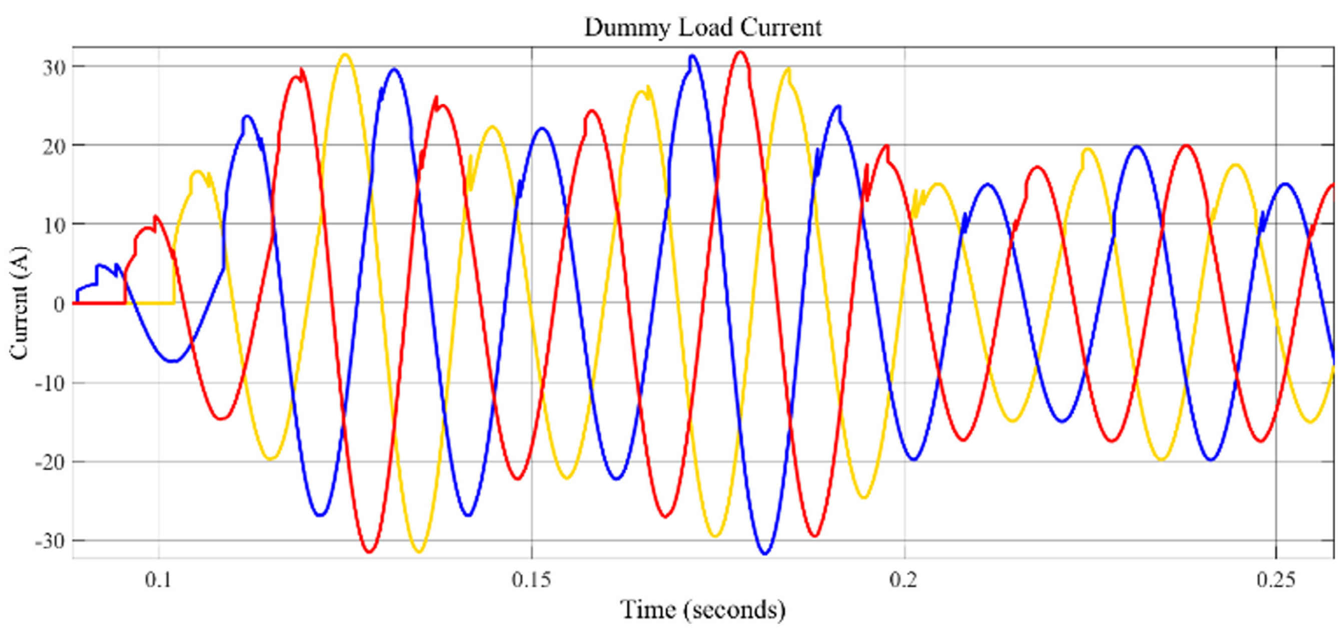

Fig. 15. Dummy load current random switching zoom-in graph.

(three phase), consumer load current for base load is 166A but increases to 176A when 10 kW load1 is turned on and change to 186A when load2 is turned on. The generator output frequency shown below the consumer load current is about 50 Hz because of ELC.

The dummy load current changes from 2A to 34A, which regulate generated power and consumer load power. The zero crossing graphs are smooth and shows a pure sine wave form while the random switching of dummy load causes harmonics and spikes in generator output frequency, voltage and currents. The wave form of generated voltage and consumer load current is not a pure sine wave, because the dummy loads are switch on and off haphazardly. The frequency also shows small fluctuations as compared to the graphs shown zero crossing switching.

To observe zero crossing switching and random switching difference more clearly, zoom in graphs of both are compared and discussed below.

As the generator output frequency increase from 50 Hz in beginning dummy loads are switched on. The Fig. 14, shows zero crossing switching of dummy load and Fig. 15, shows random

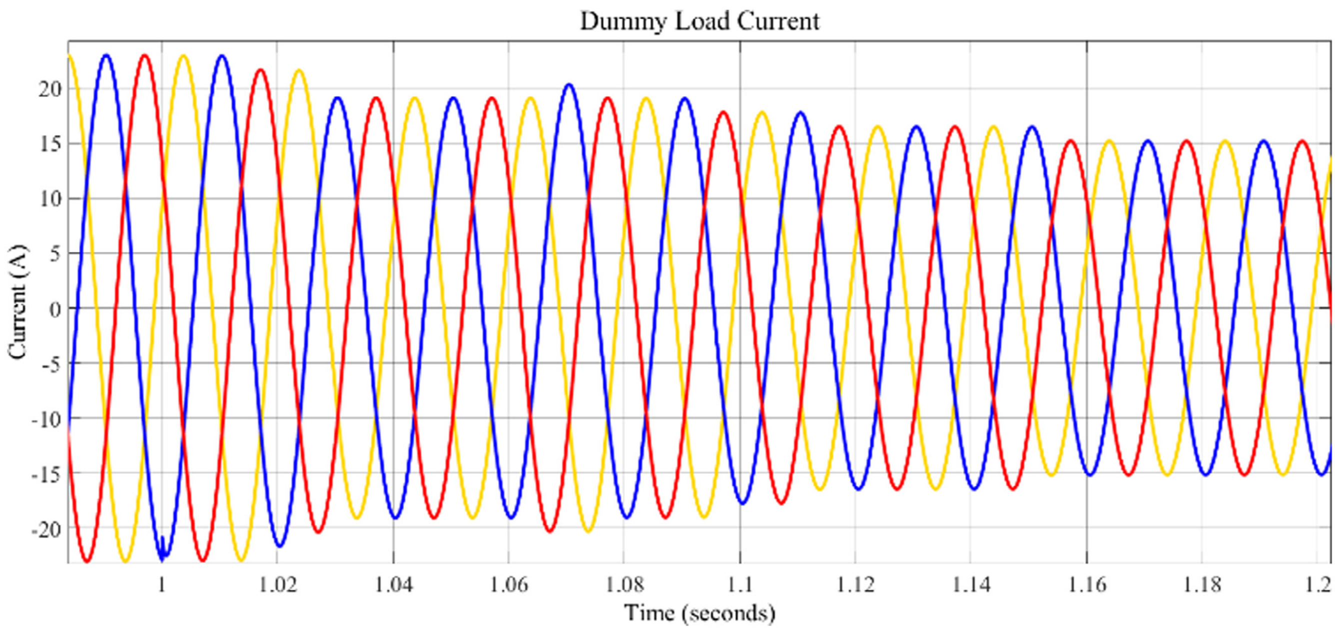

Fig. 16. Broader view of zero-crossing switching at 1sec.

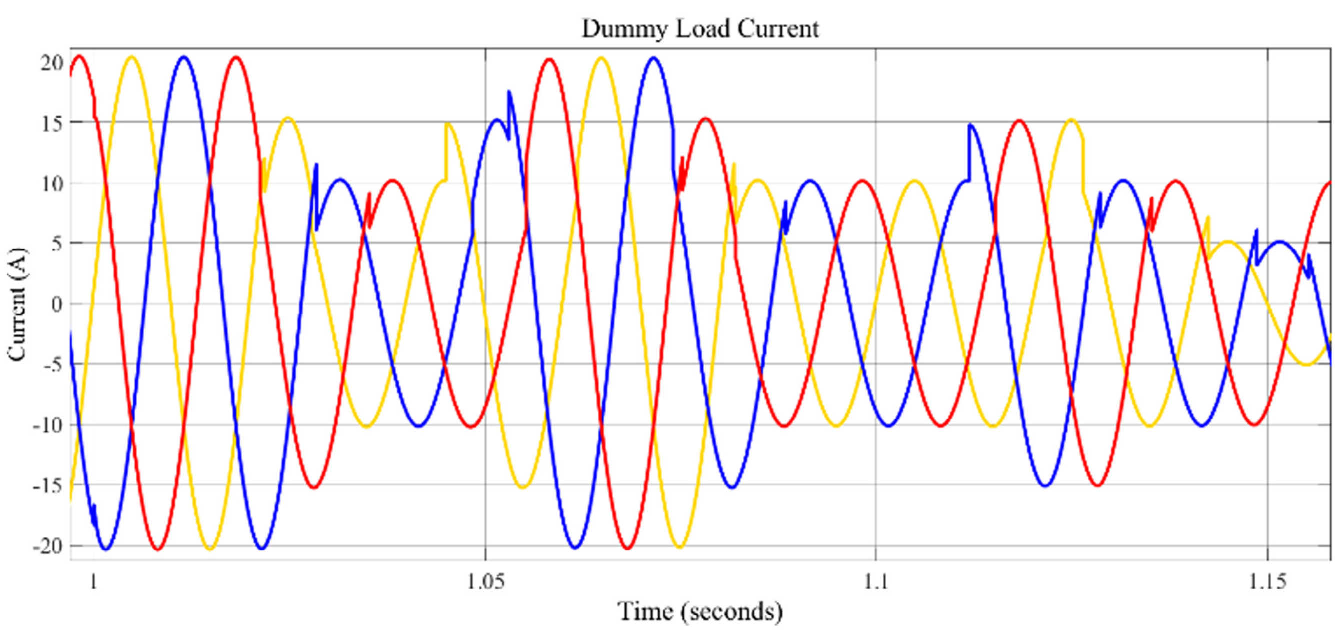

Fig. 17. Broader view at 1sec random switching.

switching of dummy load. The zero-crossing switching graph shows a pure sine wave in dummy load current while the random switching of dummy load shows spikes in sine wave. The spikes in dummy load also causes spikes in consumer load current that damage users appliances. The dummy loads are tuned on and off due to variation in frequency and the frequency variation is due to difference between generated power and consumer load required power.

When consumer load_1 is switched on at 1 s, dummy load start decreasing. The broader view of zero crossing switching of dummy load is given in Fig. 16, and random switching graph is shown in Fig. 17. 10 kW load1 is switched on at 1sec due this

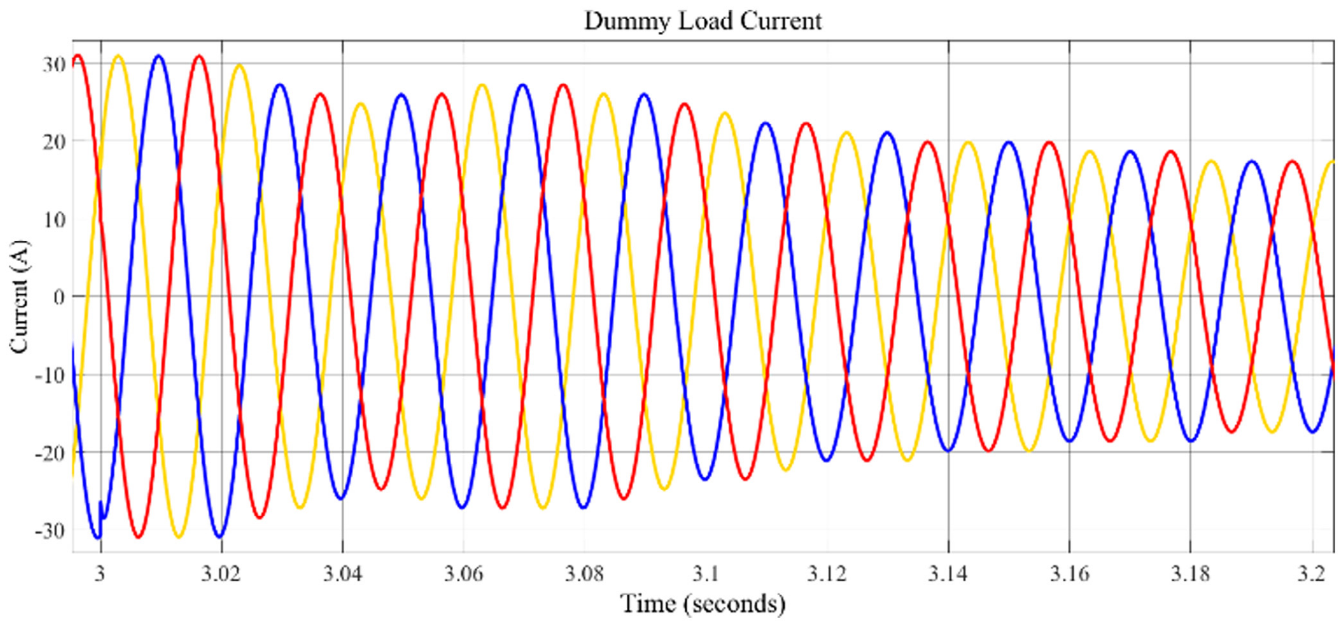

Fig. 18. Zoom in graphs at 3sec of dummy load switching at Zero-crossing.

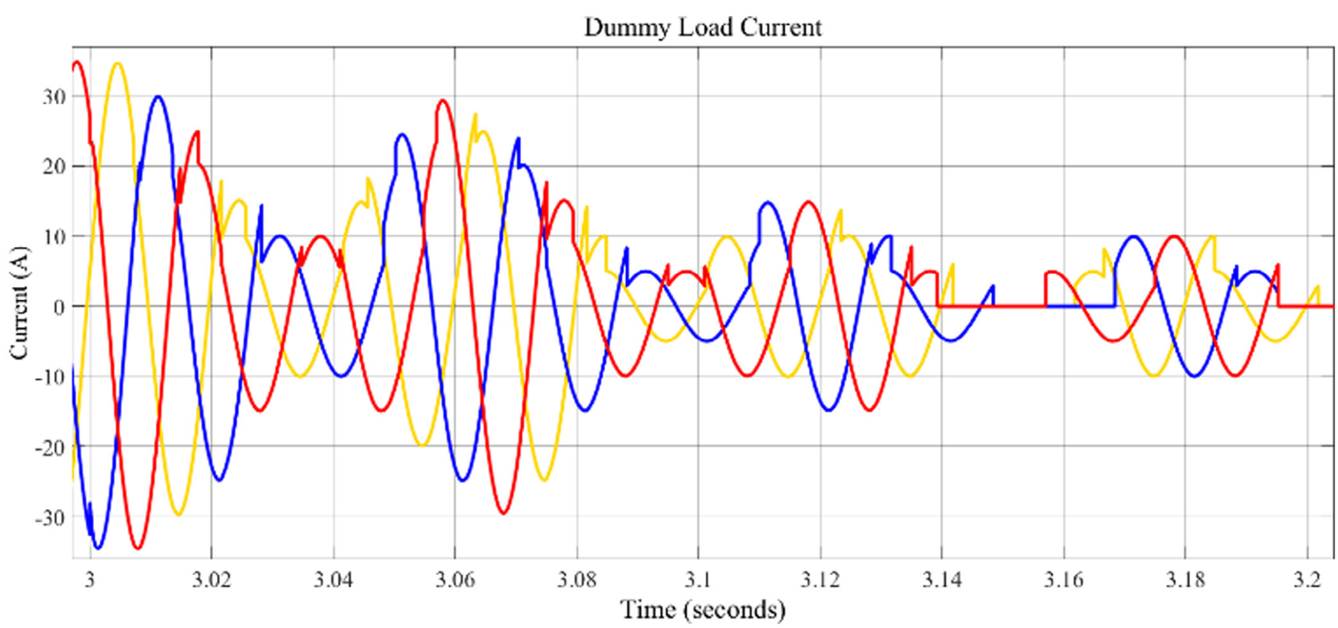

Fig. 19. Dummy Load Current Zoom in graphs at 3sec Random Switching.

generator output frequency fall from 50 Hz, the dummy load current is decreasing to keep frequency at set value 50 Hz. The zero crossing of dummy loads gives a smooth sine wave while the random switching of dummy load gives spikes, transients and harmonics.

Consumer load2 is switched on at 3sec that causes a decrease in frequency; thus, the dummy load current is decreasing to keep generated frequency at set value, 50 Hz. The zero-crossing switching and random switching of dummy loads are given in Fig. 18, and Fig. 19, respectively. The zero-crossing switching gives a pure sine wave while the random switching of dummy loads shows spikes in the current. These spikes in dummy load current also produces spikes in consumer load current that can cause impairment in the load connected this generator.

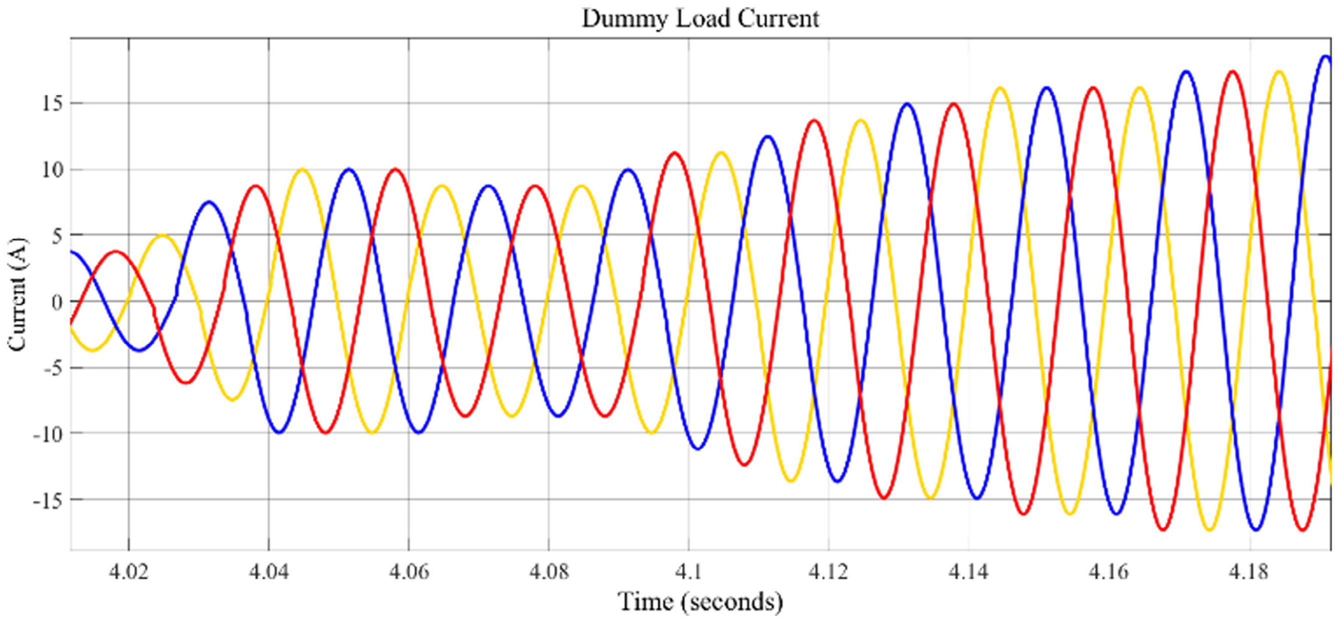

Fig. 20. Zero crossing switching of dummy loads at 4sec.

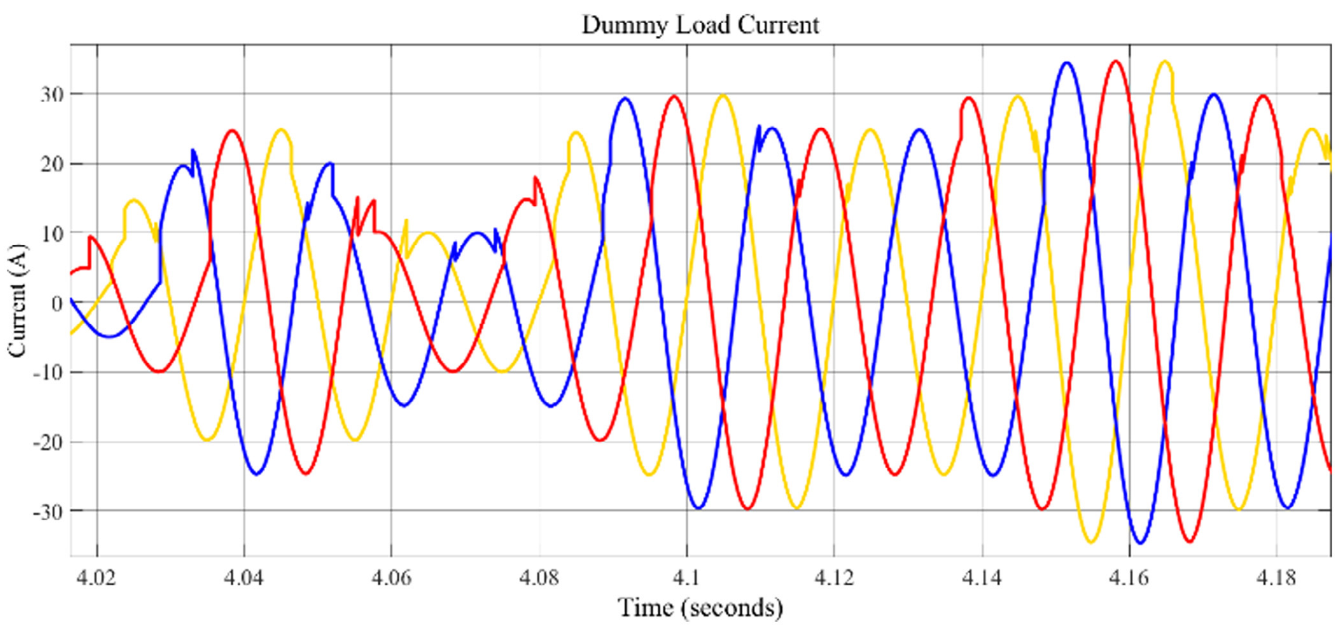

Fig. 21. Random switch on and off dummy loads at 4sec.

Consumer load2 is turned off at 4sec due to which the generated power is more than consumer required power. The dummy loads are switched on with zero-crossing technique shown in Fig. 20. The current through dummy loads show pure sine waves, in this case. But, when the dummy loads are switched on at 4 s randomly, this produced spikes in dummy load current as shown in Fig. 21.

The proposed system total harmonic distortion (THD) with zero crossing switching and random switching is calculated and given in Figs. 22 and 23 respectively. The zero-crossing switching technique shows 3.5 percent total harmonic distortion while the random switching shows 24.2 percent THD. These graphs verify that the proposed zero-crossing technique eliminates THD in generator output voltage.

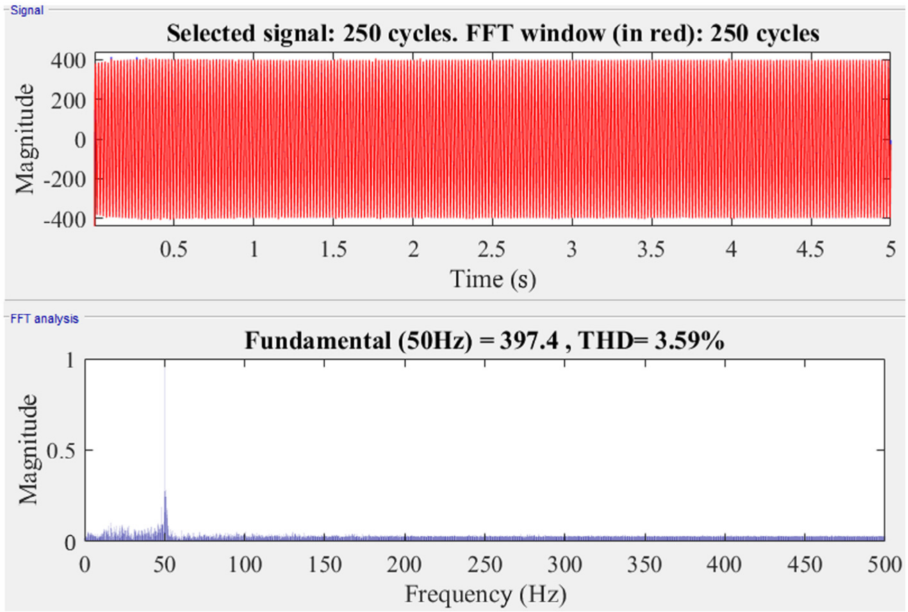

Fig. 22. ELC zero-crossing THD graph.

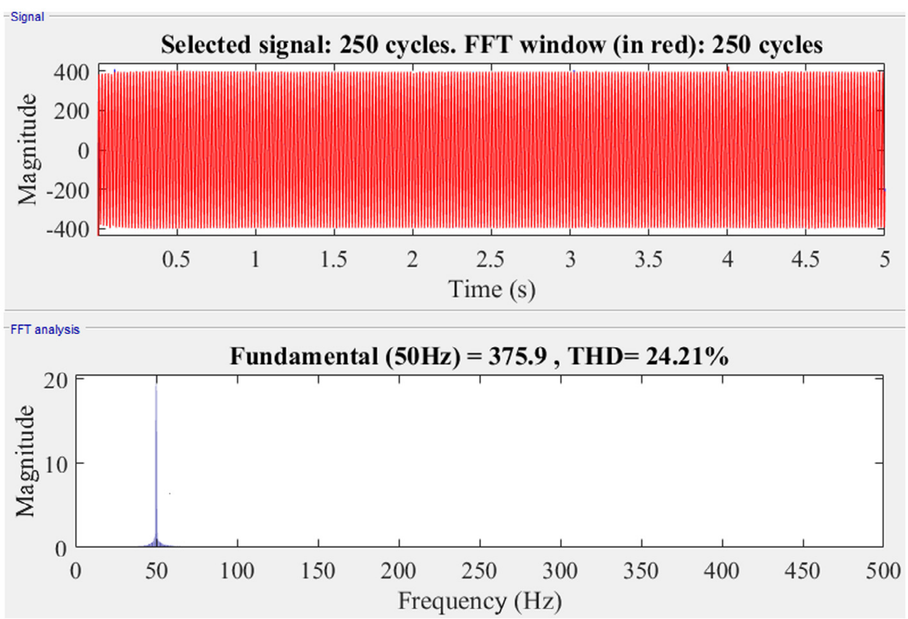

Fig. 23. ELC random switching THD graph.

5. Proteus model

The proposed system is designed in Proteus software with 10 kVA generator as shown in Fig. 24. The generator output voltage and frequency is calculated and compare with reference value. In case of variance from reference values dummy loads are turned on and off. The step down transformer converts 220 V to 9 V. The resistors and capacitor is used to keep this 9 V less than 5 V comparably and given to pin1 of Arduino mega 2560 controller. Frequency of the generator is calculated through bridge rectifier, optocoupler and given to pin 13. Triac is used to turn on and off water heaters as dummy load. Light emitting diode (LED) connected with triac shows switching of dummy load. The simulation result shows that when frequency of the generator increases from 50 Hz a dummy load is switched on at zero crossing of the sinusoidal waveform. The 20x4 liquid crystal display (LCD) screen show generator output voltage, current, frequency and power.

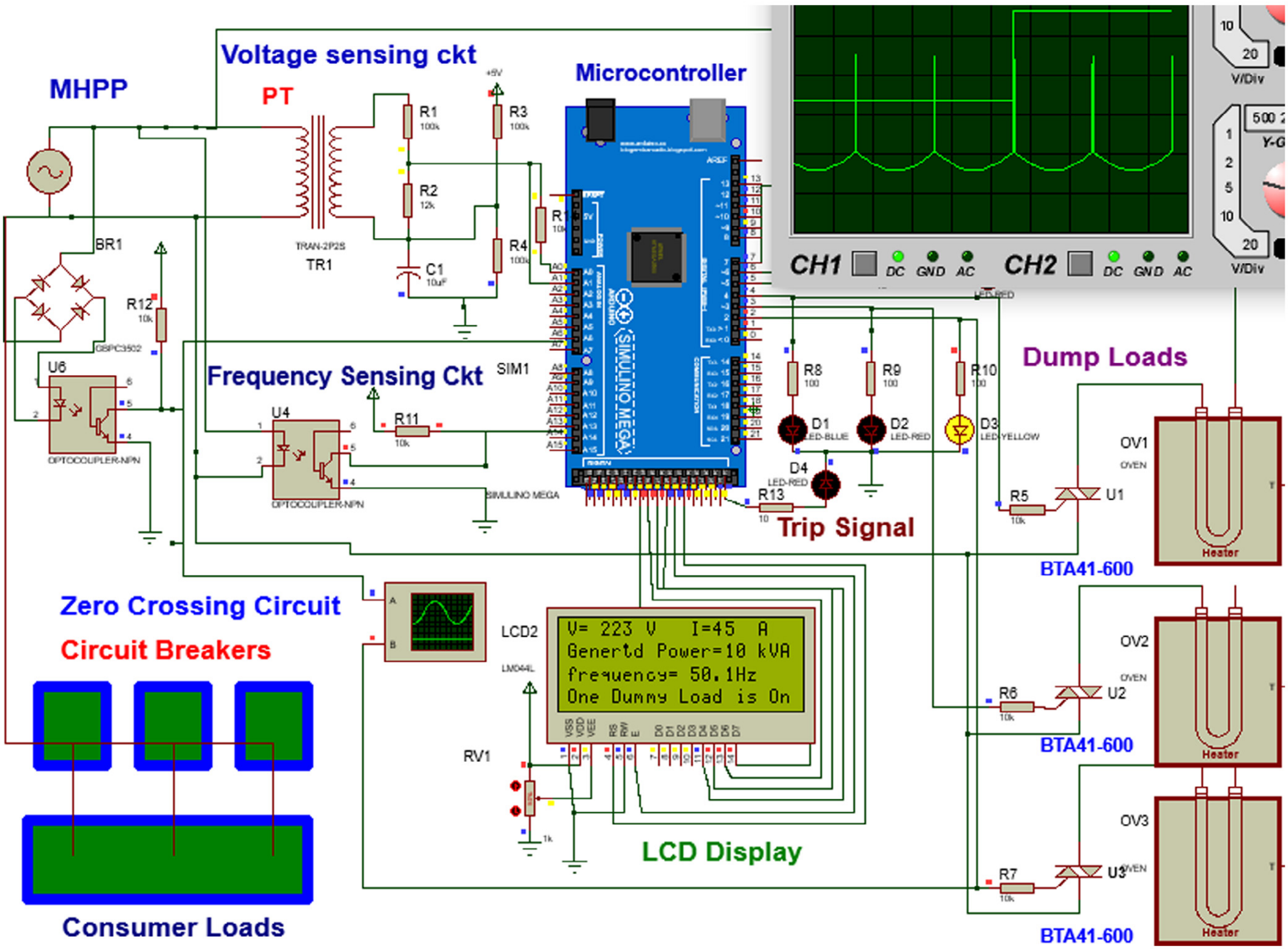

Fig. 24. Proteus model.

The block diagram of the proposed ELC design is shown in Fig. 25. The main components of the proposed ELC design are:

1. Voltage and frequency sensing circuit
2. Constant direct current (DC) power supply circuit
3. Arduino-mega 2560 controller, optocoupler and LCD display
4. Dummy load power circuit
5. Consumer load circuit

6. Hardware model

An experimental model of the proposed system is a design for lab test shown in Fig. 26. Arduino mega 2560 controller is programmed to compare generator output voltage and frequency with reference values. When the calculated values are more than reference values, dummy loads are turned on at the zero crossing of sine wave using moc3021 and triac. A 9 V step down transformer (PT) and potential divider circuit is used to sense generated voltage and given to pin1 of Arduino mega. Current transformer (CT) sense the flow of current to consumers' load and given to Arduino analogue pin zero. Frequency of the generator is calculated from the time between two consecutive zero crossings using PT and optocoupler. The generator outputs and dummy load condition is displayed on LCD screen.

7. Conclusion

To validate the zero-crossing idea, two software models and an experimental model are tested in lab. The simulink model results with zero crossing switching and random switching of dummy load is compared and found that zero crossing switching give smooth sinusoidal waveform while the random switching wave form is not pure sinusoidal. The proteus model results validate Arduino code that it is switching dummy load at the zero crossing of sine wave. The proteus model is trailed in experimental model. The zero crossing idea eliminates power losses in switching, damages in electronic components, spikes, transients and harmonics. It decreases damages in consumer load and increase lifetime of dummy loads.

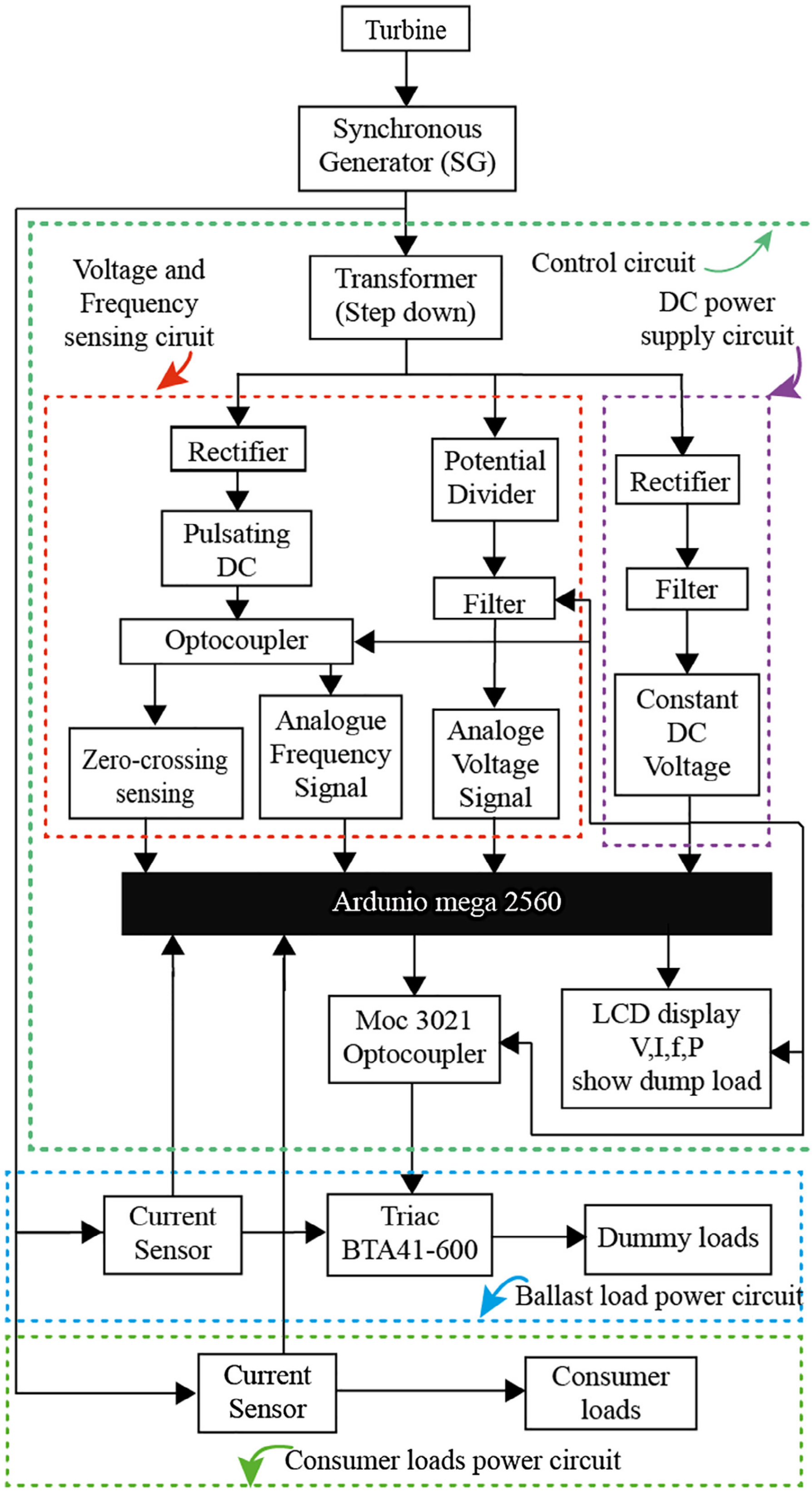

Fig. 25. Block diagram of proposed ELC scheme.

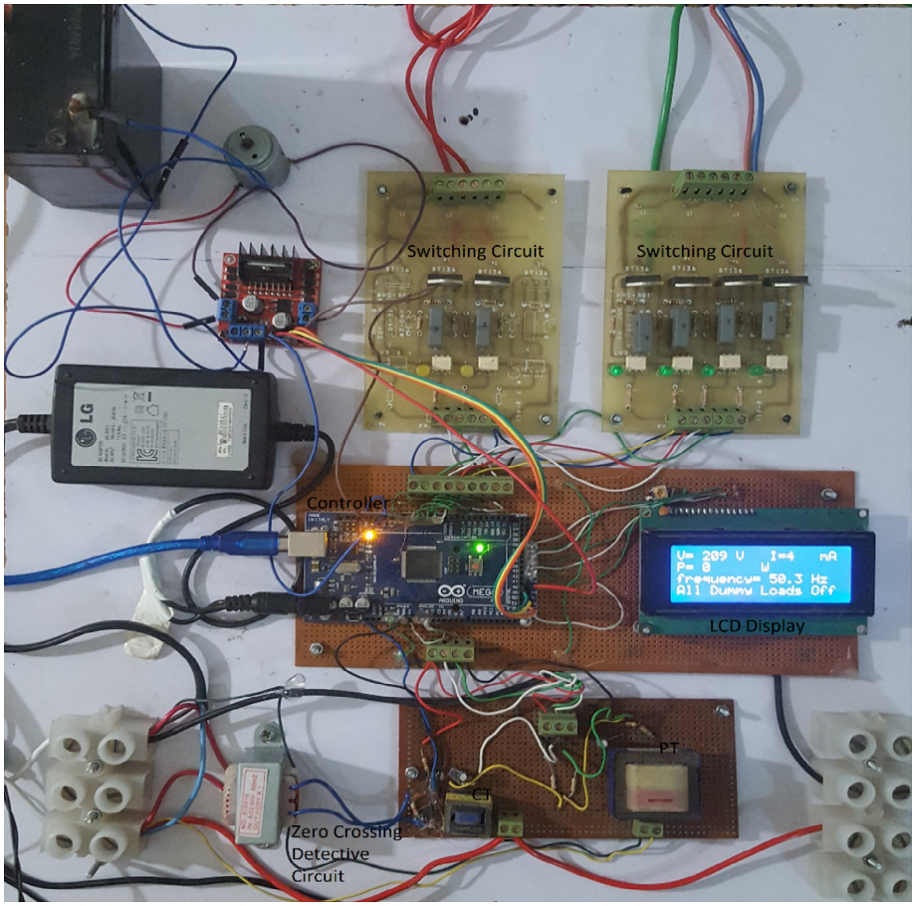

Fig. 26. Experimental model.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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