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Design and Implementation of an Automatic Changeover Switch with Generator Trip-off Mechanism

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ABSTRACT : The power supply in most developing countries like Nigeria is highly characterized by frequent or constant failures/outages. This adversely affects industrial development and productivity. Consequently, most households, offices, small and medium scale enterprises (SMEs) and multinationals depend on the electrical generator as alternative power supply, hence the need for an automatic changeover switch to facilitate automatic changeover between the mains supply and a generator. Thus, this project sets to present the design and implementation of an automatic changeover switch with a generator trip-off mechanism. The system uses relays, integrated circuits, transistors and electromechanical devices. The design was simulated with the aid of Multisim software and the prototype circuit was implemented. The experimental results from the prototype corroborate with the stimulated results.

KEYWORDS *- Power supply, Automatic switch, Trip-off mechanism, Multisim, Electro-mechanical devices*

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I. INTRODUCTION

Recurrent power outages in developing countries in which Nigeria is one have compelled the need for design and implementation of an intelligent switch to change over the supply from the power utility to that of a stand-by generator. The automatic change-over switch monitors the three phases of the public power supply and initiates the turning on of the generator and changing over of the supply whenever either of the phases of the power utility is delivering below the normal voltage or completely off; and switching back to the public power supply, whenever the normal phase voltages are restored [1, 2].

Though the era of fluctuation and failure in the supply of electricity is long forgotten in many industrialized nations of the world, many developing countries still suffer setbacks arising from incessant power failures. The provision of alternative power source (generators) has no doubt brought succour but not without an attendant challenge associated with manual operation of the changeover [3, 4] therefore, the need for an automatic changeover. Automation of power generation is required as the rate of power outages becomes predominantly high [5]. If the processes of the changeover are manual, time is wasted, mal-operation and equipment damage can also result from overloading at the changeover. In order to eliminate downtime, an automatic changeover switch is required [6 - 8].

The need for a steady source of power has called for an alternative source of power especially in Nigeria where power failure is prevalent. The introduction of these alternative sources of supply brings forth the challenge of switching smoothly and timely between the mains supply and the alternative sources whenever there is a power failure. There is also the need to reduce drudgery from switching between the two sources on the human side. Solving these challenges forms the focus of this work. The automatic power change-overs witch is a device that links the load and mains supply or the alternative supply together. This enables the use of either the mains supply or an alternative source when there is an outage on the mains source. This can either come in with three-phase or single phase. This device maintains a constant power supply to the load by automatically activating the generator when there is a need.

Due to the inherent features of the switching devices, this paper presents the design and implementation of an automatic changeover switch with generator trip-off mechanism, which switches electrical power supply from public supply to generator, in the event of a power outage. The system uses an electronic control circuit involving integrated circuits, transistors and electromechanical devices.

II. CONCEPTUAL BLOCK DIAGRAM

The conceptual block diagram of the proposed automatic change-over switch comprises the power supply, delay switch unit, generator trip-off switch, relay and the load blocks. The system consists of the power supply circuit, which functions as an AC/DC converter used to supply power to other components of the system, delay switch unit, mains supply, generator cut-off switch, relay and the load.

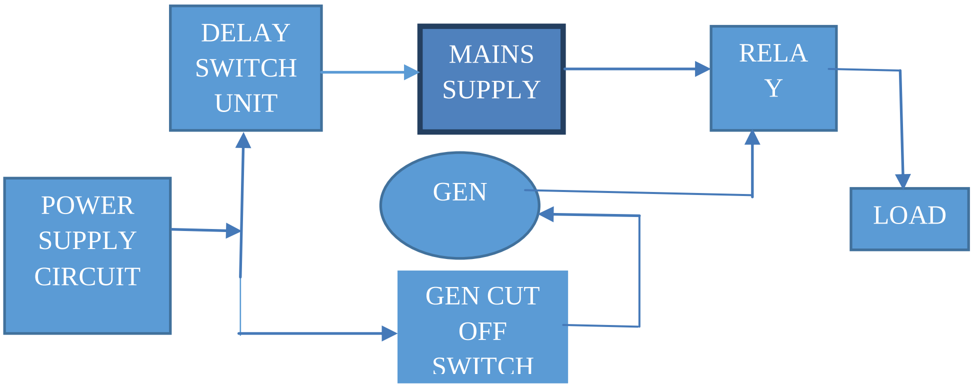

Figure 1 Conceptual Block Diagram of the proposed Automatic Change-over Switch

III. SYSTEM DESIGN AND ANALYSIS

In this section, all mathematical formulae and equations utilized for the selection of components are discussed. It also contains explicit and comprehensive analysis, specificationsand assumptions adopted in designing the system. For analysis, the circuit diagram is separated into segments and each analyzed independently.Since cost, availability and compatibility of component are major constraint of this work, the components were carefully selected based on their fast response, moderate power consumption and good noise immunity in other to achieve the desired output.

3.1 Power supply unit

The circuit of power supply unit shown in Fig. 2 is tapped from the power utility and rectified to power the circuitry. The main function of thepower supply circuit is to convert *AC to DC*. The first stage makes full-wave rectification from the a.c signal by employing a bridge rectifier. The rectified DC voltage is then filtered by using the filtering capacitor to smoothen the resulting DC signal. Finally, appropriate voltage regulators (LM7812) are selected to keep the DC signal within specified ranges.

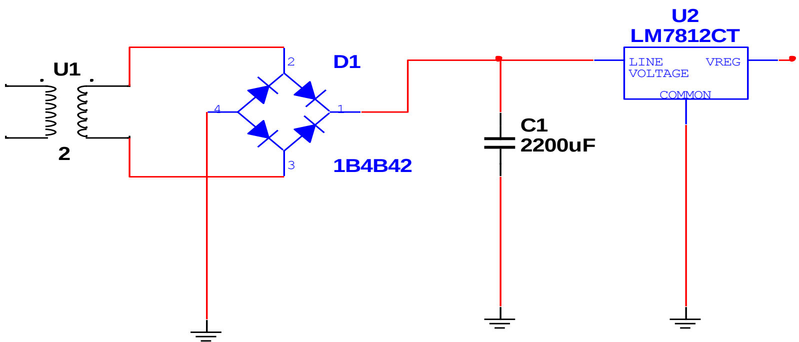

Figure 3 Power Supply Unit using Center-Tapped Transformer

Input voltage = 240 V
Output voltage = 12 V
The maximum output current 500 mA = 0.5 A
Therefore, power (VA) required = 12 x 0.5 = 6 VA

$$I = C\frac{dV}{Dt} \quad (1)$$

where I = current rating of transformer = 500 mA

C = capacitance of the electrolytic capacitor

dV = rated value of d.c. voltage of the transformer multiplied by √2 minus voltage rating of the signal.

dt = T = period of oscillation of the signal.

I = 500 mA;

dV_1 = 12 √2 - 12 = 4.97 V

dV_2 = 12 √2 – 5 = 11.970 V

dt = T= I/f = 1/50 Hz

Using equation (1), the value of capacitor can be obtained as:

$$0.5 = \frac{4.9C_1}{1/50}$$

$\therefore \quad C_1 = 2012$ μF with 2200 μF as preferred value

3.2 Change-over switch

The changeover comprises a relay, which serves as a switch, as shown in Fig. 3.

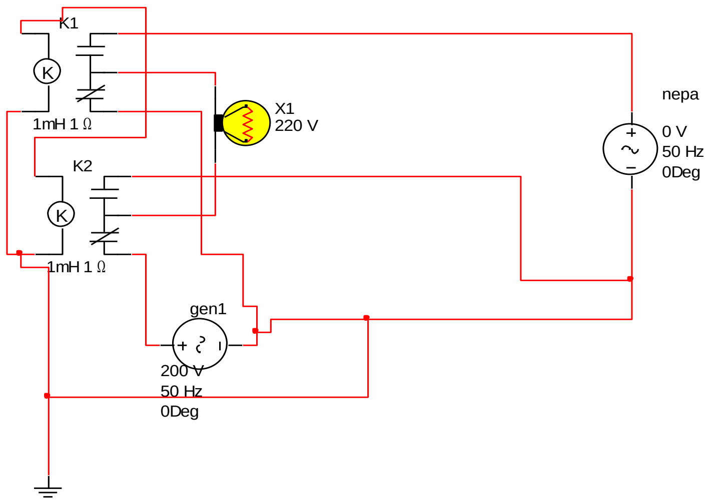

Figure 3 Changeover switch

When current passes through the coil of the relay, it has the effect of magnetizing a soft iron plate that is drawn to the coil and closes the contact, which is normally open. The contact is used to switch on the load.When the output voltage energies the relay, the relay switches on thereby closing the circuit and supplying power to the load via the mains supply. Once power from the mains supply goes off, the relay falls back to the normally closed contact wired to the generator hence supplying power to the load via the generator. The two relays are used to provide the live and neutral wire for single-phase load.

3.3 Generator cut-off switch

The circuit of Fig. 4 is utilizedin the analysis of the generator cut-off switch. The normally closed contact NO of the relay is wired to the starting coil of the generator hence, once closed the generator starting coil energies supplying power to the load. When the relay is energized by the presence of mains supply, the normally open contact closes, disconnecting the generator starting coil automatically thus, tripping it off and automatically connecting the load to the mains supply.

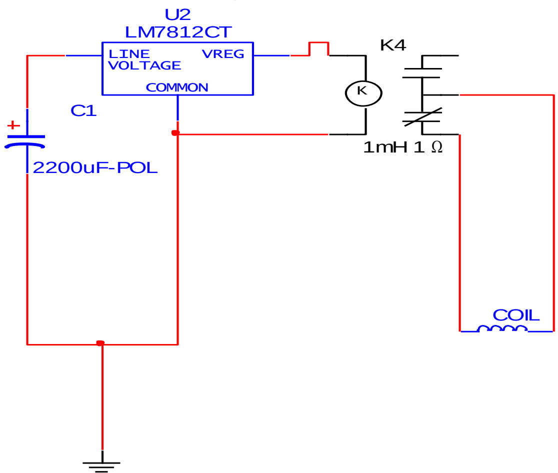

Fig. 4 Diagram of the cut-off switch

3.4 Astable mode circuit

The 555 timer can be connected to run as an Astable multi-vibrator. When used in this way, the 555 timer has no stable states, which implies that it cannot remain indefinitely in either state. Stated in another way, it oscillates when operated in the Astable mode and produces a Square or Rectangular output signal [9].The general equation of the voltage across a capacitor in an RC network is given by equation (2)

$$V_x = V_{final} + \left(V_{initial} - V_{final}\right)e^{-\frac{t}{\tau}} \quad (2)$$

Where $V_{initial}$ = initial capacitor voltage at t = 0

V_{final} = final capacitor voltage at t = ∝

τ = time constant

The schematic diagram of the astable 555 Timer is shown in Fig. 5.

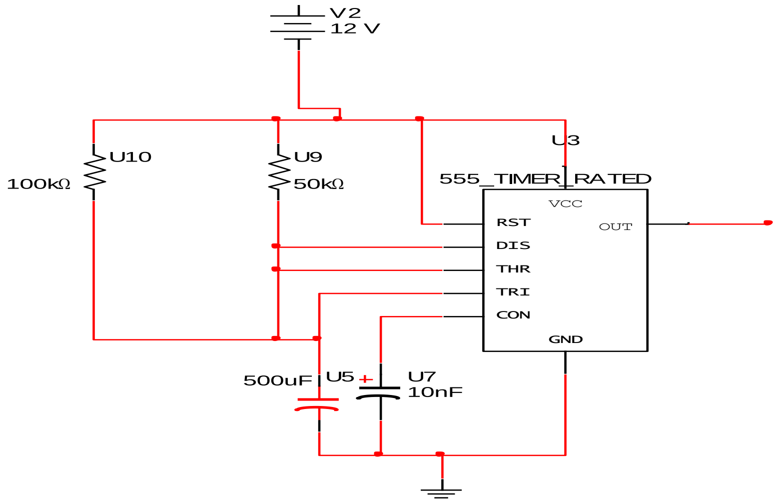

Figure. 5 The schematic diagram of the Astable 555 timer

When the timing capacitor is charging during the time $0 < t < Tc$, the capacitor voltage is expressed as equation (3).

$$V(t) = \frac{1}{3}V^+ + \frac{2}{3}V^+\left(1 - e^{-\frac{t}{\tau_A}}\right) \quad (3)$$

Where, $\tau_A = (R_A + R_B)C$. At $t = T_C$, the capacitor voltage searches the threshold level given thhe expression in equation (4).

$$V_{(T_C)} = \frac{2}{3}V^+ = \frac{1}{3}V^+ + \frac{2}{3}V^+\left(1 - e^{-\frac{T_C}{\tau_A}}\right) \qquad (4)$$

The charging time, T_C of the timing capacitor can be obtained by solving equation (4).

$$\frac{2}{3}V^+ = \frac{2}{3}V^+ + \frac{1}{3}V^+ - \frac{2}{3}V^+e^{-\frac{T_C}{\tau_A}} \qquad (5)$$

Further simplification of equation (5) andsubstituting for τ_A yields equation (6).

$$T_C = 0.693\,(R_A + R_B)C \quad (6)$$

When the timing capacitor is discharging during the time 0<t< τ_D, the capacitor voltage is as equation (7).

$$V_{(t)} = \frac{2}{3}V^+e^{-\frac{t}{\tau_B}} \qquad (7)$$

where $\tau_B = (R_B)C$. At time $t = T_D$ (discharge time), the capacitor voltage reaches the trigger level given by equation (8).

$$V_{(T_D)} = \frac{1}{3}V^+ = \frac{2}{3}V^+ e^{-\frac{T_D}{\tau_B}} \tag{8}$$

Upon simplification, equation (8) gives an expression of equation (9).

$$T_D = 0.693(R_B)C \tag{9}$$

The period T of the astable timer cycle is the sum of charging period T_C and the discharging period T_D

$$T = T_C + T_D \tag{10}$$

$$T = 0.693(R_A + R_B)C + 0.693(R_B)C$$

$$T = 0.693(R_A + 2R_B)C \tag{11}$$

The frequency of oscillation is obtained using equation (12).

$$f = \frac{1}{T} = \frac{1}{0.693(R_A + 2R_B)C} \tag{12}$$

The duty cycle of an RC circuit is defined as the percentage time the output is high during on period of oscillations. During the charging time Tc, the output is high, during the discharging time, the output is low. Therefore, the duty cycle is given by equation (13).

$$Duty\,cycle = \frac{(R_A + R_B)}{(R_A + 2R_B)} \times 100\,\% \tag{13}$$

The duty cycle approaches 50% for $R_A < R_B$ and 100% for$R_B < R_A$.The duty cycle of the timer circuit is taken to be 75% and the required period for the load to change over to the generator once mains power is OFF is taken to be 7 seconds. Thus, using equations (11) and (13), the values of R_A , R_B and C were obtained.

$$7 = 0.693(R_A + 2R_B)C \tag{14}$$

$\frac{75}{100} = \frac{(R_A + R_B)}{(R_A + 2R_B)}$ and taking $R_A = 100\ k\Omega$, R_B is obtained as $50\ k\Omega$ with a preferred value as $56\ k\Omega$. Substituting for R_A and R_B in equation (14), the value of C can be obtained as $C = 505\,\mu F$ but a preferred value of $500\,\mu F$ was selected.

The complete circuit diagram for the automatic changeover switch with generator trip-off mechanism is as depicted in Fig. 6.

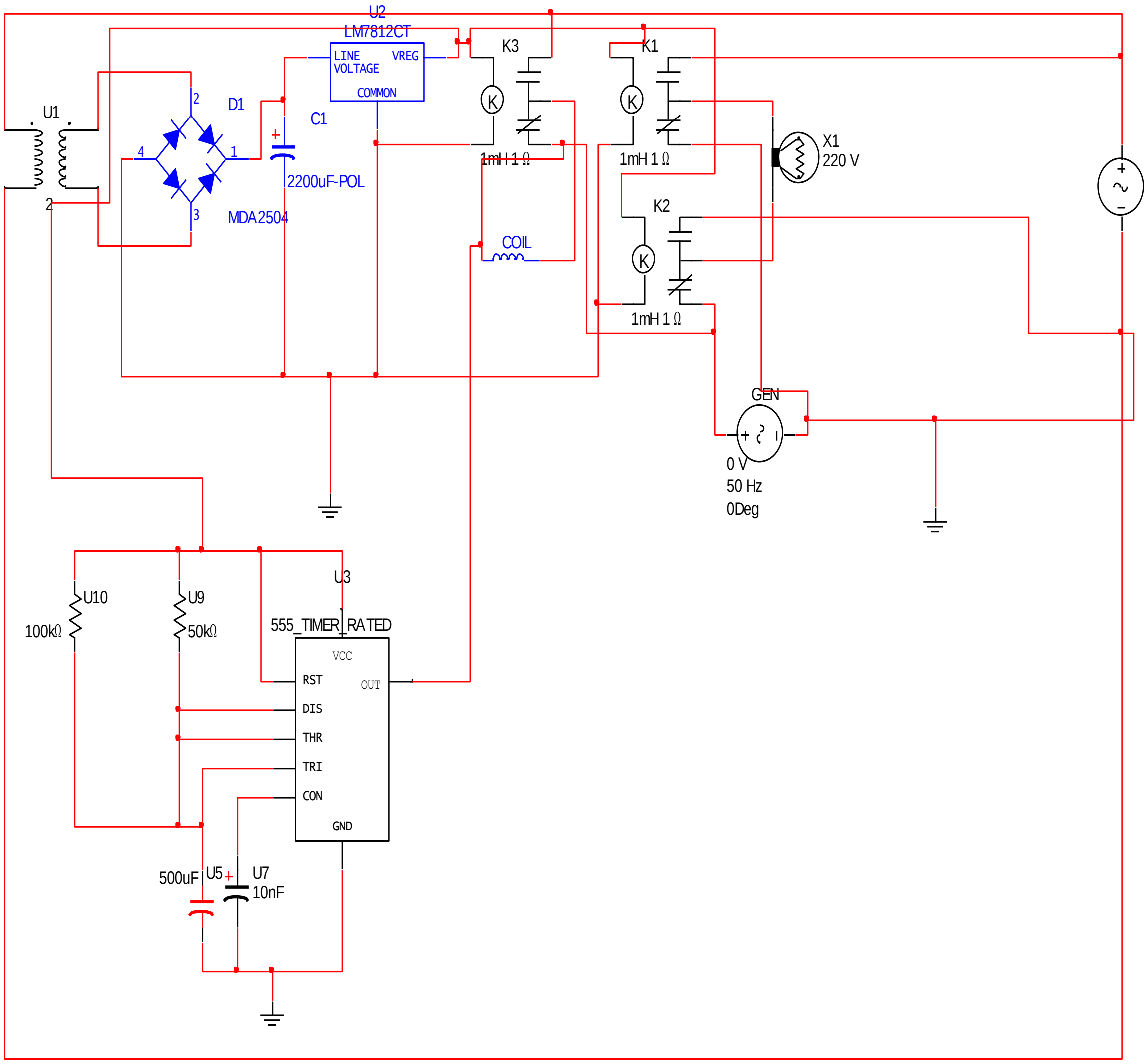

Figure6 Circuit diagram of automatic change over switch with generator trip-off mechanism

3.5 Complete circuit diagram description

The circuit consists of a power supply unit, which consists of a single transformer, rectifying diode D1, filter capacitor C1, and voltage regulator LM7812 which gives a 12VDC output. The output of LM7812 serves as the public mains supply to the circuit supplying both live and neutral. The transformer is rated 220/15V, 10A. The output of the transformer is rectified, filtered and regulated to 12VDC which is used in the circuit as Vcc for the dome of the circuit components such as a relay, 555 timer among many others.The load for this project is taken to be a 220VAC bulb which turns ON and OFF depending on the state of relay K1 AND K2. The normally closed (NC) contact of relay K3 is connected to the starting coil of the generator which enables the generator to start once the main power goes OFF. Relay K1 and K2 used for performing the switching operation are connected in parallel to provide the live and neutral wire needed for single-phase load.

The normally closed (NC) contacts of relay K1 and K2 are connected to the generator while the normally open (NO) contacts are connected to the main power supply. So long as there is power from the public power supply, the NO contacts of relay K1 and K2 closes connecting the load to the main power supply. Once the main power fails, the NC contact of K3 falls back to this original position to trigger ON the generator immediately. When the input is low, the outputgoes high and relay K3 is OFF and after 7 seconds of generator synchronization, the relay K1 and K2 falls back (closes) to its original position and connect the load to the generator.Whenever the public power is restored, the NC contact of relay K3 opens (breaking the generator connection) thus energizing the NO contact of K1 and K2 which then turns ON and connect the load under 0 seconds to the public power supply.

IV. RESULTS

4.1 Results from stimulation

This section displays the results of the tests carried out on several sections of the system using digital oscilloscope to view the various responses of the signal flow on the circuit and are shown in Fig. 7 and Fig.8

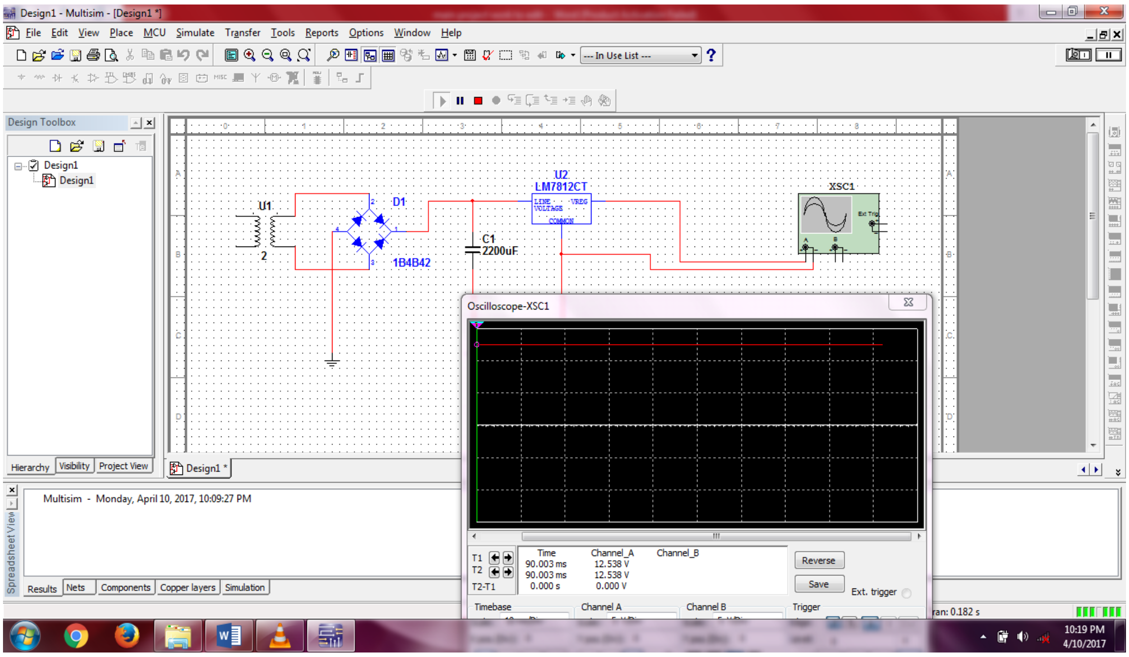

Figure 7 Signal waveform of power supply circuit

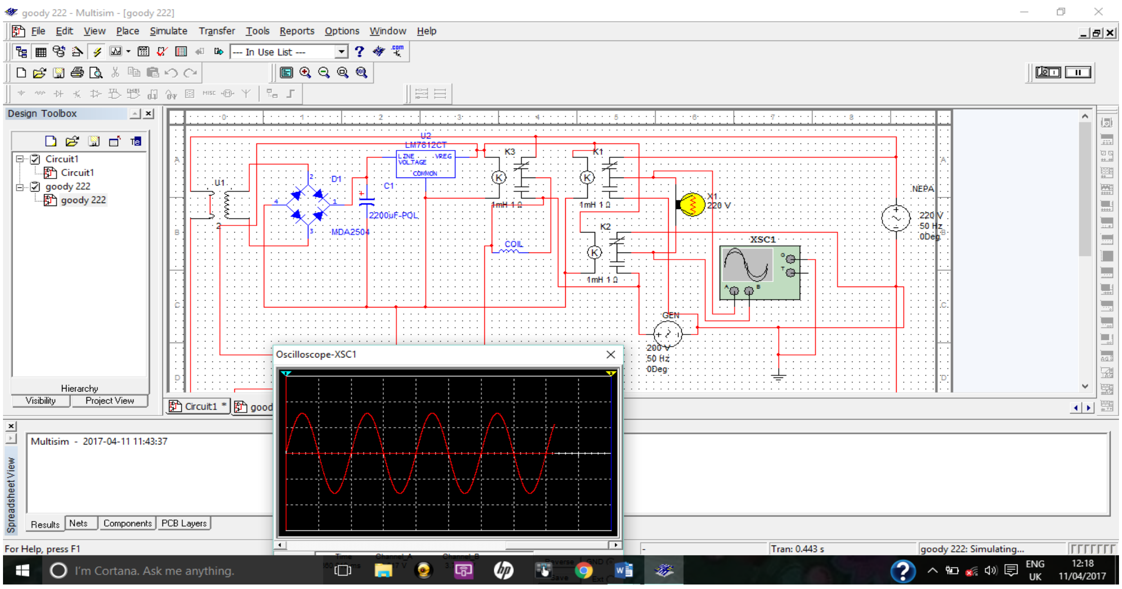

Figure 8 Signal waveform of the connected load

4.2 Experimental results

The experimental set up was done in the laboratory. According to the hardware design and specifications, the required components were selected and the component values were checked using theMultimeter. During the cause of testing of this project work, it was observed that the generator took 0.01 ms to start and once it is running, it takes the load 7s to connect to the generator and once power is restored, it takes the load 0.01msec to connect back to the power from utility supply.

At the end of this work, it was observed that the practical measurable values differ slightly from the simulated values as shown in table 1.0

Table 1 Result of Simulated and Experimental values

DATA	SIMULATION VALUES	EXPERIMENTAL VALUES	DIFFERENCE
DC Power supply output	Voltage = 12.54 V Current = 1.13 A Power = 14.16 W	Voltage = 12.0 V Current = 1.10 A Power = 13.2 W	Voltage = 0.54 Current = 0.03 Power = 0.96
555 Timer output	Voltage = 12.08 V	Voltage = 11.92 V	Voltage = 0.16
Gen. Cut off Relay output	Depending on the Generator input voltage	Depending on the Generator input voltage	Depending on the Generator input voltage
Changeover Relay output	Depending on Power from respective Power supply	Depending on Power from respective Power supply	Depending on Power from respective Power supply

V. DISCUSSION

Table 1shows the results of simulated and experimental values when the system was subjected to load. The differences between the simulated and experimental values of the output power, voltage and current of the respective models were observed. The use of preferred values of components was responsible for the differences, were almost or nearly insignificant. Fig. 7 is the representation of the signal waveform of the power supply circuit, which confirms that the current supplied to each component making up the design is a DC at all-state. Fig. 8 is a representation of the signal waveform of the connected load, which shows that for all AC loads irrespective of the source of supply to the load, AC output current travels through the loads.

VI. CONCLUSION

The detailed design, analysis and implementation of an automatic change-over switch with a generator trip-off mechanism are presented in this paper. The design of the automatic change-over switch utilizing the appropriate components was first simulated on Multisim environment and then implemented according to the preferred values of the components. The results of the implementation demonstrated that the three-phase automatic changeover switch performed its function according to specification to meet the basic requirements by sensing phase failure and the under-voltage thus,switching over to the alternative power supply. There were minor differences between the preferred values of the components used in the implementation and the ones used in the simulation. This was due to the availability of the components. The two LEDs (green and red) were incorporated into the circuit to indicate when the supply is connected to the load. The green LED turns ON when the load is connected to the utility power supply while the red LED turns ON to indicate that the load is connected to the generator.

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