

Design and Simulation of a 240V/12V Single Phase Automatic Change-Over System Using Triac Thyristor

O. A. Akinola^{a*}, A. S. Afolabi^b, O. M. Olawale^a and K. E. Ojo^c

^aDepartment of Electrical and Electronic Engineering, Federal University of Agriculture, Abeokuta, Nigeria

^bDepartment of Electrical and Electronics Engineering, University of Ilorin, Ilorin, Nigeria

^cDepartment of Electronic and Electrical Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria

Corresponding Author: akinolaoa@funaab.edu.ng

ARTICLE INFO

Received: October, 2019

Accepted: April, 2020

Published: January, 2021

Keywords:

Public mains

Change Over Switch

Triac Thyristor

Single Phase Generator

ABSTRACT

Interruption in public mains power supply in Nigeria requires alternative sources of power to back up the utility supply. The manual change-over from one power source to another during power outage or under-voltage condition imposes latency to the utility of electrical power in manual switching of load from mains supply to generator. This leads to harmonic current generated by relay switch as a result of contact bounce, mechanical damage imposed by manual switching and electrical stresses on the circuit components during the un-timely manual switching system. Hence, the design and simulation of a single phase automatic change-over system using TRIAC thyristor method. The system model comprised of power supply unit, the switching unit, the actuating unit and the alarm sectional unit. This design was achieved with TRIAC as power switching device, simulated using circuit maker and MATLAB software for different operating points and transient analyses. The LM7812 regulator was used to stabilize the rectified power supply to the actuating circuit with its output voltage of 12V. The minimum and maximum line voltages considered in this design were 180V and 270V respectively with a diversity factor of 0.75. A 5kVA single phase generator connected in parallel was used as an alternative source of power. The input and output line voltages of the switching circuit were measured as 220V and 210V at frequency of 50Hz respectively with ripple factor of 0.02. The latching and holding current of the TRIAC were measured at room temperature (25°C) were $\pm 40\text{mA}$ and $\pm 17\text{mA}$ respectively. The forward and reverse terminal voltages of the TRIAC measured as 10.8V. The latency of the design was determined from the mono stable equation of NE555 timer to be 3seconds while the Buzz time of the alarm system was measured as 5seconds.

1. INTRODUCTION

Power interruption in developing countries creates a need for the automatic integration of electrical power system with alternative sources of power to back up the utility supply. This automation method is required due to the rate of power outage which is predominantly high. Most industrial, commercial and local processes loads dependent on power supply for their operations and if the manual change-over switching method continue, serious time is not only wasted but may also damage the machines due to the harmonics generated by contact bounce in the manual switching system (Olatomiwa and Rasheed, 2014). A manual change-over switching system consists of a manual switch box, switch gear and cut-out fuse. The change-over switch box connects the load between the generator and public mains supply. When there is power outage, the change-over operates manually by changing the cut-out fuse and when the power supply is restored; the change-over switch meant for public utility is restored back manually (Leng *et al.*, 2011).

Leng *et al.* (2011) established the concepts that proliferation of semiconductor based non-linear devices in power system has caused serious concern over power quality problems. They proposed an optimization control strategy to coordinate multiple adjustable speeds drive (ASD) and elimination of the steady state speed error so that harmonic current as well as reactive power generated by nonlinear loads can be compensated. Ortiz *et al.* (2009) proposed an optimal design model of a 3.5 KV/11KW dc-dc converter for charging capacitor banks of power modulators. It was deduced that, the generation of short high power pulses in many applications, power modulators based on capacitor discharge were used, where the peak power is drawn from the input capacitor bank. Jones (2009) proposed a miniature solution for voltage isolation. The high growth in distributed power architecture has fuelled the development of miniature low-power of 2W DC/DC converters. These devices minimize the impact of the converter onboard space. Hence, the miniature of DC/DC converters with galvanic isolation offer very low output noise and high accuracy.

Eyad (1998) designed a DC-to-DC converter to control the speed of a DC motor for electric vehicle application. The power circuit of the converter consists of transistorized power switches of an Insulated Gate Bipolar Transistors (IGBTs) to step-down the voltage to the level required by the speed and load demand. The series shunt resistor method is used to control the current to maintain the maximum rate of the power transistor and the motor during the starting point. The transistor gate drive circuit was designed to provide the maximum isolation between the power and the control circuits. The simulations were performed in Simulink package prior to its implementation.

Considering the limitations of the manual change-over power system which involves; manual starting of the generator, switching from power supply to generator and from generator to power supply as a result of power failure causes latency, harmonic and power loss to the electrical appliances during the manual operation, it is expedient to design and construct a fast automatic change-over power system which can be used in hospitals, homes, airports, banks, large industries. Hence, the need for this study.

2. METHODOLOGY

The approach that was used in this design is the modular approach, where the overall design was developed from functional block diagram. Each block represented a sub-system that performed specific functions as shown in Figure 1. The circuit of the single phase automatic change-over system encompasses both the power circuit and control circuit. The power circuit is made up of 240/12V 50Hz step down transformer. The control circuit comprises of the switching unit, actuating unit and indicator/alarm unit. The switching unit integrate the voltage between the power supply and the generator while actuating unit control the switching unit to alternate the voltage when there is availability of power supply either on generator or mains supply. The switching action of the TRIAC during power outage or under-voltage condition is monitored by the actuating unit. The following features were included in the design such as under-voltage protection, over-voltage protection and over-current protection. The realization of overall circuit design

model for the automatic change over switch using triac thyristor encompasses both the power unit and control unit.

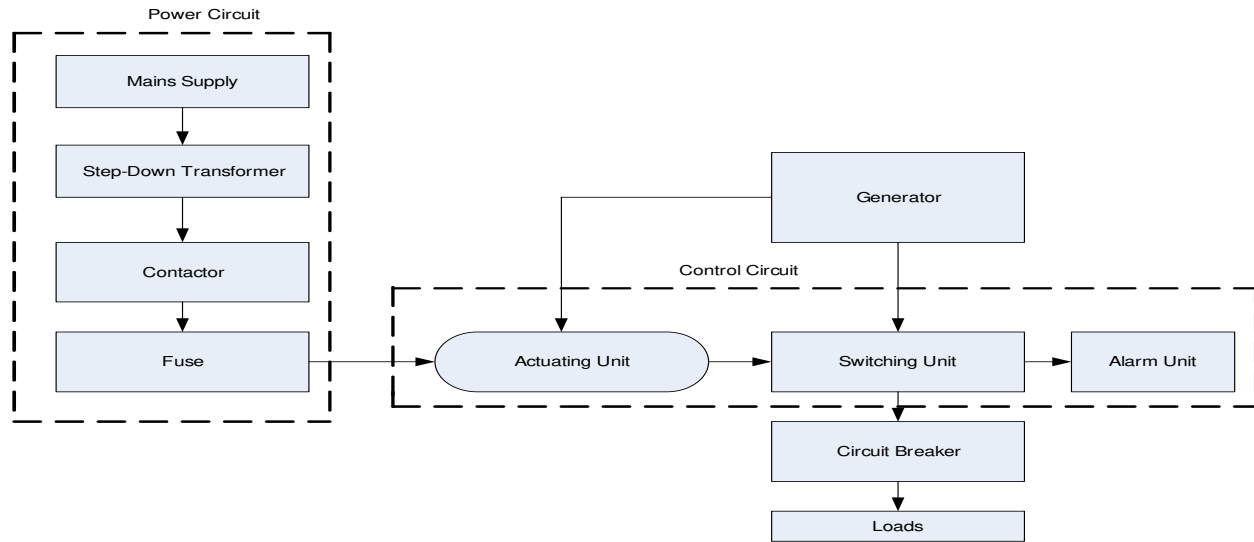


Figure 1: Diagram of a Single Phase Automatic Change-Over System

Power Unit

The major component of this unit is the transformer. It is the electrical device that converts electrical energy to electrical energy in stepping down the phase voltages to a level that will easily be monitored and get actuated by the actuating unit. An optimum voltage level of 12V was used for the Dc-to-Dc converter. Hence, the step down transformer was used to step down the voltage level of 240V/50Hz to the pre-set value of 12V for proper operation of the actuating unit as shown in Figure 2. The mathematical equation derived for the power circuit is given in equation (1):

$$\frac{V_1}{V_2} = \frac{N_1}{N_2} \quad (1)$$

Where: $V_1=V_p$ is the phase or primary voltage of the transformer in V; V_2 is the secondary voltage; N_1 is the number of turn in the primary winding of a transformer; N_2 is the number of turn in the secondary winding of a transformer. Therefore, the transformer ratio of the transformer is given in equation (2). The 240V of the primary voltage and 12V of the secondary voltage was step down to give a turn ratio of 20 according to equation 2:

$$\frac{N_1}{N_2} = \frac{240V}{12V} = 20 \quad (2)$$

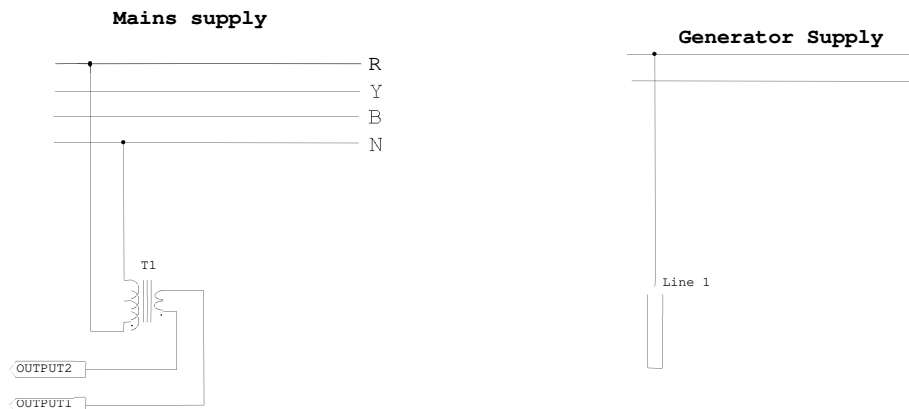


Figure 2: Power Circuit

Control Unit

This unit is made of three major subsystems which includes; the switching, actuating and alarm sections.

Switching Section

The sub-circuit section are the made up of the major components such as the TRIAC (2N6073), zero-voltage switch (MOC3041), circuit breaker, transistor, diodes, capacitor, switch and resistors. The circuit for the switching section is given in Figure 3.

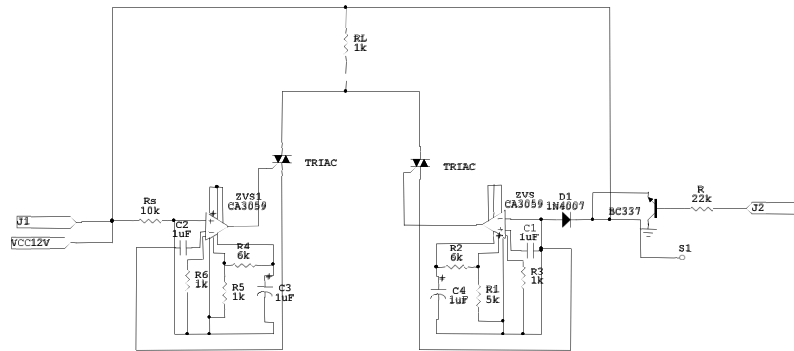


Figure 3: Switching Circuit (Horowitz and Winfield, 2002)

A single phase generator of power rating 5 KVA was selected on the basis of availability with the sizes of the components that would be required. The design mathematical equations for the generator and TRIAC thyristor are given in equation (3)

$$P = S \times \cos \theta \quad (3)$$

Where:

S is the apparent power of the generator in kVA

P is the wattage power of the generator in kW

Cos θ is the power factor of the generator, it is given as 0.8 for most electrical machines.

For 5kVA generator, the optimum wattage of the design is given in equations (4) and (5).

$$P(kW) = 5 \times 0.8kW \quad (4)$$

$$P(kW) = 4kW \quad (5)$$

The impedance Z_L is given in equation (6).

$$Z_L = \frac{V_L^2}{P_L} = \frac{(240V)^2}{4kW} = 14.4\Omega \quad (6)$$

Also, the current is given in equation (7)

$$I = \frac{P}{V} = \frac{4000W}{240V} = 16.67A \quad (7)$$

The maximum load that can be on the single phase automatic change-over system is defined as 0.75 of capacity of the design. Thus, the maximum wattage for the design is given in equation (8)

$$P_L = 0.75 \times 4kW = 3kW \quad (8)$$

According to Jackson (1962), the power dissipated in TRIAC is given in equation (9).

$$P = \frac{1}{2\pi Z_L} \int_{0+\alpha}^{2\pi+\alpha} v_m^2 \sin^2 \theta d\theta = \frac{1}{2\pi Z_L} \left[\int_{0+\alpha}^{\pi+\alpha} v_m^2 \sin^2 \theta d\theta + \int_{\pi+\alpha}^{2\pi+\alpha} v_m^2 \sin^2 \theta d\theta \right] \quad (9)$$

Where:

Z_L is the impedance of the load to be switched between generator and mains supply in Ω

V_m is the peak voltage in V

θ is the lag phase angle of the generator

α is the firing angle of the TRIAC

When MOC3041 fires the TRIAC at zero firing angle. Thus, the power dissipated during switching operation can be expressed in equations (10 - 16) as;

$$P = \frac{1}{2\pi Z_L} \int_0^{2\pi} v_m^2 \sin^2 \theta d\theta = \frac{1}{2\pi Z_L} \left[\int_0^{\pi} v_m^2 \sin^2 \theta d\theta + \int_{\pi}^{2\pi} v_m^2 \sin^2 \theta d\theta \right] \quad (10)$$

$$P = \frac{1}{2\pi Z_L} \left[\int_0^{\pi} v_m^2 \sin^2 \theta d\theta + \int_{\pi}^{2\pi} v_m^2 \sin^2 \theta d\theta \right] \quad (11)$$

$$P = \frac{V_m^2}{2\pi Z_L} \left[\int_0^{\pi} 1 \cdot \sin^2 \theta d\theta + \int_{\pi}^{2\pi} 1 \cdot \sin^2 \theta d\theta \right] \quad (12)$$

$$P = \frac{V_m^2}{2\pi Z_L} \left[\int_0^{\pi} \frac{1}{2} [1 - \cos 2\theta] + \int_{\pi}^{2\pi} \frac{1}{2} [1 - \cos 2\theta] \right] \quad (13)$$

Substitute the values of $V_m = 12V$ and $Z_L = 14.4\Omega$ into equation (13)

$$P = \frac{V_m^2}{2\pi Z_L} \times \frac{1}{2} \left[2\pi - \frac{\sin 4\pi}{2} \right] = \frac{V_m^2}{2Z_L} = \frac{12^2}{14.4} = 10W \quad (14)$$

Thus, the percentage power loss during switching mode is given as;

$$\% \text{ power loss due to switching} = 100 \times \left(1 - \frac{4000-10}{4000} \right) = 0.25\% \quad (15)$$

To specify the dimension of the copper conductor to be used when connecting the loads to the automatic change over system, the Maxwell corollary of average time Poynting vector was used. It is given by Ogata (2011);

$$P = \frac{1}{2} [E \times H^*] \quad (16)$$

Where:

E is the electric field vector for the alternating voltage in Vm^{-1}

H^* is the complex conjugate function of the electromagnetic field vector in Am^{-1}

P is the poynting vector that represents the directional energy flux of an electromagnetic field in Wm^{-2}

Considering the time varying functions of E and H fields, it can be expressed as given in equations (17 – 18)

$$E = \dot{x}E_0 e^{j(\omega t - \beta z)} \quad (17)$$

$$H = \dot{y}H_0 e^{j(\omega t - \beta z)} \quad (18)$$

Hence, the complex conjugate function of H field is given in equations (19-23).

$$H^* = \dot{y}H_0 e^{-j(\omega t - \beta z)} \quad (19)$$

$$H^* = \frac{\dot{x}E_0 e^{-j(\omega t - \beta z)}}{\eta} \quad (20)$$

$$P = \frac{1}{2} \begin{vmatrix} \dot{x} & \dot{y} & \dot{z} \\ E_x & 0 & 0 \\ 0 & H_y^* & 0 \end{vmatrix} = \dot{z} \frac{1}{2} (E_x \cdot H_y) = \dot{z} \frac{1}{2} (E_0 e^{j(\omega t - \beta z)} \cdot \frac{E_0 e^{-j(\omega t - \beta z)}}{\eta}) \quad (21)$$

$$P = \frac{1}{2} \left[\frac{E_0^2}{\eta} \right] \quad (22)$$

$$E_0 = \sqrt{2\eta P} \quad (23)$$

Thus, the current density is given in equation (24).

$$J = \sigma E_0 = \frac{i^2}{A} \quad (24)$$

$$A = \frac{i^2}{\sigma E_0} \quad (25)$$

Putting the expression for E_0 in equation (25) to give equation (26)

$$A = \frac{i^2}{\sigma \sqrt{2\eta P}} \quad (26)$$

$$A = \pi r^2 = \pi \frac{D^2}{4} \quad (27)$$

Make D the subject of the formula by equating (26) and (27)

$$D = \sqrt{\left[\frac{4 i^2}{\sigma \pi \sqrt{2\eta P}} \right]} \quad (28)$$

The conductivity of copper (σ) is $5.8108 \times 10^7 S/m$, $P = 10W$, $\eta = 120\pi$ for free space of conductivity and

$i = 16.67 A$.

$$D = \sqrt{\left[\frac{4 \times 16.67^2}{5.8108 \times 10^7 \pi \sqrt{2 \times 120\pi \times 10}} \right]} = D = 7.01 \text{ nm}$$

Actuating Circuit

This is the heart via power house of the automatic change over system which controls the activities of the entire circuit. It monitors the mains supply and send signal to the switching unit which automatically switches the load to the generator in case of power failure or undesirable conditions such as under-voltage, voltage lag, lighting striking and over voltage condition. The major component embedded in actuating unit as shown in Figure 4 encompasses Comparator/Op-Amplifier (LM393), Transistors (BC548, BC557), Diodes (IN4007), Zener diode (5V), Potentiometer (100k, 75%), LED, Bridge rectifier, Capacitors and Fuse.

The IN4007 diodes were chosen for the design of the bridge rectifier, the design calculation for the bridge rectifier based on the diagram shown in Figure 5. Thus, the ripple factor for the design was chosen as 0.02 and the load connected to it should be greater than or equal to 100k. The ripple factor formula is given in equation (29)

$$R = \frac{V_{rms}}{V_{dc}} \quad (29)$$

V_{rms} is the root mean square voltage and is given equation (30)

$$V_{rms} = \frac{0.0024 V_{dc}}{RLC_1} \quad (30)$$

Solving for C_1 from equations 30; therefore substitutes for the value of V_{rms} , R and L

$$C_1 = \frac{0.0024}{RLV_{rms}} = \frac{0.0024}{100 \times 1000 \times 0.02} = 1.2 \mu F$$

$$C_1 = 1.2\mu F \quad (1\mu F \text{ capacitor was chosen})$$

The specification of the potentiometer is taken to be 100k so as to limit current flow and power dissipation in the comparator (LM393). The power equation is given as (equation 31): $V = 12V$

$$P = \frac{V^2}{R} \quad (31)$$

$$P = \frac{144}{100 \times 1000} = 1.44mW.$$

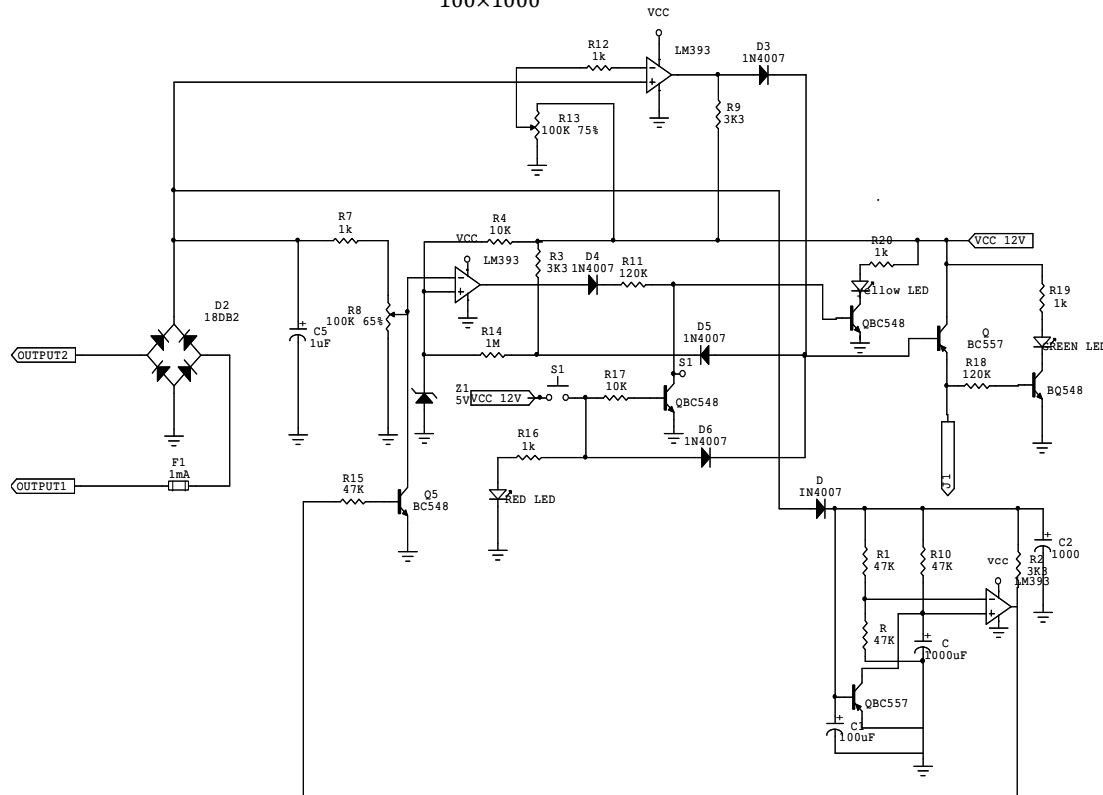


Figure 4: Actuating Circuit (Owen, 1995)

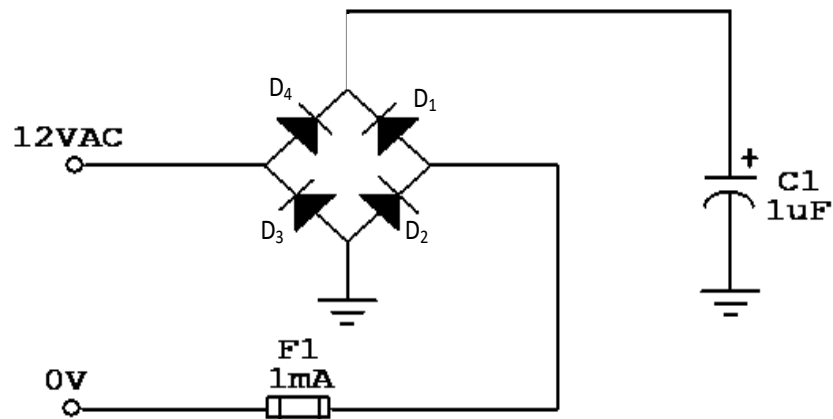


Figure 5(a): Bridge Rectifier (Theraja, 2002)

For proper operation, it is set at potentiometer co-efficient of 0.75. The zener diode chosen for regulating the inverting input of the comparator of 5V, this value ensures proper operation of the diode as the zener diode is biased by little current.

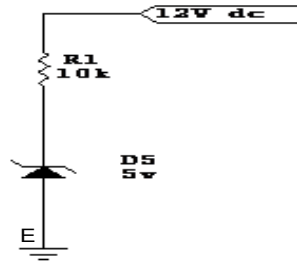


Figure 5(b): Zener diode circuit analysis

Using the KVL;

$$V_{cc} = I_{out}R_1 + V_z \quad (32)$$

Substitutes values into equation (32)

$$I_{out} = \frac{12v-5v}{10 \times 1000} = 0.7mA$$

The minimum load resistance for the Zener diode is given as,

$$R_{min} = \frac{5v}{0.7mA} = 7.14k\Omega \text{ (for design, the minimum voltage is taken to be } 10k)$$

To specify the LED indicators (red, yellow and green)

$$R_{dc} = \frac{V_{cc}-V_f}{I_f} \quad (33)$$

Where $V_{cc} = 12V$, V_f for yellow, green and red are 2.1V, 2.2V and 1.8V respectively and I_f for the LEDs is chosen as 10A. By solving for the load resistances of the LEDs, R_2 , R_3 , R_4 are 1k each.

To specify the values of the resistances R_5 and R_6

$$R = \beta \frac{V_{cc}}{I_c} \quad (34)$$

$$\frac{V_{cc}}{I_c} = R_{cc} \quad (35)$$

Hence,

$$R = \beta R_{cc} \quad (36)$$

Where, $R_{cc} = 1.1k$ and $\beta = 100$. Therefore, R_5 and R_6 are given as 110k also R_8 is given as 120k. The delay circuit is shown in Figure 6.

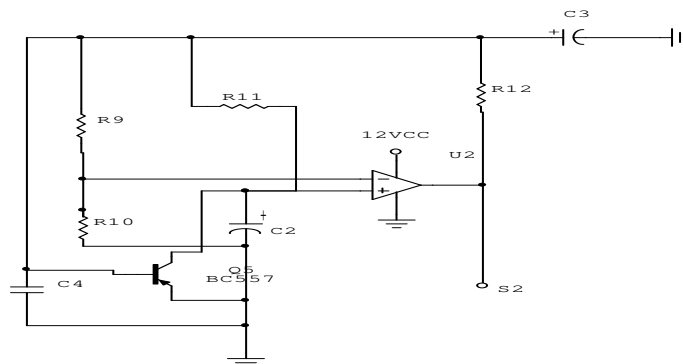


Figure 6: Delay circuit

Since R_9 and R_{10} form voltage divider across the comparator U2 (LM393) and the voltage divider rule is given as:

$$V_1 = \frac{R_9 V}{R_9 + R_{10}} \quad (37)$$

Given that, $R_9 = R_{10} = 47k$, $V = 12V$ and $V_1 = 6V$. The capacitor C_2 charges towards 6V and its value is $47\mu F$, thus, the delay time is calculated thus;

$$V_1 = \left(1 - e^{-\frac{t}{RC}}\right) \quad (38)$$

Substituting the value of V_1 and V in equation (38)

$$T = 0.693 RC \quad (39)$$

The value of $R = 100k$ and $C_2 = 47\mu F$ in equation (39)

$$T = 3.3\text{secs}$$

Alarm Sub-Circuit

The alarm section is made up of 555 timer ICs, transistors, diodes, resistors and buzzer. The design involved the determination of the period for which the alarm is to stay ringing during switching operation and incorporation of mechanism through which the generator will be automatically switched on in the event of power failure. The circuit is shown in figure 7. Time (T) for buzzing action of the alarm is calculated from the following equation;

$$T = -RC \ln \left[\frac{V - V_{c2}}{V - V_{c1}} \right] \quad (40)$$

According to the Alarm circuit, the capacitor charges from $V_{c1} = 0V$ to $V_{c2} = 2/3V$, when $V = 12V$. Hence,

$$T = 1.1RC$$

The values of R and C are chosen to be $47k$ and $100\mu F$. Hence, the timing of the buzzer is given by:

$$T = 1.1 \times 47 \times 1000 \times 100 \times 0.000001 = 5.17\text{seconds} \approx 5\text{seconds}.$$

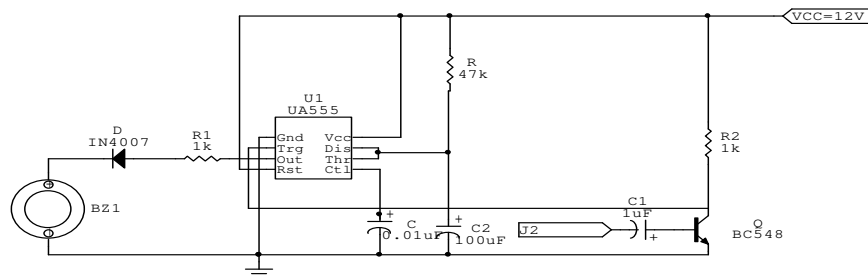


Figure 7: Alarm Circuit

3. RESULTS AND DISCUSSION

The design was implemented on Vero-board and the performance analysis was carried out with the use of MATLAB SIMULINK, CIRCUIT MAKER, LT-SPICE, and PROTEUS SOFTWARE. The validity of performance analysis were carried out in terms of the Latching current of the TRIAC $\pm 40mA$, Holding current of the TRIAC $\pm 17mA$, forward and reversed terminal voltages of the TRIAC $\pm 10.8V$, input and output line voltage of 220V and 210V respectively. The following tests were carried out using continuity test, under-voltage test and over voltage test. The results and interpretation of the simulation for the different sub-system in the circuit are given in the following section.

Simulation of TRIAC Circuit using Circuit Maker Software

The circuit in Figure 8(a) shows that, a piecewise generator created a “domestic spike” added to the AC source. This spike caused the TRIAC to fire prematurely before it is gated on by the 5V pulses. The analysis was achieved by isolating the TRIAC from the switching and firing it with the signals at its input terminals.

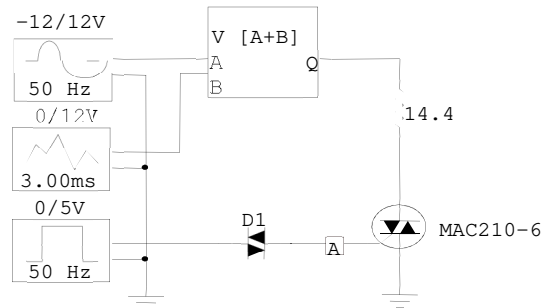


Figure 8 (a): TRIAC Firing Circuit

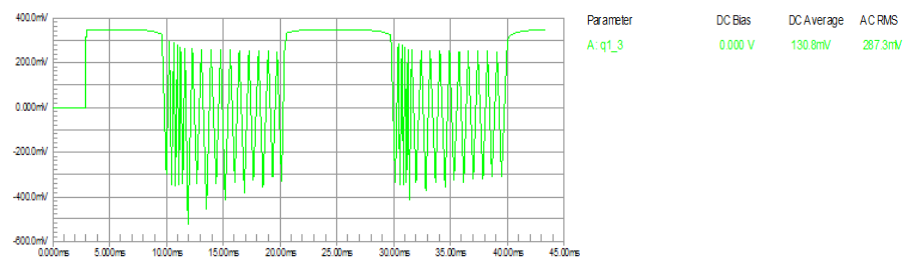


Figure 8(b): Interpretation of Transient Analysis for Gate Pulse Operating Point

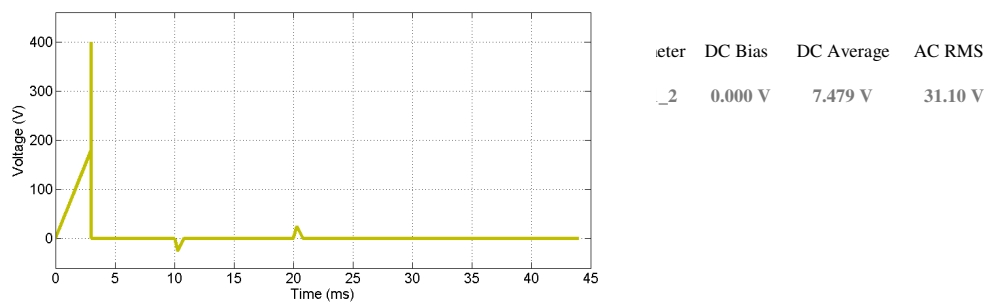


Figure 8(c): Interpretation of Transient Analysis for MT₂ Output Operating Point

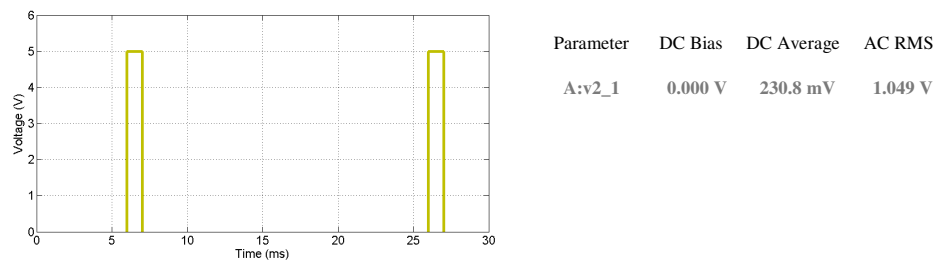


Figure 8(d): Interpretation of Transient Analysis for Gate Square pulse Operating Point

Figures 8(a-d) show the simulation results of the TRIAC switching circuit. This allowed operation between the voltage range of 180V to 270V and the minimum DC average voltage was 7.479V and the AC rms value was 31.10V. The minimum voltage for the TRIAC driver circuit was 1.049Vrms and 230mV dc average.

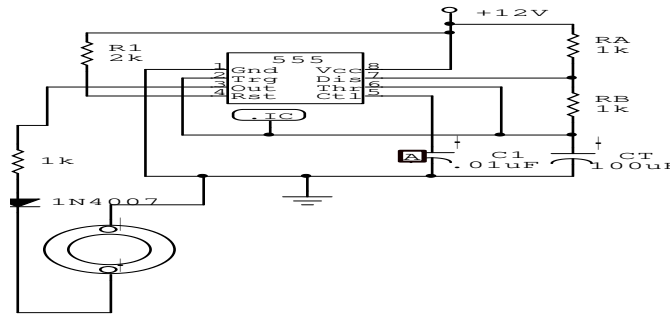


Figure 9(a): The Timer Circuit

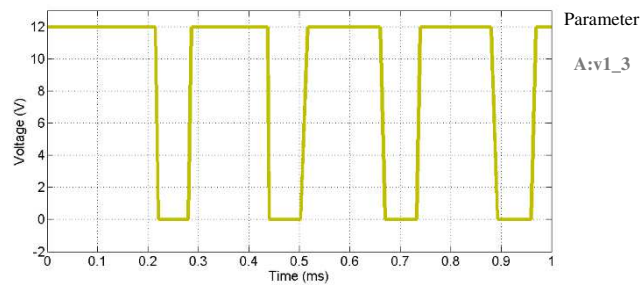


Figure 9(b): Output Pulse of the Timer Circuit

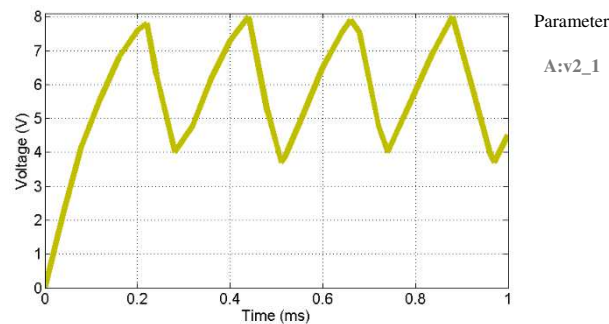


Figure 9(c): The Pulse at the trigger of the IC

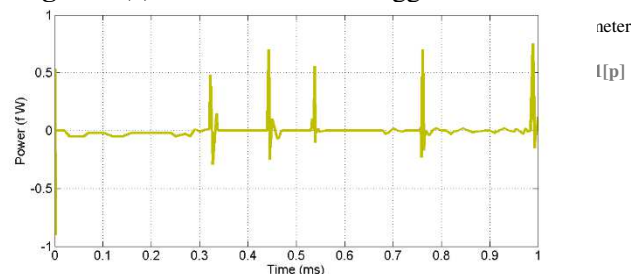


Figure 9(d): Power Pulse at the Capacitor of 0.01uF

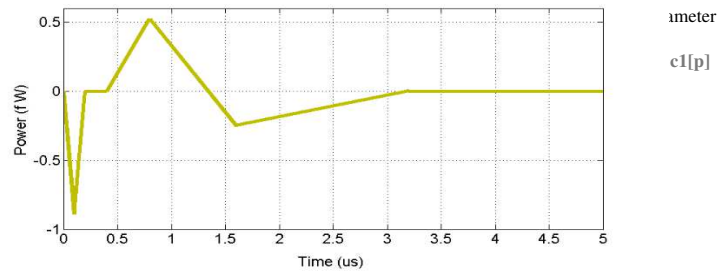


Figure 9(e): The Output Power of the Timer Circuit

Figures 9(a-e) show the simulation results of the timer circuit. It is deduced that, the peak output voltage of the stable mode 555 timer is 11.75V. Thus, this is capable of driving the buzzer. The ON time of the 555 timer was 0.2 seconds and the OFF time was 0.1second. The duty cycle was 66.67% while the peak power loss for the circuit was 0.52W.

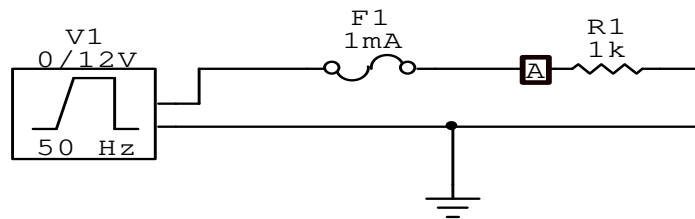


Figure 10(a): The Fuse Circuit

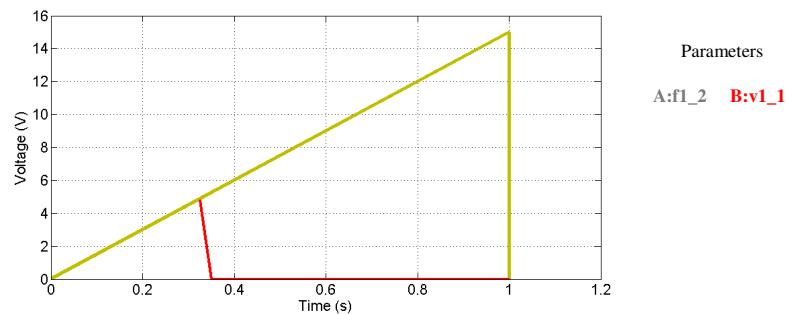


Figure 10(b): The Pulse Analysis of the Fuse.

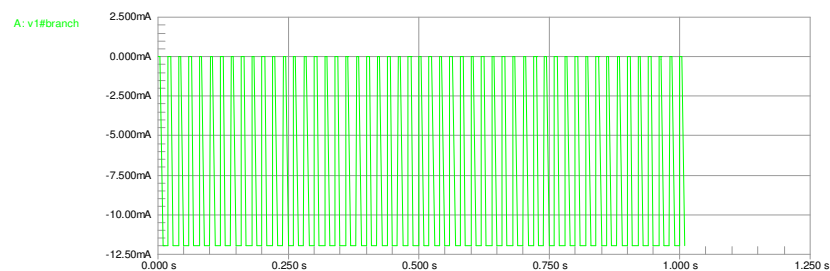


Figure 10(c): The Fuse Current Pulse Analysis

The simulation in Figures 10(a-c) indicate the resistor, voltage and current rating of the fuse used for automatic change over switch using TRIAC . The results indicate that the minimum voltage that caused breakdown of the fuse was 1500 V over voltage.

Akinola *et al.*: Design and Simulation of a 240V/12V Single Phase Automatic Change-Over System Using Triac Thyristor

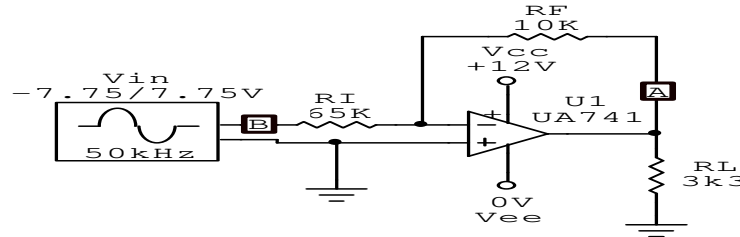


Figure 11(a): The Comparator Circuit

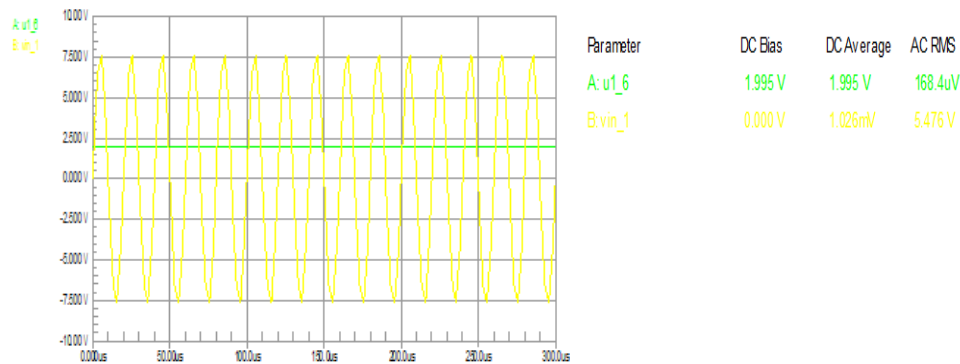


Figure 11(b): Interpretation of Transient Analysis for Terminal A and B Operating Point

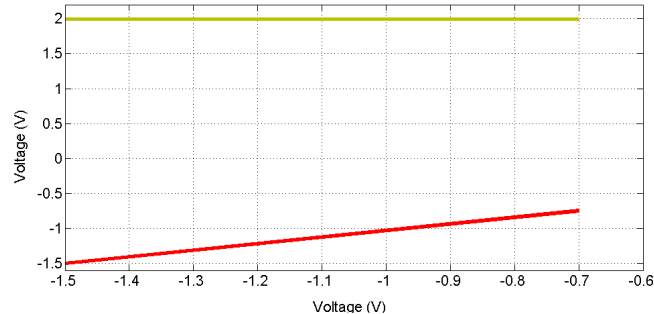


Figure 11(c): The DC Sweep

Figures 11(a-c) show the simulation results of the comparator circuit. The validity of the result explained that, the LM393 operated between +7.5V and -7.5V, while its DC bias voltage was 1.996V, DC average voltage was 1.996V and the AC rms value was 168μV.

4. CONCLUSION

The system was designed and constructed using 2N6073 TRIAC as the power switch and MOC3041 as its driver circuit. L7812 regulator was used to stabilize the rectified power supply to the actuating circuit and its output voltage was measured as 12V. The input and output line voltages of the switching circuits were measured as 220V and 210V at 50Hz respectively and the ripple factor was determined to be 0.02. Thus, the Latching and holding currents of the TRIAC were measured at room temperature (25°C) as ± 40mA and ±17mA respectively. The forward and reverse terminal voltages of the 2N6073 TRIAC were measured

as 10.8V. The latency of the design was determined from the mono-stable equation of NE555 timer to be 3seconds while the buzz time of the alarm system was measured as 5seconds. The load capacity of the single phase automatic change-over system was determined by decoupling Maxwell's Equations of 3kW and the power loss for the design was determined by using Poynting vector equation as 0.25% of the peak load (4kW).

References

- Eyad, M. R. (1998). Design and Construction of a DC-to-DC Converter for Electric Vehicle Application. Thesis for M.Sc. Thesis, Electrical and Electronic Engineering Department. Universiti Putra Malaysia, Malaysia.
- Horowitz, P. and Winfield, H. (2002). The Art of Electronics. 2nd edition, Cambridge University Press, Cambridge, UK.
- Jackson, W. D. (1962). Classical Electrodynamics. Wiley and Son, New York, USA, Pp 661.
- Jones, G. (2009). Miniature Solutions for Voltage Isolation. Available online: www.ti.com/caj.3Q Retrieved on September 8, 2013.
- Leng, S. Chung, II-Y. Edrington, C. S. and Cartes D. A. (2011). Coordination of Multiple Adjustable Speed Drives for Power Quality Improvement. *Electric Power Systems Research*, 81(6):1227–1237.
- Ogata, K. (2011). Modern Control Engineering. 5th edition, Prentice Hall, Columbus, Ohio, USA, Pp 912.
- Olatomiwa, L. and Rasheed, O. (2014). Design and Development of a Low Cost Automatic Transfer Switch (ATS) with an Over-Voltage Protection. *Journal of Multidisciplinary Engineering Science and Technology*, 1(4):190-196.
- Ortiz, G. Bortis, D. Biela, J. and Kolar, J. W. (2009). Optimal Design of a 3.5 KV/11KW DC-DC Converter for Charging Capacitor Banks of Power Modulators. *IEEE Transactions on Plasma science*, 38(10): 2565-2570.
- Owen, B. (1995). Beginner's Guide to Electronics 4th edition, A Newness Technical Book, McGraw-Hill Companies Inc, New York, USA.
- Sen, P. C. (2013). Principle of Electric Machine and Power Electronics. 3rd edition, McGraw-Hill, Columbus Ohio, USA, Pp 640.
- Theraja, B. L. and Theraja, A. K. (2002). Electrical Technology. 21st edition Ranjendra Ravida, New Delhi, India.