LAUTECH Journal of Engineering and Technology 18 (2) 2024: 161-174
10.36108/laujet/4202.81.0251

Three phase microcontroller based automatic change-over selection switch

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Article Info

Article history:

Received: April 24, 2024
Revised: June 17, 2024
Accepted: June 20, 2024

Keywords:

Microcontroller,
Switching,
Change-over,
Mains Power and
Phase Supply.

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ABSTRACT

The significance of electricity in a developed country cannot be underestimated because the power instability problem affects economic growth, productivity, and infrastructure development. The issues of phase failure, losses, and phase imbalance earth fault are the main causes that lead to unstable and erratic power supply. Most homes and office complexes where a single-phase supply is needed are supplied with three phases of power supply to allow change from one phase to another when there is fluctuation or complete outage of power supply on a particular phase. This operation is normally done manually and has caused a setback in terms of time wastage, strenuous operation, susceptibility to fire outbreaks, electric shock and high maintenance frequency. When the voltage supply on a phase is below 220V or above 415V, this system automatically disconnects the load from the phase and connects to another where the required condition is met. Therefore, this paper presents a Microcontroller-based Automatic Transfer Switching System that is made up of a voltage sensing circuit, Hall Effect current sensor, relays, LEDs, an LCD module, a DS1307 timer module, and PIC16F877A microcontroller. A system flow chart was developed, programmed with MikroC software, and simulated using Proteus electrical software design. A 10 kVA single-phase generator was used as an alternate power source. The load capacity of the design was determined by decoupling Maxwell's Equations of 8KW and power loss using the Poynting vector equation as 0.25% of the peak load. The switch is tested to function optimally within ±5% nominal voltage of 220 - 415V supply and produced approximately 20 seconds elapses during the entire process of power supply change-over. Hence this device is suitable for Industrial and Domestic use where a 3-phase power supply is available with a stand-by power source.

INTRODUCTION

In developing countries like Nigeria, power instability and phase failure have posed a serious threat to economic development. One of the factors that boost the economy of a country is its ability to supply a steady and stable power supply. However, issues such as phase failure, phase imbalance, or earth fault are the main causes that lead to unstable and erratic power supply (Agbetuyi *et al.*, 2011; Kolo, 2007) and this power is largely unreliable as the standard three-phase power is most of the time unbalanced and the quality degraded by fluctuations (Awunde *et al.*, 2021a). In some cases, the power lines are overloaded leading to power trip-off via short circuits by the circuit breakers or by the load-shedding process undertaken by the distribution authority.

Most homes and office complexes where a single-phase supply is needed are supplied with three phases of power supply to allow change from one phase to another when there is fluctuation or complete outage of power supply on a particular phase. This operation is normally done manually and has caused a setback in terms of time wastage, strenuous operation, susceptibility to fire outbreaks, electric shock, and high maintenance costs. Hence, there is a need for an automatic control switching system. The automatic switching systems can help to eliminate the manual control technique mostly used in developing countries (Oduobuk *et al*., 2014) thereby reducing the risk involved in the manual changeover process (Akpan *et al*., 2019). Several works have been done in this regard, some of which interfaced with three-phase supply to generators using various approaches with remarkable success over the years (Ahmed *et al*., 2006; Atser *et al*., 2014; Ezema *et al*., 2012; Ogundare and Ihiovi, 2017).

A manual change-over switch consists of a manual switch box embedded with a bus bar, switch gear, and cut-out fuse. The changeover box connects the load between the generator and the public utility supply. When there is a power outage, the change-over is operated manually by changing the cut-out fuse. When the power supply is restored, the cut-out fuse for the public utility is installed back manually. The consequences and problems normally encountered during manual change-over systems involve the manual starting of the generator, switching over from public supply to generator, latency during the manual operation, arcing and sparking at the contactor *(Amuzuvi et al*., 2015). With an increase in the technological advancement of electrical power, control, and automation, Automatic Transfer Switches (ATS) were developed. The Transfer Switch is an electrical device that is capable of alternating and transferring load from one source of power supply to another (Mokhtari *et al*., 2018; Nnochiri and Iroegbu, 2021; Okelola and Olabode, 2018). The basic function of a transfer switch is to make and break one source of power supply to another. It isolates power sources in the event of overvoltage and prevents the power surge (Olatinwo *et al.*, 2013). An automatic transfer switch serves as an interface between power sources to maintain a continuous supply of power to the load (Awunde *et al.,* 2021b). With an automatic transfer switch, power failures are detected immediately, and transitions from utility power to backup generator are seamless. The engineering behind an automatic transfer switch is quite complex as several components play pivotal roles in obtaining instantaneous backup power. An automatic changeover system makes use of sensors and transducers to realize the change-over in a shorter time while eliminating human interference and its attendant errors (Baraneetharan *et al*., 2016; Farhan, 2021). All automatic transfer switches for generators consist of three parts namely; contacts to connect or disconnect the load to a source of power, a transfer mechanism to move the contacts from one source to another, and an intelligent or logic control unit to constantly monitor the condition of the power sources and so provide the brain necessary for switching and relay circuit to operate correctly (Abdulhamid and Mada, 2020; Adoghe and Odigwe, 2009; Nnochiri and Iroegbu, 2021).

Maxted and Waller (2006) developed a microintelligent controller for high-power industrial generators as a replacement of the existing discrete logic design. This system could support automatic main failure start-up and shutdown, multi-channel graphical annunciation control, and monitoring of the generator’s coolant and oil temperature and pressure (Maxted and Waller, 2006). The new controller provides great advantages in terms of reduced cost, increased functionality, and flexibility. Signals were switched using relay contacts or bipolar transistor switches on external boards. However, the drawback of the project is the lack of a duty selector. In (Obikoya *et al*., 2014), in addition to controlling the shutting down timer of the generator, the generator also performs a switching function to the public utility supply when power is restored. A *microcontroller ATMEGA8* was used which makes the entire circuitry compact, more flexible, efficient, and reliable.

In Nnochiri and Iroegbu, (2021), an Arduino module with an *ATMEGA328P microcontroller* programmed using *C++ language programming* was developed for the control unit. Similarly, in (Mbaocha, 2012), an *AT89C52 microcontroller* was used in the design of a smart phase change-over system where continuous checking of phase was done. In (Islam, 2017), the author designed and implemented an automatic phase changer without the use of a microcontroller. The system is only considered under voltage protection for emergency loads.

A low-cost automatic transfer switch with overvoltage protection was developed (Olatomiwa and Olufadi, 2014) without the use of a microcontroller. Ahmed *et al*. (2006) designed and constructed an automatic power change-over switch with control logic and relay to automatically switch between public power supply and generator power supply in the event of a power outage. The work proved to be reliable, cheap, and reduce human stress (Ahmed *et al*., 2006). It employed logic control for switching between mains and generator, but the drawback is the lack of a generator starting mechanism and phase selector. Nnochiri and Iroegbu (2021) explored a phase selector for automatic three-phase switching using an *Arduino module with ATMEGA328P* whose selection was due to reliability, effectiveness, low cost, and speed. The work can be used round the clock and neglect a phase with very low voltage (Nnochiri and Iroegbu, 2021).

Kolo and Marouchos (2016) developed a GSM-based control for electrical appliances to reduce electricity wastage. The researchers were able to switch ON and OFF appliances by sending SMS through the GSM network (Kolo and Marouchos, 2016). This work has proven to be energy-saving saving, effective, but with no provision for notification in case there is a power failure. (Narvios *et al.*, 2022) looked into the IoT-based automatic transfer switch with a monitoring and control system. The system functioned via SMS notification and the Blynk application. The project consisted of blocks such as an *Arduino Uno R3 microcontroller*, power supply, voltage, current sensor, modules (for wireless communication), display, and load, and it provided automation, manual control, and monitoring.

Ezema *et al.* (2012) designed and constructed an automatic change-over switch with generator start/shut-down functions. The automatic switching mechanism ensured that consumer loads were transferred to the generator supply in case of mains power failure. Conversely, the switch automatically detects power restoration from the mains, returns the load to the mains power supply and then shuts down the generator set (Ezema *et al.*, 2012). This work has helped immensely to reduce human stress and loss time associated with switching power supply from one source to another. The project did not incorporate under-voltage and over-voltage protection. This study implemented a phase selection system, automatic starting and shutting down of the generator that drastically reduces the shortcomings of switching time between phases and generator, large power consumption, and heat generation associated with the common Automatic Voltage Switch (AVS) system. A *PIC16F877 microcontroller* is incorporated to help automate the speed. The system is controlled by a software program embedded in the microcontroller.

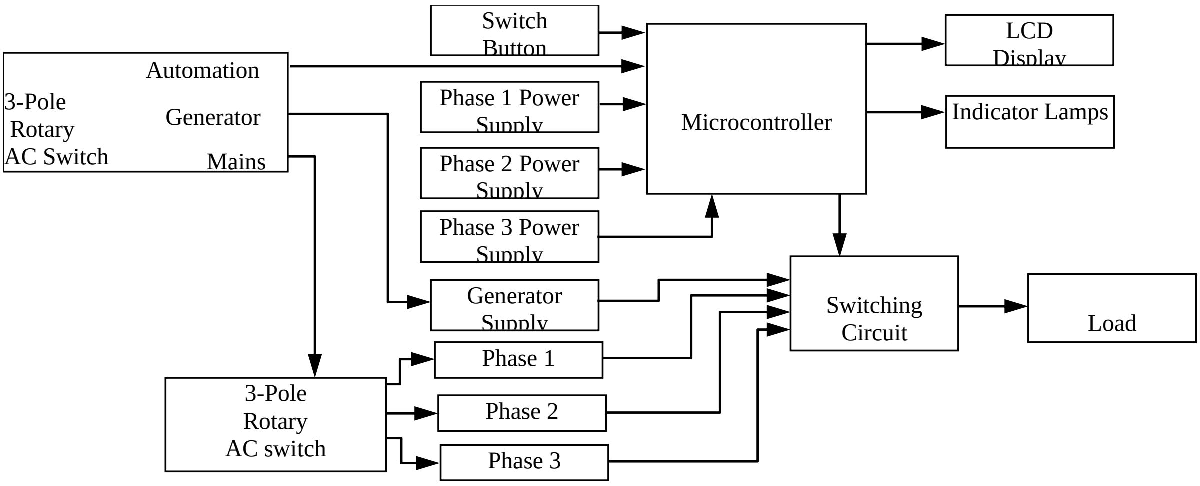

Figure 1. Developed Model of Three-Phase Microcontroller Based Automatic Change-Over Selection Switch

This device is handy and portable compared to the bulky ones produced previously. It also has important features like a battery charging unit, operation schedule, and visual display unit, which makes the system user-friendly.

The designed model realization of a *three-phase* microcontroller-based automatic change-over selection switch is presented in Figure 1. while the complete circuit diagram is shown in Figure 2. The model is made up of hardware and software modules. The hardware module comprises sub-modules of the power supply unit, microcontroller unit, display unit, load control unit, AC power switching unit, and the main housing of the machine. The software module consists of the development of the control program. The input power supply for each phase was achieved from three transformers to step down the AC voltage and send from each phase to the rectifier for DC processing by the microcontroller. When there is a power outage in the system or unbalanced phases occur, the microcontroller sends a signal to the relay to auto-start the generator. During the running operation of the generator, if the mains are available, it will take a few seconds to switch to it. The delay will check for the best available phase (normal, not too Low or too High). If none of the phases is good, it will not switch nor will it off the Generator. The generator will then work based on the scheduled time preset on the *timer IC DS1307.*

Mathematical Modeling of the Components Used

Figure 3. shows the circuit diagram of the microcontroller DC supply power; the circuit is made up of the following components used in the power supply unit. One of the components is the transformer that steps down AC voltage.

Transformer: The equation relating the voltage of a transformer and the number of turns of its windings is given as:

$$\frac{V_1}{V_2} = \frac{N_1}{N_2} \tag{1}$$

Thus, V_1 and V_2 are the primary and secondary voltages respectively. N_1 and N_2 are the number of turns of the primary and secondary windings respectively. The secondary voltage of the transformer is *12 V* when the primary voltage is *230 V*, the transformation ratio of the transformer is computed as:

$$\frac{N_1}{N_2} = \frac{230}{12} = 19.16$$

The input AC voltage is allowed to vary within a range while the nominal AC voltage is *230 V.*

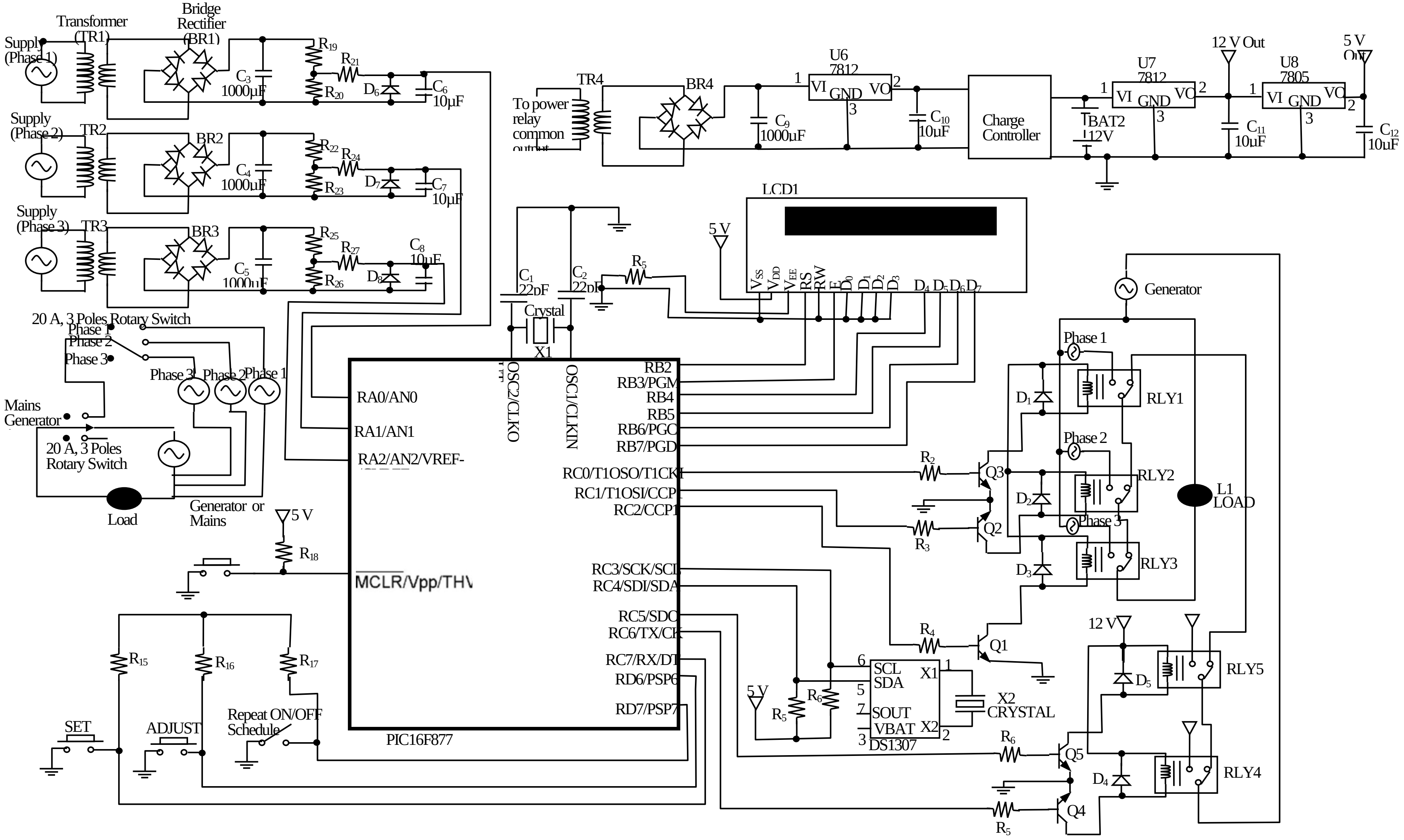

Figure 2. Circuit diagram of the Three Phase Microcontroller Automatic Change-Over Selection Switch

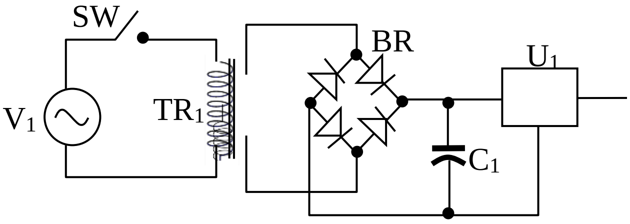

Figure 3. Regulated DC power

The design for the primary AC voltage ranges from *160-270 V*. The corresponding secondary voltage boundaries are computed using Equation (1). If the primary voltage is *160 V*, the corresponding secondary voltage V_{S2} is given as;

$$\frac{160}{V_{S2}} = \frac{230}{12}$$

$$V_{S2} = \frac{160 \times 12}{230} = 8.34\,V$$

Similarly, if the primary voltage is *270 V*, the corresponding secondary voltage V_{S2} is given as;

$$V_{S2} = \frac{270 \times 12}{230} = 14.09\,V$$

A stepped-down secondary voltage range of *8 V* to *15 V* is sufficient since the current limitation is handled by the regulator. Hence, *a 230/12 V* Step down transformer with a turn ratio of *20* was chosen for the design.

The Three-Phase Voltage Sensing Unit

The Figure 4. shows the *3-phase* circuit of the sensing unit. The unit has its power supply stage that consists of the *three-phase* step-down transformer to step the voltage down from *230 V* to *12 V*, the full wave rectifier bridge that converts the *12 V* AC from the transformer output to *12 V* pulsating DC and the filter unit which contains an electrolytic capacitor for reducing the ripple content of the *12 V* pulsating DC.

Bridge rectifier

The *2W04G rectifier* and *1N5408 power diodes* were used for the simulation process.

Diodes.

The peak voltage V_{pAC} of the diode is given by the expression

$$V_{pAC} = \sqrt{2} * V_{ac} \tag{2}$$

$$V_{pAC} = \sqrt{2} * 24\,V = 33.9411\,V$$

Because of the Full Bridge Rectifier, *24 V* was used instead of *12 V*

$$V_{dc} = \frac{2}{\pi}(V_{Pac} - 2V_D) \tag{3}$$

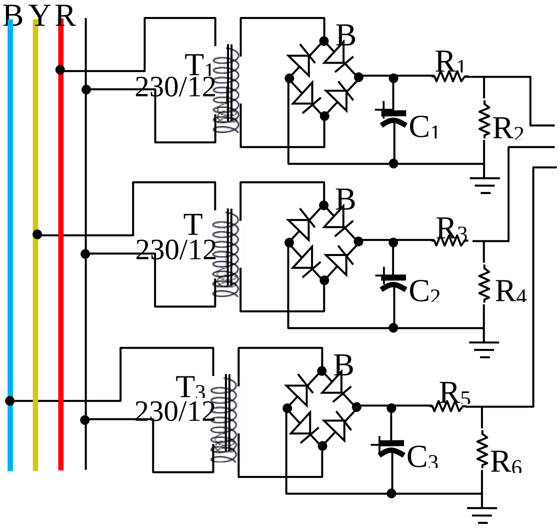

Figure 4. Three-Phase Voltage Sensing circuit

For every half cycle of the AC voltage, *2 diodes* are in operation (conducting) and they have a total voltage drop across them to be V_D

$$V_D = 2 \times 0.6\,V = 1.2\,V$$

$$V_{dc} = \frac{2}{\pi}[33.9411 - 2(1.2)]$$

$$V_{dc} = 20.0898\text{ V}$$

Filter capacitor (C)

The capacitance of the filter capacitor used for the simulation was determined from the expression of ripple factor as shown in equations (4) and (5) (Rashid, 2001; Theraja and Theraja, 2005)

$$\gamma = \sqrt{\left[\left(\frac{V_{ac}}{V_{dc}}\right)^2 - 1\right]} \qquad (4)$$

$$\gamma = \sqrt{\left[\left(\frac{24}{20.0898}\right)^2 - 1\right]} = 0.65357$$

$$\gamma = \frac{1}{\sqrt[4]{3FRLC}} \qquad (5)$$

Where;

F = Frequency in Hertz $\gamma =$ Ripple Factor

R_L = Load Resistance in ohms

$$Load\ resistance, R_L = \frac{Rated\ voltage\ of\ wired\ adapters\ in\ volts}{Rated\ current\ of\ wired\ adapters\ in\ ampere} \qquad (6)$$

$$R_L = \frac{5}{1.2} = 4.167\ \Omega$$

Assuming the *Ripple factor is 0.65357*, thus, the *capacitance of capacitor is satisfied* at *100 µF* with full wave rectifier diodes of *1N4001*.

$$C = \frac{1}{3 \times 16 \times 0.65357 \times 50 \times 4.167}$$

$$= 1.5299 \times 10^{-4}\ Farad$$

For the full-wave rectifier, the peak inverse voltage (PIV) was determined when V_p is the peak voltage

$$PIV = 2\,V_p \qquad (7)$$

$$V_p = V_{rms} \times \sqrt{2} \qquad (8)$$

V_{rms} is the root mean square voltage

$$V_p = 12 * \sqrt{2} = 16.97\ V$$

$$PIV = 2 * 16.97 = 33.94\ V$$

Power Bank Module

The power bank consists of a 6 V battery as shown in Figure 5. The charging rate and level are controlled by the programmed logic inside the microcontroller unit. The battery voltage threshold is set using a variable resistor to be *3.98 V* DC.

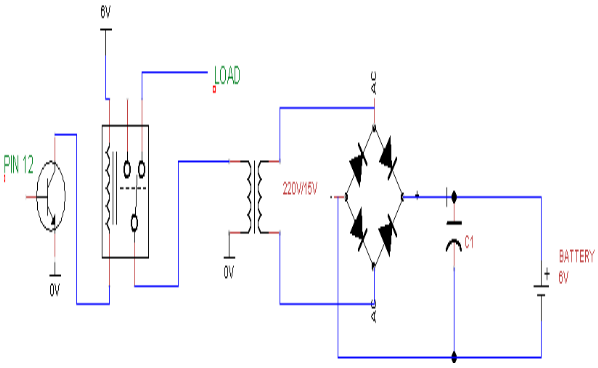

Figure 5. Power Bank Charging Circuit

The design equation for the generator is given by:

$$P = S \times cos\theta \qquad (9)$$

Where S is the apparent power of the generator in *KVA*, P is the wattage power of the generator in *KW* and $cos\theta$ is the power factor and is usually given as *0.8* for most electrical motors and generators. Thus, for a 10 KVA generator, the optimum wattage of the design is given by;

$$P = (10 \times 0.8)\ KW = 8\ KW$$

The impedance Z_L is given by;

$$Z_L = \frac{(V_1)^2}{P_L} = \frac{(240\ V)^2}{8\ KW} = 7.2\ \Omega$$

and the current is given by;

$$I = \frac{P}{V} = \frac{8000\ W}{240\ V} = 33.33\ A$$

The maximum load that can be on the single-phase automatic change-over system is defined at *0.75* of the capacity of the design. Thus, the maximum wattage of the design is given as;

$$P_L = 0.75 \times 8\ KW = 6\ KW$$

Selection of contactor

The switching relay circuit illustrated in Figure 6. indicated the supply voltage from either *power source (V) = 240 V*; *Power rating of the generator (S) = 10 KVA; Apparent power S = IV*

Therefore, the rated generator current is given as;

$$I = \frac{Rated\ power\ in\ KVA}{Rated\ voltage\ in\ Volt} \qquad (10)$$

$$I = \frac{10000VA}{240V} = 41.5\ A \approx 42\ A$$

Therefore, 42 A rated contactors are selected for the Automatic Transfer Switch (Anaza *et al.*, 2016).

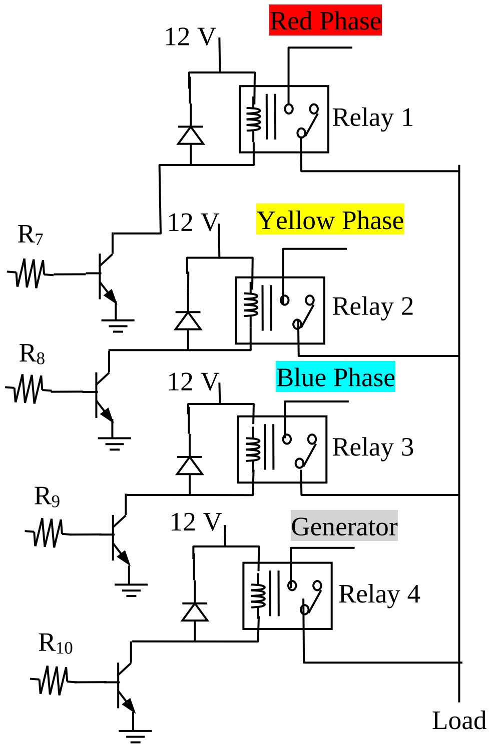

Figure 6. Switching relay circuit

RESULTS AND DISCUSSION

The simulation results obtained from the construction of the automatic change-over switch are presented in Figs. 8. and 9. The design and construction was implemented on the Vero board and also the simulation process was carried out with the use of Circuit Maker and proteus Software. The parameters in Table 1 and 2 were considered for the construction of the automatic change-over selection switch and *three-phase* voltage mains, respectively while Figure 7 shows the Flowchart of the Automatic Change-Over Selection Switch.

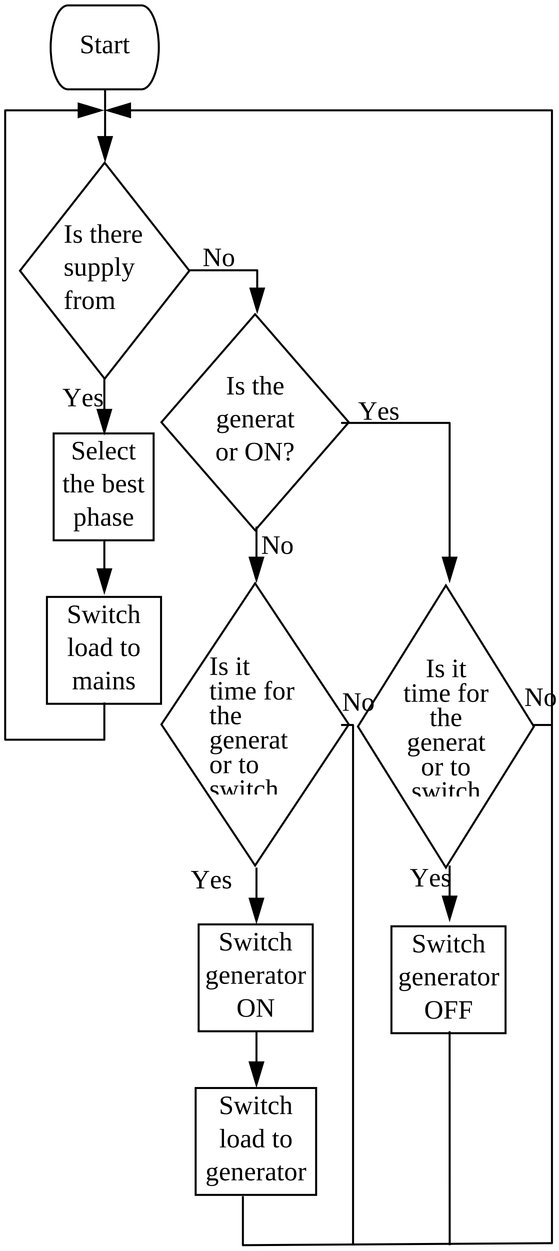

Figure 7. Flowchart of the automatic change-over selection

Table 1: Construction parameters

Parameters	Values
Switching Delay (s)	*3 ~ 10 (adjustable)*
Maximum Load Capacity (KVA)	*12*
Buzzer Sound Intensity (dB)	*70*
Nominal Input AC Voltage (V)	*240*
Nominal Output AC Voltage (V)	*240*
DC Power Supply Voltage (V)	*5, 12*

Table 2: Three-phase voltages

Parameter	Values
Phase 1 Voltage (V)	*116*
Phase 2 Voltage (V)	*122*
Phase 3 Voltage (V)	*253*

Table 3: Supply of three-phase voltage and generator

Parameter	Values
Phase 1 Voltage (V)	*33V*
Phase 2 Voltage (V)	*5V*
Phase 3 Voltage (V)	*42V*
Generator output Voltage (V)	*240V*

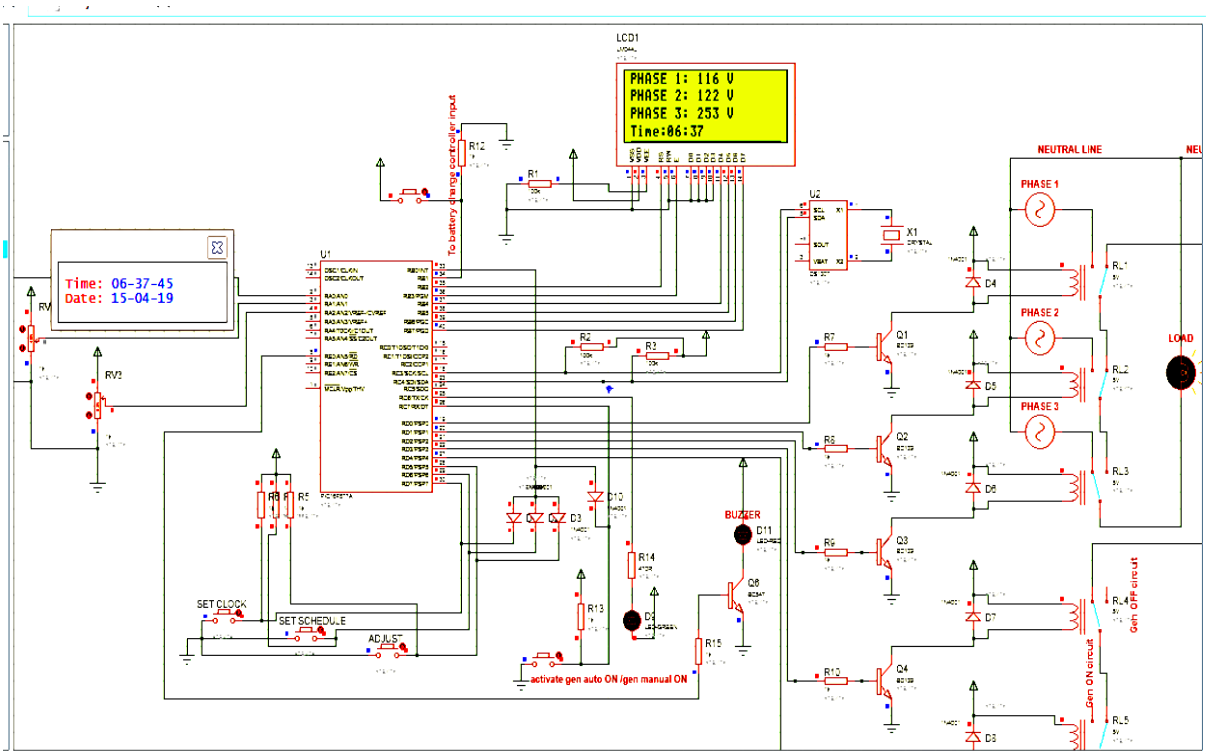

Figure 8. Complete circuit diagram for the automatic change-over selection switch to generator output processing

As illustrated in Figure 8, both *phase 1 and phase 2* are considered as low voltages and phase 3 is a normal voltage. Therefore, *phase 3 (blue)* is selected by the microcontroller and made available at the load side. Figure 9. illustrates the simulation result of the low voltage situation from the mains source and switching.

Comparative Simulation of Generator and Power Supply Using Proteus

Figure 9. indicates that the voltages of all *three phases* of power utility are considered as low voltages so the circuit system changes over from the source to the generator. Considering Figure 10. initially, the system was in normal condition of *5.0 V*. PS (Power Supply) and the Generator Set (GS) is at *0.0 V* standby modes. Throughout this condition load is served from the primary source of power PS; at this condition, GS is off, while ATS continuously checks the state of the system. As PS shuts down, ATS proceeds to further check and eventually shifts the load from PS to the generator set. Figure 10. indicates that ATS starts working when the PS is no longer available.

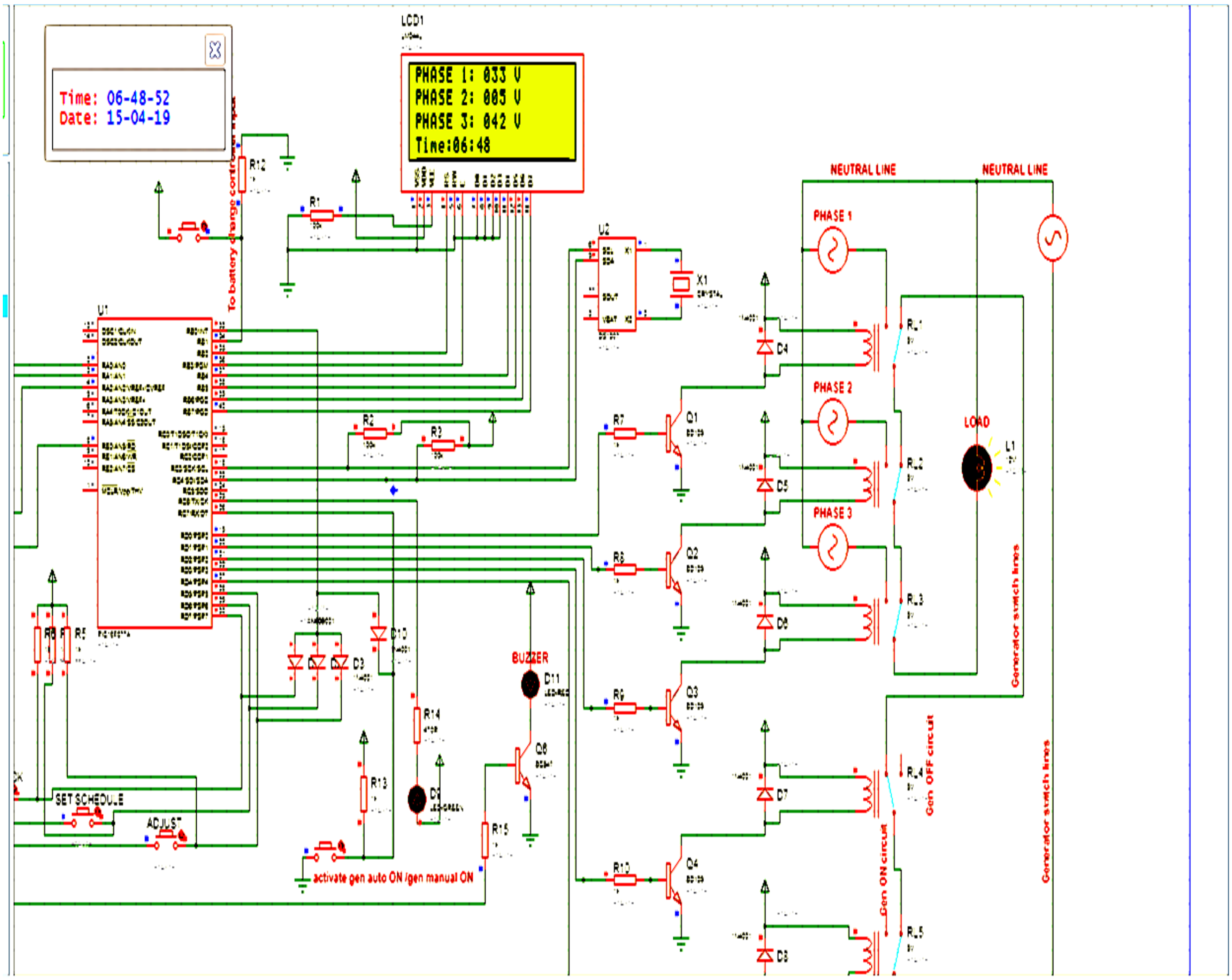

Figure 9. Simulation result of three-phase voltage mains supply

When PS shuts down, GS instantaneously turns ON and also at the same time generator starts to take itself. Self-duration is set to some extent *400* ms. A frequency-checking circuit is installed. If the generator starts within the prescribed self-time, the next progression is load shifting within *30 ms*. Figure 11. shows that when PS is not available ATS starts working which is to start the generator and load shifting from PS to the generator. In case PS returns when ATS is in self-mode then normal operation is interrupted and immediately load is shifted to PS the GS is switched off after *30 ms*. Figure 12. indicates that when the generator is in operational condition and the load is being attended from the generator, ATS constantly senses the PS and when the PS resumes, ATS shifts the load immediately to PS and turns off the generator after a delay of *30* sec. Figure 13 is a case of power failure, GS turns on and the generator drives on self-mode. If the generator fails to start after seven self's steps signal due to fuel shortage or any fault in the generator which is some hurdles that intrude the normal operation of the ATS; it indicates the interruption by an alarm, and turns off the GS and stops the self-signal. After initiating the alarm ATS must be reset manually by the user later on to clear the fault (fuel check/hardware check).

The graphs in Figure 14. and Figure 15. Show the fluctuations in the output of operational *amplifier LM741* when it changes its state from *0 V – 12 V*.

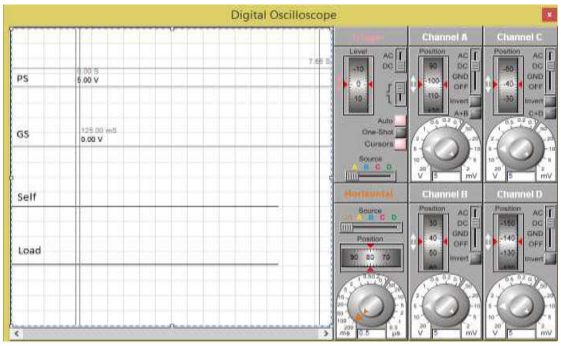

Figure 10. Graph showing the condition of the power supply ON and generator OFF

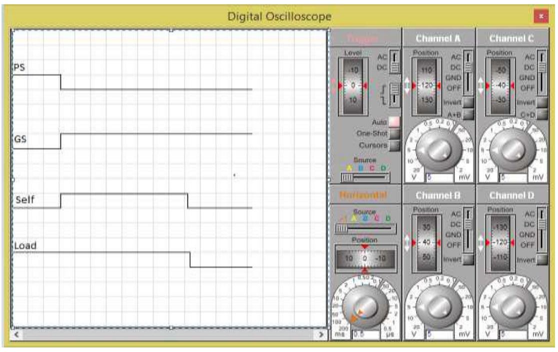

Figure 11. Graph showing the condition with PS off, the generator starting and load shifting

This fluctuation causes the relay to switch ON and OFF continuously and produce fluctuations in *220 V* line connected to the load which can cause a malfunction of the microcontroller.

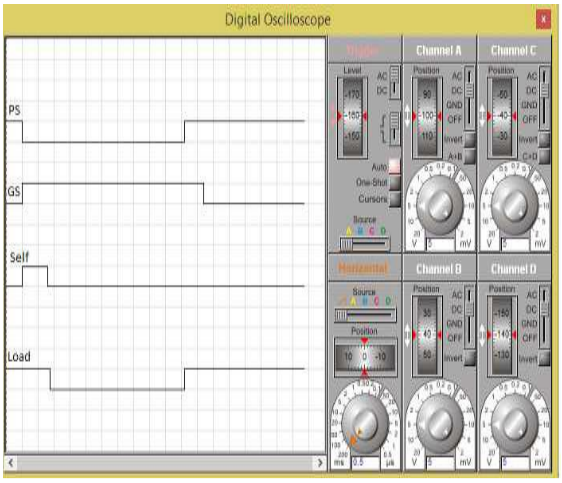

Figure 12. Graph showing the condition when PS resumed Load Shifting and Generator off

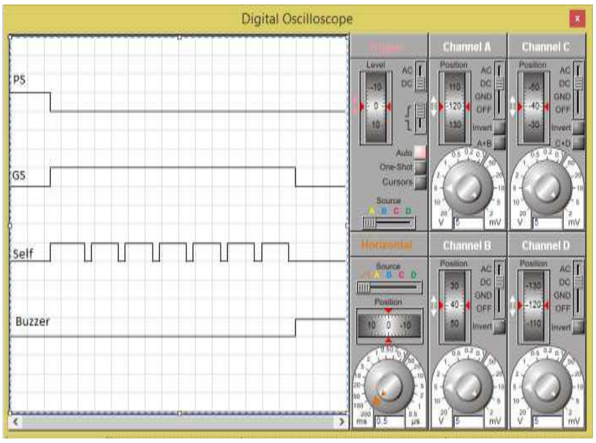

Figure 13. Graph showing the condition when the generator fails to start and buzzer on

Figure 16. shows the AC input power frequency signal from mains as peak-to-peak sinusoidal varying signal V_{AC}. Figure 17. and Figure 18. showed the complete control mode operation of the three-phase microcontroller-based automatic change-over selection switch. The system was successfully designed and constructed using a *microcontroller (PIC16F877A)* as the main circuit controller using a relay and transistors as a power switch. The *PIC16F877A* microcontroller has a fast instruction execution time of 200 nanoseconds and is available in a 40-pin package. The microcontroller offers several notable features, including 256 bytes of EEPROM data memory, an In-Circuit Debugger (ICD), 8 channels of 10-bit Analog-to-Digital (A/D) converter, 2 additional timers, 2 capture/compare/PWM functions and a versatile synchronous serial port that can be configured as either a 3-wire Serial Peripheral Interface (SPI) or a 2-wire Inter-Integrated Circuit (I^2C) bus. Additionally, it includes a Universal Asynchronous Receiver Transmitter (USART). These features of the PIC 16F877 microcontroller led to its selection for the design described in this study.

Three transformers rated *220 V / 9 V* were used for the power source sensing circuit. The input and output line voltages of the switching circuit were measured as *220 V* and *210 V* at *50 Hz* respectively and the ripple factor was determined to be *0.2 %*. The *DS1307* module was used to monitor the real-time operation of the system by allowing switching ON and OFF state of the generator in case of a power outage. The push buttons were used to set the system operating time and to enable the repeat schedule. The three-pole switch provides the manual operation of the system in case of system failure. The contractor was used to switch to three different modes; automatic, manual main supply, and manual generator supply. The buzzer sounds whenever the system fails to operate the generator after three to five trials.

The load capacity of the automatic change-over switch was determined by decoupling Maxwell's Equations as *8 kW* and the power loss for the design was determined by using the poynting vector equation as *0.25 %* of the peak load. Simulation was done using Proteus to simulate the operating points and transient analysis of the design before physical implementation. This system monitors the availability and level of voltage on the three phases and selects the most suitable one. The system switches to the generator automatically in the event of failure of the main supply through the electromechanical switches used in the circuit.

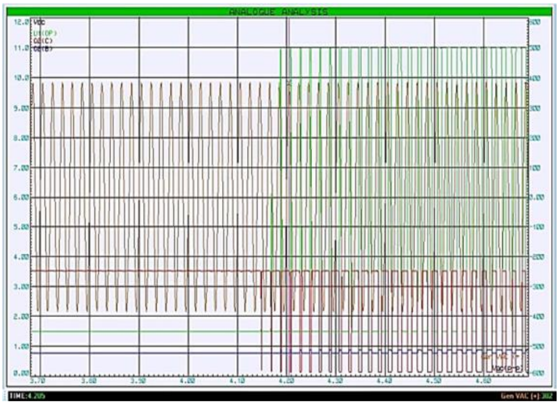

Figure 14. Output waveform of the transistor

Presented in Table 4 are the output results obtained during testing, the sensing unit was designed to interpret voltage less or equal to 3.33V as being too low, while the voltage between 3.33 to 4.34V should be interpreted as normal voltage suitable for effective functioning of the end-users connected equipment while any voltage above 4.34V should be interpreted as over-voltages.

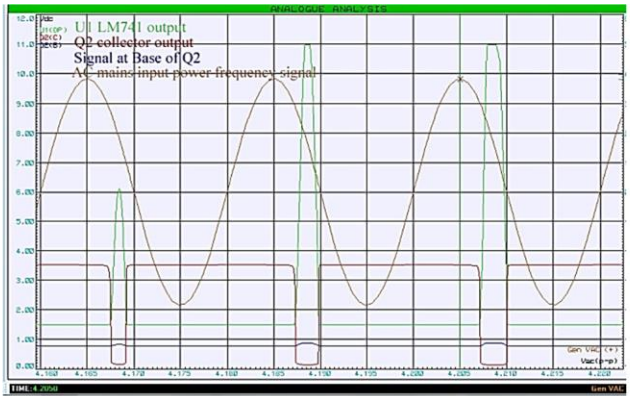

Figure 15. The AC output waveform from the generator

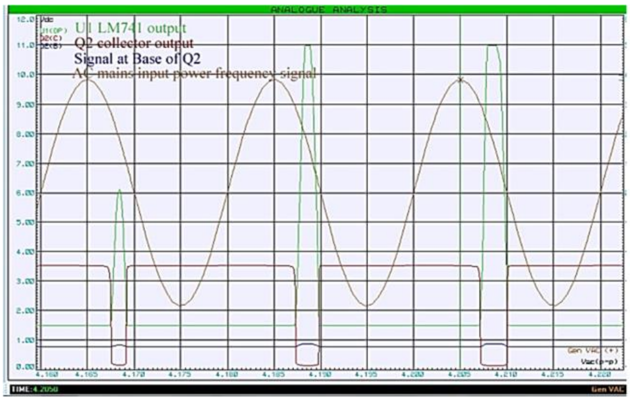

Figure 16. Waveform of AC input power from the mains

Figure 17. The front view of the constructed micro-controller-based automatic change-over.

Also, from the statutory voltage any voltage below 200 V for a single-phase supply is under-voltage, while above 220 to 250V for a single phase is a normal voltage compatible with equipment ratings while any voltage above 250 V is dangerously high for a single-phase supply. The designed micro-controller-based automatic change-over was able to detect and interpret the measured voltage appropriately as shown in Table 4

Table 4: The result of Testing at Normal, Under-voltage and Over-voltage Conditions

Utility Supply AC Voltage (V)	***Range***	***DC voltage seen at the main sensing circuit (V)***
167	*Too low*	*3.33*
217	*Normal*	*4.34*
280	*Too high*	*4.91*

Figure 18. The LCD unit displaying the working mode

CONCLUSIONS

In this paper, the three-phase microcontroller-based automatic change-over selection switch was designed and developed to help control power supply to electrical equipment, to eliminate associated problems of phase failure, losses and phase imbalance, as well as major earth faults caused by unstable and erratic power supply. The performance of the developed work was demonstrated by the prototype which showed high efficiency of operation with respect to the desired aim. It is to be used on single-phase loads that have the opportunity of interfacing with *two or three phases* of power supply. The system applies to electrical equipment operating within *220V and 415V* power supply in homes, offices and workshops.

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