Design and Simulation of a Versatile Three-Phase Automatic Changeover Switch

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***Abstract*— The importance of a changeover/ transfer switch cannot be understated. When using a generator, this switch attempts to provide a smooth transition. A transfer switch is created in this project for a college in Ghana, to enable it to switch electricity from the utility to a different source. Previously, a manual switch was used, which was activated by physically moving a lever. However, with this newly improved switch, if it deems the power to be out (due to heavy rains or an electrical accident), it will instantly and safely change-over to the generator or solar power. Ultimately providing electricity to critical functions (set precedingly). The final circuit was carefully designed and divided into two halves, for better explanation. The starter circuits were specially designed to simulate how the auto switch-over will be powered (either through a single or three phase supply). The end circuits were utilized to show how the auto switchover gives users feedback. The overall outcome of the project is a combination of the start, and end circuit. This resulted in the adaptable auto-transfer switch. The project has an immediate impact on three Sustainable Development Goals (SDGs): 7, 9, and 11. This is due to the fact that it is an innovation that promotes clean energy, while also contributing to smart cities.**

***Keywords*— Single/three phase, Solar, Generator, ATmega328, Uninterrupted power, Changeover-switch.**

I. Introduction

Ashesi University is a four-year institution that emphasizes both engineering and the liberal arts. It focusses on training ethical and entrepreneurial leaders to better Africa, and the world. This project investigates the design of a safe, efficient, and fast changeover switch that allows automatic starting. It further allows automatic power generation for the entire school, as soon as the power received from the grid is terminated. One could argue that manually operating the switch would reduce some level of cost, but the safety of Ashesi employees must be considered [1]. Any handling of a power source could have unfavorable consequences. Manually starting a generator could be disastrous, especially at night. A transfer switch removes the dangers associated with an outage entirely [1]. The many parameters required to design a suitable changeover switch for Ashesi University, was evaluated. Considering that the college is based in Ghana, all parameters (e.g.: frequency of power supply) were set to the country's nominal standards. This was acquired from the Electricity Company of Ghana's (ECG) repository. Furthermore, the Proteus software was utilized due to its uniqueness to vividly demonstrate circuit functionality.

Fig. 1. Ashesi University campus building (with solar power provision)

II. Literature Review

In [2], Arun Dev et al. designed a three-phase single mode changeover controller. It possessed two dc relays that were capable of switching the power source from the grid, to solar/ generator. The switching mechanism is very fast with the use of the relays. However, this changeover switch does not display the recent power source to the user, and it is impossible to manually operate it aside from being automatic. Hence, users do not have the choice to switch to the preferred power source, to save power at a particular time.

A digital electronics-based changeover switch is designed by Singh, et al in [3]. It is designed as a way to prevent the generator from starting – if the power has not gone out for more than two (2) seconds – to save cost from false starting the generator. This changeover nonetheless, does not allow users to select between single and three phase, and does not show them the current power source.

Durrani, et al., designed a changeover switch for a hybrid system comprising of the national grid, solar and a generator in [4]. This system makes use of efficient switching priorities, to save cost. The national grid is highly prioritized followed by the solar, and when the solar is unavailable, the generator takes

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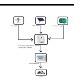
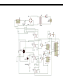
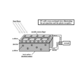
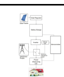
control. The system also has a charge controller that protects the battery (for solar) from overcharging, and from complete drainage. This design however, does not give feedback to users on the power source operating at any given time. It also does not allow users to switch between manual and automatic modes.

Herath, et al., also designed an intelligent changeover solution for a domestic hybrid power system in [5]. With the help of a microcontroller, this system is able to sense the power demand of the house at that moment and select the appropriate power source (either solar or the grid), to supply power. This changeover switch allows the generator to be added when there is no grid power, and the battery for the solar is below 25% of its full capacity. At any point in time, the power source is displayed on an LCD. Even so, this changeover system does not allow users to select between a single and three phase input. The four models ([2], [3], [4], and [5]) were reviewed, and their critiques displayed on a Pugh chart. The proposed model seeks to reach the full 16 marks criteria-score.

TABLE I. PUGH CHART OF RELATED MODELS

Description		**M1 [2]**	**M2 [3]**	**M3 [4]**	**M4 [5]**
Sketch					
Criteria	***Weight***	***Model 1***	***Model 2***	***Model 3***	***Model 4***
Fully Automated	5	+	+	+	+
Provides users with feedback (LCD display)	4	–	–	–	+
Allows user to switch between manual or automatic mode	4	–	–	–	+
Enables users to select between a single/ three phase input	3	0	–	–	–
Net Score (out of 16)		– 3	– 6	– 6	10

III. Design Methodology

A. *Computer Aided Design Model of Control Panel*

This is the Computer Aided Design (CAD) model of the control panel, for the three-phase automatic switch. It was designed using Solidworks. It contains components like relays, contactors, push buttons, connecting wires, and circuit breakers. The importance of using these, will be further elaborated in the component justification section.

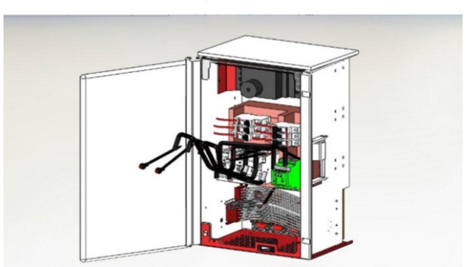


Fig. 2. Complete CAD design of the circuit and its casing

B. *System Block and Flowchart Diargam*

Figure 3 displays the block diagram of the proposed design.

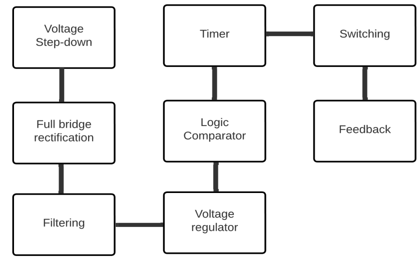


Fig.3. System block diagram

The block diagram considers rectification and filtering of the input voltage. The Proteus software was instrumental in displaying a virtual terminal, and LED indicators, to signal power in certain parts of the circuit. Proteus also helped explain two important starter-circuit methods. The flowchart of the entire system is displayed in Figure 4.

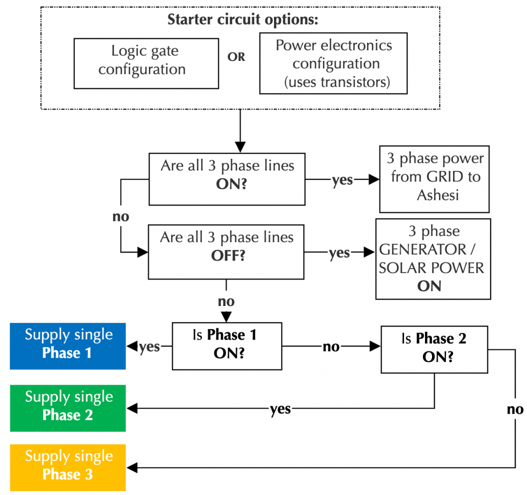


Fig.4. Flowchart for the automatic changeover switch

C. *Important Considerations and Calculations*

Calculations were made to provide accurate inputs into the respective components in Proteus. It was presumed that the switch is applied on a 220V/415V configuration, and with a 12-kilo ampere generator, operating at 50 hertz – along with a power factor of 0.8.

Using Ghana's electricity standards:

$$\text{Apparent Power} = 12\text{kVA}$$
$$\text{Line Voltage (VL)}= 415\text{V}$$
$$\text{Phase Voltage (VS)} = 240\text{V}$$
$$\text{Active power} = \text{Apparent power x Power factor} \quad (1)$$
$$= 12 \times 1000 \times 0.8 = 9.6 \text{ kW}$$

*For a balanced load

$$P = 3I_pVP\cos\acute{Ø} \quad (2)$$
$$9600 = 3 \times I_p \times 240 \times 0.8$$
$$I_p = 9600 /(3 \times 220 \times 0.8)$$
$$I_p = 18.3 \text{ A}$$

For better efficiency, the minimum current rating is given 25% more tolerance.

$$I_p = 125\% \times 18.3$$
$$I_p = 22.9 \text{ A}$$

In order to avoid any accidents, the cable carrying this current (I_p = 18.3A) was made to handle a current that is about 50% more than the calculated primary current (which is approximately 38A). Transformer calculations:

$$\frac{Vs}{Vp} = CP\sqrt{\frac{Ls}{Lp}} \tag{3}$$

where CP =coupling factor = 1.0 ;

Vs = Secondary coil voltage = 12V(rms)
Vp = primary coil voltage = 220V (rms)
Lp = primary coil inductance = 4H

$$Ls = \frac{Vs^2 x\ Lp}{CP^2\ x\ Vp^2} \tag{4}$$

$$Ls = \frac{144\ x\ 4}{48400} = 0.0119 \text{ H}$$

For the primary and secondary dc resistances, R_p and R_s respectively

$$R_p = \frac{Vp}{Ip} = \frac{220}{1} = 220\Omega \tag{5}$$

For current on the secondary coil,

$$I_s = \frac{Vp\ x\ Ip}{Vs} = \frac{220\ x\ 1}{12} = 18.33A \tag{6}$$

$$\text{Hence, } R_s = \frac{Vs}{Is} = \frac{12}{18.33} = 0.655\Omega \tag{7}$$

IV. Proteus Design

A. Implementation

After calculating for the primary-secondary inductance, as well as the primary-secondary dc resistance for the transformer with two primary and two secondary windings, assembly of the starter circuit began. For this project, the primary task was to assemble together a circuit capable of switching from a three-phase input grid supply to a three-phase generator, automatically. To take the research, and final solution to the next level, some additional considerations were made:

- In the likely occurrence that 1 or all of the 3 phase lines are faulty, the automatic 3 phase transfer switch activates the generator/solar to serve the load. That is, fans and other components in Ashesi.
- Another alternative considered was: what if a fault is in just 1 line of the 3-phase supply, and the school deems it a good idea to simply change to either second or third phase (if, for example, the first phase got damaged).

After the voltage has been stepped down by the transformer externally, it is rectified into an output dc waveform by the full wave bridge rectifier. This dc output is then filtered by an electrolytic capacitor before being fed into the voltage regulator. The linear voltage regulator then keeps the voltage at a constant level before feeding into the timer, the MOSFET, and then the relay [1]. This circuit works such that, one phase is ON at a time. When phase 1 goes OFF, that is when there is a fault in line 1, the starter circuit switches to phase 2 automatically, after a 5 second delay (using the timer 555). Accordingly, if the phase 2 line is faulty, the phase 3 comes ON. When the phase 1 returns, power supply is automatically rerouted to phase 1, followed by phase 2 – in that order.

The circuit also enables users (Ashesi) to select if they want the automatic changeover to switch to the generator in any kind of fault (as explained above). The user could also be able to switch between phases (if the problem is not a power outage, but perhaps just a single faulty wire). In so doing, users would have a constant supply of power. This will reduce generator maintenance cost by a considerable degree.

With the only disadvantage being that any 3-phase appliance would not be powered if the user selects the phase switching capabilities of the circuit. Using the concept of digital electronics, the logic for a 3 input AND gate and OR gate, was purposefully designed. Users may select the full three phase option by simply pushing the AND gate button. The OR gate button/ transistor circuit, triggers the single-phase selector capability. Table II shows a truth table for the AND and OR gates outputs when the input phases are either high or low. The highs and lows are registered as binary inputs at the end circuit.

TABLE II. Logic gates truth table

Input (Phase 1, 2, and 3)	Output (AND gate)	Output (OR gate)
000	0	0
001	0	1
010	0	1
011	0	1
100	0	1
101	0	1
110	0	1
111	1	1

B. Component Justification

The components and their functionalities, are displayed in Table III below.

TABLE III. Components used in Proteus circuit

Components	Functions
Transformers (x3)	Steps down 230V mains to 12V for testing.
Timer 555 (x3)	Used as an ON/ OFF delay for other single phases not in use (e.g.: b or c).
LEDs (x3)	To serve as indicators that a phase is in use.
3 input AND gate 4075 (x1) 3 input OR gate 4073 (x1)	This implements the full 3 phase option. This implements a single-phase option.
Motor (x1)	To mimic a load fan.
IRF3205 NPN MOSFET (x3)	The MOSFET upon receiving a minimal gate voltage of 2V, switches ON the power supply - through coils that closes the relay.
7812, 12V regulator (x3)	Regulates the input voltage from output of transformer, into steady 12V.

Capacitors (x9)	Stores energy and enables delay as it is involved in the T=RC (time constant equation).
Resistors (x6)	Resists current to LEDs and also enables delay as it is involved in the T=RC (time constant equation).
1N4007 diode (x3)	Diodes used as freewheeling to make sure entire current flows through coil.
AC supply input (x3)	Voltage input into transformer, AC.
BC 557 PNP transistor (x4)	Works as an alternative to the logic gates (this is method 2). With a specific gate current, it switches OFF other relays (for other phases), when 1 other phase is ON.
12V relay | contactors (x3)	Relay coils are essential, and coordinates the auto switches to connect to different power supply options (phase 1, 2 or 3).
ATmega328 (x1)	Microcontroller used as the central brain. It was coded with C++ to control most components in the end circuit (when conditions are met).
Push buttons (permanent) (x2)	In case of extreme emergencies, the user can interact with the system manually.
Virtual terminal / LCD (x1)	To display feedback to the user.

C. *Starter Circuit Methods*

This extensive project also covers two variations of the starter circuit's functionality. One uses logic gates, and the other uses power electronics (most predominantly BC557 transistors).

1) For *Method 1* of the starter circuit, logic gates are used. The AND gates would mean that if phase 1, 2 and phase 3 are all ON (upon the user pressing the AND gate's enable push button), then a 3-phase auto changeover mode gets activated. If the user presses the push button for the OR gate, it activates the mode of switching between phase lines in case of a fault in a single line [1].

2) For *Method 2* of the starter circuit, no logic gates are used. The delay circuit is used in conjunction with the transistor. After 5 seconds of phase 1 being OFF, the circuit switches to phase 2 and so on [1]. So, this method is another way to apply a single phase for Ashesi University, in case of a fault in any wire (at least one wire must be functional).

Engineer disclaimer: The single-phase selector capability is optional, and is most suitable for homes, hostels and appliances on campus that use single phase.

- Single phase option: When phase 1 is OFF, phase 2 is next, if phase 3 is OFF or all are OFF, then the automatic switch triggers the generator to come ON and power the load.
- Three phase option: When all three phases are off (most probably due to a power cut) or even one single phase shuts down, the switch automatically redirects to the available 3 phase generator/solar (as Ashesi has both).

V. Results and Discussion

Considering the tests conducted, the operation of the system is very effective and coordinated for efficient performance. The behavior and operation process which covers the design is outlined below:

1) All load relies primarily on the main power supply from ECG.

2) In the proteus design, a dip in power automatically results in a (three) phase switch, and the load is automatically disconnected from the mains, and transferred to the standby generator source.

3) The design's response to the mains power failure is to switch ON the starting mechanism of the generator, then the solar supply subsequently.

4) There is a delay in the loading of the generator so as to attain stability for a while. After the delay, the generator is fully loaded.

5) Once the main power supply from ECG is restored, power supply from the generator is immediately cutoff. Thus, allowing for the reuse of mains power.

A. *Starter Circuit Simulations using Proteus*

1) Relays are initially NO (Normally open), (See Figure 5).

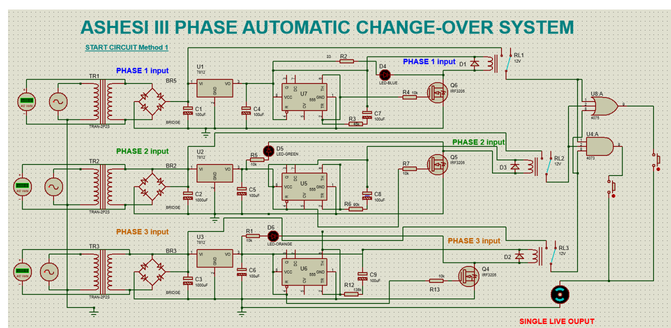


Fig. 5. Starter circuit method 1: phase 1 input activated

2) When one phase is ON (say phase 2), and the others are OFF, if the single-phase mode is selected, the motor will be powered from phase 2. Phase 2 relay closes, and the motor spins (See Figure 6).

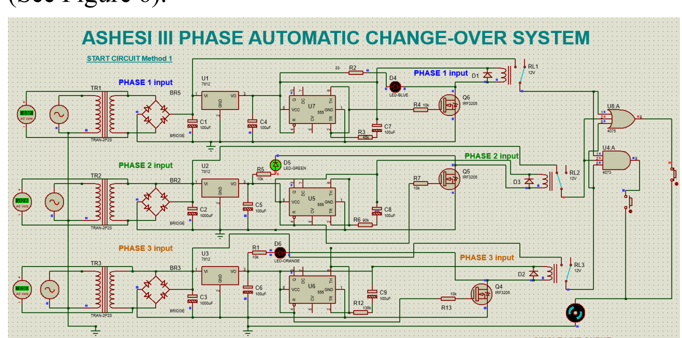


Fig. 6. Starter circuit method 1: phase 2 input activated

3) When all three phases are ON, should the three-phase mode be selected, the motor will be powered ON. Relays close now, and the motor spins. All LEDs are HIGH (See Figure 7).

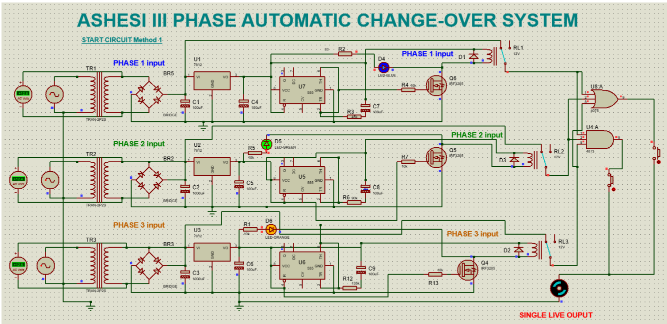


Fig. 7. Starter circuit method 1: all 3 phase inputs are activated

4) Starter method 2, using PNP transistors instead of logic gates, with OFF delays (See Figure 8).

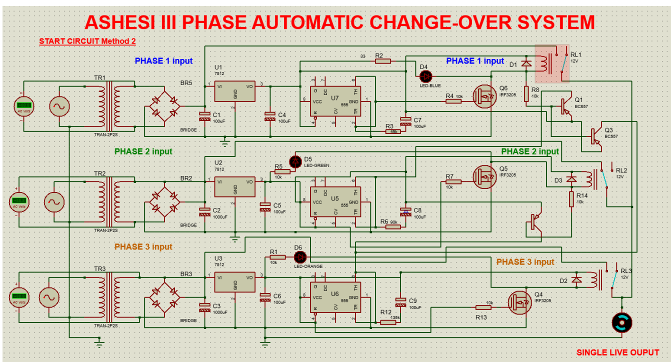


Fig. 8. Starter circuit method 2: transistor configuration used

B. End Circuit Simulations using Proteus

1) The final circuit is the combination of two halves. Here is the end circuit with full connections, and a 1 or 0 representing the state of the grid and the panel / generator (See Figure 9). The following circuits required an Arduino code to simply activate the relays based on the input of the grid or solar power. There is also an option to use the manual changeover switch. This is done by pushing the AUTO/MANUAL button down, and then pushing the GRID/SOLAR BUTTON. By default, the end circuit registers as AUTO (automatic).

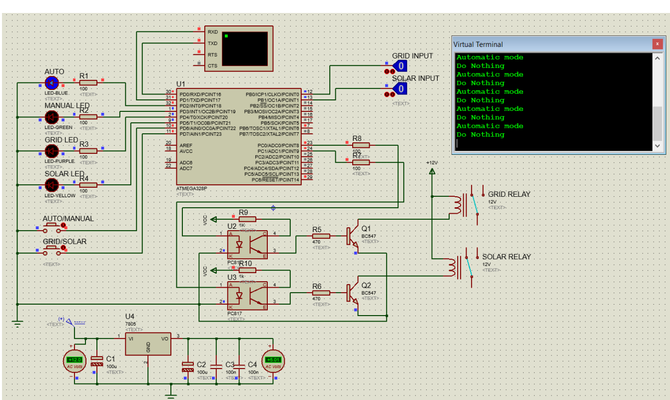


Fig. 9. Grid input – 0, solar input – 0

2) When Grid input from starter circuit is HIGH, that is "1," the LCD screen prints "Grid (Priority)." The circuit switches ON the relay for the grid automatically, while shutting down the Solar or Generator power. Notice that the LEDs shows which system is prioritized at the moment (See Figure 10).

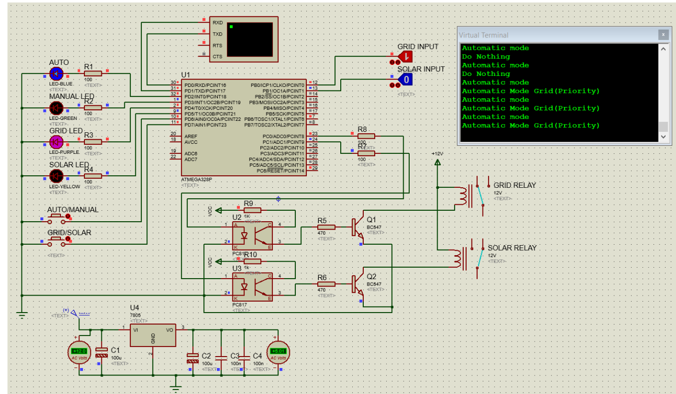


Fig. 10. Grid input – 1, solar input – 0, hence grid relay activated (closed)

3) When the grid shuts down, the microcontroller triggers the solar or generator pin input to HIGH, then the solar panels' relay coil is closed (See Figure 11). When there is a fault in our internal circuit such that both the generator/ panel and the grid pin input is connected and are on, the code recognizes this and puts OFF the relay to the grid. Whiles switching ON the available solar energy. Please note the microcontroller can easily be configured to prioritize the grid instead of the generator in case of a fault.

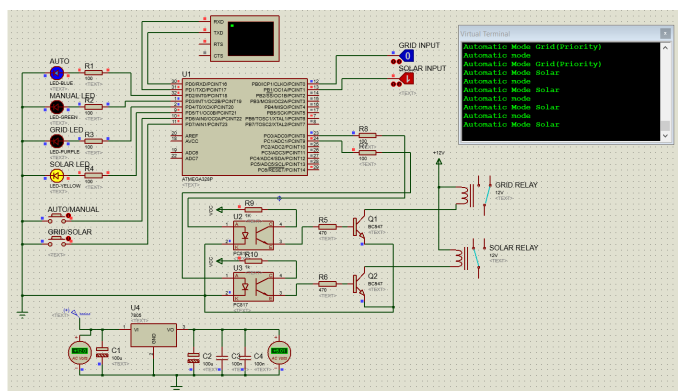


Fig. 11. Grid input – 0, solar input – 1, hence solar relay activated (closed)

C. Important Links

1) Starter circuit video:
https://drive.google.com/file/d/1o5llD95Ym59ZBjSyZJLVku4v6hiAUl6m/view

2) End circuit video:
https://drive.google.com/file/d/1A1ZG8trRXqSbL-EiCd6i5-eh4HoWARm_/view

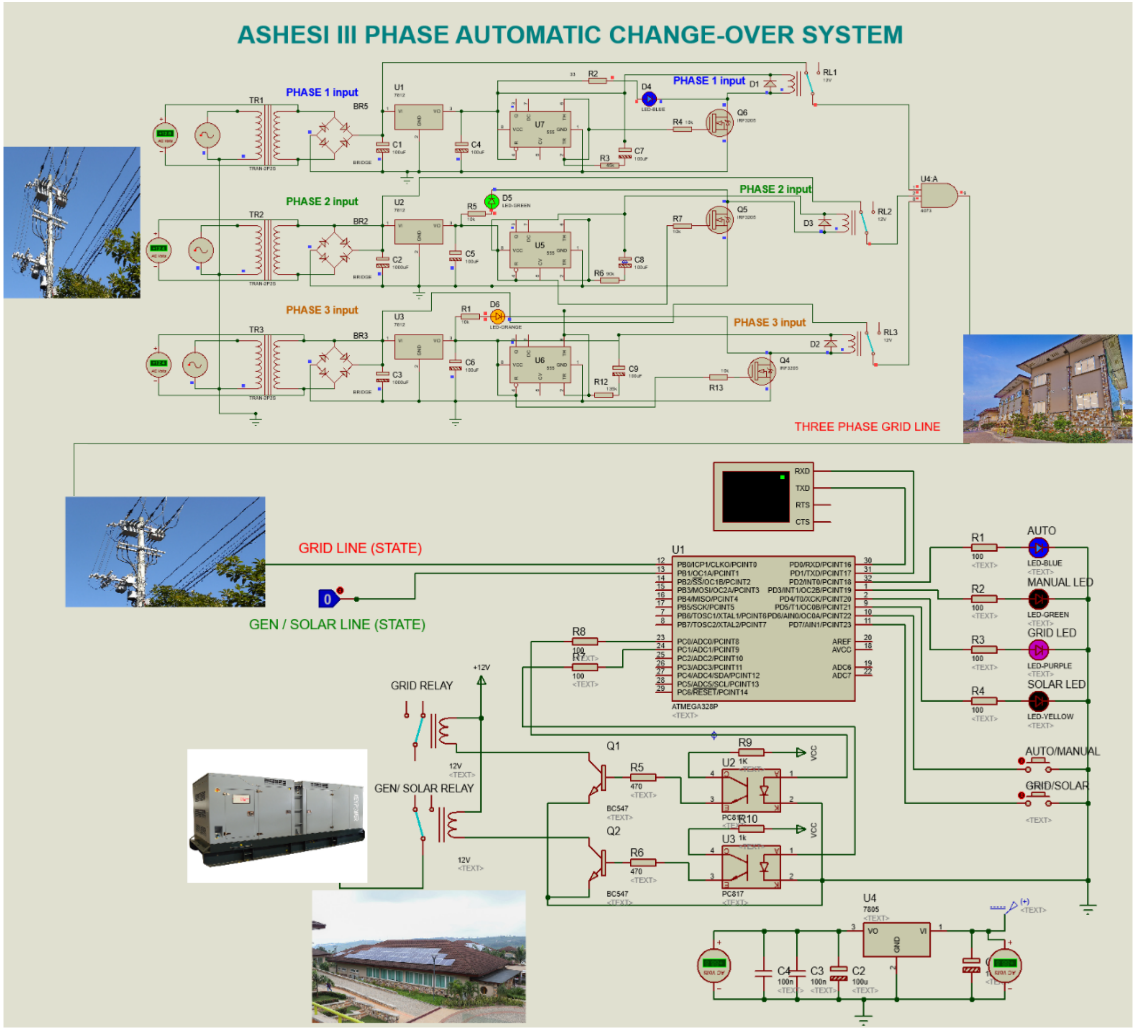


Fig. 12. Completed three phase selector/auto changeover switch in Proteus (start and end circuit)

VI. Conclusion and Future Works

The objective of this project was to move one step closer to reliable power supply. For the employees and students of a facility like Ashesi, a sudden power outage could be tremendously disruptive to the normal operation of the school. This abrupt power fluctuation could result in the loss of crucial files and materials. Therefore, it is essential to incorporate a smart and versatile control, that automatically switches between the main power source and the generator/solar (when power is cut). An automatic transfer switch guarantees power dependability, personnel safety, and streamlined operations. The construction of the product and its enclosure are among the future works. As well as the use of an ARM microcontroller – for better efficiency and functionality, as opposed to the ATmega328. Furthermore, the physical prototype would be used to establish a meaningful connection between the high voltage lines (starter circuit) and the microcontroller's inputs (at the end circuits).

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