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Development of a Hybrid Automatic Power Changeover Switch with Phase Selector

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ABSTRACT

This paper presents the design and construction of a Hybrid Automatic Power Changeover Switch with Phase Selector. The system is capable of switching between three different sources of power supply, viz: public power supply, generator and inverter circuit system. This design and implementation were achieved with the use of contactors/relays to effect the switching and at mega 328 microcontroller that is programed to compare the voltage levels of the three-phase supply. The work was simulated using an Electrical Control Technique Simulator (EKTS), while the phase selector was simulated in Proteus environment to ensure it workability. The work was tested, and results shows that it automatically switches power supply from generator to public supply and put off the generator once there is public power supply, it also automatically switches to an inverter or any alternative means of power supply other than generator once there is public power supply outage; this ensures the reliability of power supply to our loads (equipment).

1. Introduction

Presently, power availability has become a great albatross around the necks of most developing nations. This can be evidently seen in Nigeria as it battles with chronic electricity supply crisis, severe power delivery deficits and acute power quality issues to consumers connected to its grid for industrial, commercial, and domestic use (Okhaifoh *et al.*, 2021; Okhueleigbe and Okhaifoh, 2017). Also, the problem of power outage across phases is so rampant thus leading to some sensitive equipment and appliances been redundant (Gadakh *et al.*, (2021)). The deployment of alternative sources of power supply such as batteries, gas/diesel engines etc. by consumers to

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mitigate these challenges have resulted in development of hybrid energy systems (Okhaifoh *et al*., 2021). One implication of the introduction of these alternative power supplies is the challenge of integration and seamless switching between the mains supply and the alternative sources whenever there is a failure on the mains source. There is also the need to reduce drudgery from switching between these sources due to manual operations by humans. Therefore, the need for automation of changeovers and phase switch (during phase failure) between the utility power supply and the alternative channels (inverter and generator set) to back-up the utility power supply is the crux of this work. This is to ensure safe operation of appliances, optimal performance of systems, reliability, and continuity in utility power supply.

Effort on developing change over switch for hybrid energy systems is not new as different ways and methods of achieving power change-over both manual and automatic types have been developed by various researchers. Present day technology has made it possible for the changeover switch to be more effective and faster with less labour. Also, improvement has been made in terms of number of designs, using the closed loop system at feedback control as seen in (Ihedioha**,** 2017).

Ayinde et al., (2018) present the design and construction of a single-phase automatic change over switch. The design was realized using major components like a step-down transformer (220V-12V dc), atmega microcontroller, rectifiers, voltage regulators, 555 timers, relays, circuit breaker and others like resistors, diodes, and capacitors. The device automatically switches from public mains to an auxiliary whenever there is an outage in the public mains. This device also detects the public main power supply when available and switches from auxiliary power supply to the mains with a delay period of 4 seconds in switching off the generator. The design presented in this work does not only switch from between public mains and generator but also compares the voltage levels of the three-phase supply from the public utility and select the one with the best voltage. It can also switch to a backup system such as inverter when there is no supply from the public mains and the generator "Hybrid Automatic Power Changeover Switch with Phase Selector".

Ihedioha, (2017) present the design and implementation of a microcontroller based automatic three phases selector. The design comprises of transformer, a monitoring unit, a control unit, switching device (relays and relay drivers), and the transformer. The transformer used here is the step-down type of transformer (it steps down 240V to 12V) and this transformer is fed in with different phase voltage, rectified and smooth, and then fed into to a voltage regulator that has positive output.

Ofualagba and Udoha, (2017) presented the design and simulation of automatic phase selector and changeover switch for 3-phase supply. In this design, they employed the characteristics analogue multiplexers (CD4052), analogue to digital converter (ADC0804), AT89C51 microcontroller and relay switches in the design and implementation of an automatic phase selector and change over switch. However, the design was done to change overpower supply between public power supply and generator only.

Atser et al., (2014) worked on the design and implementation of a 3-Phase automatic power change-over switch. The design was implemented using three voltage Comparators (LM741 AH1883), 3-input-AND gate (4073), two BC 108 transistors and 12V, 30mA relay as well as some biasing resistors. The voltage Comparators (LM741 AH1883) were biased to sense the unregulated voltage - one for each of the three phases (Rø, Yø, Bø) and then couple the analogue outputs to the 3-input-AND gate (4073). Uchechukwu et al., (2015) presented the design of an automatic power phase selector. The design employs switching characteristics of contactors and relays. The design presented does not only check for the active phases but also `compare the voltage levels of the three phase and select the one with the healthiest voltage.

The main goal of this paper is to develop a hybrid automatic power changeover and phase selector system. **The scope is limited to switching power supply from a three-phase supply system to varied back up power supply system such as inverter circuit and generating set in residential buildings, offices, small and medium scale industrial setting, and hospitals.** It can automatically disconnect the load from the inverter and connect it to the generator supply as soon as there is supply from the generator. This makes this design more superior and state of the art.

2. Methodology and System Design Analysis

2.1 Methods

The top-down approach was adopted in this design. This approach involves breaking down of the system into smaller units to enable the designer to get more insight to the system. Considerations were made on the type of platform, software component, hardware component and mode of operation of the hybrid automatic power changeover and phase selector. Also, cost of components, availability, reliability, flexibility, and simplicity were considered in the selection of components for the design (Okhaifoh and Ogbekhiulu, 2018). The block diagram of the entire system is shown in fig. 1. Its two major constituent units are:

(a) **The Automatic Power Changeover:** In this unit, contactor and relays are used to effect the switching between the three sources of power supply viz; public power supply (i.e. the single phase from the automatic phase selector), generator and inverter.

(b) **The Automatic Phase Selector:** The Automatic Phase Selector is microcontroller-based system that is made up of phase voltage sensing units which are three rectifier circuits for each line of the three-phase connected to the microcontroller chip. The microcontroller compares the inputs from the rectifier circuits and triggers the relay which belongs to the one that has the highest voltage.

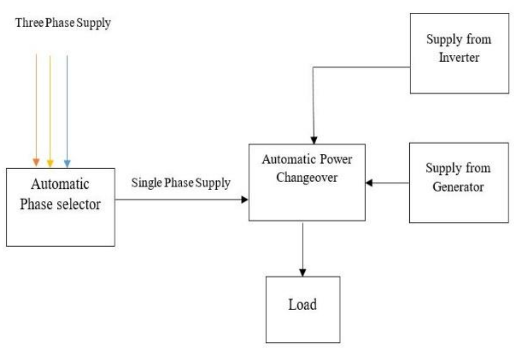

Fig.1 Block diagram of the design.

2.2 System Design Analysis

2.2.1 Hardware Analysis

The Hybrid Automatic Power Changeover Switch with Phase Selector is a combination of two circuit models. Hence, the analysis and implementation of this design was carried out in two sections viz:

(a) The automatic changeover.

(b) The automatic phase selector which is further broken down into subsections viz:

i. Three phase voltage sensing unit.
ii. Processing unit.
iii. Display unit.
iv. Switching unit.
v. Power unit.

2.2.1.1 The Automatic changeover

In this work, 220V AC relays and 220V-240V, 25A contactors were used in the design. The contactors and relays are assembled and connected such that priority is given to each of the power sources. The first priority is given to the public power supply, i.e., if any of the other sources of supply (generator and inverter) is being used when the public power supply is restored, the system automatically disconnects the load from either the inverter or the generator and connects it to the single-phase power supply from the public utility. The second priority is given to the supply from the generator such that if the inverter is being used when there is supply from the generator, the system automatically disconnects the load from the inverter and connect it to the generator. The supply from the generator can only be cut off if power is restored to the public utility. The third priority is given to the inverter which is serving as backup to hold the load if there is no supply from both the generator and the public utility as shown in fig. 2.

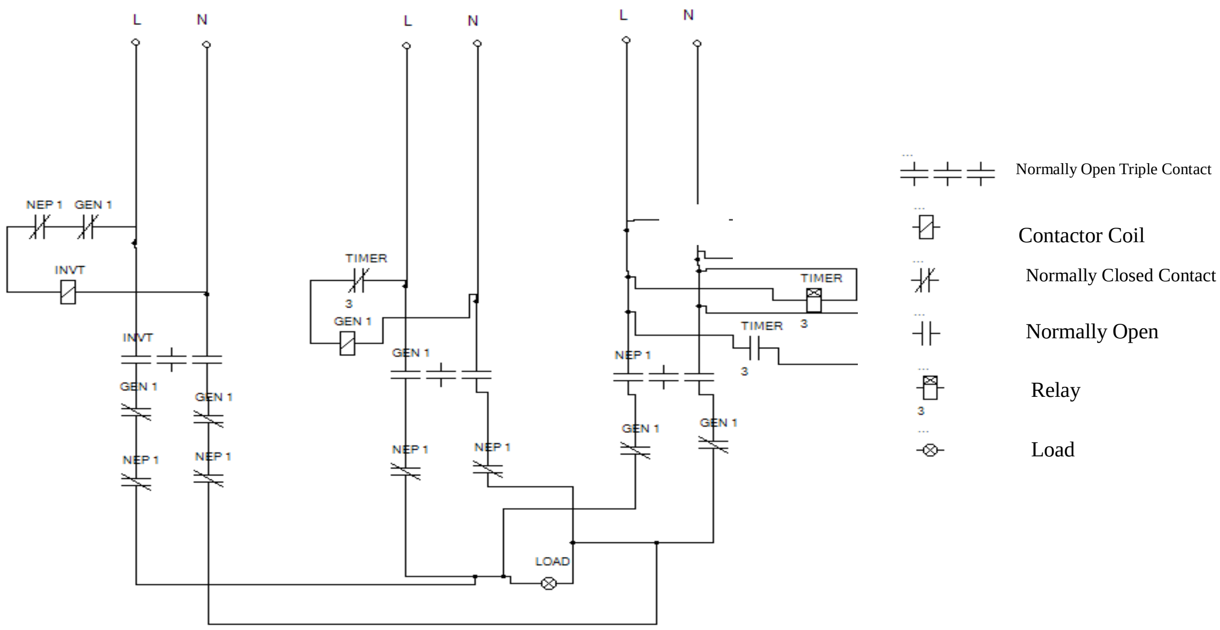

Fig. 2 Circuit diagram of the automatic power changeover.

2.2.1.2 The Automatic Phase Selector

(i) Three phase voltage sensing unit

As the name implies, this three-phase voltage sensing unit shown in figure 3 sense the three phases from the public utility power supply unit. In other words, this represents the input unit of the system because the three-phase ac power supply enters the circuit through this point. It consists of three 240V- 6V step down transformers that steps the voltage down from 240V to 6V, the full wave rectifier bridge which converts the 6V ac from the transformer output to 6V pulsating dc and then filter by the electrolytic capacitor. A variable resistor which acts as voltage divider is connected after the capacitor.

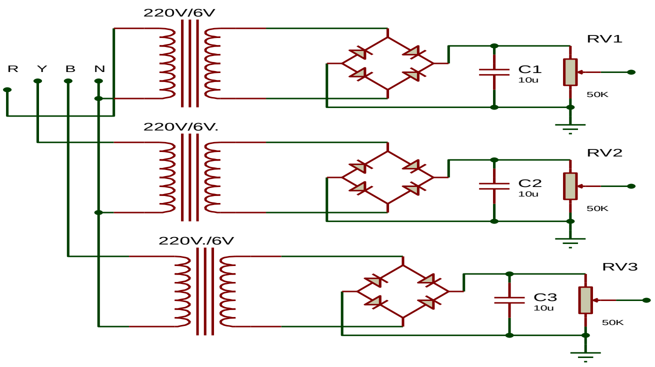

Fig. 3 Circuitry of three phase voltage sensing unit

The transformer used in the voltage sensing unit of this design is a step-down transformer which steps down the minimum input voltage from $220V_{AC}$ to $6V_{AC}$. The specification of the transformer used is given below:

Primary voltage, $E_1 = 220V_{AC}$
Secondary voltage, $E_2 = 6V_{AC}$
Output current = 500mA

1N4001 diodes which has a voltage rating of 50V are used to develop full wave bridge rectifier circuit used for rectifying the $6V_{AC}$ to $6V_{DC}$. The specifications of the diode used in the bridge rectifier is given below:

Peak inverse voltage = 2 x V_{rms} = 2x 6 = 12V

Max current of the rectifier = 1A

Forward voltage drops = diode bias voltage x number of conducting diode (1)

Forward voltage drops = 0.7V x 2 = 1.4V

Since a voltage of $6V_{rms}$ AC is supplied by the transformer

The equivalent DC voltage in R.M.S is given by

V_{rms} (DC) = V_{rms} (AC) – Forward Voltage drop of Diodes (2)

= 6V – 1.4V

= $4.6V_{DC}$

Peak voltage V_p = V_{rms} (DC) x $\sqrt{2}$ (3)

= 4.6V x $\sqrt{2}$

= 6.50 V_{DC}

A 10 μ F electrolytic capacitor was used to filter the ripples in the rectified DC voltage. Lastly, a variable resistor of 47KΩ was used to divide the output voltage into two and fed to the analog pin of the microcontroller.

(ii) Processing Unit

The processing unit comprises of the ATMEGA 328 PU microcontroller unit which houses the programmed logic as shown in figure 4. ATMEGA 328 is an 8bit, 28-Pin AVR Microcontroller, manufactured by Microchip, follows RISC Architecture, and has a flash-type program memory of 32KB with an operating voltage of 1.8 to 5.5v. The programmed logic in the microcontroller operates by sensing the three different phase reduced filtered dc voltage (non-pulsating dc) obtained from the voltage sensing unit and processes the information.

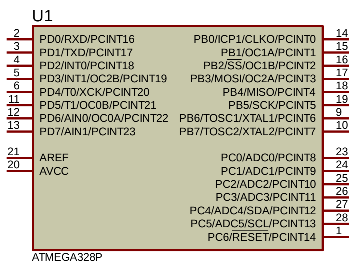

Fig. 4. Processing unit (ATMEGA 328 microcontroller)

(iii) The Display Unit

The display unit shown in figure 5 displays the state of the resultant phase voltage switching and digital selection of the system. It comprises of a 1602 16 x 2 Liquid Crystal Display (LCD) module based on HD44780 Controller which is interfaced with the microcontroller used to display the selected healthiest available phase to feed the load as it is processed.

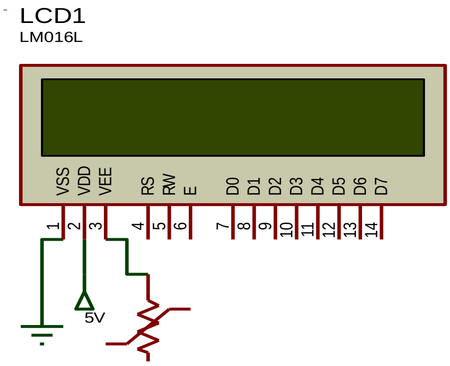

Fig.5. Display Unit (LCD)

(iv) The Switching Unit

The Switching Unit oversees the make and break contact in every electrical system. However, this unit consist of NPN transistors which operate to drive 5V dc relays as shown in figure 6. Other devices used are relays as the active components and resistors, diodes as the passive elements. The output from the processing unit switches ON the respective transistor which in turn actuates the relays. The incoming phases from the public utility supply are connected to the respective relay terminals and the single-phase output to the load is also interfaced with the relay outputs.

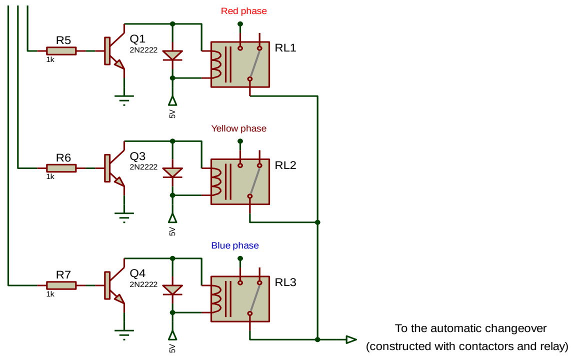

Fig. 6 Circuitry of the switching unit

The switching circuit of this design consist of 5V relays which are used for switching from one phase to another. The specifications of the relay used is given below.

Coil Voltage: 5V DC.

Load capacity: 10A, 250Vac/125Vac/30Vdc/28Vdc

The NPN transistor (2N2222) transistor was chosen for switching the relay controlling the output unit. The characteristics of the transistor are shown in Table 1.

Table 1: Transistor characteristic

Type	**Material**	**P_T(W)**	**I_C(A)**	**V_{CBO}(V)**	**h_{FE}**
2N2222	NPN	0.5	0.8	60.0	100.0

The value of the resistor that will limit the base current with respect to the supply voltage from the microcontroller to the base of the transistor was determined by using Equations (4) and (5).

$$\beta = \frac{I_c}{I_b} \quad (4)$$

$$R = \frac{V_{cc} - V_{be}}{I_b} \quad (5)$$

where β is the transistor gain, I_c is the collector current, I_b is the base current, V_{be} is base emitter voltage, V_{cc} is the supply voltage and R is the base resistor.

(v) Power Unit

The unit is used for constant supply of electrical energy to microcontroller. It consists of an inbuilt 6V battery whose charging rate and level is controlled by a charging circuit. Other supportive components such as voltage regulators are also contained in the circuit.

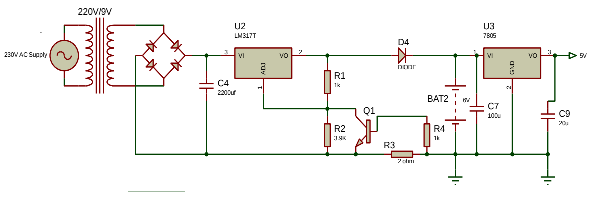

Fig. 7 Circuitry of power unit.

The transformer used in the power unit of this design is a step-down transformer which steps down the min input voltage from 220VAC to 9VAC. The transformer produces a maximum output current of 500mA. The specification of the transformer used is given below:

Primary voltage, E_1 = 220VAC

Secondary voltage, E_2 = 9VAC

Output current = 500mA.

Diodes in the circuit of figure 7 are used to develop full wave bridge rectifier circuit used for rectifying the 9VAC to 9VDC. The specifications of the diode used in the bridge rectifier is given below:

Peak inverse voltage = 2 x Vrms

2x 9 = 18V

Max current of the rectifier = 1A

Required diode is 1N4001 which has a voltage rating of 50V

Forward voltage drops = diode bias voltage x number of conducting diode. (6)

Forward voltage drops = 0.7V x 2 = 1.4V

Since a voltage of 6Vrms AC is supplied by the transformer,

The equivalent DC voltage in R.M.S is given by

Vrms (DC) = Vrms (AC) – Forward Voltage drop of Diodes (7)

= 9V – 1.4V

= 7.6V DC

Peak voltage Vp = Vrms (DC) x $\sqrt{2}$ (8)

= 7.6V x $\sqrt{2}$ = 10.75 d.c

2.2.1.3 Voltage Regulator

The voltage regulator is used to maintain a steady voltage of 5VDC at the output irrespective of voltage fluctuation at the input. The type of voltage regulator used is the power unit of this design is LM7805. LM7805 is a simple three pin voltage regulator that can provide up to 750mA and it is suitable for a wide range of input voltages. It takes an input voltage and produces constant 5V output. The specification of the regulator used is given below:

Regulated output voltage = 5V

Input Voltage Range is 6V – 35V

Internal reference voltage 3V,

Output current = 1.5A.

The minimum input voltage is given as:

Note, for a regulator to operate, the input voltage must be higher than the rated output voltage.

2.3 Software Analysis

The control algorithm of the designed Hybrid Automatic Power Changeover with Phase Selector is represented by the flow chart shown in Figure 8. The software code implementation was written in Aduino-Uno R3 programmer and was used to program the Atmega 328 microcontroller. The automatic changeover circuit was then simulated using an Electrical Control Technique Simulator (EKTS), while the phase selector was simulated in Proteus environment to ensure it workability.

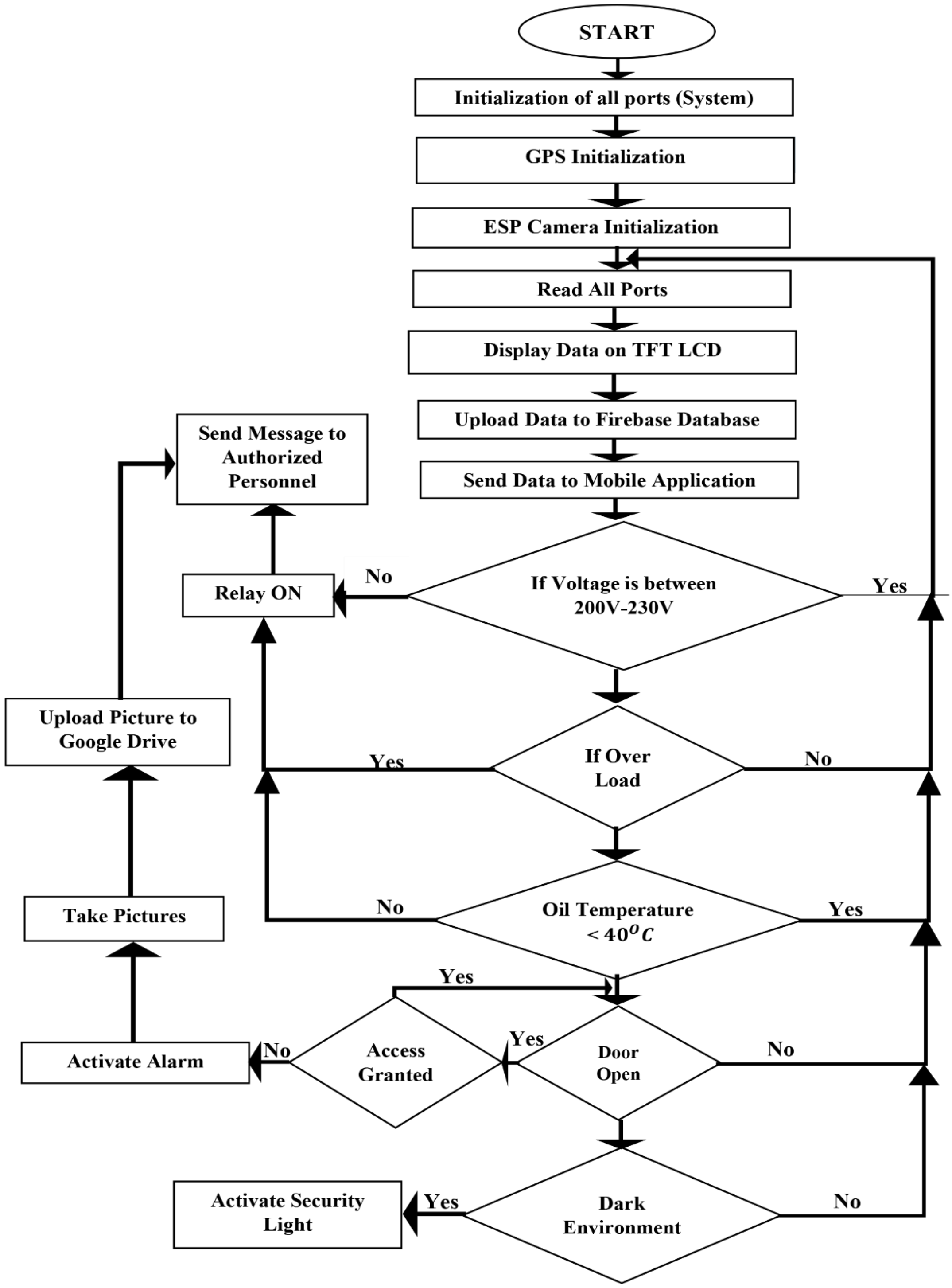

Fig: 8 System Flowchart

2.3.1 Principle of Operation of the Hybrid Automatic Power Changeover with Phase Selector

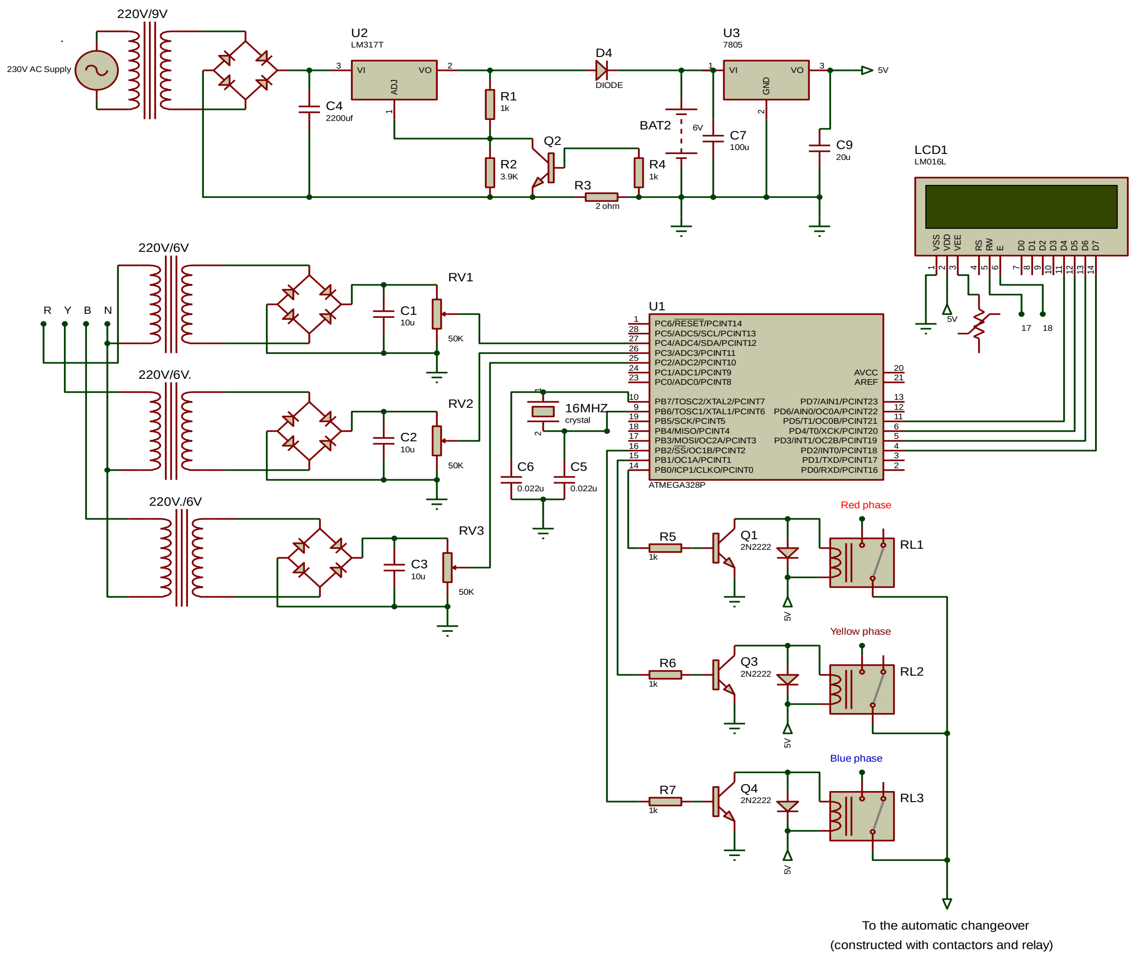

Fig.9. Circuit diagram of the Hybrid Automatic Power Changeover with Phase Selector

The complete circuit diagram of the Hybrid Automatic Power Changeover with Phase Selector is shown in fig. 9. The hybrid automatic power changeover with phase selector is a combination of two circuit models, which are the automatic phase selector and the automatic changeover. The automatic phase sector comprises of three phase voltage sensing unit, processing unit, display unit, switching unit and power unit. The three-phase voltage sensing unit is made up of three 220V/6V transformers T1, T2, T3, each connected to the red phase, yellow phase and blue phase of the public power supply respectively. The transformers step down the phase voltages to 6V AC. The 6V Ac from the transformers is then converted to a 6V pulsating DC with bridge rectifiers made of diodes and then filtered by electrolytic capacitor. The non- pulsating 6V DC is further stepped down to a maximum of 4V dc by a voltage divider variable resistor. The output from the voltage sensing unit is then fed to the analog pin of the processing unit. The processing unit is an Atmega328 microcontroller which houses the programmed logic, it operates by sensing the three different phase reduced filtered DC voltage obtained. It compares the three inputs and make decision according to programmed logic loaded on it. The output relay of the best voltage is switched by an NPN transistor connected to the digital pin of the microcontroller to give a single-phase output. The single-phase output from the phase selector is fed to the automatic power changeover which is an arrangement of contactors and relay which are connected for power switching between the public power supply, generator and an alternative means of power supply such as inverter. A normally closed contact from the contactor is used to replace the generator switch, the contact opens whenever there is supply from the phase selector, thereby shutting down the generator and connect the load to the single-phase output from the phase selector.

3. Testing and Results

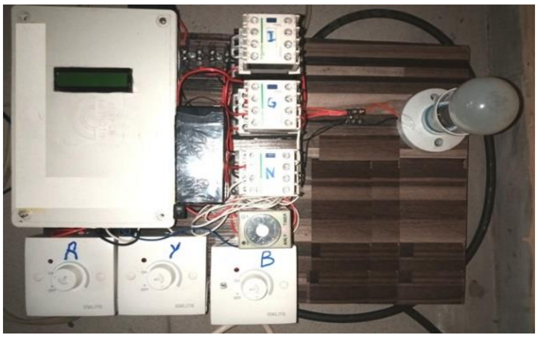

Fig.10. Completed hybrid automatic power changeover with phase selector

Several tests were conducted to verify the effectiveness and correct operation of the constructed hybrid automatic power changeover with phase selector system. Table 2 represents the test result for automatic phase selector section which was tested by turning the nub on the dimmer switches.

Table 2. The Automatic Phase Selector Test Result

Cases	Red phase	Yellow phase	Blue phase	Observations
1	> 200V	> 200V	> 200V	Red phase was selected
2	> 200V	< 200V	> 200V	Red phase was selected
3	> 200V	< 200V	< 200V	Red phase was selected
4	< 200 but > Yellow also > Blue	< 200V and < Red	< 200V and < Red	Red phase was selected
5	< 200V	> 200V	> 200V	Yellow phase was selected
6	< 200V	> 200V	< 200V	Yellow phase was selected
7	< 200V and < Yellow	< 200V but > Red also > Blue	< 200V and < Yellow	Yellow phase was selected
8	< 200V	< 200V	> 200V	Blue phase was selected
9	< 200V and < Blue	< 200V and < Blue	< 200V but > Red also > Yellow	Blue phase was selected

It was observed from the result table that the most priority is given to the red phase, followed by yellow phase, then the blue phase. This shows that the instructions programmed on the microcontroller was executed accordingly. The changeover which was constructed with three contactors and a time relay was tested with supplies from three different sockets, one connected to contactor for public power supply, one connected to contactor for generator supply and the other connected to the contactor for inverter. Table 3 shows the result of the test

Table 3. The Automatic Changeover Test Result

Cases	Mains Switch	Generator Switch	Inverter Switch	Observations			
				Mains contactor	Generator Contactor	Inverter Contactor	Load
1	ON	ON	ON	ON	OFF	OFF	ON
2	OFF	ON	ON	OFF	ON	OFF	ON
3	OFF	OFF	ON	OFF	OFF	ON	ON
4	ON	OFF	OFF	ON	OFF	OFF	ON
5	ON	ON	OFF	ON	OFF	OFF	ON
6	ON	OFF	OFF	ON	OFF	OFF	ON
7	OFF	ON	OFF	OFF	ON	OFF	ON
8	OFF	OFF	OFF	OFF	OFF	OFF	OFF

It was observed that:

(i) Anytime the mains switch is ON, it automatically switches OFF any other contactor (generator or inverter or both) that was ON and the supply from the mains gets to the load.

(ii) When the inverter switch was ON and the generator and the mains switches were OFF, the inverter contactor switched ON immediately the mains switch was switched off. The load took supply from the inverter.

(iii) When the inverter switch was ON (load on inverter) and the mains switch was OFF, the generator contactor switched ON immediately the generator switch was switched ON and the inverter contactor went OFF. Then the load was connected to the generator supply.

Conclusion

The Hybrid Automatic Power Changeover with Phase Selector was designed, constructed, and tested. Based on the result, the system is useful in any homes, offices, companies, and hospitals. The design ensures availability of power at any point in time and ensures power outage problems or delay in changing over from one supply to another in homes and business centres is eliminated. It also helps to feed our load with the healthiest voltage from three phase main supply system. When compared with the existing manual changeover, this design is automatic and makes life easy and comfortable for the consumer. It prevents risk of electric shocks that usually occur with manual changeover in the process of changing over from one supply to another. It reduces change over timing to the minimum due to its fast response to power outage. It also maintains high quality of service through its fast and prompt response. However, this work is limited to switching power supply from a three-phase supply system to varied back up power supply system such as inverter circuit and generating set in residential buildings, offices, small and medium scale industrial setting, and hospitals.

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