

Research article

# Design and Implementation of Automatic Three Phase Changer Using LM324 Quad Integrated Circuit

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## ABSTRACT

Design and implementation of an automatic three phase changer using LM324 quad integrated circuit was carried out. The system was designed and simulated using (Multisim). The circuit components were mounted a Vero board. LM324 integrated circuit (comparator) and 2N2222 transistors were used as active components alongside other passive components. Result shows that, when the three phase a.c inputs: Red phase ( $P_1$ ), yellow phase ( $P_2$ ) and blue phase ( $P_3$ ) from public utility supply was fed to the system, the system compared the inputs with regard to phase imbalances, and the input with the highest voltage appears across the output. It also changes over from one phase to another immediately the circuit senses further phase imbalance. **Copyright © IJEATR, all rights reserved.**

**KEYWORDS:** Relay, Switch, Comparator, Phase Changer, Automatic

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## I. INTRODUCTION

In developing countries like Nigeria and Bangladesh, power instability and phase failure has posed serious threat to their economic development [4]. That is to say, where there is an erratic power supply, there is no development. This

is because one of the factors that boost economic of a country is the availability of steady and stable power supply [5] [1].

However, most companies; Industrial, commercial and even domestic are dependent on public power supply which have erratic supply such as phase failure, phase imbalances or total power failure due to one or more technical problem in power generation, transmission or distribution [2]. Hence, there is need for automation of phase change during phase failure or total power failure in order to safe guard consumer appliances from epileptic power supply.

In most cases, many manufacturing companies, be it domestic or industrial, which employ single phase equipment for its operation sometimes experience challenges during unbalance voltages, overloads and under-voltages, in power supply, much time would be required in the process of manual change over. This means that time and the process needed for the phase change may cause serious damages to machines and even the products, hence, there is need for automatic phase switching system.

In a case where a single phase public utility prepaid meter is operated with a single phase power supply unit and there is phase failure from the public utility power supply, the prepaid meter will stop reading. At this point if the phase is not manually changed, the single phase prepaid meter will stop reading. That is to say someone needs to be present always to make the changes at any point in time. But to overcome these protocols, automatic systems need to be used.

The importance and advancement of control system in engineering have created different ways in which automatic switching systems can solve domestic and industrial problems especially in the developing countries.

An automatic phase changer was designed. The system provides a single phase correct voltage in the same power supply lines through relays from the other phase where correct voltage is available. The system operates by stepping down 220 Volts AC to 12 Volts, rectified and fed into the operational amplifiers through the voltage divider circuit. The operational amplifiers compare the three phases ( $P_1$ ,  $P_2$  and  $P_3$ ) and switch the relays through the transistor drivers.

The automatic phase changer was made from several electronic components which includes; operational amplifiers, diodes, resistors, capacitors, Zener diodes, transformers, relays and fuses. Results obtained during the test shows that, whenever the system senses a higher voltage across the three inputs and then engages the load [7].

The system was designed to handle light load and not big loads. This is because of the use of 12 Volts by 6A relay switch in the system. This load includes; Television set, radio set, standing Fans and small lighting points. Also, system reliability, compatibility, reliability and durability in this work were not considered.

Furthermore, the main aim of this project is to present the real idea of an automatic phase switch for 220V to 240V alternating current. Although, there are many designs and prototype systems that can perform almost similar functions like, single phase change-over switches, two phase automatic transfer switch and three phase automatic change-over switch, but this prototype is about an automatic phase switchover (phase selector) which is designed for only three phase A.C input power to single phase output applications.

The system is basically designed to select between the three phases at reasonable speed, and also address phase imbalances with respect to loads. This means automatic switching between the three phases and output only single

phase. In other words, the switching consideration demonstrates the real and practical situation for mainly domestic, moderate industrial advanced needs.

## II. System Design and Implementation

The design procedure in this work was sub-divided into two sub-sections as theory and system analysis.

### Stage of Implementation

The automatic three phase changer design was implemented in three units as shown figure 1

- Power supply Unit
- Voltage sensing unit
- Switching Unit

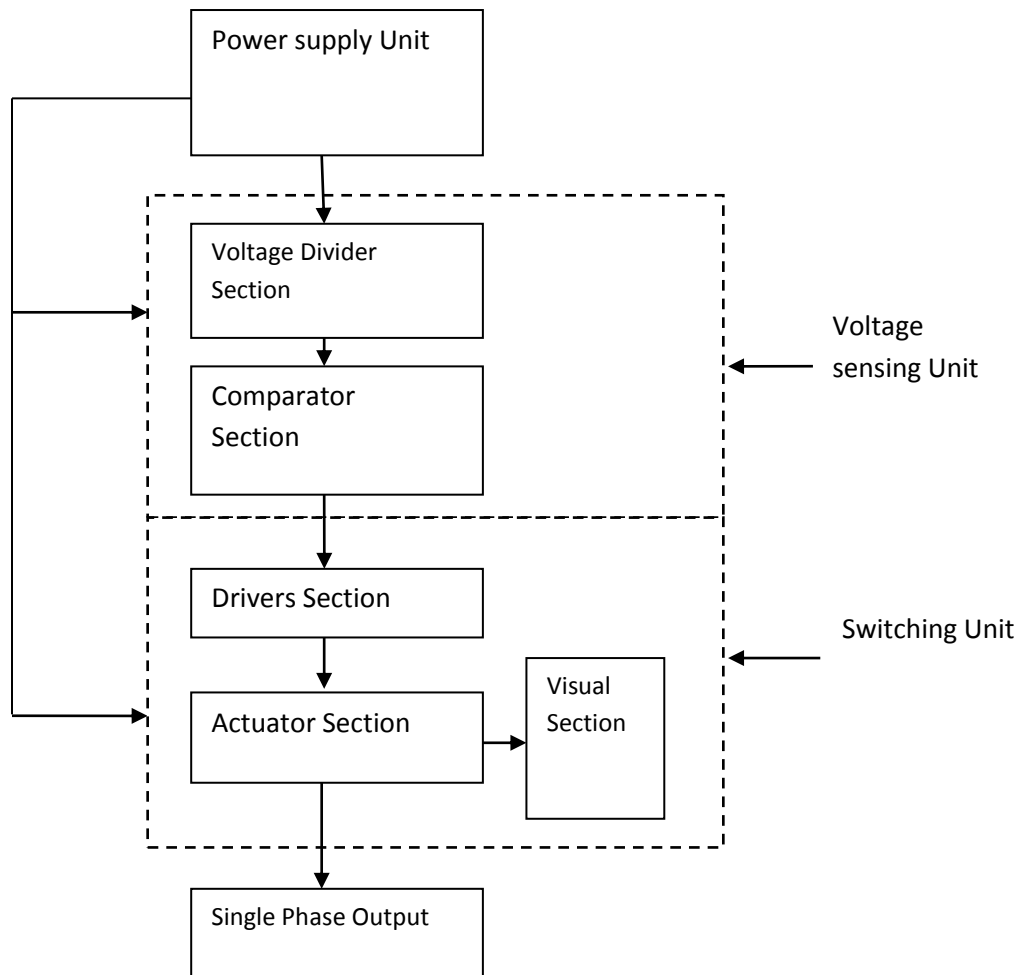
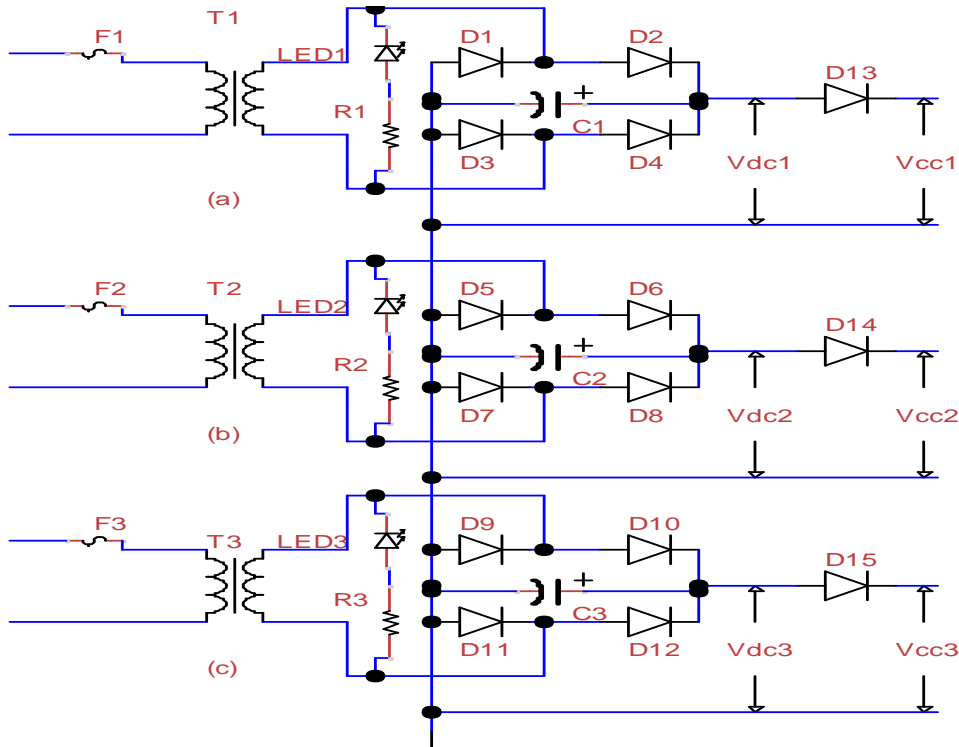


Figure 1.0 Block diagram of automatic Three Phase Changer.

1. **Power Supply Unit:** This serves as input unit to the system because AC mains enter the circuit through this point. In this unit, power is converted from A.C to D.C and filtered as shown in figure 1.1 (a), (b) and (c).



**Figure 1.1** Circuit diagram of three power supply Unit

The circuit diagram of three phase power supply consist of step-down transformers ( $T_1, T_2, T_3$ ), diodes ( $D_1$  to  $D_{12}$ ), Fuses ( $F_1, F_2, F_3$ ), capacitors ( $C_1, C_2, C_3$ ), Resistors ( $R_1, R_2, R_3$ ) and Light emitting diodes ( $LED_1, LED_2, LED_3$ ).

The operation of the power supply unit occurs in three stages; the transformer stage, rectifier stage and filter stage.

- a. **Transformer Stage:** This section consists of three Step-down transformers (240V/12V), three fuses (1 ampere), and light emitting diodes (Red, Yellow, and Blue).

The rating of transformers was chosen because of the conversion of 240V to 12V AC which was the circuit requirement. Fuses were also used to protect excess current coupled with resistors as current limiters for Light emitting diodes. The light emitting diodes serve as indicators for presence of the mains supply.

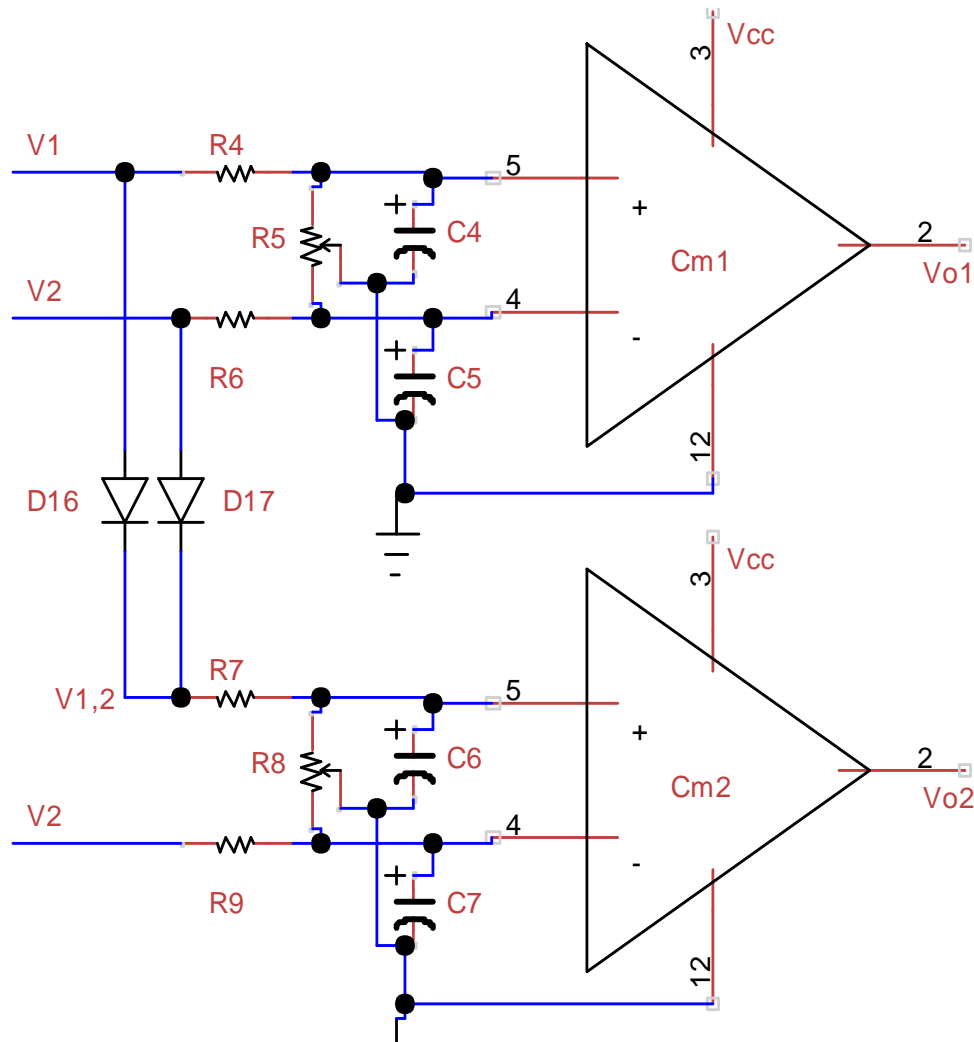
- b. **Rectifier Stage:** In rectifier section, diodes were configured in a full wave bridge rectifier so as to boost the circuit efficiency. The rectifier convert 12V AC voltage from the Supply from the transformer output to 12 V pulsating DC.

During circuit operation, diode  $D_2$  and  $D_3$  conducts and produce a positive cycle, that is forward biased, while diodes  $D_4$  and  $D_1$  becomes reverse biased. In negative cycle, diodes  $D_4$  and  $D_1$  conduct and becomes

forward biased. But since load current is in the same direction in both half cycles, full wave rectifier appears across the output terminals [9].

- c. **Filter Stage:** An electrolytic capacitor is used to filter the pulsating D.C voltage that comes out from the rectifier section. During operation, the capacitor charges up (i.e store energy) during conduction of half cycle thereby opposing any changes in voltage. Hence, filter out voltage pulsations.

## 2. Voltage Sensing Unit



**Figure 1.2** Circuit diagram of Voltage Sensing Unit

The voltage sensing Unit consists of Comparator ( $C_{m1}$  and  $C_{m2}$ ), diodes ( $D_{16}$  and  $D_{17}$ ), resistor ( $R_4$ ,  $R_5$ ,  $R_6$ ,  $R_7$ ,  $R_8$  and  $R_9$ ) and capacitors ( $C_4$ ,  $C_5$ ,  $C_6$  and  $C_7$ ).

These circuit operates by reducing the rectified voltages ( $V_1$ ,  $V_2$  and  $V_3$ ) to half with the help of voltage divider. The resistors used to form the voltage dividers includes ( $R_4$ ,  $R_5$ ,  $R_6$ ,  $R_7$ ,  $R_8$  and  $R_9$ ) (see table 1.0). The reduced voltages are compared through the inverting and the non-inverting inputs of the comparators. During the process, when the

voltage in the non-inverting input is greater than the inverting, input the output of the comparator ( $V_{o1}$  or  $V_{o2}$ ) becomes “high” (1). But in a situation where the voltage in the inverting inputs is greater or equal to the non-inverting inputs, the output ( $V_{o1}$  or  $V_{o2}$ ) will become “low” (0) [3].

### 3. Switching Unit

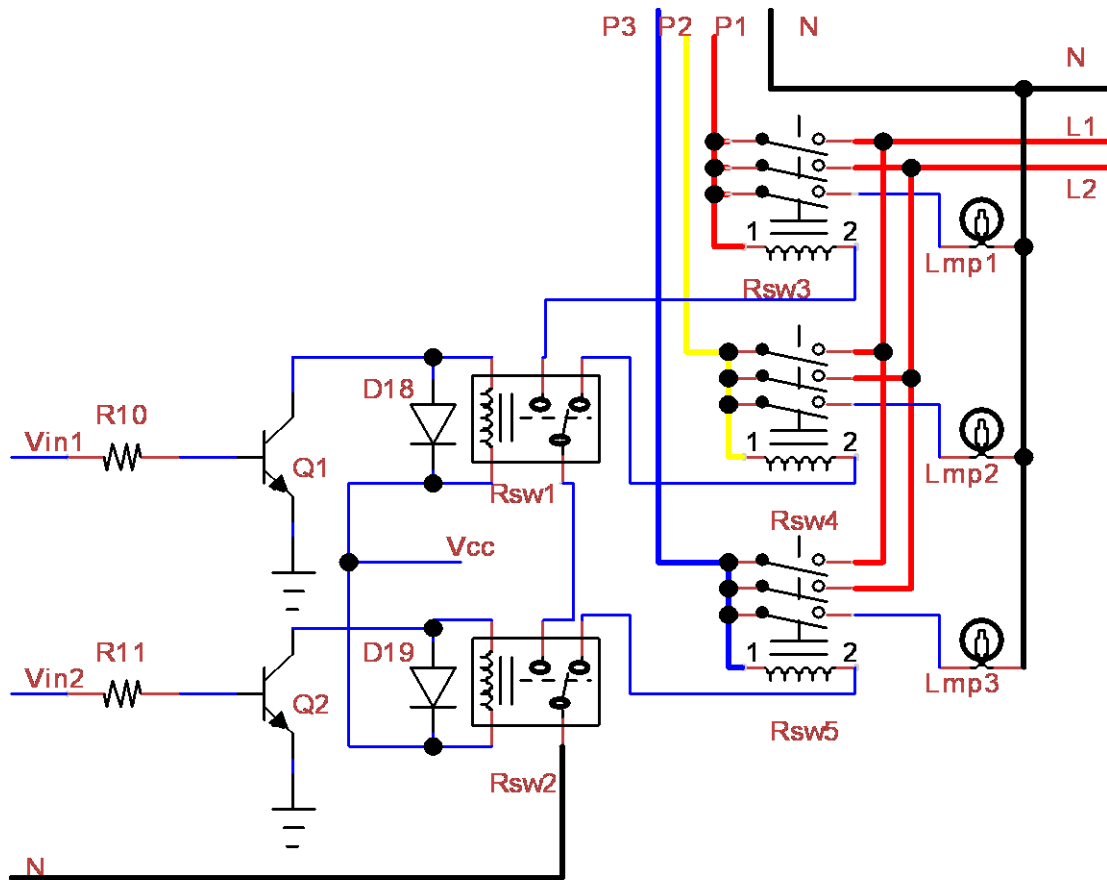


Figure 1.3 Circuit diagram of Switching Unit

The switching unit is responsible for making and breaking electrical contacts. It is subdivided into drivers, actuators and display sections. The devices involved were resistor ( $R_{10}$  and  $R_{11}$ ), relays ( $R_{sw1}$  and  $R_{sw2}$ ) and contactors ( $R_{sw3}$ ,  $R_{sw4}$  and  $R_{sw5}$ ).

#### a. Drivers Section

Transistors are used to drive the relays in this unit. The unit consists of two NPN transistors ( $Q_1$ ,  $Q_2$ ) and resistors ( $R_{10}$ ,  $R_{11}$ ). Transistors ( $Q_1$ ,  $Q_2$ ) conducts when its base senses voltage  $V_{in1}$  and  $V_{in2}$  from the outputs of the comparators. This transistor were used to swings the collector current to the quantity required by the coils of the relays.

### **b. Actuator Section**

The actuator section consist of relays and contactors switches. The relays ( $R_{sw1}$  and  $R_{sw2}$ ) are used to actuate the contactors ( $R_{sw3}$ ,  $R_{sw4}$  and  $R_{sw5}$ ). This is because the contactors coils used operate with A.C voltage.

### **c. Visual Section**

The visual unit was design with three incandescent lamps ( $L_{mp1}$ ,  $L_{mp2}$ ,  $L_{mp3}$ ). This section displays the nature of the output system. In other words, the phase that appear across the system output is indicated with the colour of the Lamp weather Red Lamp ( $L_{mp1}$ ), Yellow Lamp ( $L_{mp2}$ ) or Blue Lamp ( $L_{mp3}$ ).

## **4. General Circuit Operation**

The schematic diagram showed in figure 1.5 displays the interconnectivity of the phase changer. The circuit has three transformers ( $T_1$ ,  $T_2$  and  $T_3$ ) which receive the inputs voltages. The transformers step-down the 240V AC to 12V AC. Full wave bridge rectifiers were used to convert 12V AC voltage to 12V DC voltage.

However, the rectified voltages are fed into the inverting and non-inverting inputs of the two comparators through the voltage dividers. The voltage dividers were used to reduce each of the rectifier voltages to half so that the comparators will not sink. In this section, the system compares the input voltages and takes logical decisions. These logical decisions are in two ways, for instant (i) the output of the comparator becomes High (1) when the voltage in the non-inverting is greater than the inverting input. (2) When the voltage in the inverting is greater than or equals to the non-inverting, the comparator output remains low (0).

Accordingly, Transistors ( $Q_1$ ,  $Q_2$ ) were connected across the comparator outputs so as to swing and drive a sufficient current to operate the relay coils ( $R_{sw1}$  and  $R_{sw2}$ ).

But since the system include contactors because of handling big loads, the small relays ( $R_{sw1}$  and  $R_{sw2}$ ) are used to actuate the contactors ( $R_{sw3}$ ,  $R_{sw4}$  and  $R_{sw5}$ ) (see figure 1.4)

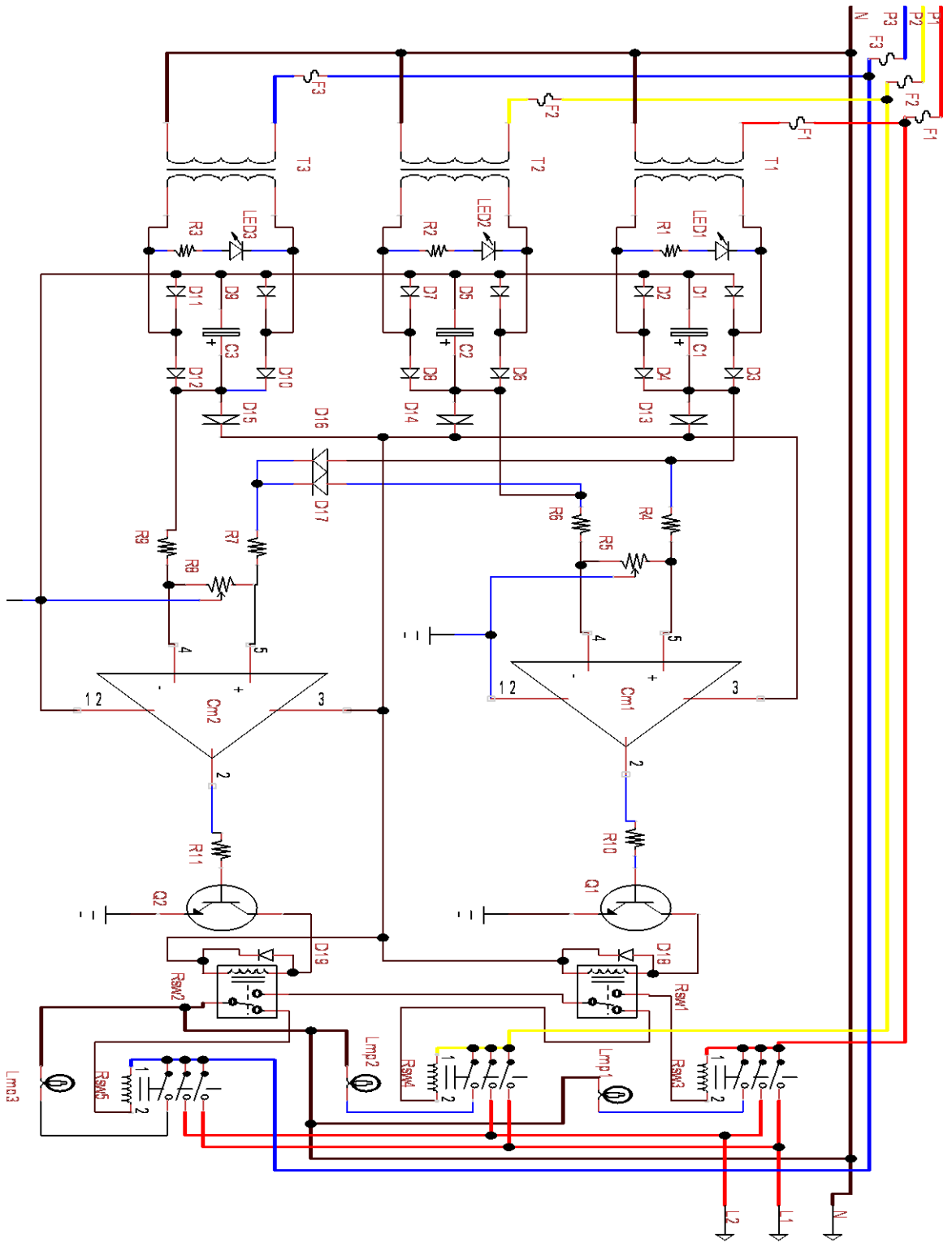


Figure 1.4 Circuit diagram of automatic three phase change



## 5. List of components

Symbols	Components	Rating
$T_1, T_2$ and $T_3$	Transformers	220V/12V
$LED_1, LED_2$ and $LED_3$	Light emitting diodes	2.2V/35mA
$R_1, R_2$ and $R_3$	Fixed Resistors	280 $\Omega$ , 250 $\Omega$ and 220 $\Omega$
$R_5$ and $R_8$	Variable Resistors	5K $\Omega$
$R_4, R_6, R_7$ and $R_9$	Fixed Resistors	2.5
$R_{10}$ and $R_{11}$	Fixed Resistors	4.8K $\Omega$
$C_1, C_2$ and $C_3$	Capacitors	330 $\mu$ F/16V
$C_4, C_5, C_6,$ and $C_7$	Capacitors	100 $\mu$ F/16V
$D_1$ to $D_{18}$	Diodes	1N4001
$C_{m1}$ and $C_{m2}$	Comparators	LM324 IC
$Q_1$ and $Q_2$	Transistors	BC 547
$R_{sw1}$ and $R_{sw2}$	Relays	12V/400 $\Omega$
$R_{sw3}, R_{sw4}$ and $R_{sw5}$	Contactors	240V/60A
$Lmp_1, Lmp_2$ and $Lmp_3$	Incandescent Lamps (Red, Yellow and Blue)	20W

**Table 1.0** List of Circuit components

### III. System Design Analysis

#### 1. The power supply Unit

In power supply sections, 240V/12V transformers and 1A fuses rating were chosen because it's met the requirement of the circuit.

##### a. Current Limiting Resistors ( $R_1, R_2$ and $R_3$ )

$V_s = 12V$  (supply voltage),  $V_{LED} = 2.2V$ ,  $I_{LED} = 35mA$  (maximum allowable current across the LED) [8]

$$R_1 = \frac{V_s - V_{LED}}{I_{LED}}$$

$$R_1 = \frac{(12 - 2.2)V}{35mA} = \frac{9.8}{0.035}$$

$$R_1 = 280\Omega$$

Therefore, current drawn by Red LED;

$$I_{LED} = \frac{V_s}{R_1}$$

$$I_{LED} = \frac{12}{280} = 0.043A$$

$$I_{LED} = 43mA$$

To determining  $R_2$ ,  $V_{LED} = 3.2$ ,  $V_s = 12V$  (supply voltage) and  $I_{LED} = 35mA$  (maximum allowable current across the LED)

$$R_2 = \frac{V_s - V_{LED}}{I_{LED}}$$

$$R_2 = \frac{(12 - 3.2)V}{35mA} = \frac{8.8}{0.035}$$

$$R_2 = 251\Omega$$

Therefore, current drawn by Yellow LED;

$$I_{LED} = \frac{V_s}{R_2}$$

$$I_{LED} = \frac{12}{250} = 0.048A$$

$$I_{LED} = 48mA$$

To determining  $R_3$ ,  $V_{LED} = 3.8$ ,  $V_s = 12V$  (supply voltage) and  $I_{LED} = 35mA$  (maximum allowable current across the LED)

$$R_3 = \frac{V_s - V_{LED}}{I_{LED}}$$

$$R_3 = \frac{(12 - 3.8)V}{35mA} = \frac{8.2}{0.035}$$

$$R_3 = 234\Omega$$

Since 234 $\Omega$  resistor is not standard, 250 $\Omega$  resistor was used as the closest value in the design.

Therefore, current drawn by Blue LED;

$$I_{LED} = \frac{V_m}{R_3}$$

$$I_{LED} = \frac{12}{250} = 0.048A$$

$$I_{LED} = 48mA$$

### b. Peak Inverse Voltage

Peak Inverse voltage is twice the maximum voltage across the half wave [6];

That is  $P_1 V = 2V_m = 2V_s$

Therefore, PIV = 2 X 12 = 24V

The value of diode used in full wave bridge rectifier circuit was 1N4001 because it has voltage rating of 50V as required by the circuit. The rating is also chosen to avoid any damage to the diode in case of reverse operation occurs.

### c. Average DC Current ( $I_c$ )

The average DC current was calculated using the expression [9];

$$I_{dc} = \frac{2V_m}{\pi R_L}$$

A 200Ω load resistance was considered across the outputs.

Root mean square (R.m.s) of the secondary = 12V

Maximum voltage across the secondary ( $V_m$ ) = 12 x  $\sqrt{2}$  = 17V

Dc current flowing through the load ( $I_{dc}$ ) =  $\frac{2 \times 17}{3.142 \times 200} = \frac{34}{628.4} = 0.054A$

Average dc voltage across the load ( $V_{dc}$ ) =  $I_{dc} \times R_L = 0.054 \times 200 = 10.8V$

However, the values of dc voltages ( $V_{dc1}$ ,  $V_{dc2}$ ,  $V_{dc3}$ ) and currents ( $I_{dc1}$ ,  $I_{dc2}$ ,  $I_{dc3}$ ) across the three phases were equally 10.8Volts and 54mA respectively.

### d. Filter capacitors ( $C_1$ , $C_2$ and $C_3$ );

The filter capacitors were calculated using the expression [9];

$$C = \frac{1}{4\sqrt{3}fyR}$$

But for full wave rectifier circuit [8];

f = frequency of ripple voltage = 50Hz

y = Ripple factor = 5% = 0.05

R = Diode resistance = ?

$$R = \frac{V_{dc}}{I_{dc}} = 200\Omega$$

$$C = \frac{1}{4\sqrt{3} \times 50 \times 0.05 \times 200} = 0.000288F$$

**C = 288μF**

Since 288μF capacitor is not standard, 330μF capacitors were used as ( $C_1$ ,  $C_2$  and  $C_3$ ) in the standard value in the design.

## 2. Voltage Sensing Unit

Since voltage is considered in this unit, the values of  $R_4$ ,  $V_-$  and  $V_{cc}(V_1)$  were taken to be 2.5KΩ, 6V and 12V respectively. Thus the value of  $R_5$  was calculated using the expression;

$$V_- = \frac{R_5 V_1}{R_4 + R_5}$$

$$V_-(R_4 + R_5) = R_5V_1$$

$$V_-R_4 + V_-R_5 = R_5V_1$$

$$V_-R_4 = RR_5V_1 + R_5V_-$$

$$V_-R_4 = R_5(V_1 - V_-)$$

$$R_5 = \frac{V_-R_4}{V_1 - V_-}$$

$$R_5 = \frac{6 \times 2500}{12 - 6} = \frac{15000}{6}$$

$$R_5 = 2500\Omega$$

$$R_5R_5 = 2.5K\Omega$$

The value of  $R_5$  with respect to  $R_6$  is also calculated using the expression

$$R_5 = \frac{V_-R_4}{V_1 - V_-}$$

$$R_5 = \frac{6 \times 2500}{12 - 6} = \frac{15000}{6}$$

$$R_5 = 2500\Omega$$

$R_5R_5 = 2.5K\Omega$  Since resistor  $R_5$  is common to resistors ( $RR_4$  and  $RR_6$ ) and each having  $2.5K\Omega$  resistances,  $5K\Omega$  variable resistor was adopted in the design so as to produce  $2.5K\Omega$  resistance to resistors ( $RR_4$  and  $RR_6$ ) when tuned to its midpoint.

However, the same calculation is also done in second voltage divider stage and the value of  $RR_8 = RR_5 = 5K\Omega$ .

### 3. Switching Unit

#### a. Collector Current ( $I_C$ )

From the expression;

$$I_C = \frac{I_c}{\beta}$$

Where supply voltage ( $V_{CC}$ ) = 12V

Base emitter voltage ( $V_{BE}$ ) = 0.6; [6]

Gain ( $H_{FE}$ ) = 25

Recall coil resistance  $R_L = 400\Omega$

$$I_C = \frac{V_{CC}}{R_L} = \frac{12}{400} = 0.03A$$

$$I_C = 30mA$$

**Base Current ( $I_B$ )**

$$I_B = \frac{0.03}{25}$$

$$I_B = 0.0012 A$$

But to ensure sufficient base current to drive the transistor into saturation, the quantity of the base current is doubled.

i.e  $I_B = 2 \times 0.0012$

$$I_B = 0.002A$$

$$I_B = 2mA$$

**b. Base Resistance ( $R_{10}, R_{11}$ )**

$$R_{10} = \frac{V_{CC} - V_{BE}}{I_B}$$

$$R_{10} = \frac{12 - 0.2}{0.002} = \frac{11.3}{0.002}$$

$$R_{10} = 4708\Omega$$

$$R_{10} = 4.7K\Omega$$

In this case, since the resistor  $R_{11}$  is also for the same purpose, the value of  $R_{10}$  used in the design was 4.7K $\Omega$ .

#### **IV. Construction**

The construction of the system was done in two stages. This includes the circuit construction and the casing construction. The circuit construction was done using Vero board. Also, components were carefully tested to confirm its values, polarities as well as terminals before soldering it to the Vero board. This was accomplished section by sections. These are; power section, voltage section and switching section. The sections were coupled after one and the other following the circuit diagram in figure 1.5.

#### **V. Testing, Result and Discussion**

##### **a. Testing**

Circuit testing was only carried out after the circuit construction is fully completed. In this case, since the circuit has been sub-divided into sections, measuring of input and output signals is obtained using a multi-meter instrument. This is done in sequential order (steps) for the purpose of accuracy and understanding. The four steps are;

**Step 1:** The system is set up as shown figure 3.2.

**Step 2:** The three phases of AC Supply from the public utility are measured and recorded.

**Step 3:** The DC voltage across the 4 half-wave rectifiers is measured and recorded.

**Step 4:** All the voltage divider across the comparators are replaced with variable resistors and the comparator inputs and outputs are varied, measured and recorded respectively

## b. Results

Comparator one ( $C_{m1}$ )		Comparator Two ( $C_{m2}$ )		Output (Q)	Output phase Interpretation
Inverting input ( $V_-$ )	Non-inverting input ( $V_+$ )	Inverting input ( $V_-$ )	Non-inverting input ( $V_+$ )		
0	0	0	0	0	Shutdown
0	1	0	1	1	Red Phase
0	0	0	1	1	Yellow Phase
0	0	1	0	1	Blue Phase
1	1	1	1	0	No Response

**Table 1.1** Truth Table Showing Summaries of result.

**Note:** High (1);  $V_+ > 5V$

Low (0);  $V_- \leq 5V$

## c. Discussion of Result

The table in 1.1 describes summaries of the result during the testing of the system. It also narrates the switching process of the system.

However, the 0 and 1 signify “Low” and “High” respectively. In other words, 1 is considered 5V and above while 0 indicate signal less than 5V.

It shows that when P1 is High (1), P2, P3 are low, the output signal is “High” (1). This is because the signal at non-inverting input is greater than the inverting input, hence, P1(Red phase) will appear in the output. Secondly, when P1, P3 are low, the output P2 (Yellow Phase) will become “High”. Also, when P1, P2 are all low and P3 is high, automatically P3 (Blue Phase) will appear across the output.

## d. Conclusion

In this work, an automatic three phase changer using LM 324 comparator has been designed, built and tested. The system operates smoothly as expected. It is reliable, durable and portable. The cost involved in developing it, makes it much more affordable than comparable product.

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