Three Phase Sequence Protection (Relay)

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DEDICATION

I dedicate this project to my God and almighty father for his faithfulness, love, care and provision throughout my academic program and also to my parents Mr and Mrs David Ajayi for their parental care from birth to the end of my first degree program.

DECLARATION

I ABRAHAM DAVID, declare that this work was done by me and has never been presented elsewhere for the award of a degree. I also hereby relinquish the copyright to the Federal University of Technology, Minna.

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ABSTRACT

A Phase Sequence Protection Relay circuit is desired to switch on electromagnet relay when the phases are in right sequence. The system is one which first and second resistors (R_1,R_2) and the first capacitor (C_1) all having equivalent impedance are connected in Y configuration and to power source leads (A,B,C,) of a three-phase power supply, resistor R_1 being coupled to phase B, capacitor C_1 to phase A and resistor R_2 to phase C. A comparator network (ABC) is connected in line with the first resistor (R_1) and will cause solid state switches (Q_1,Q_2,Q_3) to conduct when the phases are in right sequence. Relay coils (K_1,K_2,K_3) are in turn energized and used to energize a load.

Another comparator network is connected in line with the second resistor (R_2) and will only light up the LED connected to it when the three phases are out of sequence.

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CHAPTER ONE

INTRODUCTION

DEFINITION:- Phase sequence by definition means the order in which the three line voltages become successively positive. By phase sequence is meant the order in which the three phases attain their peak or maximum values.

Electric power is generated and distributed in three-phase, at the operating frequency of 60Hz (or w=377rad/s) in the united states or 50Hz (or w=314rad/s) in some other parts of the world like Nigeria. The three-phase system is more economical than the single-phase and is very important today because most of the machines in industries are operated under three-phase condition and this makes three-phase sequence an important property of a three-phase system as well the three-phase sequence protection more interesting because it protects the three-phase motors especially against reverse rotation.

Phase sequence is important because it determines the direction of rotation of three-phase motors and whether one three phase system can be connected in parallel with another. Consequently, in three-phase systems, phase sequence is as important as the frequency and voltage are.

In the development of the three-phase e.m.fs., clockwise rotation of the field system was assumed. This assumption made the e.m.fs. of phase 'b' lag behind that of 'a' by 120^0 and in a similar way, made that of 'c' lag behind that of 'b' by 120^0 (or that of 'a' by 240^0). Hence, the order in which the e.m.fs. of phases a, b, and c attain their maximum values is a b c. It is called the phase order or phase sequence a→ b → c.

If, now, the rotation of the field structure is reversed i.e. made anticlockwise, then the order in which the three phases would attain their corresponding maximum voltages would also be reversed. The phase sequence would become c → b → a. This means that e.m.f. of phase 'c' would now lag behind that of phase 'a' by 120^0 instead of 240^0 as in previous case. By repeating the letters, this phase sequence can be written as acbacba which is the same thing as cba. Obviously, a three-phase system has only two possible sequences: abc and cba (i.e. abc read in the reverse direction).

In general, the phase sequence of the voltages applied to load is determined by the order in which the 3-phase lines are connected. The phase sequence can be reversed by interchanging any pair of lines. In the case of an inductor motor, reversal of sequence results in the reversed direction of motor rotation. In the case of 3-phase unbalanced loads, the effect of sequence reversal is, in general, to cause a completely different set of values of the currents. Hence, when working on such systems, it is essential that phase sequence be clearly specified otherwise unnecessary confusion will arise. Incidentally, reversing the phase sequence of a 3-phase generator which is to be paralleled with a similar generator can cause extensive damage to both the machines.

1.2 CAUSES OF WRONG PHASE SEQUENCE

i. Interchanging any pair of the AC lines or contactors of the motor.

ii. Voltage unbalance (negative phase sequence) This causes negative sequence components and results in excessive heating of the motor windings. An unbalanced voltage may occur due to unevenly distributed single-phase loads.

iii. A voltage unbalance may also be due to unequal phase impedances of the feeding HT line and may be a result of unequal spacing between the horizontal and vertical formation of conductors or asymmetrical conductor spacings. These effects cause an unequal induced magnetic field and hence an unequal impedance of each conductor. The implication of such a system can be studied by assuming it to be composed of two balanced systems, one positive and the other negative (the negative system having the reverse rotating field and tending to rotate the rotor in the reverse direction). Each field produces a balanced current system, the phasor sum of which will decide the actual current the motor windings will draw. The main effect of a negative sequence current is thus to increase iron losses and reduce the output of the motor. In such a condition, as the current drawn by the motor increases, the torque and the power developed reduce, and the motor operates at a higher slip. All these losses appear in the rotor circuit as slip losses. The rotor operates at a higher slip and becomes relatively more heated than the stator and more vulnerable to damage.

1.3 AIMS AND OBJECTIVES

i. To prevent a three phase uninterrupted power supply (UPS) and other electrical appliances that are sensitive to phase sequence of three phase power supply from getting damaged whenever any pair of AC lines are interchanged.

ii. To prevent reverse rotation of a motor especially in an industry where the motor is required to rotate in one direction only.

iii. To protect three phase motor and other electrical appliances against voltage unbalance caused by phase loss.

1.4 METHODOLOGY

This project titled Three-phase Sequence Protection (Relay) circuit apparatus for interfacing a three phase AC power source on respective three AC power source leads with a load comprising first and second resistors each having a first value of impedance and a first capacitor having an impedance equivalent to the first value, the first and second resistors and the first capacitor being coupled together in a Y configuration, the resistors and capacitor being coupled to respective power source leads, comparator networks coupled to only two of the AC power source leads comprising diodes to rectify AC current conducted through the first and second resistors to provide voltage source rails for the protection circuit, the DC magnitude of the voltage source rails being dependent upon the sequence of connection of the power source leads with a load, comparators having inverting and non-inverting inputs and transistors outputs, voltage regulator means coupled to the rails to provide fixed reference voltages, the reference voltages coupled to the inverting inputs, voltage dividers comprising resistors connected between the rails and the respective line, the junctions formed between the voltage divider resistors, the junctions coupled to the non-inverting inputs, the outputs of the comparators coupled to the solid state switches, the voltage at the inverting inputs of the comparators connected to the second resistor being less than the voltage at the non-inverting inputs when the first and second resistors and the first capacitor are coupled to the three AC power source leads with the phases in sequence thereby biasing the transistors outputs into conduction and the voltage at the inverting input of the comparator connected to the line containing the first resistor being less than the voltage at the non-inverting input when the first and second resistors and the first capacitor are coupled to the three AC power source leads with the phases out of sequence thereby turning off the output of the transistor connected to it, the solid state switches turning on depending on the sequence of the AC power source leads.

1.5 SCOPE

This apparatus is designed to provide a good protection for motors that are required to rotate in one direction and in any three phase – three wire system. It is also capable of protecting the three phase UPS against reverse rotation of generators. The apparatus is designed to be voltage sensitive, meaning difference or change in any pair of the AC line will be detected by the apparatus and the indicator will correspond to the phase sequence of the phase input lines.

CHAPTER TWO

LITERATURE REVIEW AND THEORETICAL BACKGROUND

2.1 LITERATURE REVIEW

In a modern control system, electronic intelligence controls some physical process. Control systems are the "automatic" in such things as automatic pilot and automatic washer. Because the machine itself is making the routine decisions, the human operator is freed to do other things. In many cases, machine intelligence is better than direct human control because it can react faster or slower (keep track of long-term slow changes), respond more precisely, and maintain an accurate log of the system's performance.

Control systems can be classified in several ways. A regulator system automatically maintains a parameter at (or near) a specified value. An example of this is a home heating system maintaining a set temperature despite changing outside conditions. A follow-up system causes an output to follow a set path that has been specified in advance. An example is an industrial robot moving parts from place to place. An event control system controls a sequential series of events. An example is a washing machine cycling through a series of programmed steps.

Natural control systems have existed since the beginning of life. Consider how the human body regulates temperature. If the body needs to heat itself, food calories are converted to produce heat; on the other hand, evaporation causes cooling. Because evaporation is less effective (especially in humid climates), it is not surprising that our body temperature (98.6°F) was set near the high end of Earth's temperature spectrum (to reduce demand on the cooling system). If temperature sensors in the body notice a drop in temperature, they signal the body to burn more fuel. If the sensors indicate too high a temperature, they signal the body to sweat.

Man-made control systems have existed in some form since the time of the ancient Greeks. One interesting device described in the literature is a pool of water that could never be emptied. The pool had a concealed float-ball and valve arrangement similar to a toilet tank mechanism. When the water level lowered, the float dropped and opened a valve that admitted more water.

Electrical control systems are a product of the twentieth century. Electromechanical relays were developed and used for remote control of motors and devices. Relays and switches were also used as simple logic gates to implement some intelligence. Using vacuum-tube technology, significant development in control systems was made during World War II. Dynamic position control systems (servomechanisms) were developed for aircraft applications, gun turrets, and torpedoes. Today, position control systems are used in machine tools, industrial processes, robots, cars, and office machines, to name a few.

Meanwhile, other developments in electronics were having an impact on control system design. Solid-state devices started to replace the power relays in motor control circuits. Transistors and integrated circuit operational amplifiers (IC op-amps) became available for analog controllers. Digital integrated circuits replaced bulky relay logic.

Perhaps most significantly, the microprocessor allowed for the creation of digital controllers that are inexpensive, reliable, able to control complex processes, and adaptable (if the job changes, the controller can be reprogrammed). The subject of control systems is really many subjects: electronics (both analog and digital), power-control devices, sensors, motors, mechanics, and control system theory, which ties together all these concepts. Every control system has (at least) a controller and an actuator (also called a final control element). Shown in the block diagram in Figure 2.1, the controller is the intelligence of the system and is usually electronic. The input to the controller is called the set point, which is a signal representing the desired system output. The actuator is an electromechanical device that takes the signal from the controller and converts it into some kind of physical action. Examples of typical actuators would be an electric motor, an electrically controlled valve, or a heating element. The last block in Figure 2.1 is labeled process and has an output labeled controlled variable. The process block represents the physical process being affected by the actuator, and the controlled variable is the measurable result of that process. For example, if the actuator is an electric heating element in a furnace, then the process is "heating the furnace," and the controlled variable is the temperature in the furnace. If the actuator is an electric motor that rotates an antenna, then the process is "rotating of the antenna," and the controlled variable is the angular position of the antenna.

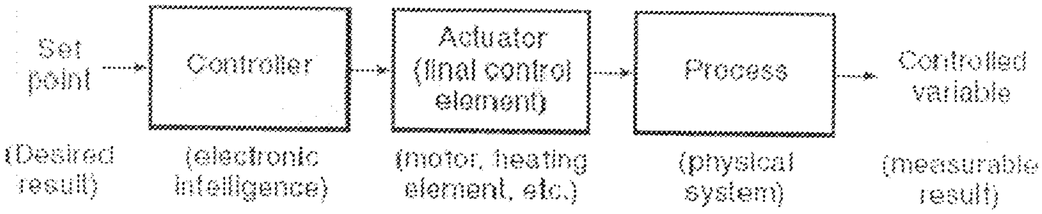

Fig. 2.1 A block diagram of a control system

Phase Monitor Relays are sometimes called 3 Phase Monitors, Three Phase Monitor Relays, Phase Loss Relays, Single Phase Relays, Phase Sequence Relays, Protective Relays, Motor Protection Relays or Phase Failure Relays. They provide motor protection against premature equipment failure caused by voltage faults on 3 Phase systems. These devices are designed to be compatible with most Wye or Delta systems. In Wye systems, a connection to a neutral is not required. Phase Monitor Relays protect against unbalanced voltages or single phasing regardless of any regenerative voltages.

This invention relates generally to polyphase power supplies and more particularly to apparatus for preventing damage to loads caused by incorrectly wiring such loads or polyphase electrical equipment coupled to such loads to the polyphase power supply.

Certain equipment, such as scroll compressors, are designed to rotate in a given direction and will be severely damaged if caused to rotate in the reverse direction. In the case of a scroll compressor even a single partial rotation in the reverse direction will permanently damage the scroll plates. It is typical to use three phase motors to drive such compressors and, if the motor phase sequence is miswired, reverse rotation will result. That is, with respect to a three phase motor having windings A, B and C, spaced 120° apart, if these windings are coupled to phases A, C, B, respectively of a three phase power supply, the motor will run in a direction reversed to that intended.

It is therefore important that the wiring sequence be verified prior to energization of such a compressor system. A known method for detecting phase miswiring in a three phase system utilizes two neon indicator lamps and a capacitor. The resistance of the neon lamps and the reactance of the capacitor are chosen to be approximately the same and are connected in a Y configuration with the lamps coupled to what are believed to be phases A and C and the capacitor coupled to phase B. If in fact the phase sequence is as intended the second lamp coupled to phase C will glow due to the voltage drop of approximately $1.37\times V_{Line}$. The voltage drop across the other, first, lamp will be approximately $0.37\times V_{Line}$, below the level required for illumination. On the other hand, if in fact the phase sequence is miswired, i.e., A-C-B, the voltage drop across the first lamp will be approximately $1.37\times V_{Line}$ and it will glow and the second lamp will be approximately $0.37\times V_{Line}$, below that voltage level required for illumination thereby indicating a miswired condition.

Although this method can be used effectively, it does not represent a satisfactory solution to the problem. The possibility exists of someone servicing the compressor, or associated equipment, requiring the disconnection and subsequent reconnection of the leads, either not having the

Although this method can be used effectively, it does not represent a satisfactory solution to the problem. The possibility exists of someone servicing the compressor, or associated equipment, requiring the disconnection and subsequent reconnection of the leads, either not having the neon lamps and capacitor or of making an error by misinterpreting the results. Even during initial set-up of the installation the compressor system is frequently out of the direct control of the manufacturer of the system and therefore the manufacturer is not in a position to ensure that tile wiring will be done correctly. Since the cost of the compressor can be up to thousands of dollars, it would be very desirable to obviate the possibility of damage to the system occasioned by miswiring of the phase sequence.

It is therefore an object of the invention to overcome the above noted prior art limitations. Another object is the provision of apparatus which is reliable and inexpensive and yet will protect a load from being damaged due to miswiring of the phase sequence of a polyphase power supply.

Briefly, in accordance with the invention, first and second resistors having a first impedance and a capacitor having an equivalent impedance are connected in a Y configuration and analog comparator networks are coupled in line with the first resistor to monitor the voltage differential which occurs when the phases are in and out of sequence. According to a feature of the invention, the output of each of the comparator network is coupled to the base of a transistor which serves as a switch to provide a signal to suitable control circuitry. Amplifier circuit is used to amplify the output of each of the comparator

2.2 THEORETICAL BACKGROUND

The principles to be considered here are those of operations of a three-phase wye-connection system, regulated power supply, phase sequence detector circuit, and the switching circuit which comprise of the transistor and relay. The block diagram of figure 2.2 illustrates these.

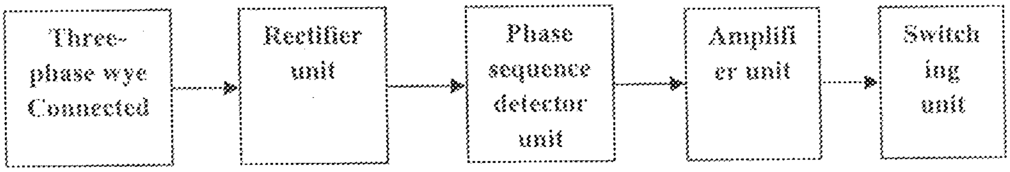

Figure 2.2 Block Diagram of The Design

2.2.1 IDEAL THREE PHASE STAR CONNECTION

Three-phase power is created by a three-phase generator that has three separate field windings spaced 120° apart.

The relationship of **phase voltages** A, B, and C is presented in Figure 2.3, which shows each phase voltage with respect to neutral. Each phase makes a complete cycle in one period and is 120° apart; at any particular time, all phases add to 0 V (for example, add the magnitudes of the three voltages when $t = 0$). Notice in Figure 2.3 that the **phase sequence** is ABC (first A, then B, then C). The other possible sequence would be ACB. Typically, three-phase power is distributed within a facility as wye-connected. If all the load impedances in a star connected load are the same, then the system is said to be balanced, and there would actually be no current in the neutral wire. Under these conditions, the neutral wire could be removed, and the motor

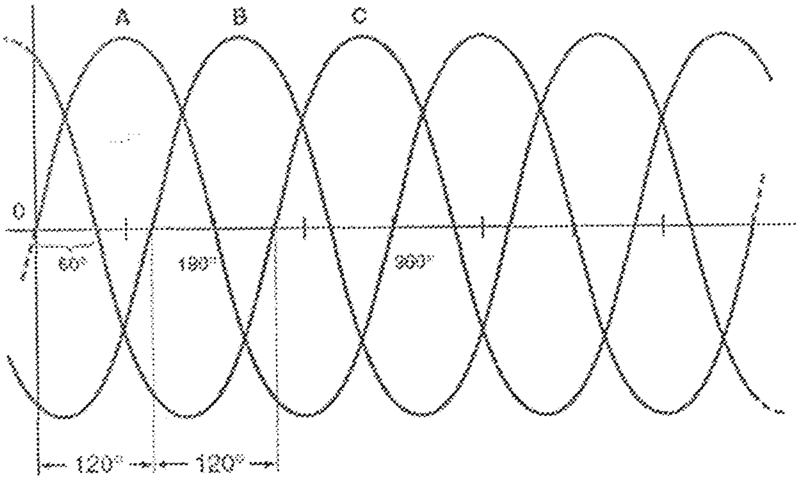

Figure 2.3 Three-Phase Line Voltages

would continue to run just fine. In real life, it is unlikely that any particular facility would present a purely balanced load to the power lines, because each phase voltage, if considered separately, can be used as a standard single-phase voltage. Therefore, a single-phase load such as a light bulb could be (and frequently is) connected between one of the phase voltages and neutral. The system would now be unbalanced, and some current will flow in the neutral wire. In practice, effort is made to keep the load on each phase equal. Finally, the specified **line voltage** of a three phase wye-connected system is the vector sum of two individual phase voltages in series. This relationship is given in Equation1.0:

For wye-connected: $V_{Line} = 3\ V_{Phase}$ (1.0)

V_{Line} = three-phase line voltage (voltage between any two lines)

V_{Phase} = individual phase voltage (voltage across one coil, which for a wye system is also the voltage between a line and neutral).

For a delta-connected system, the line and phase voltages are the same.

Wye-connected three-phase power is mainly used for distribution within a facility because the neutral wire allows separate single-phase loads to be pulled off as needed. Delta-connected systems have no neutral wire and are inherently balanced. The power company typically uses three wires to transmit the three-phase power over the power lines. Once at the site the power is easily converted to wye-connected power with special transformers designed for that purpose. Three-phase transformers can be made as one unit or from three single-phase transformers.

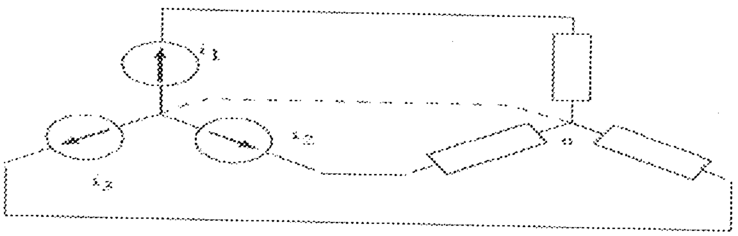

Fig. 2.4 Zero-neutral current in a Y-connected balanced system

Compared to single phase systems, three phase systems offer definite advantages: for the same power and voltage there is less copper in the windings, and the total power absorbed remains constant rather than oscillate around its average value.

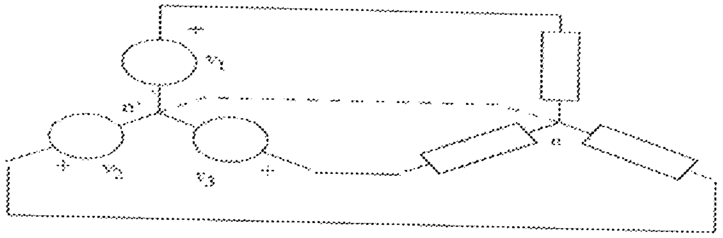

Fig. 2.5 Zero-neutral current in a voltage-fed Y-connected balanced system

Let us take now three sinusoidal current sources that have the same amplitude and frequency, but their phase angles differ by 120^0. They are:

$$\begin{aligned} i1(t) &= \sqrt{2}I\sin(\omega t+\varphi) \\ i2(t) &= \sqrt{2}I\sin\left(\omega t+\varphi-\frac{2\pi}{3}\right) \\ i3(t) &= \sqrt{2}I\sin(\omega t+\varphi+\frac{2\pi}{3}) \end{aligned} \tag{2}$$

If these three current sources are connected as shown in figure 2.4, the current returning though node *n* is zero, since:

$$\sin(\omega t+\varphi)\sin\left(\omega t-\varphi+\frac{2\pi}{3}\right)+\sin(\omega t+\varphi+\frac{2\pi}{3})\equiv 0 \tag{3}$$

Let us also take three voltage sources:

$$\begin{aligned} Va(t) &= \sqrt{2}V\sin(\omega t+\varphi) \\ Vb(t) &= \sqrt{2}V\sin(\omega t+\varphi-\frac{2\pi}{3}) \\ Vc(t) &= \sqrt{2}\,V\sin(\omega t+\varphi+\frac{2\pi}{3}) \end{aligned} \tag{4}$$

connected as shown in figure 2.5. If the three impedances at the load are equal, then it is easy to prove that the current in the branch *n- n'* is zero as well. Here we have a first reason why three phase systems are convenient to use. The three sources together supply three times the power that one source supplies, but they use three wires, while the one source alone uses two. The wires of the three phase system and the one phase source carry the same current, hence with a three phase system the transmitted power can be tripled, while the amount of wires is only increased by 50%.

The loads of the system as shown in figure 2.6 are said to be in Y or star. If the loads are connected as shown in figure 1.11, then they are said to be connected in Delta, Δ, or triangle. For somebody who cannot see beyond the terminals of a Y or a Δ load, but can only measure currents and voltages there, it is impossible to discern the type of connection of the load. We can therefore consider the two systems equivalent, and we can easily transform one to the other without any effect outside the load. Then the impedances of a Y and its equivalent Δ symmetric loads are related by:

$$Z_Y = \frac{1}{3} Z\Delta$$

Let us take now a balanced system connected in Y, as shown in figure 2.6. The voltages between the neutral and each of the three phase terminals are $Vin = V < \varphi, V2n = V < \varphi - \frac{2\pi}{3}, V3n = V < \varphi + \frac{2\pi}{3}$. Then the voltage between phases 1 and 2 can be shown either through trigonometry or vector geometry to be:

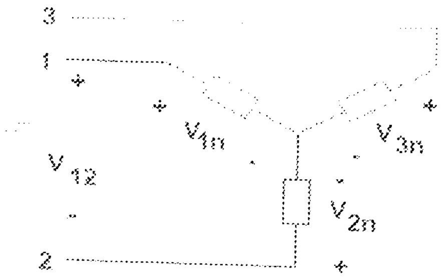

Fig. 2.6 Y connected loads: voltage and current

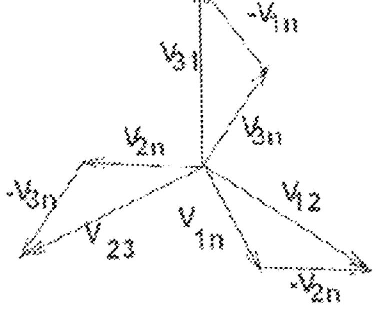

Fig. 2.7 Y connected voltage phasors

$$V12 = V1 - V2 = \sqrt{3}V < \varphi + \frac{\pi}{3}$$

This is shown in the phasor diagrams of figure 2.7, and it says that the rms value of the line to line voltage at a *Y* load, *Vll*, is √3 times that of the line to neutral or phase voltage, *Vln*. It is obvious that the phase current is equal to the line current in the *Y* connection. The power supplied to the system is three times the power supplied to each phase, since the voltage and current amplitudes and the phase differences between them are the same in all three phases. If the power factor in one phase is *pf* $=\cos(\varphi v - \varphi i)$, then the total power to the system is:

$$S_{3\phi} = P_{3\phi} + jQ_{3\phi}$$

$$= 3V1I1'$$

$$= \sqrt{3}VllIl\cos(\varphi v - \varphi i) + j\sqrt{3}VllIl\sin(\varphi v - \varphi i)$$

CHAPTER THREE

DESIGN AND IMPLEMENTATION

3.1 DESIGN

3.2 THREE PHASE INPUT WYE CONNECTED

This is where input to the circuit is connected. The three phase circuit connection is a star (wye) connection as shown in fig. 3.1 below.

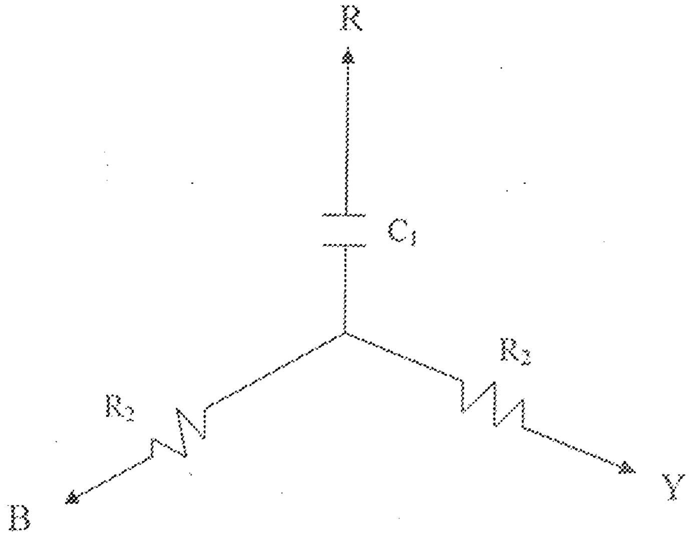

Fig. 3.1 Three phase star connected

The resistors have an ohmic resistance equal to R(KΩ) each and the capacitor has a value C(μf) with capacitive reactance equal to R.

Choosing R1=R2=22KΩ

The value of C_1 is calculated from the formula

$$Xc = \frac{1}{2\pi f C} = R1 = R2 = 22000\Omega$$

$$C_1 = \frac{1}{2\pi f Xc} = \frac{1}{2\pi f R} = \frac{1}{2\pi X50X22000} = 0.1447X10^{-6} farad = 0.1\mu f$$

A mica capacitor of value 0.1μf, 400V AC is chosen because of its high voltage rating.

We are connecting three reactance of the same value in a three-star system arrangement, without neutral wire. With all the reactance of the resistive type the system will be equilibrated and the neutral point will have no voltage. But the capacitor introduces a phase displacement (the current leads 90 degrees over the phase voltage), thus the system will no longer be equilibrated and the star's neutral point O now has certain voltage (Von).

As line voltage is constant, phase voltages will rearrange in order to give the neutral point voltage Von observed.

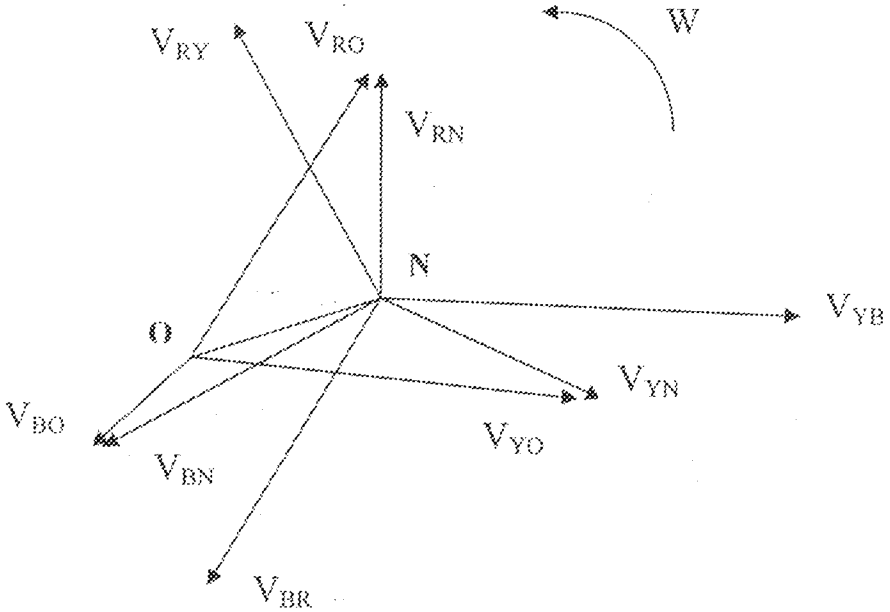

Fig. 3.2 Phasors in complex plane

The mathematical solution for a 3 X 230Volt three phase 3 wire system is;

V_{line} = line voltage = $\left(\sqrt{3}XVphase\right)$: V_{RY}, V_{YB}, V_{BR}

V_{phase} = phase voltage = $\left(\frac{Vline}{\sqrt{3}} = 230V\right)$: V_{RN}, V_{YN}, V_{TN}

Z_R = Xc; Z_Y = R; Z_B = R Indicators branch impedance.

Z_R = -j22000Ω; Z_Y = 22000Ω; Z_B = 22000Ω

Y_R = 1/Z_R; Y_Y = 1/Z_Y; Y_B = 1/Z_B Branch Admittance

$Y_R = \frac{1}{-j22000} = \frac{1}{-j22000} X \frac{+j22000}{+j22000} = 0.000045 < 90°\Omega^{-1}$;

$Y_Y = \frac{1}{22000} = \frac{1}{22000+j0} = 0.000045 < 0°\Omega^{-1}$;

$Y_B = \frac{1}{22000} = \frac{1}{22000+j0} = 0.000045 < 0°\Omega^{-1}$

It may be shown that the neutral point O of the star connection will be submitted to a voltage Von in relation to the neutral wire N of the main supply:

$$\text{Von} = \frac{Vrn\ X\ Yr + Vyn\ X\ Yy + Vbn\ X\ Yb}{Yr+Yy+Yb}$$

$V_{RN}Y_R$, $V_{YN}Y_Y$ and $V_{BN}Y_B$ would be taken as negative because currents due to V_{RN}, V_{YN} and V_{BN} flow away from the node.

$$= \frac{-230<0°v\ X\ 0.000045<90° - 230<+120°\ X\ 0.000045<0° - 230<-120°\ X\ 0.000045<0°}{j0.000045+0.000045+0.000045}$$

$$= \frac{-j0.01035+0.005175-j0.008963+0.005175+j0.008963}{0.00009+j0.000045}$$

$$= \frac{0.01035-j0.01035}{0.00009+j0.000045} X \frac{0.00009-j0.000045}{0.00009-j0.000045} = 138 - j138 = 195.16 < -45°$$

Therefore, the new displaced phase voltage due to the neutral point O displacement referred to N if measured will be: 195.16V.

Branch phase voltage:

$V_{RO} = V_{RN} - \text{Von} = 230 - 138 - j138 = 92 + j138 = 165.86 < 56.31°$

$V_{YO} = V_{YN} - \text{Von} = -115 + j199.19 - 138 + j138 = -253 + j337.19$

$$= 421.56 < -53.12^\circ$$

$$V_{BO} = V_{BN} - V_{on} = -115 - j199.19 - 138 + j138 = -253 - j61.19$$

$$= 260.29 < 13.60^\circ$$

Branch phase current (equal to line current)

$I_R = V_{RO} \text{ x } Y_R = 165.86 < 56.31^\circ \, x \, 0.000045 < 90^\circ = 7.46 < 146.31^\circ mA$

This current leads the reference voltage i.e. its voltage by 90°.

$I_Y = V_{YO} \text{ x } Y_Y = 421.56 < -53.12^\circ \, x \, 0.000045 < 0^\circ = 18.97 < -53.12^\circ mA$

This current lags behind the reference vector i.e. V_{RO} by 53.12° which amounts to being in phase with its phase voltage V_{YO} by 53.12°.

$I_B = V_{BO} \text{ x } Y_B = 260.29 < 13.60 \, x \, 0.000045 < 0^\circ = 11.71 < 13.60^\circ mA$

This current leads the reference vector i.e. V_{RO} by 13.60° which amounts to being in phase with its phase voltage V_{BO} by 13.60°.

Now we have verified that due to the neutral point displacement:

$$V_{RO} + V_{YO} + V_{BO} = -3V_{on}$$

And as line voltage is constant

$$V_{RY} = V_{RO} - V_{YO} = 92 + j138 - 253 + j337.19 = 345 - j199.19$$

$$= 398.37 < -30^\circ$$

$$V_{YB} = V_{YO} - V_{BO} = -253 + j337.19 - 253 - j61.19 = j398.38$$

$$= 398.38 < 90^\circ$$

$$V_{BR} = V_{BO} - V_{RO} = -253 - j61.19 - (92 + j138) = -345 - j544.19$$

$$= 644.34 < 57.63^\circ$$

As we can see the branch with the greatest voltage (assuming the indicator was connected in the right sequence RYB) is the branch with 421.56volts, i.e.: the voltage from the terminal is higher than the one submitted to 260.29volts. Therefore the phase that follows the capacitor branch is the one connected to the terminal with the highest voltage and is used for the phase sequence detector circuit. With the indicator connected in the right sequence, the voltage from this terminal will be will be compared with a reference value and used to energize relays that will deliver power supply to the load.

3.3 RECTIFIER UNIT CALCULATION

The rectification is implemented with two 1N4007/1A/600V given large tolerance.

The peak inverse voltage (PIV) rating for the diode is 0.6v is used for the rectification of the AC voltage. Therefore, for the two diodes the PIV would be 2 x 0.6V = 1.2V.

3.3.1 VOLTAGE DIVIDER NETWORK

The AC voltage to be rectified is 421.56V for **Y-phase** and 260.29V for **B-phase,**

But 421.56V will be used for the calculation of various components to be used in the design.

Two resistors are connected in parallel so that this 421.56V will be reduced to approximate value of 14V that will be regulated and used to power the circuit.

Taking R_4 to be equal to 1.5kΩ ($R4 = R_6 = 1.5k\Omega$), V_{R4} equal to 14V ($V_{R4} = 14V$), V_{dc} due to the drop across diodes would be;

$$V_{dc} = 421.56 - 1.2 = 420.36V$$

$$V_{R4} = \left(\frac{R4}{R3+R4}\right) x\ Vdc$$

$$R_3 = \frac{R4(Vdc-VR4)}{VR4} = \frac{1.5k\Omega\ x\ (420.36-14)}{14} = 43.5k\Omega$$

$R_3 = R_5$ would be chosen to be 45kΩ.

3.3.2 FILTER CALCULATION

A shunt capacitor filter is employed for this project to provide good smoothening of AC ripple component in the DC supply.

Assuming 20% ripple voltage, V_r after filteration

$$V_r = 12.6Vpeak\ x \frac{20}{100} = 2.52Vripple$$

Time between half-cycle, dt = ½ T

$$T = \frac{1}{2}\left(\frac{1}{F}\right) = 1/2F$$

Where T is the period for one cycle

PHCN frequency F = 50Hz

$$T = \frac{1}{2\ x\ 50} = \frac{1}{100} = 0.01Second$$

With a maximum current, $I = 1A$ for the diode, $V_r = 2.52V$ and $t = 0.01sec$

And using $Q = CV$

$$C = \frac{Q}{V}, \text{But } Q = It$$

$$\therefore \qquad C = \frac{It}{Vr} = \frac{14\,x\,0.015Sec.}{2.52V} = 3.968\,x\,10^{-3}f = 3968\mu f$$

A capacitor with a capacitance value of 4700μf is chosen for this project for perfect smoothening of the AC ripple.

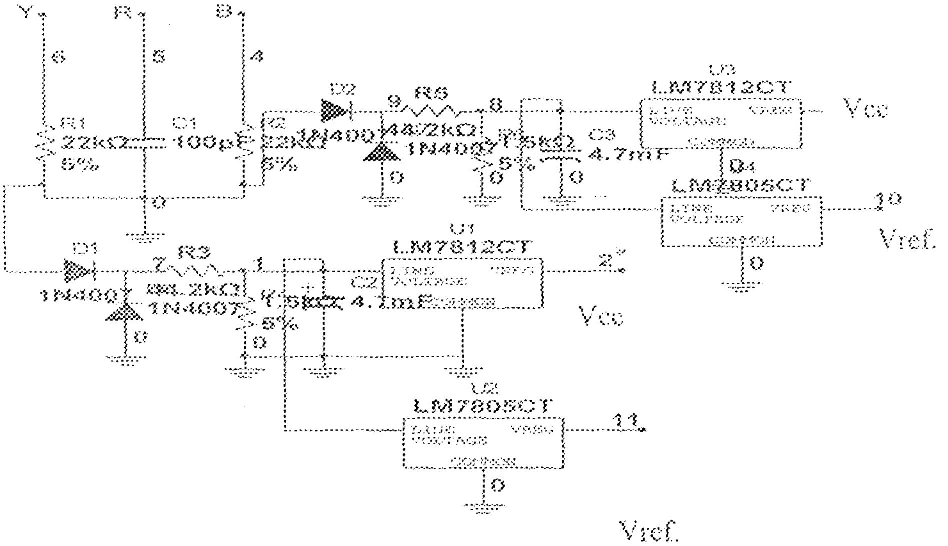

Fig. 3.3 Rectified 3-phase input lines.

3.3.3 VOLTAGE REGULATOR

LM7812 is connected to the output of the rectified DC voltage to give a precise voltage value of 12V that will serve as the Vcc to be used for the comparators and other components. LM7805 is also connected to the rectified DC to give a precise voltage value of 5V to serve as the reference voltage to applied to the inverting inputs of the comparators.

3.4 POSITIVE OR CLOCKWISE SEQUENCE DETECTOR

When the three inputs of the circuit are connected to the three phases (the neutral connection is not for this test), the green LEDs connected to the output of amplifiers connected to the output of comparators soldered to V_{YO} phase will light to indicate a clockwise phase sequence. In this connection, clockwise is defined as R, Y, B. Anticlockwise, not surprisingly, is the other way 'round; the red LED connected to the output of the comparator soldered to V_{BO} phase will light.

When the phases are in right sequence, the voltage at the non-inverting inputs of the three comparators soldered to Y phase (i.e., the input line with the highest voltage) will be higher than the voltage at the inverting inputs (V_{ref})so the comparators will give outputs of approximately 3.0v because the reference voltage, V_{ref} = 5.0v while the voltage to the non-inverting inputs is 8v. The output voltage of each of the comparators is used as input to the amplifier circuits. The output of each of the amplifiers is used to turn on the switching transistors which will make our relay to be energized and consequently close contact and make power to be supplied to the load connected to it. Conversely, when the phase sequence is reversed, i.e.: anticlockwise, the voltage in this terminal will be very low and will not be enough to turn on the transistor thus, making the load to be disconnected.

With the reference voltage, V_{ref} = 5.0V and the voltage to the non-inverting inputs of the comparators equal to 8V, $R_7 = R_8 = R_9 = R_{10} = 1K\Omega$, $R_{15} = R_{16} = R_{17} = R_{18}$, $R_{11} = R_{12} = R_{13} = R_{14}$ and $V_{R15} = V_{R16} = V_{R17} = V_{R18} = 8V$

$$V_{R15} = \left(\frac{R15}{R7+R15}\right) x\ Vcc$$

$$R_{15} = \frac{R7\ x\ V15}{Vcc-V15} = \frac{1\ x\ 8}{12-8} = 2k$$

$$R_{15} = R_{16} = R_{17} = R_{18} = 2K\Omega$$

R_{11}, R_{12}, R_{13}, R_{14} are to provide positive feedback, and they show a signal-conditioning circuit known as Schmitt trigger.

However, when V_{ref} and V_{in} are very close together or the input voltage varies slowly, the output voltage is no longer deterministic i.e, the output voltage V_O, randomnizes or become transient output, between high state and low state.

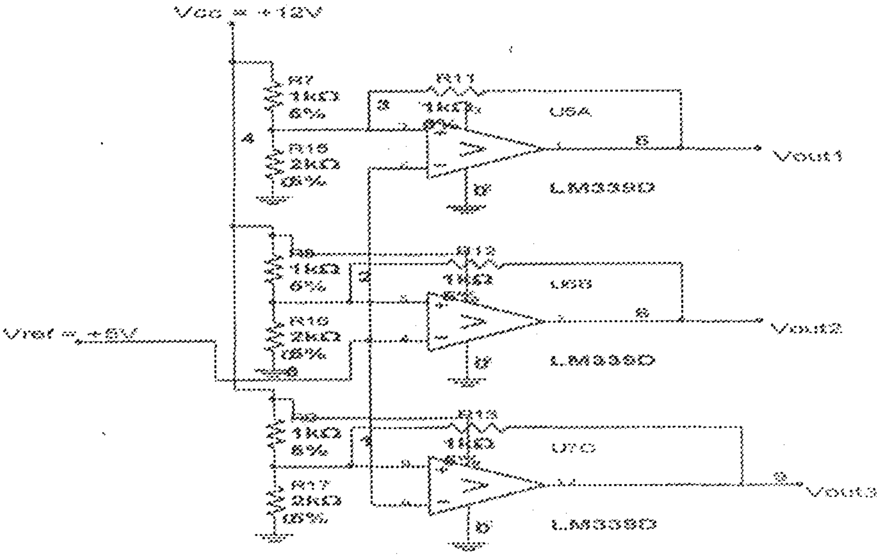

Fig. 3.4 Positive sequence detector circuit

To prevent this oscillation (transient state), positive feedback is employed to provide snap action response. The circuit has two separate well defined switching thresholds: V_{ON} and V_{OFF}.

Assuming the output is initially at HIGH

$$V_{switches}(1) = V_t(1) = \frac{Vcc\ x\ R15}{\left(\frac{R7\ x\ R11}{R7+R11}\right)+R15} \qquad \text{(i)}$$

With the output at low:

$$V_{switches}(2) = V_t(2) = \frac{Vcc\,x\left(\frac{R11\ x\ R15}{R11+R15}\right)}{R7+\left(\frac{R11\ x\ R15}{R11+R15}\right)} \qquad \text{(ii)}$$

The difference in the switching thresholds i.e. $V_t(2) - V_t(1)$ is the hysteresis. Assuming $R_7 = 1K\Omega$, $R_{15} = 2K\Omega$ and R_{11},Rremembering that $V_{ON} = ⅔V_{cc} = 8V$ and

$V_{OFF} = ⅓V_{cc} = 4V$

The value of the feedback resistor R_{11} can be calculated by making R_{11} the subject of the formula from either of the equations i.e,

$$R_{11} = \frac{R7}{\left[\left(\frac{Vcc\,x\,R15}{Vt(1)}\right)-R15\right]} = \frac{1}{[(12\,x\,2)/8)-2]} = 1k\Omega$$

The implication of the above result is that circuit switches ON and OFF at two different voltages. The inherent hysteresis prevents random switching when the input voltages are close together.

3.5 ANTICLOCKWISE SEQUENCE DETECTOR

This circuit is employed connecting a comparator to B line. With the phases out of sequence the red LED connected to its output pin will light indicating negative or wrong phase sequence and therefore, the load remain isolated until the error is corrected.

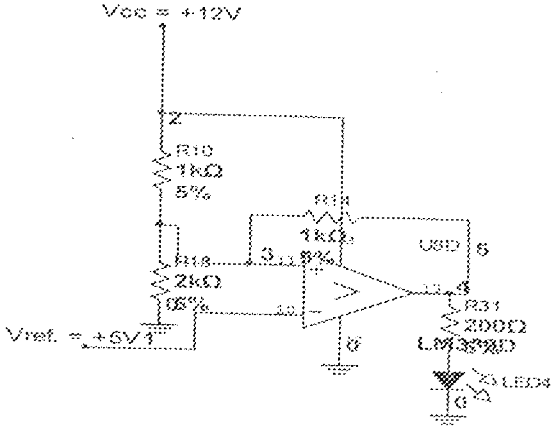

Fig. 3.5 Negative sequence detector circuit

3.6 AMPLIFIER CIRCUIT CALCULATION

Amplifier is connected to each of the output of the comparators to amplify the output of the comparators to a voltage value that will be enough to turn on the transistor. A non-inverting amplifier is used and it`s implemented using LM741.

The output of the comparator is connected to the non-inverting input, input resistor connected to the inverting input and grounded, and the feedback resistor connected to the inverting input. The amplifier is designed to give an amplifier gain of 2.1 (i.e. $A_v = 2.1$).

Assuming Vin = 3.0V,input resistors $R_{19}=R_{20}=R_{21}=11K\Omega$ and $A_v = 2.1$, and feedback resistors $R_{22}=R_{23}=R_{24}$

Then,

$$A_v = \left(\frac{Rf}{Rin}\right) + 1 = \left(\frac{R22}{R19}\right) + 1$$

$$2.1 = \left(\frac{R22}{11}\right) + 1$$

$$2.1 - 1 = \frac{R22}{11} = 1.1$$

$$R_{22} = 11 \times 1.1 = 12.1K\Omega \approx 12K\Omega$$

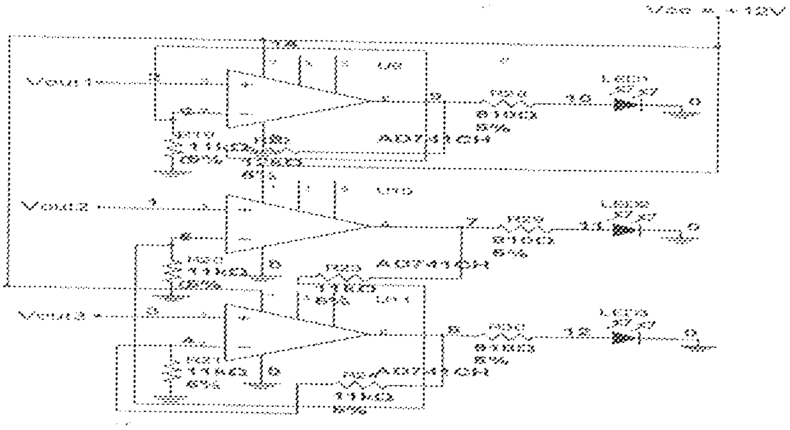

Fig. 3.6 Amplifier circuit

3.7 LIGHT EMITTING DIODES

Three green LEDs were connected to the output pins of the amplifier to indicate right phase sequence and a red LED to the output of a single comparator connected to V_{BO} phase to indicate wrong phase sequence.

3.7.1 GREEN LEDS

Taking the output of the amplifier to be Vo = 6.3V, drop across the LED as $V_d = 2V$ and diode current $I_d = 5mA$

$$R_{28} = R_{29} = R_{30} = \frac{Vo-Vd}{Id} = \frac{(6.3-2)V}{5mA} = \frac{4.3V}{5\,x\,10^{-3}A} = 860\Omega$$

3.7.2 RED LED

Taking the output of the comparator to be 3V

$$R_{31} = \frac{Vo-Vd}{Id} = \frac{(3-2)V}{5mA} = \frac{1V}{5\,x\,10^{-3}A} = 200\Omega$$

3.8 SWITCHING TRANSISTORS

Switching transistors are connected to the outputs of the amplifiers with light emitting diodes and relays connected to the collector of the transistors. Green LEDs are used to indicate right sequence while Red LED is used to indicate wrong sequence.

The transistor used in this project is 2N3904 and has a typical current gain of 3.0 with the connections shown in the figure below.

$$V_{cc} = I_c R_c + V_{ce}$$

The relay has coil resistance of 157Ω at a coil voltage of 12V.

$$I_{coil} = V_{coil} / R_{coil} = 12V / 157\Omega = 76.4mA$$

I_c = collector current and is used to drive the relay, hence, $I_c = I_{coil} = 76.4mA$

$$\beta = I_c / I_B$$

$$I_B = I_c / \beta = 76.4mA / 30 = 2.55mA$$

$$\text{But } R_B = (V_{BB} - V_{BE}) / I_B$$

Where LM741's output voltage swing = 13V maximum

V_{BE} = 0.7V (silicon semiconductor)

$$R_B = (13 - 0.7) / 2.55 \times 10^{-3} = 12.3 / 2.55 \times 10^{-3}$$

$$R_B = 4824\Omega = 4.8K\Omega$$

But a maximum voltage of 8V input to the transistor is required.

Therefore, base resistor for the transistor R_B = 2.7KΩ

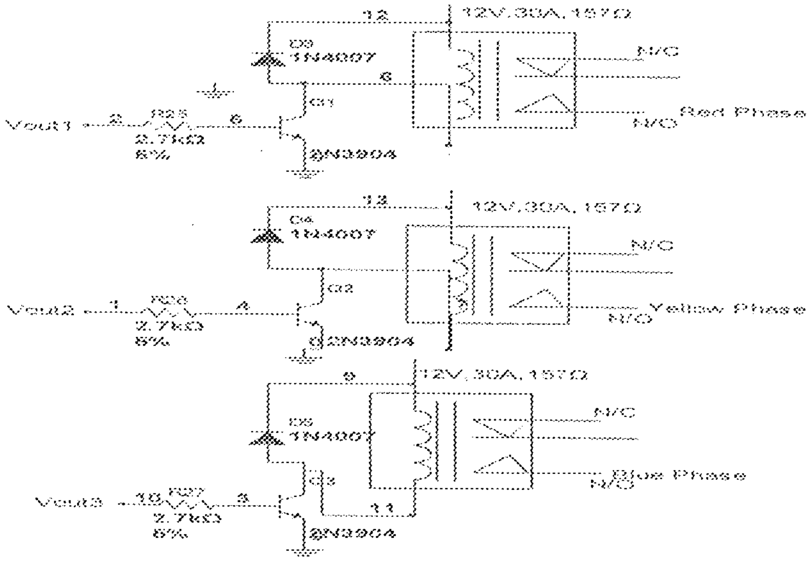

Fig. 3.7 Switching circuit

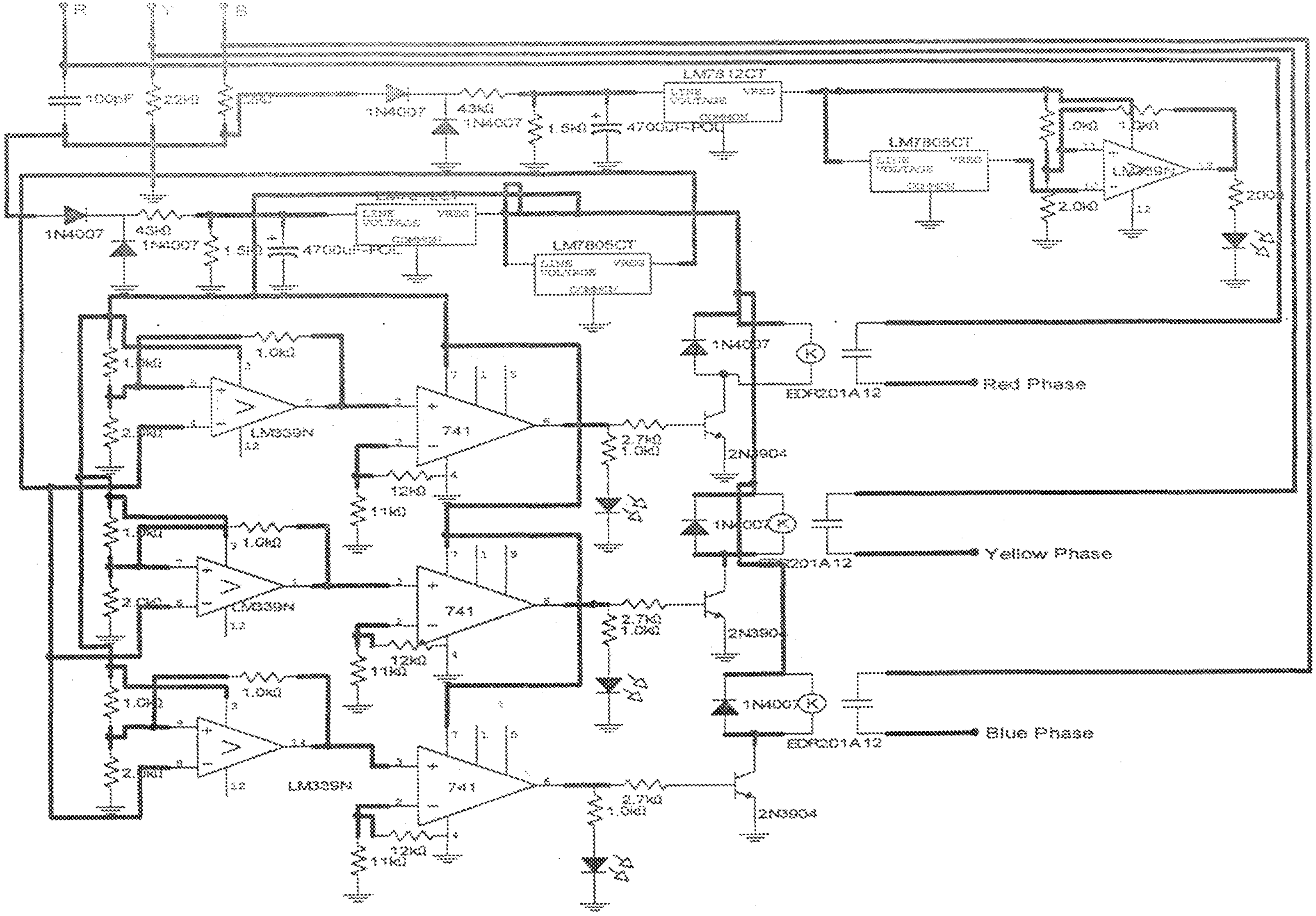

Fig. 3.8 Complete circuit diagram of a three phase sequence protection (Relay)

CHAPTER FOUR

TEST, RESULT AND DISCUSSION

4.1 TEST

The physical realization of the project is vital. This is where the fantasy of the whole idea meets reality. The designer will see his or her work not just on paper but also as a finished hardware.

After carrying out all the paper design and analysis, the project was implemented and tested to ensure its working ability, and was finally constructed to meet desired specifications.

At this point, the various components bought were soldered on a Vero-board as shown on the circuit diagram. The soldering were done at intervals, that is stage by stage. Each stage was tested to see whether it gave the desired output.

Resistors R_1, R_2 and capacitor C_1 were first soldered on the board in star connection and connected to the three-phase mains power supply. Diodes were soldered to the phases containing R_1 and R_2 to convert the voltage to DC and voltage divider network was also soldered to the diodes to reduce the output DC to approximately 14V. The 14V DC voltage obtained was fed through a filter circuit to remove the ripples in it. An electrolytic capacitor was soldered and its negative side grounded. Then the voltage regulator ICs (7805 and 7812) were connected across the output filtered DC output and was measured. The outputs of the voltage regulator ICs were measured and found to be approximately 5V and 12V.

The 12v output was connected to the non-inverting inverting input of the comparator network, 5v to the inverting input to serve as the reference voltage to each of the comparator and an output of 3v was obtained at the output of each comparator.

Three green LEDs were soldered to the output pins of LM741 amplifier to indicate right sequence and a red LED to the output pin of the comparator soldered to V_{BO} phase to indicate wrong sequence.

IC LM741 and with a gain of 2.1 (A_v=2.1) was connected across each comparator to amplify the output of the comparators to approximately 2.1 times the input voltage, this in turn was connected to the base of 2N3904 transistors. Relay coils were connected to the collector of each transistor, the coils were energized and there was a supply to the load connected to the normally open terminals of the relays.

4.2 RESULTS

Table 4.1 Results

QUANTITY	CALCULATED RESULT	TEST RESULT
V_{RO}	165.86V	160.10V
V_{YO}	421.56V	420.03V
V_{BO}	260.29V	259.01V
I_R	7.46mA	7.20mA

I_Y	18.97mA	18.90mA
I_B	11.71mA	11.66mA
V_{ON}	195.16V	195.16V
V_{RY}	398.37V	
V_{YB}	398.38V	
V_{BR}	644.34V	
V_{DC}	14V	13.27V
Vcc	12V	12V
Vref.	5V	5V

4.3 DISCUSSION

The 3v obtained at the output of the comparators connected to V_{YO} phase indicates right or clockwise sequence and at this time, the comparator soldered to V_{BO} phase has a very low input of which the output voltage is consumed by the resistor connected in series with the red LED and so the LED will not light up until any of the phases are interchanged.

4.4 COMPONENT SPECIFICATION

Having designed and mathematically analysed the system circuit, all the components to be used were known. Some of the components used are not exactly the same in values with the calculated values; hence very close values were chosen. The lists of components used are listed below;

RESISTORS (Ω):

R3 --- 200,

R28, R29 R30 --- 910,

R4, R5 --- 1.5K,

R7, R8, R9, R10, R11, R12, R13, R14, --- 1K,

R15, R16, R17, R18 --- 2K

R25, R26, R27 --- 2.7K

R19, R20, R21 --- 11K

R22, R23, R24 --- 12K

R1, R2 --- 22K

R3, R5 --- 45K

CAPACITORS (μf):

C1 --- 0.1, C2, C3 --- 4700

DIODES:

D1, D2, D3, D4, D5, D6, D7 --- IN4007

LED1, LED2, LED3 --- Green, LED4 --- Red

INTEGRATED CIRCUITS (ICs):

U2, U4 --- LM7805, U1, U3 --- LM7812

U5, U6, U7, U8 --- LM339

U9, U10, U11 --- LM741

TRANSISTORS:

Q1, Q2, Q3 --- 2N3904

CHAPTER FIVE

CONCLUSION, LIMITATION AND RECOMMENDATION

5.1 CONCLUSION

It is therefore an object of the invention to overcome the above noted prior art limitations.

Another object is the provision of apparatus which is reliable and in-expensive and yet will prorect a load from being damaged due to miswiring of the phase sequence of a polyphase power supply.

Briefly, in accordance with the invention, first and second resistors having a first impedance and a capacitor having an equivalent impedance are connected in a Y configuration and analog comparator networks are coupled in line with the first and second resistor to monitor the voltage differential which occurs when the phases are in and out of sequence. According to a feature of the invention, the outputs of the comparator networks are coupled to amplifier circuits and to the base of transistors which serve as switches to provide signals that will energize relay coils.

The circuit can provide visual or audio indication of incorrect phase sequencing and preferably prevents energization of the loads, e.g, compressor system, when the phases are out of sequence.

5.2 LIMITATIONS

In an industry where the rotation of motors in opposite direction is sometimes required, this apparatus will not allow it because the project is designed to make motors work in one direction only, when the phase sequence is positive. Secondly, the project is designed using two of the AC lines for the actual measurement and is sensitive to voltage difference.

The project can be modified by using only one of the AC line for the actual measurement instead of two used in this project.

5.3 RECOMMENDATION

I believe after this project has been examined, it will be recommended to industries, homes where they use three phase appliances and also Computer Department of the National Examination Council (NECO) where they use three phase Uninterrupted Power Supply (UPS) that is sensitive to phase sequence of power supply and phase rotation of a three phase generator because the apparatus will provide a good protection against all these short comings as it is sensitive voltage and phase difference.

It is also capable of protecting a motor against voltage unbalance since it is designed to energize electromagnetic relays only when three AC lines are present.

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