EXTRACTION OF SYMMETRICAL COMPONENTS AND FAULT INDICATION

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EXTRACTION OF SYMMETRICAL COMPONENTS AND FAULT INDICATION

A Thesis Submitted in Partial Fulfilment of the requirement for the Degree of

Bachelor and Technology in Electrical Engineering

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MAY-2015

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CERTIFICATE

This is to certify that the draft thesis entitled **"Extraction of Symmetrical Components and Fault Indication"**, submitted to the National Institute of Technology, Rourkela by **Ms. Rudraa Nayak(111EE0222), Mr. Akshaya Kumar Sahu(111EE0230)** and **Mr. Narendra Yadav(111EE0240)** in partial fulfilment of the requirements for the award of BACHELOR OF TECHNOLOGY in ELECTRICAL ENGINEERING during session 2014-2015 at National Institute of Technology, Rourkela is a bona fide record of research work carried out by them under my supervision and guidance.

The candidates have fulfilled all the prescribed requirements.

The draft report/thesis which is based on candidate's own work, has not submitted elsewhere for a degree/diploma.

In my opinion, the draft report/thesis is of standard required for the award of a BACHELOR OF TECHNOLOGY in Electrical Engineering.

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ACKNOWLEDGEMENTS

We would like to express our gratitude towards all the people who have contributed their precious time and effort to help us. Without whom it would not have been possible for us to understand and complete the project.

We would like to thank **Dr. S. Gopalakrishna, Department of Electrical Engineering**, our Project Supervisor for his guidance, support, motivation and encouragement for this project work. His readiness for consultation at all times, his educative comments, his concern and assistance even with practical things have been invaluable.

We are grateful to **Prof. Anup Kumar Panda, Head, Department of Electrical Engineering** for Providing necessary facilities in the department.

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Electrical Engineering

Dedicated to

Our Parents and Faculties

ABSTRACT

At present the conventional and practical problems are being solved by computer based softwares known as Simulation softwares due to their higher precision and accuracy. In our project we encounter one of such problems like the following. There are many faults we come across in electrical power system such as Line to ground (**LG**) fault, Line to Line (**LL**) fault and **3-PHASE** Fault. In this project the main focus is to design a circuit for extraction of Symmetrical Components and indicating the type of fault. The project consists of both Software and Hardware parts. A part of this circuit consists of transformers, phase shifters and low pass filters which result in symmetrical components. The faults are detected by various combinations of symmetrical components through AND gate and NOT gate. The faults are indicated by glowing a LED in that respective circuit. First the simulation of the circuit is done in **PSPICE** simulation software to generate symmetrical components and the output is verified. After the verification of output, the whole setup is designed in hardware and it is tested to run according to the desired parameters.

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ABBREVIATIONS AND ACRONYMS

LG – Line to Ground

LL – Line to Line

3-ϕ – Three phase

LED – Light Emitting Diode

AC – Alternating Current

DC – Direct Current

IC – Integrated Circuit

CHAPTER - 1

INTRODUCTION

1.1 INTRODUCTION:

In Electrical Engineering, the method of **Symmetrical Components** is used to simplify analysis of unbalanced 3-phase power systems under both normal and abnormal conditions. [1]. In this project “Symmetrical Components Theory” plays a very pivotal rule to detect different kinds of faults mentioned above. When a fault occurs in a power system, the system becomes unbalanced and, the fault analysis of an unbalanced system is very tedious and complex. So the process “extraction of symmetrical components from an unbalanced system” comes into play. In 1918, Dr. C.L. Fortescue wrote a paper entitled “Method of Symmetrical Coordinates Applied to Solution of Polyphase Networks” which depicts that an arbitrary system of unbalanced 3-phase voltages (or currents) could be transformed into 3 sets of balanced 3-phase components. [2]. This method is used in the formulation section of the project.

Faults usually occur in a power system due to insulation failure, flashover and physical Damage or human error. These faults may either be symmetrical in nature involving all the three phases or may be asymmetrical where usually only one or two phases may be involved. Faults may also occur by either short-circuits to earth or between live conductors, or may be caused due to broken conductors in any one or more phases. Sometimes simultaneous faults may occur which involves both short-circuit and broken conductor fault or open circuit fault. Balanced three phase faults can be analyzed using an equivalent single phase circuit. But in case of asymmetrical faults it is quite complex to analyze by taking any one phase into consideration, in that case the use of “Symmetrical Components Theory” helps to reduce the complexity of the calculations and to analyze the faults.

The simulation software PSPICE is used in the extraction of Symmetrical Components and the faults are indicated by glowing a LED respective to that fault.

1.2 LITERATURE SURVEY:

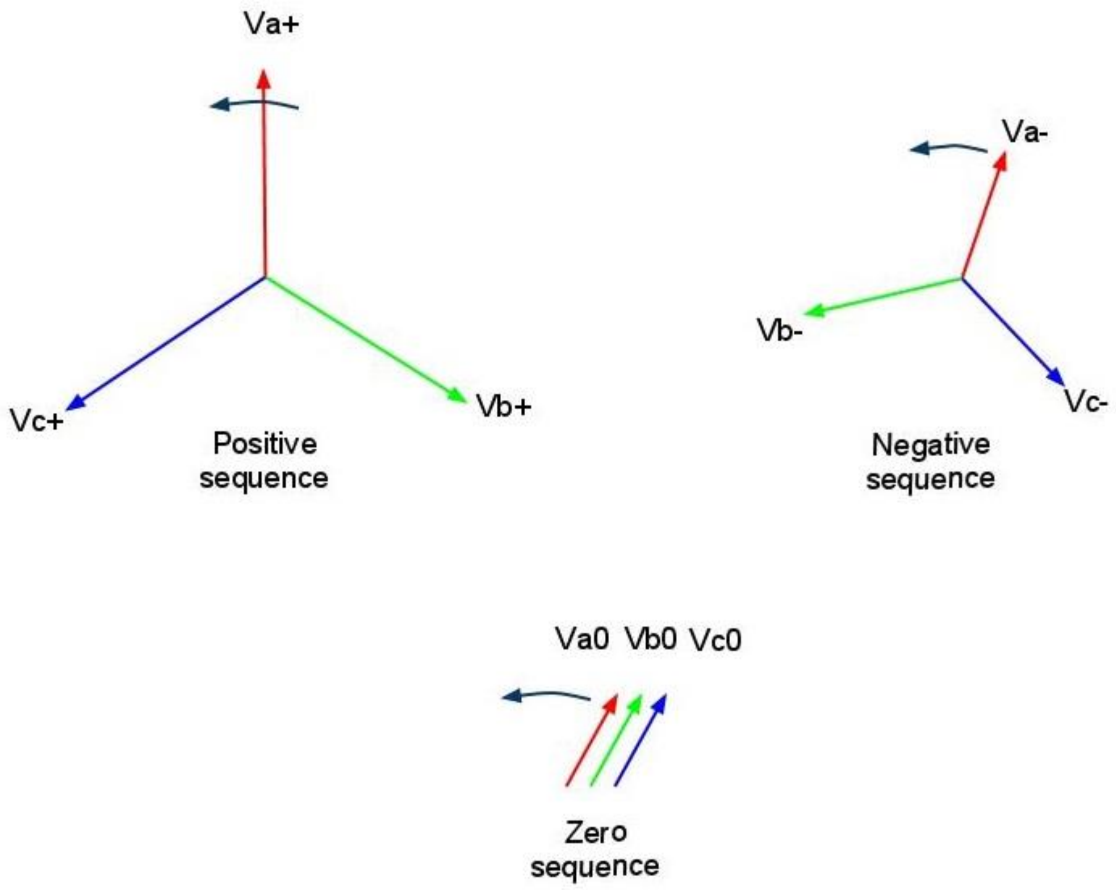
Symmetrical component extraction has been done by Fotrescue’s theorem. But fault calculation methods have been improvised a lot over the time. Now-a-days, most of the fault detections have been done by electronic (microprocessor) relays which replaced the electromechanical relays providing better interface, better accuracy and better control.

In historic *submarine telegraph cables*, sensitive *galvanometers* were used to measure fault currents; by testing at both ends of a faulted cable, the fault location could be isolated to within a few miles, which allowed the cable to be grappled up and repaired. The *Murray loop* and the *Varley loop* were two types of connections for locating faults in cables.[3] But now-a-days, many software tools exist to accomplish this type of analysis effortlessly.

Though Symmetrical component calculation is still done by conventional methods, Fault calculation methods have been emerged as par with the emergence of computer based technology.

1.3 SYMMETRICAL COMPONENTS THEORY:

Symmetrical Components is a balanced system of 3 vectors of equal magnitudes and all are equi-spaced.



[Figure 1: Symmetrical Components]

Positive sequence component: It consists of 3 phasors equal in magnitude displaced from each other by 120^0 in phase and having same phase sequence as the original phasors. The positive sequence is assumed abc with subscript +.

$V_{b+}=\omega^2 V_{a+}$

$V_{c+}=\omega V_{a+}$

Negative sequence component: It consists of 3 phasors equal in magnitude displaced from each other by 120^0 in phase and having opposite phase sequence to that of original phasors. The negative sequence is assumed acb with subscript -.

$V_{b-}=\omega V_{a-}$

$V_{c-}=\omega^2 V_{a-}$

Zero sequence component: It consists of 3 phasors equal in magnitude and with zero phase displacement from each other. The zero sequence is assumed with subscript 0.

$V_{b0}=V_{a0}$

$V_{c0}=V_{a0}$

**In all the above cases phasor 'a' is taken as reference.*

Operator 'ω': In electrical systems, we deal mostly with the 3-phase systems and as in 3-phase systems the phases are displaced by 120^0 in phase, thus we define an operator 'ω' which has a magnitude of *unity* and causes a rotation of 120^0 in anti-clockwise direction when operated on any complex number.

$\omega=-0.5+j0.866=1\angle 120^0$ $\quad\quad$ $* j=1\angle 90^0$

$\omega^2=-0.5-j0.866=1\angle -120^0$

$\omega^3=1=1\angle 360^0$

Also, $\omega+\omega^2+\omega^3=0$

According to Fotrtescue's theorem and above notations, any system of unbalanced vectors can be represented as:

$V_a = V_{a0} + V_{a+} + V_{a-}$

$V_b = V_{b0} + V_{b+} + V_{b-} = V_{a0} + \omega^2 V_{a+} + \omega V_{a-}$

$V_c = V_{c0} + V_{c+} + V_{c-} = V_{a0} + \omega V_{a+} + \omega^2 V_{a-}$

So, the symmetrical components obtained from the system of unbalanced vectors can be represented as following:

$$\boxed{\begin{aligned} V_{a0} &= 1/3(V_a + V_b + V_c) \\ V_{a+} &= 1/3(V_a + \omega V_b + \omega^2 V_c) \\ V_{a-} &= 1/3(V_a + \omega^2 V_b + \omega V_c) \end{aligned}}$$

CHAPTER – 2

ANALYSIS OF DIFFERENT TYPES OF FAULTS IN 3-Φ CIRCUIT

2.1 TYPES OF FAULTS:

Normally over current or short circuit and sometimes overload on the power system cause faults in power system. There occur many types of faults in power system but the ones we are concerned with are LG (Line to Ground) fault, LL (Line to Line) fault and 3 phase fault. Out of all types of faults in power system LG fault is most occurring and least hazardous while 3-phase faults are least occurring and most hazardous.

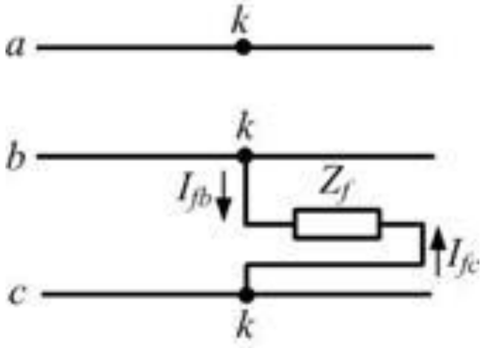
2.2 LINE TO GROUND FAULT:

[Figure 2.1: Line to Ground Fault]

L1=phase a, L2=phase b, L3=phase c

V_{a0}, V_{a+} and V_{a-} exist and have finite values.[2]

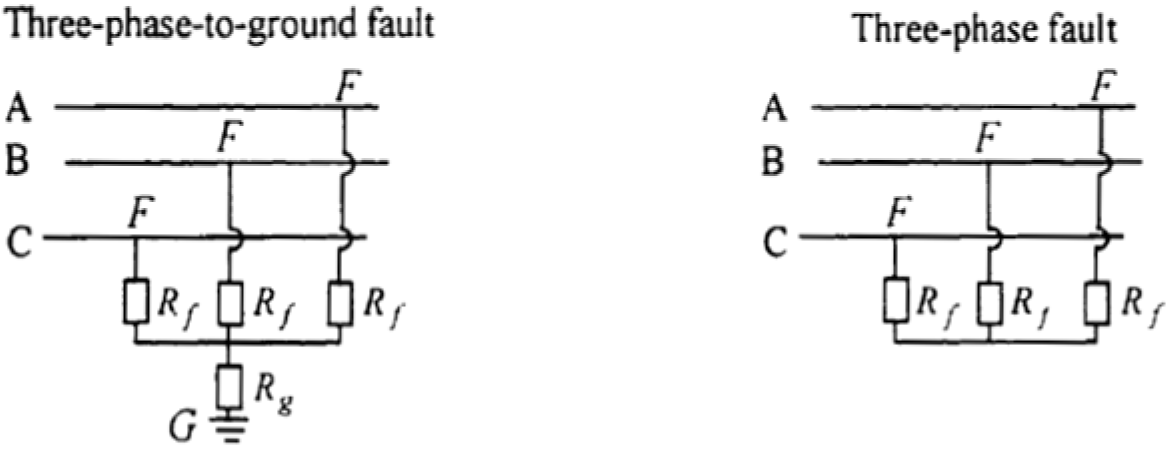
2.3 LINE TO LINE FAULT:



[Figure 2.2: Line to Line Fault]

$I_{a0}=0$, $I_{a+}=-I_{a-}$=finite value.[2]

2.4 3-PHASE FAULT:



[Figure 2.3: 3 Phase Fault]

$I_{a0}=0$, $I_{a+}=$finite, $I_{a-}=0$; $V_{a0}=0$, $V_{a+}=0$, $V_{a-}=0$.[4]

We can summarize the above results in a table:

Types of fault	V_{a0}	V_{a+}	V_{a-}	Additional Information[7]
LG	finite	finite	finite	$V_{a0}\neq V_{a+}\neq V_{a-}$
LL	0	finite	finite	$V_{a+}=V_{a-}$
3-PHASE	0	0	0	$V_{a0}=V_{a+}=V_{a-}\approx 0$
NO FAULT	0	finite	0	$V_{a+}=V_a$

[Table 1: Symmetrical Voltage Component Values in different Fault Conditions]

Types of fault	I_{a0}	I_{a+}	I_{a-}	Additional Information[8]
LG	finite	finite	finite	$I_{a0}=I_{a+}=I_{a-}$
LL	0	finite	finite	$I_{a+}=-I_{a-}$
3-PHASE	0	finite	0	$I_{a0}=V_{a-}\approx 0$, $V_{a+}\neq 0$

[Table 2: Symmetrical Current Component Values in different Fault Conditions]

CHAPTER – 3

PSPICE SIMULATION AND RESULT

3.1 INTRODUCTION:

OrCAD PSPICE is an electronic schematic capture and simulation program which is a part of circuit design programs. We have used its ‘Capture Student’ component for our simulation purpose.

As this project doesn’t involve hardware interfacing, this simulation is only used for verification purpose. The steps to be followed for calculation of sequence components are:

Step 1 Supply of three phase voltages through transformer

Step 2 Phase shifting of input waveforms

Step 3 Feeding of shifted waveforms to summer circuit

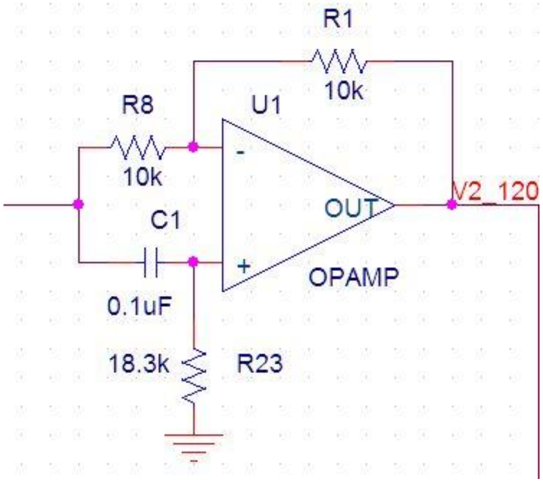
Step 4 Rectification and Filtration

Step 5 Calculation of sequence components for unbalanced condition

The complete circuit diagram of “Extraction of Symmetrical Components” is made on the PSPICE simulation software. In actual circuit, there were 3 transformers of rating 230V/12V, 230V/13V, 230V/14V and 1A each, but due to ‘netlisting problem’ in PSPICE, those transformer models have not been used. Instead, direct sinusoidal sources of 12V, 13V and 14V have been given and hence initializing the circuit. After that, there are ‘phase shifters’ used to shift the phase of input waveform 120^0 or 240^0 depending upon the requirement.

3.2 PHASE SHIFTERS:

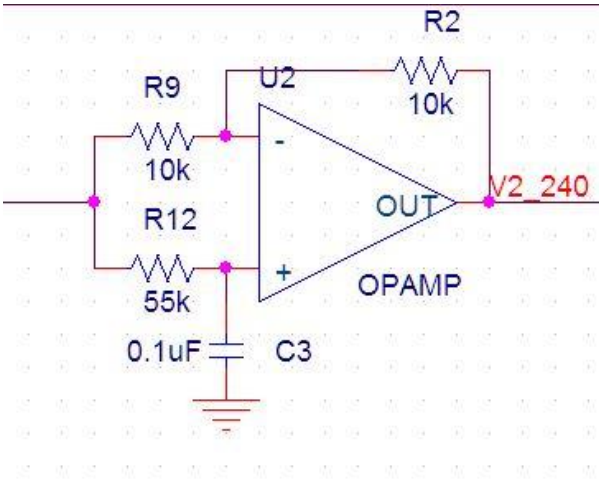
The All Pass Filter-120^0 Phase Shifter circuit is as follows:



[Figure 3.1: 120^0 Phase Shifter]

It shifts the phase of input waveform by 120^0 thereby output waveform 'leading' the input by an angle of 120^0.

The All Pass Filter-240^0 Phase Shifter circuit is as follows:



[Figure 3.2: 240^0 Phase Shifter]

It shifts the phase of input waveform by 240^0 thereby output waveform 'leading' the input by an angle of 240^0.

The R and C value is chosen by the relation:

$\phi=\tan^{-1}(X_c / R)$,

Where $X_c=1/(2\pi fC)$ and f=frequency of input waveform=50Hz

To obtain a phase shift of 120^0 at a frequency of 50 HZ, the values of RC is computed as RC = 0.001838.

So the values calculated are R=18.3KΩ and C=0.1uF. If two components, i.e. R&C are inter changed, values of R&C are equal to 55KΩ and 0.1μF respectively then the phase shift of the circuit is twice, i.e. 240^0. These values of R and C have been used in the circuits shown in above figures.

Using the phase shifting circuits a phase shift of 120^0 or 240^0 can be obtained for voltages V2 and V3. In order to extract the sequence components we have to sum up V1, V2 and V3 according to the following formulas:

$V_{10}=1/3(V_1+V_2+V_3)$

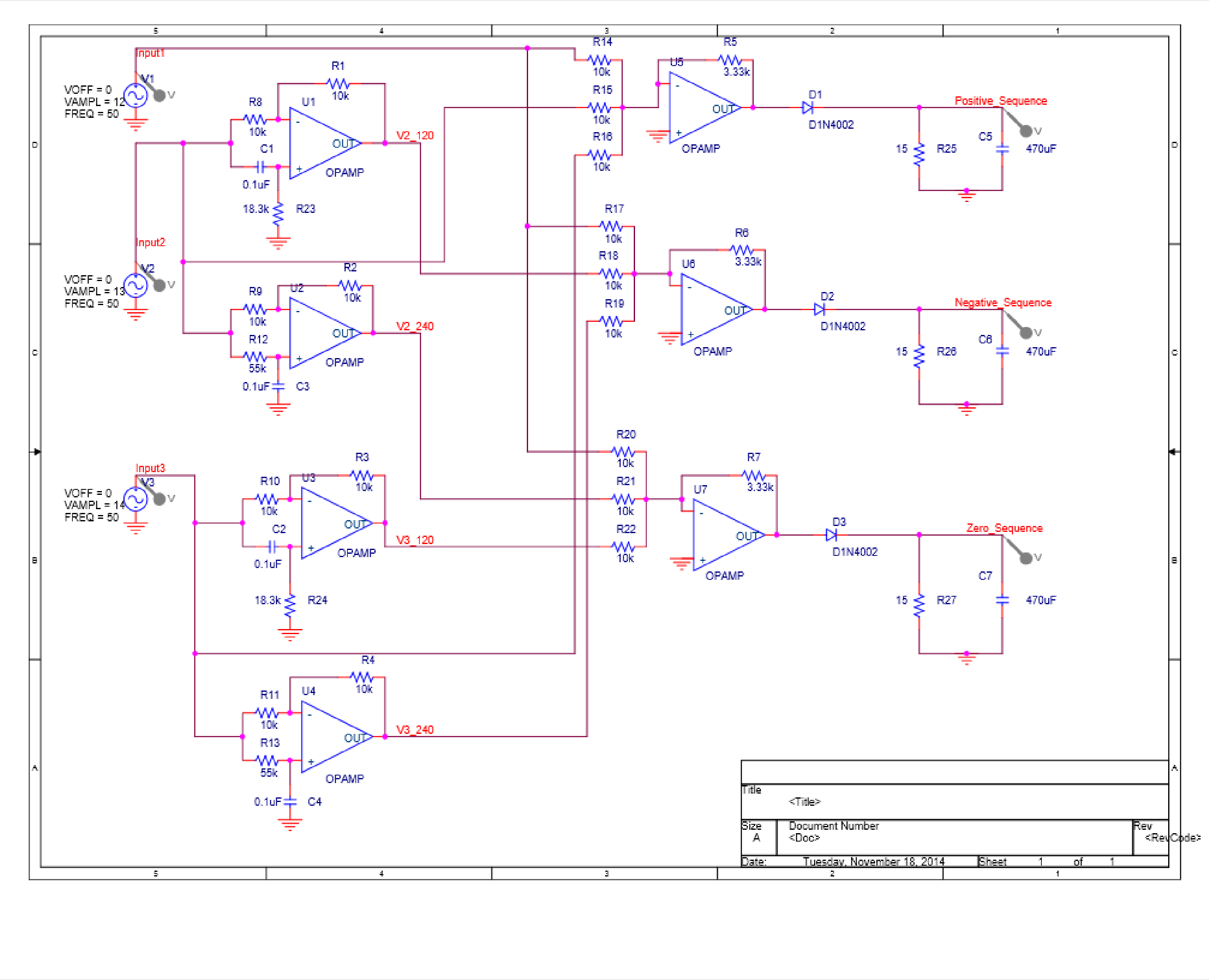
$V_{1+}=1/3(V_1+\omega V_2+\omega^2 V_3)$

$V_{1-}=1/3(V_1+\omega^2 V_2+\omega V_3)$

The sequence component voltages are then rectified and fed into the filter circuit to get a proper DC output. Now that DC outputs are compared with a constant voltage 1V by the comparator circuit. If the filtered sequence component voltage is higher than the reference voltages then the output of comparator is the offset voltage of the comparator. Now according to the comparator output for individual faults we can set up logics such that one LED will glow.

3.3 SIMULATION CIRCUIT FOR OBTAINING VOLTAGE SEQUENCE COMPONENTS:

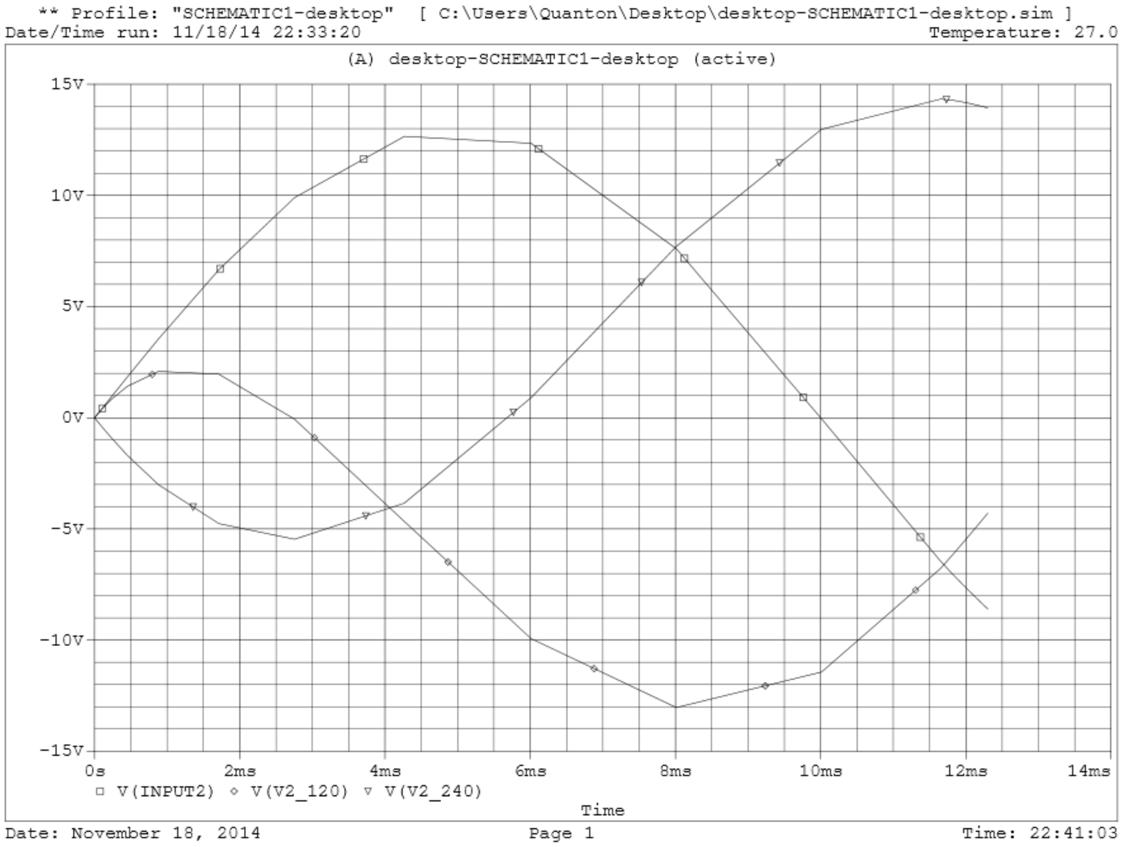
The complete circuit is shown below:



[Figure 3.3: PSPICE circuit for Extraction of Symmetrical Components]

3.4 SIMULATION RESULTS:

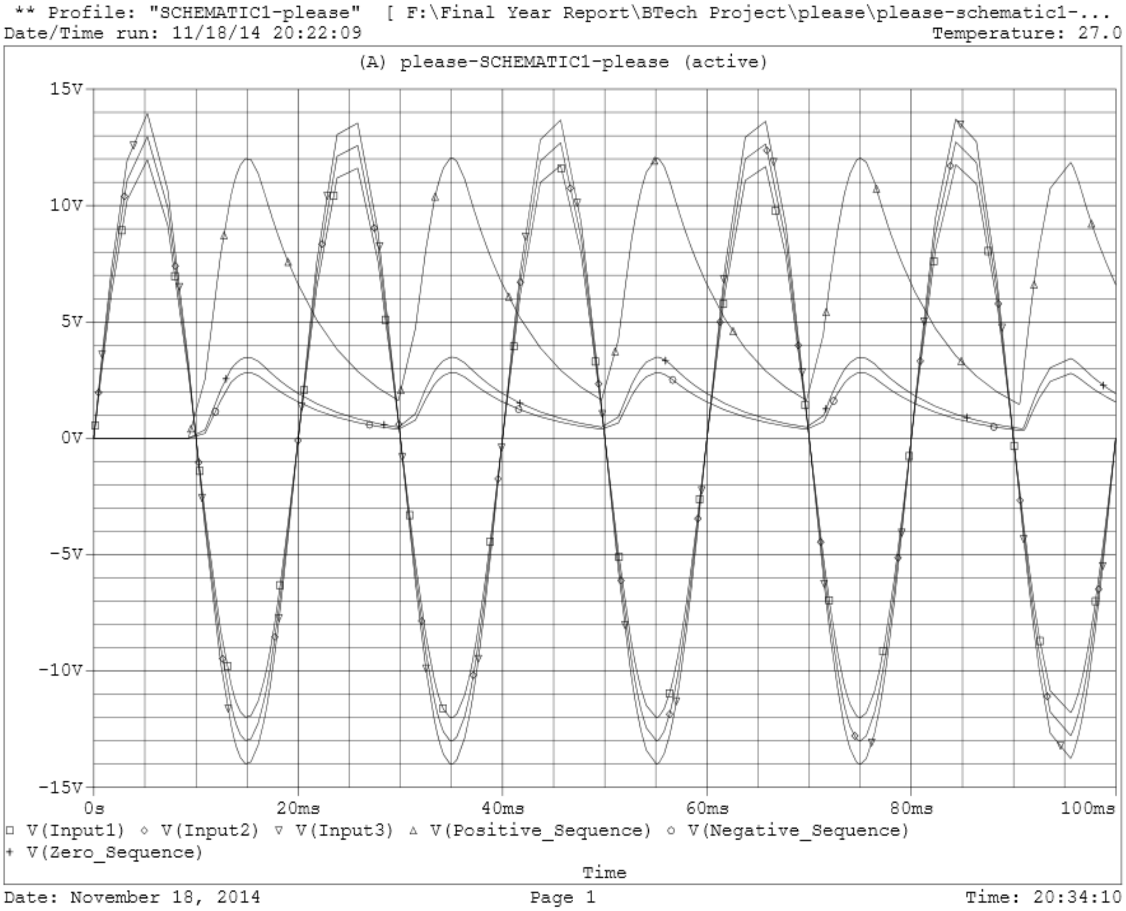
The simulation is done successfully and the symmetrical component waveforms were obtained. The phase shifter circuit output also was also checked and verified. The shifting output is as follows:



[Figure 3.4: Phase Shifting Waveforms]

The output is obtained for one half cycle of the waveforms to clearly demonstrate the phase differences.

The Symmetrical Component Output is obtained as follows:



[Figure 3.5: Symmetrical Component Waveforms]

- The sinusoidal waveforms passing through origin are Input faulty waveforms. The rectified waveforms next to Input waveforms are Symmetrical Components.
- The waveform having maximum peak than the other two is *‘+ve Sequence Component’*. It remains present largely in faulty conditions and have maximum value.
- The waveform having slightly greater peak than the other waveform is *‘-ve Sequence Component’*.
- The waveform having lowest peak is *‘Zero Sequence Component’*. It remains present on only those faulty conditions where ground is involved.

*All these components and their values have been illustrated with an example in the ‘Project Record Book’.

3.5 BOOLEAN LOGIC FOR FAULT INDICATION:

The hardware implementation has been done for fault indication by glowing LED. The Boolean Logic to design the hardware components is:

LG: AND (V_{a0}, V_{a+}, V_{a-})

LL: AND {NOT (V_{a0}), V_{a+}, V_{a-}}

3-PHASE: AND {NOT (V_{a0}), NOT (V_{a+}), NOT (V_{a-})}

NO FAULT: AND {NOT (V_{a0}), V_{a+}, NOT (V_{a-})}

The expected output in Fault Indication by LED glowing:

NO FAULT: $V_{10}=0$, $V_{1+}=1$, $V_{1-}=0$, so LED will glow when $V_{10}'\times V_{1+}\times V_{1-}'=1$

LG : $V_{10}=1$, $V_{1+}=1$, $V_{1-}=1$, so LED will glow when $V_{10}\times V_{1+}\times V_{1-}=1$

LL : $V_{10}=0$, $V_{1+}=1$, $V_{1-}=1$, so LED will glow when $V_{10}'\times V_{1+}\times V_{1-}=1$

3-PHASE : $V_{10}=0$, $V_{1+}=0$, $V_{1-}=0$, so LED will glow when $V_{10}'\times V_{1+}'\times V_{1-}'=1$

In the Hardware designing part, we have taken inputs from 3 transformers, which act as faulty supplies. We connect the switches in the input line to the circuit from Transformers so that we create the desired fault by closing respective switches. All the components (ICs, resistors, capacitors, LEDs) have been soldered into a PCB (Programmable Circuit Board) according to the circuit diagram and following Pinout diagrams of respective ICs. Then we have implemented the Boolean Logic to indicate the fault by manually triggering the switch. When there is direct supply from the Transformers and no fault is present then the "No Fault" LED should glow. When we close the switch which interconnects the 2 transformer secondaries then the "Line-to-Line Fault" LED should glow. Rest faults also can be created and indicated likewise.

Later, in the "Hardware Circuit Design" section, all the components and circuits have been explained. There are 3 pictures of circuits. First one is 'Supply Circuit'; in which 3 Transformers have been connected to supply power to the circuit. Second one is; 'Phase Shifter and Summer Circuit' in which phase shifting (120^0 and 240^0) and summing of resultants have been performed to give the output of Positive, Negative and Zero sequences across RC filter. Third and last one is 'Logic Implementation and Fault Indication Circuit'; in which the sequence components are fed to comparators for calibration and the resultants are used in Boolean logic formation. The Boolean logic is done according to the logics derived earlier. Finally, the outputs are connected to LEDs through resistors to indicate the output.

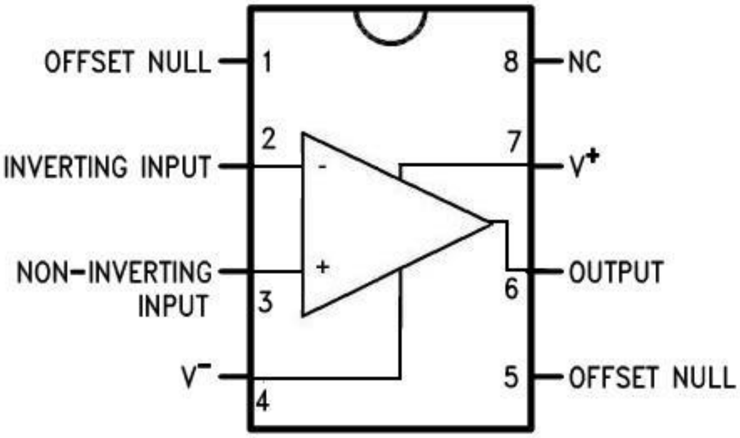
CHAPTER – 4

HARDWARE CIRCUIT DESIGN

4.1 COMPONENTS USED:

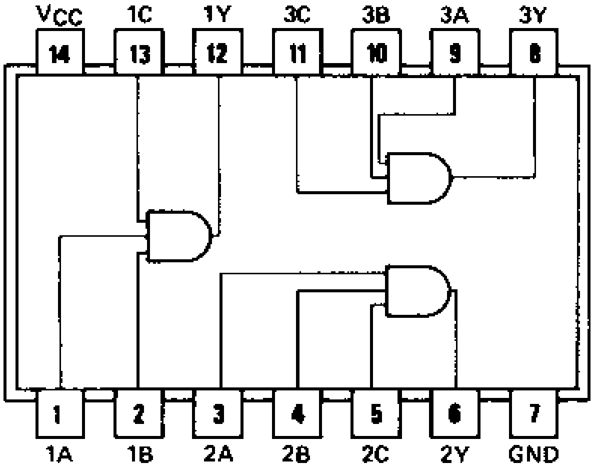
- → Transformers (**230/12V, 1.5A**)

- → Op-amps (**LM 741**)



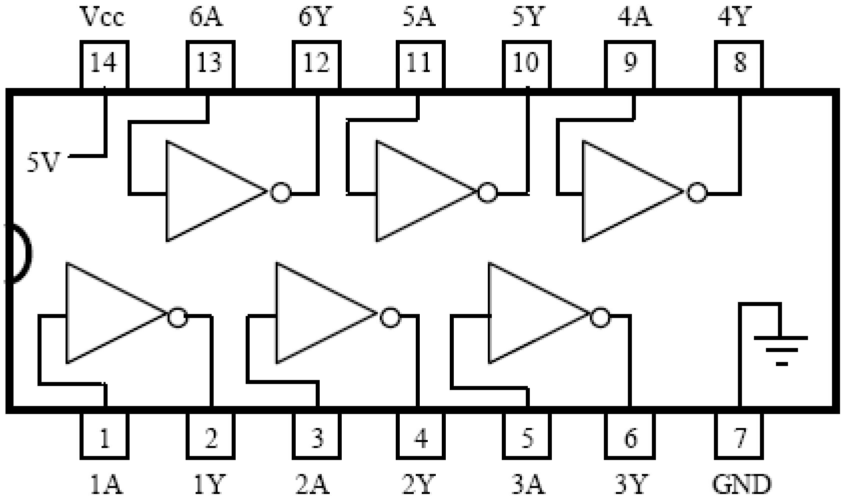
[Figure 4.1: Pinout diagram of LM 741]

- → AND Gates (**IC 7411**)



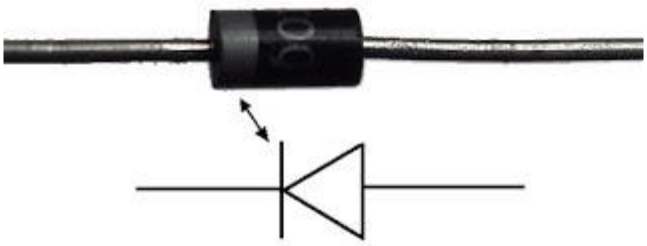
[Figure 4.2: Pinout diagram of IC 7411]

→ NOT Gates (**IC 7404**)



[Figure 4.3: Pinout diagram of IC 7404]

→ Diodes (**IN 4007**)



[Figure 4.4: Pinout diagram of IN 4007]

→ Resistors (**135k, 55k, 18.3k, 10k, 3.3k, 100 ohms**)

→ Capacitors (**20pF**)

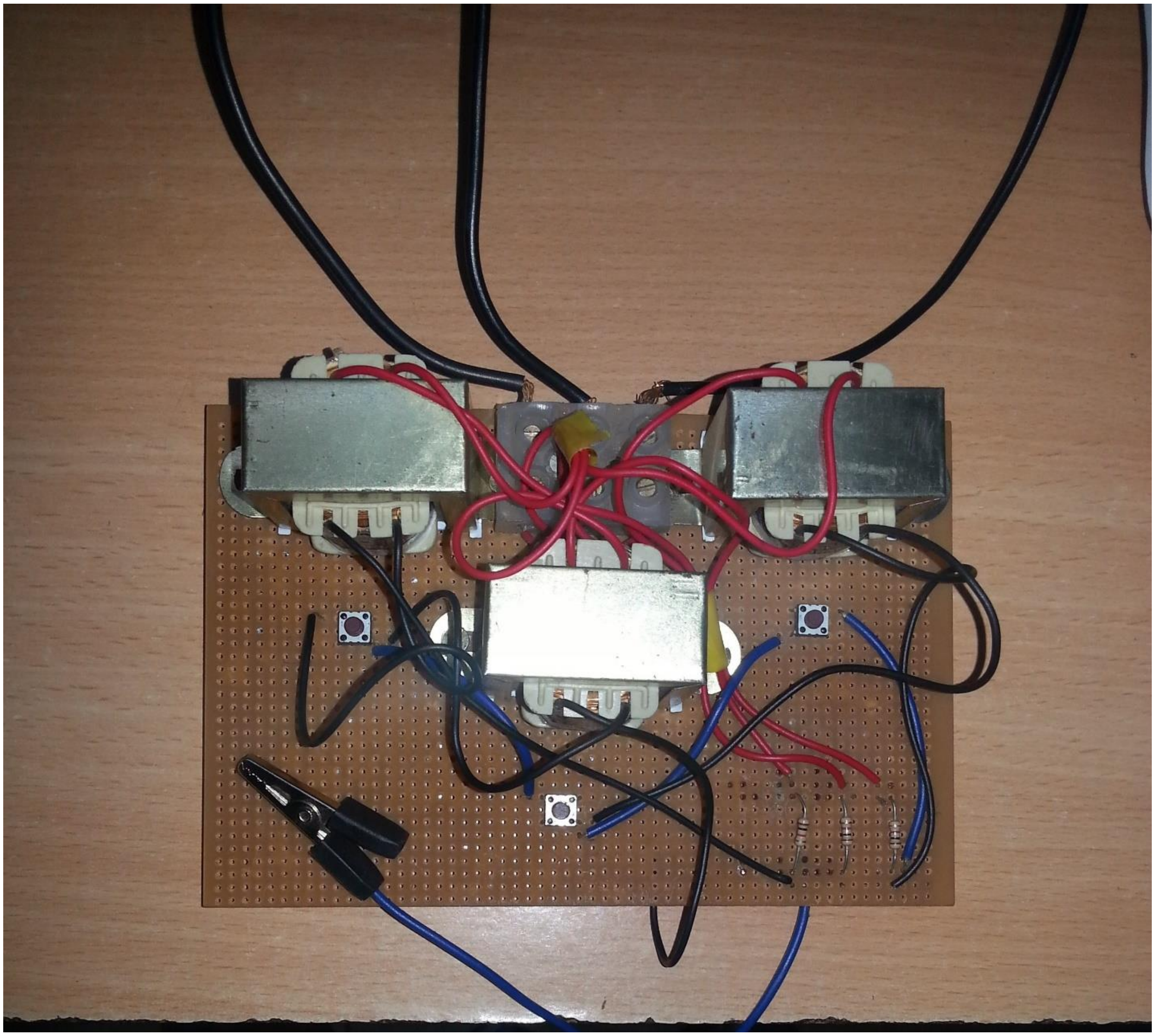
→ DC Power supply (**9V**)

→ LEDs

→ Connecting wires

4.2 SUPPLY CIRCUIT:

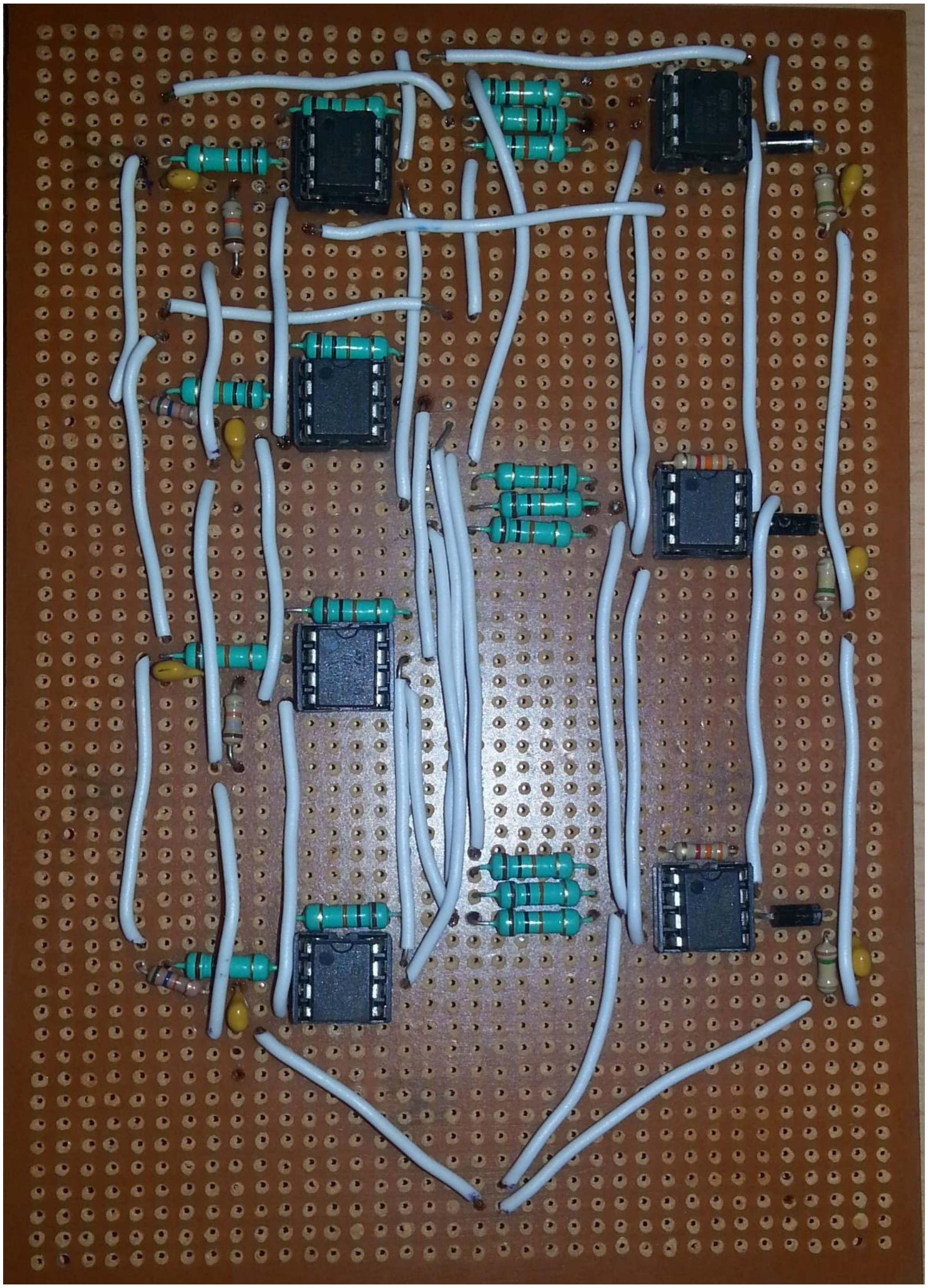
It is supplied through 3 single phase transformers.



[Figure 4.5: Transformer Circuit]

In this, we have taken inputs from 3 transformers, which act as faulty supplies. We connect the switches in the input line to the circuit from Transformers so that we create the desired fault by closing respective switches. The black wires indicate the 3-phase supply and the blue clipper indicates the 'Ground' terminal.

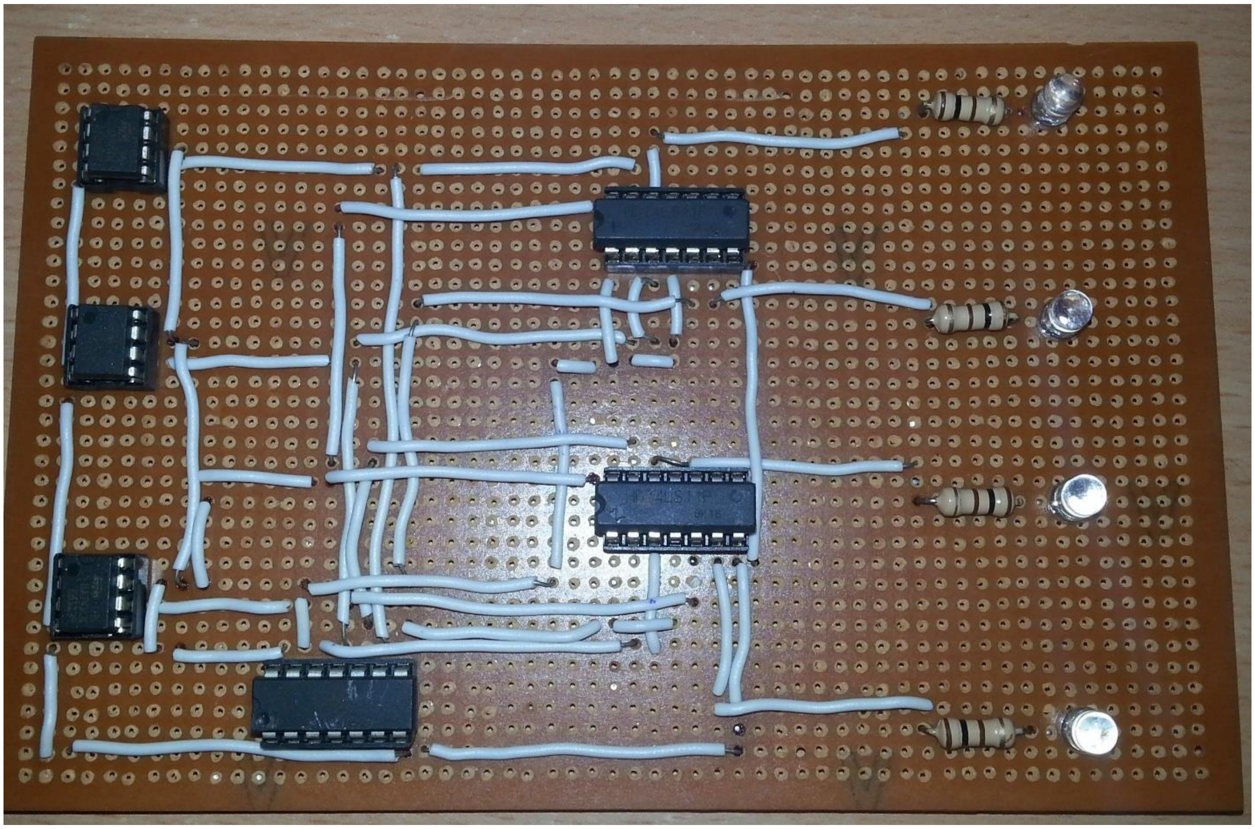
4.3 PHASE SHIFTER AND SUMMER CIRCUIT:



[Figure 4.6: Phase Shifter and Summer Circuit]

In this, all the components (ICs, resistors, capacitors) have been soldered into a PCB (Programmable Circuit Board) according to the circuit diagram and following the Pinout diagrams of respective ICs. In the above figure, out of the 4 op-amps in the first half of the circuit 1st & 3rd are 120^0 phase shifters and 2nd & 4th are 240^0 phase shifters. In the second half of the circuit summing action is performed. Here phase shifting (120^0 and 240^0) and summing of resultants have been performed to give the output of Positive, Negative and Zero sequences across RC filter.

4.4 LOGIC IMPLEMENTATION AND FAULT INDICATION CIRCUIT:

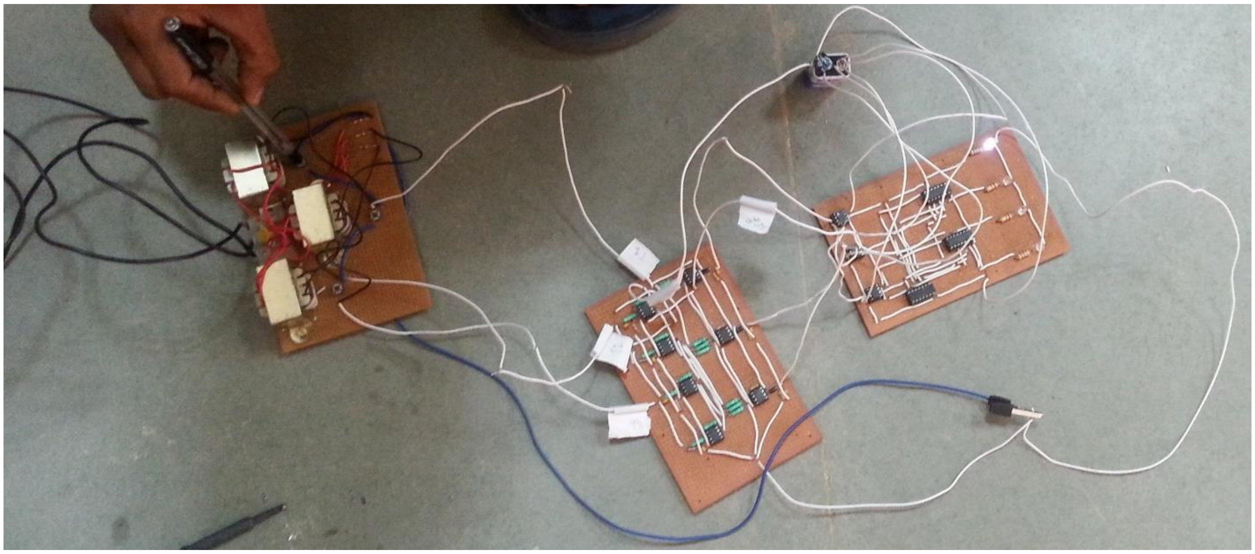


[Figure 4.7: Logic Implementation and Fault Indication Circuit]

In this, the sequence components are fed to the comparators for calibration and the resultants are used in Boolean logic formation. The Boolean logic is done according to the logics derived earlier. Finally, the outputs are connected to LEDs through resistors to indicate the output. Fault creation and indication is explained in the “Boolean Logic for fault indication” section.

4.5 FAULT INDICATION (RESULT):

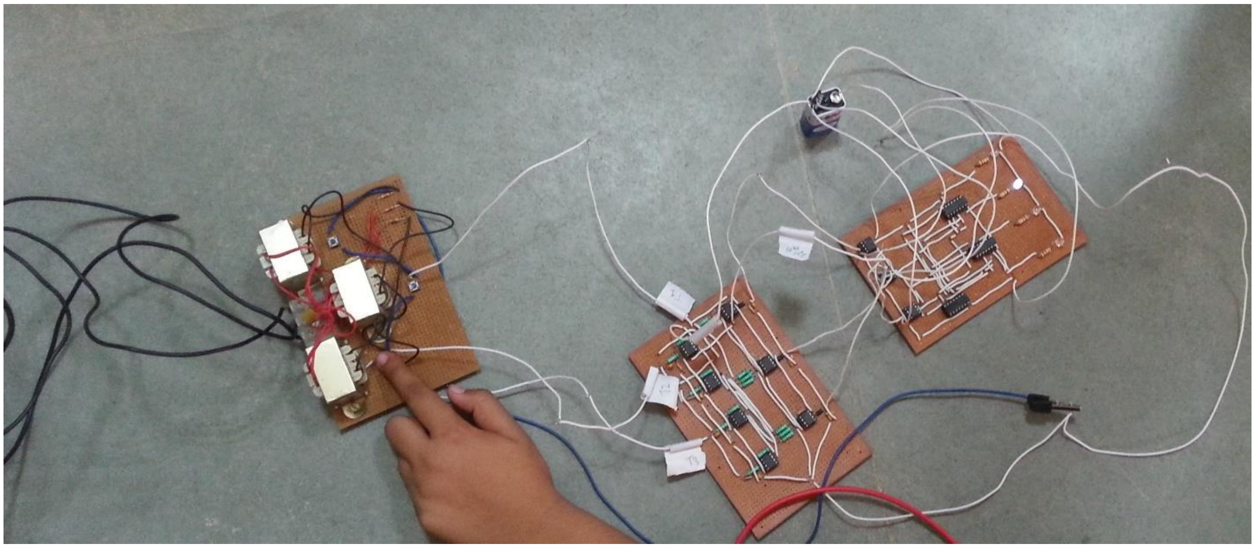
- Line-to-Ground (**LG**) Fault



[Figure 4.8: LG Fault Indication by glowing 1st LED]

It occurs due to closing of the switch connected in one transformer secondary.

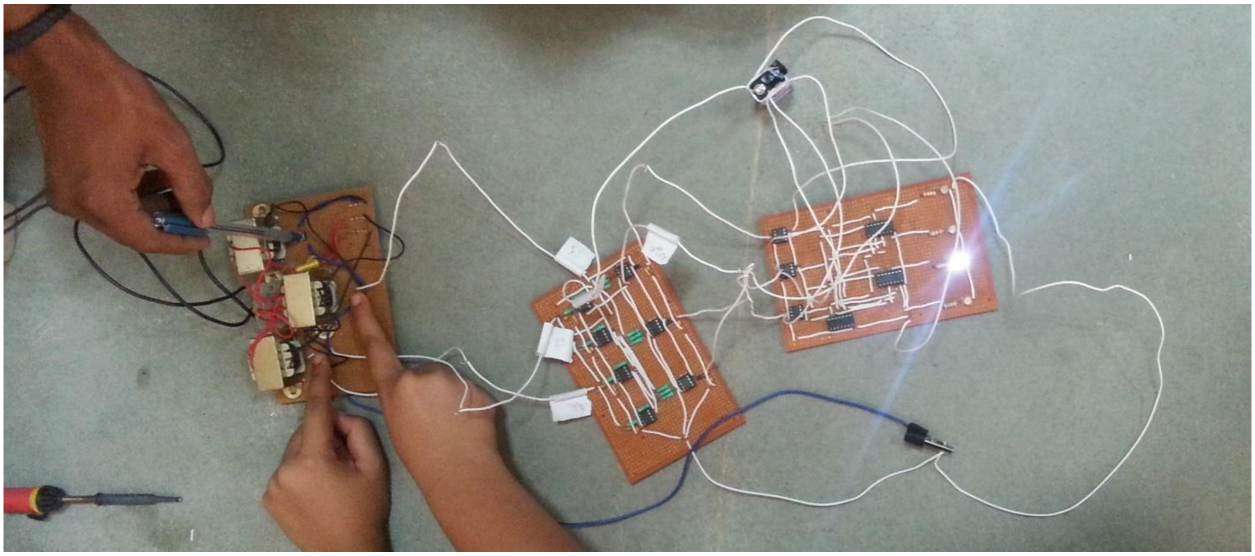
- Line-to-Line (**LL**) Fault



[Figure 4.9: LL Fault Indication by glowing 2nd LED]

It occurs due to closing of the switch interconnected between two transformer secondaries.

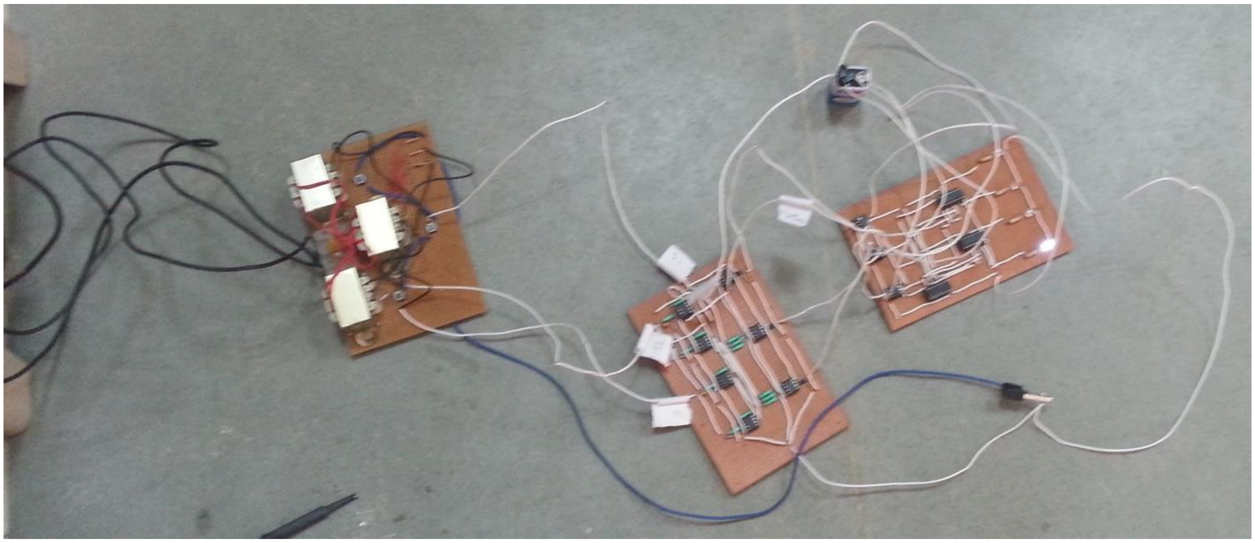
- **3-Phase** Fault



[Figure 4.10: 3-Phase Fault Indication by glowing 3rd LED]

It occurs due to closing of all the switches connected in transformer secondaries shorting all the line to the ground.

- **No** Fault



[Figure 4.11: No Fault Indication by glowing 4th LED]

The LED glows when the supply is given and no fault is made to happen.

CHAPTER – 5

CONCLUSION AND SCOPE FOR FURTHER WORK

5.1 CONCLUSION:

An emulated approach to detect any fault in 3-phase circuit has been shown in this project. The complete advancement of project on fault indication is based on “Symmetrical Component Theory”. Though the simulation work done by PSPICE has not been used for any Hardware interfacing but instead worked as a platform for verification of ‘symmetrical components’ which in sort is the heart of this project.

The faulty 3-phase supply was provided by set of 3 transformers. The faulty voltage has been taken into consideration. Basic requirement for calculation of symmetrical component requires phase shifting of faulty voltages. The OPAMPs (Operational Amplifiers) as all pass filters is used to shift the voltages by 120^0 or 240^0. Again the OPAMP (LM741) as summer gave the symmetrical voltage components. The waveform obtained after OPAMP is passed through Diode (IN4007) for rectification purpose. We are focused only on the magnitude of symmetrical components, the output of summer circuit passed through a RC filter circuit. The comparator circuit used after filter circuit gave either high or low output, which facilitated to use the Boolean logic (dictated in Formulation Section) to indicate different kinds of fault. All of the above circuit is then done on PCB and the circuit operation & function are illustrated accordingly.

5.2 SCOPE FOR FURTHER WORK:

This draft covers only three faults occurring in the power system. Other faults such as Double Line to Ground (LLG) fault, 3-phase (LLL) faults also can be accounted for by some modification and extension to the circuit. In addition to the variation of voltage/current magnitude, there happens other variations also in frequency, harmonics and temperature. So further study of this thesis also can be led in that direction towards a better reliable and efficient fault detection method in power system. Another direction along which this project can be led is towards the extent of hazardousness impacted on the line equipments and analysis of their protection from that. So severity analysis also can serve as an extension to this project.

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