University of Global Village (UGV)

Department of Electrical and Electronic Engineering

Switch Gear & Protection (High Level)

Course Title: Switch Gear & Protection (High Level) Lab

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Course Rationale

The Switchgear & Protection (High Level) Lab course aims to equip students with advanced knowledge and practical skills in the operation, design, and analysis of protective devices and systems. This includes understanding circuit breakers, relays, starters, and their use in safeguarding electrical systems under various conditions, such as faults and transient phenomena. By combining theoretical principles with hands-on experiments and MATLAB simulations, students gain a comprehensive understanding of electrical protection, enabling them to design reliable, efficient, and safe power systems.

Course Objectives

1. **To deepen understanding of the working principles and applications of protective devices such as circuit breakers, relays, and motor starters.**
2. **To introduce advanced concepts like arc extinguishing, restriking voltage, and fault analysis in power systems.**
3. **To enable students to simulate and analyze protection systems using tools like MATLAB.**
4. **To provide hands-on experience in designing and implementing protection circuits for motors and power systems.**
5. **To analyze and evaluate power system performance under normal and fault conditions.**
6. **To foster critical thinking in troubleshooting and improving protection system reliability.**

Course Learning Outcomes (CLOs)

CLO Number	Learning Outcome
CLO1	Understand the principles and construction of protection devices like starters, circuit breakers, and relays.
CLO2	Design and configure control and power circuits for motor starters and protection.
CLO3	Use simulation tools like MATLAB to model and analyze protection systems and transient phenomena.
CLO4	Evaluate the effects of transient recovery voltage and restriking voltage on circuit breaker performance.
CLO5	Develop and test fault protection mechanisms for electrical systems and evaluate overcurrent relay behavior.
CLO6	Analyze transmission line parameters and power systems under normal and fault conditions.

Table 1: Lab activities overview for Switchgear & Protection (High Level) Lab course

Sl.	Experiment Title	Topics Covered	Theory Time (hours)	Practical Time (hours)	Learning Outcomes	CLO
1	Study the resistance starter of a motor	Working principle of resistance starters, current limitation, and motor protection	1.5	2	Understand resistance starters and their role in controlling starting current in motors.	CLO1, CLO2
2	Connect FOR-STOP-REV control and power circuit for a small 3-phase induction motor	Forward-reverse motor starter wiring, control circuit design, and reversing operation of 3-phase motors	1.5	2	Design forward-reverse control circuits and understand motor rotation reversal using DOL starters.	CLO2, CLO3
3	Study the arc extinguish phenomenon of a circuit breaker using MATLAB	Circuit breaker operation, arc formation, and methods of arc extinguishing	2	2.5	Simulate and analyze arc extinguishing in circuit breakers using MATLAB.	CLO3, CLO5
4	Study restriking & recovery voltage using MATLAB	Transient recovery voltage, restriking voltage, and their impact on breaker performance	2	2.5	Simulate and evaluate restriking and recovery voltage effects on circuit breakers using MATLAB.	CLO4, CLO5

5	**Modeling of Overcurrent Relay using MATLAB**	**Overcurrent relay modeling, settings, and fault current analysis**	**2**	**2.5**	**Develop and analyze overcurrent relay models in MATLAB to study fault protection mechanisms.**	**CLO3, CLO5**
6	**Determination of transmission line parameters using MATLAB**	**Transmission line modeling, ABCD parameters, and per-unit analysis**	**2.5**	**2.5**	**Calculate transmission line parameters, simulate power flows, and evaluate system performance.**	**CLO5, CLO6**
7	**Analysis of power systems under fault conditions**	**Types of faults (balanced/unbalanced), fault current analysis, and symmetrical components**	**2.5**	**2.5**	**Analyze power systems under fault conditions and simulate fault behavior using symmetrical components.**	**CLO5, CLO6**

Table 2: Week-wise details with assessment and resources for Switchgear and Protection Lab.

Week	Experiment Title	Topics Covered	Theory Time (hours)	Practical Time (hours)	Learning Outcomes	CLO
1	Study the resistance starter of a motor	Working principle of resistance starters, current limitation, and motor protection	1.5	2	Understand resistance starters and their role in controlling starting current in motors.	CLO1, CLO2
2-3	Connect FOR-STOP-REV control and power circuit for a small 3-phase induction motor	Forward-reverse motor starter wiring, control circuit design, and reversing operation of 3-phase motors	1.5	2	Design forward-reverse control circuits and understand motor rotation reversal using DOL starters.	CLO2, CLO3
4-5	Study the arc extinguish phenomenon of a circuit breaker using MATLAB	Circuit breaker operation, arc formation, and methods of arc extinguishing	2	2.5	Simulate and analyze arc extinguishing in circuit breakers using MATLAB.	CLO3, CLO5
6-7	Study restriking & recovery voltage using MATLAB	Transient recovery voltage, restriking voltage, and their impact on breaker performance	2	2.5	Simulate and evaluate restriking and recovery voltage effects	CLO4, CLO5

					on circuit breakers using MATLAB.	
8-9	**Modeling of Overcurrent Relay using MATLAB**	**Overcurrent relay modeling, settings, and fault current analysis**	**2**	**2.5**	**Develop and analyze overcurrent relay models in MATLAB to study fault protection mechanisms.**	**CLO3, CLO5**
10-11	**Determination of transmission line parameters using MATLAB**	**Transmission line modeling, ABCD parameters, and per-unit analysis**	**2.5**	**2.5**	**Calculate transmission line parameters, simulate power flows, and evaluate system performance.**	**CLO5, CLO6**
12-14	**Analysis of power systems under fault conditions**	**Types of faults (balanced/unbalanced), fault current analysis, and symmetrical components**	**2.5**	**2.5**	**Analyze power systems under fault conditions and simulate fault behavior using symmetrical components.**	**CLO5, CLO6**

Experiment no. 01

Name of the Experiment: To study the resistance starter of a motor.\

Objective

To understand the working principle, construction, and significance of a resistance starter in controlling the starting current of a motor.

Theory

A resistance starter is used to limit the high starting current of a motor, which can damage the motor windings and electrical supply system. It introduces resistances in series with the motor windings during startup and gradually reduces them as the motor reaches its rated speed.

Key Components:

1. **Starting Resistors**: Resistances added in series with the motor to limit current.
2. **Contactors**: Electromechanical devices that connect and disconnect resistors during operation.
3. **Control Circuit**: Manages the sequence of operations for the resistance starter.

Working Principle:

When a motor starts, it draws a high inrush current due to the absence of back EMF. The resistance starter:

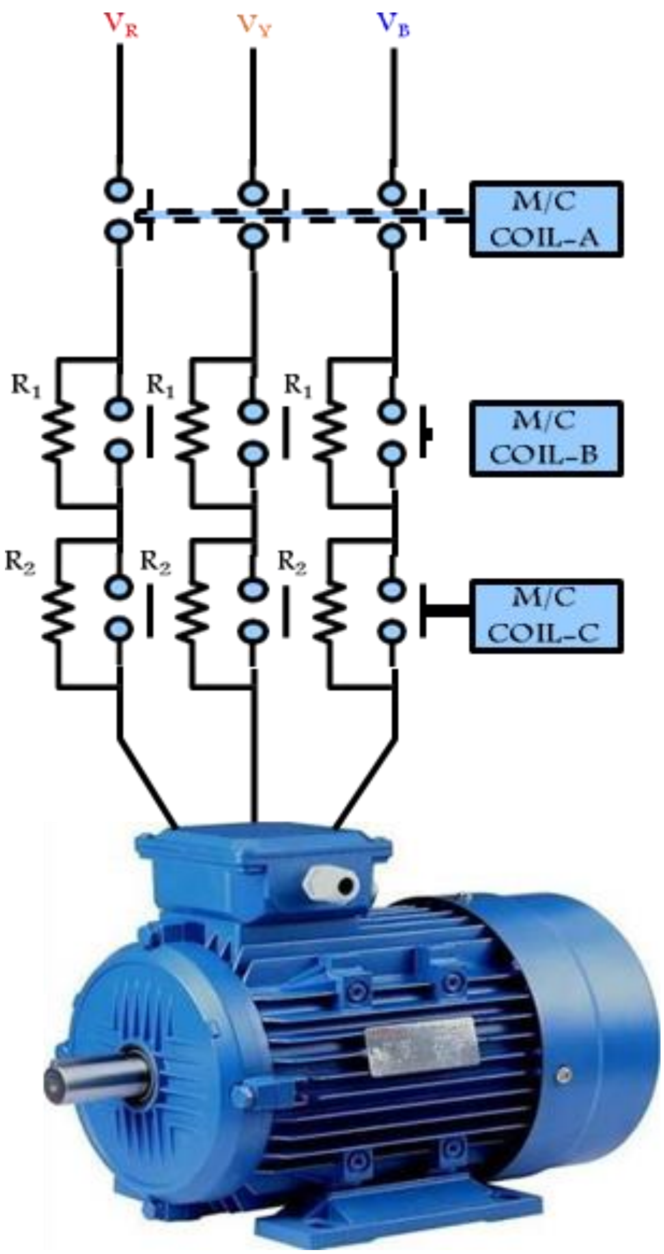
- Introduces resistance into the motor circuit to limit the initial current.
- Reduces resistance step-by-step (or continuously) as the motor accelerates.
- Removes all resistances when the motor attains its normal operating speed.

This ensures a smooth and safe motor startup.

Apparatus Required

- Three-phase induction motor (or the specific motor under study)
- Resistance starter
- Voltmeter
- Ammeter
- Tachometer
- Connecting wires
- Switchgear and protective devices

Circuit Diagram



Procedure

1. **Initial Setup:**
    - ✓ Ensure the motor and resistance starter are properly connected as per the circuit diagram.
    - ✓ Verify that all connections are tight and secure.
    - ✓ Ensure the voltmeter, ammeter, and tachometer are appropriately connected.

2. **Starting the Motor:**
    - ✓ Close the main power supply.
    - ✓ Gradually increase the motor speed by reducing the resistance using the starter.
    - ✓ Observe the ammeter and voltmeter readings during the process.
3. **Observations:**
    - ✓ Record the starting current and voltage.
    - ✓ Measure the motor speed using the tachometer at different resistance levels.
4. **Shut Down:**
    - ✓ Turn off the motor by disconnecting the power supply.
    - ✓ Ensure the motor comes to a complete stop before disconnecting any wires.

Data Table

Observations and Table

Step	**Resistance Level**	**Voltage (V)**	**Current (A)**	**Speed (RPM)**
1	High			
2	Medium			
3	Low			
4	None			

Calculations

1. **Starting Current Limitation:**

    Calculate the percentage reduction in starting current using the resistance starter.

2. **Efficiency Analysis:**

    Compare the motor efficiency during startup with and without the resistance starter.

Precautions

1. Ensure all connections are correct before switching on the power supply.
2. Do not touch any live wires or terminals.
3. Gradually adjust the resistance to prevent sudden current changes.
4. Use appropriate safety gear, such as gloves and goggles.

Result

Conclusion

Experiment No.: 02

Experiment Name: Connect FOR-STOP-REV control and power circuit for a small rating 3ph induction motor.

Apparatus: MCB, Over Load Relay, Contactors , Push Buttons-NO,NC.

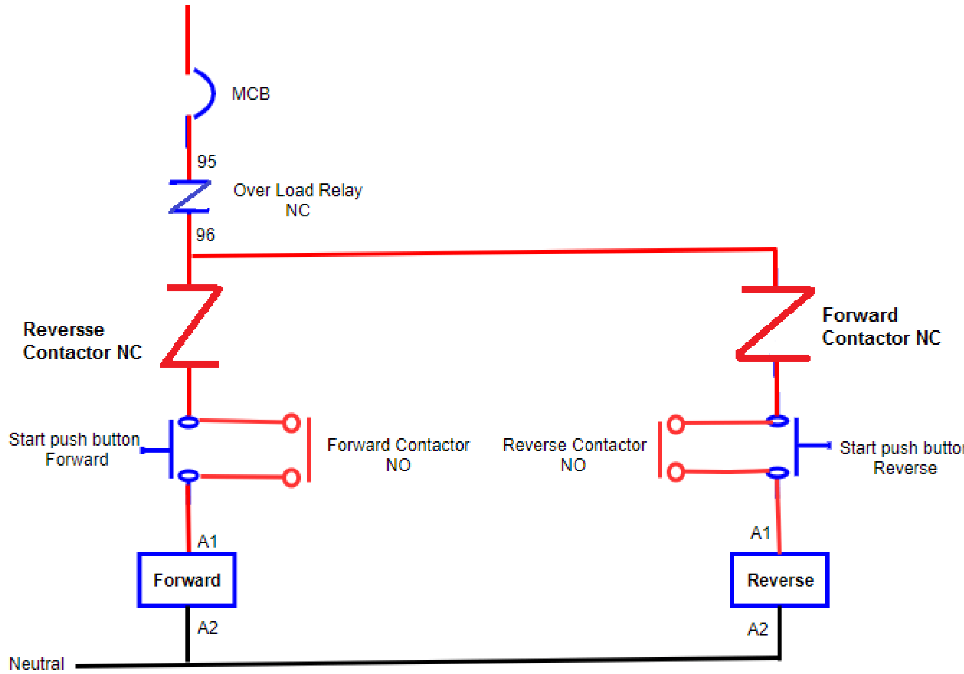
Procedure:

1. Make the connections as shown in the diagram first of all we need to connect the power supply in the MCB (Miniature Circuit Breaker).
2. Output of the MCB have to connect with overload relay NC point for reset.
3. After that wire has to connect with NC points of the contactor of opposite directions as shown in the diagram e.g for forward contactor connecct to the NC point of reverse contactor and for reverse contactor connect to the NC point of the forward contactor.
4. Then the output of these NC points connect to the Start push buttons.
5. Then connect two wires from input and output of the push buttons to the NO point of the contactor for holding of the contactor.
6. After holding connect the wire from the output of the start push button to the A1 of the both contactor. Connect the neutral wire to the A2 of the contactor.

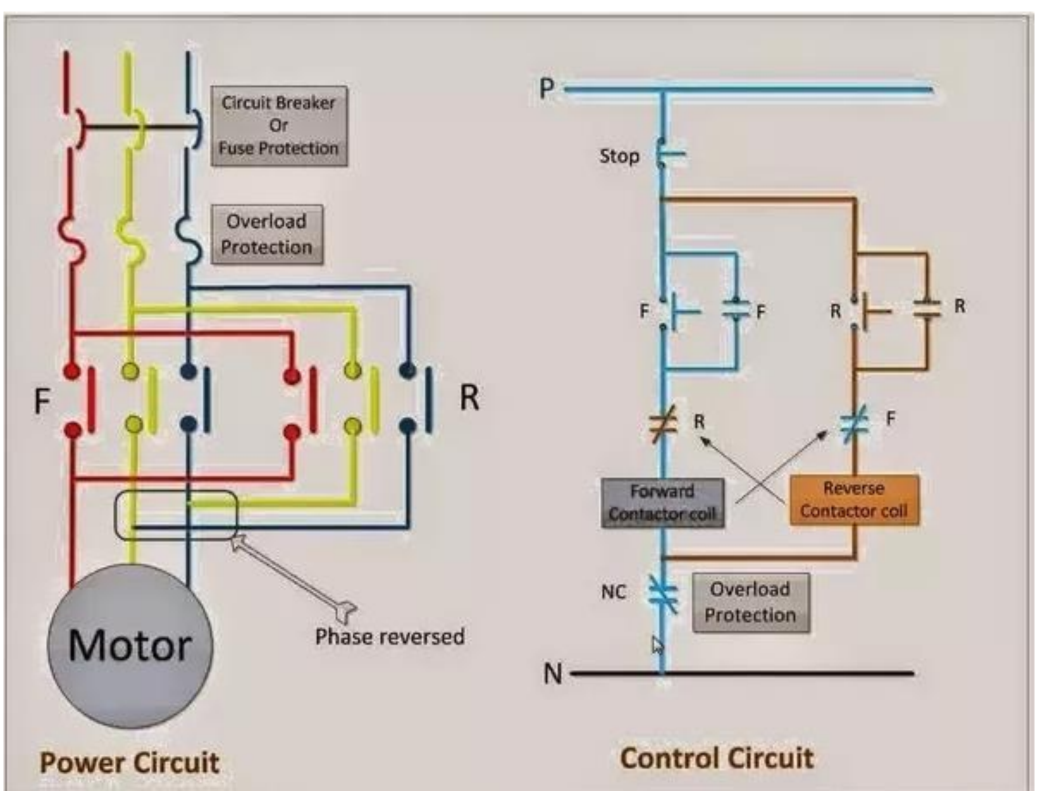
Concept Structure :

The forward reverse starter is used to run the motor in both sides forward and reverse. The figure given below shows the control and power diagram of forward and reverse starter diagram. These forward and reverse starters are DOL type and not used above the 05 HP motors. To run the motor of above 05 HP rating circuit has to made in star delta. These type of starters are used in various applications e.g- mixing of materials, dying machines etc.

Wiring Diagram of FOR-STOP-REV :

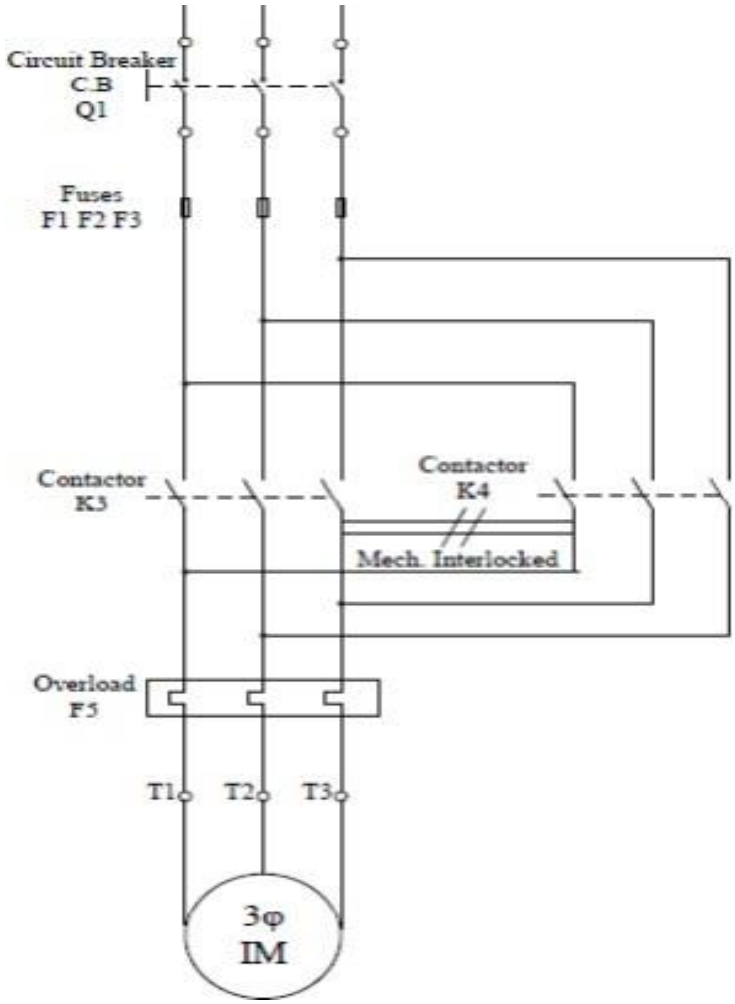


Power Circuit and Control Circuit of FOR-STOP-REV starter :



FORWARD / REVERSE OPERATION :

When a squirrel-cage rotor is placed inside a rotating magnetic field, it is pulled around in the same direction as the rotating field. Interchanging the power connections to two of the stator windings (interchanging A with B for example) interchanges two of the three currents and reverses the phase sequence. This causes the rotating field to reverse direction. As a result, the direction of rotation of the motor is also reversed. The power diagram for reversing the direction of rotation of the motor and the associated control circuits are shown in Figure below.



Reversing direction of rotation of a three phase induction motor, Power diagram

Observations:

Conclusion:

Experiment no. 03

Name of the Experiment: To study the arc extinguish phenomenon of a Circuit Breaker (CB) using MATLAB.

Objectives:

1. To Study working of circuit breaker
2. To study reasons of arc in circuit breaker
3. To study arc extinguish phenomenon in circuit breaker
4. To study different types of arc extinguish methods in circuit breaker

Theory:

There are following two methods of arc extinguishing interruption.

1) High resistance interruption:

In this method of arc interruption, resistance of the arc is increased so as to reduce the current to small value insufficient to maintain the arc. The arc resistance can be increased by cooling, lengthening, constraining, and splitting the arc. In this method if the voltage is very high and more than the withstanding capacity of the gap between the contact the arc will strike again. Therefore, this method is not suitable for a large current interruption. This method can be used for lower power AC and DC circuit breaker.

2) Current zero interruption:

This method is applicable in case of AC circuit breaker only. In case of AC circuit breaker, the current waveform passes through zero point, 100 times per second of the supply frequency of 50 Hz. This feature of AC is used for arc interruption. The current is interrupted at zero current instant only, otherwise a large transient voltage will occur across the contact gap.

There are two theories to explain zero current interruption as follows: -

i) Recovery rate theory / Slepian's theory: -

The arc is a column of ionized gas. To extinguish the arc, the electrons and the ions are to be removed from the gap immediately after a current reach to natural zero. The arc is interrupted if ions are removed at the rate faster than the rate of ionization. In this method the rate at which the gap recovers its dielectric strength is compared with the rate at which the gap recovers its dielectric strength is compared with the rate at which the restriking voltage across the gap rises. The arc is extinguished if dielectric strength is less than the restriking voltage.

ii) Energy Balance Theory / Cassie's Theory:-

At the current zero moment, power is zero because restriking voltage is zero. When the arc is finally extinguished, the power again becomes zero, the gap is fully deionized, and its resistance is infinitely high. Due to the rise of restriking voltage and associated current,

energy is generated in the space between the contact. The energy appears in the form of heat. The circuit breaker is designed to remove this generated heat as early as possible by cooling the gap, giving a blast of air and flow of oil at high velocity and pressure. If the rate of removal of heat is faster than the rate of heat

generation, the arc is extinguished. If the rate of heat generation is more than the rate of heat dissipation, the space breakdown again resulting in arc for another half cycle., the arc is extinguished.

Equipment

Sr. No	Name of Equipment	Specification	Quantity
1	Circuit Breaker		1
2	MATLAB Software		

Procedure

(1) Enter the value of voltage, reactance, capacitance and resistanceconnected across the contact of circuit breaker.

(2) Calculate inductance (l), natural frequency(f), damped frequency(fn), critical resistance(rc) by using formula.

(3) Calculate value of critical resistance if damped frequency is equal to 1/4th of

natural frequency.

Programming/simulation model: (matlab program)

Matlab Program:

```
% Problems on arc extinguished phase of circuit
breaker%
 V=input("Enter the value of voltage in kv=");
X=input("Enter the value of reactance=");
c=input("Enter the value of capacitance in farad=");
r=input("Enter the value of resistance connected across
circuit breaker=");
l=X/(2*pi*50)
f=1/(2*pi*((1*c)^0.5))
% natural frequency
 fn=(1/2*pi)*sqrt((1/(1*c))-(1/(4*r*r*c*c)))
% damped frequency
rc=0.5*sqrt(l/c)
% critical resistance
f2=f/4
% one fourth of the natural frequency
R=sqrt(1/((4*c/1)- 16*f2*f2*c*c*pi*pi))
```

Student's task:

Find out the Output for the followings:

Output:

Enter the value of voltage in kv=100 Enter
the value of reactance=10

Enter the value of capacitance in farad=10

Enter the value of resistance connected across circuit breaker=10

RESULT & ANALYSIS:

Arcs extinguish phenomenon is studied. Matlab programming to calculate critical resistance is developed. The results obtained for critical resistance is **R =** is obtained.

Experiment. No. 04

Name of the Experiment: To study Restriking & Recovery Voltage using MATLAB

Objectives:

1. To study Transient Recovery Voltage.

2. To simulate Restriking and Recovery voltage in MATLAB.

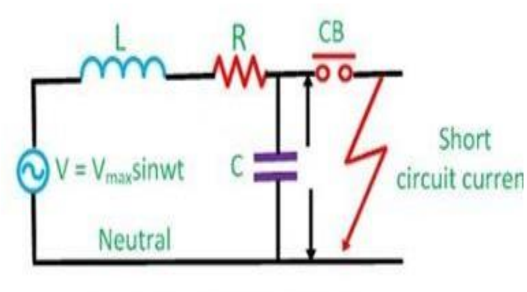
3. To study behaviour of Restriking and Recovery voltage.

Theory:

When the current across the contact of the circuit breaker is zero, a high-frequency transient voltage develops in the whole breaker contact and is produced by the sudden distribution of energy between the electric and magnetic field. This transient voltage is called restriking voltage. The voltage appears across the breaker contacts at the moment of final current has a serious influence on the arc extinction process. Under the influence of this voltage, the arc tries to restrike and hence it is named as the restriking voltage.

After the zero current, the arc gets extinguished, if the rate of rising of restriking voltage between the contact is less than the rate at which the dielectric strength of the medium between the contact gains. Immediately after the final current interruption, the voltage that appears across the breaker contacts (transient voltage) superimposed on the power frequency system voltage (recovery voltage).

Circuit Diagram:



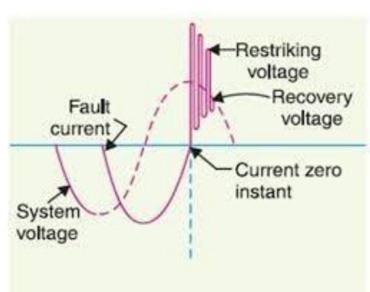


Fig .Fault & its Equivalent Circuit with waveform

Apparatus:

MATLAB Software

Procedure:

1. From MATLAB Open New M file

2. Go to Simulink Library

3. Drag Ac source from SimPowerSystem to Mfile. Select Parameters of AC Source.

4. Drag RLC Series Branch from SimPowerSystem to Mfile. Select Parameters RLC branch.

5. Drag Breaker from SimPowerSystem to Mfile. Select Parameters of Breaker.

6. Drag Voltmeter from Measurement to Mfile.

7. Drag Scope from Sink to m file

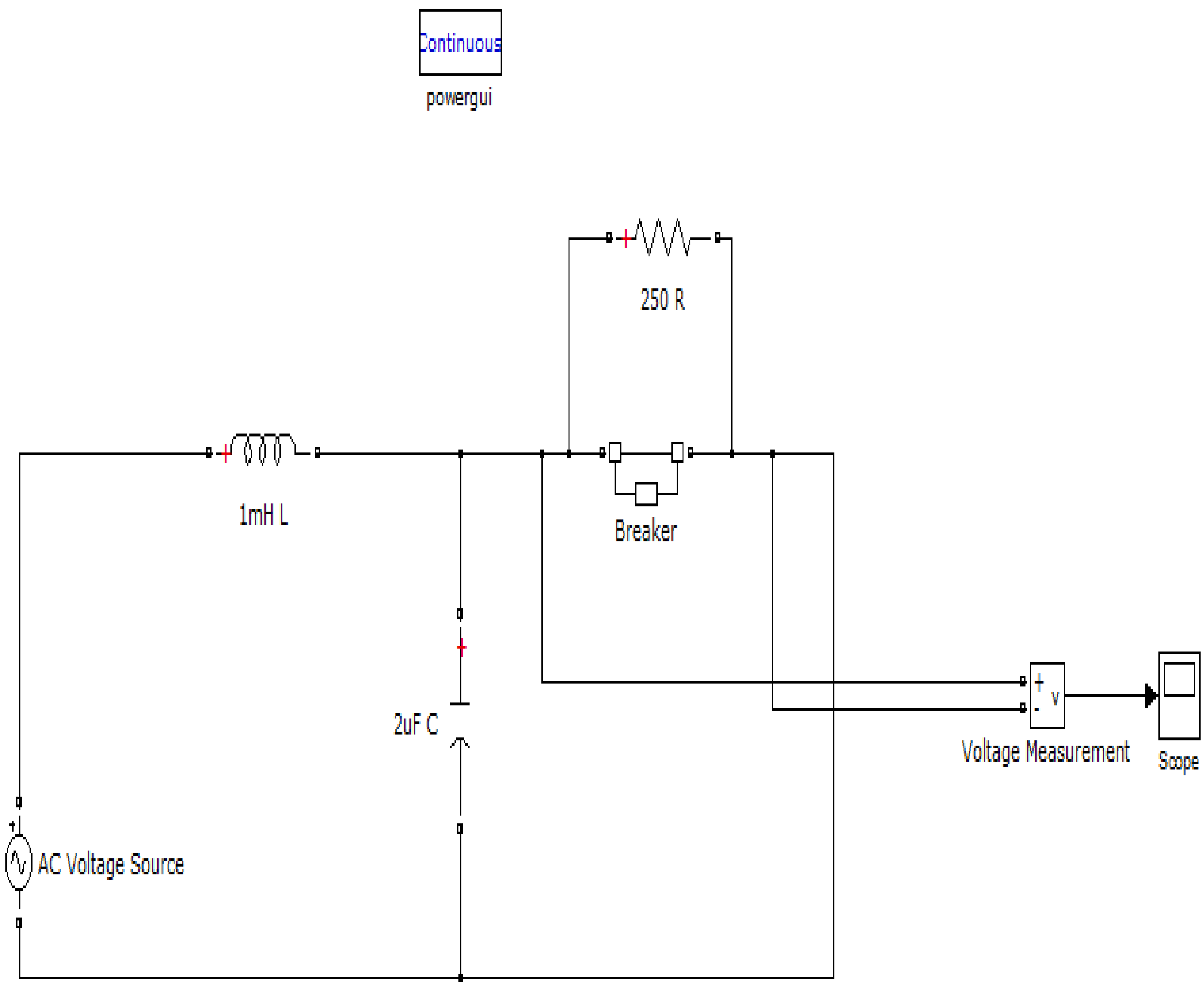
8. Connect all the elements.

9. Select PowerGui Block and drag to MFile.

10. Set Simulation Time & Run theSimulation.

11. Double Click on Scope to view Waveform.

Simulation Diagram:



Simulation Result:

Experiment No. 05

Experiment Name: Modeling of Over Current Relay Using MATLAB

Objectives:

- To Implement “Over Current Relay” by using Matlab Simulink Libraries.
- Set the “Current Setting” of Over Current Relay.
- Learn how to create an electrical subsystem.

Theory:

Introduction

Utilities are responsible for the generation, transmission and distribution of electricity to customers. Part of this responsibility is ensuring a safe but yet reliable power supply to customers. For the purpose of safety and protecting the transmission and distribution network from faults, utilities worldwide have sophisticated protective equipment. Collectively, these are known as secondary equipment and include the current transformers (CT), potential transformer (PT) and protective relays.

Protective Relays

A protective relay is one which monitors the current, voltage, frequency, or any other type of electric power measurement either from a generating source or to a load for the purpose of triggering a circuit breaker to open in the event of an abnormal condition. These relays are referred to in the electrical power System as protective relays.

The function of protective relaying is to cause the prompt removal from service of a power system when it suffer a short circuit, or when it starts to operate in any abnormal manner that might cause damage or otherwise interference with the effect operation of the rest of system.

Circuit Breakers

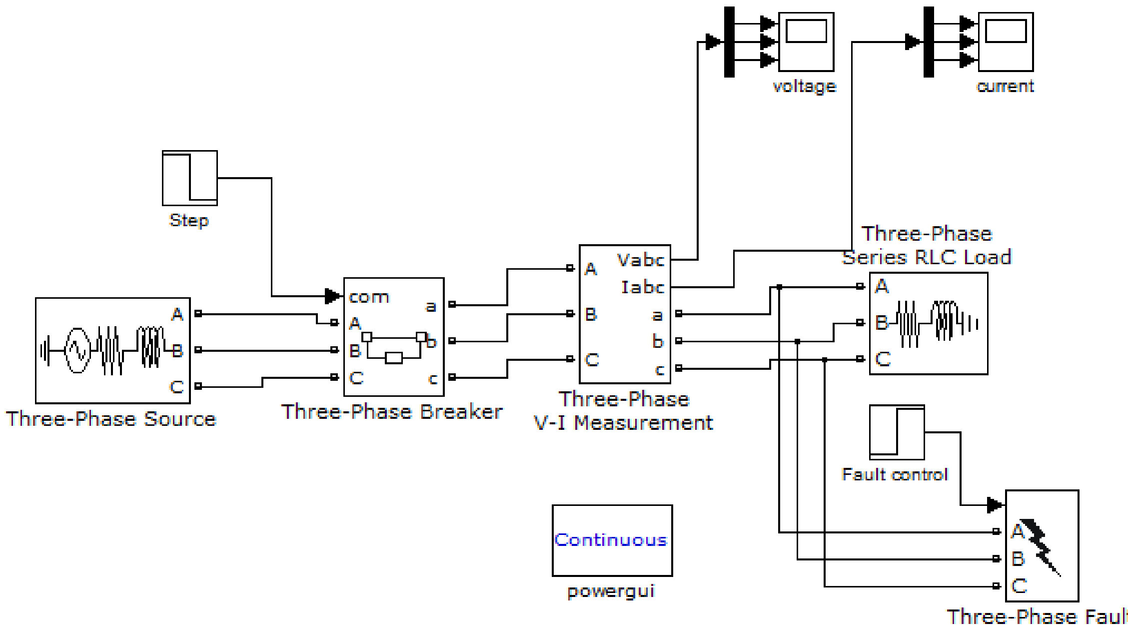
Circuit breakers are generally located so that each generator, transformer, bus, transmission line, etc. can be completely disconnected from rest of the system. These circuit breakers must have sufficient capacity so that they can carry momentarily the maximum short-circuit current that can flow through them, and then interrupt this current.

Over Current Relay

Over current relay is one which monitors the current only and gives trip signal to the circuit breaker in faulty (short circuit) condition. In case of short circuit faults, current in the system increases from its normal value. This short circuit current can be many times greater than the full load current. The magnitude of short circuit current depends upon the fault impedance and other parameters of system.

Procedure

Step 1: Draw a simple power system having a **3-φ** source, three single phase circuit breakers, **3-φ** VI measurement unit, **3-φ** RLC series load and block of **3-φ** fault to implement different types of fault in system. Connect the blocks as shown below.



Set the parameters of each block as mentioned below. Accept default values for all other parameters.

Total Simulation Time: **0.25 s**
Solver: **Ode23tb (stiff/TR-BDF2)**

Note: To select the solver go to menu bar > Simulation > Configuration Parameters **OR** press **(Ctrl + E)** and select the solver. Also set following solver options.

Relative tolerance: **1e-3 (default)**
Solver reset Method: **Robust**
System Frequency: **50 Hz**

Three phase source:
Voltage (Phase to Phase): 11e3 V
Internal connection: Y grounded
Specify impedance using short-circuit level: Select this option
(*This option is selected to specify internal impedance using the inductive short-circuit level and X/R ratio.*)

3 phase short circuit level: 500e6 VA

The three-phase inductive short-circuit power, in volts-amperes (VA), at specified base voltage, is used to compute the internal inductive reactance **X**. This parameter is available only if Specify impedance using short circuit level is selected.

The internal inductance L (in H) can also be computed from the inductive three-phase short-circuit power Psc (in VA), base voltage Vbase (in Vrms phase-to-phase), and source frequency f (in Hz) as follows:

$$\boldsymbol{L = \frac{(V_{base})^2}{P_{Sc}} \cdot \frac{1}{2\pi f}}$$

Base voltage:	11e3 V
X/R ratio:	(keep default value)

This parameter is available only if **Specify impedance using short circuit level** is selected. The internal resistance **R** (in Ω) is computed from the source reactance **X** (in Ω) at specified frequency, and X/R ratio as follows:

$$\boldsymbol{R = \frac{X}{(X\,/\,R)} = \frac{2\pi f}{(X\,/\,R)}}$$

Three-Phase Breaker:

Initial status of breakers:	closed
Enable switching of all Phases	
External control of switching times:	Select this option
Measurements:	None
Breakers resistance $\mathbf{R_{on}}$**:**	0.001
Snubbers resistance $\mathbf{R_p}$**:**	1e6
Snubbers capacitance **Cp**:	inf

Three-Phase V-I Measurement:

Voltage measurement:	phase-to-phase
Current measurement:	Yes

(Uncheck **labels** and **per-unit** measurements)

Three-Phase Series RLC Load:

Configuration:	Y grounded
Nominal voltage:	11e3 V
Active Power (MW):	**200e6** W
Inductive reactive power:	100 VAR
Capacitive reactive Power:	0 VAR

Three Phase Fault:
Ground fault: Select this option
External control of fault timing: Select this option
Initial status of fault: [0 0 0]

Step Sources:

There are two step sources used in this model to control circuit breaker and fault blocks. There step time and initial value are set in such a way that "breaker" remains close up to 0.1s and "fault" does not occur during simulation time. As simulation time is 0.25s and step-time of "Fault Control (Step source)" is 1s. It means the output of this step source will remain "0" during simulation time.

Step:
Step time: 0.1
Initial value 1
Final value 0

Fault Control:
Step time: 1
Initial value 0
Final value 1

Run the simulation and observe the current and voltage wave form on Scope. Find the peak value of current and voltage in each phase when the circuit breakers are close and note in the space given below.

Observations:

$\mathbf{I_a}$ = 13116.23 angle -20.70^0 $\mathbf{I_b}$ = 13116.23 angle -140.70^0 $\mathbf{I_c}$ = 13116.23 angle 99.30^0

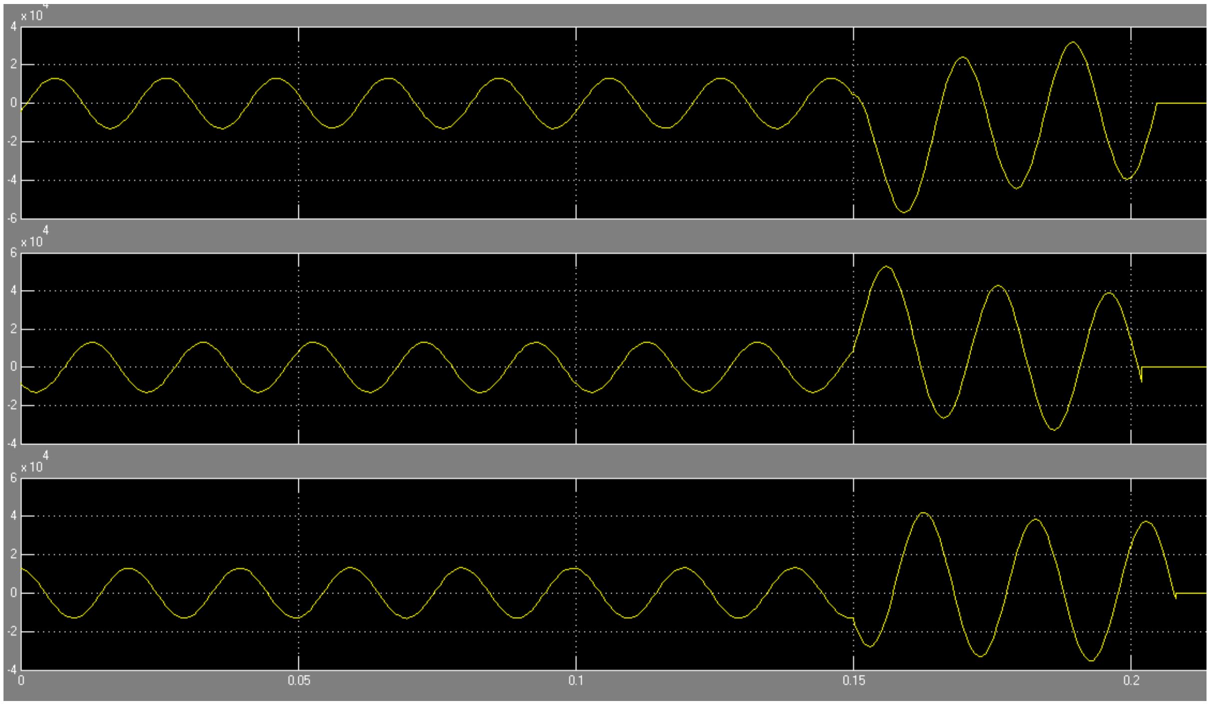
$\mathbf{V_a}$ = 13744.37 angle 9.3^0 $\mathbf{V_b}$ = 13744.37 angle -110.7^0 $\mathbf{V_c}$ = 129.30^0

Connect the RMS block in each phase of output current and find rms value of current in each phase.

Different RMS bocks are available in Matlab Simulink libraries. Select appropriate RMS block that has constant output.

$\mathbf{I_a}$ **=** 9274.58 angle -20.70^0 $\mathbf{I_b}$ **=** 9274.58 angle -140.7^0 $\mathbf{I_c}$ **=** 9274.58 angle 99.3^0

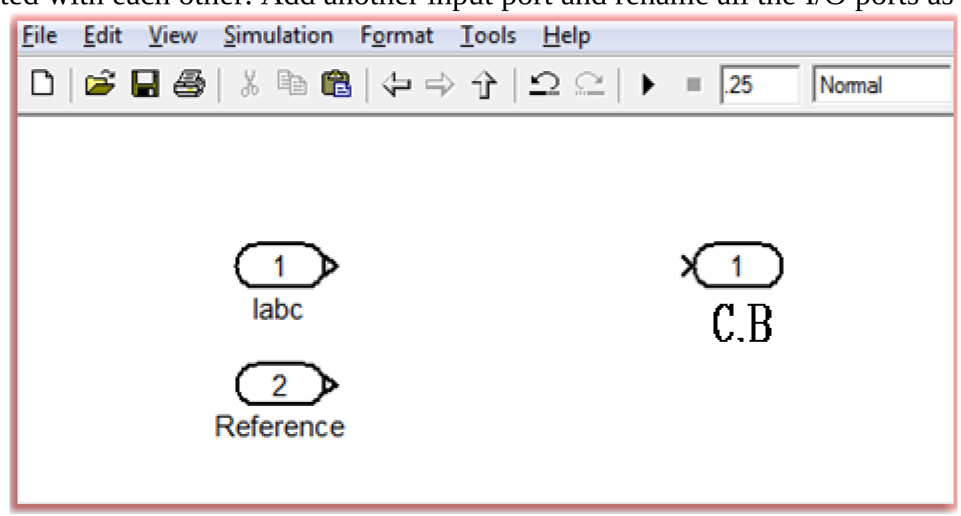
Graph



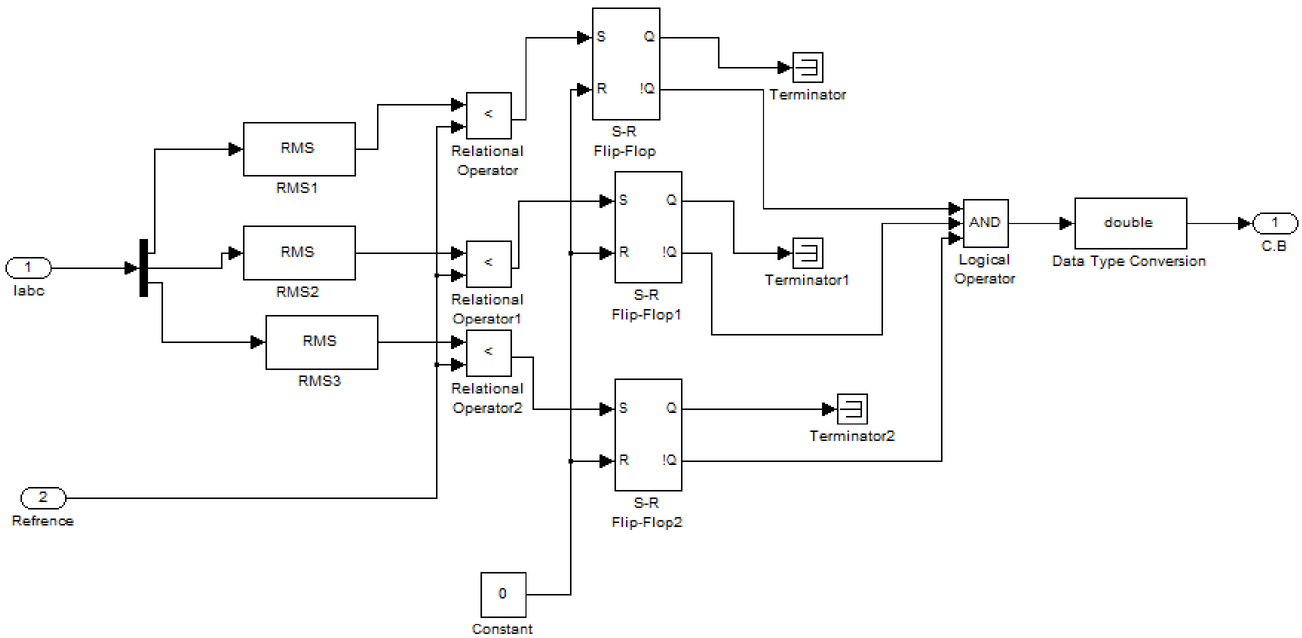
Step 2: The rms value observed in Step 1 is rated load current of the system. System can be overloaded up to 40%. So over current relay must not consider this over loaded condition as faulty condition. But as soon as current exceed this over load current value over current relay must trip the circuit breakers.

To model this condition in Simulink compare the rms value of currents with constant. The value of constant will be 1.4 times of rms value of rated load current.

Insert a subsystem in the model. Rename this subsystem as “Over Current Relay”. Open this Over Current Relay (Subsystem). By default it has one input and one output port that is directly connected with each other. Add another input port and rename all the I/O ports as shown.



Add different block in this subsystem and connect with each other as shown in figure.



In above figure of "over current relay" RMS value of current is compared with a reference value. If the current is greater than the reference value then it is faulty condition and the output of "Relational operator" will be logic '1'. Logical inverse of this output can be fed directly to the control input of the circuit breaker. But there is a problem with this implementation.

In case of fault RMS value of current will be greater than the "reference" value and the output of relational operator will open the circuit breaker. As soon as circuit breaker will open the current in the system will decrease to zero and RMS value of current will become less than the reference value. Again this is a condition of normal operation so the output of relational operator will change and it will close the circuit breaker. As fault exists in the system again relay will give a trip signal to the breaker. This opening and closing of circuit breaker will go on, that is not required.

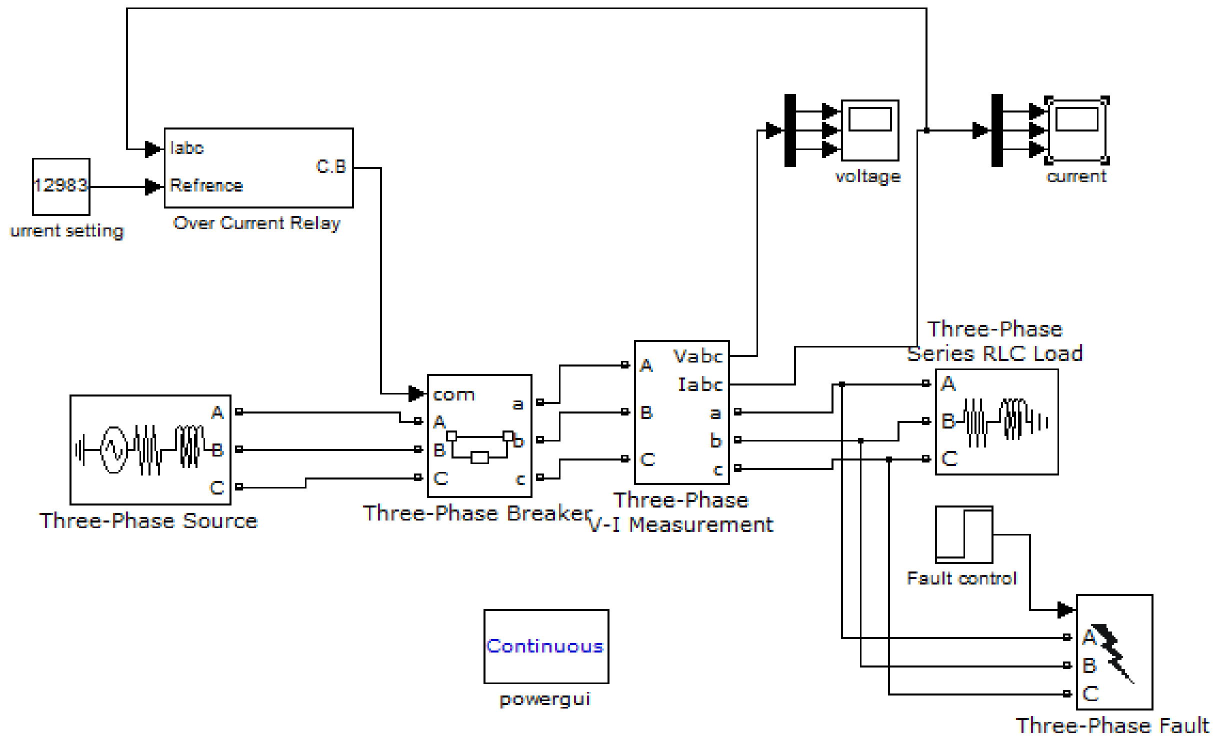
To avoid this *S-R Flip-Flop* is used between breaker and relational operator. These flip-flops will retain the state. Initial condition (state of Q) is set to '0', so '!Q' will be '1'. See truth table and further detail about the operation of flip-flop in Matlab "Help".

Mismatch data-type:

The default data-type of output of relational operators, flip-flops and logic operators is "boolean". To connect the blocks with each other the output data-type of first block must be consistent with the input data-type of second block.

Input data-type of breaker is 'double' and in this system breaker is connected at the output of logic AND gate. So to avoid this data-type mismatch the output data-type of logic AND gate must be 'double'. This can be done either by connecting "data-type conversion" block at the output of Logic AND gate or by setting the output data-type of logic AND gate ('double'). For further detail see the help of "Logic operator".

Now connect the relay in the system as shown in the following figure. Set the “Step-Time” 0.1s of fault control (step source). By setting this timing fault will occur at 0.1s.



Check the output of “Over Current Relay” in following fault conditions.

1) **Single Line to Ground fault**
2) **Double Line to Ground fault**
3) **3-φ Grounded fault**

Experiment No. 06

Experiment Name: Determination of transmission line parameters using MATLAB

Theory:

Transmission line parameters are the most important aspects that can ever be considered when dealing with transmission lines. Transmission lines are often categorized in three major categories which are, the short lines, the medium lines and the long lines. Upon obtaining the transmission line parameters, it is often much easier to predict the performance of a transmission line through efficiency measurement and per unit analysis

Introduction

The steady state operation of a transmission line is a very important state when it comes to transmission line modelling. Results obtained from the steady state analysis are often ideally used in the analysis of transmission line and apply when the line conditions are balanced and also during unbalance. The ABCD parameters of a transmission line have a handful of importance and knowing them enables us to predict and manipulate the performance of a transmission line. During design one often tends to look for the most efficient power system ad yet also considers the costs to erect the power system. This all start with the analysis and acquisition of the power system's ABCD parameters and hence continues with the further manipulation of these parameters to obtain the required system The are basically three types of transmission lines. These are the short transmission line model, the medium transmission, the model and the ling transmission line model. The medium transmission line model is further subdivided into the T lines and the PI lines.

Short transmission lines

These are transmission lines that are usually less than 80KM long.

- In the analysis of these lines, the capacitance and the leakage resistance to the earth are neglected and hence only the wire resistance and the inductive reactance are considered.

- This is a simple series circuit and hence the current flowing through the circuit is simply the same.

This is the easily analysed transmission line and it is not commonly used in power systems due to the fact that transmission lines are usually aimed to go for a long distance as to reduce the transmission costs.

Π Modeled transmission line

- Medium lines usually have a length that varies between 80KM to 250km

In the model for this line's parameters, the total shunt capacitance is usually lumped together and is located half at each end.

T modeled transmission line

- This is another form of representing a medium transmission line. In this line model, half of the line impedance is lumped at the end of each line. This line also is analyzed by assuming a wye connected circuit.

Long transmission line

- These are the types of transmission lines that usually cover very long distances and could represent a minimum distance of 250KM.
- They represent very high voltage transmission lines because long distance transmission with high voltage reduce the line power losses.
- In this transmission lines, the current is kept to it very minimum to avoid effects of overheating and hence reduce maintenance costs as they might take long to repair in times of damages.
- The equivalent circuit is somehow very similar to the alternative PI representation but the elements are now represented using trigonometric ratios such as cosh and sinh.The ABCD parameters are now derived from the equivalent circuit diagrams and are purely functions of impedance and admittance values.

  Program outline

1. The program must allow for its user to enter the values that are provided and will be the baseline for the whole simulation.
2. The program will then be able to evaluate the impedance and admittance of the line.
3. Since the ABCD parameters are represented using the impedances and admittances, they are than evaluated.

$$V_S = AV_R + BI_R$$
$$I_S = CV_R + DI_R$$

4. Since the values of Vs and Is are now obtained, one is now able to evaluate the sending end power, the voltage regulation, the efficiency, the sending end power factor.
5. This part of the program should than be the part where the bases of for the system are chosen in order to give all the circuit quantities in per unit.
6. The per unit quantities are thus evaluated and displayed.
7. The program should then go on and allow the user to enter the power factor that they want their system to be corrected to.
8. It will than calculate the value of the reactive power that needs to be supplied by the capacitor bank and also the per phase capacitance of the capacitor bank.
9. The program for the short line is than modified so that it accommodates a looping structure and also be able to obtain the different values of the capacitance bank when the length of line is being veried.

Codes used for the simulation of the transmission lines

```
%program for short lines

clear;

clc;

%continue with the program

vl = input('enter line load voltage: ');

f = input('enter local frequency: ');

l = input('enter line constant in H/KM: ');

length = input('enter length of line: ');

r = input('enter the resistive constant: ');

power = input('enter the load power: ');

pf = input('enter load power factor: ');

%evaluate the parameters

xl=l*length*pi*2*f;

p=power/3;

res=r*length;

z=complex(res,xl);

A=1;

B=z;

C=0;

D=1;

vlo=vl/sqrt(3);

%evaluate the load current

ilmag=p/(vlo*pf);
```

```
%assuming a lagging power factor

il=complex(ilmag*cos(acos(pf)),-ilmag*sin(acos(pf)));

vload=complex(vlo,0);

%evaluate the value of Vsending end and Isending end

vs=A*vload + B*il;

is=C*vload + D*il;

%calculte sending end power

s=conj(is)*vs;

%calculate voltage regulation

vr=((abs(vs)-abs(vlo))/abs(vlo))*100;

%calculate efficiency

pin=real(s);

pout=p;

n=(pout/pin)*100;

%evaluating the power factor

theta=atan(imag(s)/ real(s));

pfactor=cos(theta);

fprintf ('VS=');

disp(vs);

fprintf('IS=');

disp(is);

fprintf('power factor at sending end=');

disp(pfactor);
```

```
fprintf('sending end complex power=');

disp(s);

fprintf('voltage regulation=');

disp(vr);

fprintf('effiency=');

disp(n);

%evaluate the per unit values of the line parameters

%choosing the base values as follows

vbase=vlo;

sbase=p/pf;

zbase=mpower(vbase,2)/sbase;

ibase=sbase/vbase;

zpu=z/zbase;

vreceivingpu=vload/vbase;

ireceivingpu=il/ibase;

vsendingpu=vs/vbase;

isendingpu=is/ibase;

ssendingpu=s/sbase;

precevingpu=p/sbase;

fprintf('the per unit value of the impedance=');

disp(zpu);

fprintf('the per unit value of the receiving end voltage=');

disp(vreceivingpu);

fprintf('the per unit value of the receiving end current=');
```

```
disp(ireceivingpu);

fprintf('the per unit value of the sending end voltage=');

disp(vsendingpu);

fprintf('the per unit value of the sending end current=');

disp(isendingpu);

fprintf('the per unit value of the sending end apparent power=');

disp(ssendingpu);

fprintf('the per unit value of the receiving end real power=');

disp(precevingpu);

%for power factor correction

thetanew=acos(pfdesired);

qold=imag(s);

qnew=real(s)*tan(thetanew);

%evaluating the value of the capacitor bank

qc=qold-qnew;

pfdesired = input('enter the desired power factor: ');

c=qc/(mpower(abs(vs),2)*2*pi*f);

fprintf('value of the capacitor bank in farads=');

disp(c);

fprintf('the reactive power to be supplied by the capacitane bank
invar=');

disp(qc);
%program for medium pie lines

clear;
```

```
clc;

%start with the system inputs

vl = input('enter load voltage: ');

f = input('enter local frequency: ');

l = input('enter line constant in H/KM: ');

r = input('enter the resistive constant in OHM/KM: ');

power = input('enter the load power in WATTS: ');

pf = input('enter load power factor: ');

m = input('enter your month of birth as a number: ');

d = input('enter your date of birth: ');

%evaluate the capacitive constant%specifically for the vaues assigned to myself

x=d;

ca = x*(mpower(10,-1.05*m));

%evaluate the length

length=7*d;

%evaluate the parameters

xl=l*length*pi*2*f;

p=power/3;

xc=ca*length*2*pi*f;

res=r*length;

vlo=vl/sqrt(3);

z=complex(res,xl);

yc=complex(0,xc);
```

```
squ=mpower(yc,2);

A=(0.5*(z*yc))+1;

B=z;

C=yc+(0.25*(squ*z));

D=1+(0.5*(z*yc));

%evaluate the load current and load voltage

ilmag=p/(vlo*pf);

il=complex(ilmag*cos(acos(pf)),-ilmag*sin(acos(pf)));

vload=complex(vlo,0);

%evaluate the value of Vsending end and Isending end

vs=A*vload + B*il;

is=C*vload + D*il;

%calculte sending end power

s=conj(is)*vs;

%evaluating the power factor

theta=atan(imag(s)/ real(s));

pfactor=cos(theta);

%calculate voltage regulation

vr=((abs(vs)-vlo)/vlo)*100;

%calculate efficiency

pin=3*abs(vs)*abs(is)*pfactor;

pout=3*abs(vload)*abs(il)*pf;

n=(pout/pin)*100;
```

```
fprintf ('voltage at the sending end=');

disp(vs);

fprintf('current at the sending end=');

disp(is);

fprintf('power factor at sending end=');

disp(pfactor);

fprintf('sending end complex power=');

disp(s);

fprintf('voltage regulation=');

disp(vr);

fprintf('effiency=');

disp(n);

%evaluate the per unit values of the line parameters

%choosing the base values as follows

vbase=vlo;

sbase=p/pf;

zbase=mpower(vbase,2)/sbase;

ibase=sbase/vbase;

zpu=z/zbase;

ycpu=yc/zbase;

vreceivingpu=vload/vbase;

ireceivingpu=il/ibase;

vsendingpu=vs/vbase;
```

```
isendingpu=is/ibase;

ssendingpu=s/sbase;

precevingpu=p/sbase;

fprintf('the per unit value of the impedance=');

disp(zpu);

fprintf('the per unit value of the receiving end voltage=');

disp(vreceivingpu);

fprintf('the per unit value of the receiving end current=');

disp(ireceivingpu);

fprintf('the per unit value of the sending end voltage=');

disp(vsendingpu);

fprintf('the per unit value of the sending end current=');

disp(isendingpu);

fprintf('the per unit value of the sending end apparent power=');

disp(ssendingpu);

fprintf('the per unit value of the receiving end real power=');

disp(precevingpu);

fprintf('the per unit value of the shunt admittance=');

disp(ycpu);

%for power factor correction

pfdesired = input('enter the desired power factor: ');

thetanew=acos(pfdesired);

qold=imag(s);
```

```
qnew=real(s)*tan(thetanew);

%evaluating the value of the capacitor bank

qc=qold-qnew;

capa=qc/(mpower(abs(vs),2)*2*pi*f);

fprintf('value of the capacitor bank in farads=');

disp(capa);

fprintf('the reactive power to be supplied by the capacitane bank invar=');

disp(qc);
```

OUTPUT

```
enter load voltage: 138000
enter local frequency: 50
enter line constant in H/KM: 0.0016902
enter the resistive constant in OHM/KM: 0.11287
enter the load power in WATTS: 49000000
enter load power factor: 0.85
enter your month of birth as a number: 8.703
enter your date of birth: 25
voltage at the sending end=  9.1828e+004 +1.7327e+004i

current at the sending end=  1.9634e+002 -4.1302e+001i

power factor at sending end=    0.9234

sending end complex power=  1.7314e+007 +7.1945e+006i

voltage regulation=   17.2876

efficiency=   94.3378

the per unit value of the impedance=   0.0598 + 0.2813i

the per unit value of the receiving end voltage=     1

the per unit value of the receiving end current=   0.8500 - 0.5268i

the per unit value of the sending end voltage=   1.1525 + 0.2175i
```

the per unit value of the sending end current= 0.8141 - 0.1712i

the per unit value of the sending end apparent power= 0.9010 + 0.3744i

the per unit value of the receiving end real power= 0.8500

the per unit value of the shunt admittance= 0 +3.0269e-006i

enter the desired power factor: 1
value of the capacitor bank in farads= 2.6225e-006

the reactive power to be supplied by the capacitance bank invar= 7.1945e+006

Experiment No.07

Experiment Name: ANALYSIS OF POWER SYSTEMS UNDER FAULT CONDITIONS

Theory:

INTRODUCTION: During normal operating conditions, current will flow through all elements of the electrical power system within pre-designed values which are appropriate to these elements' ratings. Any power system can be analyzed by calculating the system voltages & currents under normal & abnormal scenarios.

Unfortunately, faults could happen as a result of natural events or accidents where the phase will establish a connection with another phase, A falling tree on a transmission lines could cause a three-phase fault where all phases share a point of contact called fault location. In different occasions, fault could be a result of insulation deterioration, wind damage or human vandalism.

Faults can be defined as the flow of a massive current through an improper path which could cause enormous equipment damage which will lead to interruption of power, personal injury, or death. In addition, the voltage level will alternate which can affect the equipment insulation in case of an increase or could cause a failure of equipment start-up if the voltage is below a minimum level. As a result, the electrical potential difference of the system neutral will increase. Hence, People and equipment will be exposed to the danger of electricity which is not accepted.

In order to prevent such an event, power system fault analysis was introduced. **The process of evaluating the system voltages and currents under various types of short circuits is called fault analysis.** Which can determine the necessary safety measures & the required protection system?

There are two **types of faults** which can occur on any transmission lines; **balanced faults & unbalanced faults**. In addition, unbalanced faults can be classified into **single line-to-ground faults, double line faults and double line-to-ground faults.**

The most common types taking place in reality are as follow: Line-to-ground fault: this type of fault exists when one phase of any transmission lines establishes a connection with the ground either by ice, wind, falling tree or any other incident. 70% of all transmission lines faults are classified under this category. Line-to-line fault: as a result of high winds, one phase could touch anther phase & line-to-line fault takes place. 15% of all transmission lines faults are considered line-to-line faults. Double line-to-ground: two phases will be involved instead of one at the line-to-ground faults scenarios. 10% of all transmission lines faults are under this type of faults . Three phase fault: in this case, falling tower, failure of equipment or even a line breaking and touching the remaining phases can cause three phase faults. In reality, this type of fault not often exists which can be seen from its share of 5% of all transmission lines faults.

In order to analyze any unbalanced power system, C.L. Fortescue introduced a method called symmetrical components in 1918 to solve such system using a balanced representation. Its mathematical model will be presented. After that, a 6-bus system will be under fault for analysis. This analysis will take place using the manual calculations. These results will be compared later with the results of Matlab codes.

Fault Analysis in Power Systems

In general, a fault is any event, unbalanced situation or any asymmetrical situation that interferes with the normal current flow in a power system and forces voltages and currents to differ from each other. It is important to distinguish between series and shunt faults in order to make an accurate fault analysis of an asymmetrical three-phase system. When the fault is caused by an unbalance in the line impedance and does not involve a ground, or any type of inter-connection between phase conductors it is known as a series fault. On the other hand, when the fault occurs and there is an inter-connection between phase-conductors or between conductor(s) and ground and/or neutral it is known as a shunt fault.Statistically, series faults do not occur as often as shunt faults does. Because of this fact only the shunt faults are explained here in detail since the emphasis in this project is on analysis of a power system under shunt faults.

Three-Phase Fault

By definition a three-phase fault is a symmetrical fault. Even though it is the least frequent fault, it is the most dangerous. Some of the characteristics of a three-phase fault are a very large fault current and usually a voltage level equals to zero at the site where the fault takes place. A general representation of a balanced three-phase fault is shown in Figure 3.8 where F is the fault point with impedances Zf and Zg . Figure 3.9 shows the sequences networks interconnection diagram.

Single Line-to-Ground Fault

The single line-to-ground fault is usually referred as “short circuit” fault and occurs when one conductor falls to ground or makes contact with the neutral wire. The general representation of a single line-to-ground fault where F is the fault point with impedances Zf. . Phase a is usually assumed to be the faulted phase, this is for simplicity in the fault analysis calculations.

Line-to-Line Fault

A line-to-line fault may take place either on an overhead and/or underground transmission system and occurs when two conductors are short-circuited. One of the characteristic of this type of fault is that its fault impedance magnitude could vary over a wide range making very hard to predict its upper and lower limits. It is when the fault impedance is zero that the highest asymmetry at the line-to-line fault occurs.

Double Line-to-Ground Fault

A double line-to-ground fault represents a serious event that causes a significant asymmetry in a three-phase symmetrical system and it may spread into a three-phase fault when not clear in appropriate time. The major problem when analyzing this type of fault is the assumption of the fault impedance Zf , and the value of the impedance towards the ground Zg

Data for 6-Node Network

6-Node network with impedances in pu on a 50 MVA Base

Impedance Number	Connecting Nodes	Self Impedance		Mutual Impedance	
		Z1=Z2	Z0	ZM	Branch
1	1-6	0.123+j0.518	0.492+j1.042		
2	1-4	0.080+j0.370	0.400+j0.925	0.250+j0.475	3
3	4-6	0.097+j0.407	0.450+j1.030	0.250+j0.476	2
4	5-6	0.000+j0.300	0.000+j0.300		
5	2-5	0.282+j0.640	1.410+j1.920		
6	2-3	0.723+j1.050	1.890+j2.630		
7	3-4	0.000+j0.133	0.000+j0.133		
8	0-4	0.000-j34.100			
9	0-1	0.000-j29.500			
10	0-6	0.000-j28.500			
11	Gen 1	0.010+j0.120			
12	Gen 2	0.015+j0.240	0.000+j0.016		

Fault Analysis Calculations:..

```
% This code is to perform Fault Analysis of 6-bus system. The sys. c
% was provided by Paul Anderson's book as one of its examples. The
% following functions "Copyright (C) 1998 H. Saadat" were utilized t
% calculate the fault at bus number 4:
% 1)symfaul
% 2)lgfault
% 3)dlgfault
% 4)llfault
clc
```

System Data:

```
% the 6-bus system: line positive sequence parameters
PosSeqData=[ 0, 1, 0.02, 0.24;
            0, 2, 0.03, 0.48;
            1, 4, 0.16, 0.74;
            1, 6, 0.24, 1.036;
            2, 3, 1.446, 2.1;
            2, 5, 0.564, 1.28;
            3, 4, 0, 0.266;
            6, 4, 0.194, 0.814;
            5, 6, 0, 0.6];
% the 6-bus system: line negative sequence parameters
NegSeqData=PosSeqData;
% the 6-bus system: line zero sequence parameters
% without the mutual coupling
ZerSeqData=[ 0, 2, 0, 0.032;
            0, 4, 0, 0.266;
            0, 6, 0, 0.6;
            1, 4, 0.8, 1.85;
            1, 6, 0.98, 2.084;
            2, 3, 3.78, 5.26;
            2, 5, 2.82, 3.84;
            6, 4, 0.90, 2.06];
```

Sequence matrices:

```
% Positive Sequence Matrix:
Z1bus=[ 0.02253+1i*0.21503  -0.00609+1i*0.04974  0.02635+1i*0.16117
0.02254+1i*0.17266  0.02118+1i*0.12825 0.01831+1i*0.16379;
       -0.00609+1i*0.04974   0.04422+1i*0.38094 -0.01594+1i*0.15713 -
0.00786+1i*0.13434 -0.00698+1i*0.22306 0.00023+1i*0.15223;
        0.02635+1i*0.16117  -0.01594+1i*0.15713  0.16244+1i*0.73912
0.14333+1i*0.53368  0.06192+1i*0.27007 0.07295+1i*0.32786;
        0.02254+1i*0.17266  -0.00786+1i*0.13434  0.14333+1i*0.53368
0.13269+1i*0.57694  0.06506+1i*0.27818 0.06881+1i*0.34726;
        0.02118+1i*0.12825  -0.00698+1i*0.22306  0.06192+1i*0.27007
0.06506+1i*0.27818  0.16569+1i*0.80649 0.13256+1i*0.46538;
        0.01831++1i*0.16379  0.00023+1i*0.15223  0.07295+1i*0.32786
0.06881+1i*0.34726  0.13256+1i*0.46538 0.13034+1i*0.61119];
% Negative Sequence Matrix:
Z2bus=Z1bus;
% Zero Sequence Matrix:
Z0bus=[0.36392+i*1.11336  0+1i*0       0+1i*0         -
0.0112+1i*0.11474    0+1i*0          0.02526+1i*0.3412;
    0+1i*0              0+1i*0.032   0+1i*0.032      0+1i*0
0+1i*0.032      0+1i*0 ;
    0+1i*0              0+1i*0.032   3.75+1i*5.292   0+1i*0
0+1i*0.032      0+1i*0            ;
   -0.0112+1i*0.11474   0+1i*0       0+1i*0          0.00756+1i*0.24138
0+1i*0         -0.01706+1i*0.05554;
    0+1i*0              0+1i*0.032   0+1i*0.032      0+1i*0
2.82+1i*3.872   0+1i*0;
    0.02526+1i*0.3412   0+1i*0       0+1i*0         -0.01706+1i*0.05554
0+1i*0          0.03849+1i*0.047472];
```

Fault Analysis Calculations:

```
% pre-fault voltages at all buses:
Vpre=[1.05;1.1;1;1;1;1];
symfaul(PosSeqData,Z1bus,Vpre)
lgfault(ZerSeqData, Z0bus, PosSeqData, Z1bus, NegSeqData, Z2bus, Vpre)
dlgfault(ZerSeqData, Z0bus, PosSeqData, Z1bus, PosSeqData, Z1bus, Vpre)
llfault(PosSeqData, Z1bus, PosSeqData, Z1bus, Vpre)
```

Results:

```
Warning: Invalid escape sequence appears in format string. See help sprintf for valid
escape sequences.
> In symfaul at 34
  In zimp at 57

Balanced three-phase fault at bus No. 4
Total fault current =   1.6892 per unit

Bus Voltages during fault in per unit

     Bus     Voltage       Angle
     No.     Magnitude     degrees
      1       0.7432      -2.2887
      2       0.8629      -4.6653
      3       0.0753      26.7701
```

```
      4       0.0000        0.0000
      5       0.5174        0.1972
      6       0.4027       -2.5905


Line currents for fault at bus No.  4

     From      To     Current      Angle
     Bus       Bus    Magnitude    degrees
      G         1      1.2824     -79.7218
      1         4      0.9816     -80.0882
      1         6      0.3202     -78.8887
      G         2      0.5199     -70.1230
      2         3      0.3136     -62.9284
      2         5      0.2503     -78.0835
      3         4      0.2829     -63.2299
      4         F      1.6892     -77.0478
      5         6      0.1948     -80.1551
      6         4      0.4812     -79.1853
Line-to-ground fault analysis

Single line to-ground fault at bus No. 4

I012 =

   0.1350 - 0.6903i
   0.1350 - 0.6903i
   0.1350 - 0.6903i

Ifabc =

   0.4051 - 2.0709i
   0.0000 + 0.0000i
   0.0000 + 0.0000i


Ifabcm =

    2.1101
    0.0000
    0.0000

Total fault current =    2.1101 per unit

Bus Voltages during the fault in per unit

     Bus    -------Voltage Magnitude-------
     No.    Phase a      Phase b     Phase c
     1      0.7289       1.0422      1.0148
     2      0.9179       1.0360      1.0784
     3      0.2308       0.8999      0.8466
     4      0.0000       0.9413      0.8624
     5      0.5986       0.9232      0.9093
     6      0.4663       0.9312      0.8935
     Bus    ------- Complex Voltage -------
     No.    Zer-Seq      Pos-Seq     Neg-Seq
     1  0.0811 -163.3565  0.9278 -0.4790  0.1225
 -176.3693
     2  0.0000  0.0000  1.0086 -1.3389  0.0947
 -165.5831
     3  0.0000  0.0000  0.6128  2.5134  0.3887
 176.0353
     4  0.1699 -170.7255  0.5840  1.3431  0.4164
 178.1162
     5  0.0000  0.0000  0.7992  0.5267  0.2009
 177.9048
     6  0.0409 -151.8564  0.7510  0.0463  0.2490
 179.8604
Line currents for fault at bus No.  4

    From      To      -----Line Current Magnitude----
     Bus       Bus     Phase a     Phase b     Phase c
```

```
Ink2 =

         0                  0                  0            -0.0805 + 0.4605i        0
-0.0277 + 0.1407i
         0                  0          -0.0637 + 0.1263i          0           -0.0167 +
0.0959i       0
         0          0.0637 - 0.1263i          0            -0.0637 + 0.1263i        0
0
   0.0805 - 0.4605i         0           0.0637 - 0.1263i          0                0
0.0451 - 0.2363i
         0          0.0167 - 0.0959i          0                   0                0
-0.0167 + 0.0959i
   0.0277 - 0.1407i         0                  0            -0.0451 + 0.2363i   0.0167 -
0.0959i       0
```

Outcome of the simulation stage can be listed in the following points:

1. In three-phase fault, the voltages at faulted bus phases dropped to zero during the fault. The faulted bus is bus number four where Phase A, B and C has a zero voltage potential.
2. However, only voltage at Phase A is equal to zero in single line-to-ground fault. In addition, only Phase A has current since it is the faulted phase in this type of fault as we assumed earlier in the mathematical model. This current is the second highest fault currents of all types.
3. Since Phase B and Phase C are in contact in line-to-line fault, the voltages at both phases are equal. The fault current are passing from B to C. in Phase A, the current is equal to zero compared to the fault current.
4. In double line-to-ground fault, Phase B and C voltages are equal to zero. The faulted current is flowing through both phases only. In addition, this type of fault is the most sever fault on the system which can be seen from its current value.