



# **NED University of Engineering & Technology**

## **Department of Electrical Engineering**

### **LAB MANUAL**

#### **For the course**

### **POWER SYSTEM ANALYSIS**

#### **(EE-362) For T.E.(EE)**

**Instructor name:** \_\_\_\_\_

**Student name:** \_\_\_\_\_

**Roll no:** \_\_\_\_\_ **Batch:** \_\_\_\_\_

**Semester:** \_\_\_\_\_ **Year:** \_\_\_\_\_

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**POWER SYSTEM ANALYSIS**

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Content Revision Team:

Ms. Ayesha Saeed, Dr Mohsin Aman

Approved By

**The Board of Studies of Department of Electrical Engineering**

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Summary of Rubric Sheets for Data Entry in OBE MIS System [to be entered as they are on OBE portal with no scaling]

Add six <sup>total</sup> <sup>comes</sup> from above to set total Dushanze <sup>comes</sup> Out of 102

Add six total scores from above to get a total of 25 marks (B/100)\*25

Scaled to 25 marks (R/192)\*25

### Lab Attendance percentage from portal:

Attendance scaled to 5 marks:  $(A/100)^*5$

## Future of education

PBL/OEL		Total out of 32	Total out of 32
Extent of achievement		Extent of achievement	
	Final		

Add two total scores from above to get total final Rubric Score Out of 64

Add two total scores from above to get total final Rubric Score Out of 64  
For entry on NED exam portal Total Final Lab Marks scaled to 20 marks ( $Z/64)*20$

## CONTENTS

S.No.	Date	Title of Experiment	Signature
1		Modeling of a network on Simulink	
2*		Determination of the significance of surge impedance of transmission line.	
3		Introduction to Electrical Transient Analyzer Program (ETAP).	
4*		Studying the operation of a power transmission line in no-load conditions.	
5*		To observe and analyse the impact of load changes on Generator Controls and Transmission Lines.	
6*		Short circuit analysis on ETAP	
7		Symmetrical component analysis on Simulink	
8		Digital faults simulation in stand-alone mode on AEL-CPSS-01S.	
9		Solution of Non Linear Algebraic Equations on MATLAB	
10*		Sequence Networks	
11*		Load Flow Analysis on ETAP	
12*		<b>Open Ended Lab:</b> Asymmetrical fault analysis on ETAP	

Note: \*Lab evaluation is rubric based.

## LAB SESSION 1

### TITLE

Network Modeling on Simulink.

### THEORY

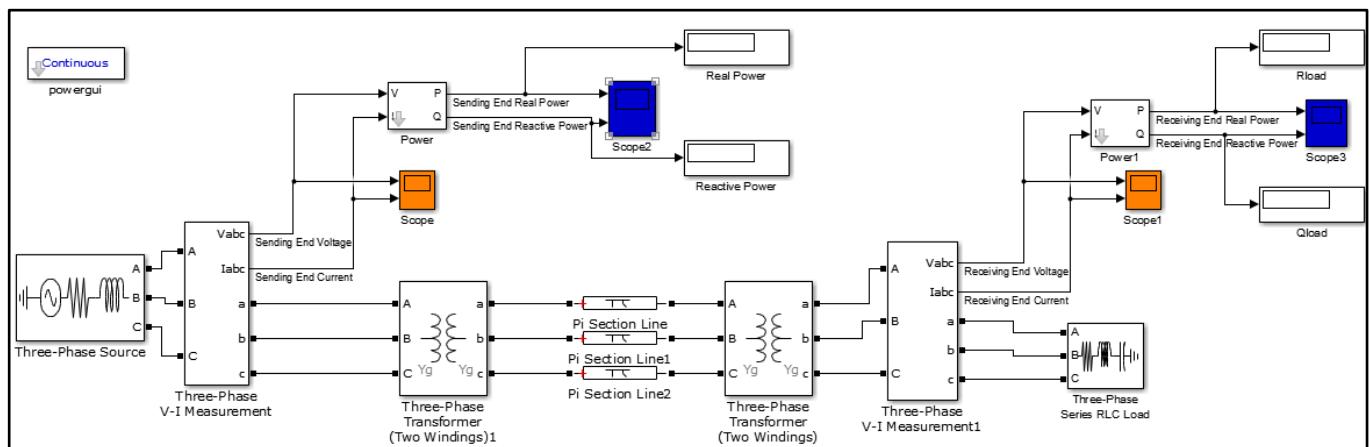
Simulink is an environment for simulation and model-based design for dynamic and embedded systems. It provides an interactive graphical environment and a customizable set of block libraries that let you design, simulate, implement, and test a variety of time-varying systems, including power system, controls, signal processing etc.

The Simulink Library Browser is the library where you find all the blocks you may use in Simulink. Simulink software includes an extensive library including SimPowerSystems, Aerospace Blockset, Communication Blockset.

Simscape Power Systems™ provides component libraries and analysis tools for modelling and simulating electrical power systems. It includes models of electrical power components, including three-phase machines, electric drives, and components for applications such as flexible AC transmission systems (FACTS) and renewable energy systems. Harmonic analysis, calculation of total harmonic distortion (THD), load flow, and other key electrical power system analyses are automated, helping you investigate the performance of your design.

### EXERCISE

- Open MATLAB and select the Simulink icon from the main toolbar or type Simulink on the command window. This opens the Simulink library browser.
- Create a new model. Drag and drop the elements given in the table below to build the following model:



Blocks	Library Path	Quantity
Three Phase Voltage Source	SimPowerSystems > Fundamental Blocks > Electrical Sources	1
Three Phase VI measurement	SimPowerSystems > Fundamental Blocks > Measurements	2
Three Phase Transformer (2 winding)	SimPowerSystems > Fundamental Blocks > Elements	2
Pi Section Line	SimPowerSystems > Fundamental Blocks > Elements	3
Three Phase Series RLC load	SimPowerSystems > Fundamental Blocks > Elements	1
Power	SimPowerSystems > Control & Measurements > Measurements	2
Scope	Simulink> Commonly Used Blocks	4
Display	Simulink>Sinks	4
Powergui	SimPowerSystems > Fundamental Blocks	1

- Connect the blocks as shown.
- Set the three-phase voltage source to 11kV, 50 Hz.
- Set the three-phase VI measurement block's voltage measurement to 'phase to ground'.
- The sending end transformer is 250 MVA 11/66kV step up transformer and the receiving end transformer is step down 66/11 kV transformer.
- Both the transformers have  $R = 0.002$  pu and  $L = 0.05$  pu
- The load is a series Y grounded RLC load.
- Use ode23tb as the solver for the given system.

## **OBSERVATION**

- Note the steady state voltages by opening powergui.
- Observe the waveforms on different scopes.
- Attach the waveforms.

## LAB SESSION 2

### TITLE

Studying the significance of surge impedance of transmission line.

### THEORY

The theoretical significance of the surge impedance is that if a purely resistive load that is equal to the surge impedance were connected to the end of a transmission line with no resistance, the voltage at the receiving end would have the same magnitude as the sending end voltage. Surge impedance load (SIL) is such a load at which natural reactive balance occurs as shown below:

MVar Produced by Capacitance of the line = MVar Used by Inductance of the line

$$\frac{kV^2}{X_C} = I^2 X_L$$

$$\frac{kV^2}{I^2} = X_C X_L$$

$$\text{Surge Impedance} = \sqrt{\frac{L}{C}}$$

$$\text{SIL} = \frac{kV_{L,L}^2}{\text{Surge Impedance}}$$

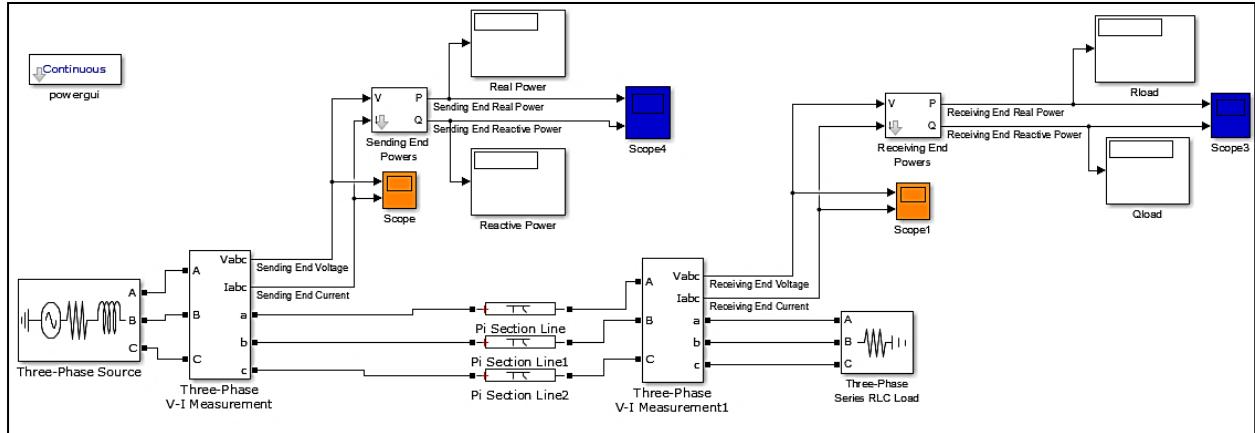
From the above equation it can be observed that SIL only depends on the voltage level and surge impedance of the line. It is independent of the length of the line.

It is a useful quantity as it suggests transmission line loading with minimum reactive power requirement. Lines loaded above SIL are inductive in their behavior while those loaded below SIL are capacitive.

Power system engineers find it convenient to express power transmitted by line in terms of per unit of SIL i.e as a ratio of power transmitted to SIL.

## EXERCISE

- Open MATLAB and build the model given in the figure below.
- The transmission line is of (Your Roll Number) kV with  $R = 1 \text{ n}\Omega$ ,  $L = 2 \text{ mH/km}$ ,  $C = 8 \text{ nF/km}$ . The resistance is set to a very low value so that the effect of SIL can be observed in the simulation.
- Calculate SIL. Use this value to complete the table given below.



## OBSERVATION

Complete the following table and explain your observations.

Load	$V_s$ (kV)	$V_R$ (kV)	$P_s$ (MW)	$P_R$ (MW)	$Q_s$ (Vars)	$Q_R$ (Vars)
<b>Load &lt; SIL</b>						
<b>Load = SIL</b>						
<b>Load &gt; SIL</b>						

Line Length (km)	Capacitance (nF)	Inductance (mH)	Surge Impedance (ohms)	Line Reactance (ohms)	Surge Impedance Loading SIL (MW)	$P_{\text{limit}}$ (3-Phase) (MW)	$P_{\text{limit}}$ (in terms of SIL)
<b>200</b>							
<b>400</b>							

## CONCLUSION



Course Code: **EE-362**

Laboratory Session No.:

Course Title: **Power System Analysis**

Date:

<b>Psychomotor Domain Assessment Rubric for Laboratory (Level P3)</b>					
Skill(s) to be assessed	Extent of Achievement				
	0	1	2	3	4
<b>Software Initialisation and Configuration:</b> Set up and <u>recognise</u> software initialisation and configuration steps	Completely unable to recognise initialisation and configuration	Able to recognise initialisation but could not configure	Able to recognise initialisation but configuration is erroneous	Able to recognise/perform initialisation and configuration with minimal errors	Able to recognise/perform initialisation and configuration with complete success
<b>Software Menu Identification and Usage:</b> Ability to <u>operate</u> software environment <u>under supervision</u> , using menus, shortcuts, instructions etc.	Unable to understand and use software menu	Little ability and understanding of software menu operation, makes many mistakes	Moderate ability and understanding of software menu operation, makes lesser mistakes	Reasonable understanding of software menu operation, makes no major mistakes	Demonstrates command over software menu usage with frequent use of advance menu options
<b>Modeling of given SLD/Network Diagram:</b> Ability to <u>operate</u> software environment in order to create simulation model of given network parameters	Unable to operate software, could not create simulation model	Moderately able to operate software, could not create simulation model	Adequately able to operate software, simulation model contains errors	Adequately able to operate software, simulation model is error free	Demonstrates mastery over software, error free simulation model is created and simulation is started
<b>Detecting and Removing Errors:</b> <u>Detect</u> Errors/Exceptions and in simulation model and <u>manipulate</u> model to rectify the simulation	Unable to check and detect error messages and indications in software	Able to find error messages and indications in software but no understanding of detecting those errors and their types	Able to find error messages and indications in software as well as understanding of detecting some of those errors and their types	Able to find error messages in software as well as understanding of detecting all of those errors and their types	Able to find error messages in software along with the understanding to detect and rectify them

Psychomotor Domain Assessment Rubric for Laboratory (Level P3)					
Skill(s) to be assessed	Extent of Achievement				
	0	1	2	3	4
<b>Graphical Visualisation and Comparison of Model/Network Parameters:</b> <u>Manipulate</u> given model/simulation under supervision, in order to produce graphs/plots for measuring and comparing network parameters	Unable to understand and utilise visualisation or plotting features	Ability to understand and utilise visualisation and plotting features with frequent errors	Ability to understand and utilise visualisation and plotting features successfully but unable to compare and analyse them	Ability to understand and utilise visualisation and plotting features successfully, partially able to compare and analyse them	Ability to understand and utilise visualisation and plotting features successfully, also able to draw conclusions after analysis
<b>Following step-by-step procedure to complete lab work:</b> <u>Observe, imitate and operate</u> software to complete the provided sequence of steps	Inability to recognise and perform given lab procedures	Able to recognise given lab procedures and perform them but could not follow the prescribed order of steps	Able to recognise given lab procedures and perform them by following prescribed order of steps, with frequent mistakes	Able to recognise given lab procedures and perform them by following prescribed order of steps, with occasional mistakes	Able to recognise given lab procedures and perform them by following prescribed order of steps, with no mistakes
<b>Recording Simulation Observations:</b> <u>Observe and copy</u> prescribed or required simulation results in accordance with lab manual instructions	Inability to recognise prescribed or required simulation measurements	Able to recognise prescribed or required simulation measurements but does not record according to given instructions	—	Able to recognise prescribed or required simulation measurements but records them incompletely	Able to recognise prescribed or required simulation measurements and records them completely, in tabular form
<b>Discussion and Conclusion:</b> <u>Demonstrate</u> discussion capacity on the recorded observations and draw conclusions from it	Complete inability to discuss recorded observations and draw conclusions	Slight ability to discuss recorded observations and draw conclusions	Moderate ability to discuss recorded observations and draw conclusions	Reasonable ability to discuss recorded observations and draw conclusions	Full ability to discuss recorded observations and draw conclusions

## LAB SESSION 3

### TITLE

Introduction to Electrical Transient Analyzer Program (ETAP)

### THEORY

ETAP is a power system simulation software suite that contains a group of sub-programs that handle a variety of power system analysis. The analysis types include balanced and unbalanced load flow analysis, short circuit analysis, arc flash analysis, real-time simulation, distribution system design, grounding, protection scheme simulations, and others. The software is used mostly by engineers at the facility design and control levels, and includes energy management modules and substation automation.

### PROCEDURE

#### **Create a new project**

New projects can be created in ETAP through file menu in status bar. The editor window ‘Create new project’ asks for the name of project. The ‘User information’ editor asks user name, full name and description related to your project.

#### **Mode Toolbar**

When you click the One-Line Diagram (Network Systems) button on the System toolbar, the Mode toolbar is available that contains all the study modules related to the one-line diagram.

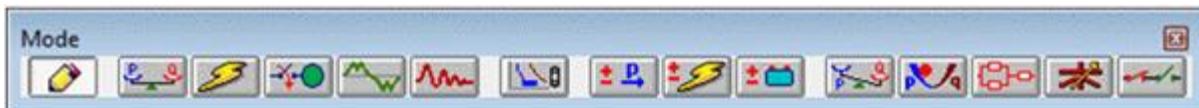
In general, ETAP has three modes of operation under Network Systems; Edit, AC Study, and DC Study. The AC Study mode consists of analyses such as Load Flow, Short Circuit, Motor Acceleration, Transient Stability, and Protective Device Coordination.



Mode Toolbar with Motor Acceleration Mode Selected

#### **Edit Mode**

Edit mode enables you to build your one-line diagram, change system connections, edit engineering properties, save your project, and generate schedule reports in Crystal Reports formats. You can select this mode by clicking the Edit button (graphically represented by a pencil). The Edit toolbars for AC Elements, DC Elements, and Instrumentation Elements will be displayed to the right side of the ETAP window.



Mode Toolbar with Edit Mode Selected

This mode provides access to editing features that include:

- Dragging and Dropping Elements
- Connecting Elements
- Changing IDs
- Cutting, Copying, and Pasting Elements
- Moving Items from System Dumpster
- Inserting OLE Objects
- Cutting, Copying, and Pasting OLE Objects
- Merging Two ETAP Projects
- Hiding/Showing Groups of Protective Devices
- Rotating Elements
- Sizing Elements
- Changing Symbols
- Editing Properties
- Running Schedule Report Manager

### Study Mode

Study modes enable you to create and modify study cases, perform system analysis, view alarm/alert conditions, and view output reports and plots. When a study mode is active (selected), the toolbar for the selected study is displayed on the right side of the ETAP window. By clicking the buttons on the study toolbar, you can run studies, transfer data, and change display options. Two of the available study modes which you will use and associated study toolbars are shown in the table below.

Study Mode Toolbar	Study Mode Toolbar
<p><b>Load Flow</b></p> <ul style="list-style-type: none"> <li>• Load Flow</li> <li>• Auto-Run Load Flow</li> </ul> 	<p><b>Short Circuit</b></p> <ul style="list-style-type: none"> <li>• ANSI Short Circuit Duty</li> <li>• ANSI 30 Cycle Faults</li> <li>• ANSI Unbalanced Faults</li> <li>• IEC Short Circuit Duty</li> <li>• IEC 909 Short Circuit</li> <li>• IEC Unbalanced Faults</li> <li>• IEC 363 Short Circuit</li> <li>• Arc Flash Analysis</li> </ul> 

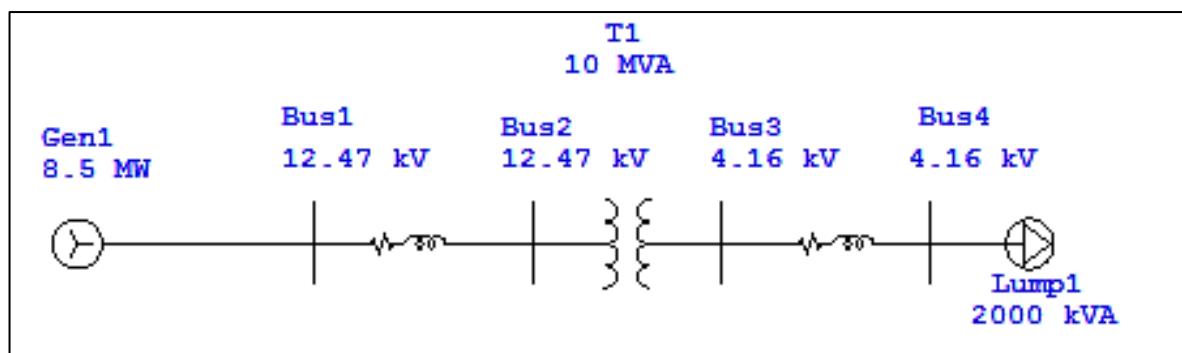
In addition to the Study toolbar, a Study Case toolbar is displayed automatically when one of the study modes becomes active. The Study Case toolbar allows you to control and manage the solution parameters and output reports. The Study Case toolbar is available for all ETAP configurations.



## EXERCISE

**Task 1** Model a simple 4 bus system as shown in the figure below:

### Editors



1. Double-click the generator symbol on the one-line diagram and view the editor. This is where you enter data for the generator model.
2. Select different pages of this editor and look over the type of information that you can provide to model a utility machine.
3. Click OK and close the editor.
4. Double-click other elements and explore their editors. Each available element has a customized editor.
5. Double-click the lumped load and view its editor. This is where you enter data used for load.

### Task 2

Complete this exercise to familiarize yourself with how the program works.

Set the following parameters in the respective editors of each elements by using the information given below:

- The source is a 12.47 kV line-to-line infinite bus (swing). It is a 10 MVA generator with a power factor of 0.85. The generator is Y connected and solidly grounded.
- Both the transmission lines are 2000 ft with a vertical configuration. Further details of the conductors are given below:

Phase Conductor: 336,400 26/7

GMR = 0.0244 ft., Resistance = 0.306  $\Omega$ /mile, Diameter = 0.721 inch

Ground Conductor: Penguin 4/0

GMR = 0.00814 ft., Resistance = 0.592  $\Omega$ /mile, Diameter = 0.563 inch

The conductors have a horizontal configuration with 2.5 ft spacing between A and B and 4.5 ft spacing between B and C. The distance CG is 4 ft and the total height of conductors is 28 ft.

- The transformer is a step down 10000 kVA, 12.47/4.16 kV two winding transformer with X/R ratio equal to 6. Both the windings are Y connected and solidly grounded.
- The lumped load runs at 4.16 kV and is 1800 kW with 0.9 lagging power factor.

Run load flow analysis to check your system.

## **RESULTS**

Attach a snapshot of the network modeled after running load flow successfully.

## LAB SESSION 4

### TITLE

Studying the operation of a power transmission line in no-load conditions (no-load current of the transmission line).

### APPARATUS

- Industrial Power Supply (N-ALI01)
- Instrumentation Module 1 (N-PPIM2)
- Control and Protection of Turbine-Generator Group Module 1 (N-PPCM1)
- Power Generation Substation Module 1 (N-PSUB3)
- Network Analyzer Unit with Computer Data Acquisition (N-EALD) (2 units)
- Transmission Lines Simulation module (N-AEC1D)
- GMG4.5K2PH. 4,5 kW Generator-Motor Group (GMG4.5K3PH)

### THEORY

Power transmission lines are designed to transmit large volumes of power between even far points (hundreds and sometimes thousands of kilometers). Generally power plants are erected where an energy source is available, then these plants will serve all the users located in urban and industrial areas. The term “Line” will include both the overhead lines (usually bare conductors spaced from each other) and the cable lines (insulated conductors grouped even under a further common sheath). Three-phase cable lines show some troubles when their length exceeds 40 km, therefore they are used to distribute energy between the substations and the final users at medium voltage. Overhead lines cannot be used, for instance, for undersea connections between mainland and islands. The main factor for the design/construction of a line is the power to be transmitted. Apart from some particular cases, long-distance power lines consist of three-phase systems almost everywhere. The operating voltage is chosen according to the power in order to minimize Joule effect losses ( $R I^2$ ). It can immediately be realized that losses will be reduced when current is reduced, but, when huge volumes of power have to be sent, energy will exclusively be transmitted with high voltages (of some hundreds of kV). All that will lead to consider also the accessories, that is step-up transformers at the origin and the respective step-down transformers at the destination of the lines.

### EXERCISE

- Carry out the step described in the paragraph “Starting up the application” (See Appendix)
- The table below shows the final position of the switches placed in the N-PSUB module and sequence needed to control automatically the motor-generator group:

SWITCHES	POSITION
Local/SCADA Control Mode	UP (Local Control Mode)

Manual/Automatic Speed Control	DOWN (Automatic Speed Control)
Manual/Automatic Excitation Control	DOWN (Automatic Excitation Control)
Enable/Disable 52NET	Right (Disable 52NET)
Start/Stop Turbine	Left (Start Turbine)
52G Synchronization Permission	UP

- A Network Analyzer is connected before and after the transmission line to measure the powers and other parameters at no-load.
- When the pre-established conditions (380-400V and 50Hz) are automatically reached, the automatic speed and voltage controller will close the circuit breaker and the 52G indicator will be turned on.
- Start this exercise considering the transmission LINE with the following constants: Resistance =  $33 \Omega$ ; Capacitance =  $2 \mu\text{F}$  on both sides of pi-model; Inductance =  $0.033 \text{ H}$ .
- The reference electric diagram, the connections and configuration of the line are respectively shown in the Figures 1 and 2.
- Read the electric quantities on the network analyzers and write them down in the following table.
- Remove left side capacitor bank, right side capacitor bank and then both the capacitor banks and respectively read the electric quantities on the network analyzers in all configurations.

## **OBSERVATION**

Actual measurements carried out on the LINE with: Resistance =  $33\Omega$ ; Capacitance =  $2\mu\text{F}$ ; Inductance =  $0.033 \text{ H}$ .

The reactive power that must be provided by each capacitor in a three-phase transmission line system with star connected line capacitors is:

$$Q_{C_1} = X_c * I_{phase}^2 = X_c * \left( \frac{V_{phase}}{X_c} \right)^2 = V_{phase}^2 / X_c$$

$$Q_{C_1} = \omega C_L * V_{phase}^2 = 2\pi * 50 * 2 * 10^{-6} * 220^2 = 30.41 \text{ VAR}$$

$$Q_1 = \omega C_L * V_L^2 = 2\pi * 50 * 2 * 10^{-6} * 380^2 = 90.73 \text{ VAR}$$

$Q_{C_1}$  = reactive power due to the capacitance between two active conductors  
 $Q_{C_1}$  resulting from the formula indicated above is calculated for only one phase.

Total reactive power of the three-phase transmission line:

$$Q_{Total} = 3 * Q_{C_1} = 90 \text{ VAR}$$

Compare the reactive power measured on the line to that calculated with the above formulae.

The no-load operation of the transmission line detects some active power, and this is due to the dielectric losses and due to the discharge resistances available in capacitors.

Repeat and record the measurements excluding the set of capacitors.

	<b>Voltage measured at the origin of the line <math>V_1</math> (V)</b>	<b>Line current measured at the origin of the line <math>I_1</math> (A)</b>	<b>Active power measured at the origin of the line <math>P_1</math> (W)</b>	<b>Reactive power measured at the origin of the line <math>Q_1</math> (Var)</b>
Both the capacitor banks ( $2\mu F$ each) are present in the transmission network				
Excluding the left-side capacitor bank from the transmission network				
Excluding the right-side capacitor bank from the transmission network				
Excluding both the capacitor banks from the transmission network				

## **CONCLUSION**

**No load is connected**



Figure 1. Reference electric diagram  
Power transmission line in no-load condition.

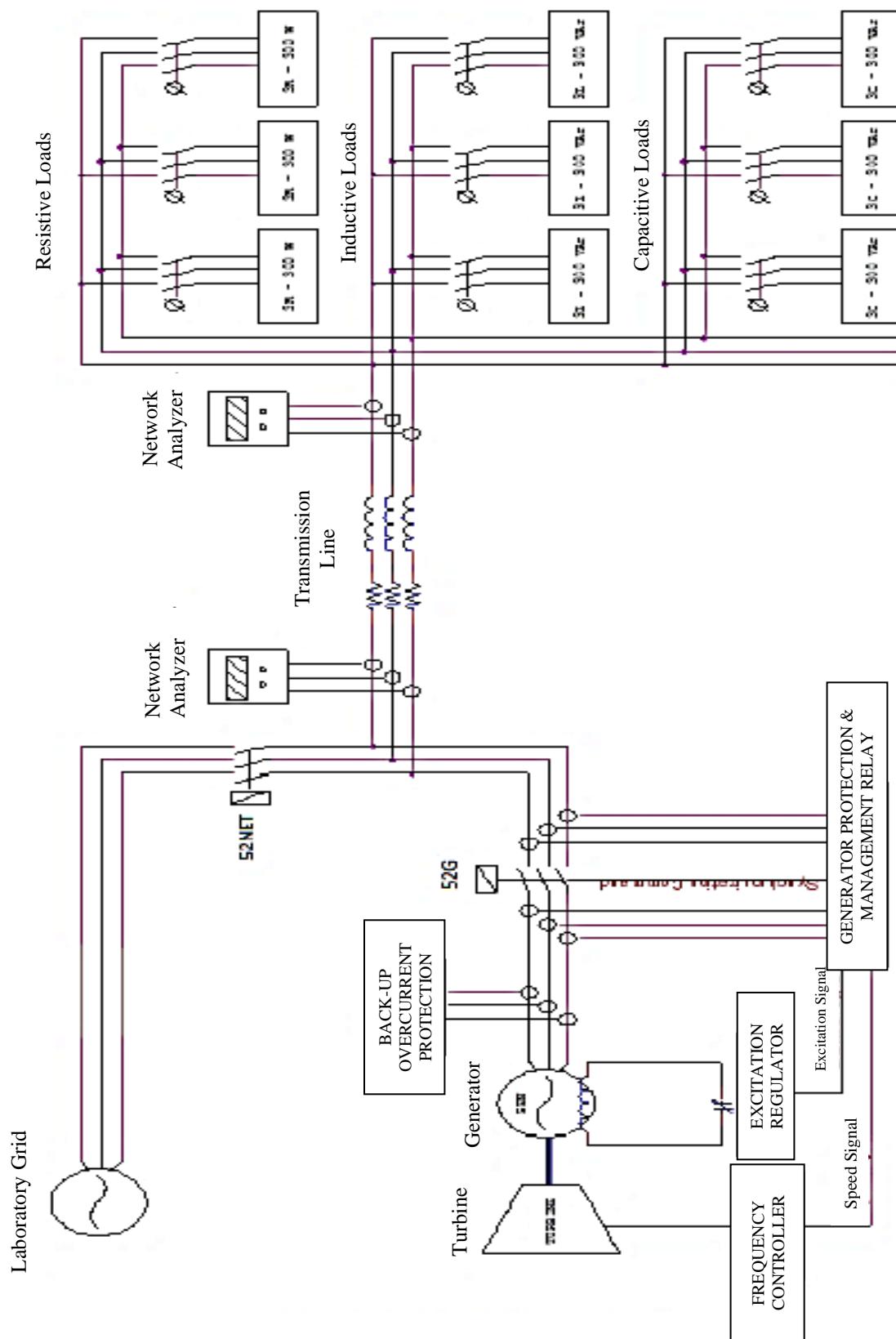


Figure 2. AEL-CPSS-01S electrical diagram

# Appendix

## Starting up the application

Follow the steps below to assembly the AEL-CPSS-01S modules, activate the protections and turn on the unit:

1. Connect the modules as it is shown in paragraph “Cable assembly of the AEL-CPSS-01S modules”.
2. Verify the position of the magneto-thermal circuit breaker placed at the N-ALI01. It must be activated.
3. Turn the removable key to select the ON position in the N-ALI01 module.
4. Adjust the manual control potentiometers to the minimum values allowed and turn on the ON/OFF switch in the N-PSUB module.
5. Turn the selector switches of the N-REFT/3C, N-INDT/3C and N-CAR19T/3C modules to disconnect all loads.

## Shutting down the application

1. Stop the turbine selecting this option in the N-PSUB module (local control mode) or in the SCADA software (remote control mode).
2. Wait until the turbine is turned off and, if the unit has been controlled in remote mode, stop the SCADA system and close it.
3. Switch off the N-PSUB module.
4. Turn off the N-ALI01 module



Course Code and Title: \_\_\_\_\_

Laboratory Session: No. \_\_\_\_\_ Date: \_\_\_\_\_

<b>Psychomotor Domain Assessment Rubric-Level P3</b>					
<b>Skill Sets</b>	<b>Extent of Achievement</b>				
	<b>0</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>
<b>Equipment Identification</b> Sensory skill to identify equipment and/or its component for a lab work.	Not able to identify the equipment.	--	--	--	Able to identify equipment as well as its components.
<b>Equipment Use</b> Sensory skills to describe the use of the equipment for the lab work.	Never describes the use of equipment.	Rarely able to describe the use of equipment.	Occasionally describe the use of equipment.	Often able to describe the use of equipment.	Frequently able to describe the use of equipment.
<b>Procedural Skills</b> Displays skills to act upon sequence of steps in lab work.	Not able to either learn or perform lab work procedure.	Able to slightly understand lab work procedure and perform lab work.	Able to somewhat understand lab work procedure and perform lab work.	Able to moderately understand lab work procedure and perform lab work.	Able to fully understand lab work procedure and perform lab work.
<b>Response</b> Ability to imitate the lab work on his/her own.	Not able to imitate the lab work.	Able to slightly imitate the lab work.	Able to somewhat imitate the lab work.	Able to moderately imitate the lab work.	Able to fully imitate the lab work.
<b>Observation's Use</b> Displays skills to perform related mathematical calculations using the observations from lab work.	Not able to use lab work observations into mathematical calculations.	Able to slightly use lab work observations into mathematical calculations.	Able to somewhat use lab work observations into mathematical calculations.	Able to moderately use lab work observations into mathematical calculations.	Able to fully use lab work observations into mathematical calculations.
<b>Safety Adherence</b> Adherence to safety procedures.	Doesn't adhere to safety procedures.	Slightly adheres to safety procedures.	Somewhat adheres to safety procedures.	Moderately adheres to safety procedures.	Fully adheres to safety procedures.
<b>Equipment Handling</b> Equipment care during the use.	Doesn't handle equipment with required care.	Rarely handles equipment with required care.	Occasionally handles equipment with required care	Often handles equipment with required care.	Handles equipment with required care.
<b>Group Work</b> Contributes in a group-based lab work.	Never participates.	Rarely participates.	Occasionally participates and contributes.	Often participates and contributes.	Frequently participates and contributes.

## LAB SESSION 5

### **TITLE**

To observe and analyze the impact of load changes on Generator Controls and Transmission Lines.

### **APPARATUS**

- Industrial Power Supply (N-ALI01)
- Instrumentation Module 1 (N-PPIM2)
- Control and Protection of Turbine-Generator Group Module 1 (N-PPCM1)
- Power Generation Substation Module 1 (N-PSUB3)
- Network Analyzer Unit with Computer Data Acquisition (N-EALD) (2 units)
- Transmission Lines Simulation module (N-AEC1D)
- GMG4.5K2PH. 4,5 kW Generator-Motor Group (GMG4.5K3PH)
- 3 x 300 W Three-Phase Configurable Resistors Module (N-REFT/3C)
- 3 x 300 VAr Three-Phase Configurable Inductances Module (N-INDT/3C)
- 3 x 300 VAr Three-Phase Configurable Capacitors Module (N-CAR19T/3C)

### **EXERCISE**

- Carry out the step described in the paragraph “Starting up the application” (See Appendix)
- The table below shows the final position of the switches placed in the N-PSUB module and sequence needed to control automatically the motor-generator group:

SWITCHES	POSITION
Local/SCADA Control Mode	UP (Local Control Mode)
Manual/Automatic Speed Control	DOWN (Automatic Speed Control)
Manual/Automatic Excitation Control	DOWN (Automatic Excitation Control)
Enable/Disable 52NET	Right (Disable 52NET)
Start/Stop Turbine	Left (Start Turbine)
52G Synchronization Permission	UP

- A Network Analyzer is connected before and after the transmission line to measure the powers and other parameters at different load conditions.
- When the pre-established conditions (380-400V and 50Hz) are automatically reached, the automatic speed and voltage controller will close the circuit breaker and the 52G indicator will be turned on.
- Start this exercise considering the transmission LINE with the following constants: Resistance =  $33 \Omega$ ; Capacitance =  $2 \mu F$  on both sides of pi-model; Inductance =  $0.033 H$ .
- Increase the load by gradually adding resistive, inductive and capacitive load and observe its effect on generator parameters and how the controller compensates them.
- The reference electric diagram, the connections and configuration of the line are respectively shown in the Figures 1 and 2.

- Read the electrical quantities on the network analyzers and write them down in the following table.

**TEST RESULTS**

Load	P <sub>G</sub>	Q <sub>G</sub>	I <sub>G</sub>	p.f <sub>G</sub>	V <sub>G</sub>	Field I <sub>G</sub>	P <sub>L</sub>	Q <sub>L</sub>	I <sub>L</sub>	p.f <sub>L</sub>	V <sub>L</sub>
<b>R1</b>											
<b>R2</b>											
<b>R3</b>											
<b>R3L1</b>											
<b>R3L2</b>											
<b>R3L3</b>											
<b>R3L3C1</b>											
<b>R3L3C2</b>											
<b>R3L3C3</b>											

**DISCUSSION ON RESULTS**

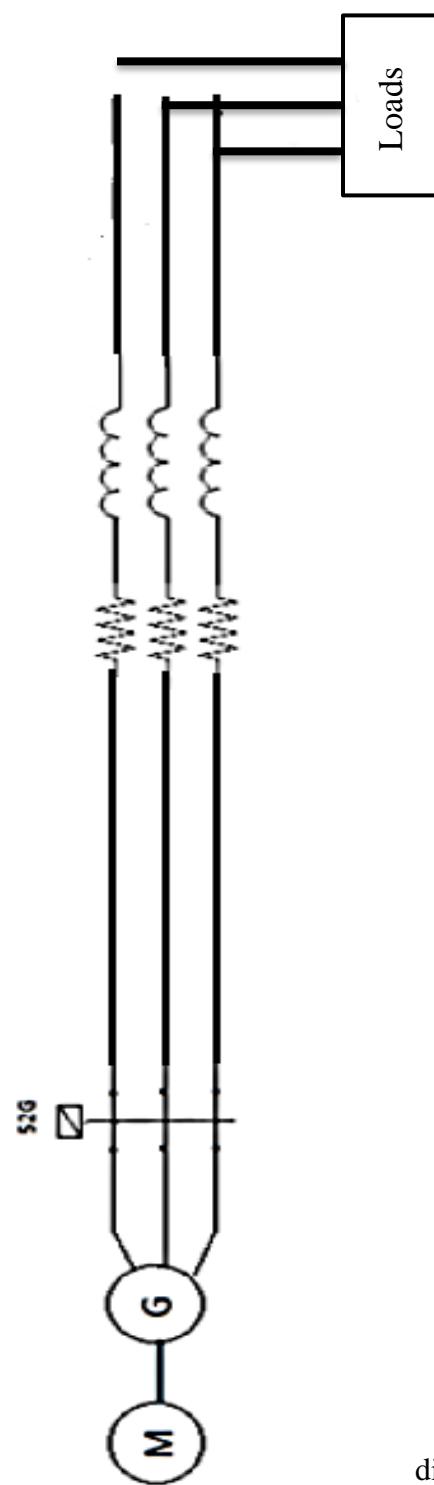


Figure 2. Reference electric Power transmission line in

diagram loaded condition.

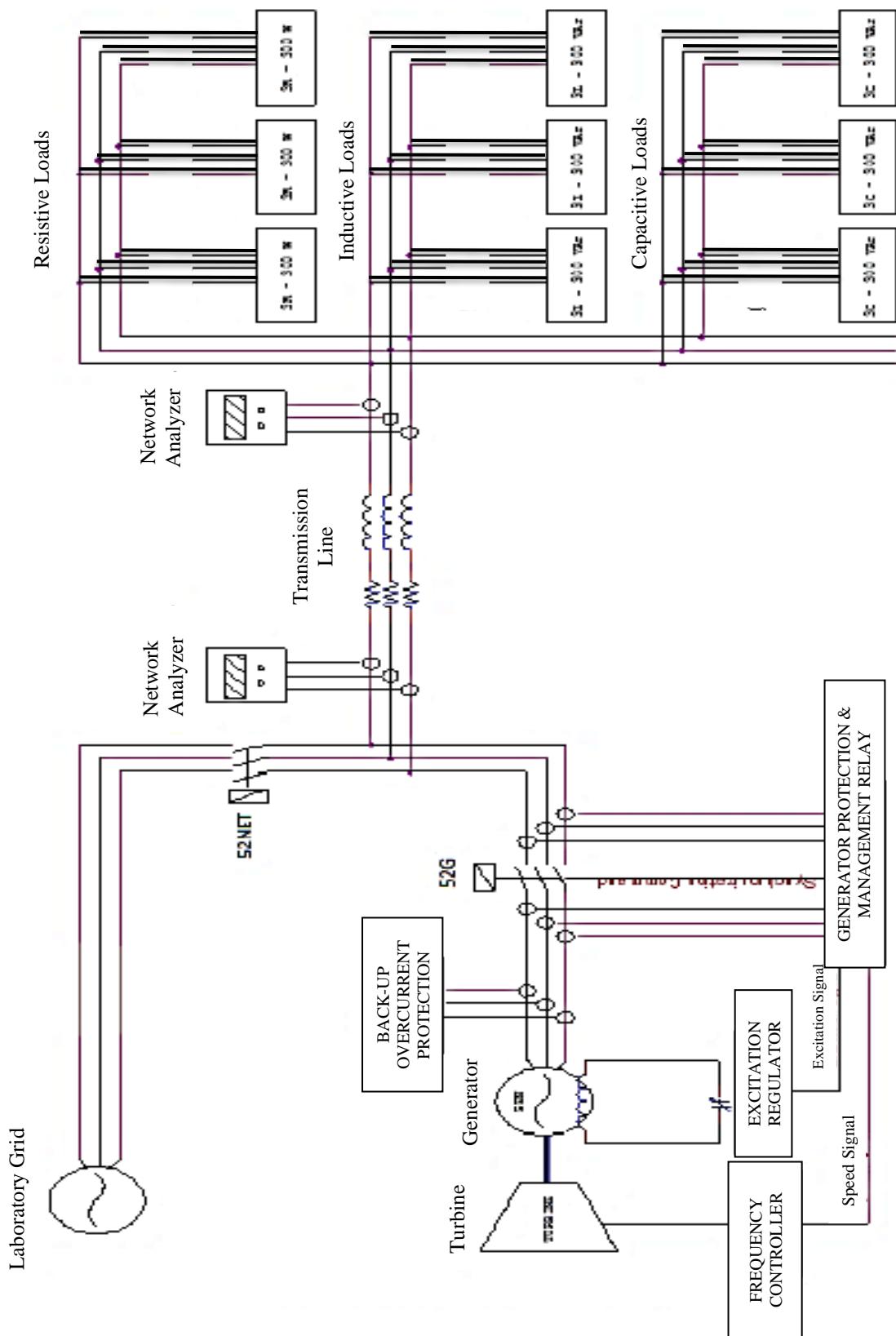


Figure 2. AEL-CPSS-01S electrical diagram



Course Code and Title: \_\_\_\_\_

Laboratory Session: No. \_\_\_\_\_ Date: \_\_\_\_\_

<b>Psychomotor Domain Assessment Rubric-Level P3</b>					
<b>Skill Sets</b>	<b>Extent of Achievement</b>				
	<b>0</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>
<b>Equipment Identification</b> Sensory skill to identify equipment and/or its component for a lab work.	Not able to identify the equipment.	--	--	--	Able to identify equipment as well as its components.
<b>Equipment Use</b> Sensory skills to describe the use of the equipment for the lab work.	Never describes the use of equipment.	Rarely able to describe the use of equipment.	Occasionally describe the use of equipment.	Often able to describe the use of equipment.	Frequently able to describe the use of equipment.
<b>Procedural Skills</b> Displays skills to act upon sequence of steps in lab work.	Not able to either learn or perform lab work procedure.	Able to slightly understand lab work procedure and perform lab work.	Able to somewhat understand lab work procedure and perform lab work.	Able to moderately understand lab work procedure and perform lab work.	Able to fully understand lab work procedure and perform lab work.
<b>Response</b> Ability to imitate the lab work on his/her own.	Not able to imitate the lab work.	Able to slightly imitate the lab work.	Able to somewhat imitate the lab work.	Able to moderately imitate the lab work.	Able to fully imitate the lab work.
<b>Observation's Use</b> Displays skills to perform related mathematical calculations using the observations from lab work.	Not able to use lab work observations into mathematical calculations.	Able to slightly use lab work observations into mathematical calculations.	Able to somewhat use lab work observations into mathematical calculations.	Able to moderately use lab work observations into mathematical calculations.	Able to fully use lab work observations into mathematical calculations.
<b>Safety Adherence</b> Adherence to safety procedures.	Doesn't adhere to safety procedures.	Slightly adheres to safety procedures.	Somewhat adheres to safety procedures.	Moderately adheres to safety procedures.	Fully adheres to safety procedures.
<b>Equipment Handling</b> Equipment care during the use.	Doesn't handle equipment with required care.	Rarely handles equipment with required care.	Occasionally handles equipment with required care	Often handles equipment with required care.	Handles equipment with required care.
<b>Group Work</b> Contributes in a group-based lab work.	Never participates.	Rarely participates.	Occasionally participates and contributes.	Often participates and contributes.	Frequently participates and contributes.

## LAB SESSION 6

### **TITLE**

Short circuit analysis on ETAP

### **OBJECTIVES**

1. To run short analysis on a test system for determining values of Short Circuit current, line currents and bus voltages.
2. To observe the effect of fault location on the fault currents.
3. To study the effect of motor contributions to fault current.
4. To study the effects of reactor placement.

### **THEORY**

A short-circuit fault takes place when two or more conductors come in contact with each other when normally they operate with a potential difference between them. The contact may be a physical metallic one, or it may occur through an arc. In the metal-to-metal contact case, the voltage between the two parts is reduced to zero. On the other hand, the voltage through an arc will be of a very small value. Short-circuit faults in three-phase systems are classified as:

1. Balanced or symmetrical three-phase faults.
2. Single line-to-ground faults.
3. Line-to-line faults.
4. Double line-to-ground faults.

Generator failure is caused by insulation breakdown between turns in the same slot or between the winding and the steel structure of the machine. The same can take place in transformers. The breakdown is due to insulation deterioration combined with switching or lightning overvoltage. Overhead lines are constructed of bare conductors. Wind, sleet, trees, cranes, kites, airplanes, birds, or damage to supporting structure are causes for accidental faults on overhead lines. Contamination of insulators and lightning overvoltage will in general result in short-circuit faults. Deterioration of insulation in underground cables results in short circuit faults. This is mainly attributed to aging combined with overloading. About 75 percent of the energy system's faults are due to single-line-to-ground faults and result from insulator flashover during electrical storms. Only one in twenty faults is due to the balanced category.

A fault will cause currents of high value to flow through the network to the faulted point. The amount of current may be much greater than the designed thermal ability of the conductors in the power lines or machines feeding the fault. As a result, temperature rise may cause damage by annealing of conductors and insulation charring. In addition, the low voltage in the neighborhood of the fault will cause equipment malfunction.

Short-circuit and protection studies are an essential tool for the electric energy systems engineer. The task is to calculate the fault conditions and to provide protective equipment designed to isolate the faulted zone from the remainder of the system in the appropriate time.

The least complex fault category computationally is the balanced fault. It is possible that a balanced fault could (in some locations) result in currents smaller than that due to some other type of fault. The interrupting capacity of breakers should be chosen to accommodate the largest of fault currents, and hence, care must be taken not to base protection decisions on the results of a balanced three phase fault.<sup>1</sup>

## **ETAP SHORT CIRCUIT ANALYSIS<sup>2</sup>**

The ETAP Short-Circuit Analysis program analyzes the effect of 3-phase, line-to-ground, line-to-line, and line-to-line-to-ground faults on electrical distribution systems. The program calculates the total short circuit currents as well as the contributions of individual motors, generators, and utility ties in the system. Fault duties are in compliance with the latest editions of the ANSI/IEEE Standards (C37 series) and IEC Standards (IEC 60909 and others).

### **ANSI/IEEE Calculation Methods**

In ANSI/IEEE short circuit calculations, an equivalent voltage source at the fault location, which equals the pre-fault voltage at the location, replaces all external voltage sources and machine internal voltage sources.

All machines are represented by their internal impedances. Line capacitances and static loads are neglected. Transformer taps can be set at either the nominal position or at the tapped position, and different schemes are available to correct transformer impedance and system voltages if off-nominal tap setting exists. It is assumed that for 3-phase fault, the fault is bolted. Therefore, arc resistances are not considered. You can specify fault impedance in the Short Circuit Study Case for single-phase to ground fault. System impedances are assumed to be balanced 3-phase, and the method of symmetrical components is used for unbalanced fault calculations.

Three different impedance networks are formed to calculate momentary, interrupting, and steady-state short circuit currents, and corresponding duties for various protective devices. These networks are:  $\frac{1}{2}$  cycle network (sub transient network), 1.5-4 cycle network (transient network), and 30 cycle network (steady-state network).

ANSI/IEEE Standards recommend the use of separate R and X networks to calculate X/R values. An X/R ratio is obtained for each individual faulted bus and short circuit current. This X/R ratio is then used to determine the multiplying factor to account for the system DC offset.

Using the  $\frac{1}{2}$  cycle and 1.5-4 cycle networks, the symmetrical rms value of the momentary and interrupting short circuit currents are solved first. These values are then multiplied by appropriate multiplying factors to finally obtain the asymmetrical value of the momentary and interrupting short circuit currents.

### **$\frac{1}{2}$ Cycle Network**

This is the network used to calculate momentary short circuit current and protective device duties at the  $\frac{1}{2}$  cycle after the fault. The  $\frac{1}{2}$  cycle network is also referred to as the sub-transient network, primarily because all rotating machines are represented by their sub-transient reactance.

---

<sup>1</sup> Introduction to Electrical Power System by Mohamed E. El Hawary

<sup>2</sup> ETAP Help

## 1½-4 Cycle Network

This network is used to calculate the interrupting short circuit current and protective device duties 1.5-4 cycles after the fault. The 1.5-4 cycle network is also referred to as the transient network.

## 30 Cycle Network

This is the network used to calculate the steady-state short circuit current and duties for some of the protective devices 30 cycles after the fault. Induction machines, synchronous motors, and condensers are not considered in the 30 cycle fault calculation.

## ANSI Short Circuit Toolbar<sup>3</sup>

This toolbar is active when you are in Short-Circuit mode and the standard is set to ANSI in the Short Circuit Study Case editor.



- 3-Phase Faults – Device Duty**
- Panel/1-Ph UPS/ 1-Ph System Device Duty**
- LG, LL, LLG & 3-Phase Faults – ½ Cycle**
- LG, LL, LLG & 3-Phase Faults – 1.5-4 Cycle**
- LG, LL, LLG & 3-Phase Faults – 30 Cycle**
- Arc Flash Hazard Calculation (3Ph and 1-Ph)**
- Short-Circuit Display Options**
- Alert View**
- Short-Circuit Report Manager**
- Arc Flash Report Analyzer**
- Halt Current Calculation**
- Get On-Line Data**
- Get Archived Data**

### 3-Phase Faults - Device Duty

Click this button to perform a 3-phase fault study per ANSI C37 Standard. This study calculates momentary symmetrical and asymmetrical rms, momentary asymmetrical crest, interrupting symmetrical rms, and interrupting adjusted symmetrical rms short circuit currents at faulted buses. ETAP checks the protective device rated close and latching, and adjusted interrupting capacities against the fault currents, and flags inadequate devices. Generators and motors are modeled by their positive sequence sub-transient reactance. Note that device duty calculation for protective devices that are connected to single-phase loads is carried out only when you run the Panel/UPS/1-Ph System Device Duty calculation.

<sup>3</sup> ETAP Help

**LG, LL, LLG, & 3-Phase Faults - ½ Cycle (Max. Short-Circuit Current)**

Click on this button to perform 3-phase, line-to-ground, line-to-line, and line-to-line-to-ground fault studies per ANSI Standards. This study calculates short circuit currents in their rms values at ½ cycle at faulted buses, which are considered the maximum short-circuit current values.

Generators and motors are modeled by their positive, negative, and zero sequence sub-transient reactance. Generator, motor, and transformer grounding types and winding connections are taken into consideration when constructing system positive, negative, and zero sequence networks.

**LG, LL, LLG, & 3-Phase Faults - 1.5 to 4 Cycle**

Click on this button to perform 3-phase, line-to-ground, line-to-line, and line-to-line-to-ground fault studies per ANSI Standards. This study calculates short circuit currents in their rms values between 1.5 to 4 cycles at faulted buses.

Generators are modeled by their positive, negative, and zero sequence sub-transient reactance, and motors are modeled by their positive, negative, and zero sequence transient reactance. Generator, motor, transformer grounding types, and winding connections are taken into considerations when constructing system positive, negative, and zero sequential networks.

**LG, LL, LLG, & 3-Phase Faults - 30 Cycle (Min. Short-Circuit Current)**

Click on this button to perform 3-phase, line-to-ground, line-to-line, and line-to-line-to-ground fault studies per ANSI Standards. This study calculates short circuit currents in their rms values at 30 cycles at faulted buses, which are the minimum, short-circuit current values.

Generators are modeled by their positive, negative, and zero sequence reactance, and short circuit current contributions from motors are ignored. Generator and transformer grounding types and winding connections are taken into consideration when constructing system positive, negative, and zero sequence networks.

**Short-Circuit Display Options**

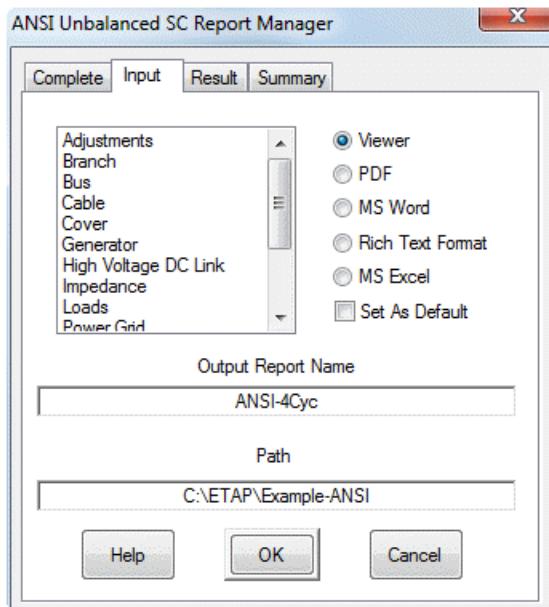
See the Display Options section to customize the Short-Circuit Annotation Display options on the one-line diagram. This dialog box contains options for ANSI short-circuit study results and associated device parameters. This includes displayed results for 3-phase and unbalanced faults (LG, LL, and LLG) and their individual contributions.

**Alert**

After performing a short-circuit device duty calculation, you can click on this button to open the Alert View, which lists all devices with critical and marginal violations based on the settings in the Study Case.

## Short-Circuit Report Manager

Short-Circuit Output Reports are provided in Crystal Report format. The Report Manager provides four pages (Complete, Input, Result, and Summary) for viewing the different parts of the output report. Available formats for Crystal Reports are displayed in each page of the Report Manager for ANSI short-circuit studies. You can open and save the report in PDF, MS Word, Rich Text Format, or Excel format. You can open the whole short-circuit output report or only a part of it, depending on the format selection.



You can also view output reports by clicking on the View Output Report button on the Study Case toolbar. A list of all output files in the selected project directory is provided for short circuit calculations. To view any of the listed output reports, click on the output report name, and then click on the View Output Report button.

## EXERCISE

- Open the network modeled in IEEE 4 Bus System.
- Open Short Circuit Mode.
- Set the standard to ANSI.
- Place fault one at a time on each bus and click 3-Phase Faults - Device Duty.
- It can be seen that fault current is also contributed by the motor.
- Run 3 phase faults for different cycles. Note the values in tables given below.
- Open the network modeled in IEEE 9 Bus System.
  - Set G1's  $X_d'' = 0.4$
  - Set G2's  $X_d'' = 0.8$
  - Set G3's  $X_d'' = 3$
- Place a reactor in series with generator G1. Design the reactor such that the generator G1's current is limited to 100 times the full load current. Show your calculations.

## **OBSERVATION**

### **Fault at Bus 1 - 3-Phase Fault**

	$I_{sc}$	Current (A)	Generator Contribution	Motor Contribution
Bus 1	<b><math>\frac{1}{2}</math> Cycle (Max. Short-Circuit Current)</b>			
	<b>1.5 to 4 Cycle (Transient Short- Circuit Current)</b>			
	<b>30 Cycle (Min. Short- Circuit Current)</b>			

### **Fault at Bus 2 - 3-Phase Fault**

	$I_{sc}$	Current (A)	Generator Contribution	Motor Contribution
Bus 2	<b><math>\frac{1}{2}</math> Cycle (Max. Short-Circuit Current)</b>			
	<b>1.5 to 4 Cycle (Transient Short- Circuit Current)</b>			
	<b>30 Cycle (Min. Short- Circuit Current)</b>			

### **Fault at Bus 3 - 3-Phase Fault**

	$I_{sc}$	Current (A)	Generator Contribution	Motor Contribution
Bus 3	<b><math>\frac{1}{2}</math> Cycle (Max. Short-Circuit Current)</b>			
	<b>1.5 to 4 Cycle (Transient Short- Circuit Current)</b>			
	<b>30 Cycle (Min. Short- Circuit Current)</b>			

### **Fault at Bus 4 - 3-Phase Fault**

	$I_{sc}$	Current (A)	Generator Contribution	Motor Contribution
Bus 4	<b><math>\frac{1}{2}</math> Cycle (Max. Short-Circuit Current)</b>			
	<b>1.5 to 4 Cycle (Transient Short- Circuit Current)</b>			
	<b>30 Cycle (Min. Short- Circuit Current)</b>			

**Fault at Bus 1 of IEEE 9 Bus System - 3 Phase Faults -  $\frac{1}{2}$  Cycle (Max. Short-Circuit Current)**

After placing a series reactor in series with the generator G1.

Bus 1	$I_{sc}$	Current (A)	Generator Contribution
	<b><math>\frac{1}{2}</math> Cycle (Max. Short-Circuit Current) Before Placement of Series Reactor</b>		
	<b><math>\frac{1}{2}</math> Cycle (Max. Short-Circuit Current) After Placement of Series Reactor</b>		

## CALCULATION OF SERIES REACTOR

## CONCLUSION



Course Code: **EE-362**

Laboratory Session No.:

Course Title: **Power System Analysis**

Date:

<b>Psychomotor Domain Assessment Rubric for Laboratory (Level P3)</b>					
Skill(s) to be assessed	Extent of Achievement				
	0	1	2	3	4
<b>Software Initialisation and Configuration:</b> Set up and <u>recognise</u> software initialisation and configuration steps	Completely unable to recognise initialisation and configuration	Able to recognise initialisation but could not configure	Able to recognise initialisation but configuration is erroneous	Able to recognise/perform initialisation and configuration with minimal errors	Able to recognise/perform initialisation and configuration with complete success
<b>Software Menu Identification and Usage:</b> Ability to <u>operate</u> software environment <u>under supervision</u> , using menus, shortcuts, instructions etc.	Unable to understand and use software menu	Little ability and understanding of software menu operation, makes many mistakes	Moderate ability and understanding of software menu operation, makes lesser mistakes	Reasonable understanding of software menu operation, makes no major mistakes	Demonstrates command over software menu usage with frequent use of advance menu options
<b>Modeling of given SLD/Network Diagram:</b> Ability to <u>operate</u> software environment in order to create simulation model of given network parameters	Unable to operate software, could not create simulation model	Moderately able to operate software, could not create simulation model	Adequately able to operate software, simulation model contains errors	Adequately able to operate software, simulation model is error free	Demonstrates mastery over software, error free simulation model is created and simulation is started
<b>Detecting and Removing Errors:</b> <u>Detect</u> Errors/Exceptions and in simulation model and <u>manipulate</u> model to rectify the simulation	Unable to check and detect error messages and indications in software	Able to find error messages and indications in software but no understanding of detecting those errors and their types	Able to find error messages and indications in software as well as understanding of detecting some of those errors and their types	Able to find error messages in software as well as understanding of detecting all of those errors and their types	Able to find error messages in software along with the understanding to detect and rectify them

Psychomotor Domain Assessment Rubric for Laboratory (Level P3)					
Skill(s) to be assessed	Extent of Achievement				
	0	1	2	3	4
<b>Graphical Visualisation and Comparison of Model/Network Parameters:</b> <u>Manipulate</u> given model/simulation under supervision, in order to produce graphs/plots for measuring and comparing network parameters	Unable to understand and utilise visualisation or plotting features	Ability to understand and utilise visualisation and plotting features with frequent errors	Ability to understand and utilise visualisation and plotting features successfully but unable to compare and analyse them	Ability to understand and utilise visualisation and plotting features successfully, partially able to compare and analyse them	Ability to understand and utilise visualisation and plotting features successfully, also able to draw conclusions after analysis
<b>Following step-by-step procedure to complete lab work:</b> <u>Observe, imitate and operate</u> software to complete the provided sequence of steps	Inability to recognise and perform given lab procedures	Able to recognise given lab procedures and perform them but could not follow the prescribed order of steps	Able to recognise given lab procedures and perform them by following prescribed order of steps, with frequent mistakes	Able to recognise given lab procedures and perform them by following prescribed order of steps, with occasional mistakes	Able to recognise given lab procedures and perform them by following prescribed order of steps, with no mistakes
<b>Recording Simulation Observations:</b> <u>Observe and copy</u> prescribed or required simulation results in accordance with lab manual instructions	Inability to recognise prescribed or required simulation measurements	Able to recognise prescribed or required simulation measurements but does not record according to given instructions	—	Able to recognise prescribed or required simulation measurements but records them incompletely	Able to recognise prescribed or required simulation measurements and records them completely, in tabular form
<b>Discussion and Conclusion:</b> <u>Demonstrate</u> discussion capacity on the recorded observations and draw conclusions from it	Complete inability to discuss recorded observations and draw conclusions	Slight ability to discuss recorded observations and draw conclusions	Moderate ability to discuss recorded observations and draw conclusions	Reasonable ability to discuss recorded observations and draw conclusions	Full ability to discuss recorded observations and draw conclusions

**LAB SESSION 7****TITLE**

Symmetrical component analysis on Simulink.

**OBJECTIVES**

1. To observe the set of symmetrical components currents and voltages using sequence analyzer in MATLAB
2. To observe the effect of neutral grounding on the flow of zero sequence current
3. To observe different cases of unbalancing (Unbalanced loads, unbalanced faults)
4. To observe the complex power associated with the symmetrical components

**THEORY**

The method of symmetrical components is used to simplify fault analysis by converting a three-phase unbalanced system into two sets of balanced phasors and a set of single-phase phasors, or symmetrical components. These sets of phasors are called the positive-, negative-, and zero-sequence components. These components allow for the simple analysis of power systems under faulted or other unbalanced conditions. Once the system is solved in the symmetrical component domain, the results can be transformed back to the phase domain.

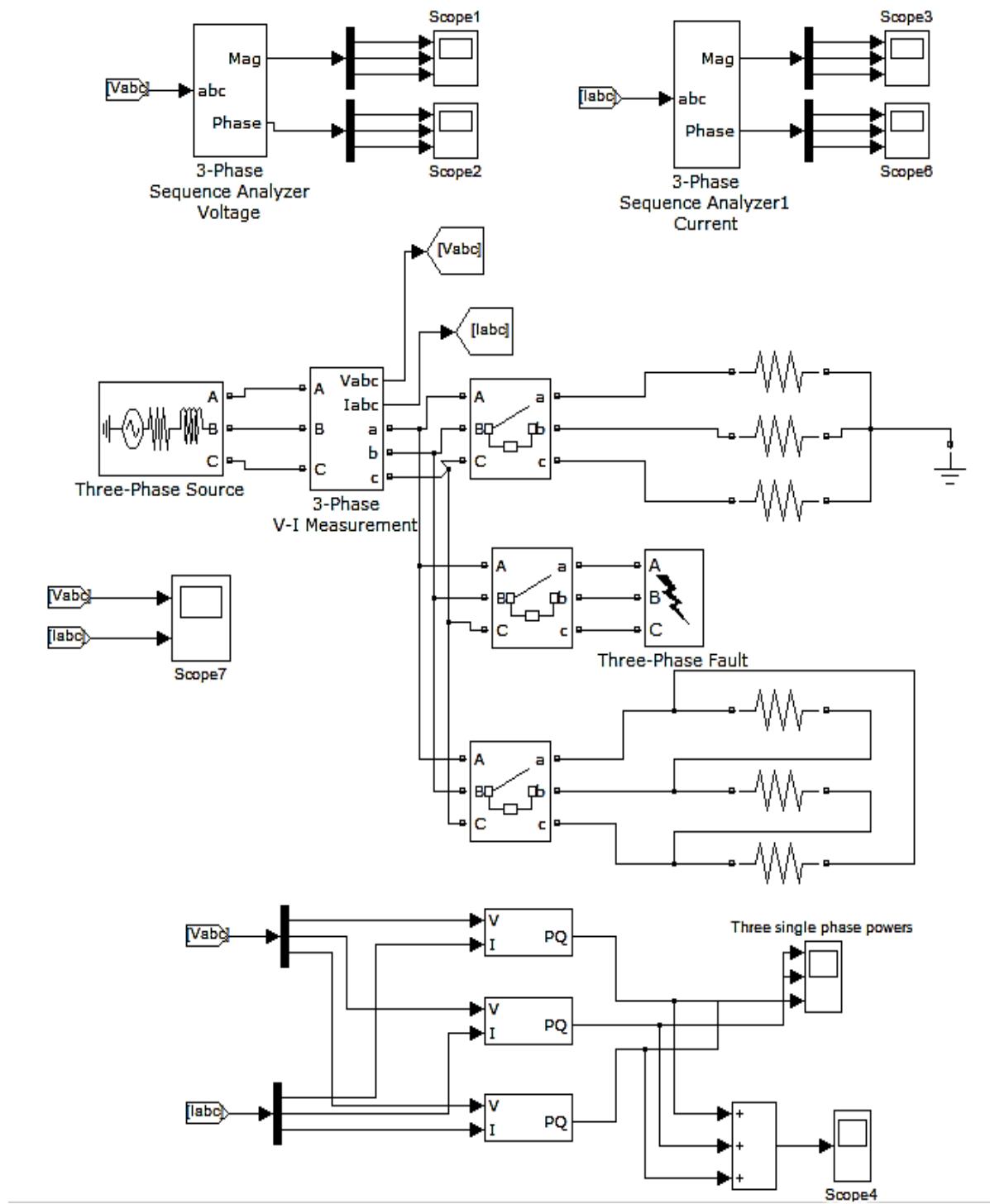
**EXERCISE**

- Build the model shown on next page.
- Run the different conditions and fill the observation table

**OBSERVATION**

Complete the following table by ticking the appropriate column.

Condition	Currents			Voltages		
	$I_0$	$I_1$	$I_2$	$V_0$	$V_1$	$V_2$
Balanced Star connected load						
Balanced Delta connected load						
Unbalanced star load (grounded)						
Unbalanced star load (ungrounded)						
Unbalanced delta connected load						
Single line to ground fault						
Line to Line fault						
Double line to ground fault						



## **CONCLUSION**

**LAB SESSION 8****TITLE**

Digital faults simulation in stand-alone mode on **AEL-CPSS-01S**.

**APPARATUS**

- Industrial Power Supply (N-ALI01).
- Instrumentation Module 1 (N-PPIM2).
- Control and Protection of Turbine-Generator Group Module 1 (N-PPCM1).
- Power Generation Substation Module 1 (N-PSUB3).
- Transmission Lines Simulation module (N-AE1CD).
- 3 x 300 W Three-Phase Configurable resistors Module (N-REFT/3C).
- 3 x 300 VAr Three-Phase Configurable Inductances Module (N-INDT/3C).
- 3 x 300 VAr Three-Phase Configurable Capacitors Module (N-CAR19T/3C).
- Distribution Busbar Module (N-BUS08).
- Coupling Busbar (NBUS09).
- GMG4.5K2PH. 4,5 kW Generator-Motor Group (GMG4.5K3PH).
- Digital Fault Simulator Module (N-ERP-MF01).

**EXERCISE**

- Carry out the step described in the paragraph “Starting up the application”. (See Appendix)
- Carry out the wiring shown in the cable assembly section, “ Stand –alone configuration with transmission line and loads wiring”. (See Appendix)
- Back-up protections parameters are already set so the students must not vary its potentiometers:

<i>Back-up protections</i>	Level	Hysteresis	Delay
Overcurrent protection	115%	10%	3s
Inverse power protection	20%	1%	2s

- The table below shows the final position of the switches placed in the N-PSUB module and the sequence needed to control automatically the motor-generator group:

SWITCHES	POSITION
Enable/Disable 52NET	Right (Disable 52NET)
Local/SCADA Control Mode	UP (Local Control Mode)
Manual/Automatic Speed Control	DOWN (Automatic Speed Control)
Manual/Automatic Excitation Control	DOWN (Automatic Excitation Control)

Start/Stop Turbine	Left (Start Turbine)
52G Synchronization Permission	UP

- The digital fault simulation module is injected on the load.
- The three resistive loads must be turned on and consuming power.
- Set the type of fault to be injected. Play also with the impedances of the fault line and check its effects.
- Push the button “fault injection” to start the fault simulation.
- Check the effect of the fault injection.
- Remove the neutral connection with ground and check the effect on different fault currents.
- Do not forget to carry out the step described in the paragraph “Shutting down the application” (See Appendix) to turn off the unit.

## **OBSERVATION**

Line Current before occurrence of any fault: \_\_\_\_\_ A

<i>Trip Time = 0.2 s</i>	<b>Type of Fault</b>	<b>Three – Phase Fault Current (A)</b>	<b>Single Line to Ground Fault Current (A)</b>	<b>Line to Line Fault Current (A)</b>
Grounded System	Bolted			
	Unbolted			
Ungrounded System	Bolted			
<i>Trip Time = 0.3 s</i>	<b>Type of Fault</b>	<b>Three – Phase Fault Current (A)</b>	<b>Single Line to Ground Fault Current (A)</b>	<b>Line to Line Fault Current (A)</b>
Grounded System	Bolted			
	Unbolted			
Ungrounded System	Bolted			

## **CONCLUSION**

**LAB SESSION 9****TITLE**

Solution of Non Linear Algebraic Equations on MATLAB

**THEORY**

Non Linear Algebraic Equations such as N Power Flow Equations for N number of buses are solved using techniques called Iterative solutions of Non Linear Algebraic equations.

The most common solution techniques are Gauss-Seidel method and Newton-Raphson method.

**GAUSS-SEIDEL METHOD**

Consider the solution of a non linear equation given by:

$$F(x) = 0$$

This function can be rearranged and written as :

$$x = g(x)$$

If  $x^{(k)}$  is an initial estimate of the variable x, the following iterative sequence is formed:

$$x^{(k+1)} = g(x^{(k)})$$

A solution is obtained when the difference between the absolute value of the successive iteration is less than a specified accuracy, i.e.

$$|x^{(k+1)} - x^{(k)}| < \epsilon$$

where  $\epsilon$  is the desired accuracy.

Consider a non linear algebraic equation:

$$F(x) = x^3 - 6x^2 + 9x - 4 = 0$$

Solving for x ;

$$X = -1/9 x^3 + 6/9 x^2 + 4/9 = g(x)$$

Apply the Gauss Seidel algorithm and use an initial estimate of :

$$x^{(0)} = 2$$

$$x^{(1)} = g(2) = 2.2222$$

$$x^{(2)} = g(2.2222) = 2.517$$

.

.

.

$$x^{(7)} = g(3.956) = 3.998$$

$$x^{(8)} = g(3.998) = 4.0000$$

$$x^{(9)} = g(4.000) = 4.000$$

So the first root is 4.

## NEWTON RAPHSON METHOD

Consider the following non linear algebraic equation:

$$F(x) = 0$$

Find  $d F(x) / dx = J$  & Find  $-F(x) = 0$

At an initial estimate  $x^{(0)}$ , find  $\Delta x^{(0)}$ :

$$\Delta x^{(0)} = [-F(x^{(0)}) / (d F(x) / dx)^{(0)}]$$

$$x^{(1)} = x^{(0)} + \Delta x^{(0)}$$

Successive use of this procedure yields Newton Raphson Algorithm:

$$x^{(k+1)} = x^{(k)} + \Delta x^{(k)}$$

A solution is obtained when the difference between the absolute value of the successive iteration is less than a specified accuracy, i.e.

$$|x^{(k+1)} - x^{(k)}| < \epsilon$$

where  $\epsilon$  is the desired accuracy.

Consider a non linear algebraic equation:

$$F(x) = x^3 - 6x^2 + 9x - 4 = 0$$

$$d F(x) / dx = 3x^2 - 12x + 9$$

$$F(x) = -x^3 + 6x^2 - 9x + 4 = 0$$

use an initial estimate of  $x^{(0)} = 6$

$$(d F(x) / dx)^{(0)} = 3(6)^2 - 12(6) + 9 = 45$$

$$-F(x^{(0)}) = -6^3 + 6(6)^2 - 9(6) + 4 = -50$$

$$\Delta x^{(0)} = -50 / 45 = -1.111$$

$$x^{(1)} = x^{(0)} + \Delta x^{(0)} = 6 - 1.1111 = 4.8889$$

$$x^{(2)} = x^{(1)} + \Delta x^{(1)} = 4.8889 - 13.44 / 22.03 = 4.278$$

.

.

.

$$x^{(5)} = x^{(4)} + \Delta x^{(4)} = 4.0011 - 0.0095 / 9.0126 = 4.0000$$

So the first root is 4.

It can be seen that:

- Newton Raphson requires less number of iterations to achieve the desired accuracy
- There is no guarantee, but relatively more probability of convergence.
- Convergence depends on the value of initial estimate .
- The initial estimate cannot be a value at which rate of change of function is zero.
- Calculations for Newton Raphson are relatively complex.
- One root at a time is calculated. For other solutions, the process has to be repeated with a different initial estimate.

## **EXERCISE**

Following commands shows the procedure for the solution of the given equation by using Gauss- Seidel method with an initial estimate of  $x^{(0)} = 2$ . Enter them in MATLAB command window.

```
dx=1;
x=2;
iter=0;
disp('Iter  g  dx  x')
while abs(dx) >= 0.001 & iter < 100
iter= iter + 1;
g= -1/9*x^3+6/9*x^2+4/9;
dx=g-x;
x= x + dx;
fprintf('%g', iter), disp([g,dx,x])
end
```

Following commands shows the procedure for the solution of the given equation by using Newton- Raphson method with an initial estimate of  $x^{(0)} = 6$ . Enter them in MATLAB command window.

```
dx = 1;
x = input('Enter initial estimate - > ') ;
iter = 0 ;
disp(' iter  Dc  J  dx  x')
while abs(dx) >= 0.001 & iter < 100
iter= iter +1;
Dc = 0 - (x^3 - 6*x^2 + 9*x - 4) ;
J= 3*x^2 - 12*x +9 ;
Dx = Dc/J ;
x= x + dx ;
fprintf('%g' , iter),disp([Dc,J,dx,x])
end
```

## **LAB SESSION 10**

### **TITLE**

Sequence networks

### **OBJECTIVES**

1. To study effect of winding configuration on symmetrical and asymmetrical faults.

### **EXERCISE**

- In the model given in lab 3, observe the effect of change in ground connections of the generator on fault at the generator bus.
- In the model given in lab 3, observe the effect of change in winding connections of the transformer on different fault types, on both sides of the transformer.
- Justify your observations by constructing relevant sequence networks.

### **OBSERVATION**

Attach different models here. Also explain results of each model with its figure respectively.

## **CONCLUSION**



Course Code: **EE-362**

Laboratory Session No.:

Course Title: **Power System Analysis**

Date:

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Skill(s) to be assessed	Extent of Achievement				
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<b>Software Initialisation and Configuration:</b> Set up and <u>recognise</u> software initialisation and configuration steps	Completely unable to recognise initialisation and configuration	Able to recognise initialisation but could not configure	Able to recognise initialisation but configuration is erroneous	Able to recognise/perform initialisation and configuration with minimal errors	Able to recognise/perform initialisation and configuration with complete success
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<b>Detecting and Removing Errors:</b> <u>Detect</u> Errors/Exceptions and in simulation model and <u>manipulate</u> model to rectify the simulation	Unable to check and detect error messages and indications in software	Able to find error messages and indications in software but no understanding of detecting those errors and their types	Able to find error messages and indications in software as well as understanding of detecting some of those errors and their types	Able to find error messages in software as well as understanding of detecting all of those errors and their types	Able to find error messages in software along with the understanding to detect and rectify them

Psychomotor Domain Assessment Rubric for Laboratory (Level P3)					
Skill(s) to be assessed	Extent of Achievement				
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<b>Discussion and Conclusion:</b> <u>Demonstrate</u> discussion capacity on the recorded observations and draw conclusions from it	Complete inability to discuss recorded observations and draw conclusions	Slight ability to discuss recorded observations and draw conclusions	Moderate ability to discuss recorded observations and draw conclusions	Reasonable ability to discuss recorded observations and draw conclusions	Full ability to discuss recorded observations and draw conclusions

## LAB SESSION 11

### **TITLE**

To perform the load flow analysis on ETAP.

### **OBJECTIVES**

1. To design a power system such that
  - a. It has a swing bus with at least 2 generators in parallel. The voltage of the generators is in the range of 11-18kV with a rating ranging from 10-50 MVA.
  - b. At least 2 transmission circuits are radiating out from the swing bus. Each transmission circuit is connected to at least 1 distribution grid which steps down the voltage to 11kV.
  - c. Distribution grid of the city is at least 40 km away from the generation station. Connect the primary feeders to different loads and show details of appropriate load sizing.

### **THEORY**

The load flow or the power flow problems involves calculating voltages magnitudes and angles, current and power injections at the various buses in the power system. The load flow is a static network analysis, that is, the values of the impedances and currents must be the same. There can be various methods to calculate the load flow analysis like Gauss Siedel method, Gauss Jacobi method, Newton Raphson method etc.

### **ETAP LOAD FLOW ANALYSIS<sup>4</sup>**

The ETAP Load Flow Analysis module calculates the bus voltages, branch power factors, currents, and power flows throughout the electrical system. ETAP allows for swing, voltage regulated, and unregulated power sources with multiple power grids and generator connections. It is capable of performing analysis on both radial and loop systems. ETAP allows you to select from several different methods in order to achieve the best calculation efficiency.

### **LOAD FLOW TOOLBAR<sup>1</sup>**

The Load Flow Toolbar will appear on the screen when you are in the Load Flow Study mode.



### **RUN LOAD FLOW STUDIES<sup>1</sup>**

Select a study case from the Study Case Editor. Then click on the Run Load Flow Study icon to perform a load flow study. A dialog box will appear to specify the output report name

<sup>4</sup> ETAP Help

if the output file name is set to Prompt. The study results will then appear on the one-line diagram and in the output report.

## **LOAD FLOW DISPLAY OPTIONS<sup>1</sup>**

The results from load flow studies are displayed on the one-line diagram. To edit how these results look, click on the Load Flow Display Options icon.

## **ALERT VIEW<sup>1</sup>**

After performing a load flow study, you can click on this button to open the Alert View, which lists all equipment with critical and marginal violations based on the settings in the study case.

## **LOAD FLOW REPORT MANAGER<sup>1</sup>**

Load flow output reports are provided in the form of a Crystal Report. The Report Manager provides four pages (Complete, Input, Result, and Summary) for viewing the different parts of the output report for Crystal Reports. Available formats for Crystal Reports are displayed in each page of the Report Manager for load flow studies. You can view the report in the Crystal Reports viewer, or save the report in PDF, MS Word, Rich Text Format, or Excel format. If you wish this selection to be the default for reports, click the Set As Default check box.

Choosing any format in the Report Manager activates the Crystal Reports. You can open the whole load flow output report or only a part of it, depending on the format selection. The format names and corresponding output report sections are given below:

- Adjustments Indicates tolerance and temperature correction adjustments
- Alert-Complete Provides complete report of system alerts
- Alert-Critical Provides summary of critical alerts only
- Alert-Marginal Provides summary of marginal alerts only
- Branch Loading Branch loading results
- Branch: Branch input data
- Bus Loading Displays overloaded bus information
- Bus: Bus input data
- Cable: Cable input data
- Complete output report including all input and output
- Cover Title page of the output report
- Equipment Cable Equipment cable input data
- High Voltage DC Link High Voltage DC Link input data
- Impedance Provides detailed information about impedance elements in the system
- Line Coupling Displays Transmission Line coupling impedance data
- Load Flow Report Load Flow calculation results
- Losses Branch loss results
- NO Protective Devices Displays Normally Open protective devices
- Panel Report Load Flow calculation results for panel systems
- Reactor: Reactor input data
- Summary: Summary of load flow calculation

- SVC Static Var Compensator (SVC) input data
- Transformer: Transformer input data
- UPS Report Load Flow calculation results for UPS systems

## **OBSERVATION**

Attach your model here. Also mention details of your model including sizing of different equipment, type of conductors used etc. Give reasons for your selection.

## **CONCLUSION**



Course Code: **EE-362**

Laboratory Session No.:

Course Title: **Power System Analysis**

Date:

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Psychomotor Domain Assessment Rubric for Laboratory (Level P3)					
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## **LAB SESSION 12**

### **OPEN ENDED LAB**

Asymmetrical Fault analysis on ETAP

### **OBJECTIVES**

1. To design a 4-6 bus power system such that the maximum fault current on any bus does not exceed the three-phase bolted fault current on that bus.
2. To perform asymmetrical short circuit analysis (SLG, L-L, DLG) using ETAP.
3. To observe the effect of neutral grounding in asymmetrical faults.

### **Submission Details:**

**The open-ended lab must be submitted as a separate document.**

You must write and submit complete report in both soft and hard copy.

The report must consist of the following sections:

- Introduction
- Methodology
- Test System Details
- Simulation and Discussion (Show calculations where needed)
- Conclusion

## Cover Page for Each PBL/OEL

<b>Course Code:</b>	
<b>Course Name:</b>	
<b>Semester:</b>	
<b>Year:</b>	
<b>Section:</b>	
<b>Batch:</b>	
<b>Lab Instructor name:</b>	
<b>Submission deadline:</b>	

### PBL or OEL Statement:

Asymmetrical fault analysis on ETAP

### Deliverables:

Following are deliverables for the assigned task:

Introduction

Test system details

Simulation and discussion

Conclusion

### Methodology:

Development of proper SLD of suitable size network

Proper insertion of equipment capacities as per the selected network

Perform and record short circuit analysis (asymmetrical) results

Discuss the effect of neutral grounding on fault analysis

Guidelines:

Develop report of the task as per described methodology

Rubrics:

Properly written introduction of the problem [2.5 marks]

Description the test system details in tabular or para form [2.5 marks]

Drawing/SLD of test system implementation [2.5 marks]

Results interpretation [2.5 marks]



Course Code: **EE-362**

Laboratory Session No.:

Course Title: **Power System Analysis**

Date:

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