DEPARTMENT OF ELECTRICAL ENGINEERING

MANUAL
FOR
POWER SYSTEMS LABORATORY

(B.TECH)

Fourth Edition

COLLEGE OF ENGINEERING TRIVANDRUM

THIRUVANANTHAPURAM – 695016. KERALA

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DEPARTMENT OF ELECTRICAL ENGINEERING

COLLEGE OF ENGINEERING TRIVANDRUM, THIRUVANANTHAPURAM – 695016. KERALA

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DEPARTMENT OF ELECTRICAL ENGINEERING

COLLEGE OF ENGINEERING TRIVANDRUM,

Thiruvananthapuram – 695016

VISION:

Be a center of excellence and higher learning in Electrical Engineering and allied areas.

MISSION:

- To impart quality education in Electrical Engineering and bring up professionally competent engineers
- To mould ethically sound and socially responsible Electrical Engineers with leadership qualities.
- To inculcate research attitude among students and encourage them to pursue higher studies.

Program Educational Objectives (PEOs)

Graduates will

1. Excel as technically competent Electrical Engineers.
2. Excel in higher studies and build on fundamental knowledge to develop technical skills within and across disciplines.
3. Have the ability to function effectively as members or leaders in technical teams.
4. Adapt to changes in the global technological area and social needs through lifelong learning.

Program outcomes

PO1 Apply the knowledge of mathematics, science and engineering fundamentals and an engineering specialization to the solution of complex engineering problems.

PO2 Identify, formulate, review research literature and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences

PO3 Design solutions for complex engineering problems and design system components or processes that meet the specific needs with appropriate consideration for the public health and safety, and the cultural, societal and environmental considerations

PO4 Use research based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

PO5 Create, select and apply appropriate techniques, resources and modern engineering and IT tools including predictions and modelling to complex engineering activities with an understanding of the limitations.

PO6 Apply reasoning informed by the contextual knowledge to assess social, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

PO7 Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

PO8 Function effectively as an individual and as a member or leader in diverse teams and in multidisciplinary settings.

PO9 Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentation and give and receive clear instructions.

PO10 Demonstrate knowledge and understanding of the engineering and management principles and apply these to one’s work, as a member and leader in a team to manage projects and multidisciplinary environments.

PO11 Recognize the need for and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

PCEEL609 (Power Systems Lab)

Course Outcomes

CO1	Apply fundamental power system analysis techniques to determine the operating parameters under steady state and faulty conditions.
CO2	Develop mathematical models and conduct steady state and transient analysis of power system networks using standard software.
CO3	Develop a frequency domain model of the power system network and conduct a stability analysis.
CO4	Conduct appropriate tests on any power system component in accordance with relevant standards.

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INTRODUCTION TO HIGH VOLTAGE TESTING

With a large number of high-voltage and extra-high-voltage transmission systems being constructed in our country, expensive electrical equipment is being put in service. It is necessary to ensure that such equipment is capable of withstanding the over-voltages normally encountered in service. Overvoltages may be due to natural causes, such as lightning, or system-originated ones, such as switching power frequency transient voltages. The over-voltage tests are classified into two groups:

i) Power frequency voltage tests and

ii) Impulse voltage tests.

These tests together ensure the over-voltage withstand capability of an apparatus.

Definitions:

In test codes and standard specifications, certain technical terms are used to specify and define conditions or procedures.

- **Disruptive Discharge Voltage**

  This is defined as the voltage which produces the loss of dielectric strength of insulation. It is the voltage at which the electric field stress in the insulation causes a failure, which includes a collapse of voltage and passage of current.

- **Withstand Voltage**

  The voltage which has to be applied to a test object under specified conditions in a withstand test is called the withstand voltage. (As per IS: 731 and IS: 2099-1963)

- **50% Flash overvoltage**

  This is the voltage that has a 50% probability of flashover when applied to a test object. This is usually applied in impulse tests in which the loss of insulation strength is temporary.

- **100% Flash over Voltage**

  The voltage that causes flashover at each of its applications under specified conditions when applied to test objects is specified as the 100% flashover voltage.

- **Creepage Distance**

  It is the shortest distance on the contour of the external surface of the insulator unit or between two metal fittings on the insulator.

1) AC test voltages

Alternating test voltages of power frequency should have a frequency range of 40 to 60 Hz and should be approximately sinusoidal. The deviation allowed from the standard sine curve is about 7%.

2) Impulse Voltages

Impulse voltages are characterized by polarity, peak value, time to front (t_f) and time to half the peak value after the peak (t_t) - The time to front is defined as 1.67 times the time between 30% and 90% of the peak value in the rising portion of the wave. According to IS: 2071 (1973), a standard impulse is defined as one with t_f = 1.2 µs, t_t = 50 µs (called 1/50 µs wave).

3) Reference Atmospheric conditions

The electrical characteristics of the insulators and other apparatus are generally referred to the reference atmospheric conditions. According to IS, they are

Temperature: 27^{o}C

Pressure: 1013 milli bars (760 mm of Hg)

Absolute humidity: 17 gm/m^3

Since it is not always possible to do tests under these reference conditions, correction factors have to be applied

SAFETY REGULATIONS FOR HIGH VOLTAGE EXPERIMENTS

Experiments with high voltages could become particularly hazardous for the participants. So adequate safety precautions should be taken. Here any voltage greater than 250V against earth is understood to be a high voltage.

Fundamental rule before entering a high voltage setup:

Everyone must convince themselves by personal observation that all conductors that can assume high potential and lie in the contact zone are earthed and that the main leads are interrupted.

Earthing:

Fixing the earthing leads on to the parts to be earthed should be done with the aid of insulating rods. Earthing may only be established after switching the current source off and may be removed only when no one is present within the fence. All metallic parts of the setup which do not carry potential during normal service must be earthed reliably and with an adequate cross-section of at least 1.5 mm^2 copper wire.

Circuit and test set up:

All components of the setup must be either rigidly fixed or suspended so that they cannot topple during operation or be pulled down by the leads. A test set-up may be pulled into operation only after the circuit has been checked and permission to begin work has been given by an authorized person.

Conduct during accidents:

Mode of action in the case of an electrical accident:

- Switch off the setup on all poles. So long as this has been done, the victim of the accident should not be touched under any circumstances.
- If the victim is unconscious, notify the lifesaving service at once: Immediate attempts to restore respiration by artificial respiration.

- Even during accidents with no unconsciousness, it is recommended that the victim lie quietly and that a doctor's advice be sought.

Conducting the experiments:

Everyone carrying out experiments in the laboratory is personally responsible for the setup placed at their disposal and for the experiments performed with it. For experiments conducted during working hours, it is advisable, in the interest of personal safety, to ensure that a second person is present in the testing room. If several people are working with the same setup, they must know who is responsible for performing the switching operations for a particular experiment. Before activating high voltage setups, a warning ("Attention! Switch on") must be given through either short signals or a call.

INTRODUCTION TO SIMULATION SOFTWARES

ETAP

ETAP is the most comprehensive solution for the design, simulation, and analysis of generation, transmission, distribution, and industrial power systems. It provides all necessary tools and support for modelling and analysing an electrical power system. In this, each project provides a set of users, user access controls, and a separate database in which its elements and connectivity data is stored.

ETAP can utilize real-time operating data for advanced monitoring, real-time simulation and optimization, and high-speed intelligent load shedding. ETAP allows you to work directly with graphical one-line diagrams, underground cable raceway systems. Three dimensional cable systems, advanced time current coordination and selectivity plots, geographic information system schematics (GIS), as well as three-dimensional ground grid systems. It incorporates new concepts for determining protective device coordination directly from the online diagram

ETAP combines the electrical, logical, mechanical and physical attributes of system elements in the same database. ETAP keeps track of detailed data for each electrical apparatus. The ETAP one-line diagram supports several features to assist you in constructing networks of various complexities; it also provides you with a variety of options for presenting or viewing your electrical system

Among ETAP's most powerful features are the composite network and motor elements. ETAP also contain built-in-libraries that are accessible from project files. New libraries can be created, or existing libraries can be modified to include custom manufacturer data

ETAP to be the foremost integrated database for electrical systems, allowing for multiple presentations of a system for different analysis or design purposes

MATLAB

The name MATLAB stands for Matrix Laboratory. MATLAB was written originally to provide easy access to matrix software developed by the LINPACK (linear system package) and EISPACK (Eigen system package) projects. MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and a programming environment. Furthermore, MATLAB is a modern programming language environment. It has sophisticated data structures, contains built-in editing and debugging tools, and supports object-oriented programming. These factors make MATLAB an excellent tool for teaching and research. MATLAB has many advantages compared to conventional computer languages (e.g., C, FORTRAN) for solving technical problems. MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. The software package has been commercially available since 1984 and is now considered as a standard tool at most universities and industries worldwide. It has powerful built-in routines that enable a very wide variety of computations. It also has easy to use graphics commands that make the visualization of results immediately available. Specific applications are collected in packages referred to as a toolbox. There are toolboxes for signal processing, symbolic computation, control theory, simulation, optimization, and several other fields of applied science and engineering.

The order in which MATLAB performs arithmetic operations is exactly that taught in high school algebra courses. Exponentiations are done first, followed by multiplications and divisions, and finally by additions and subtractions. However, the standard order of precedence of arithmetic operations can be changed by inserting parentheses. For example, the result of $1+2\times3$ is quite different from the similar expression with parentheses $(1+2)\times3$. The results are 7 and 9, respectively. Parentheses can always be used to overrule priority, and their use is recommended in some complex expressions to avoid ambiguity. MATLAB by default displays only four decimals in the result of the calculations, for example, -163.6667, as shown in the above examples. However, MATLAB does numerical calculations in double precision, which is 15 digits. The command format controls how the results of computations are displayed.

To view the online documentation, select MATLAB Help from the Help menu or MATLAB Help directly in the Command Window. The preferred method is to use the Help Browser. The Help Browser can be started by selecting the **?** Icon from the desktop toolbar.

Features:

- It is possible to keep track of everything done during a MATLAB session with the diary command.
- The command clear or clear all removes all variables from the workspace. This frees up system memory.
- It is possible to enter multiple statements per line. Use commas (,) or semicolons (;) to enter more than one statement at once. Commas (,) allow multiple statements per line without suppressing output.
- MATLAB offers many predefined mathematical functions for technical computing, including a large set of mathematical functions. There is a long list of mathematical functions that are built into MATLAB. These functions are called built-ins. Many standard mathematical functions, such as sin(x), cos(x), tan(x), e^x, ln(x), are evaluated by the functions sin, cos, tan, exp, and log, respectively, in MATLAB.
- MATLAB has an excellent set of graphic tools. Plotting a given data set or the results of computation is possible with very few commands.
- It is possible to specify line styles, colors, and markers (e.g., circles, plus signs, etc.)
- Matrices are fundamental to MATLAB.
- MATLAB has two different types of arithmetic operations: matrix arithmetic operations and array arithmetic operations.
- MATLAB provides many matrix functions for various matrix/vector manipulations

M-File Scripts:

A script file is an external file that contains a sequence of MATLAB statements. Script files have a filename extension .m and are often called M-files. M-files can be scripts that simply execute a series of MATLAB statements, or they can be functions that can accept arguments and produce one or more outputs.

M-File functions:

As mentioned earlier, functions are programs (or routines) that accept input arguments and return output arguments. Each M-file function (or function or M-file for short) has its own area of workspace, separated from the MATLAB base workspace.

Control Flow and Operators:

MATLAB is also a programming language. Like other computer programming languages, MATLAB has some decision-making structures for control of command execution. These decision-making or control flow structures include for loops, while loops, and if-else-end constructions. Control flow structures are often used in script M-files and function M-files. By creating a file with the extension .m, we can easily write and run programs. We do not need to compile the program since MATLAB is an interpretative (not compiled) language. MATLAB has thousands of functions, and you can add your own using m-files. MATLAB provides several tools that can be used to control the flow of a program (script or function

SIMULINK

SIMULINK is an interactive environment for modelling, analyzing and simulating a wide variety of dynamic systems. SIMULINK provides a graphical user interface for constructing block diagram models using drag and drop operations. A system is configured in terms of a block diagram representation using a library of standard components. A system in block diagram representation can be built easily, and simulation results are displayed quickly.

Experiment No. 1

FORMATION OF Y BUS

Aim:

To formulate a Y-Bus using an appropriate algorithm for at least a four-bus system.

Course Outcome (CO) Mapping

CO	Description	Bloom's Level
CO1	Apply fundamental power system analysis techniques to determine the operating parameters under steady state and faulty conditions	K3

Program Outcome (PO) Mapping with Justification

PO	Description	Relevance	Justification
PO1	Engineering Knowledge	3	Developing mathematical models for a power system—which involves applying Kirchhoff's laws, and understanding the behaviour of components like generators, transformers, and transmission lines—is a direct demonstration of this PO.
PO2	Problem Analysis	3	Formulation of bus admittance matrix and interpretation of system model.
PO3	Design/Development of Solutions	2	Formulate network equations and apply them to different configurations.
PO4	Conduct investigations of complex problems	3	Analyzing bus connections and system response through software.
PO5	Engineering Tool Usage	3	Use of MATLAB or any power system software to model Y-bus.
PO7	Ethics	3	Maintain accuracy and academic Integrity in numerical analysis
PO8	Individual and Collaborative Team Work	3	Collaborative development of the system models.
PO9	Communication	3	Report writing
PO11	Life-long Learning	2	Exposure to different network modelling tools and numerical methods.

Program Specific Outcome (PSO) Mapping with Justification

PSO No.	PSO Description	Justification
PSO1	Apply engineering knowledge to analyse, model, design and operate modern systems for power systems	Y-bus matrix is a foundational modelling tool for power system analysis

CO-PO Mapping Matrix

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO1	3	3	2	3	3		3	3	3		2

CO-PSO Mapping Matrix

CO	PSO1	PSO2
CO1	3	

Theory:

Most of the power system studies require the formation of a bus admittance matrix. Y bus may be formed by inspection method only, if there is no mutual coupling between the lines. Shunt impedances are added to the diagonal elements corresponding to the buses at which these are connected.

Algorithm for Y Bus Formation:

1. Read
   a. Number of lines nline, Number of buses - n.
   b. Starting and ending bus numbers of lines Lp(k), Lq(k), Line charging admittance at each end of the line Ycp (k) and Ycq (k), Resistance R(k), Reactance X(k), Tap(k) for k=1 to n line
   c. Shunt admittance at buses Yshunt (i) for i=1:n
2. Print input data.
3. Calculation of the primitive admittances of all the lines

   For k = 1 to n line

   Yline(k)=1/(R(k)+i*X(k))

   If Tap(k)≠1

   T1= 1-(1/Tap(k))

T2= (-1)*(T1/Tap(k))

Ycp(k)=T2*Yline(k)

Ycq(k)=T1*Yline(k)

Yline(k) =Yline(k)/Tap(k)

4. Initialise Ybus

   Y(i,j)=0.000 for i=1 to n, j= 1 to n

5. For k= 1 to n line

   p=Lp(k), q= Lq(k)

   Y(p,p)=Y(p,p)+Ylin
   e(k)+Ycp(k)

   Y(q,q) =Y(q,q)+Yline(k)+Ycq(k)

   Y(p,q) =Y(p,q) - Yline(k)

   Y(q,p) =Y(q,p) – Yline(k)

6. For I =1 to n

   Y(i,i) = Y(i,i)+Yshunt(i)

7. Print Y(i,j) for I =1 to n, j= 1 to n

Procedure:

- Enter the command window of MATLAB.
- Create a new M-file by selecting File ⟹ New M-file.
- Type and save the program in the editor window.
- Execute the program by clicking on Tool ⟹ Run.
- View the results.

Sample data:

```
busdata= [ 0   1  0   1.0
0              2  0   0.8
1              2  0   0.4
1              3  0   0.2
2              3  0   0.2
3              4  0   0.08 ];
  Y= ybus (busdata)
```

Problem 1:

- Form the Y Bus matrix for the given network

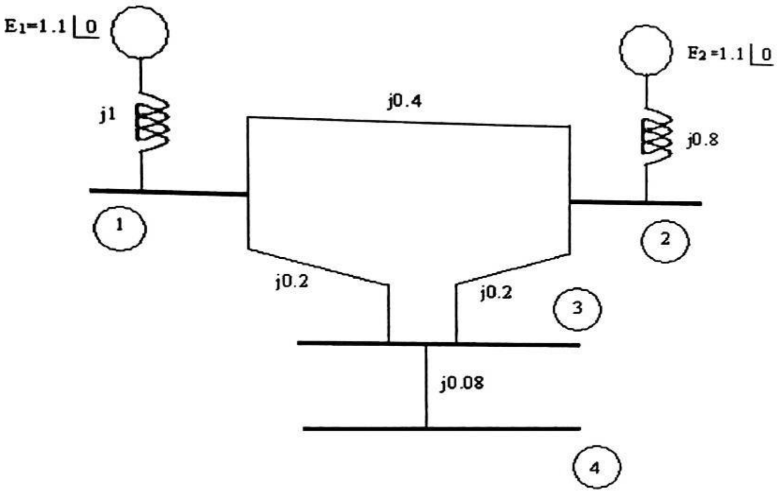


Fig 1.1 Single Line Diagram

Result:

Inference:

Experiment No. 2

LOAD FLOW ANALYSIS

Aim:

To conduct load flow analysis of power system networks on any dedicated software platform using the following methods, and to verify by manual calculation at least for one iteration.

- Gauss-Seidel method
- Newton—Raphson Method
- Fast Decoupled Method.

Course Outcome (CO) Mapping

CO	Description	Bloom's Level
CO1	Apply fundamental power system analysis techniques to determine the operating parameters under steady state and faulty conditions	K3

Program Outcome (PO) Mapping with Justification

PO	Description	Relevance	Justification
PO1	Engineering Knowledge	3	The experiment requires a strong theoretical understanding of power system analysis, including bus classifications (slack, PV, PQ), the formation of the bus admittance matrix (Ybus), and the underlying mathematical principles of load flow equations.
PO2	Problem Analysis	3	Analysis of power mismatch and convergence through iteration.
PO4	Conduct investigations of complex problems	3	Stability and convergence analysis of different algorithms.
PO5	Engineering Tool Usage	3	Use of MATLAB/ETAP/PSCAD for algorithm implementation.
PO7	Ethics	3	Ensure ethical handling of fault data and simulations.
PO8	Individual and Collaborative Team Work	3	Collaborative fault simulation and result interpretation.
PO9	Communication	3	Documenting and presenting fault analysis results.

PO11	Life-long Learning	2	Adapting different solver techniques for modern grid simulations.

Program Specific Outcome (PSO) Mapping with Justification

PSO	Description	Relevance	Justification
PSO1	Apply simulation tools for power flow and system analysis	3	Core experiment for steady-state simulation using various algorithms.

CO-PO Mapping Matrix

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO1	3	3		3	3		3	3	3		2

CO-PSO Mapping Matrix

CO	PSO1	PSO2
CO1	3	

Theory:

Power flow programs are used to study the power system under both normal operating conditions and disturbance conditions. The essential requirements for successful power system operation under normal conditions require the following:

- Generators supply the load plus losses
- Bus voltage magnitudes remain close to rated values
- Generators operate within specified real and reactive power limits
- Transmission lines and transformers are not overloaded

The power flow computer program, commonly called load flow, is the basic tool for investigating the above requirements. This program computes the voltage magnitude and angle at each bus in a power system under balanced steady state conditions. Real and reactive power flows for all equipment interconnecting the buses, as well as equipment losses, are also computed. Both existing power systems and proposed changes, including new generation load growth, are of interest.

ETAP

ETAP is the Electrical Transient Analyzer Program. It is the most comprehensive solution for the design, simulation and analysis of generation, transmission, distribution and industrial power systems. It provides all the necessary tools and support for modelling and analyzing an electrical power system. In this, each project provides a set of users, user account controls and a separate database in which its elements and connectivity are stored. ETAP can utilize real-time operating data for advanced monitoring, real-time simulation, optimization and high-speed intelligent load shedding. ETAP allows for working directly with graphical one-line diagrams of underground cable raceway systems.

Procedure:

Refer to the manual on **ETAP.**

Problem 1:

The transmission line impedances and line charging admittances in per unit on a 100 MVA base are given in Table 2.1. The scheduled generation and loads, and the assumed per unit bus voltages are given in Table 2.2. With bus 1 as the slack, use the following methods to obtain a load flow solution.

- Gauss-Seidel using Y_{BUS}, with acceleration factors of 1.4 and tolerances of 0.0001 and 0.0001 per unit for the real and imaginary components of voltage.
- Newton-Raphson using Y_{BUS}, with tolerances of 0.0001 per unit for the changes in the real and reactive bus powers.
- Fast Decoupled.

Table 2.1

Impedance and line charging

Bus code p-q	**Impedance Z_{pq}**	**Line charging $Y_{pq}/2$**
1-2	0.002+j0.06	0.0+j0.030
1-3	0.08+j0.24	0.0+j0.025
2-3	0.06+j0.18	0.0+j0.020
2-4	0.06+j0.18	0.0+j0.020
2-5	0.04+j0.12	0.0+j0.015
3-4	0.01+j0.03	0.0+j0.010
4-5	0.08+j0.24	0.0+j0.025

Table 2.2

Scheduled generation and load

Bus code	Assumed Bus Voltage (p.u.)	Generation		Load	
		MW	MVAR	MW	MVAR
1	1.06+j0.0	Slack		0	0
2	1.00+j0.0	40	30	20	10
3	1.00+j0.0	0	-	45	15
4	1.00+j0.0	0	-	40	5
5	1.00+j0.0	0	-	60	10

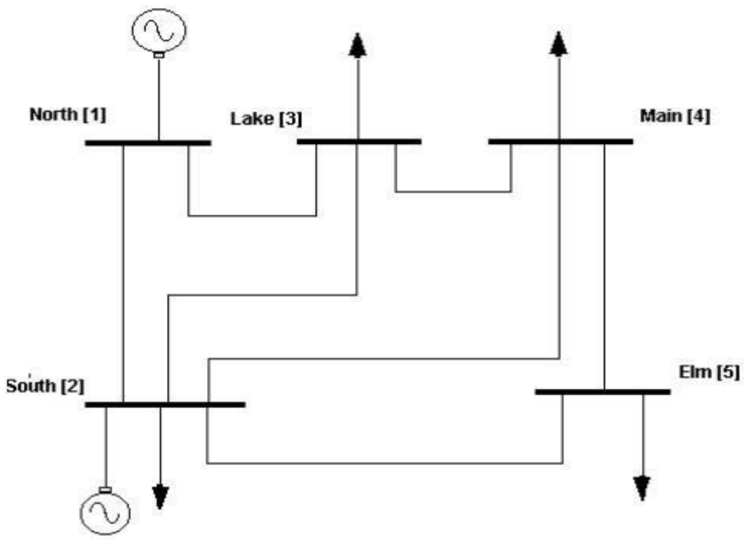


Fig 2.1: Single line diagram

Result:

Inference:

Experiment No. 3

SHORT CIRCUIT ANALYSIS

Aim:

To conduct the fault analysis of power system networks on any dedicated software platform to solve symmetrical and unsymmetrical faults, and to verify by manual calculation.

- 3 Phase L-G fault
- L-L fault
- L-L-G fault

Course Outcome (CO) Mapping

CO	Description	Bloom's Level
CO1	Apply fundamental power system analysis techniques to determine the operating parameters under steady state and faulty conditions	K3

Program Outcome (PO) Mapping with Justification

PO	Description	Relevance	Justification
PO1	Engineering Knowledge	3	Application of symmetrical components and network modelling.
PO2	Problem Analysis	3	Identify fault type and calculate fault currents.
PO3	Design/development of solutions	2	Application of sequence networks for various fault conditions.
PO4	Conduct investigations of complex problems	3	Study of effect of faults on system parameters.
PO5	Engineering Tool Usage	3	Use of software for simulating fault conditions.
PO7	Ethics	3	Ensure ethical handling of fault data and simulations.
PO8	Individual and Collaborative Team Work	3	Collaborative fault simulation and result interpretation.
PO9	Communication	3	Documenting and presenting fault analysis results.
PO11	Life-long Learning	2	Knowledge of current trends in protection and system reliability.

Program Specific Outcome (PSO) Mapping with Justification

PSO	Description	Relevance	Justification
PSO1	Apply simulation tools for power flow and system analysis	3	Core experiment for various fault conditions in power systems

CO-PO Mapping Matrix

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO1	3	3		3	3		3	3	3		2

CO-PSO Mapping Matrix

CO	PSO1	PSO2
CO1	3	

Theory:

Short circuit studies are performed to determine the magnitude of currents flowing throughout the power system at various time intervals after the occurrence of the fault. The magnitude of the current flowing through the power system after a fault varies with time until it reaches a steady state condition. This behavior is due to system characteristics and dynamics during this time. The various types of faults occurring in a system, in the order of frequency of occurrence, are

- Single-line to ground
- Line-to-line
- Double line-to-ground
- Three phase faults.

Other types of faults include,

- One conductor open
- Two conductors open

This can occur when conductors break or when one or two phases of a circuit breaker inadvertently open. The path for the fault current may have either zero impedance (dead short circuit) or a definite impedance.

The current flowing in different parts of a power system immediately after a fault differs from that flowing a few cycles later, just before circuit breakers open the line on both sides of the fault.

Both of these currents differ widely from the steady-state current that would flow if the fault were not isolated from the rest of the system by the operation of the circuit breakers. Two of the factors upon which the proper selection of the circuit breakers depends are

- The current flowing immediately after the fault and
- The current breaker must interrupt

Fault analysis consists of determining these currents for various types of faults at various locations in the system. The short-circuit information is used to select fuses, breakers, and switchgear ratings, in addition to setting protective relays. The short-circuit program computes the steady-state current for the impedance considered.

Procedure:
Refer to the **ETAP** Manual.

Problem 1:
Consider the 6-bus system shown in the fig. 3.1. Buses 1 and 2 are generator buses, and 3 and 4 are load buses. The generators are rated 11kV, 100 MVA, with transient reactance of 10% each. Both transformers are 11/110 kV, 100 MVA with a leakage reactance of 5%.
The reactance of the lines to a base of 100 MVA, 110 kV, is given. Obtain the short circuit solution for a three-phase solid fault on bus 4 (load bus). The transformer and generator details are given in the tables below.

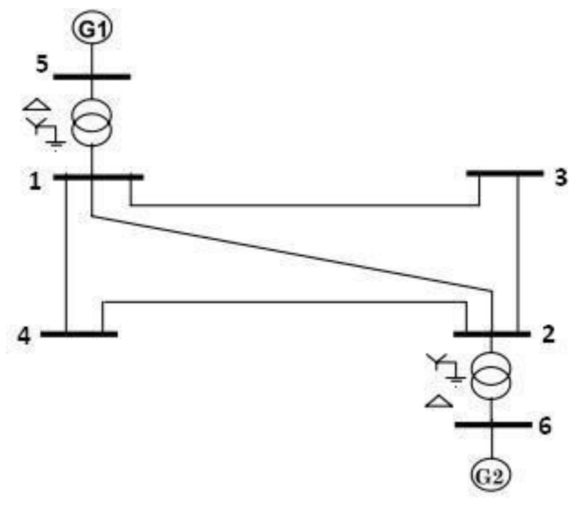


Fig 3.1: Single Line Diagram

Table 3.1

Transmission Line Details	
Line No.	Impedance
1-2	0.0+j0.2
1-3	0.0+j0.15
1-4	0.0+j0.1
2-3	0.0+j0.2
2-4	0.0+j0.15

Table 3.2

BASE MVA = 100	
Generator Details	
kV Rating	11kV
MVA Rating	100MVA
Transient Reactance	10%

Table 3.3

Transformer Details	
kV Rating	11/110kV
MVA Rating	100MVA
Leakage Reactance	5%

Result:

Inference:

Experiment No. 4

TRANSIENT STABILITY ANALYSIS

Aim:

To find the critical clearing angle by applying the equal area criterion for any power system network, and verify the same using any dedicated software.

Course Outcome (CO) Mapping

CO	Description	Bloom's Level
CO2	Develop mathematical models and conduct steady state and transient analysis of power system networks using standard software.	K4

Program Outcome (PO) Mapping with Justification

PO	Description	Relevance	Justification
PO1	Engineering Knowledge	3	Apply system modelling techniques to stability analysis.
PO2	Problem Analysis	3	Analyse effects of compensation on power transfer and system dynamics
PO3	Design/development of solutions	2	Modelling pre-fault, during fault, and post-fault curves.
PO4	Conduct Investigations of Complex Problems	3	Analysing transient swing using analytical and graphical methods.
PO5	Engineering Tool Usage	3	Use of simulation tools (e.g., MATLAB, MiPower) for stability verification.
PO7	Ethics	3	Promote responsible analysis of critical system behaviours.
PO8	Individual and Collaborative Team Work	3	Case study analysis and simulation tasks assigned in groups.
PO9	Communication	3	Interpretation of area-based stability margin and reporting.
PO11	Life-long Learning	2	Exposure to system security enhancement under contingency.

Program Specific Outcome (PSO) Mapping with Justification

PSO	PSO Description	Justification
PSO1	Apply engineering knowledge to analyse, model, design and operate modern systems for power systems	Stability analysis ensures reliable operation under faults

CO-PO Mapping Matrix

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO2	3	3	2	3	3		3	3	3		2

CO-PSO Mapping Matrix

CO	PSO1	PSO2
CO2	3	

Theory:

The transient behaviour of a power system resulting from major disturbances such as a fault followed by switching operations, sudden rejection of load or generation, etc., is referred to as transient stability. A transient stability solution is obtained in the time domain. Transient stability simulation studies are carried out to study these phenomena, and the results enable the planning and coordination of the protection and control schemes efficiently. Critical clearing times of circuit breakers can be computed and protection zones of distance relays during transient swings can be adjusted. Proper restoration/islanding schemes can be suitably designed. Compared to load flow and short circuit studies, transient stability studies are more complex since they involve electromechanical dynamics of rotating machines and their associated controls, viz., excitation and governor systems. The period of investigation varies from a fraction of a second when first swing stability is being determined, to over several seconds when multiple stabilities are to be examined.

The program requires the base case load flow solutions to establish the initial conditions. The program uses the Fast Decoupled Load Flow Method for the network solution, and the implicit trapezoidal rule of integration method for the solution of the differential equation representing the dynamics of machines, controllers, etc.

Procedure:

Refer manual on **ETAP.**

Problem 1:

Fig. 4.1 shows a single line diagram of a 5-bus system with three generating units, four lines and two transformers and two loads. Per-unit transmission line series impedances and shunt susceptance are given on a 100MVA base, the generator's transient impedance and transformer leakage reactance are given in the accompanying table.

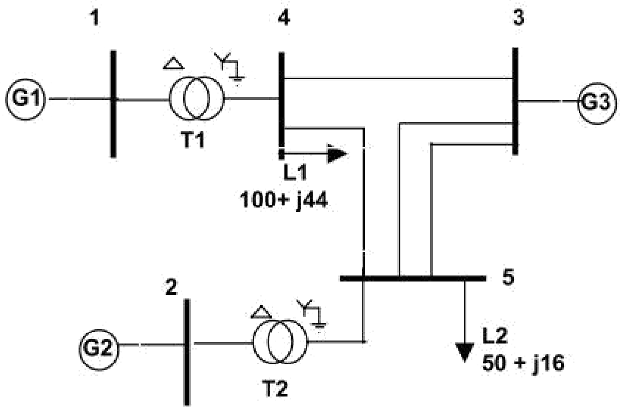


Fig. 4.1: Single line diagram

Values given are on 100MVA base, frequency = 50Hz.

If a 3-phase fault occurs on line 4-5 near bus 4, and the fault is cleared by simultaneously opening the circuit breaker at the ends of line 4-5 at the critical clearing time. Compute t_c and comment on the stability of machine 1 & machine 2.

The details of the system are given below:

Transformer details:

T1 = 20/230 kV 400MVA with leakage reactance = 0.022 pu

T2 = 18/230 kV 250 MVA with leakage reactance = 0.040 pu

Generator details:

G1 = 400 MVA, 20 kV, X_d' = 0.067 pu, H = 11.2 MJ / MVA

G2 = 250 MVA, 18 KV, X_d' = 0.10 pu, H = 8.0 MJ / MVA

G3 = 1000 MVA, 230 KV, X_d' = 0.00001 pu, H = 1000 MJ / MVA (Infinite Bus Modelling)

Table 4.1

Transmission Line Details		
Bus - code	Impedance	Line charging
p-q	Zpq	Y'pq/2
3 - 4	0.007 + j0.04	j0.041
3 -5(1)	0.008 + j0.047	j0.049
3 -5 (2)	0.008 + j0.047	j0.049
4 - 5	0.018 + j0.110	j0.113

Table 4.2

Generation and Load Details					
Bus Code 'p'	Generation		Load		Specified Voltage
	MW	Mvar	MW	Mvar	
1	350	71.2	0	0	1.03
2	185	29.8	0	0	1.02
3	800	0	0	0	1.0
4	0	0	100	44	Unknown
5	0	0	50	16	Unknown

Calculation:

To find the critical clearing time.

Solve for the critical clearing angle δ:

$$\cos \delta_c = \frac{P_m}{P_{max}}(\delta_{max} - \delta_0) + \cos \delta_{max}$$

The corresponding critical clearing

time is:

$$t_c = \sqrt{\frac{2H\ (\delta_c - \delta_0)}{\pi f_0\ P_m}}$$

Where,

H is the inertia constant

f_0, is the normal frequency

Pmax is the maximum power

δ_0 is the initial torque angle

Swing curve:

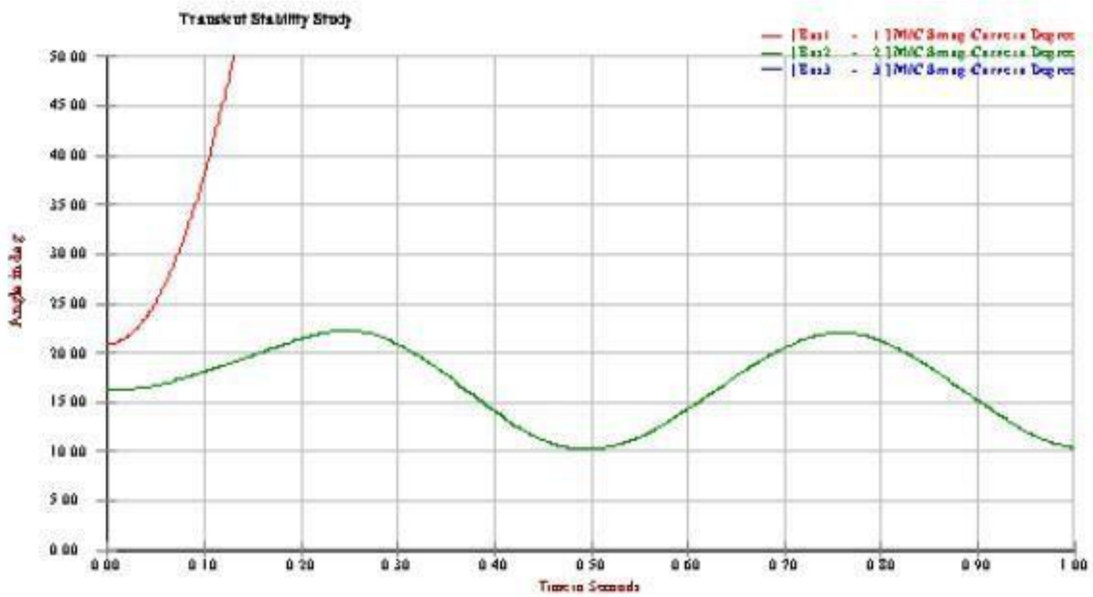


Fig 4.2: Swing curve

Result:

Inference:

Experiment No. 5

AUTOMATIC GENERATION CONTROL

Aim:

To determine the change in speed, frequency and steady state error corresponding to a load disturbance in a single area and a two-area power system, with and without supplementary control using software.

Course Outcome (CO) Mapping

CO	Description	Bloom's Level
CO3	Develop a frequency domain model of the power system network and conduct a stability analysis.	K4

Program Outcome (PO) Mapping with Justification

PO	Description	Relevance	Justification
PO1	Engineering Knowledge	3	The experiment requires a deep understanding of the principles of Load Frequency Control (LFC). Understanding dynamic system response and governor control.
PO2	Problem Analysis	3	Analyse frequency deviations and control strategy performance.
PO3	Design/development of solutions	2	Design of LFC loop and selection of gain constants.
PO4	Conduct investigations of complex problems	3	Analysing the impact of load changes on frequency.
PO5	Engineering Tool Usage	3	Simulation using MATLAB/Simulink with controllers and AGC block.
PO7	Ethics	3	Ensure reliability and responsible control under changing load conditions.
PO8	Individual and Collaborative Team Work	3	Group-based experimentation for multi-area case.
PO9	Communication	3	Reporting system response curves and controller performance.
PO11	Life-long Learning	2	AGC is evolving with smart grid integration – learning adaptive tuning.

Program Specific Outcome (PSO) Mapping with Justification

PSO	PSO Description	Justification
PSO1	Apply engineering knowledge to analyse, model, design and operate modern systems for power systems	AGC plays a central role in maintaining grid frequency and load balance

CO-PO Mapping Matrix

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO1	3	3	2	3	3		3	3	3		2

CO-PSO Mapping Matrix

CO	PSO1	PSO2
CO1	3	

Theory:

SIMULINK is an interactive environment for modelling, analysing and simulating a wide variety of dynamic systems. SIMULINK provides a graphical user interface for constructing block diagram models using drag and drop operations. A system is configured in terms of a block diagram representation using a library of standard components. A system in block diagram representation can be built easily, and simulation results are displayed quickly.

Single Area System:

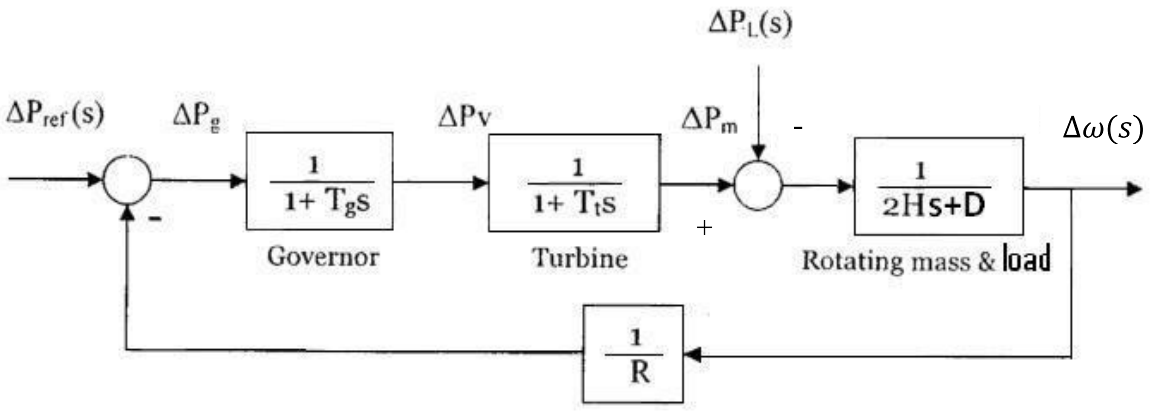


Fig 5.1: Load frequency control block diagram of an isolated power system

Problem 1:

An isolated power system has the following parameters:

Turbine time constant, T_t = 0.5 Sec

Governor time constant, T_g = 0.2 Sec

Generator time constant, H = 5 Sec

Governor Speed regulator, R = R pu.

The load varies by 0.8% for 1% change in frequency, i.e., D=0.8. The governor speed regulation is set to R= 0.05 pu. The turbine rated output is 250 MW. At a normal frequency of 50 Hz, a sudden load change of 50MW (ΔP_L= 0.2pu) occurs. Construct a SIMULINK block diagram and obtain the frequency deviation response for the condition given above.

Two Area System:

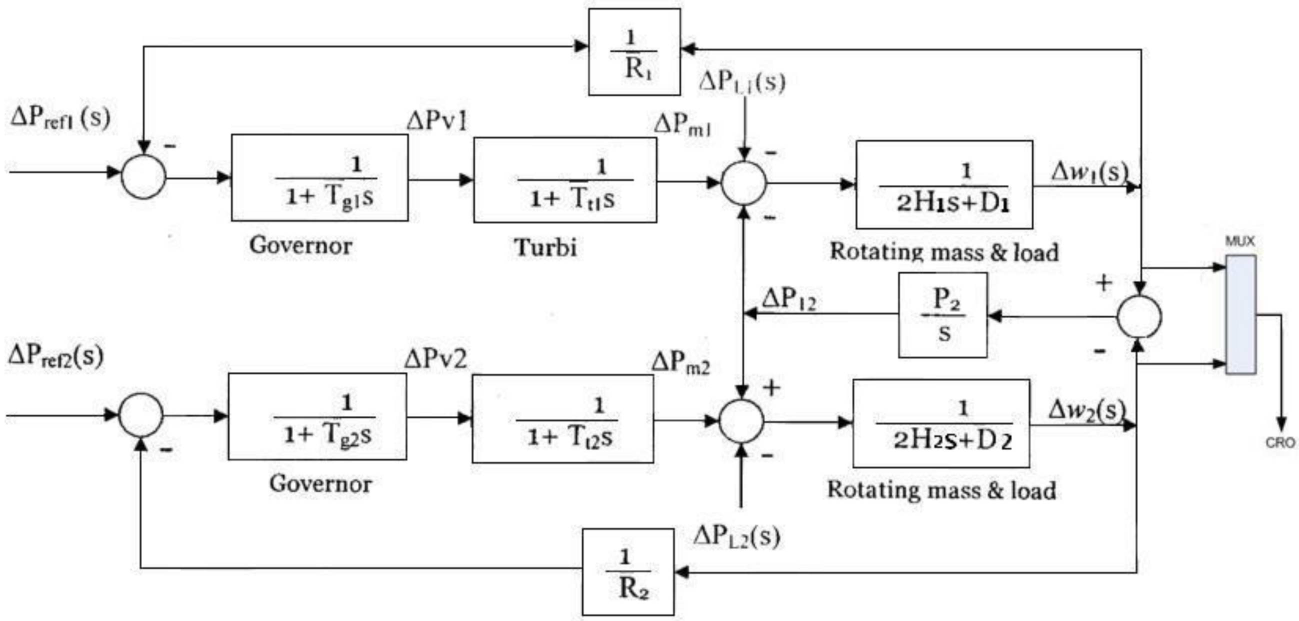


Fig 5.2: Two area system with only primary LFC Loop

Problem 2:

A two-area system connected by a tie line has the same parameters on a 1000 MVA common base. The units are operating in parallel at normal frequency at 50 Hz.

AREA	**1**	**2**
Speed regulation	R_1= 0.05	R_2=0.0625
Frequency load coefficient	D_1=0.6	D_2=0.8
Inertia constant	H_1=5	H_2=4
Base power	1000 MVA	1000 MVA
Governor time constant	T_{g1}=0.2s	T_{g2}=0.3s
Turbine time constant	T_{t1}= 0.5s	T_{t2}=0.6s

The synchronizing power coefficient is computed from the initial operating condition and is given to be Ps = 2.0 pu. A load change of 187.5 MW occurs in area 2.

a) Determine the new steady state frequency and the change in the line flow.
b) Construct a SIMULINK block diagram and obtain the frequency deviation response for the given condition

Result:

Inference:

Experiment No. 6

HIGH VOLTAGE TESTING

Aim:

- To test the given power system component (Circuit Breaker/ Insulator/Lightning Arrestor/ Air Blast Circuit Breaker) using AC voltage.
- To test the given power system component (Circuit Breaker/ Insulator/Lightning Arrestor/ Air Blast Circuit Breaker) using impulse voltage

Course Outcome (CO) Mapping

CO	Description	Bloom's Level
CO4	Conduct appropriate tests on any power system component in accordance with relevant standards.	K3

Program Outcome (PO) Mapping with Justification

PO	Description	Relevance	Justification
PO1	Engineering Knowledge	3	Understanding of insulation and withstand capability of components.
PO4	Conduct Investigations of Complex Problems	3	Identify breakdown voltage and insulation condition using test data.
PO5	Engineering Tool Usage	3	Usage of HV testing kits, impulse generator, and measurement devices.
PO6	The Engineer and The World	3	Ensures safety of systems used in public infrastructure.
PO7	Ethics	3	Promotes ethical handling of test data and high-voltage protocols.
PO8	Individual and Collaborative Team Work	3	Collaborative testing and teamwork during operation.
PO9	Communication	3	Presentation and interpretation of test results.
PO11	Life-long Learning	2	Exposure to testing practices and evolving international standards.

Program Specific Outcome (PSO) Mapping with Justification

PSO	PSO Description	Justification
PSO1	Apply engineering knowledge to analyse, model, design and operate modern systems for power systems	HV testing is critical to ensure equipment operational integrity

CO-PO Mapping Matrix

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO3	3			3	3	3	2	3	3		2

CO-PSO Mapping Matrix

CO	PSO1	PSO2
CO3	3	

INSULATORS

A. Power frequency tests

- **Flashover tests**: AC voltage of power frequency is applied across the insulator and increased at a uniform rate of 3kV/s to such a value that a breakdown occurs along the surface of the insulator.

- **Withstand tests**: The voltage specified in the relevant specification is applied for a period of 1 minute with the insulator mounted as in service conditions. The test piece should withstand the specified voltage. (Withstand voltage for 11 kV pin and disc insulators is 35kV for 1 minute.)

B. Impulse Tests

- **Impulse withstands voltage test**

The test is done by applying a standard impulse voltage of specified value with both positive and negative polarities of the wave. If five consecutive waves do not cause flashover or puncture, the insulator is deemed to have passed the test (this is verified by the spark over in the sphere gap). If two applications of the pulse cause flashover, the object is deemed to have failed. If there is only one failure, an additional ten applications of the voltage wave are made. If the test object has withstood the subsequent applications, it is said to have passed the test.

- **Impulse flashover tests:**

The test is done as above with the specified voltage. Usually, the probability of failure is determined for 40% and 60% or 20% and 80% failure values, since it is difficult to adjust the test voltage for the exact 50% flashover values. The average value of the upper and lower limits is taken. The insulator surface should not be damaged by these tests, but slight marking on its surface or chipping off of the cement is allowed.

LIGHTNING ARRESTER (SURGE DIVERTER)

A surge diverter has to be a non-conductor for operating power frequency voltages. It should behave as a short circuit for transient over voltages of impulse character, discharge the heavy current, and recover its insulation without allowing the follow-up of the power frequency current. It is expected to discharge surge currents of very large amplitude, thousands of amperes, but since the time is very short in terms of microseconds, the energy that is dissipated through the lightning arrester is small compared to that produced by a power frequency current.

Two types of tests are used for lightning arresters.

A. Power Frequency Voltage Tests

All power frequency tests shall be made with an AC voltage having a frequency between the limits of 48 Hz and 52 Hz and an approximately sinusoidal shape. The test piece shall withstand for one minute without flashover, the application of the dry power frequency specified voltage. Usually, a voltage of 1.5 times the rating is applied for one minute. After that, it is checked whether the negative resistance property of the arrester is retained by repeating the experiment after a few minutes.

B. Standard lightning- Voltage impulse spark over test

With the test sample arrester in the circuit, the impulse generator is adjusted to give a 1.2/50μs voltage wave shape with the correct peak value (75kV for 9/11kV LA). With this adjustment, five positive and five negative impulses shall be applied to the test sample, and the series gaps of the arrester shall spark over in every impulse. If in either of the five impulses, the gap fails to spark over once only, an additional ten impulses of that polarity shall be applied, and the gap shall spark over on all of these pulses.

Instruments Required

HV Transformer:

Input: 0-220V

Output: 0-100 kV

Current: 75-200mA

Impulse Voltage Generator: 220/280kV

Earthing rod.

***Power frequency tests*:**

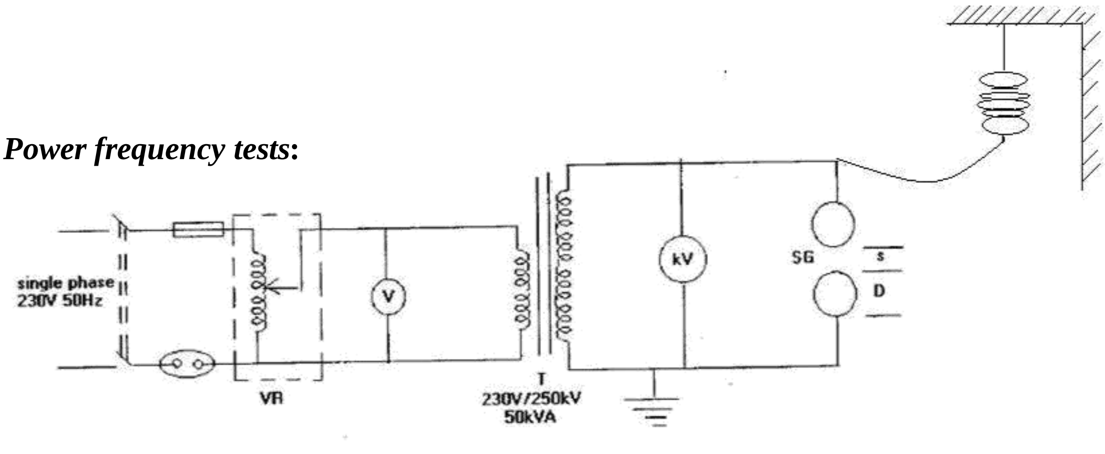


Fig 6.1: Circuit Diagram

Procedure

Power frequency tests

INSULATORS- 11 kV

- **Flashover tests:** In these tests, the ac voltage of power frequency is applied across the insulator and increased at a uniform rate of about 3 kV/s. Record the voltage at breakdown, which occurs when a breakdown occurs along the insulator's surface, using the partial discharge meter.

- **Withstand tests**: Apply 35 kV for 1 minute and see whether the test piece is withstanding the voltage without flashover.

LIGHTNING ARRESTOR – 9kV

Apply 1.5 times of 9 kV (i.e., 13.5 kV) for one minute, check for no flashover.

AB switches

Power frequency withstand test is to be done for closing and opening of contacts as follows: For 11 kV, withstand voltage is 35 kV between line and| earth (closing the contacts) for 1 minute, and 45 kV between open contacts for 1 minute.

Fuses

For LT fuses, apply 1.5 kV withstand voltage to the insulation for 1 minute.

Impulse tests:

PIN INSULATOR-11 kV

Connect a sphere gap across the test piece. Apply a standard impulse voltage of 75kV with both positive and negative polarities of the wave. If five consecutive waves do not cause flashover or puncture, the insulator is deemed to have passed the test (this is verified by the spark over in the sphere gap). If two applications cause flashover, the insulator fails the test. If there is only one failure, an additional ten applications of the voltage wave are made. If the test object has withstood the subsequent applications, it is said to have passed the test.

LIGHTNING ARRESTOR- 9 kV

With the test sample arrester in the circuit, the impulse generator is adjusted to give a 1.2/50 μs, 75 kV voltage wave with the specified shape. With this adjustment, five positive and five negative impulses shall be applied to the test sample, and the series gaps of the arrester shall spark over in every impulse (the sphere gap connected across the test piece should not spark over). If in any of the five impulses, the gap fails to spark over once only, an additional ten impulses of that polarity shall be applied, and the gap shall spark over on all of these pulses.

Result:

Inference:

Experiment No. 7

RELAY TESTING

Course Outcome (CO) Mapping

CO	Description	Bloom's Level
CO3	Conduct appropriate tests on any power system component in accordance with relevant standards.	K3

Program Outcome (PO) Mapping with Justification

PO	Description	Relevance	Justification
PO1	Engineering Knowledge	3	Understand protection coordination and relay characteristics.
PO4	Conduct Investigations of Complex Problems	3	Perform practical fault simulations and analyze relay response.
PO5	Engineering Tool Usage	3	Use of relay test kits and software platforms.
PO6	The Engineer and The World	3	Ensures reliability of power systems to safeguard public infrastructure.
PO7	Ethics	3	Ethical handling of test outcomes and settings.
PO8	Individual and Collaborative Team Work	3	Relay setting and testing is often done in coordinated team settings.
PO9	Communication	3	Interpreting test results and documenting relay settings.
PO11	Life-long Learning	2	Exposure to evolving digital relays and protection trends.

Program Specific Outcome (PSO) Mapping with Justification

PSO	PSO Description	Justification
PSO1	Apply engineering knowledge to analyze, model, design and operate modern systems for power systems	Protective relays are integral to reliable system operation

CO-PO Mapping Matrix

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO3	3			3	3	3	3	3	3		2

CO-PSO Mapping Matrix

CO	PSO1	PSO2
CO3	3	

(A) OVER CURRENT RELAY

Aim:

To test pickup, drop-out, and plot the time-current characteristics of the relay.

IDMT Relay characteristics:

PSM	2	3	4	5	7	10	12	18	20
Operating time in sec (TMS=1)	10	6.3	5	4.4	3.6	3	2.75	2.3	2.2

Theory:

In a power system consisting of generators, transformers, transmission and distribution circuits, some failure will inevitably occur somewhere in the system. When a failure occurs on any part of the system, it must be quickly detected and isolated from the system.

The main reasons are:

- The fault may cause unnecessary interruption of services to the customers.
- Faulted apparatus causes spreading of instability in the system

The detection of a fault and disconnection of a faulty section or apparatus can be achieved by using fuses or relays in conjunction with circuit breakers. A fuse performs both detection and interruption functions automatically, but is limited only to the protection of low-voltage circuits. For higher voltage circuits, relays and circuit breakers are employed to serve the desired function of automatic protective gear. The relays detect the fault and supply information to the circuit breaker, which performs the circuit interruption.

A Protective Relay is a device that detects a fault and initiates the operation of the circuit breaker to isolate the defective element from the rest of the system. The relays detect abnormal conditions in the electrical circuits by constantly measuring the electrical quantities that differ under normal and fault conditions. The electrical quantities which may change under fault conditions are voltage, current, frequency and phase angle.

Test Set Up for Directional Over-Current Relay - VPST-81A:

Directional Over-Current Protection

- The overcurrent circuit protection can be given a directional feature by adding a directional element in the protection system. Directional over-current protection responds to over-currents for a particular direction.
- If the power flow is in the opposite direction, the directional overcurrent protection remains inoperative.
- Directional over-current protection comprises an over-current relay and a power directional relay in a single relay casing. The power directional relay does not measure the power but is arranged to respond to the direction of power flow.

Directional operation of a relay is used, where the selectivity can be achieved by directional relaying. The directional relay recognizes the direction in which the fault occurs, relative to the location of the relay. It is set such that it actuates for faults occurring in one direction only and not for faults occurring in the other direction. Consider feeder XY passing through subsection A. The circuit breaker in feeder AY is provided with a directional relay 'R' which will trip the breaker if fault power flows only in direction A. Therefore, faults in feeder AX prevent the circuit breaker from tripping. However, faults in feeder AY cause the circuit-breaker to trip because its protective relaying is set with a directional feature to act in the direction AY.

Test Setup for Directional Over-Current Relay

Directional power protection operates in accordance with the direction of power flow. Reverse power protection operates when the power direction is reversed in relation to the normal power flow. The construction of the Reverse power relay is different from that of the directional over-current relay.

In a directional overcurrent relay, the directional current does not measure the magnitude of power. It senses only the direction of power flow. However, in Reverse power Relays, the directional element measures the magnitude and direction of power flow.

Relay connections of single-phase directional overcurrent Relay:

The current coils in the directional over-current relay are normally connected to the secondary of the line CT. The voltage coil of the directional element is connected to a line VT having a phase-to-phase output of 110 V. There are four common methods of connecting the relay, depending upon the phase angle between the current in the current coil and the voltage applied to the voltage coil

Relay-connection (e.g., 90°, 60°, 30°, etc.) refers to the angle by which the current applied in the relay is displaced from the voltage applied to the relay. The maximum torque angle refers to the angle between the current voltages applied to the relay to produce maximum torque.

The choice of a relaxed connection is basically to select the phase across which the voltage coil is connected with respect to the current coil. The number of different connections can he used. The suitability of each connection should be examined by considering the limiting conditions of voltage and current, limiting fault conditions, source and line impedances, etc.

Experimental procedure:

Relay operates when the voltage G1<G2, i.e., the current reverses., Refer to Fig. 7.1.

Instantaneous operation:

Set the voltage of G1 at a constant value. Instantaneous operation is for a current range of 2.5 A to 20 A. Increase G2 until the current exceeds 2.5 A; then the relay's instantaneous operation flag operates.

Directional operation:

Set PSM =1 and TMS=1. Now adjust the voltage G2 to set a current value less than 2A as given in table 7.1. Note the time setting and PSM of the relay. Then reset the relay and apply the current using the start and stop switch. Note down the time taken when the relay trips.

Repeat this procedure by changing the values of G2 for different currents. Plot the characteristics. Change the value of TMS (0.8) with the same PSM and repeat the above procedure. Plot the characteristics.

Observation:

Table 7.1

TMS	Vl (V)	V2(V)	Trip current (A)	Trip Time(s)
1.0			1.0 1.2 1.4 1.6 1.8 2.0	

Table 7.2

TMS	V1 (V)	V2(V)	Trip current (A)	Trip Time(s)
0.8			1.0 1.2 1.4 1.6 1.8 2.0	

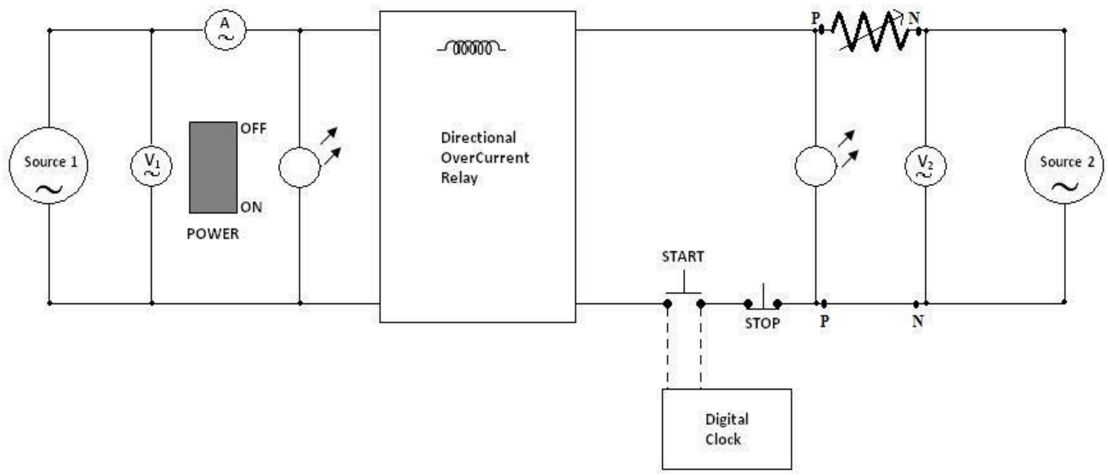


Fig 7.1: Over Current Relay

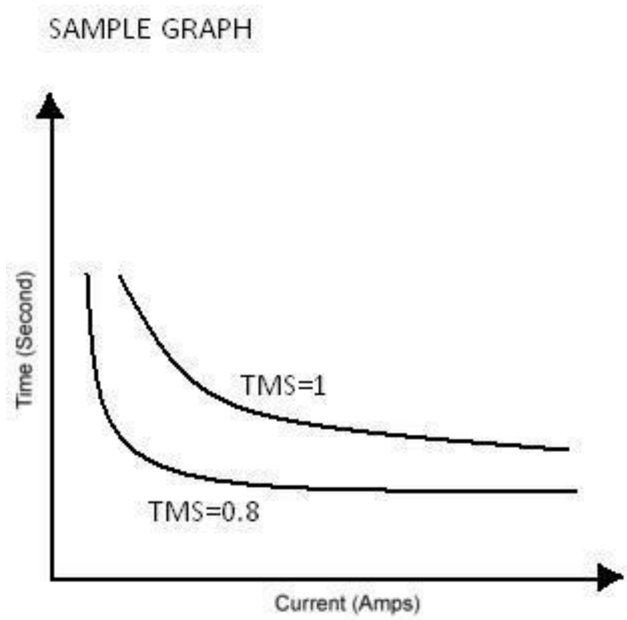


Fig 7.2: Sample graph

Result:

Inference:

(B) OVER VOLTAGE RELAY

Aim:

To test the pick-up, drop out, and plot the time current characteristics of the relay.

Theory:

The principle of operation of an overvoltage relay is that the relay operates and trips the circuit when the voltage reaches above the specified value. The type of overvoltage relay employed in our test setup is the electromechanical type overvoltage relay.

Relay timing is nothing but the duration from the instant when the actuating element is energized to the instant when the relay contacts are closed. The overvoltage relay used here is an inverse definite minimum time type. An inverse time relay is one where operating time is approximately inversely proportional to the magnitude of the actuating parameter. The actuating parameter here is the voltage. In this relay, an inverse time delay can be introduced when the voltage is just equal to the normal value. In this case, the movement of the plunger will be very slow. But when the voltage rises to higher values, the plunger moves faster with less time delay and stops when the relay contact is open.

Equipment required:

Relay test set up (VPST 103), Over Voltage Relay

Procedure:

Set the voltage at any value from 190 to 250V (i.e., 190, 220, 230, 240, 250) using the voltage setting plunger on the left side of the unit, refer to Fig 7.2. Switch on the trainer's power ON/OFF switch. To connect the relay to the voltage source, press the start switch. Then adjust the variac to set the fault voltage in the voltmeter. The fault voltage shall be greater than the normal voltage. Reset and press the stopwatch twice to initialize.

Press the start switch. Now the fault voltage is applied to the relay coil. At the same time, the clock starts counting the time taken in seconds taken for the relay coil to trip and stops when the relay contact is open. The opening of the relay contact can be observed by the lowering of the flag. Note down the time in seconds required for the relay to operate, set voltage and fault voltage. Reset the trip flag and repeat the above procedure for different fault voltages. Note down the readings in tabular form. Draw a graph for time versus fault voltage

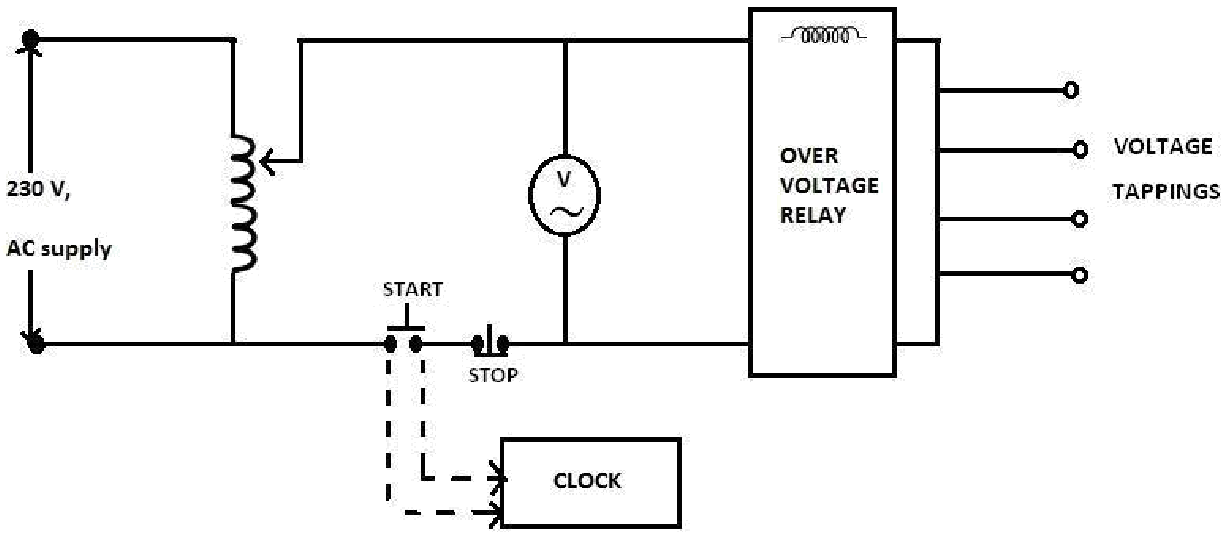


Fig. 7.3: Circuit Diagram

Table 7.3

Sl.no	Set Voltage(V)	Fault Voltage(V)	Time(s)
1	-	- - - -	
2	-	- - - - -	

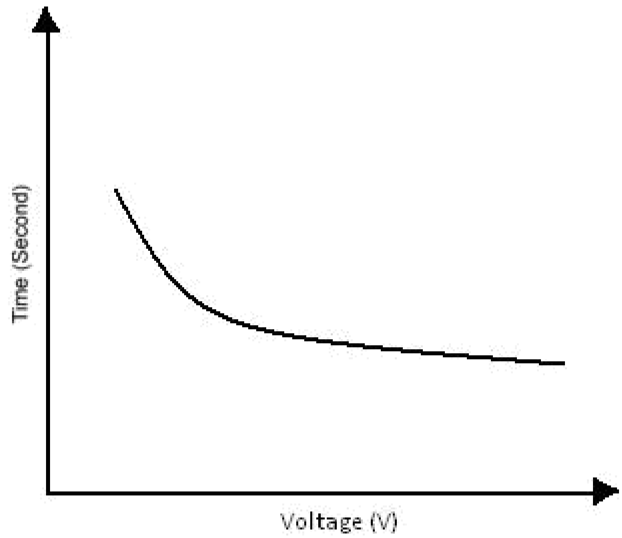


Fig 7.4: Sample graph

Result:

Inference:

Experiment No. 8

INSULATION TESTING

Aim:

To determine the insulation resistance of the given LT &HT cable by using appropriate testing equipment.

Reference:

- IS - 10 810 (part-43) - 1984 -Method of test for cables - Insulation resistance
- IS - 5831 — 1984 -Specification for PVC insulation and sheath of electric cables

Course Outcome (CO) Mapping

CO	Description	Bloom's Level
CO4	Conduct appropriate tests on any power system component in accordance with relevant standards.	K3

Program Outcome (PO) Mapping with Justification

PO	Description	Relevance	Justification
PO1	Engineering Knowledge	3	Understand insulation resistance principles and the impact of deterioration.
PO4	Conduct Investigations of Complex Problems	3	Perform insulation resistance measurement using appropriate tools.
PO5	Engineering Tool Usage	3	Use of megger or insulation resistance tester.
PO6	The Engineer and The World	3	Ensures safety and operational readiness of electrical installations.
PO7	Ethics	3	Ethical handling of test equipment and reporting results accurately.
PO8	Individual and Collaborative Team Work	3	Cooperative testing process during field/lab work.
PO9	Communication	3	Accurate recording and interpretation of measured data.
PO11	Life-long Learning	2	Familiarity with evolving insulation standards and testing methods.

Program Specific Outcome (PSO) Mapping with Justification

PSO	PSO Description	Justification
PSO1	Apply engineering knowledge to analyse, model, design and operate modern systems for power systems	Insulation quality is critical to cable reliability and power system safety

CO-PO Mapping Matrix

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO3	3			3	3	3	3	3	3		2

CO-PSO Mapping Matrix

CO	PSO1	PSO2
CO3	3	

Apparatus required:

Micrometer, voltmeter, insulation megger

1. Meg ohm meter (5 kV, 20000 MΩ)
2. Thermostatically controlled water bath
3. Test specimen-minimum length of 3m length of the cable or the entire drum.

Theory:

The dielectric material in a cable is used to insulate the conductors from one another and from ground, as well as to provide mechanical support to the components. Hence it is desirable that the insulation resistance be as high as possible, consistent with acceptable mechanical, chemical and heat resistant properties. During manufacturing, non-uniformities may develop in the dielectric, affecting the quality of the cable. This test helps in detecting such imperfections. The volume resistivity and insulation resistance constants specified for various types of PVC insulators are as follows:

Table 8.1

Type of insulation (PVC)	Vol. Resistivity (ohm.cm)		Ins. Resi. Const (MegaOhm.km)	
	At 27° C	At Max. Temp.	At 27° C	At Max. Temp.
A	$1x10^{13}$	$1x10^{10}$	36.7	0.037
B	$1x10^{14}$	$1x10^{11}$	367	0.37
C	$1x10^{13}$	$1x10^{10}$	36.7	0.037

Type A: General-purpose insulation with maximum conductor temperature of 70°C intended for cables with rated voltages up to and including 3.3 kV.

Type B: General purpose insulation with a maximum conductor temperature of 70°C, intended for cables with rated voltages above 3.3 kV

Type C: Heat resistant insulation for maximum conductor temperature of 85° C and rated voltages up to and including 1100 V

For carrying out this test at an ambient temperature of 27°C ± 2 °C on single-core (armoured/screened) and multicore screened (armoured/unarmoured) cable, no special conditioning is required except that the temperature of the specimen attains the temperature of the test room.

For belted multicore cables (armoured/unarmoured) and single core cable (unscreened and unarmoured), this test is performed by removing the insulated core from finished cable and immersing the sample in a water bath maintained at ambient temperature of 27 °C ± 2 °C. The duration of immersion shall be 12 hours for elastomeric insulated cables and 1 hour for other types of cables. The ends of the cables shall project at least 200 mm above the water level.

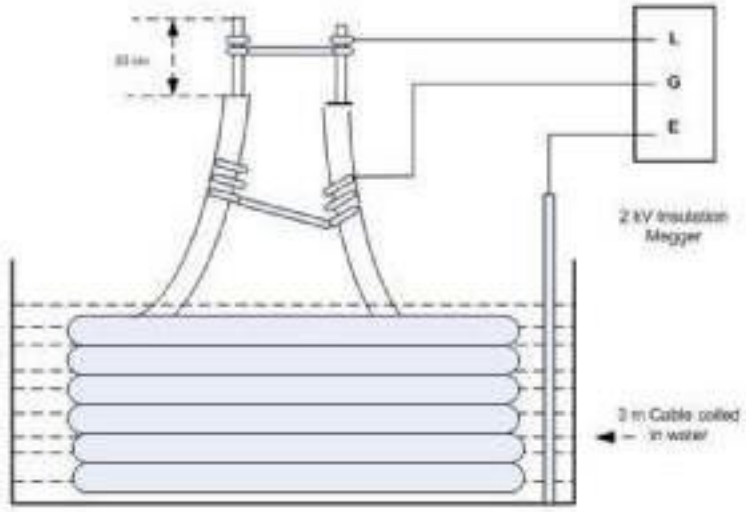


Fig 8.1: Test Setup

Procedure:

- The test specimen is connected to the insulation resistance measuring equipment. The conductor is connected to the high voltage terminal, and the screen/armour or the water bath is earthed.
- The insulation resistance of the test specimen is measured after electrification has continued regularly for 1 minute. The ambient temperature is recorded when the test is performed at ambient temperature, but at the time of doing the test at elevated temperature, the temperature of the water bath is recorded. The apparatus shall be checked by comparing the values with the standard resistance before taking every set of readings.
- The volume resistivity or insulation resistance constant is calculated from the measured insulation resistance value.

Tabulation of Observations:

Table 8.2

Sample No.	Nominal conductor size	Material of Dielectric	Length(m)	Temperature(°C)	Observed insulation resistance(MΩ)

Calculation:

The volume resistivity and insulation resistance constant are calculated from the observed insulation resistance as indicated below.

$$\text{Volume resistivity} = \frac{2\pi LR}{\ln(D/d)} \times 10^8 \text{ ohm-cm}$$

$$\text{Insulation resistance constant } K = \frac{LR}{1000 \log_{10}(D/d)} \text{ Mega ohm.km}$$

Where

R = measured resistance (MΩ)

L = length of cable (m)

D = diameter over insulation (excluding screens if any), (mm)

d = diameter over conductor (including screens if any), (mm)

Result:

Inference:

Experiment No. 9

EARTH RESISTANCE

Aim:

To determine the resistance to earth of the given earthing system and design an earthing system based on the soil resistivity of the given area.

Reference:

IS-3043

Course Outcome (CO) Mapping

CO	Description	Bloom's Level
CO4	Conduct appropriate tests on any power system component in accordance with relevant standards.	K3

Program Outcome (PO) Mapping with Justification

PO	Description	Relevance	Justification
PO1	Engineering Knowledge	3	Understanding principles of earthing, resistance, and soil resistivity.
PO4	Conduct Investigations of Complex Problems	3	Performing tests using earth resistance meters.
PO5	Engineering Tool Usage	3	Use of earth testers and interpretation of results.
PO6	The Engineer and The World	3	Critical for electrical safety and human protection.
PO7	Ethics	3	Adherence to IS-3043 testing standards.
PO8	Individual and Collaborative Team Work	3	Testing and verification tasks are done in groups.
PO9	Communication	3	Clear reporting of soil resistivity and earthing resistance.
PO11	Life-long Learning	2	Learn field methods to assess earthing efficiency per standards.

Program Specific Outcome (PSO) Mapping with Justification

PSO	PSO Description	Justification
PSO1	Apply engineering knowledge to analyze, model, design and operate modern systems for power systems	Earthing is critical for equipment safety and protection systems

CO-PO Mapping Matrix

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO3	3			3	3	3	3	3	3		2

CO-PSO Mapping Matrix

CO	PSO1	PSO2
CO3	3	

Theory:

The resistance of earth connections is measured by the fall of potential method, as illustrated in the Fig. 9.1. A current is passed through the electrode E to an auxiliary electrode A in the earth at a distance away from the plate. A secondary auxiliary electrode B is inserted between E and A, and the potential difference between B and A is measured for a given current I, so that the resistance of the earth connection is V/I.

Procedure:

1. To determine earth electrode resistance

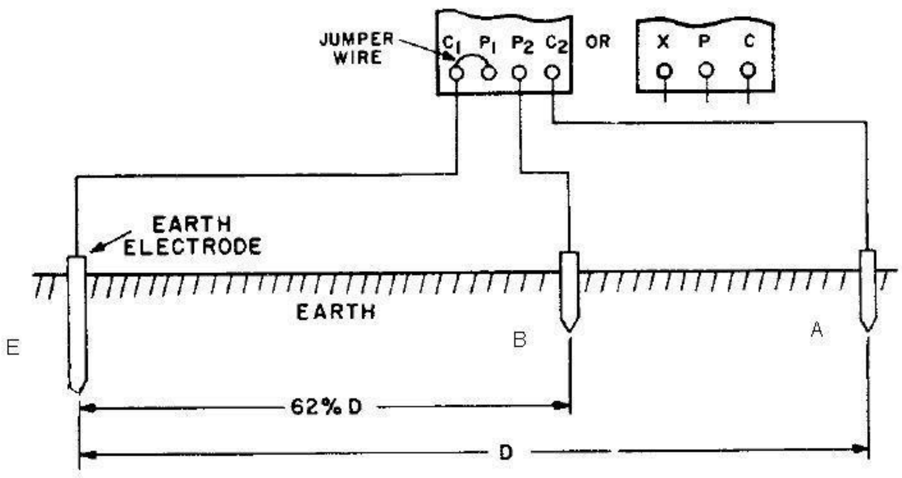


Fig 9.1: Representation of Earth resistance

Two auxiliary electrodes are driven such that E, B and A are in a line and the distance EA is 20m. For various values of 'D' (distance Ep) at an interval of 2 m, keeping EA constant.

The megger readings are taken, noting the reading when the handle is driven at the maximum possible speed. The reading is plotted as shown. The graph shows a value R at which the reading remains almost constant when 'D is varied. This value gives the resistance of the earth electrode

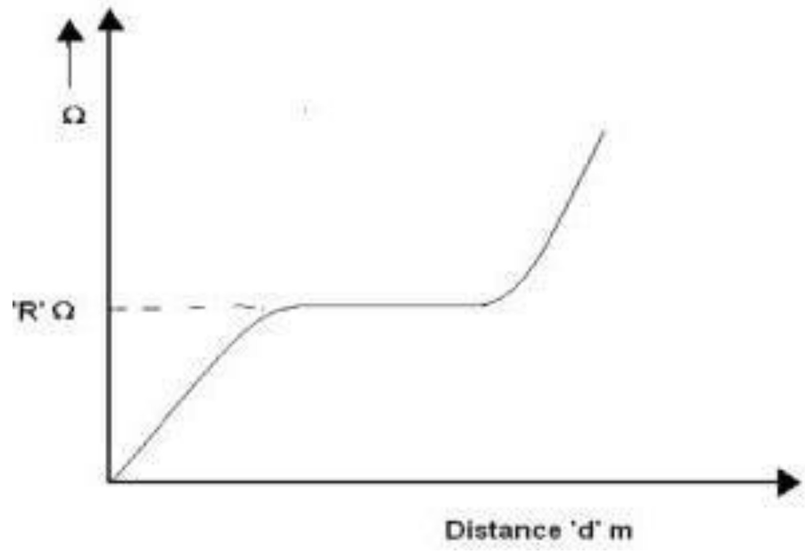


Fig 9.2: Sample Graph

2. To determine the specific resistance of the earth in the locality:

A four-terminal instrument is used to measure earth resistivity. Four rods are driven down to the same depth and at equal distances apart in a straight line at a spacing of 'A' meter as shown in Fig. 9.3. The outer rods are connected to C1 and C2, and the middle rods to P1 and P2. The handle is rotated at the maximum possible speed, and Megger readings are taken. Let it be "R" Ohms. The specific resistance is determined from the formula

$\rho = 2\pi AR\ \Omega m$

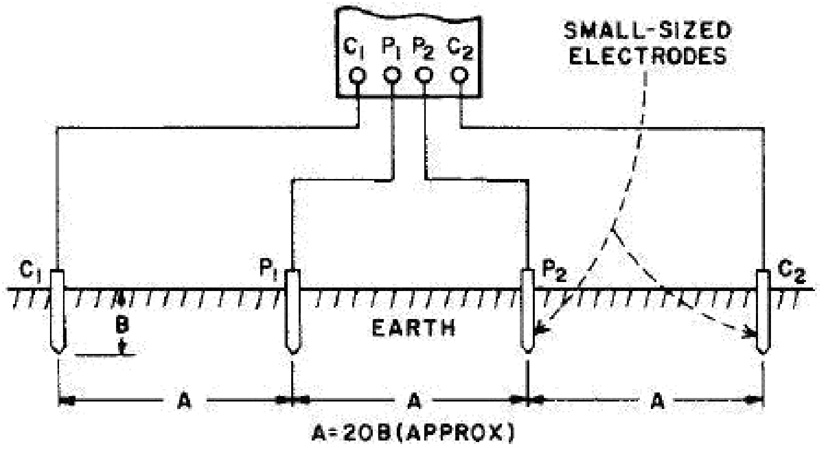


Fig 9.3: Specific resistance of earth in the locality determination

Observation:

Table 9.1

Sl. No.	**R** **Ω**

$\rho = 2\pi AR\ \Omega\,m$

Result:

Inference:

Experiment No. 10

TESTING OF INSULATING MATERIALS

Course Outcome (CO) Mapping

CO	Description	Bloom's Level
CO4	Conduct appropriate tests on any power system component in accordance with relevant standards.	K3

Program Outcome (PO) Mapping with Justification

PO	Description	Relevance	Justification
PO1	Engineering Knowledge	3	Understand breakdown characteristics of insulating materials.
PO4	Conduct Investigations of Complex Problems	3	Conduct transformer oil and solid insulation breakdown tests.
PO5	Engineering Tool Usage	3	Use of test kits for dielectric strength and oil quality testing.
PO6	The Engineer and The World	3	Ensures reliability and safety of transformers and electrical systems.
PO7	Ethics	3	Ensures accurate testing and compliance with standards.
PO8	Individual and Collaborative Team Work	3	Laboratory experiments performed collaboratively.
PO9	Communication	3	Interpretation and documentation of test results.
PO11	Life-long Learning	2	Awareness of current testing standards and procedures.

Program Specific Outcome (PSO) Mapping with Justification

PSO	PSO Description	Justification
PSO1	Apply engineering knowledge to analyze, model, design and operate modern systems for power systems	Ensures operational safety through insulation health monitoring

CO-PO Mapping Matrix

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO3	3			3	3	3	3	3	3		2

CO-PSO Mapping Matrix

CO	PSO1	PSO2
CO3	3	

A) TESTING OF TRANSFORMER OIL

Aim:

To measure the dielectric strength of the given sample of Transformer oil.

Reference:

IS 6792 - Method of determination of dielectric strength of insulating oil

IS 1866 - Code of practice for maintenance and supervision of insulating oil in service

Apparatus:

- Insulating oil testing apparatus
- Sample of transformer oil
- Thermometer

Theory:

The test for dielectric strength is a conventional test intended to reveal the extent of physical pollution by water and other suspended matter in insulating oil. This test indicates the suitability of a sample for its use in the apparatus. The permissible breakdown voltage for different voltage classes of equipment is as follows.

- Equipment above 170 kV > 50 kV .
- Equipment from 70kV to 170 kV > 40 kV
- Equipment below 70 kV > 30 kV

Any result below the permissible value will necessitate reconditioning of drying and filtration to reduce the oil for water content and suspended matter. The sample oil is prepared in a test cell made of glass or plastic with an effective volume of 300 to 500 ml. The test electrodes are either spherical or spherical-shaped. The electrodes are mounted on a horizontal axis, and the spacing between them is 2.5 mm. The recommended frequency of testing is as follows:

- Immediately prior to energizing the equipment
- After three months of energizing
- Thereafter once every year

Diagram:

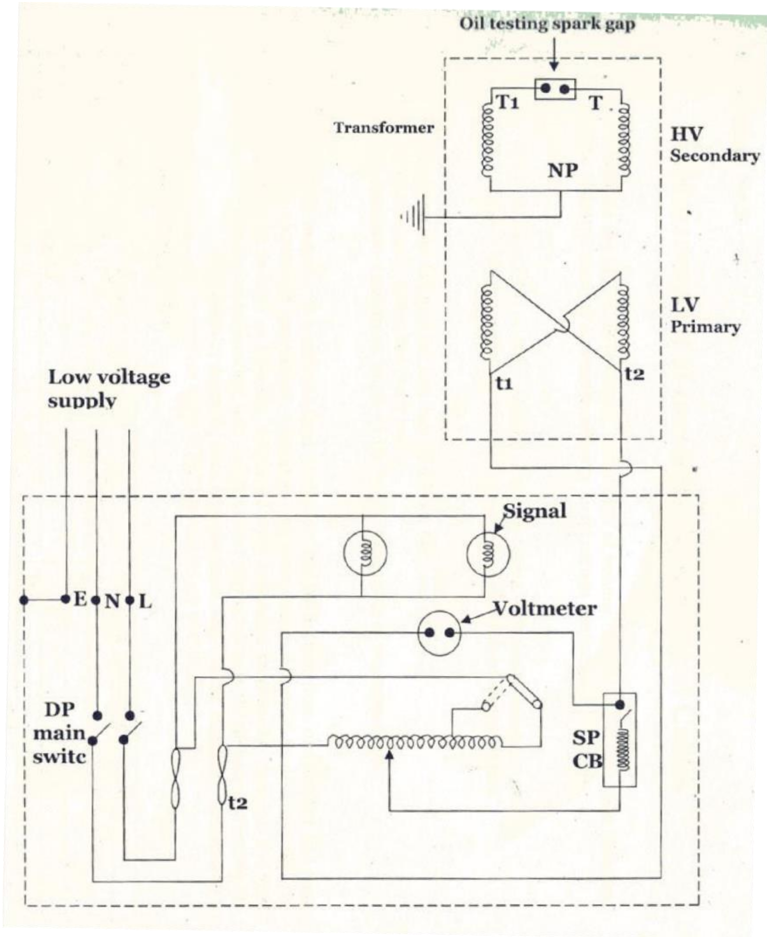


Fig 10.1: Circuit diagram

Procedure:

Agitate and turn over the vessel containing the sample oil several times to ensure a homogenous distribution of impurities without causing the formation of air bubbles. Pour the sample oil into the test cell slowly, to avoid the formation of air bubbles. The oil temperature at the time of testing is to be the same as the ambient temperature.

The level of oil in the test cell shall be such that the axis of the electrode is at a depth of 40 mm. Switch on the supply and increase the voltage at a uniform rate of 2 kV/s, starting from zero to the value causing breakdown. The circuit will be opened automatically if an arc is established.

On the other hand, if a transient spark (audible or visible) occurs, the circuit may have to be opened manually. The breakdown voltage is the voltage reached during the test at the time of the first spark, whether it is a transient or an established spark. The test is to be carried out within 10 minutes of first filling. After each breakdown, stir the oil gently between the electrodes by a clean glass rod. Repeat the test six times on the sample. Compute the electric strength as the arithmetic mean of the six values.

Observation:

Table 10.1

Sl No.	**VOLTAGE (kV)**	**DIELECTRIC STRENGTH (kV/cm)**

Gap between electrodes =
Type of electrode
Frequency =

Result:

Inference:

B) MEASUREMENT OF DIELECTRIC-STRENGTH OF SOLID INSULATING MATERIALS

Aim:

To measure the dielectric strength of different solid insulating materials using appropriate methods.

Equipment required:

0-10 kV HV. Breakdown Test Set

Procedure:

The breakdown test set is an essential gadget to test the quality of insulation provided in electrical equipment. It is the most important test, essential for routine and periodical maintenance of electrical equipment. Different dielectric materials (paper/mica/glass/cable, etc.) are connected between the input and earth of the test set, and voltage is applied gradually till breakdown occurs, which is indicated by the tripping of the equipment, and the corresponding voltage is noted.

Result:

Inference:

C) TESTING OF DIELECTRIC STRENGTH OF AIR

Aim:

To determine the dielectric strength of air by gradually increasing the voltage across a pair of electrodes in an air gap until breakdown occurs.

Theory:

Air, under normal conditions, acts as an insulating medium between two conductors. When the electric field intensity across the air gap exceeds a certain critical value, known as the breakdown strength, the air becomes ionized and starts conducting electricity.
The dielectric strength of air is defined as the maximum electric field (in kV/cm or kV/mm) that air can withstand without breakdown.

P**rocedure:**

Connect the circuit as per the standard high-voltage test setup. Adjust the electrode gap distance (e.g., 2 mm, 3 mm, 4 mm, etc.) using the micrometer screw arrangement. Set the variac to zero and ensure the setup is properly grounded. Gradually increase the voltage from the variac and observe the voltage at which spark (breakdown) occurs across the gap. Note the breakdown voltage for that particular gap distance. Repeat the experiment for different gap distances and record the readings.
Plot a graph of breakdown voltage (kV) vs. gap distance (mm).

Observation:

Table 10.2

Sl. No.	**Gap Distance (mm)**	**Breakdown Voltage (kV)**	**Dielectric Strength (kV/mm)**

Average Dielectric Strength = kV/mm

Result:

Inference:

Experiment No. 11

EXPERIMENT ON TRANSMISSION LINE SIMULATOR

Course Outcome (CO) Mapping

CO	Description	Bloom's Level
CO4	Conduct appropriate tests on any power system component in accordance with relevant standards.	K3

Program Outcome (PO) Mapping with Justification

PO	Description	Relevance	Justification
PO1	Engineering Knowledge	3	Understand theory and application of power factor correction.
PO4	Conduct Investigations of Complex Problems	3	Determine capacitor rating based on experimental data.
PO5	Engineering Tool Usage	3	Use of simulation tools/meters for PF analysis and capacitor selection.
PO6	The Engineer and The World	3	Power factor improvement reduces energy losses in society.
PO7	Ethics	3	Ensure correct reporting and analysis of improvement results.
PO8	Individual and Collaborative Team Work	3	Collaborative lab activity in PF correction study.
PO9	Communication	3	Report writing and explanation of PF improvement results.
PO11	Life-long Learning	2	Reinforces need for ongoing optimization of power systems.

Program Specific Outcome (PSO) Mapping with Justification

PSO	PSO Description	Justification
PSO1	Apply engineering knowledge to analyse, model, design and operate modern systems for power systems	Power factor correction is crucial for loss minimization and voltage regulation

CO-PO Mapping Matrix

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO3	3			3	3	3	3	3	3		2

CO-PSO Mapping Matrix

CO	PSO1	PSO2
CO3	3	

A) FERRANTI EFFECT AND REACTIVE POWER COMPENSATION

Aim:

To show how to use reactive power compensation to fix the high voltage caused by the Ferranti effect.

Instruments Required:

- EPLTS, Wattmeter-(2Nos): 500 V, 5A, Lpf.
- Resistive load, Inductive load.

Theory:

Ferranti Effect

The Ferranti effect is a phenomenon observed in long AC transmission lines where the voltage at the receiving end of the line is higher than the voltage at the sending end. This counterintuitive effect occurs under no-load or very light load conditions.

The primary cause of the Ferranti effect is the distributed capacitance and inductance along the length of the transmission line. Here's a breakdown of the theoretical principles:

- Line Capacitance and Charging Current: A transmission line consists of conductors separated by a dielectric (air), which creates a capacitive effect. When an AC voltage is applied to the line, this capacitance draws a "charging current" to charge and discharge itself every half cycle of the voltage waveform. This charging current leads the voltage by 90 degrees.
- Line Inductance: The conductors of the transmission line also have inductance due to the

magnetic field created by the current flowing through them.

- Interaction at No-Load: Under no-load or light-load conditions, the current flowing through the transmission line is predominantly the charging current. This leading charging current flows through the series inductance of the line. The voltage drop across the inductor is 90 degrees ahead of the charging current.
- Phasor Relationship: Due to the phase relationships, the voltage drop across the inductor ends up being in phase with the sending-end voltage. This causes the receiving-end voltage to be the arithmetic sum of the sending-end voltage and the voltage drop across the line inductance, resulting in a higher voltage at the receiving end.

Transmission line representation:

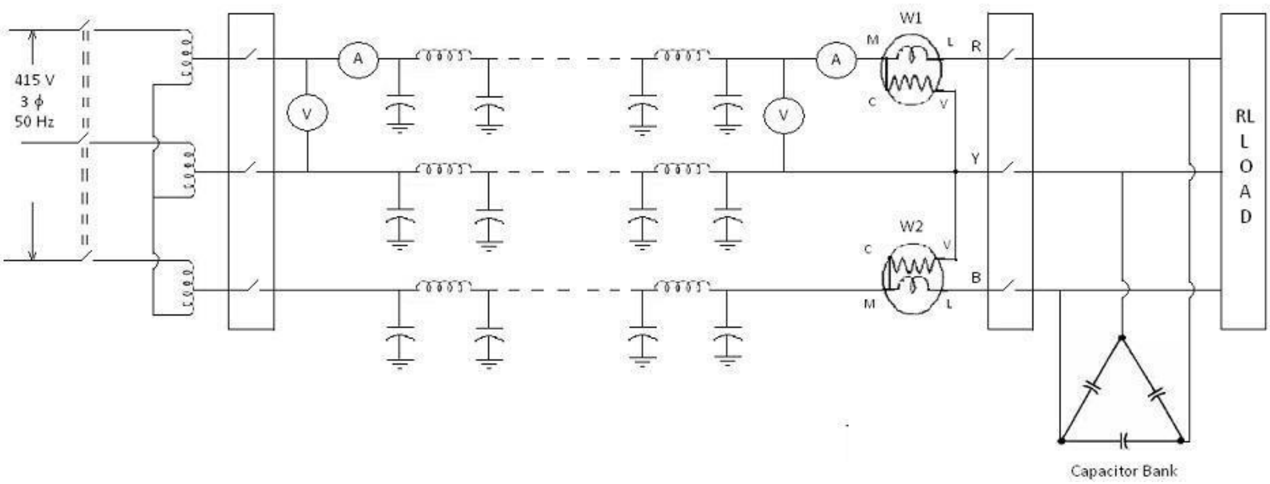


Fig 11.1: Circuit Diagram

The Transmission line is represented by four distributed parameters at a power frequency of 50 Hz. They are

- Series resistance ‘R’ in ohms/km
- Series inductive reactance ‘X’ in ohms/km
- Shunt Conductance ‘G’ in mho/km
- Shunt Susceptance ‘B’ in mho/km

The ‘G’ shunt conductance is usually ignored because its value relative to other parameters is significantly small. All these parameters are functions of the line design, i.e. conductor size, type, their bundles, inter-conductor spacing, phase spacing, height above ground, frequency, temperature, tower configurations, etc.

1. **Generating station**
   a. The line charging voltage source is 0-55-110-330V line-line.
   b. Circuit Breaker for overload protection and switching on/off of the system

c. Digital Voltmeter with a function indicator switch for sending end voltage

d. Digital Ammeter with function indicator switch for sending end current measurement, phase value(line-line)

2. Transmission Line

3-phase Artificial Transmission line of 180km line length, and each pi-section for every 30 km.

a. Line inductors with resistance -18 Nos

b. Line capacitors – 36 Nos

3. Receiving station

a. Digital voltmeter with a function indicator switch for measurement of the receiving end voltage line-line value.

b. Digital ammeter with a function indicator switch for measurement of the receiving end line-line voltage value.

c. Circuit Breaker for overload protection and switching ON/OFF the load.

d. R-L loading terminals connect the load externally to the systems.

4. VAR Compensators

a. Shunt Reactor 3-phase star-connected 300 volts line-line, variable reactance

b. Shunt Capacitance of 6 kVAR in steps of 1 kVAR delta connected; 3-phase (leading VARs)

c. Series Reactor 3 phase, 392.5 VAR. Variable in steps (lagging VARs).

Procedure:

Ferranti effect: Switch on the system on no load, low voltage (200V L- L) is applied, and note down the rise in voltage at the receiving end.

Shunt Reactor Compensation: Voltage rise at the receiving end can be reduced by adding shunt reactors. For the above condition (1), ($V_S < V_R$) connect the shunt reactor at the receiving end in steps and note down the reduction in V_R

Observation:

Table 11.1

V_S	I_S	V_R	I_R	W1	W2	W_1 x mf	W_2 x mf	P.F	Remarks

Table 11.2

	Sending End Voltage(V)	Receiving End Voltage(V)	Remark
No Load			
With the Shunt Reactor			

Result:

Inferences:

B) POWER FACTOR IMPROVEMENT

Aim:

To calculate the rating of capacitors for power factor correction for a load and verify it experimentally.

Theory:

Power Factor Improvement

Power factor of the given R-L load is cos Φ1. In order to improve it to cos Φ2 a shunt capacitor can be installed at the load end. As the power factor is improved to cos Φ2 lagging, the in-phase component of current will remain constant as the load is not changed; only the reactive component will change.

Load current (Line) $=I_1$

Active component of Load = $I_1 \tan \Phi_1 = I_p$

Reactive component of Load = $I_1 \sin \Phi_1 = I_{q1} = I_p \tan \Phi_1$

New reactive component of current= $I_p \tan \Phi_2 = I_{q2}$

Component of current to be Neutralized = Current to be drawn by the capacitor

$I_c = I_{q1} - I_{q2} = I_p \tan \Phi_1 - I_p \tan \Phi_2$

But $I_c = \omega C V$ where V is the L-L voltage.

The capacitor bank is delta-connected.

Procedure:

Power Factor Improvement: Connect the RL load to the system, voltage is applied, take the readings and calculate the power factor of the load applied (cos Φ_1**).**

Problem 1:

Calculate the per-phase value of Capacitance to be connected to improve the power factor to the required value. Connecting six capacitors in parallel, find the new power factor at the receiving end of the transmission line.

Observation:

Table 11.3

	P.F	Remark
Without C		
With C		

Result:

Inferences:

Precaution:

- **The maximum loading limit of the transmission line system training simulator not to exceed 3A under normal loading conditions.**
- **During experiment, the receiving station bus voltage should be controlled between 180V-280V line-neutral in all phases of the 3-phase system.**

Experiment No. 12

MEASUREMENT OF POWER USING CTs & PTs

Aim:

To measure active power in a three-phase system using instrument transformers **Current Transformers (CTs)** and **Potential Transformers (PTs),** and to study their role in power measurement applications in power systems.

Course Outcome (CO) Mapping

CO	Description	Bloom's Level
CO4	Conduct appropriate tests on any power system component in accordance with relevant standards.	K3

Program Outcome (PO) Mapping with Justification

PO	Description	Relevance	Justification
PO1	Engineering Knowledge	3	Understand fundamentals of power measurement using CTs and PTs.
PO4	Conduct Investigations of Complex Problems	3	Measuring three-phase power accurately using instrument transformers.
PO5	Engineering Tool Usage	3	Use of wattmeters and CTs/PTs for experimental setup.
PO6	The Engineer and The World	3	Accurate measurements ensure safe and fair energy billing.
PO7	Ethics	3	Precise and ethical handling of measurement instruments.
PO8	Individual and Collaborative Team Work	3	Team-based lab experimentation and verification.
PO9	Communication	3	Reporting and presenting measured values and interpretations.
PO11	Life-long Learning	2	Awareness of metering accuracy and transformer testing procedures.

Program Specific Outcome (PSO) Mapping with Justification

PSO	PSO Description	Justification
PSO1	Apply engineering knowledge to analyse, model, design and operate modern systems for power systems	CTs and PTs are integral to measurement and protection schemes

CO-PO Mapping Matrix

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO3	3			3	3	3	3	3	3		2

CO-PSO Mapping Matrix

CO	PSO1	PSO2
CO3	3	

Instruments required:

Current Transformer: Primary 1/5/10/25A, Secondary 5A, Potential Transformer: Primary 440V, Secondary 110/220V Auto-Transformer, Wattmeter, 250V, 5A, lpf, Ammeter 0-10A, Voltmeter 0-250V (2 nos.), AVO meter, Resistive, Inductive & Capacitive loads.

Theory:

When the current and voltages to be measured are high, then use an instrument transformer along with a wattmeter, as with ammeters and voltmeters.

When the wattmeter is used in conjunction with an instrument transformer, the correction factor shall be applied for the ratio and phase angle errors of instrument transformers. Let the load voltage, current and load power factor be V, I and cos ø, respectively

- Current in current coil of wattmeter = current in secondary of CT = Is
- Voltage across pressure coil of wattmeter = Voltage across secondary of PT = Vs
- Current in the pressure coil of the wattmeter is lagging behind voltage by a small angle ø due to the inductance of the pressure coil.

Phase angle of PT = δ

Phase angle of CT = β

Phase angle between currents in the current and potential coils of wattmeter,

for inductive load :

$$\boldsymbol{\gamma = \emptyset - \theta - \beta - \delta}$$

for capacitive load:

$$\gamma = \emptyset + \theta + \beta + \delta$$

Since the phase angle of PT may be lagging or leading. Neglecting the transformation ratio errors of instrument transformers.(Given $\beta = 2^0$ $\partial = 1^o$ and $\theta = 0^o$)

- Correction factor K =$\frac{cos\emptyset}{cos\theta\cos(\emptyset-\theta-\beta\pm\delta)}$ for capacitive load
- Correction factor K =$\frac{cos\emptyset}{cos\theta\cos(\emptyset+\theta+\beta\pm\delta)}$ for inductive load
- True power = K x Actual ratio of CT x Actual ratio of PT x Wattmeter reading

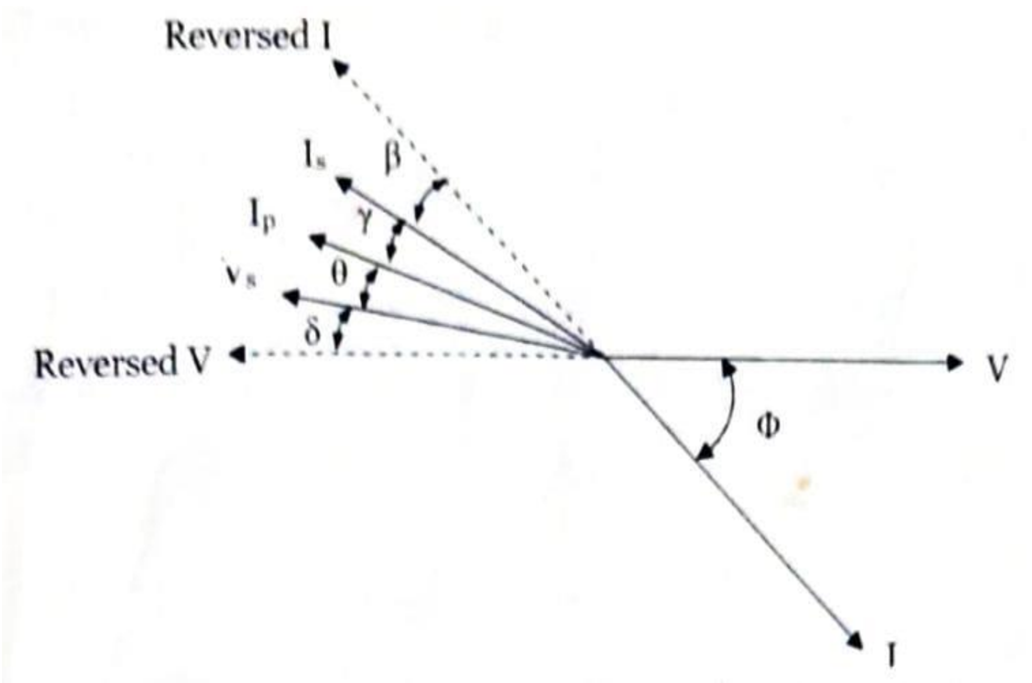


Fig 12.1: Vector diagram for inductive load

$$\gamma = \emptyset - \theta - \beta - \delta$$

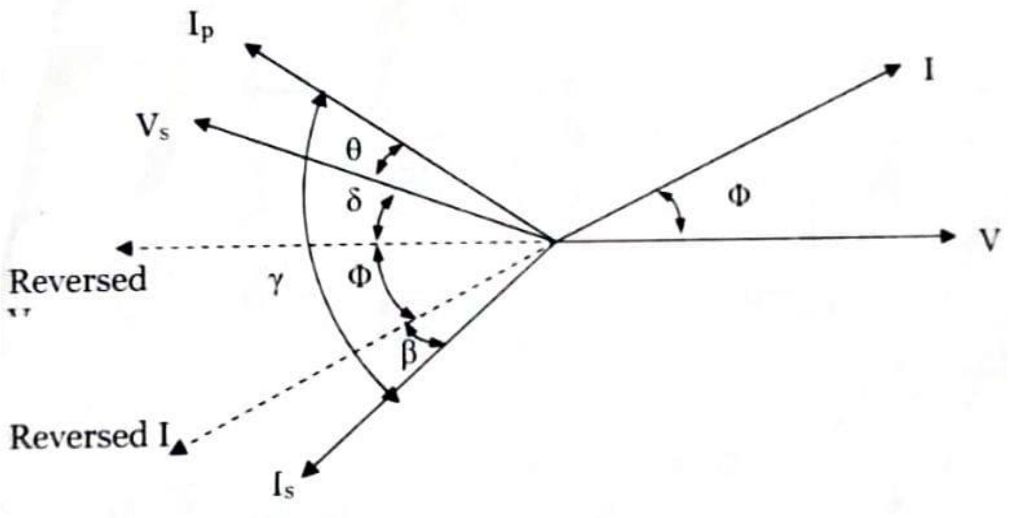


Fig 12.2: Vector diagram for capacitive load

$$\gamma = \emptyset + \theta + \beta + \delta$$

Procedure:

- Make the connections as per the circuit diagram, Fig 12.3
- Connect the given R-L load. Apply rated voltage to the primary of the PT. Vary the load and note down the readings of the meters. Repeat the Experiment with R-C load also.
- Tabulate the readings and calculate the true power. Measure the resistance of the load for each reading using an AVO meter.
- CT secondary should not be opened while the primary is energized.

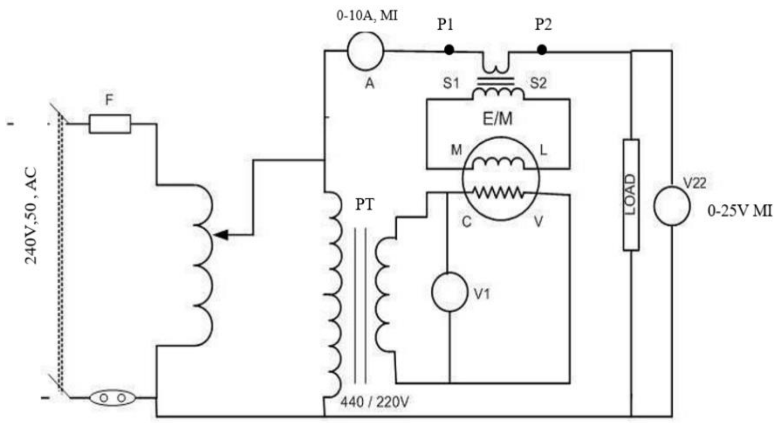


Fig 12.3: Circuit Diagram

Observations:

Table 12.1

<table>
<tr><td rowspan="2">Sl. No.</td><td colspan="2">Voltmeter Reading</td><td rowspan="2">Ammeter Reading (A)</td><td rowspan="2">Wattmeter Reading (W)</td><td rowspan="2">Load Z= V2/I (ohm)</td><td rowspan="2">Load Res. (R ohm)</td><td rowspan="2">Cos ϕ</td><td rowspan="2">K</td><td rowspan="2">True power</td></tr>
<tr><td>V1</td><td>V2</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Result:

Inference:

Experiment No. 13

VI CHARACTERISTICS OF A PV MODULE AND THE MAXIMUM POWER POINT

Aim:

Plot the VI characteristics of a PV module and determine the maximum power point

Course Outcome (CO) Mapping

CO	Description	Bloom's Level
CO4	Conduct appropriate tests on any power system component in accordance with relevant standards.	K3

Program Outcome (PO) Mapping with Justification

PO	Description	Relevance	Justification
PO1	Engineering Knowledge	3	Understand solar PV system layout and power flow configuration.
PO3	Design/Development of Solutions	2	Interpret PV system layout and performance from datasheet and test results.
PO4	Conduct Investigations of Complex Problems	3	Evaluate performance and verify load sharing among AC/DC loads.
PO5	Engineering Tool Usage	3	Use of training kits and software to simulate and analyze PV systems.
PO6	The Engineer and The World	3	Assess relevance and impact of renewable energy use.
PO7	Ethics	3	Follow safe practices and compliance in solar energy systems
PO8	Individual and Collaborative Team Work	3	Hands-on familiarisation in a team-based learning environment.
PO9	Communication	3	Interpret and explain results obtained during lab/field setup.
PO10	Project Management and Finance	2	Interpret basic cost-benefit and efficiency parameters of PV system.
PO11	Life-long Learning	2	Exposure to evolving solar technologies and grid standards.

PSO Mapping with Justification

PSO	Description	Relevance	Justification
PSO1	Apply simulation tools for power system analysis	3	Simulate and analyse standalone PV power systems with loads.

CO-PO Mapping Matrix

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO4	3		2	3	3	3	3	3	3	2	2

CO-PSO Mapping Matrix

CO	PSO1	PSO2
CO4	3	

Theory:

A stand-alone system can be used for both AC and DC loads and is installed near the location of the load. These systems are easy to install and understand. These systems can be used without batteries, but they perform best with a battery bank. These systems are best suited for locations where grid connectivity is not present, and they fulfil the requirements of these locations. Use DC power to charge the battery and run the DC load, but use AC power to run the AC load. It includes a charge controller, batteries, a DC load, an inverter and an AC load in this system. It runs the AC and DC loads simultaneously and can fulfil the demand of both types of pf loads.

The Solar PV Training & Research System is a mini-Solar PV Plant Prototype which enables students and faculty to understand in-depth concepts about stand-alone PV systems. The product also provides research orientation on several concepts such as MPPT, inverter control etc. The system consists of individual plug-in units, each with components for different experimental arrangements. The conception of the system allows indoor and outdoor experiments. Additional options include changing the slope angle of the module to observe the effect of tilt.

Features and Specification:

Table 13.1

COMPONENTS	SUBCOMPONENTS
Power generating unit	Solar PV module
Artificial source of radiation	Halogen- with regulator
Power conditioning unit	DC-DC Converter- Auto/Manual mode
	Inverter - Auto/Manual mode
Control and measuring unit	Measuring meters
	Battery bank
	Load AC/DC
Accessories	Radiation meter
	Battery charger
	Module cooling system
	manual

Experimental setup:

Refer to the Solar PV training system manual. It consists of a module stand, charge controller, inverter and meters for measurement. The stand- alone PV system to supply both AC and DC types of load can be achieved by making the connections in the control board as shown in Fig. 13.1 . The voltage and current of the DC load, AC load and battery can be measured by the meters available in the control board.

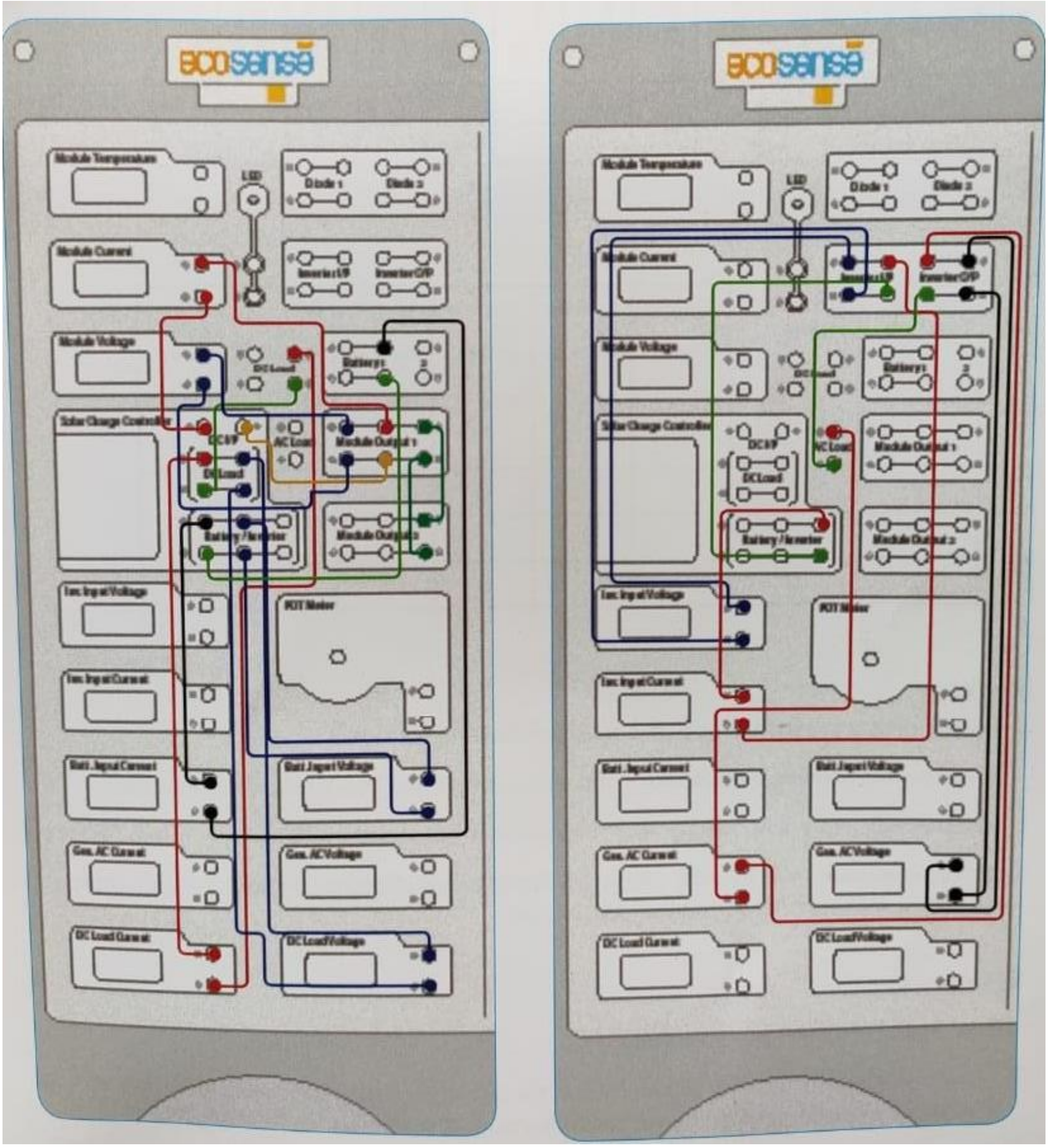


Fig 13.1: Control board connections for a standalone PV system to supply both AC and DC load

Observation:

Table for stand-alone PV system calculation:

Table 13.2

Sl. No.	No. of modules in series	No. of modules in parallel	Array current (A)	Array voltage (V)	Array power(W)	DC load current(A)	DC load voltage(V)	DC load power (W)
1.	1	1						
2.	1	2						

Table 13.3

Sl. No.	Inverter input current (A)	Inverter input Voltage (V)	Inverter input Power (W)	Battery current (A)	Battery voltage (V)	Battery power (W)
1.						
2.						

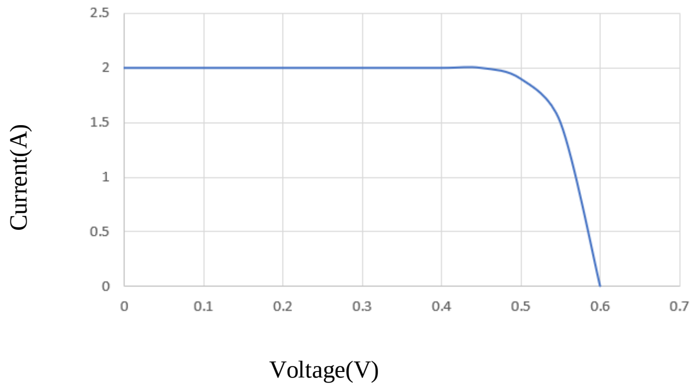
Table for inverter efficiency:

Table 13.4

Sl. No.	Modules in series	Modules in parallel	Inverter input current (A)	Inverter input Voltage (V)	Inverter input Power (W)	AC load current (A)	AC load Voltage (V)	AC load power (W)

- Plot the VI characteristics of a PV module and determine the maximum power point

PV module is characterized by its I-V and P-V characteristics. At a particular solar insolation and temperature, module characteristics curves are shown in Fig. 13.2



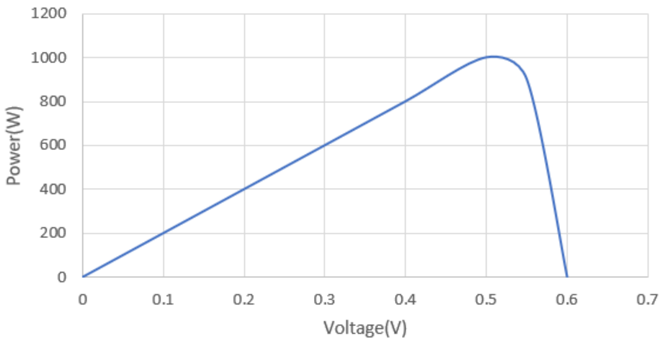


Fig 13.2: Characteristic curves of Solar PV module

In these curves, the maximum current at the zero voltage is called short circuit current (Isc) and the maximum voltage is known as open circuit voltage (Voc). In P-V curve the maximum power is achieved only at a single point which is called MPP (Maximum Power Point), and the voltage and current corresponding to this point referred to as Vm and Im. This single point corresponds to a load resistance, known as critical load resistance.

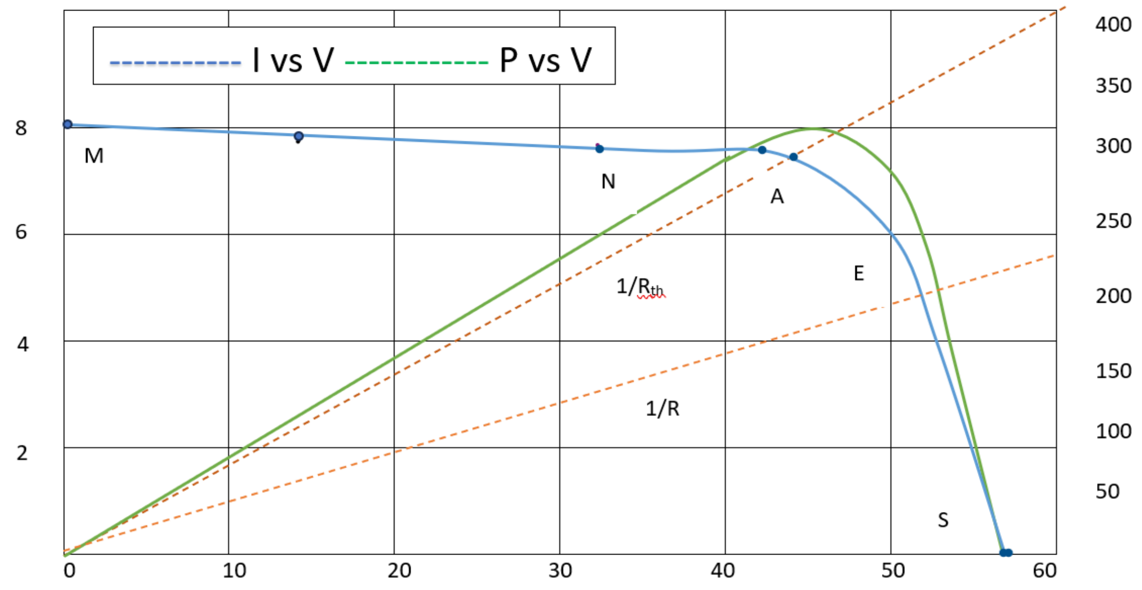


Fig 13.3: P-V curves for different values of load resistance

Experimental setup:

The circuit diagram to evaluate the MPP of a module is shown in Fig.13.4. In this circuit, modules will be connected to the variable resistance through an ammeter and a voltmeter. The circuit diagram in fig. 13.4, which illustrates that the module port(s) will be connected to the module ammeter, module voltmeter, and Pot meter ports using connecting cables. At the same time, the logger plotter box ports will also be connected to the module ports through connectors and to the PC through USB.

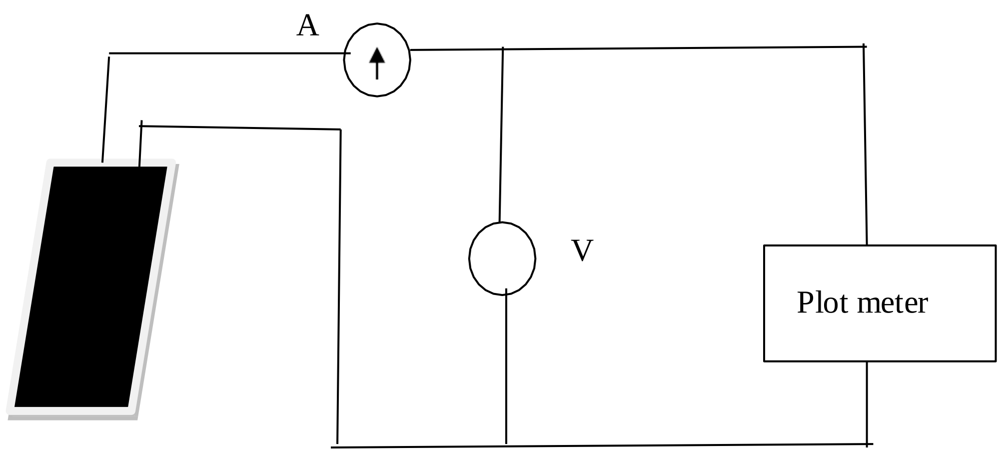


Fig 13.4: Circuit diagram for P-V characteristics

Observations:

For the fixed radiation and temperature, note the following reading for different values of load resistance R.

Table 13.5

Sl. No.	V(volts)	I(amps)	R(ohms)	P (watts)
1.				
2.				
3.				

Results:

The following are the results:

1. Draw the I-V curves (manually and with the help of software) of all the sets on a single graph and show the characteristics at different radiation and temperature levels.

2. Draw the P-V curves (manually and with the help of software) of all the sets on a single graph and show the characteristics at different radiation and temperature levels.

3. From the table, find the maximum value of P. This will correspond to a particular value of R. Note down the value of Pmax and the corresponding R.

Vm =

Im =

Pm =

Ropt =

Inference:

Precautions:

1. Readings for one set should be taken within 1-2 minutes of otherwise temperature of the module can change as radiation source is halogen lamps.

2. Halogen lamp position should not be changed during one set otherwise radiation on modules may be changed.

3. Connections should be tight.

4. Experiment without a battery in the circuit.

Experiment No. 14

RELAY COORDINATION

Aim:

To study relay coordination and verify the sequence of operation of relays for a radial system.

Course Outcome (CO) Mapping

CO	Description	Bloom's Level
CO1	Apply fundamental power system analysis techniques to determine the operating parameters under steady state and faulty conditions.	K3

Program Outcome (PO) Mapping with Justification

PO	Description	Relevance	Justification
PO1	Engineering Knowledge	3	Understanding relay operation and fault protection principles.
PO4	Conduct Investigations of Complex Problems	3	Analyse coordination between relays under varying conditions.
PO5	Engineering Tool Usage	3	Use of relay testing kits and simulation tools.
PO6	The Engineer and The World	3	Ensures system safety and minimizes blackout risks.
PO7	Ethics	3	Adheres to protection standards and safety norms.
PO8	Individual and Collaborative Team Work	3	Requires coordinated testing and teamwork.
PO9	Communication	3	Preparation of coordination curve reports and test results.
PO11	Life-long Learning	2	Reinforces up-to-date knowledge on protection systems and relays.

Program Specific Outcome (PSO) Mapping with Justification

PSO	PSO Description	Justification
PSO1	Apply engineering knowledge to analyse, model, design and operate modern systems for power systems	Relay coordination ensures system protection reliability and continuity of supply

CO-PO Mapping Matrix

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO3	3			3	3	3	3	3	3		2

CO-PSO Mapping Matrix

CO	PSO1	PSO2
CO3	3	

Theory

Using intelligent one-line diagrams, comprehensive protective device libraries, and a three-dimensional database, ETAP Star offers insight into troubleshooting false trips, relay mis-operation, and miscoordination. Along with plotting protective device operating curves, ETAP Protective Device Coordination software provides tools for plotting the starting, inrush, and damage curves for equipment like motors, trans formers, generators, and cables and offering insight into troubleshooting false trips, relay and breaker maloperation, and miscoordinations.

Procedure:

- Drag and place the elements on OLV & proceed to enter data as given.
- Enter the nameplate and protection related details for the load.
- Drag and place protective devices & connect them by providing CT data.
- Click on the overcurrent/overload relay and go to the Settings page, select manufacturer & model from the library
- Update all relay data from the library in OCR page
- Update all HV & LV circuit breaker operating times. Double click on circuit breaker, go to the Rating page update the minimum time delay.
- LV Circuit Breaker – (eg : 0.04 sec)
- HV Circuit Breaker – (eg: 0.06 sec)
- On each bus go to rating page and update the type and continuous ampere rating of the bus
- Go to the Star-Protective Device Coordination Module. Edit the Study case, and create fault at all buses.

- Click on Run/ Update Short-Circuit kA in the star toolbar.
- Check the SC current ratings of various protective devices, and set the currents as per the SC analysis.
- If motor loads are used: In the motor protection, for the overload relay, go to the settings page & set the following:

a. Click on Thermal page for overcurrent or overload setting:
Current pickup = 1.1 times the FLC of the motor.
Time delay should be above motor start & below stator thermal damage curve.

b. Click on the Jam page for locked rotor or jam or stall protection.
Current pick up (Trip) = 150% of FLC of motor = 137% of thermal overload pickup
Time delay should be above motor start & below stator thermal damage curve.

c. Adjust the time delay using the time handle on the OLR jam protection curve. Set it above the motor starting curve and below the motor stator & rotor thermal damage curve.

- For OCRs, set the curve type as IEC – extremely inverse & set the pickup values with proper grading (eg: 0.98, 0.96, 0.94 etc.).
- Adjust the time delay by using a time handle on plot such that it is above characteristics of the protective device and below the incomer cable thermal withstand characteristics.
- Check the time delay of other relays by using a time handle such that it is above the first set relay's curve with a time difference (say; 300 ms) by using Time Difference tool.

CHECK SEQUENCE OF OPERATION:

1. Double click on Relay1, go to the Output page and then click on Add to interlock Relay1 with CB2.
2. Similarly update all relay interlocks as given in the table below.

Relay ID	Relay Element	Level / Zone	Device	ID	Action
Relay 1	Any	Any	HVCB	CB1	Open
Relay 2	Any	Any	LVCB	CB2	Open

Table 14.1: Interlock Editor page setting data

3. Click on Fault Insertion and apply a fault at motor terminals. Check for the flashing devices to know the sequence of operation.

4. To check the normalized star view, create one more star view with all protection devices and click on Normalized TCC in the star view toolbar.
5. Click on Sequence Viewer to view the sequence of operation events with time.

Question 1:

Study the relay coordination and verify the sequence of operation of the relays in the circuit shown below.

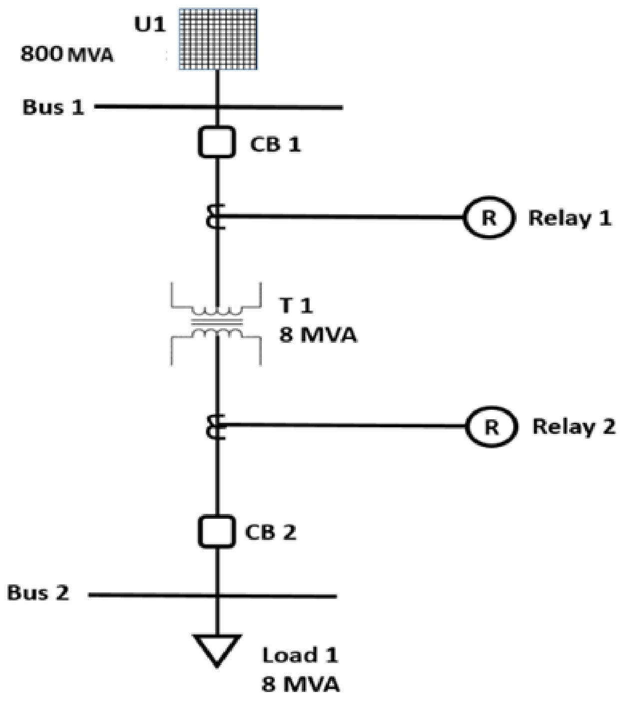


Fig 14.1: Single line diagram of radial circuit

GRID DATA

Nominal voltage = 33 kV

SC kA = 800 MVA

X/R = 40

BUS DATA:

Bus1 voltage = 33 kV

Bus 2 voltage = 11 kV

TRANSFORMER DATA:

CAPACITY = 10 MVA

PRIMARY = 33 kV

SECONDARY = 11 kV

X/R = 8.35

LOAD DETAILS:

8 MVA

CT RATIOS:

Table 14.2

CT NAME	**CT 1**	**CT 2**
PRIMARY RATING	200	1000
SECONDARY RATING	1	1

RELAY DETAILS:

TYPE: ALSTOM

MODEL: P139

FUNCTIONS: OVERCURRENT RELAY

APPLICATION: PROTECTION, MONITORING AND CONTROL OF MOTORS, TRANSFORMERS AND LINE

Result:

Inference:

Experiment No. 15

POWER LINE SERIES COMPENSATOR

Aim:

Determine

i. Power transfer capability of the transmission line with and without series compensation.
ii. Effects of series compensation on power transfer capability and system stability.

Course Outcome (CO) Mapping

CO	Description	Bloom's Level
CO1	Apply fundamental power system analysis techniques to determine the operating parameters under steady state and faulty conditions.	K3

Program Outcome (PO) Mapping with Justification

PO	Description	Relevance	Justification
PO1	Engineering Knowledge	3	Apply transmission line and compensation principles.
PO2	Problem Analysis	3	Identify and solve power transfer and stability issues.
PO3	Design/development of solutions	2	Model and evaluate system improvements using series compensation.
PO4	Conduct Investigations of Complex Problems	3	Simulate and analyse compensated vs. uncompensated systems.
PO5	Engineering Tool Usage	3	Use tools to study transient and steady-state responses.
PO7	Ethics	3	Ensure safe and standard practices in system modelling.
PO8	Individual and Collaborative Team Work	3	Collaborate on system modelling and reporting.
PO9	Communication	3	Present compensation analysis and insights.
PO11	Life-long Learning	2	Understand evolving technologies in system stability and compensation.

Program Specific Outcome (PSO) Mapping with Justification

PSO	PSO Description	Justification
PSO1	Apply engineering knowledge to analyse, model, design and operate modern systems for power systems	Series compensation directly influences the load ability and voltage profile of the transmission system

CO-PO Mapping Matrix

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO1	3	3	2	3	3		3	3	3		2

CO-PSO Mapping Matrix

CO /PSO	PSO1	PSO2
CO1	3	

Specifications:

Transmission line 1 (non-compensated):

Simulated length… .... 200 km

Impedance

R_{L1} .... 8.9 Ω
X_{L1} .... 50 Ω
X_{c1} .... 750 Ω
X_{c2} .... 750 Ω

Transmission line 2 (compensated):

Simulated length… .... 300 km

Impedance

R_{L1} .... 10 Ω
X_{L1} .... 75 Ω
X_{c1} .... 500 Ω
X_{c2} .... 500 Ω

Series capacitors

17% compensation… ....173.4µF, 15.3 Ω, @60Hz
25% compensation… ....117.9µF, 22.5 Ω, @60Hz
34% compensation… ....86.7µF, 30.6 Ω, @60Hz

Shunt capacitors

100 MVAR… ....0.49µF, 5.4kΩ, @60Hz
200 MVAR… ....0.98µF, 2.7kΩ, @60Hz
400 MVAR… ....1.96µF, 1.35kΩ, @60Hz
800 MVAR… ....3.93µF, 675Ω, @60Hz

Shunt Inductors

150 MVAR… ....9.55 H, 3.6 kΩ, @60 Hz
300 MVAR ....4.77 H, 1.8 kΩ, @60 Hz
600 MVAR… ....2.39 H, 900 Ω,   @60 Hz

Resistance loads

225 MVAR… ....2.4 kΩ
450 MVAR… ....1.2 kΩ
900 MVAR… ....600 kΩ
1800 MVAR… ....300 kΩ
3600 MVAR… ....150 kΩ

Theory:

The circuit representation of the transmission lines operating at very high voltage and running for many kilometres can be simplified to one resistance R_L, one inductance X_L, and two equal capacitances X_c located at the end of the line.

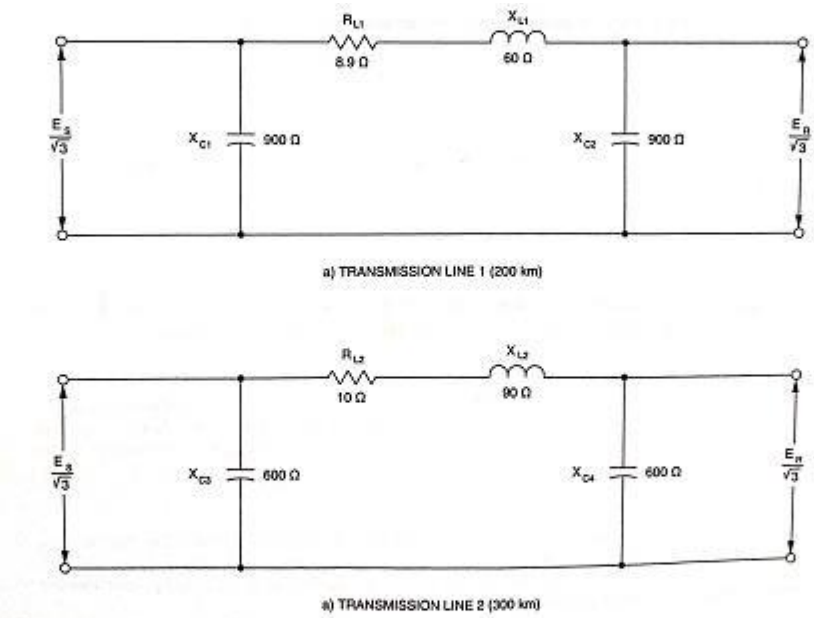


Fig 15.1 Circuit representing one phase of transmission lines 1 and 2 of the demonstrator.

Because very long high voltage lines are mainly inductive, it is possible to demonstrate that the active power transferred through such lines is given by:

$$P_T = \frac{E_S E_R}{X_L} \sin\theta$$

Where

P_T is the transferred power (W)

E_S is the line-to-line sender voltage (V)
E_R is the line-to-line receiver voltage (V)
X_L is the reactance of the line (ohm)
θ is the phase shift between the sender and receiver voltages (°)

The transferred power is maximum when the sender and receiver voltages are equal and when the phase shift between these voltages is 90°. However, because of the need to provide safety factors, phase shifts greater than 30° are not normally exceeded deliberately. For a given line reactance and sender voltage, this sets a limit on the maximum power a transmission line can transfer. When the compensation demand becomes high, there will come a time when an additional transmission line is required. Obtaining a corridor, environmental impact limitations, and line cost can all make the provision of a new line difficult. A preferred option is to increase the power transfer capability of an already existing line by means of series compensation.

Series compensation consists in reducing the inductive reactance of a transmission line by connecting a capacitor in series with the line, as in the Fig. 15.2. With this method, the active power transferred through line becomes,

$$P_T = \frac{E_S E_R}{X_L - X_{CS}} \sin\theta$$

Where

P_T is the transferred power (W)

E_S is the line-to-line sender voltage (V)
E_R is the line-to-line receiver voltage (V)
X_L is the reactance of the line (Ω)
X_{CS} is the reactance of the series capacitor(Ω)
θ is the phase shift between the sender and receiver voltages (°)

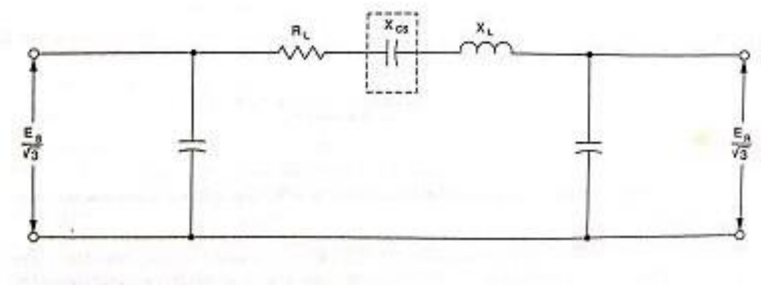


Fig 15.2 Series compensation

The decrease in the line reactance created by series compensation is named the compensation factor, k. The value of k as a percentage is given by

$$k_{(\%)} = \frac{X_{CS}}{X_L} \times 100$$

The power transfer capability of a line increases as the compensation factor is increased. The increase in power transfer capability for a given compensation factor is given by

$$increase\ (\%) = \frac{k}{1-k}\ x\ 100$$

If, for example, the line is compensated 34%, the increase in power transfer capability will be 51.1%. Compensation factors between 20% and 70% are generally used, thereby providing an increase in power transfer capability between 25 and 33%.

Because the series compensation increases the power transfer capability, it also improves the system stability. In effect, for any given phase shift between the sender and receiver voltages, the amount of transferred power is greater with a compensated line. The fig.15.3 shows the power transfer capability of a line without compensation and with 50% compensation.

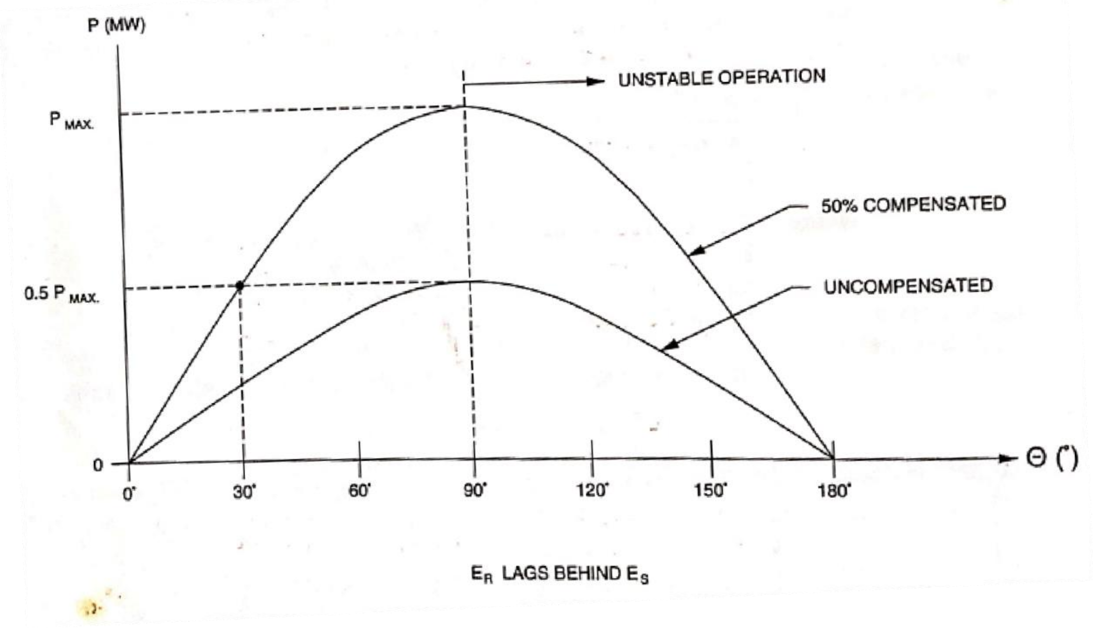


Fig 15.3 Power transfer capability of a transmission line with and without series compensation.

If the maximum power demand is $0.5P_{MAX}$, the phase shift between the sender and receiver voltages will be 30° for the compensated line, which corresponds to a very stable operating point. However, the phase shift will be 90° for the uncompensated line, which is just on the edge of instability. In all likelihood, the uncompensated line will be unstable to carry the load, and its breaker will open.

Procedure:

WITHOUT SERIES COMPENSATION:

1. Open all the demonstrator switches. Put transmission line 1 in service by closing both switches S1 and S2.
2. Adjust the sender voltage to 735 kV using the SOURCE adjustment.
3. Connect a resistive load of 900 MW to line 1.
4. Observe that the receiver voltage exceeds the sender end voltage due to reactive power being generated in excess by the line capacitanceX_{CS}.
5. Compensate the line 1 so that the sender and receiver voltages are equal. To do so, connect the required shunt inductor (about 450 MVAR) across the load for the receiver voltage to be as close as possible to the sender end voltage of 735 kV.
6. On the phasemeter, observe the phase shift between the sender and receiver voltages. The phase shift is about 6°, which is much less than 30°. Therefore, the power demand is well below the power transfer capability of line 1.
7. Increase the load on line 1 to 1800 MW.
8. Readjust the shunt inductor across the load so that the receiver voltage is as close as possible to the sender voltage of 735 kV. The receiver shunt inductor should be around 150 MVAR.
9. The phase shift now observed on the phasemeter is about 12°, which is less than 30°. Therefore, the power demand is still below the power transfer capability of line 1.
10. Further increase the load on line 1 to 3600 MW.
11. Compensate the line 1 so that the sender and receiver voltages are equal. First disconnect the shunt inductor from the load. Then connect the required shunt capacitor (around 800 MVAR) across the load for the receiver voltage to be as close as possible to the sender voltage of 735 kV.
12. The phase shift now observed on the phasemeter is about 25°. Therefore, the power transfer capability of line 1 has not been reached yet.
13. Further increase the load on line 1 to 4500 MW.
14. Readjust the shunt capacitor across the load so that the receiver voltage is as close as possible to the sender voltage of 735 kV. The required shunt capacitor should not be about 1500 MVAR.
15. The phase shift now observed is about 30°. Therefore, the power transfer capability of line 1 has been reached and is 4500 MW.
16. Open all the demonstrator switches.
17. Put the transmission line 2 in service by closing switches S3 and S4. Set the series compensation selector to 0%.

18. Connect a resistive load of 1800 MW to line 2.
19. Compensate the line 2 so that the sender and receiver voltages are equal. To do so, connect the required shunt inductor (about 300 MVAR) across the load for the receiver voltage to be as close as possible to the sender voltage of 735kV.
20. On the phasemeter, observe the phase shift between the sender and receiver voltages. The phase shift is about 17°, which is much less than 30°. Therefore, the power demand is below the power transfer capability of line 2.
21. Increase the load on line 2 to 3600 MW.
22. Compensate the line 2 so that the sender and receiver voltages are equal. First disconnect the shunt inductor from the load. Next, connect the required shunt capacitor (approximately 1000 MVAR) across the load to minimize the difference between the receiver voltage and the sender voltage of 735 kV.
23. The phase shift now observed on the phasemeter is about 38°, which is much more than 30°. Therefore, the power demand exceeds the power transfer capability of line 2.
24. Decrease the load on line 2 to 2925MW.
25. Readjust the shunt capacitor across the load so that the receiver voltage is as close as possible to the sender voltage of 735 kV. The required shunt capacitor should be about 400 MVAR.
26. The phase shift now observed is about 30°. Therefore, the power transfer capability of line 2 is 2925 MW.

    NOTE: If the displayed phase shift differs from 30° by more than 3°, you may want to readjust the load on line 2 to measure its power transfer capability at 30° accurately.

WITH SERIES COMPENSATION:

1. Open all the demonstrator switches.
2. Put transmission line 2 in service by closing switches S3 and S4. Set the series compensation selector to 0%.
3. Adjust the sender voltage to 725 kV.
4. Connect a load of 2925 MW to line 2. This corresponds to the power transfer capability of line 2 without series compensation.
5. Connect the required shunt capacitor across the load for the receiver voltage to be as close as possible to the sender voltage of 735 kV. The phase shift should now be about 30°.
6. Set the series-compensation selector to 17%.
7. Observe that the phase shift has decreased from 30° to about 24°. The power demand

on line 2, however, is still 2925 MW. Therefore, series compensation has decreased the phase shift required to transfer the same amount of power which, in turn, has improved the stability of the system.

8. Increase the load on line 2 to 3600 MW.
9. Readjust the shunt capacitor across the load so that the receiver voltage is as close as possible to the sender voltage of 735 kV.
10. The phase shift now observed is about 31°. Therefore, the 17% - series compensation has increased the power transfer capability of line 2 by

$$\frac{3600\,MW - 2925\,MW}{2925\,MW}\,X\,100 = 23\%$$

11 Set the series-compensation selector to 34%
12. Observe that the phase shift has decreased from 31° to about 25°. The power demand on line 2, however, is still 3600 MW. Therefore, the increase in compensation factor has improved the stability of the system.
13. Increase the load on Line 2 to 4500 MW.
14. Readjust the shunt capacitor across the load so that the receiver voltage is as close as possible to the sender voltage of 735 kV.
15. The phase shift now observed is about 32°. Therefore, the 34% series-compensation has increased the power transfer capability of line 2 by

$$\frac{4500\,MW - 2925\,MW}{2925\,MW}\,X\,100 = 54\%$$

Result:

Inference:

Experiment No. 16

FAMILIARISATION OF HIL EXPERIMENT USING OPAL-RT (OP4510)

Aim:
To familiarize with the use of OPAL- RT (OP4510) for Hardware in the Loop (HIL) experiments.

Course Outcome (CO) Mapping

CO	Description	Bloom's Level
CO1	Apply fundamental power system analysis techniques to determine the operating parameters under steady state and faulty conditions.	K3

Program Outcome (PO) Mapping with Justification

PO	Description	Relevance	Justification
PO1	Engineering Knowledge	3	Apply transmission line and compensation principles.
PO2	Problem Analysis	3	Identify and solve power transfer and stability issues.
PO3	Design/development of solutions	2	Model and evaluate system improvements using series compensation.
PO4	Conduct Investigations of Complex Problems	3	Simulate and analyse compensated vs. uncompensated systems.
PO5	Engineering Tool Usage	3	Use tools to study transient and steady-state responses.
PO7	Ethics	3	Ensure safe and standard practices in system modelling.
PO8	Individual and Collaborative Team Work	3	Collaborate on system modelling and reporting.
PO9	Communication	3	Present compensation analysis and insights.
PO11	Life-long Learning	2	Understand evolving technologies in system stability and compensation.

Program Specific Outcome (PSO) Mapping with Justification

PSO	PSO Description	Justification
PSO1	Apply engineering knowledge to analyse, model, design and operate modern systems for power systems	Use of HIL experiments is essential for power system analysis in a smart grid environment

CO-PO Mapping Matrix

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO1	3	3	2	3	3		3	3	3		2

CO-PSO Mapping Matrix

CO	PSO1	PSO2
CO1	3	

Theory:

The OP4510 is the natural evolution of the widely acclaimed OP4500, featuring:

- Power: Faster processor up to 3.5 GHz, FPGA Kintex7 able to process up to 410 k Cells
- Versatility: Possibility to adapt the I/O configuration to the targeted application.
- Connectivity: Active/passive PCIe, CAN bus, GPS time synchronization (IEEE 1588), Optional optical and SFP modules, Optional RS422, fibre optic or synchronization modules, Interconnectable with other OPAL-RT simulators or expansion units.

Fig 16.1: OP4510

RT-LAB is the real-time technology revolutionizing how model-based design is performed. RT-LAB is the software platform for OPAL-RT's simulation systems, eMEGASIM, eFPGASIM, and ePHASORSIM. Through its openness, it has the flexibility to be applied to any simulation and control problem, and its scalability provides a low-risk entry point for any application, allowing the developer to add compute- power where and when needed whether it is to speed up simulations or for real-time hardware in the loop applications. Fully integrated with MATLAB/Simulink, RT-LAB offers the ability to bring the most complex model-based design and have them interact in a real-world environment. RT-LAB is an industrial-grade software package for engineers who use mathematical block diagrams for simulation, control, and related applications. RT-LAB provides tools for running and monitoring the simulations or controls on various runtime targets. The software is layered on top of industry-proven commercial-off-the-shelf (COTS) components like popular diagramming tools MATLAB/Simulink. It works with viewers such as LabVIEW and programming languages, including Visual Basic and C++.

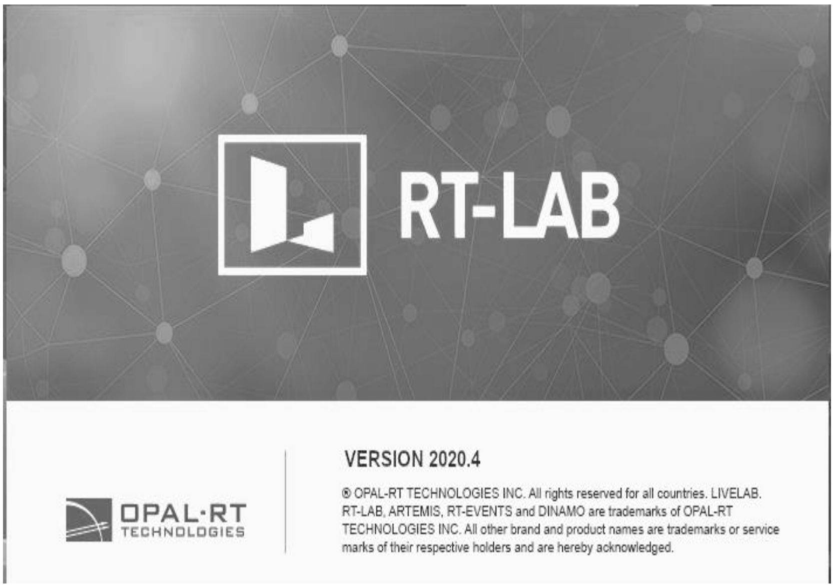


Fig.16.2: RTLAB

Procedure:

Step 1: **Preparing MATLAB file accordingly for use in OPAL RT**

- Divide the system into two subsystem SM_Master and SM_Console
- SM_ Master is computational part
- SM_Console is monitoring and user interface part
- OPComm block should be kept in Master & Console subsystem
- Put Powergui block {Sample time minimum value should be 10 microseconds}
- Take Model Settings: Type: Fixed Step Size
- Solver: ODE 5 (anything other than auto)
- Run the simulation with time "inf"

Step 2: **Establish Ethernet connection with OPAL RT (When connecting a laptop for the first time only)**

- In PC > take internet properties > Ethernet> IP4 > Copy IP address from OPAL RT (eg 192.168.10.102)] > change last 3 digits (any number other than 101, 101 is for OPAL RT)

Step 3: **Creating new project in RT LAB**

- Target > Discover target > State UP
- Create New Project
- Give a name > Next > Click "empty" > Finish
- A file will come on left side with given name
- Click it > models> rt click > import > existing RT lab model
- Browse the folder where MATLAB file is saved >(all files will be shown) > deselect all > Select our MATLAB file only

Step 4: **Editing the model**

- Take variable > add> RT Intel Compiler
- Take execution > if we want DSO out or microcontroller connection give hardware synchronized
- For hardware synchronization additional 2 files are needed. Put that files in the same folder in OPAL RT > File> models> (with MATLAB.slx file)
- We can edit without connecting to OPAL RT

Step 5: Build Model

- While building check > Assign> Run in XHP mode should be enabled(untick and then tick it)

Step 6: Load model

Step 7: **Execute model > now a separate window will open, where the SC_console blocks are visible.**

Step 8: **Reset model (u can pause and reset)**

Step 9: **Shut down RT server**

Result:

Inference: