DEPARTMENT OF ELECTRICAL ENGINEERING

MANUAL
FOR
POWER SYSTEMS LABORATORY

(B.TECH)

Third Edition

COLLEGE OF ENGINEERING TRIVANDRUM

THIRUVANANTHAPURAM – 695017. KERALA

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DEPARTMENT OF ELECTRICAL ENGINEERING

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DEPARTMENT OF ELECTRICAL ENGINEERING

COLLEGE OF ENGINEERING TRIVANDRUM,

Thiruvananthapuram – 695017

VISION:

Be a centre 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 an ability to function effectively as members or leaders in technical teams.
4. Adapt to changes in 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 analyse 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	Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of and need for sustainable development.
PO8	Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
PO9	Function effectively as an individual and as a member or leader in diverse teams and in multidisciplinary settings.
PO10	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.
PO11	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.
PO12	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.

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INTRODUCTION TO HIGH VOLTAGE TESTING

With a large number of high voltage and extra high voltage transmission systems being constructing in our country, expensive electrical equipment are being put in service. It is necessary to ensure that such equipment's are capable of withstanding the over-voltages normally encountered in service. The over-voltages may be either due to natural causes like 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**

  It is the voltage at which the electric field stress in the insulation causes a failure resulting in 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 over voltage**

  This is the voltage which has a probability of 50% flash over, when applied to a test object. This is normally applied in impulse tests in which the loss of insulation strength is temporary.

- **100% Flash over Voltage**

  The voltage that causes flash over at each of its applications under specified conditions when applied test objects is specified as 100% flash over 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_r) 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_r = 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 normally 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 test 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 himself by personal observation that all the conductors which 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 follow after switching the current source off, and may be removed only when there is no longer anyone 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 1.5mm^2 copper.

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 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: Telephone Immediate attempts to restore respiration by artificial respiration.

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

Conducting the experiments:

Every one carrying out experiments in the laboratory is personally responsible for the setup placed at his disposal and for the experiments performed with it. For experiments during working hours one should try, in the interest of personal safety, to make sure that a second person is present in the testing room. If several persons are working with the same setup, they must know who is to perform the switching operations for a particular experiment. Before switching high voltage setups on, warning (“Attention! Switch on”) should be given either by short term signals or by the 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 modeling and analyzing 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 data base. ETAP keeps track of detailed data for each electrical apparatus. ETAP one-line diagram supports a number of 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 of existing can be modified to include custom manufacturer data

ETAP to be the fore-most 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 [1] is a high-performance language for technical computing. It integrates computation, visualization, and 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 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 than 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 4 decimals in the result of the calculations, for example −163.6667, as shown in 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 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 which contains 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, colours, 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 can 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). In a simple program as shown in the previous Chapter, the commands are executed one after the other. Here we introduce the flow control structure that make possible to skip commands or to execute specific group of commands. MATLAB has four control flow structures: the if statement, the for loop, the while loop, and the switch statement.

SIMULINK

SIMULINK is an interactive environment for modeling, 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 block diagram representation using library of standard components. A system in block diagram representation is 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.

Theory:

Most of the power system studies require the formation of 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)+Yline(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 the 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

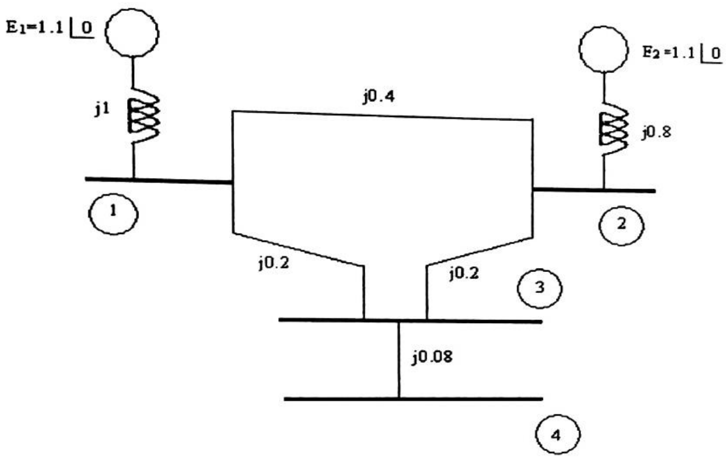


Fig 2.1 Single Line Diagram

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.

Theory:

Power flow programs are used to study 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

Power flow computer program commonly called as 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 condition. 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 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 necessary tools and support for modeling and analyzing an electrical power system. In this each project provides a set of users, user account controls and separate database in which its elements and connectivity 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 to work directly with graphical one line diagrams underground cable race way systems.

Procedure:

Refer 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. The scheduled generation and loads and the assumed per unit bus voltages are given. 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 I

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 II

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

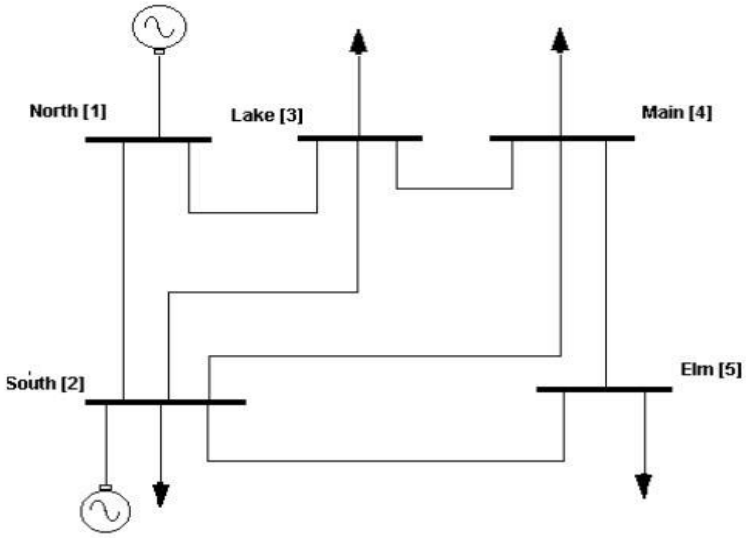


Fig 2.1: Single line diagram

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

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 they reach steady state condition. This behavior is due to system characteristics and dynamics during this time, the protective is called to detect, interrupt and isolate these faults. 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

which 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 impedance.

The current which flows in different parts of a power system immediately after, occurrence of a fault differs from that flowing a few cycles later just before circuit breakers open the line on both sides of the fault. Both these currents differ widely from the current which would flow under steady state conditions, if the fault were not isolated from the rest of 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 the breaker must interrupt

Fault analysis consists of determining these currents for various type fault at various location 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 Manual on **ETAP.**

Problem 1:

Consider the 4-bus system shown in figure. 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 the 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, are 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 table below:

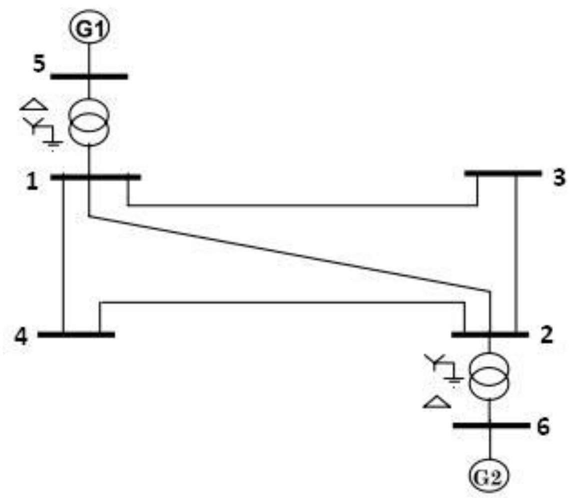


Fig 3.1: Single line diagram

Table I

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

Table II

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 III

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

Result:

Inference:

Experiment no. 4

STABILITY ANALYSIS

Aim:

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

Theory:

The transient behavior of a power system resulting from major disturbances such as 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 time domain. Transient stability simulation studies are carried out to study these phenomena and the results enable to plan and coordinate 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 fraction of a second when first swing stability is being determined, to over several seconds when multiples in stability is to be examined.

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

Procedure:

Refer manual on **ETAP.**

Problem 1:

Figure 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 susceptances are given on 100MVA base, generator's transient impedance and transformer leakage reactances are given in the accompanying table.

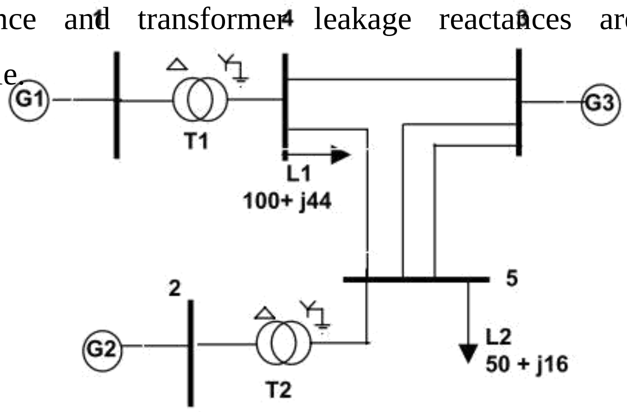


Fig. 4.1: Single line diagram

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 the line 4-5 at the critical clearing time. Compute t_c and comment on 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 I

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 II

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 angleδ_c :

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

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

P_{max} is the Maximum power

δ_c is the Initial torque angle

Swing curve:

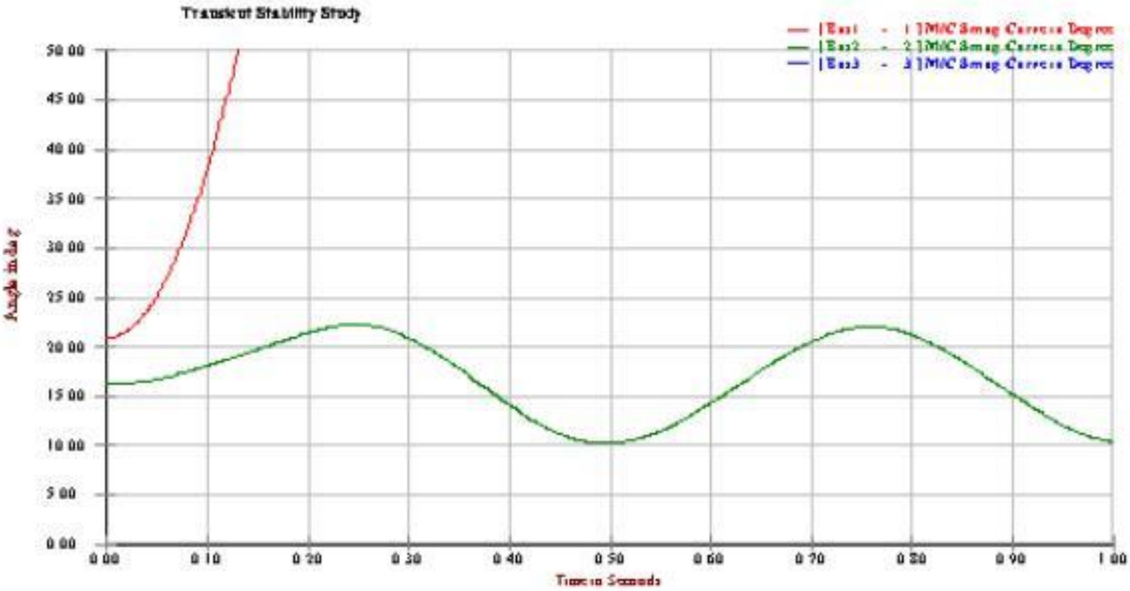


Fig 4.2: Swing curve

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.

Theory:

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 block diagram representation using library of standard components. A system in block diagram representation is built easily and simulation results are displayed quickly.

Single Area System:

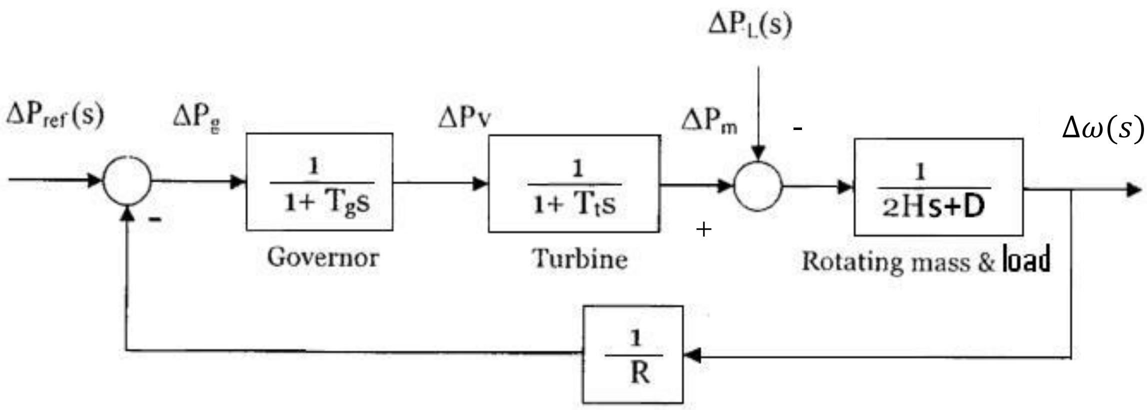


Fig 5.1: Load frequency control block diagram of an isolated power system

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 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:

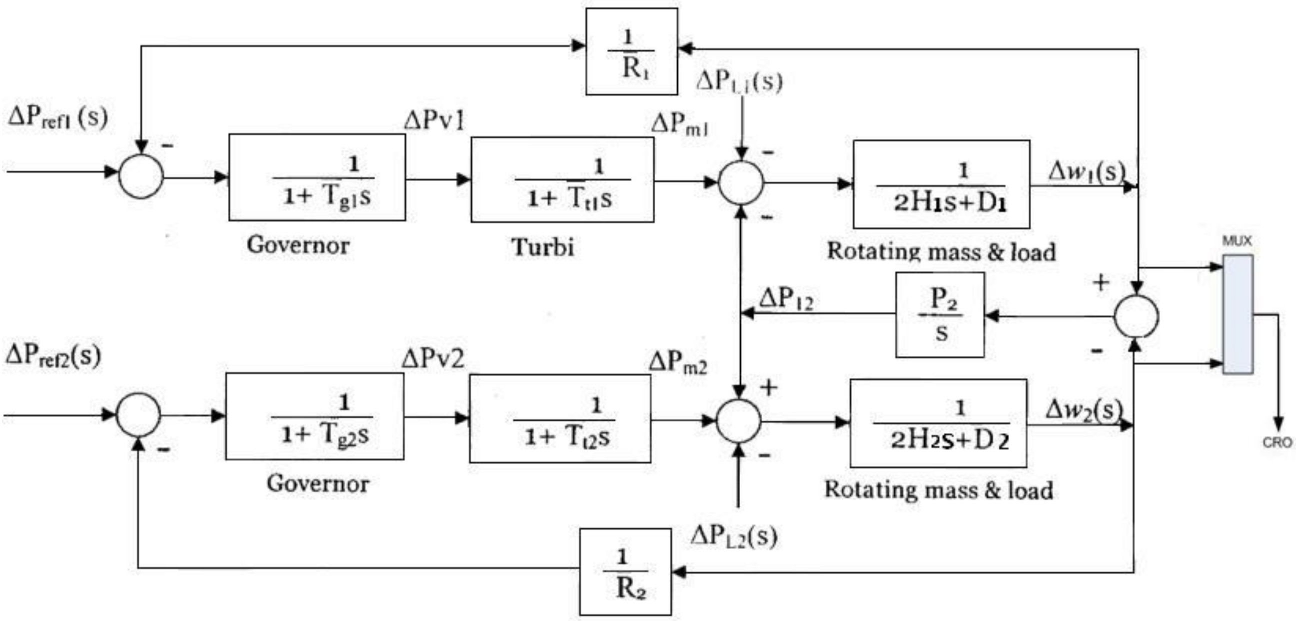


Fig 5.2: Two area system with only primary LFC Loop

Problem 2:

A two area system connected by a tie line has the same parameters on a 446 MVA common base. The units are operating in parallel at normal frequency at 50 Hz. The synchronizing power coefficient is computed from 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 SIMULINK block diagram and obtain the frequency deviation response for the give 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
- To test the power system component (Circuit Breaker/ Insulator/Lightning arrestor/ Air Blast Circuit Breaker) using DC voltage

INSULATORS

a. Power frequency tests

- **Flashover tests**: The 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 surface of the insulator.

- **Withstand tests**: The voltage specified in the relevant specification is applied for a period of 1 minute with 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 withstand 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 application of the pulse cause flashover, the object is deemed to have failed. If there is only one failure, 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 the 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, arrester.

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 flash over, 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 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, additional 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

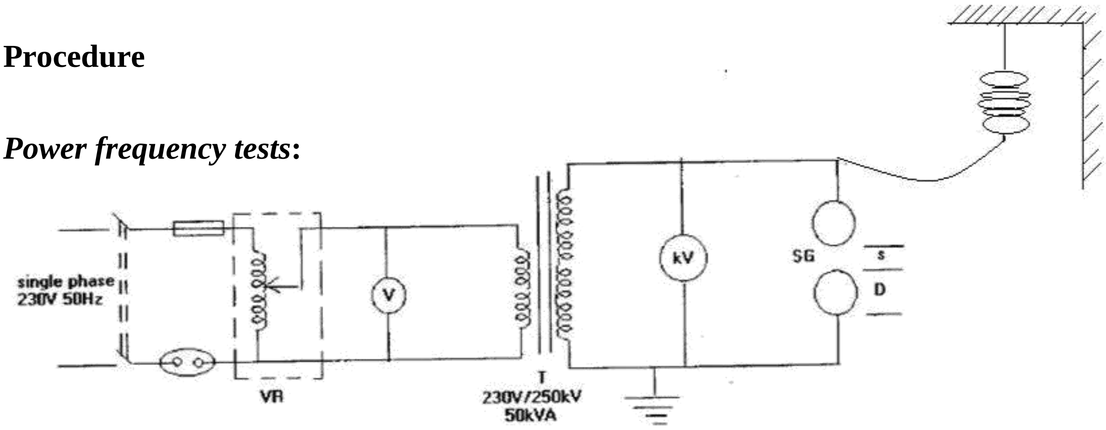
Current : 75-200mA

Impulse Voltage Generator: 220/280kV

Earthing rod.

Procedure

***Power frequency tests*:**



220/280kV
10 kVA

Figure 6.1: Circuit Diagram

INSULATORS- 11 kV

- **Flashover tests:** In these tests the ac voltage of power frequency is applied across the insulator an increased at a uniform rate of about 3kV/s. to such a value that a breakdown occurs along the surface of the insulator and note down the Voltage at breakdown from Partial discharge meter.

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

LIGHTNING ARRESTOR – 9kV

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

AB switches

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

Fuses

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

***Impulse tests*:**

PIN INSULATOR-11 KV

Connect a sphere gap across the test piece. Apply 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, 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- 9KV

With the test sample arrester in the circuit, the impulse generator is adjusted to give 1.2/50μs, 75kV voltage wave, and 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, 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

(A) OVER CURRENT RELAY

Aim:

To test pick up, 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, it is inevitable that some failure will 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 into 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 for 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 the fault and initiates the operation of the circuit breaker to isolate the defective element from the reset system. The relays detect the abnormal conditions in the electrical circuits by constantly measuring the electrical quantities which are different 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 over current circuit protection can be given directional feature by adding directional element in the protection system. Directional over-current protection responds to over-currents for a particular direction.
- If power flow is in the opposite direction, the directional over current protection remains inoperative.
- Directional over - current protection comprises of over-current relay and 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 relay is used where the selectivity can be achieved by directional relaying. The directional relay recognizes the direction in which 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 breaker, if fault power flow only in direction A. Therefore for faults in feeder AX the circuit breaker does not trip. However for faults in feeder AY the circuit-breaker trips because it’s 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 Reverse power relay is different from that of directional over-current relay

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

Relay connections of single phase directional Over -current Relay:

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

Relay-connection, (e.g.: 90°, 60°, 30° etc.) refer 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 relax connection is basically to select the phase across which the voltage coil is connected with respect to current coil. 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 us source and line impedances etc

Experimental procedure:

Relay operates when the voltage G1<G2, ie, the current reverses.

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 till the current is greater than 2.5 A, then the instantaneous operation flag of the relay 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. Note the time setting and PSM of the relay. Then reset the relay and apply the current by 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 I:

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	

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	

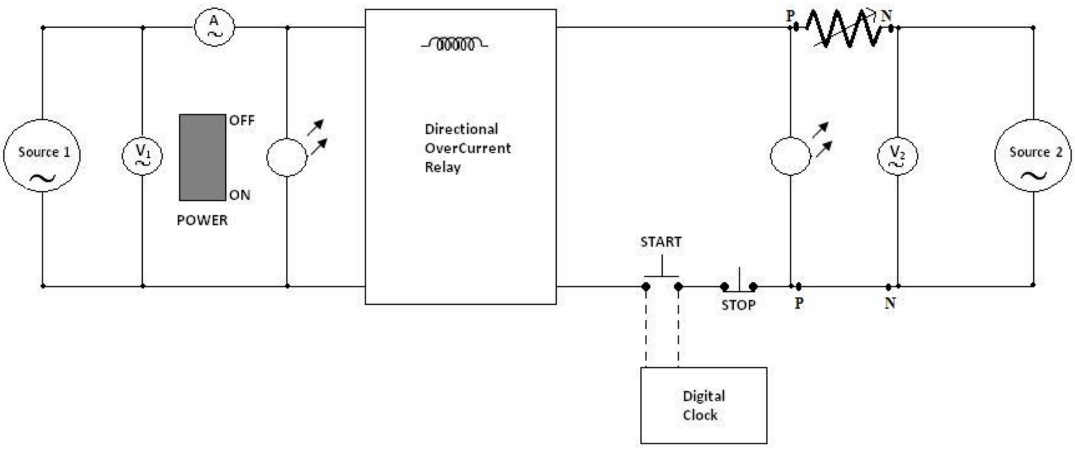


Fig 7.1: Over Current Relay

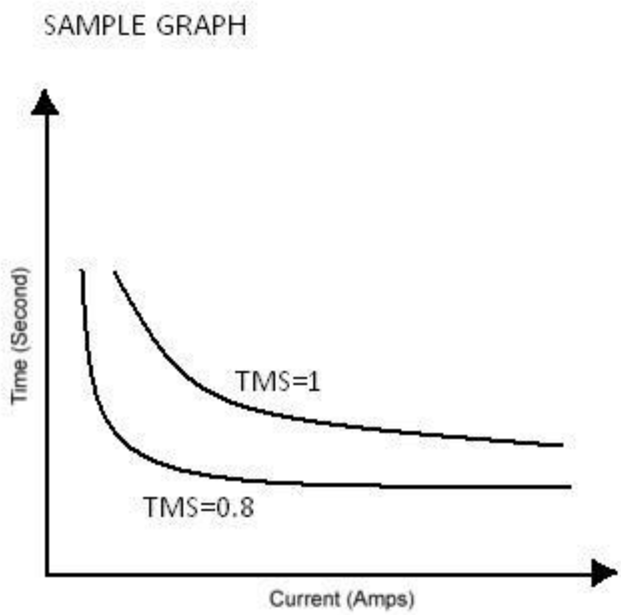


Fig 7.2: Sample graph

Result :

Inference:

(B) OVER VOLTAGE RELAY

Aim:

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

Theory:

Principle of operation of over voltage relay is that the relay operates and trips the circuit when the voltage reaches above the specified value. The type of over voltage relay employed in our test set up is the electromechanical type over voltage 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 over voltage relay used here is inverse definite minimum time type. An inverse time relay is the one where, operating time is approximately inversely proportional to the magnitude of actuating parameter. The actuating parameter here is the voltage. In this relay, inverse time delay can be introduced when voltage is just equal to normal value. In this case movement of plunger will be very slow. But when voltage rises to higher values the plunger moves faster with less time delay and stops when 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 voltage setting plunger in the left side of the unit. 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 stop watch twice, for initializing.

Press the start switch. Now the fault voltage is applied to the relay coil. At the same time the clock starts counting the time in seconds taken for the relay coil to trip and stops when the relay contact is open. 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 the tabular form. Draw a graph for time versus fault voltage

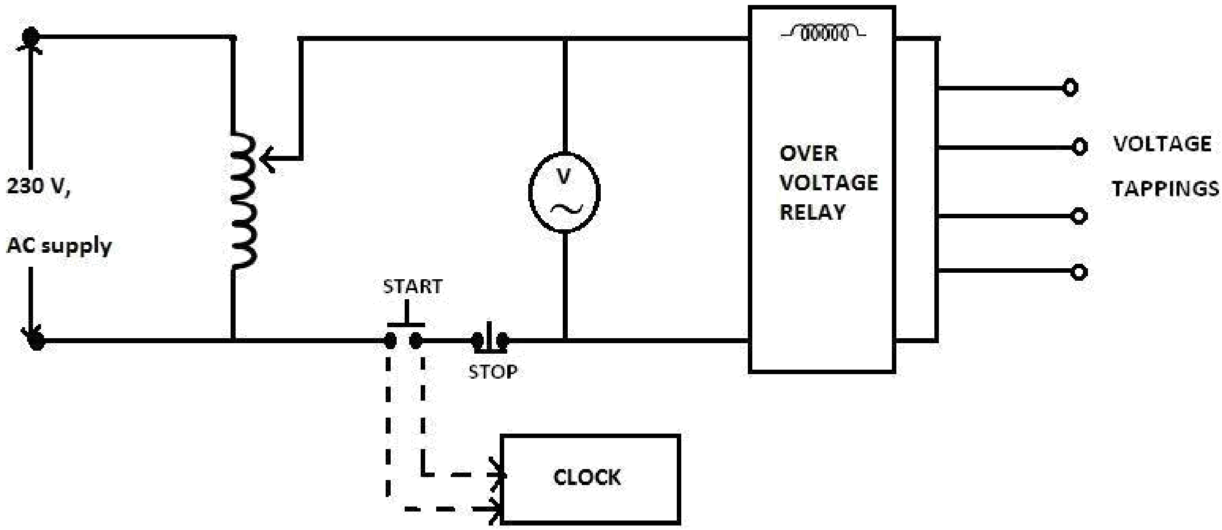


Fig. 7.3: Circuit Diagram

Table I:

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

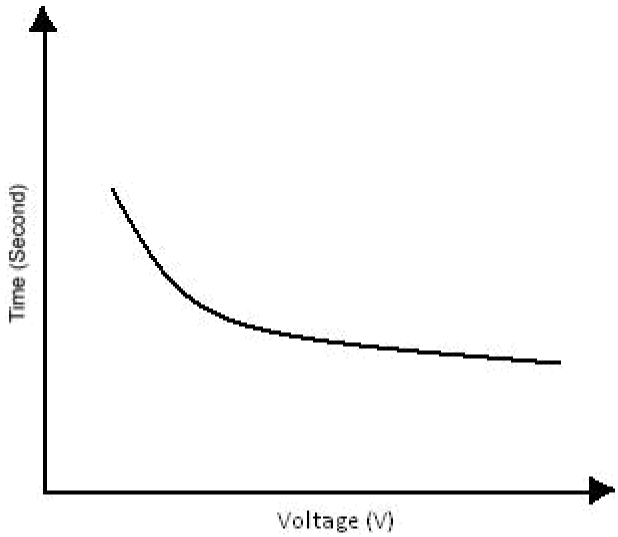


Fig 7.4: Sample graph

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

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

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 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 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 taking out the bath maintained at ambient elastomeric insulated cables insulated core from the finished cable and immersing the ...sample, in a water temperature of 27 C ± 2° C. The duration of immersion shall be, 12; hours, for and 1 hour for other types of cables. The ends of the cables shall project at least by 20.0mm above the water level.

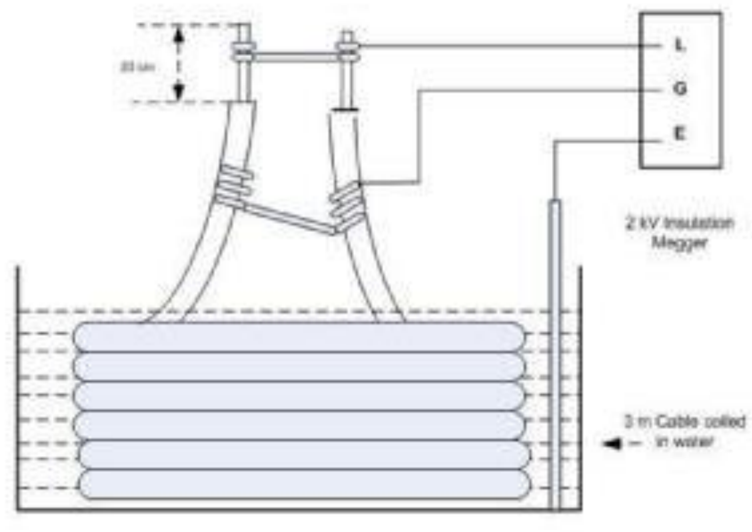


Fig 8.1: Insulator Setup

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 in a regular manner for 1min. 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 standard resistance before taking every set of reading.
- The volume resistivity or insulation resistant constant is calculated from the measured insulation resistance value.

Tabulation of Observations:

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

Calculation:

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

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

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

Where

R = measured resistance (MΩ)

L = length of cable (m)

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

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 from soil resistivity of the given area.

Reference:

IS-3043

Theory:

Resistance of earth connections are measured by a fall of potential method, as illustrated by the figure. 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 B 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

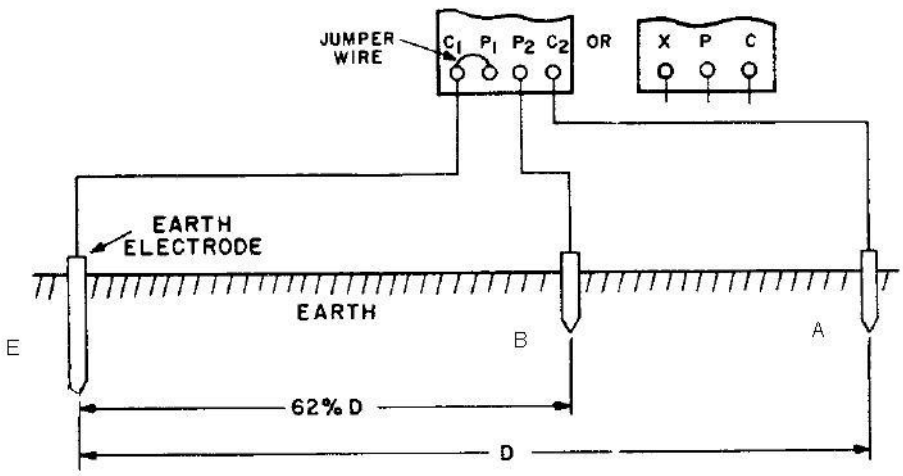


Fig 9.1: Representation of Earth resistance

Two auxiliary electrodes are driven such that E, P and C are in a line and the distance EC is 20m. For various values of ‘D’ (distance Ep) at an interval of 2 m.

The megger reading are taken noting the reading when the handle is driven at 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 earth electrode

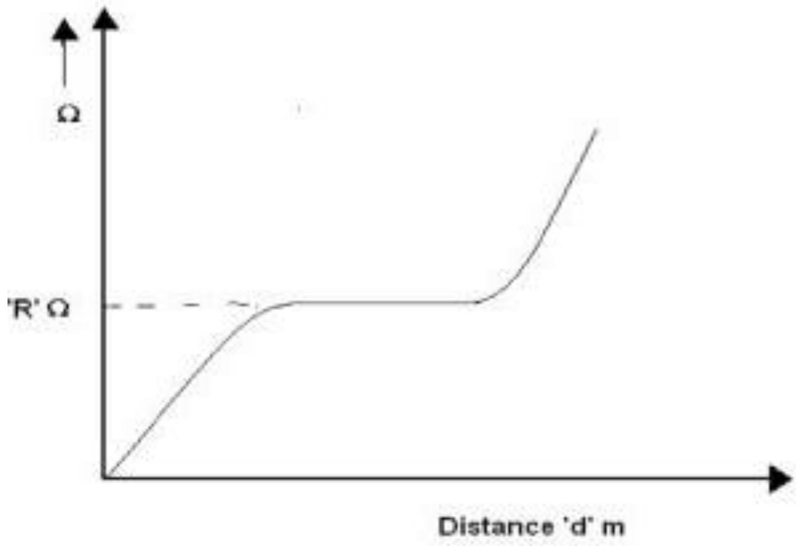


Fig 9.2: Sample Graph

2. To determine the specific resistance of 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. The outer rods are connected to C1 and C2 and middle rods to P1 and P2. The handle is rotated at maximum possible speed and Megger readings are taken. Let it be “R” Ohms. The specific resistance is determined from the formula

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

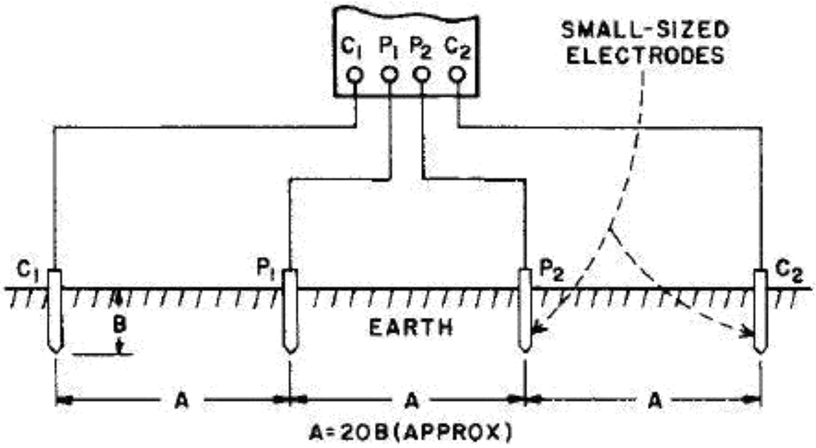


Fig 9.3 : Specific resistance of earth in the locality determination

Observation

Sl No.	R

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

Result:

Inference:

EXPERIMENT NO. 10

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:

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 gives an indication of the suitability of a sample for its use in the apparatus. The permissible breakdown voltage for different voltage class of equipment are as follows.

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

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 in 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
- There after once in every year

Procedure:

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

The level of oil in the test cell shall be such that the axis of the electrode is at a depth of 40 mrn; 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 established arc occurs. On the other hand if a transient spark (audible or visible) occurs, the circuit may be opened manually. The breakdown voltage is the voltage reached during the test at the time of the first spark, whether it is transient or 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 for six times on the sample. Compute the electric strength as the arithmetic mean of the six values.

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:

0-10kV HV. Breakdown Test Set.

Diagram:

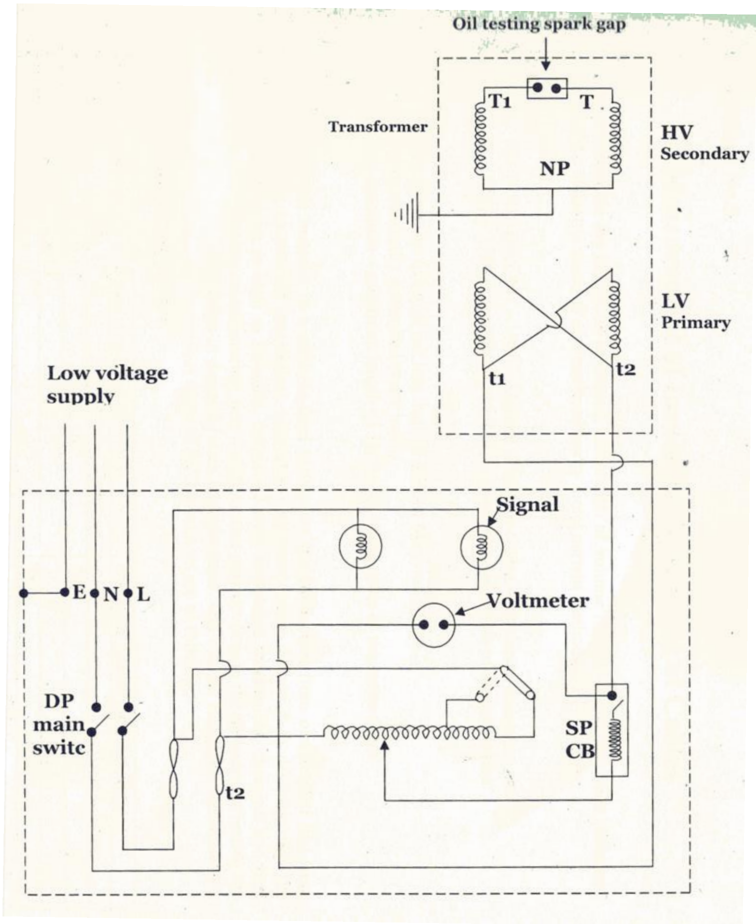


Fig 10.1: Circuit diagram

Procedure:

It is an essential gadget to test the quality of insulation provided in electrical equipment. It is a most important test, essential for routine and periodical maintenance of electrical equipment’s. Different dielectric materials (paper / mica / glass / cable etc.) is connected between 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 corresponding voltage is noted.

Result:

Inference:

Experiment No. 11

POWER FACTOR IMPROVEMENT

Aim:

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

Instruments Required:

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

Theory:

Power factor Improvement

Power factor of the given R-L load is cos Φ_1. In order to improve it to cos Φ_2 a shunt capacitor can be installed at the load end. As the power factor is improved to cos Φ_2 lagging, the in-phase component of current will remain constant as the load is not changed, only reactive component will change.

Load current (Line) $=I_1$

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

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 taken by the capacitor

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

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

Capacitor bank is delta connected.

Transmission line representation:

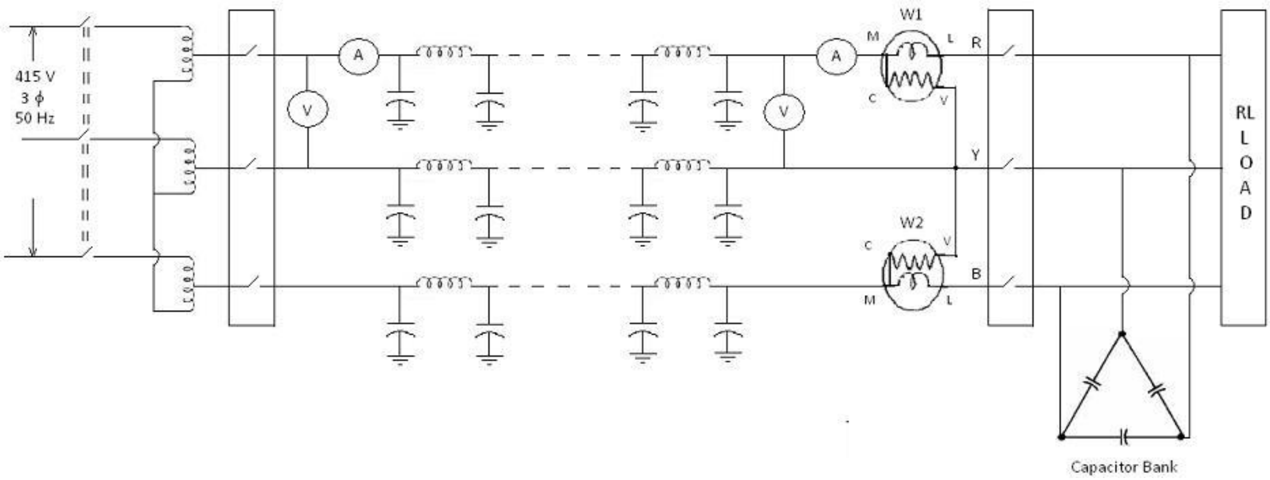


Fig 11.1: Circuit Diagram

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

- Series resistance 'R' in ohm/km
- Series inductive reactance 'X' in ohm/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 0-55-110-330V line-line.

   b. Circuit Breaker for over load protection and switching on/off of the system

   c. Digital Voltmeter with 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. Voltmeter digital with function indicator switch for measurement of receiving end voltage line-line value.

b. Ammeter digital with function indicator switch for measurement of receiving end voltage line-line value.

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

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

4. VAR Compensators

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

b. Shunt Capacitance of 6kVAR 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, some low voltage. (200V L-L) is applied and note down the rise in voltage at receiving end.

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

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 ($\cos\Phi_1$**).**

Problem 1:

Calculate the per phase value of Capacitance to be connected to improve the power factor to the required value. Connecting 6 capacitors in parallel, find the new power factor at the receiving end of the transmission line.

Observation:

Table I

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

Table II

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

Table III

	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 check the specifications of the given Current Transformer and Potential Transformer.

Instruments required:

Current Transformer: Primary 1/5/1025A, Secondary 5A Potential Transformer: Primary 440V, Secondary 110/220V Auto-Transformer, Wattmeter, 250V, 5A, PF 1 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 instrument transformer made with wattmeter just as with ammeters and voltmeters.
- When the wattmeter is used in conjunction with 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 pressure coil of wattmeter is lagging behind voltage by a small angle ø due to inductance of pressure coil

Procedure:

- Make the connections as per the circuit diagram.
- Connect the given RL 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 RC load also. Tabulate the readings and calculate the true power. Measure the resistance of the load for each reading using AVO meter.

- CT secondary should not be opened while primary is energized.

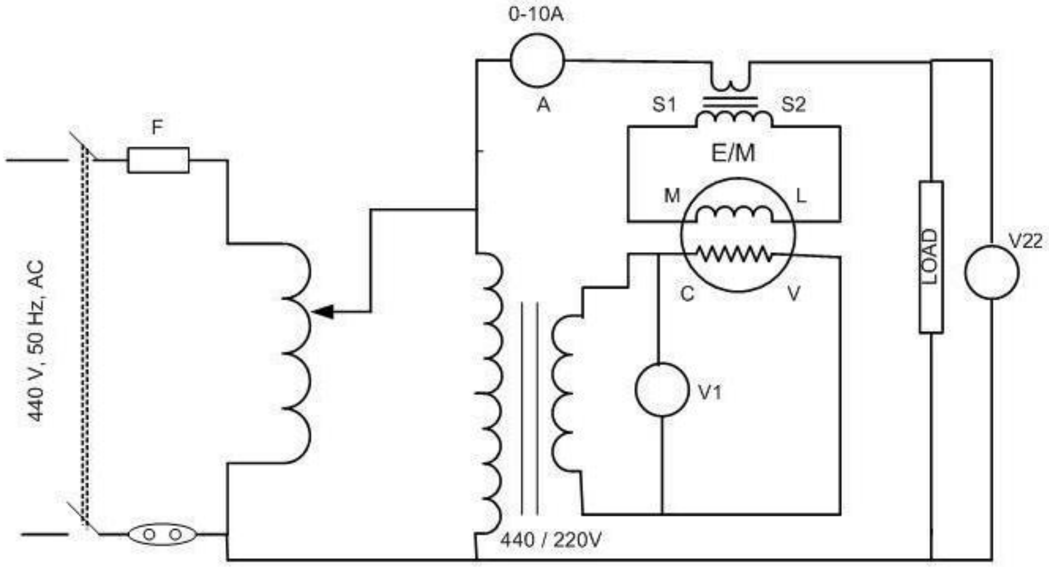


Fig 12.1: Circuit Diagram

Observation:

Voltage(V)		Current(A)	Wattmeter reading (W)	W*mf	Load = Vz/I	Load resistance	cosØ	K	True power
V1	V2								
RL LOAD									
RC LOAD									

Result:

Inference:

Experiment No. 13

FAMILIARIZATION OF SOLAR PV TRAINING SYSTEM

Aim:

Power flow calculation of stand-alone PV system with combined DC and AC load.

Theory:

Stand-alone system is the one which can be used for both AC and DC loads and installed near the location of the load. These systems are easy to install and understand. These systems can be used without batteries also but they perform best with battery bank. These systems are best suited for locations where grid connectivity is not present and they fulfil the requirements of these locations.

They use DC power to charge the battery and run the Dc load but, use AC power to run the Ac load. These are modules, charge controller, batteries, DC load, inverter and AC load in this system. It runs the AC and DC load simultaneously and can fulfill 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 are the change of slope angle of the module to see the effect of tilt.

Features and Specification:

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:

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

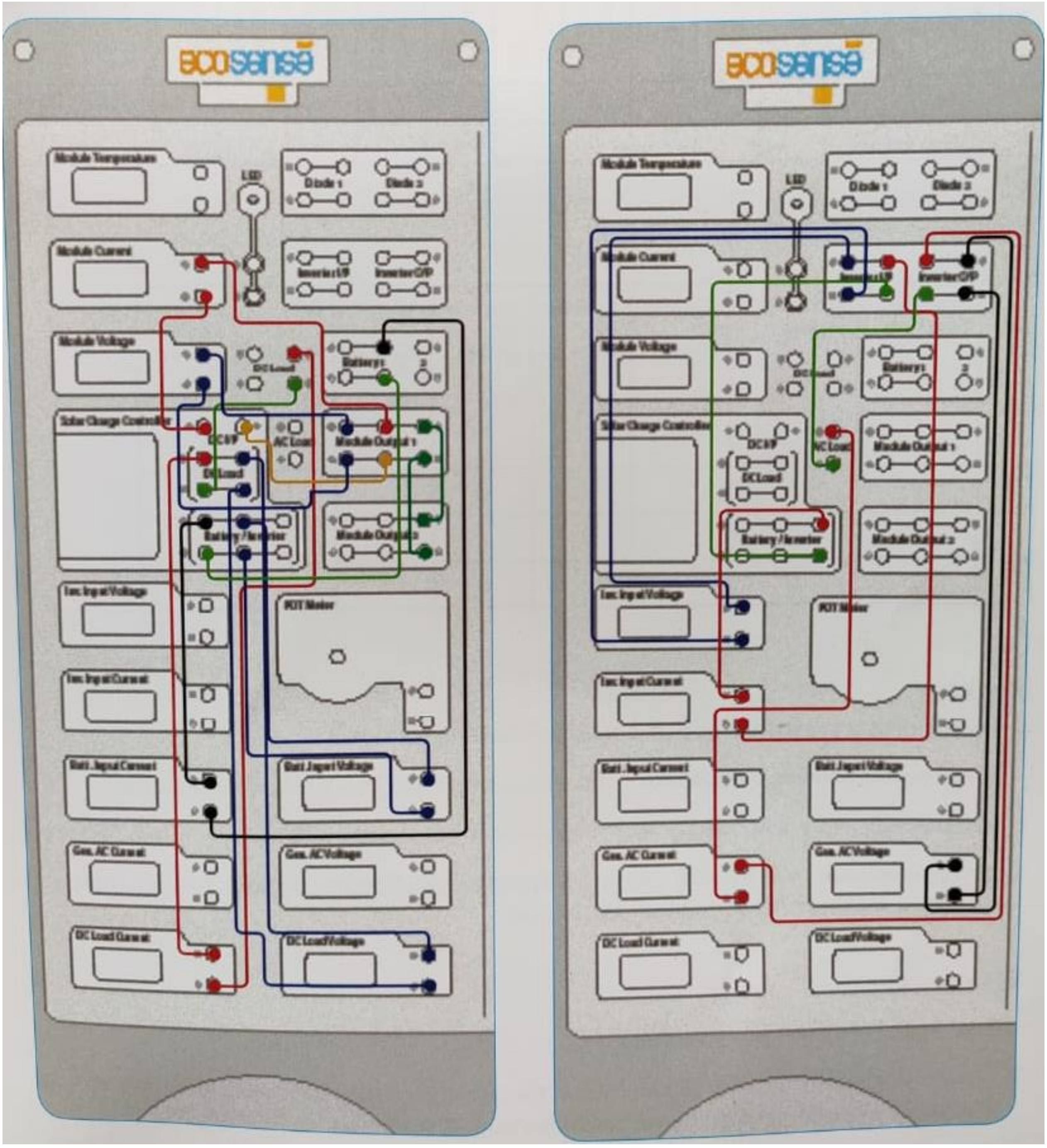


Fig 13.1: Control board connections for standalone PV system to supply both AC and DC load

Observation:

Table for stand-alone PV system calculation:

S.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						

S.no	Inverter I/P current (A)	Inverter I/P Voltage (V)	Inverter I/P Power (W)	Battery current (A)	Battery voltage (V)	Battery power (W)
1.						
2.						

Table for inverter efficiency:

S.no	Modules in series	Modules in parallel	Inverter I/P current (A)	Inverter I/P Voltage (V)	Inverter I/P Power (W)	Ac load current(A)	Ac load Voltage (V)	Ac load power (W)

Results:

Inference:

Experiment No. 14

DETERMINATION OF MPP OF SOLAR PV PANEL

Aim:

Perform the experiment of manually finding the MPP by varying the resistive load across the PV panel.

Theory:

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.

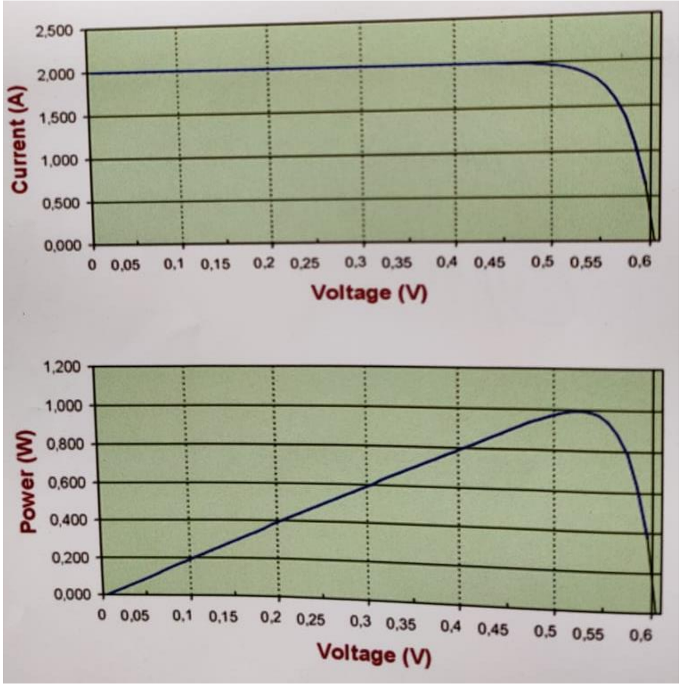


Fig 14.1: Characteristic curves of Solar PV module

In these curves 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 fi referred to as Vm amd Im. This single point is corresponding to a load resistance, known as critical load resistance.

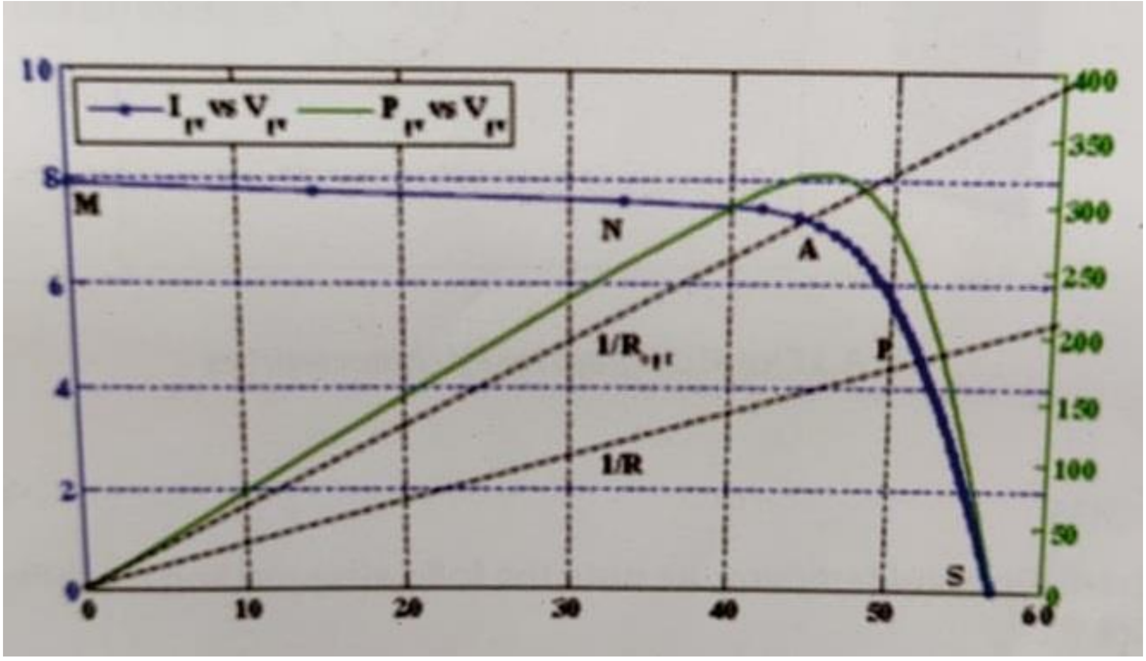


Fig 14.2: P-V curves for different values of load resistance

Experimental setup:

The circuit diagram to evaluate MPP of a module is shown in Fig. In this circuit, modules will be connected to the variable resistance through ammeter and voltmeter. In PVTR, connections will be done as shown in figure below which shows that the module port(s) will be connected to module ammeter, module voltmeter and Pot meter ports with the means of connecting cables. At the same time logger plotter box ports will also be connected to the module ports through connecters and to the PC through USB.

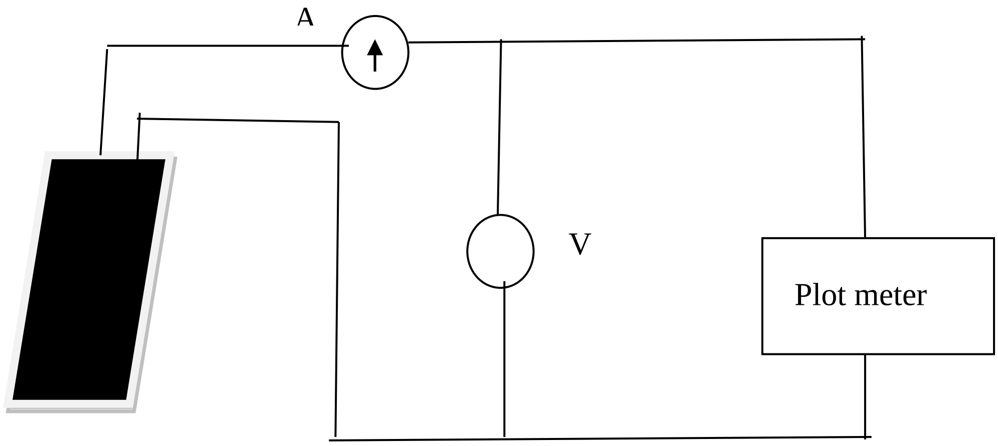


Fig 14.3: Circuit diagram for P-V characteristics

Observations:

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

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

Results:

Following are the results:

1. Draw the I-V curves (manually and with 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 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 value of maximum value of P. this will be corresponding to a particular value of R. Note down the value of Pmax and corresponding R.

Vm =

Im =

Pm =

Ropt =

Inference:

Precautions:

1. Readings for one set should be taken within 1-2 minutes 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 can be changed.

3. Connections should be tight.

4. Perform the experiment without battery in the circuit.

Experiment No. 15

CALIBRATION OF THREE PHASE ENERGY METER BY PHANTOM LOADING

Aim:

To calibrate the three phase energy meter at 0.6 pf, 0.7 pf (lead and lag) using phase shifting transformer.

Apparatus and instruments needed:

Energy meter, Phase shifting transformer, wattmeter, three phase auto transformer, voltmeter and ammeter.

Procedure:

The current coils of wattmeter and energy meter are connected in series with the input current terminals of phase shifting transformer (AA',BB',CC').The current coil of the energy meter is energized from a low voltage using three phase auto transformer. Adjust the phase shifting transformer for the various power factor from 0-1 lag, 0-1 lead at 2A and 4A. Note the readings of the wattmeter and ammeter, time taken for 5 impulses of the energy meter is also recorded.

Sample calculations:

Number of impulses	= n
Load current I_1	=…………….A
Time taken t	= ……………s
E/m constant	= …………….rev/kWh
Wattmeter reading	= ………..…..W [W_1 + W_2]
Actual reading (E_a)	= [W.t]/3600 Wh
Indicated reading (E_i)	= [n/k] *1000 Wh
% Error	= (E_a -E_i)/ E_a * 100 %

Circuit diagram:

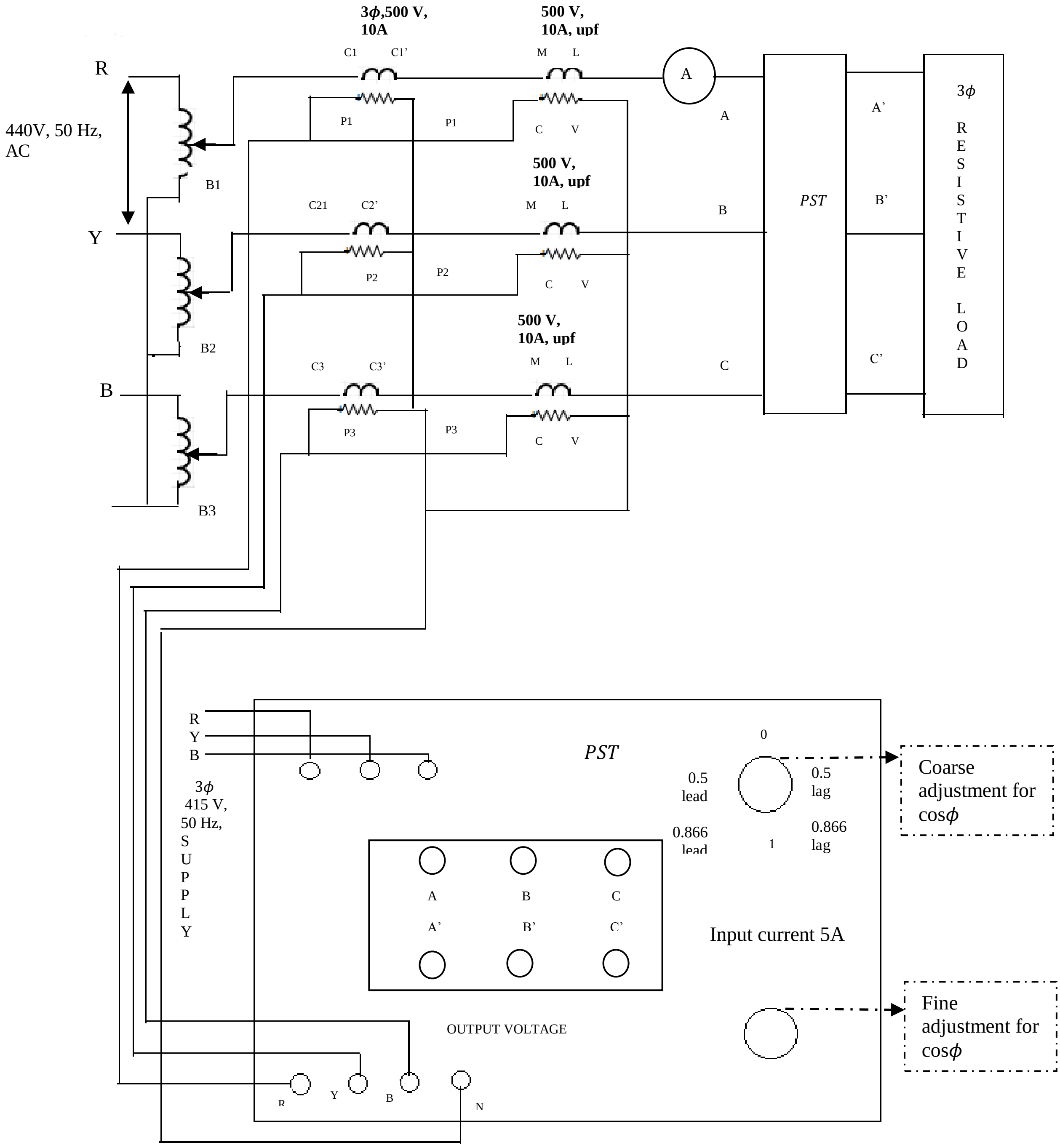


Fig 15.1: Connection of three phase energy meter and phase shifting transformer.

Tabular column:

P.F.	Load current (A)	Wattmeter reading						Time for 5 rev(s)	Actual energy (W_a)	Indicated energy (W_i)	% Error
		W_1	W_2	W_3	W_1 * mf	W_2 *mf	W_3 *mf				

Result:

Inference:

Experiment No. 16

RELAY COORDINATION

Aim:

To perform the study of relay coordination for the radial system shown below.

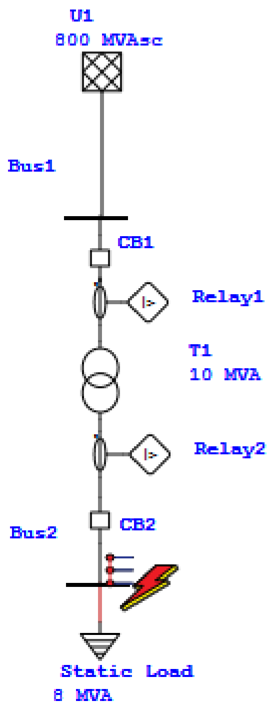


Fig 16.1: Single Line Diagram

CT Ratios:

Table I

Relay name	CT 1	CT 2
Primary rating	200	1000
Secondary rating	1	1

System parameters:

Voltage	33 kV, 50Hz
Fault MVA level	800.2 MVAsc
Fault kA	14 kA
X/R ratio	40

Transformer details:

Primary	33 kV
Secondary	11 kV
Capacity	10 MVA
Impedance	8.35

Load details:

8 MVA

Relay data:

Type :	ALSTOM
Model :	P139
Functions :	Overcurrent relay
Application :	Protection, monitoring and control of motors, transformers and lines

Theory:

ETAP Star overcurrent device protection and coordination evaluation software provides an intuitive and logical approach to Time-Current Characteristic (TCC) curve analysis with features and capabilities such as an easy-to-use graphical user interface, accurate protective device modelling, device settings report creation, extensive Verified & Validated (V&V) protection device library, and embedded analysis modules, all within an integrated, rule-based design.

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 mis-coordination.

Along with plotting protective device operating curves, ETAP Protective Device Coordination software provides tools capable of plotting the starting, inrush, and damage, curves for equipment like motors, transformers, generators, and cables. Offering insight into troubleshooting false trips, relay and breaker mis-operation, and mis-coordination.

Procedure:

1. Click the Overcurrent Relay button  from Edit toolbar and drop it into the OLV1 presentation.
2. Double-click the Overcurrent Relay element to open the Relay editor.
3. Go to the OCR page and then click the Library button. This will display the Library Quick pick - Relay dialog box. Select manufacturer ALSTOM and model P139 and click OK ALSTOM P139 relay data is populated in the OCR page.
4. Set the relay as shown in the figure; ensure that 'Link TOC + IOC and instantaneous for this level is unchecked for OCR. Provide the necessary pickup value.

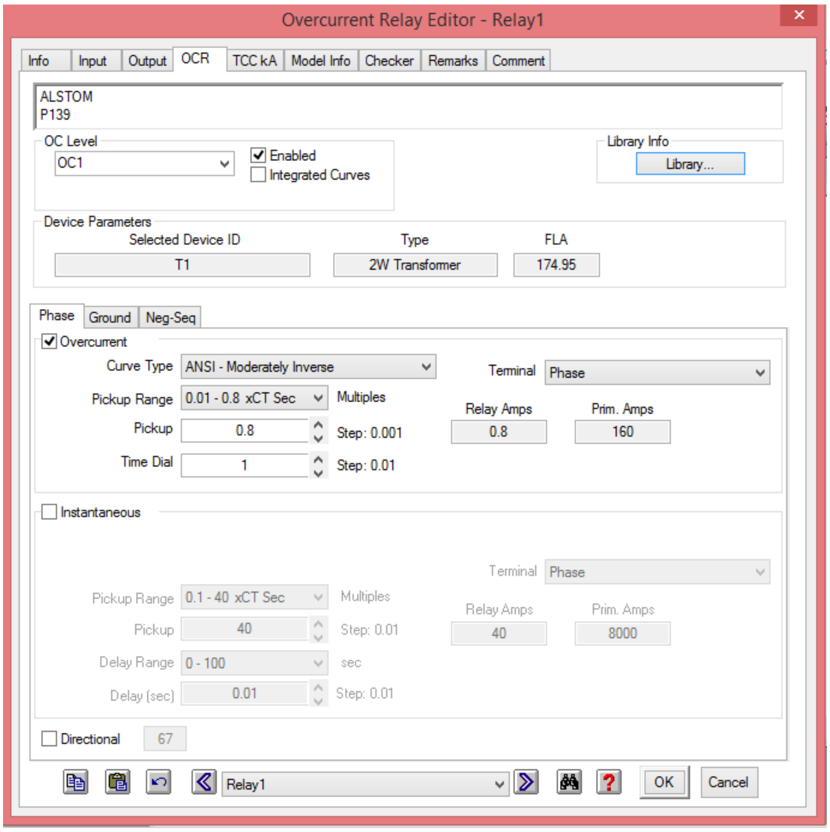


Fig 16.2: Multi-function Relay Editor

5. Select the output button and add the circuit breaker to be opened by the selected relay.

6. Uncheck the thermal option under the OLR section

7. Select the circuit breaker from the toolbar and provide the ratings.

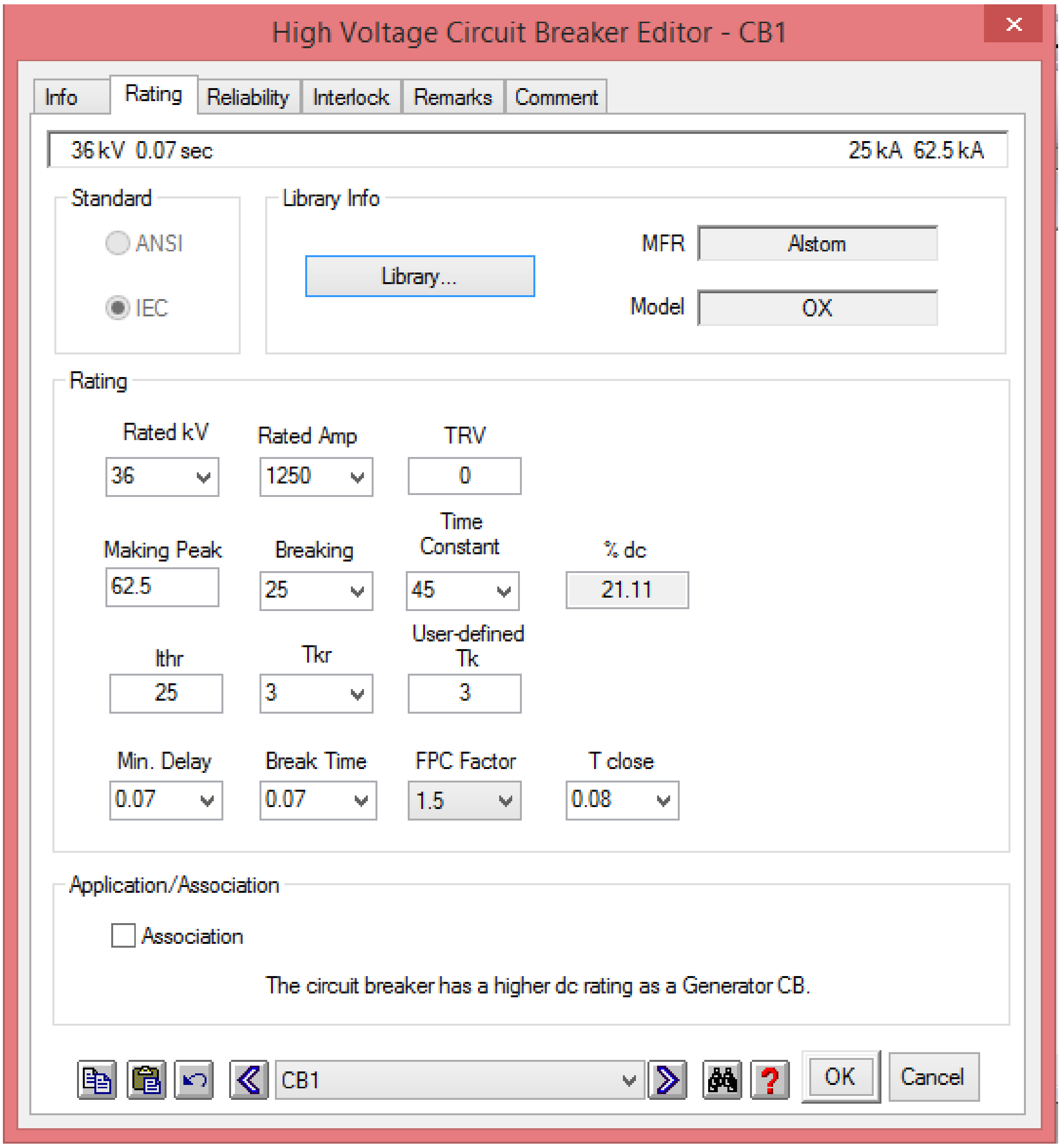


Fig 16.4: High Voltage Circuit Breaker Editor

8. Select the bus from the toolbar and provide the ratings.

9. Select the current transformer from the toolbar and specify the transformation ratio as given in data.

10. Select the two winding transformer from the toolbar and provide the ratings and impedances (typical values) as shown in the figures.

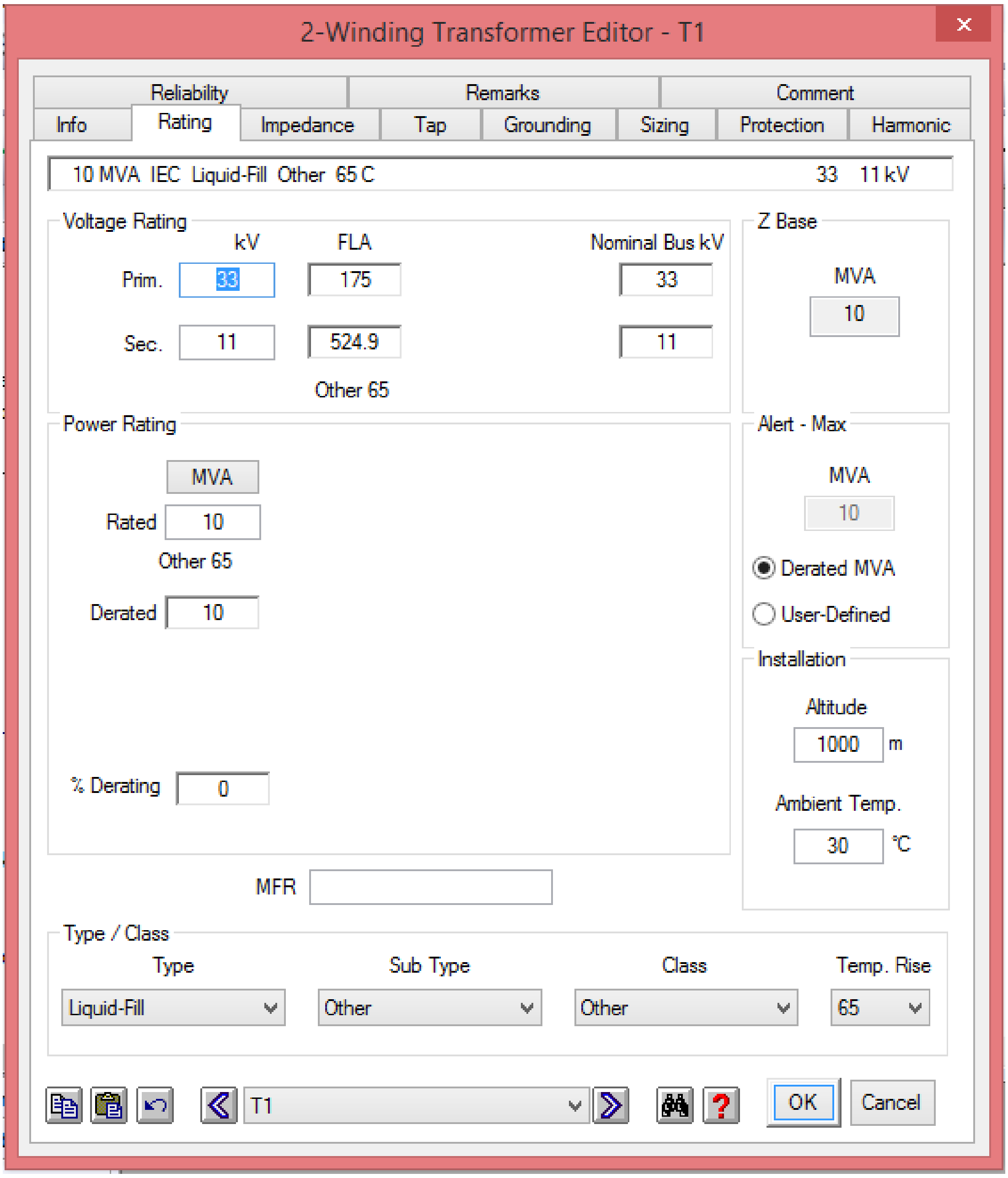


Fig 16.6: Winding Transformer Editor

11. Select the static load from the toolbar and provide the ratings as shown in fig.16.11

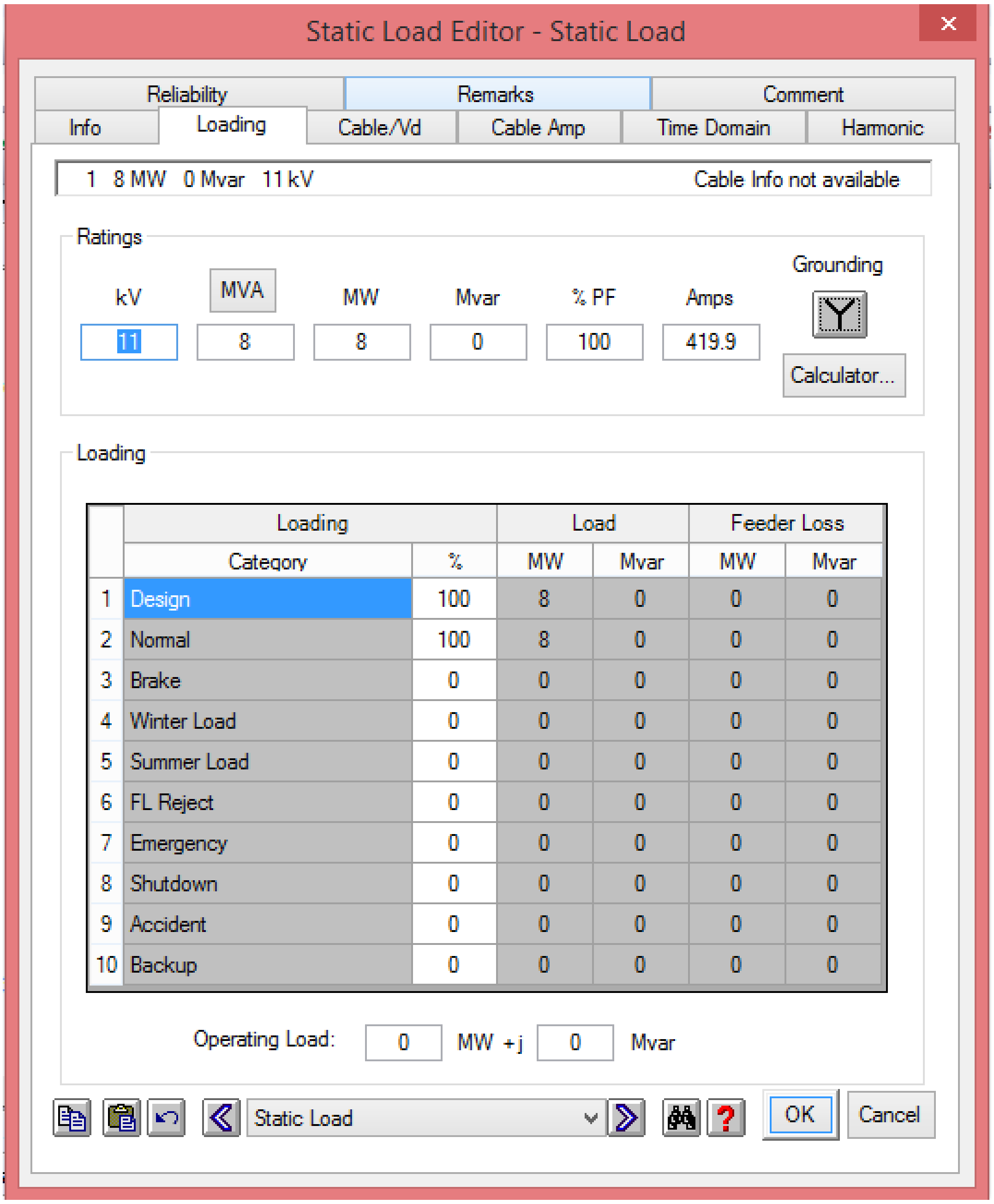


Fig 16.12: Static Load Editor

Running Relay Coordination

1. From the Mode toolbar, click the Star – Protective Device Coordination button to switch to the Star mode 1.

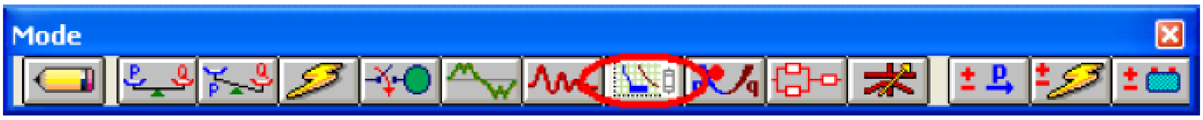


Fig 16.13: Mode toolbar

2. To generate the Star View, select the relay, and then click the Create Star View button from the right-hand side Star Mode toolbar.

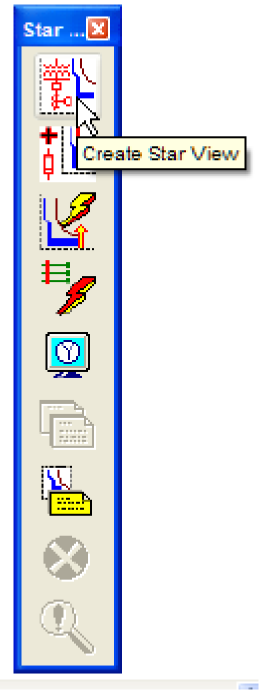


Fig 16.13: Star view

3. This opens a new Star TCC View with the selected Relay1 curve. Star Views for other protective devices can be generated in a similar manner.. Right click on the

label tag associated with the curve and check the Settings options. This will show more information related to the relay settings in the label tag.

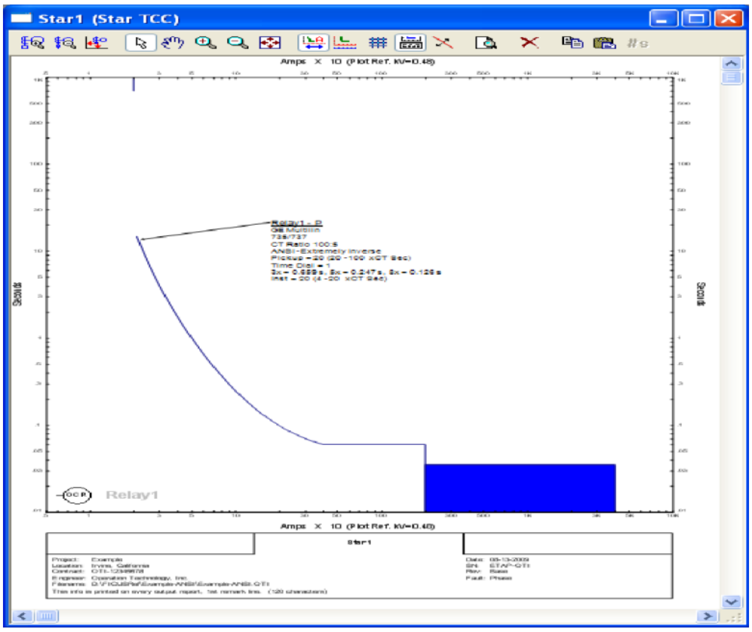
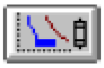
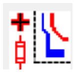


Fig 16.14 : Star TCC

4. Switch to Star Mode  using the Mode toolbar. Select Fuse1 and click on Append to Star view button  to open the Star View Selection editor. Select Star1to append Fuse1 to Star1 view and click OK.

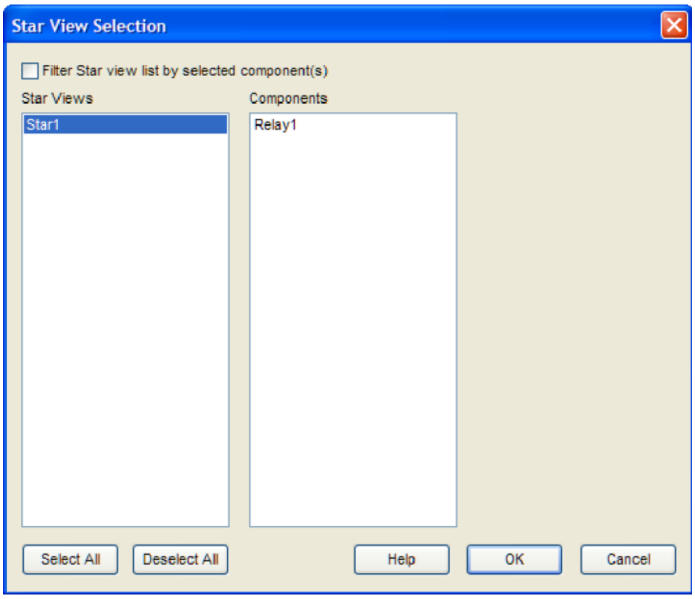


Fig 16.15 : Star View Selection Editor

5. Star1 view opens with the Relay 1 curve added. Element or group of elements on the one-line-diagram can be appended to one or more Star views in a similar manner.

Problem 1:

Repeat the relay coordination experiment for a three phase grid system if a 3 phase fault occurs at bus 3.

Observation:

The sequence of operation is as follows:

Time(ms)	**ID**	**If(kA)**
	Relay2	
	CB2	
	Relay1	
	CB1	

Result:

Inference:

Experiment No. 17

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.

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

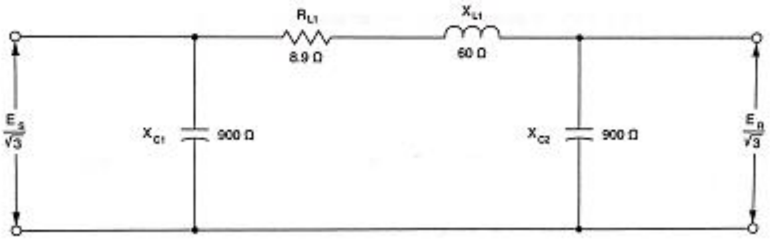
150 Mvar……………………………….……...9.55 H, 3.6 kΩ, @60 Hz
300 Mvar…………………………………...4.77 H, 1.8 kΩ, @60 Hz
600 Mvar…………………………….….…2.39 H, 900 Ω, @60 Hz

Resistance loads

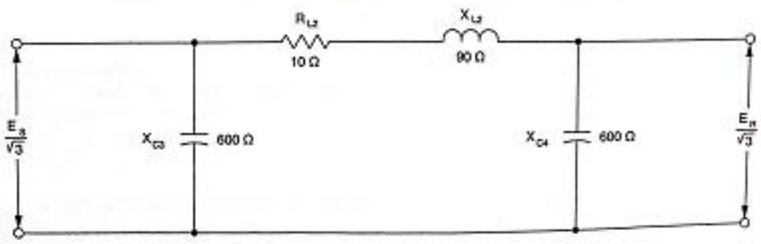
225 Mvar……………..……………………2.4 kΩ
450 Mvar……………….…………………..1.2 kΩ
900 Mvar……………….……..……………600 kΩ
1800 Mvar…………………………………300 kΩ
3600 Mvar…………………...…………150 kΩ

Theory:

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



a) TRANSMISSION LINE 1 (200 km)



a) TRANSMISSION LINE 2 (300 km)

Fig 17.1 shows the 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 id 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 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 figure. 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 (°)

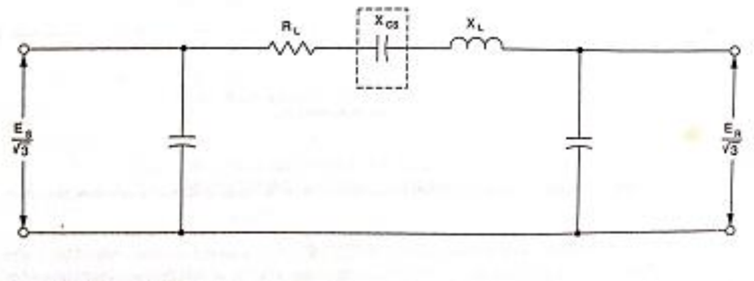


Fig 17.2 Series compensation

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

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

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

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

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 increase 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 figure shows the power transfer capability of a line without compensation and with 50% compensation.

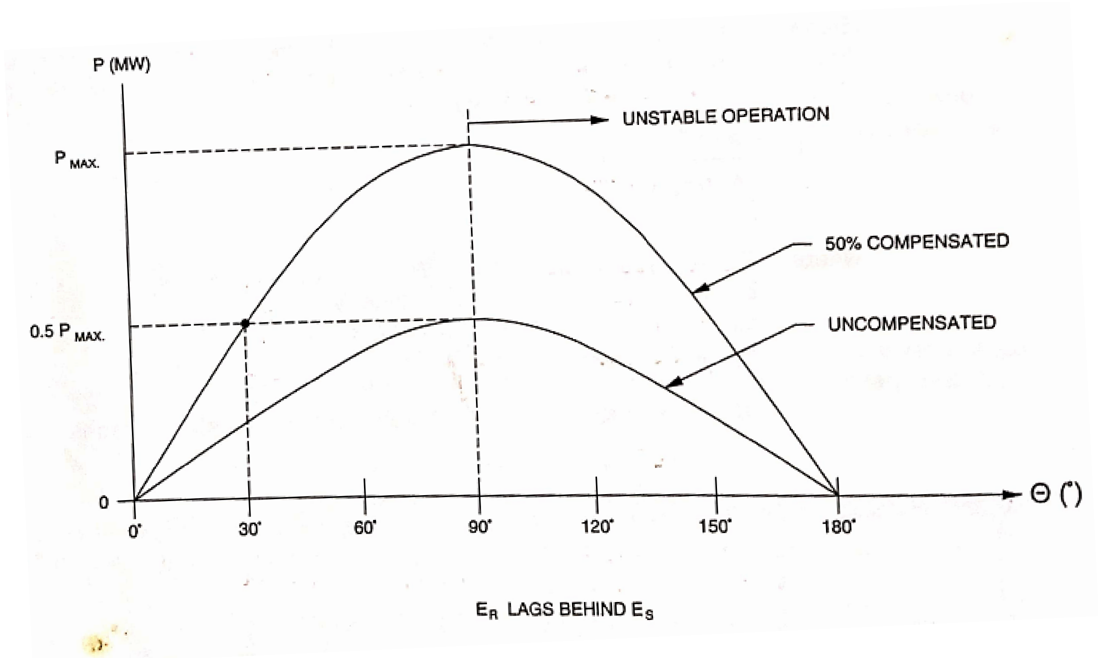


Fig 17.3 Power transfer capability of a transmission line with and without series compensation.

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_{C2}.
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 in order 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 in order for the receiver voltage to be as close as possible to the sender voltage pf 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 300Mvar) across the load in order 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. Then connect the required shunt capacitor (about 1000 Mvar) across the load in order for the receiver voltage to be as close as possible to the sender voltage of 735kV.
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 in order to accurately measure its power transfer capability at 30°.

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 in order 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 till 3600 MW. Therefore the increase in compensation factor has improved the stability of the system.
13. Increase the load on the line 2 to 4500 MW.
14. Readjust the shunt capacitor across the load so that the receiver voltage is as closease 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: