Ahsanullah University of Science and Technology

Department of Electrical and Electronic Engineering

LABORATORY MANUAL

FOR

ELECTRICAL AND ELECTRONIC SESSIONAL COURSE

Student Name :

Student ID :

Course no : EEE 3106

Course Title : Power System I Lab

For the students of
Department of Electrical and Electronic Engineering
3rd Year, 1st Semester

Experiment No.: 1

Experiment Name : Study of Power Factor Improvement (PFI) Plant.

Equipment required :

Capacitor bank
Induction load
AC Voltmeter
AC Ammeter
AC Wattmeter

Introduction :

For fixed power and voltage, the load current is inversely proportional to the power factor. Lower the power factor, higher the load current and vice-versa. At lower power factor the KVA rating of the equipment has to be made more, making the equipment larger and expensive. Moreover, to transmit or distribute a fixed amount of power, the conductor size has to be greater at low power factor. Consequently, more I^2R losses result. Therefore, low power factor is objectionable in the power system.

The low power factor is mainly due to the fact that most of the industrial loads are inductive and therefore take lagging currents. In order to improve the power factor, some elements or devices taking leading current should be connected in parallel with the load. One of such element could be capacitor bank. In this experiment, study will be made on a PFI plant controlled by manually where capacitor bank switches are turned ON and OFF according to the power factor such that nearly standard power factor is achieved.
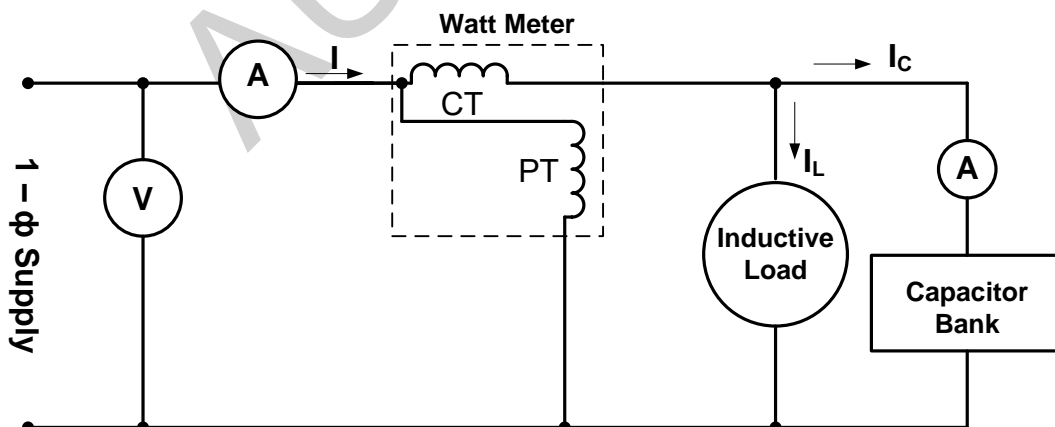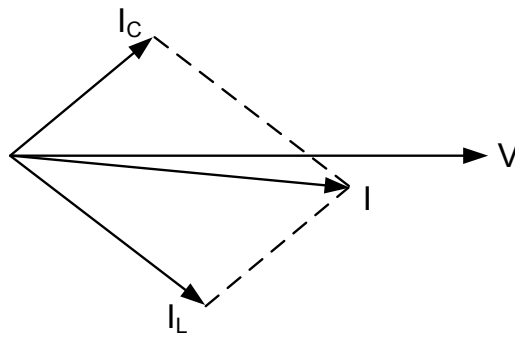

Figure 1.1 :

Figure 1.2 :

Procedure :

1. Connect the load with the PFI plant and arrange the supply for the combination.
2. Vary the load and observe the switching of the capacitors. Also notice the overall power factor.
3. For each set of load, take reading of the load currents, voltage across the load, total watt for the load and calculate the power factor for each set of load.

Table 1.1 :

Observation	V (Volt)	I (mA)	Power (Watt)	Pf	Capacitance (Practical)	I_C (mA)	Capacitance (Theor)
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

Report :

1. Give an idea to design a dynamic PFI plant for a load with variable power factor.
2. Describe in brief the types of reactive power compensation system.
3. An industry operating at 220V (L-N) has a maximum load of 400KVA per phase and the minimum load is half of its rated load. It is assumed that the reactive power requirement of the industry is 40% of its KVA demand. If the targeted power factor is 95%, design a 5 step switching module for 5 different load conditions in between the maximum and minimum capacity. What will be the values of 5 capacitances for optimum pf control and what should be the worst scenario with this system?

Experiment No.: 2

Experiment Name : Observation the phase shift in Δ-Y transformer in a 3-φ transmission line.

Equipment required :

3-φ transformer
3-φ variac
AC voltmeter(0 – 500V,0 – 100V)
Oscilloscope × 2

Theory :

Normally, to remove the zero sequence current in a Power System Network, one of the sides of the transformer is connected in Δ. Depending on the type of connection,Δ-Y or Y-Δ or Δ-Z ; there is a definite phase shift between the primary and secondary voltages. These phase shifts will have to be determined or known to calculate the fault currents and for paralleling purpose. The connection of the phases of two windings of a transformer together with the phase shift between the primary and the secondary is known as the vector group. The numerical index (hour no.) shows the displacement of the vectors. Capital letters apply to H.V. winding and the small letter L.V. windings. If shows (numerical index) by what multiple of 30° the L.V. vector lags(anti-clockwise rotation of vectors) behind the H.V. vector.
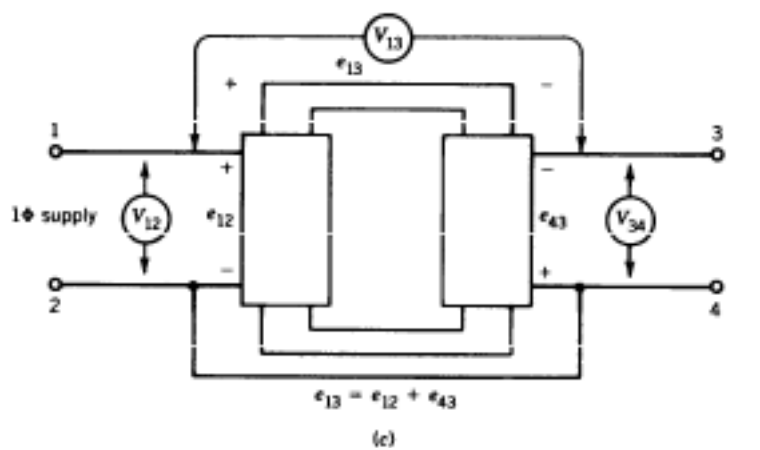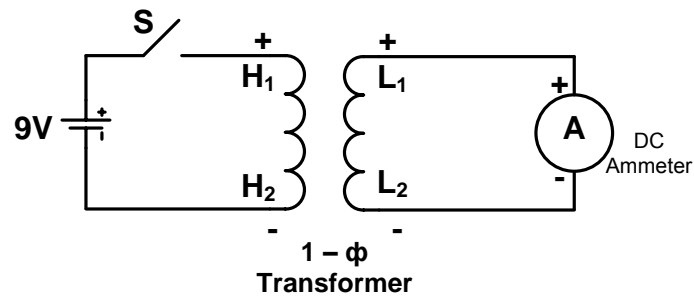

Figure 2.1 :

For example , Dy5 means H.V. in Δ, L.V. in Y and the voltage in H.V. side(Δ) leads L.V. side (Y) by 5 X 30= 150°.

Determining the relative polarity of a Transformer :

The polarity test of the Transformer should be required for performing this experiment otherwise you cannot get the actual result (30° phase shift between the Primary and Secondary side of the Transformer) from this experiment. There are two ways to verify the polarities as illustrated in the forgoing figure. In the 1st approach, which is suitable for laboratory work, a dc voltage is applied through a switch to one side and a dc ammeter is connected to the other side. On connecting the switch , if the ammeter deflection is in forward direction then the terminal connected to the positive terminal of the ammeter is considered positive.

A more realistic approach is to use KVL after applying a single phase supply (A.C or D.C) to one side of the winding as illustrated in the later figure.

1 – ɸ
Transformer

$e_{13} = e_{12} + e_{43}$

(c)

- If V13≅V12+V34 then 1 and 4 identical
- If V13 ≅ V12-V34 then 1 and 3 identical

Figure 2.2

A) PRIMARY DELTA AND SECONDARY WYE (Mode-1):

Connect the Primary and Secondary as per following diagram.

$V_{RY} = -V_{H3-H4}$.

$V_{ab} = V_{an} - V_{bn}$.

Apply 50V to the primary.

Find the phase shift between the Primary and Secondary.

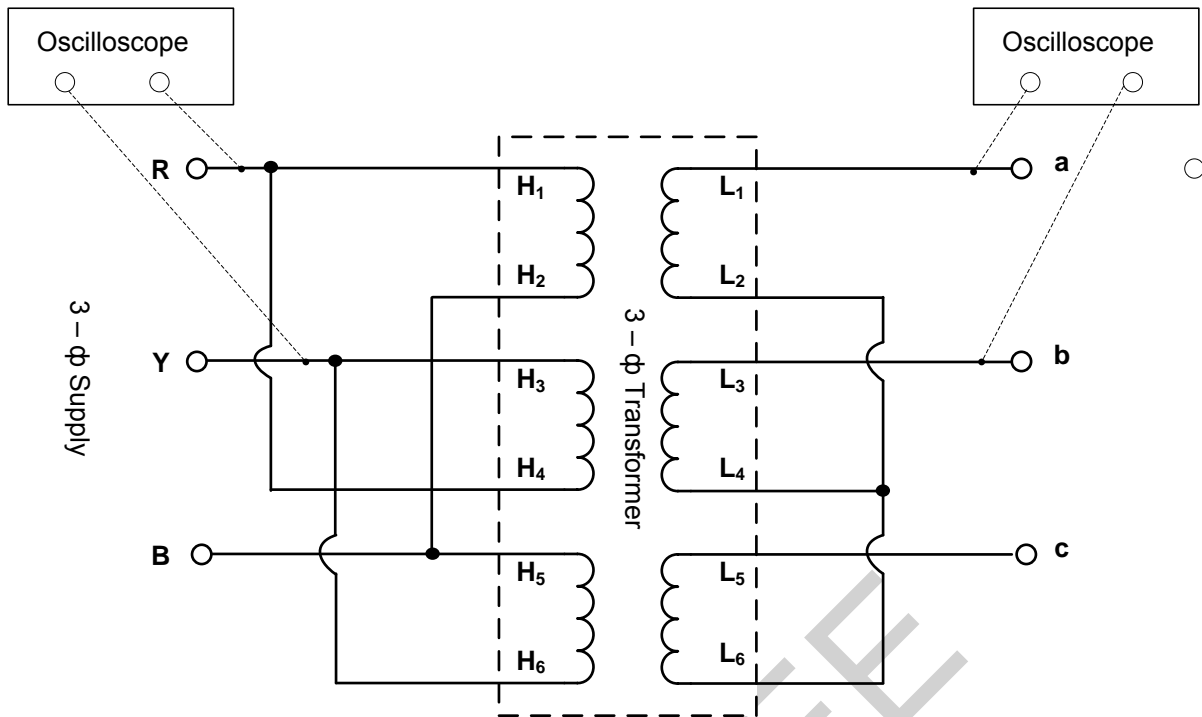Confirm whether the vector Group is Dy1.
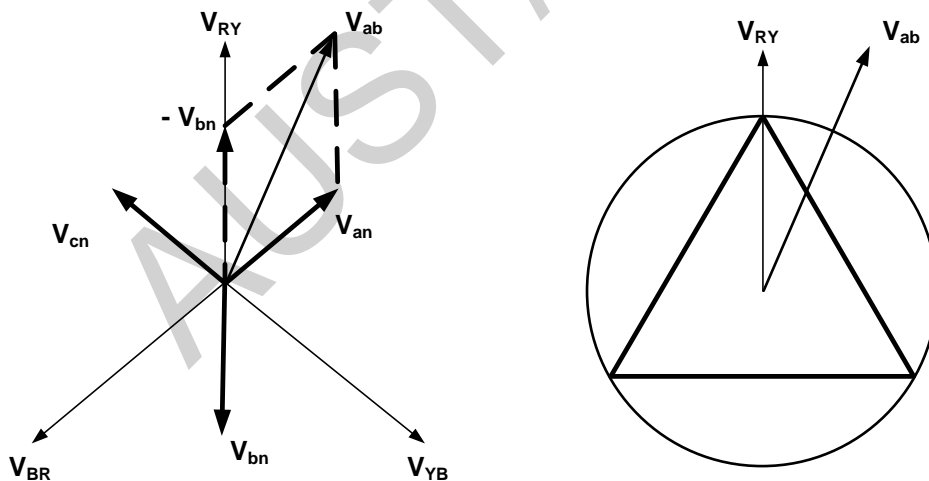
Figure 2.3 : $\Delta - Y$ Connection (Mode – 1)

Figure 2.4 : Vector Diagram (Mode – 1)

B) PRIMARY WYE AND SECONDARY DELTA (Mode-2):

Connect the primary as per following diagram, keeping the Secondary fixed. Through variac apply a small 3-Ø voltage (say 50V). See the phase shift between RY and ab on a duel channel oscilloscope. Confirm whether the vector is Dy11.

$V_{RY} = V_{H1-H2}$(phase-b)

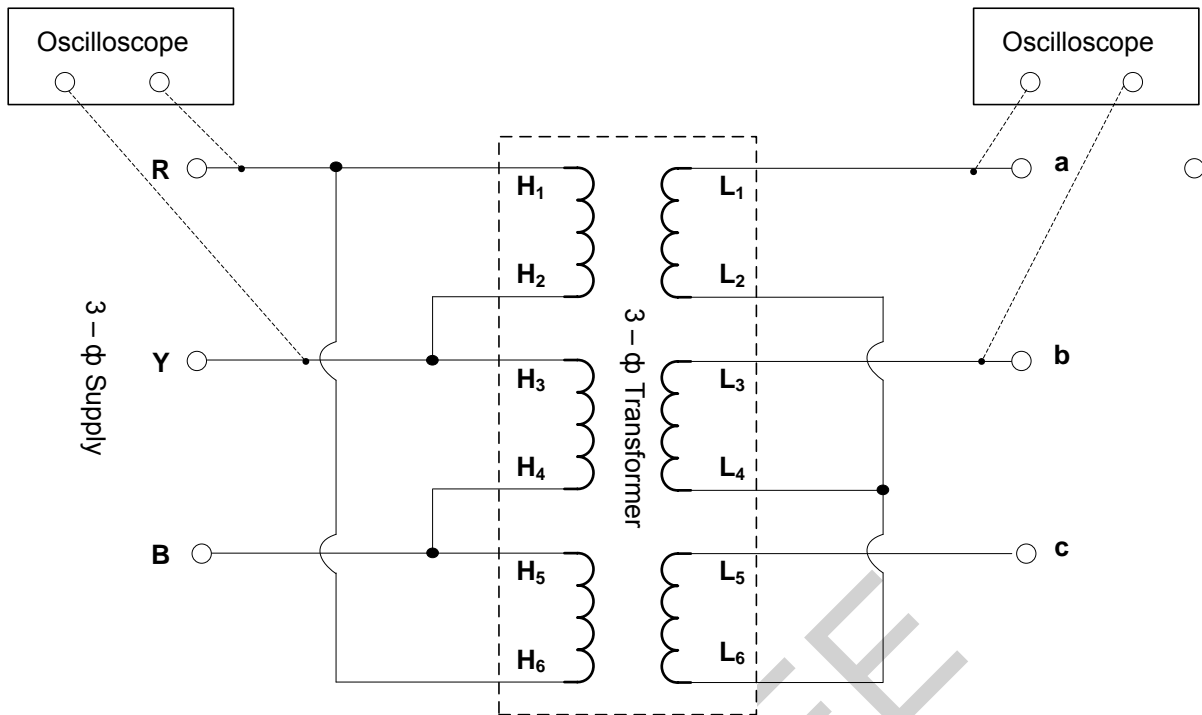Figure 2.5 : $\Delta - Y$ Connection (Mode – 2)

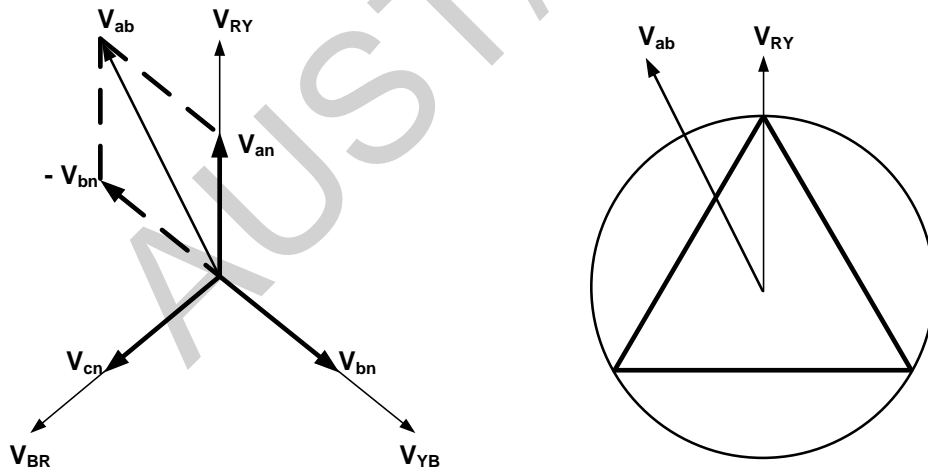Figure 2.6 : Vector Diagram (Mode – 2)

Report:

1. Why Delta (Δ) connection is required in high tension side and Wye(Y) connection is required in low tension side in a transmission line.

2. Explain the necessity of using the Wye-Delta transformer in power sytem?

3. Draw the connection and vector diagram for the group Dy5.

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Experiment No.: 3

Experiment Name : Determination of Symmetrical Components of current under different fault conditions of a synchronous Generator.
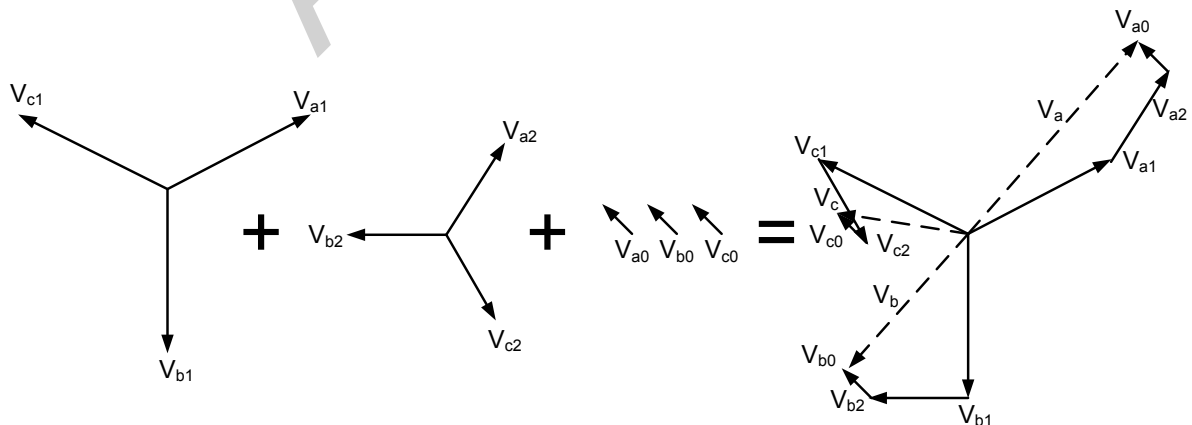

Equipment required :

Synchronous Motor/Generator.
3Ø induction Motor
AC Ammeter (0-3A)
AC Voltmeter (0-500V)
Variac

Introduction:

According to Fortescue's theory, three unbalanced vectors V_a ,V_b and V_c can be replaced by a set of three balanced system of vectors.

The Three symmetrical component vectors replacing V_a , V_b and V_c are :

1. Positive sequence component vectors of equal magnitude but displaced in phase from each other by 120° and as the same phase sequence as the original vector.

2. Negative sequence component which has three vectors of equal magnitude but displaced in phase from each other by 120° and has the phase sequence opposite to the original vectors.

3. Zero sequence component which has three vectors of equal magnitude and are in phase with each other.

(A) Single line to Ground fault on an unloaded Generator:

Simulate a single line to ground fault on the phase "a" of the unloaded Generator.
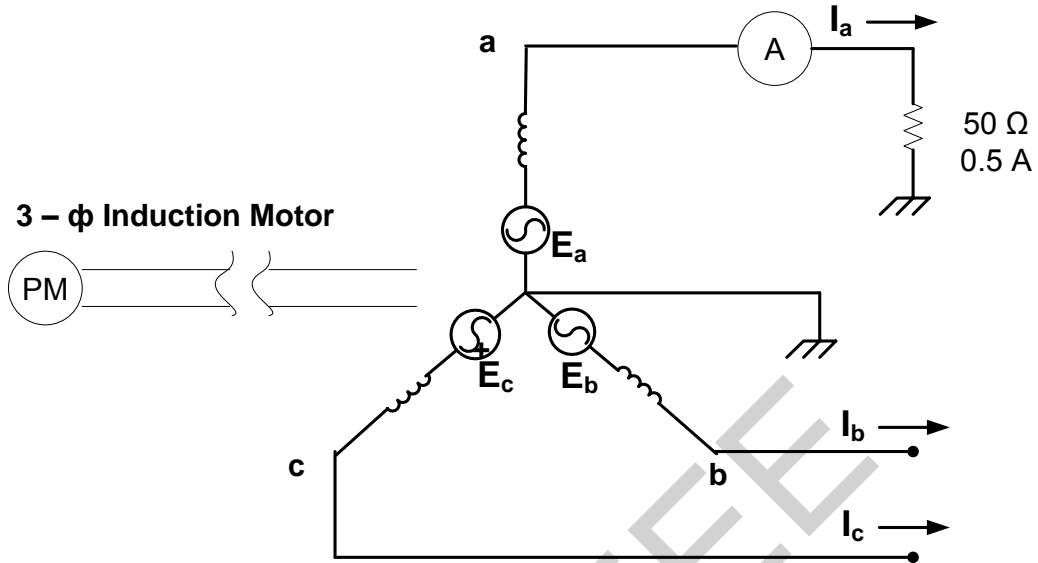

Figure 3.1 : Single Line to ground fault of an unloaded Generator.

The condition at the fault are: $I_b = 0$, $I_c = 0$

From the following matiix, determine Ia_0, Ia_1, Ia_2.

Measure I_a with an ammeter.

$$\begin{bmatrix} Ia_0 \\ Ia_1 \\ Ia_2 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} Ia \\ 0 \\ 0 \end{bmatrix}$$
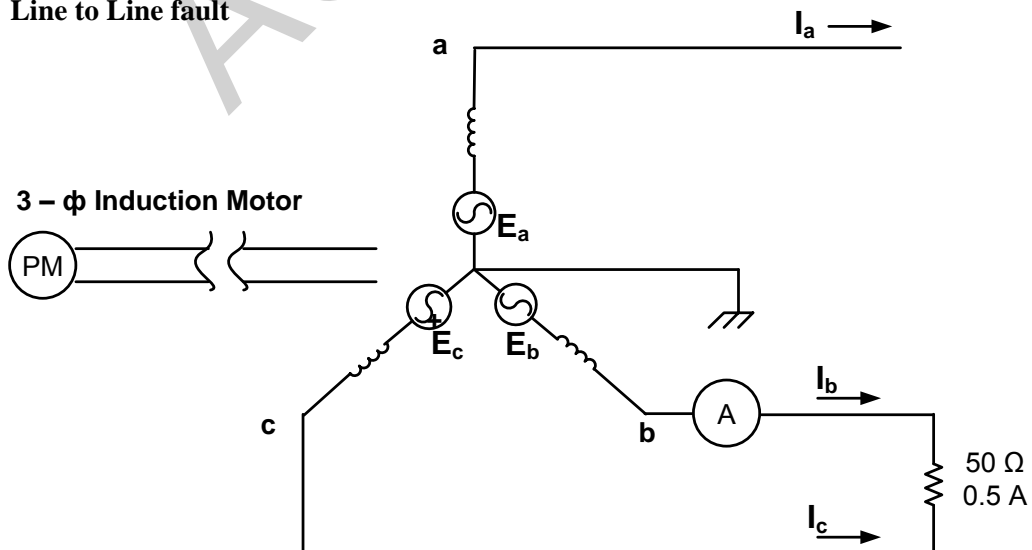
(B) Line to Line fault

Figure 3.2 : Line to Line fault.

Here, $I_b = -I_c$ & $I_a = 0$

After putting these values we will get

$$\begin{bmatrix} Ia_0 \\ Ia_1 \\ Ia_2 \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} 0 \\ -I_c \\ I_c \end{bmatrix}$$

$\therefore Ia_0 = 0$

$Ia_1 = 1/3[a^2I_c - aI_c] = 1/3I_c[a^2-a]$

Measure I_b or I_c by an ammeter.

$Ia_2 = 1/3[aI_c - a^2I_c] = 1/3\ I_c[a-a^2]$
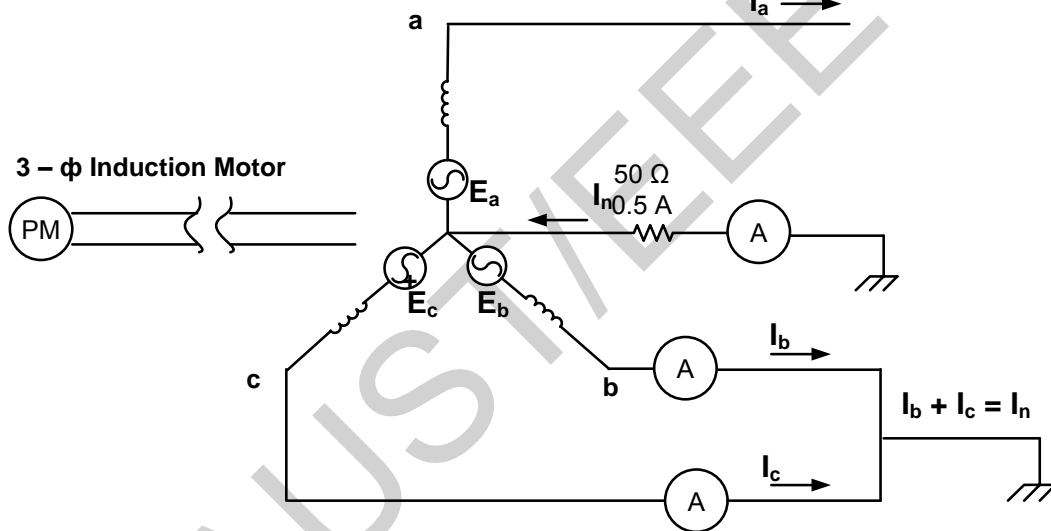
$\therefore Ia_1 = -Ia_2$

(C) Double line to Ground fault

Figure 3.3 : Double Line to Ground fault.

$$\begin{bmatrix} Ia_0 \\ Ia_1 \\ Ia_2 \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} 0 \\ I_b \\ I_c \end{bmatrix}$$

$Ia_0 = 1/3[I_b+I_c] = In/3$

$Ia_1 = 1/3[aI_b + a^2Ic]$

$Ia_2 = 1/3[a^2I_b + aI_c]$

Measure In by an ammeter.

Report :

1. For the different type of fault, discuss and compare the different sequence network currents.
2. What are the advantages of analyzing a fault by sequence network?

Experiment No.: 4

Experiment Name : Measurement of Positive Sequence Impedances for Rotating Machine.
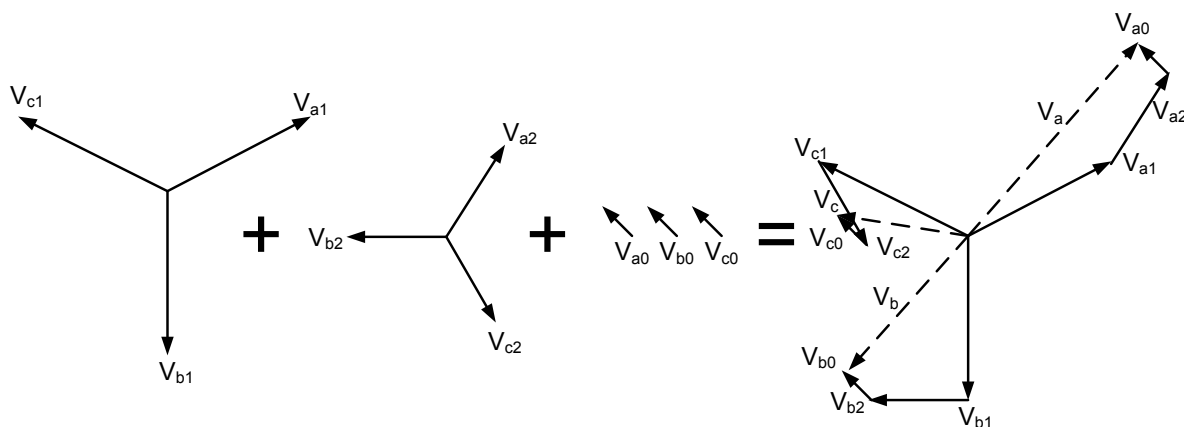
Equipment required :

Synchronous Motor/Generator
3-Ø Induction Motor
A.C. Ammeter (0-1A) × 2
A.C. Voltmeter (0-250V)
Variac

Introduction:

According to Fortescue's theory, three unbalanced vectors V_a , V_b and V_c can be replaced by a set of three balanced system of vectors.

The Three symmetrical component vectors replacing V_a , V_b and V_c are :

1. Positive sequence component vectors of equal magnitude but displaced in phase from each other by 120° and as the same phase sequence as the original vector.

2. Negative sequence component which has three vectors of equal magnitude but displaced in phase from each other by 120° and has the phase sequence opposite to the original vectors.

3. Zero sequence component which has three vectors of equal magnitude and are in phase with each other.

$Va = Va_1 + Va_2 + Va_0$

$V_b = V_{b1} + V_{b2} + V_{b0} = a^2Va_1 + aVa_2 + Va_0$

$Vc = Vc_1 + Vc_2 + Vc_0 = aVa_1 + a^2Va_2 + Va_0$

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} Va_0 \\ Va_1 \\ Va_2 \end{bmatrix} \quad => \quad \begin{bmatrix} Va_0 \\ Va_1 \\ Va_2 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

Objective:

The objective of this experiment is to observe the sequence impedances and sub-transient reactances of rotating machine.

Measurement of Positive Sequence Impedance (Z_1) :

Connect the machine as per following diagram and run the machine at synchronous speed in proper direction with the help of prime mover. Keep the switch in the OFF position to perform the open circuit test. Take reading of voltmeter (V) for various I_f. Next reduce the excitation to minimum by putting total resistance in the field circuit and take readings of short circuit current (I_{sc}) for the similar I_f. Draw V vs I_f and I_{sc} vs I_f. Calculate the positive sequence impedance from the graph. At constant If, divide Voc by Isc to determine Z1.
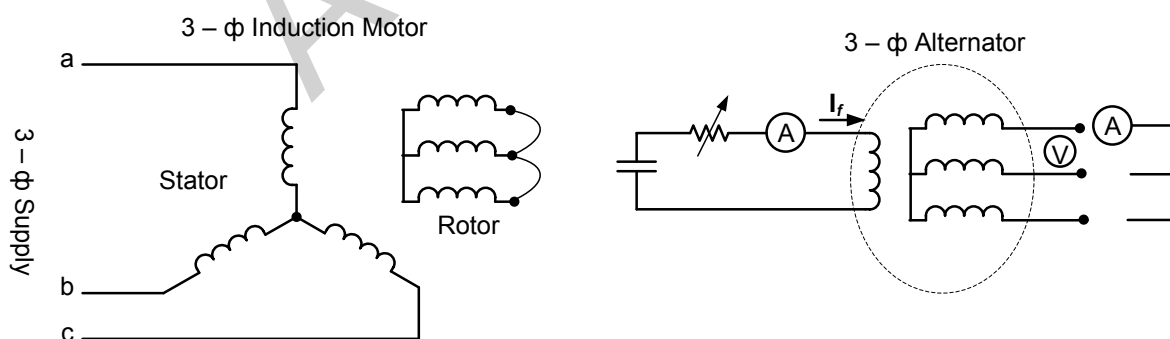

Fig : Experimental setup

Table 1

I$_f$(ma)	V$_{oc}$(volt)	I$_{sc}$(ma)

Report:

1. In first step how can we calculate that the measured impedance is the positive sequence impedance of the machine? Also show that the same result can be obtained from the following equation.

$$Z_1 = \frac{I_f \ at \ rated \ I_a \ on \ syn. \ sht.ckt.}{I_f \ at \ normal \ o.c.voltage}$$

2. What is the practical application of sequence impedances of power system?

Experiment No.: 5

Experiment Name : Measurement of Sequence Impedances and Sub – Transient Reactances for Rotating Machine.
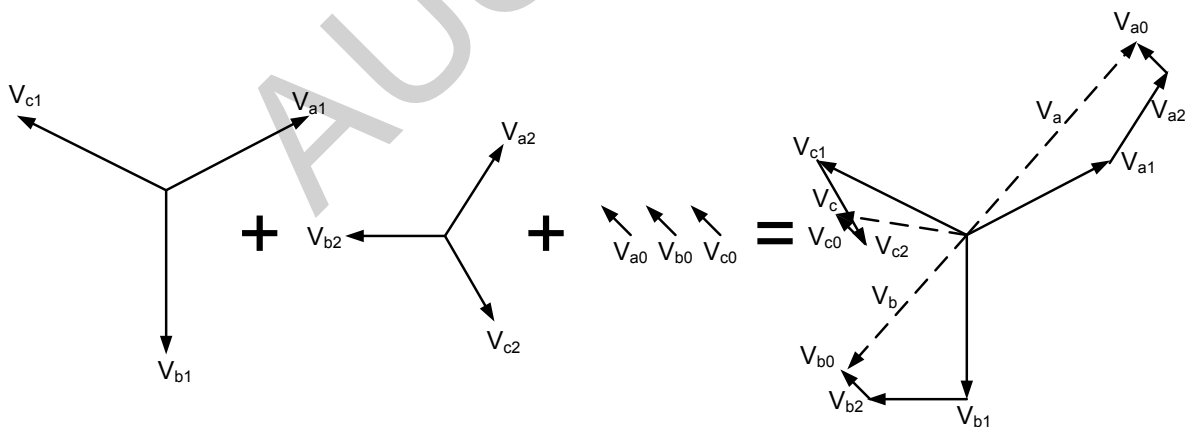

Equipment required :

Synchronous Motor/Generator
3-Ø Induction Motor
A.C. Ammeter (0-1A) × 2
A.C. Voltmeter (0-250V)
Variac

Introduction:

According to Fortescue's theory, three unbalanced vectors V_a ,V_b and V_c can be replaced by a set of three balanced system of vectors.

The Three symmetrical component vectors replacing V_a , V_b and V_c are :

1. Positive sequence component vectors of equal magnitude but displaced in phase from each other by 120° and as the same phase sequence as the original vector.

2. Negative sequence component which has three vectors of equal magnitude but displaced in phase from each other by 120° and has the phase sequence opposite to the original vectors.

3. Zero sequence component which has three vectors of equal magnitude and are in phase with each other.

$$V_a = V_{a1} + V_{a2} + V_{a0}$$

$$V_b = V_{b1} + V_{b2} + V_{b0} = a^2 V_{a1} + a V_{a2} + V_{a0}$$

$$V_c = V_{c1} + V_{c2} + V_{c0} = a V_{a1} + a^2 V_{a2} + V_{a0}$$

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} Va_0 \\ Va_1 \\ Va_2 \end{bmatrix}$$

$$\Rightarrow \quad \begin{bmatrix} Va_0 \\ Va_1 \\ Va_2 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

Objective:

The objective of this experiment is to observe the sequence impedances and sub-transient reactances of rotating machine.

A) Method of test for Sequence Impedance :

i) Measurement of Negative Sequence Impedance (Z_2) :

Connect the machine as per following diagram and drive it at rated speed and apply the reduce voltage to calculate approximately the rated current. Since negative sequence currents flow in this case there is possibility of hunting which results in oscillation of the ammeter. The negative sequence impedance is given by:

$$Z_2 = V/\sqrt{3}I$$
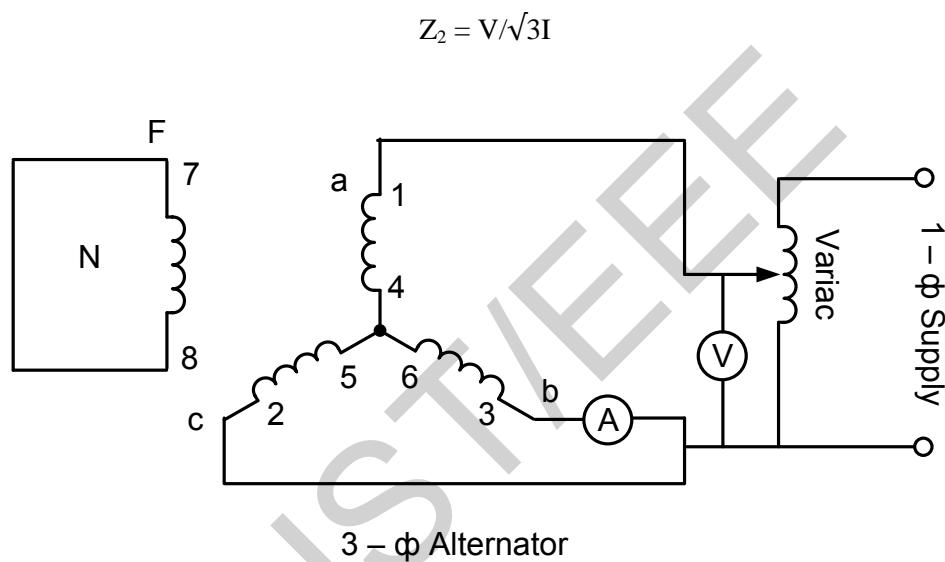
3 – φ Alternator

Since it is similar to L-L fault with alternator unloaded

$I_a = 0, I_b = I, I_c = -I, V_b = V_c$

$I_{a1} = 1/3(I_a + aI_b + a^2I_c)$, $I_{a2} = 1/3(I_a + a^2I_b + aI_c)$, $I_{a0} = 1/3 (I_a + I_b + I_c)$
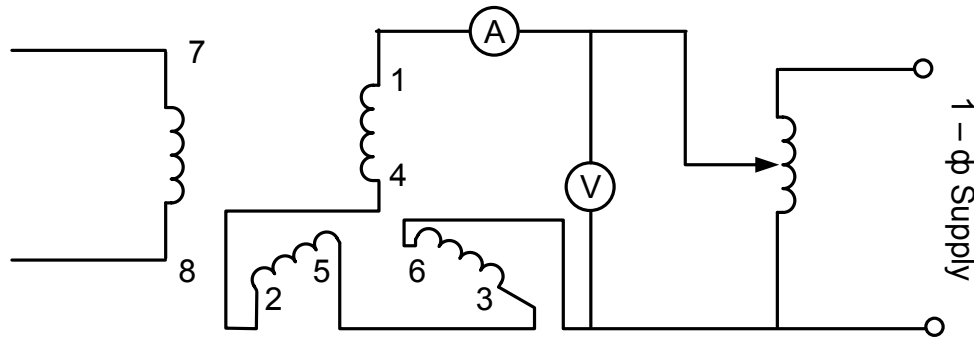
Substituting Ia, I_b & Ic

$I_{a1} = 1/3 (0 + aI_b + a^2I_c) = 1/3 (a - a^2) I_b$;

$I_{a2} = 1/3 (0 + a^2I_b + aI_c) = 1/3 (a^2 - a) I_b$;

$I_{a0} = 0$;

$\therefore I_{a1} = -I_{a2}$; similarly, $V_{a1} = V_{a2}$

iii) Measurement of Zero Sequence Impedance (Z_0) :

The machine is at stand still and a reduce voltage is applied. The zero sequence impedance is given
by: $Z_0 = V / 3I$

B) Method of test for Sub – Transient Reactances (X_d'', X_q'') :

Connect the machine as mention below and apply V across any two terminals with the rotor at rest
and short circuited through an ammeter. The rotor is rotated by hand and it will be observed that for a
fixed applied voltage, current in the field varies with the position of the rotor. When the rotor is in the
position of maximum indicated I_f (the direct axis position of the rotor), one half the voltage required
to circulate rated current is equal to the direct axis sub-transient reactance Xd" and the position of
minimum indicated If   the quad. Axis **X_d''** is obtained.

$V_{L-L} =$ $I_{max} =$ $I_{min} =$

$X_d'', = V_{L-L} / I_{min}$

$X_q'' = V_{L-L} / I_{max}$
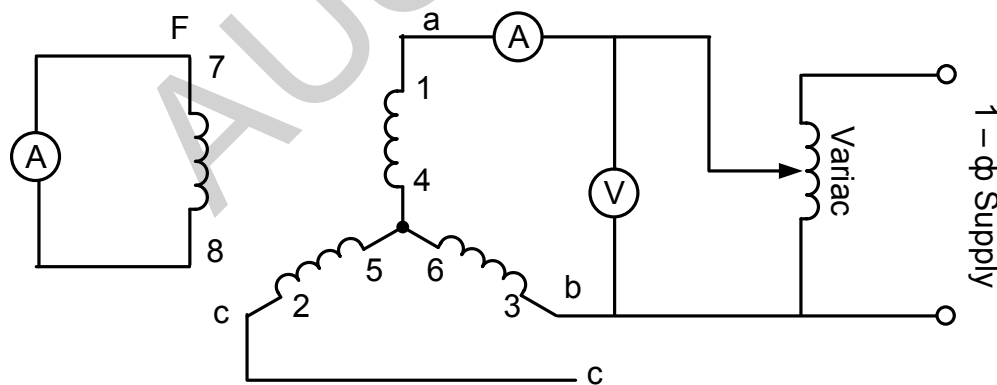
Test for sub-transient reactances

Report:

1. In first step how can we calculate   that the measured impedance is the negative sequence
impedance of the machine? Also derive the expression $Z_2 = V/\sqrt{3}I$

2. What are the practical application of positive, negative and zero sequence impedances of power
system?

Experiment No.: 6

Experiment Name : Study of voltage surge protector.

Equipment required:

IC 555
Relay-4V
X-former-6V
Diode 1N4001 × 3
Resistor - 10K,1K
Capacitor- 1μF, 1000 μF × 2, 10pF
Red LED × 1
DVM

Introduction:

We may wish to apply power to one part of a system and wait for a short interval before starting some other part of a system. For example, we may need to re-set all counter to zero before starting a personal computer at the beginning of a business day. A circuit that solves this problem is shown in Fig-02

In the circuit of Fig-01, power is applied to a system when the switch is closed. The IC555's output goes high for a period of time T and then goes low. T is found from equation $t=1.1R_aC$. This type of startup pulse is typically used to reset counters and initialized computer sequences after a power failure. It can also allow time for an operator to exit after an alarm system has been turned ON before the system is being alarmed.
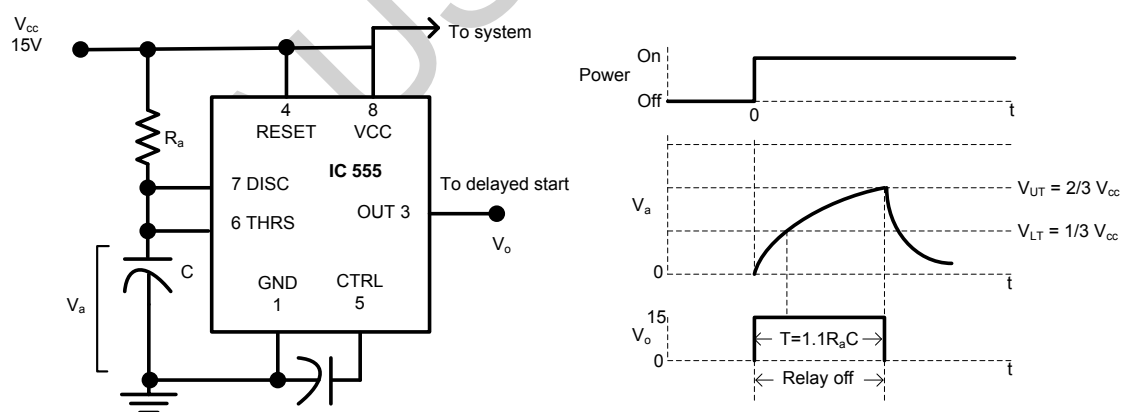

Fig 1: Output V_o does not high until a time interval after power is applied.

Sometimes while any electrical or electronic equipment is ON, the electricity might be fail. For some reasons we may not be able to switch OFF the supply after the supply is cut or power may be restored before we can switch the supply OFF. A voltage surge at the time of power ON may damage sensitive appliances like TV, VCR, Refrigerator, PC etc.

The first part of the circuit is step-down the mains supply and rectify it to DC voltage which includes a step-down transformer, two rectifier diodes, and a smoothing capacitor. The second part is a monostable multivibrator using a 555 IC. The output of this IC is sufficient to drive the relay.

It disconnects the power supply when power fails and connects it again automatically after a few sec/min. Red LED starts glowing when power comes back. The time period can be adjusted by changing the values of R_T and C_T from the equation $T = 1.1 R_T C_T$, as time interval in seconds.
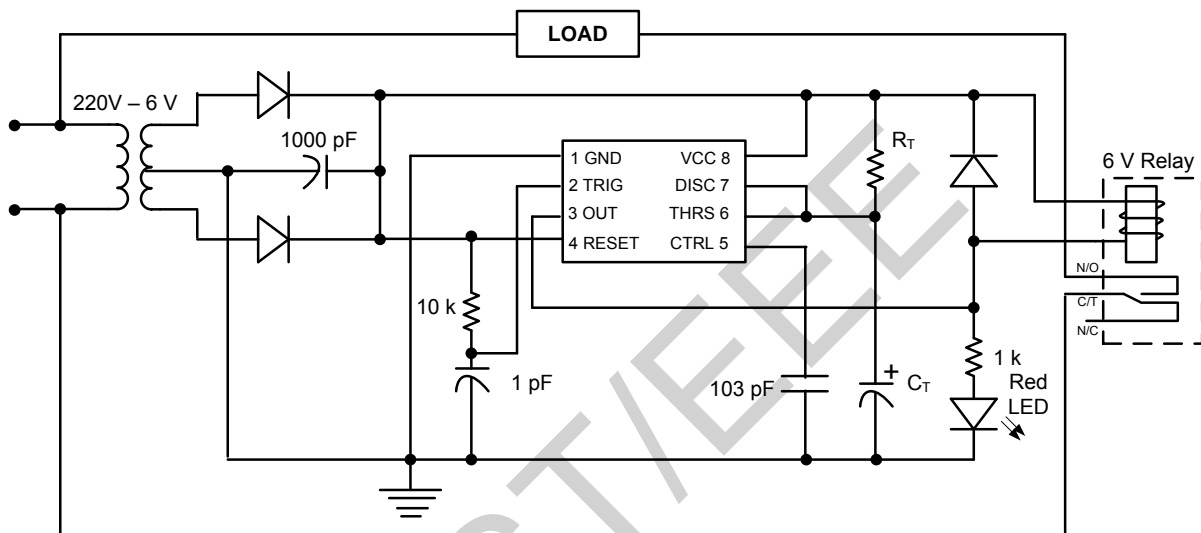
Fig 2: Voltage surge protector circuit.

Reports:

1. Describe the operation of the voltage surge protector circuit (fig-2).

2. What are the features of this circuit?

3. What will be happened if there is no voltage surge protection circuit in an electronic devices or refrigerator?

4. Can you improve this circuit? If you can, draw the circuit and describe the operation.

Experiment No.: 7

Experiment Name : Study on voltage instability protection from the mains supply.

Equipment required :

12V Transformer - 1pc
Diode(1N4001) – 2pc
Capacitor(1000 μF , 25V) – 1pc
Transistor(C828) – 2pc
Zener Diode(5.6V) – 1pc
Resistor(1K) – 3pc
Relay(12V) – 1pc
LED(red) – 1pc
Load(100W bulb or LED in series with at least 100K resistor) – 1pc
Variac – 1pc
Bread Board – 1pc

Introduction:

Voltage instability in the mains supply lines is a common phenomenon. While electric gadgets like heaters, fans, bulbs remain unaffected by it, but more sensitive devices like air conditioners, TV's, music systems etc tend to get easily damaged by such fluctuations.

Here a mains voltage limiter ('Low' to 'High' volt) circuit is discussed which can be used to protect equipment from both 'High' as well as 'Low' voltage. It is ideally suited for sensitive electronic devices and can be easily incorporated into any existing manual voltage stabilizer or used as an independent unit.
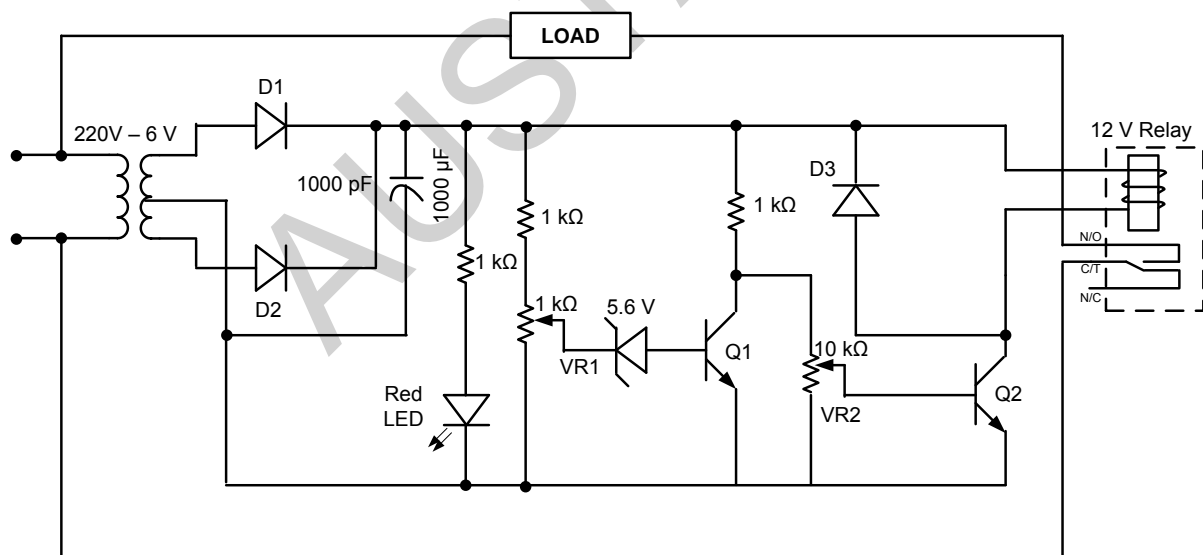
Note: VR_1 is used to set the high limit and VR_2 is used to set the low limit.

Report:

1. Explain the operation of the circuit.

2. What are the features of this circuit?

3. The purpose of using the the zener diode? Is the circuit operated properly if the value of the zener is chosen 15V or 1.5V?

Experiment No.: 8

Experiment Name : Load Flow Study Using MatLab

Introduction :

The steady state operation of power system as a topic for study is called load flow analysis. The load flow analysis is important for best operation of the existing system and for future expansion of power system. Principal information obtained from load flow analysis:

1. Magnitude of voltage at each bus.
2. Phase angle of voltage at each bus.
3. Real and reactive power flowing in each line.

Variables for load flow study are listed below

Bus Type	Known Variable	Unknown Variable
Swing/Slack/Reference Bus	V, δ (δ=0)	P,Q
PV/Generator/Voltage Controlled Bus	P,V	Q, δ
PQ/Load Bus	P,Q	V, δ

Normally only one bus is connected as slack/swing bus in a given power system. The need of such a bus is that the net complex power flow into the network is not known in advance, the system power loss is being unknown till the load flow study is complete. It is therefore necessary to have one bus as slack bus at which the complex power is unspecified, so that it supplies the difference in the total system load plus losses and the sum of the complex power specified at the remaining bus. The necessary conditions are:

1. Slack bus must be a generator bus
2. The voltage angle of the swing generator is set zero or any arbitrary value so its voltage becomes the reference point for other voltages of the system. The bus connected to the largest generating station is usually selected as slack bus.

Because of the non linearity of the equations of real and complex power of different buses, the solution is usually obtained by an iterative method. Most common two methods are:

1. Gauss Seidel method.
2. Newton Raphson method.

In this experiment we will consider the Gauss Seidel method for load flow study.

Gauss Seidel method:

Assumption:

1. Bus no 1 is swing bus.
2. Remaining generator buses are consecutively numbered as 2,3,4…………………G.
3. The load buses are numbered as G+1,G+2,………N.

Information regarding variables:

Bus Type	Known	Unknown
Swing Bus (1)	$V_1=V_1$ (angle=0)	P_1,Q_1
Generator Bus (K=2,3,……G)	P_k,V_k	Q_k, δ_k
Load Bus (K=G+1,G+2,…….N)	P_k,Q_k	V_k, δ_k

Procedure :

Development of a MATLAB based software tool for load flow analysis using Gauss-Seidal method

1. Input Data Format

(a)*Power- voltage profile of every bus should be given as follows*

Table 1

Bus(i)	P(i) $=P_g-P_d$ pu	Q(i)=Q_g-Q_d pu	V(i) pu	$\Delta(i)$	Remarks(optional)
1	-	-	1.04	0	Slack
2	0.5	-	1	-	PV
3	-1.0	0.5	-	-	PQ
4	0.3	-0.1	-	-	PQ

Note: Slack bus No=1, PV bus no =2-G, PQ bus no=G+1-N.
Where, N= Total No of Buses. G=No of the last PV bus(<=N)

(b) *The Line data should be given as follows*

Table 2

Line (from bus to bus)	R pu	X pu
1-2	0.05	0.15
1-3	0.10	0.30
2-3	0.15	0.45
2-4	0.10	0.30
3-4	0.05	0.15

2.Output format:

(a) All the unknown variables in table 1 should be known.
(b) The line to line power flow should be determined also.
(c) The iteration number of the stage when the result is found.
(d) Results should be presented in a well formatted text file.

3. Main Equations required:

$$Q\_new(i)= -Imag \left\{ V^*(i) \times \left(\sum_{K=1}^{N} Y(i,k) V(k)\right)\right\} \qquad (1)$$

$$V\_new(i)= \frac{1}{Y(i,i)} \left[\frac{P(i) - jQ(i)}{V^*(i)} - \sum_{\substack{K=1 \\ K \neq i}}^{N} Y(i,k) V(k) \right] \qquad (2)$$

Helpful hints:

1. Assume all unknown voltage to be 1 pu , all unknown δ to be 0.
2. Assume all unknown P and Q be equal to inf (a variable defined in MATLAB).
3. Take input of the total bus number. Using '*input*' function of MATLAB.
   As example:
   ```
   no_bus=input('Total no of bus is');
   ```

4. Store V, δ, P and Q in different row vectors in a user friendly way. Use '*sprintf* ' & '*input*' function in a loop.
   As example
   ```
   for i=1:no_bus
   sprintf('The voltage of bus %d is',i)
   v(i)=input('')
   end
   ```
   .
5. Formation of YBus Matrix. Use '*sprintf* ' & '*input*' function in a loop to take input of r and x from table 2. You have to use 2 for loops nested together. [Try to use the lowest number of loops]
6. set a variable for iteration count=1
7. Start calculation of bus 2 first. Try to identify whether it is a PV bus or PQ bus depending on the values of P and Q. If Its PV bus use both equation 1 and 2 to get the new value of Q and δ as **Q_new(i)** and **delta_new(i).** use '*Angle*' function to get **delta_new** from equation 2. As soon as a new value is generated do the following two tasks instantly without going for the next calculations.
   a. Find the difference between the old value and the new value for each variable and store the maximum among them in a variable may be known as '**del**'.
   b. Replace the older value with the newer value.
8. If it's a PQ Bus use only equation (2) to get **V_new(i)** and **delta_new(i)** using '*abs*' and '*angle*' functions of MATLAB. Do the same things as in 7(a) and 7(b).
9. After calculation of all buses are completed, check whether

   $$\mathbf{del} < .0001$$

   If it is so we have obtained the result and we have to go to the next step. If its not you have to increase the iteration count by 1 and go back to step 7 again.
10. Calculate the real and reactive power of bus 1 using following equations

$$P(1) = \text{abs} \left\{ V^{*}(1) \times \left(\sum_{K=1}^{N} Y(1,k) V(k) \right) \right\} \qquad (3)$$

$$Q(1) = -\text{Imag} \left\{ V^{*}(1) \times \left(\sum_{K=1}^{N} Y(1,k) V(k) \right) \right\} \qquad (4)$$

11. Calculate the line to line flow using following equation

$$S(i,j) = V(i) \left\{ (V(i) - V(k)) Y(i,k) \right\}^{*} \qquad (5)$$

Note: Use '*fprintf*' function of MATLAB for storing the results in a text file.

Report :

1. Calculate manually the values that you have obtained from computer and compare them. Show all the calculations.
2. Discuss on the experiment.

Experiment No.: 9

Experiment Name : Introduction to PowerWorld Simulator

1. Introduction

PowerWorld Simulator (PW Simulator) is a power system analysis and simulation software package that accompanies the textbook "Power System Analysis and Design" by J. Duncan Glover and Mulukutla S. Sarma. A CD is provided together with the book to install the software. The PowerWorld Simulator can be installed by following the instructions on the CD. After installing the PW Simulator, double-click on the PW icon to start the program.

There is a brief introduction of the PW Simulator in Section 1.5 of the textbook. You are encouraged to read that section and experience the features of the program yourself. This appendix also helps you to get started with the software.

2. Analyze a Sample Case

Open a sample case by clicking 'Open Case' under 'File' menu. Select case B7flatlp.pwb in 'Non-Glover & Sarma Examples' directory. The following sample case is then loaded to the Simulator. The features of the software are then introduced using this sample case.

Basic menu functions:

Similar to other Windows applications, the upper part of the figure shows the menus and toolbars of the program, the bottom part shows the current working case. The basic menu includes the following functions:

File:	open, save, close and print the study case;
Simulation:	start, pause, resume the simulation of the study case. Once the simulation is started, an animated picture of power flow will be shown;
Case Information:	The case information, input and output are summarized in the menu;
Options/Tools:	providing the analyzing tools and options;
LP OPF:	providing the options for OPF calculation;
Window:	Similar to other applications, all opened files are listed here;
Help:	providing help to the users.
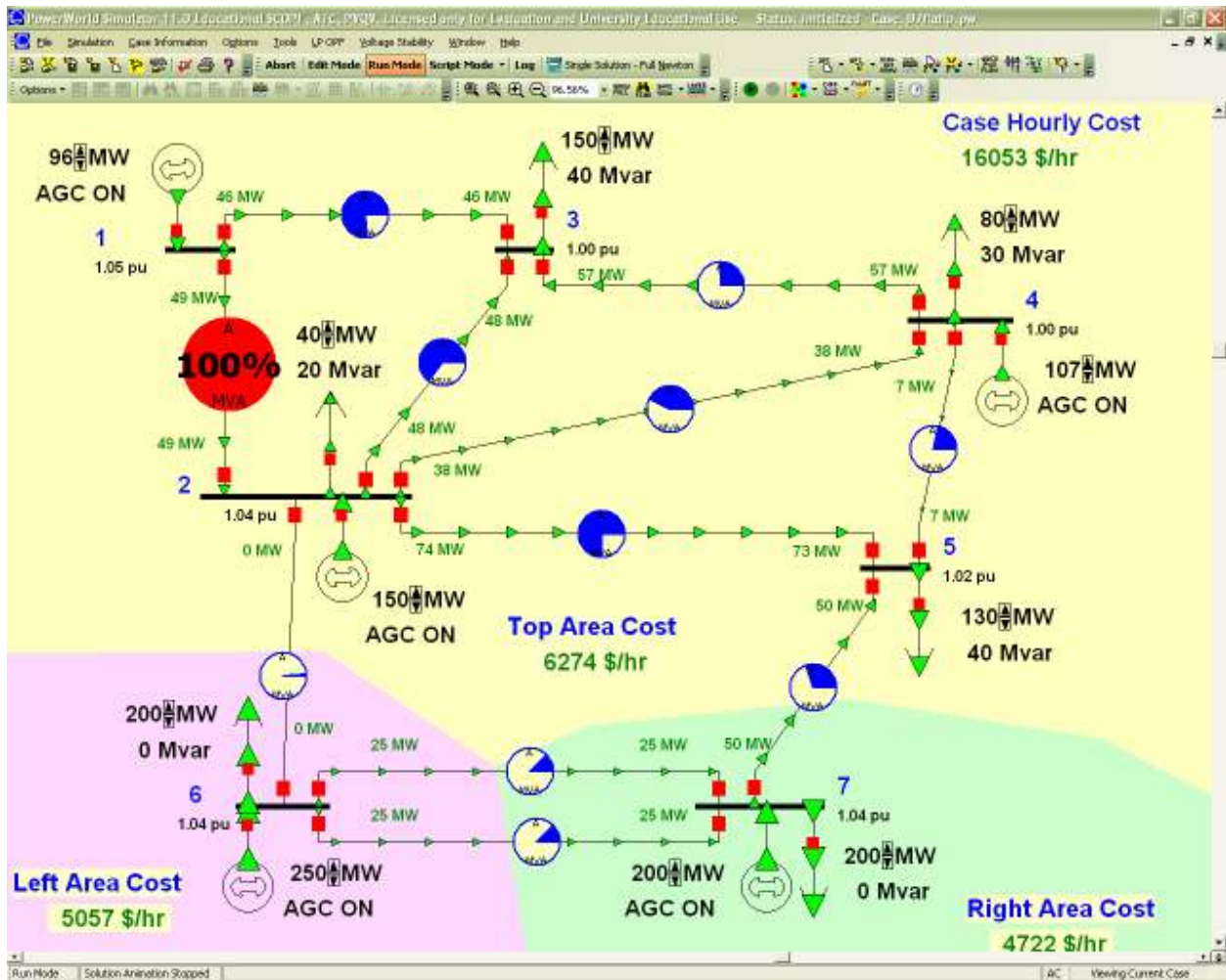
As introduced in the textbook, The PM Simulator provides two modes, one for editing and the other for running.

Solve the case:

1). Click the 'Run Mode' button.
2). Select 'Play' of the 'Simulation' menu.
3). The case is then solved. Observe the one-line diagram.

Inspect results:

1). The results can be observed directly from the one-line diagram. The voltages are listed besides the buses. The real and reactive power output of the generators, the power flows along the lines, etc. You can also change the items displayed in the one-line diagram.
2). Output results can also be obtained from 'Case Information' menu. Under 'Run Mode', select 'Buses', for example, the table containing bus records appears. Tables for generators, loads, transmission lines can also be accessed similarly.

Bus Records

	Number	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar	S Shu
1	1	1	Top	138.00	1.05000	144.900	4.43			95.54	7.43	
2	2	2	Top	138.00	1.04000	143.520	3.17	40.00	20.00	150.00	28.06	
3	3	3	Top	138.00	0.99799	137.723	-1.41	150.00	40.00			
4	4	4	Top	138.00	1.00000	138.000	-0.43	80.00	30.00	106.51	0.96	
5	5	5	Top	138.00	1.01803	140.488	-1.52	130.00	40.00			
6	6	6	Left	138.00	1.04000	143.520	3.18	200.00	0.00	250.00	-10.89	
7	7	7	Right	138.00	1.04000	143.520	0.00	200.00	0.00	200.23	32.51	

Edit input data:

You can edit the input data directly from the one-line diagram. For example, edit the input date of a generator:

1). Go to 'Edit Mode'.
2). Right-click the generator in the one-line diagram.
3). Select 'Information Dialog'. A dialog box appears and shows input date (it is shown below).
4). Change the data as you wish.

3. Create a New Case

A new case shown in the figure below can be created easily using PowerWorld Simulator.
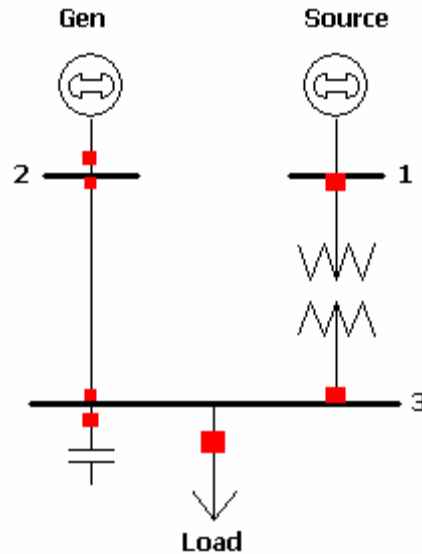
This simple case consists of 3 buses. Bus 1 is connected to the utility (Source). A generator is connected to Bus 2. Bus 3 provides power to the load. One transmission line (from Bus 2 to 3) and one transformer (from Bus 1 to 3) build up the network. A switched shunt is available to boost bus voltage.

3.1 Input of buses

Here are the steps to input Bus 1:

1). Go To 'Edit Mode'.
2). Click 'Insert' menu and select 'Bus'.
3). Place the bus to your selected position by clicking on the one-line diagram.
4). A dialog box named 'Bus Options' appears, shown in the next page.
5). Enter the necessary information shown in the dialog boxes into your computer.
6). Make sure the 'System Slack Bus' box is checked. Bus 1 is the slack bus since it is connected to the utility.
7). Click OK. This finishes the input of Bus 1.

This box defines the general information about a bus. In this example, Bus 1 has rated voltage of 69kV. It is a slack bus. Therefore, both voltage and angle settings are needed. Also the nominal voltage of the bus should be set.

Bus 2 and 3 can be input similarly. They are shown in the following figures. Please note:

- Bus 2 is a **PV** bus and is connected to a generator. Therefore voltage setting is needed. Enter '0.995' in the corresponding box. No need to input the angle setting box.
- Bus 3 is a typical **PQ** bus. Neither voltage setting nor angle setting information is needed.

3.2 Input of Components

Typical components in a power system include generator, motor and load, capacitor etc.. The utility supply system is represented as a generator with unlimited capacity. In this example, we will learn how to use PM Simulator to model these components.

Steps to input the utility supply system and generator of this example:

1). Go To 'Edit Mode'.
2). Click 'Insert' menu and select 'Generator'.
3). Place the component close to the bus that it is connected to.
4). A dialog box named 'Generator Options' appears, shown in the figure below.
5). After set the orientation to display the generator, click 'MW and Voltage Control' button. Some new fields appear in the dialog box.
6). Enter the necessary information shown in the dialog boxes into your computer.
7). Click OK. This finishes the input of the utility supply system/generator.

This box defines the display information of a generator, such as the display size, thickness, orientation etc.
The component entered here represents the utility system, which is place upward.

This box defines the control information for the utility. The MW and Mvar output will be calculated and filled in automatically by the program. The voltage setpoint is 1.0.

You can click '**Help**' at any time to find out the meanings of the required fields.

The dialog box containing the control information of the generator (connected to Bus 2) are shown below. Enter the data into your computer.

This generator outputs 2MW. The Mvar output will be calculated and filled in by the program. The voltage setpoint is 0.995 in this case.

A motor can be modeled in the same way as a generator. Just define the MW and Mvar output values to be negative.

Steps to input the load of this example:

1). Go To 'Edit Mode'.
2). Click 'Insert' menu and select 'Load'.
3). Place the component close to the bus that it is connected to (Bus 3).
4). A dialog box named 'Load Options' appears, shown in the figure below.
5). Enter the necessary information shown in the dialog boxes into your computer.
6). Click OK. This finishes the input of the load.

This box defines the general information about a load.

This load is a constant power load of 7MW and 6.3Mvar.

Steps to input the shunt capacitor of this example:

1). Go To 'Edit Mode'.
2). Click 'Insert' menu and select 'Switched Shunt'.
3). Place the component close Bus 3.
4). A dialog box named 'Switched Shunt Options' appears, shown in the figure below.
5). Enter the necessary information shown in the dialog boxes into your computer.
6). Click OK. This finishes the input of the shunt capacitor.
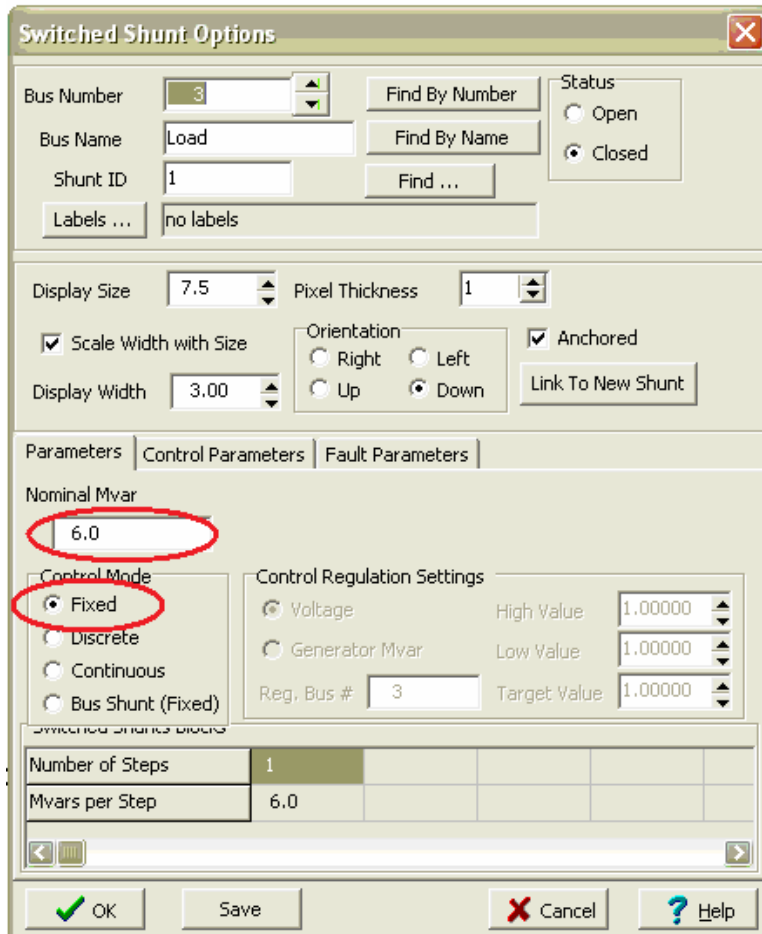
This box defines the information about a shunt capacitor.

The nominal Mvar of the shunt in this case is 6Mvar.

Click 'Help' to read instructions on data input.

3.2 Input of Lines/Transformers

Buses in a power system are usually connected by either transmission lines or transformers. PM Simulator models the transmission line and transformer as follows.

Steps to input the transmission line of this example:

1). Go To 'Edit Mode'.
2). Click 'Insert' menu and select 'Transmission Line'.
3). Place the transmission line in the one-line diagram: click the 'from bus' (Bus 2) of the line and then double click the 'to bus' (Bus 3) of the line.
4). A dialog box named 'Transmission Line/Transformer Options' appears, shown in the figure below.
5). Enter the necessary information shown in the dialog boxes into your computer.
6). Click OK. This finishes the input of the line.

This box defines the information about a transmission line. The impedance is in per unit. The per unit base value is defined in 'Solution/Environment' option.

The per unit impedance of this line is 0.06+j 0.12.

Click '**Help**' to read instructions on data input.

Steps to input the transformer of this example:

1).   Go To 'Edit Mode'.
2).   Click 'Insert' menu and select 'Transformer'.
3).   Place the transformer in the one-line diagram: click the 'from bus' (Bus 1) of the line and then double click the 'to bus' (Bus 3) of the line.
4).   A dialog box named 'Transmission Line/Transformer Options' appears, shown in the figure in the next page.
5).   Enter the impedance information shown in the dialog boxes into your computer.
6).   Click box 'Transformer Control'. Some new fields appear. Enter the corresponding control data.
7).   Click OK. This finishes the input of the transformer.

Now the simple case has been established. You may use the procedure described in Section 2 to inspect the input data in table format.

This box defines the information about a transformer. The input impedance is in per unit. The per unit base value is defined in 'Solution/Environment' option.

The per unit impedance of this line is 0.03+j 0.53.

Click '**Help**' to read instructions on data input.

This box defines the control information of transformer.

This transformer is not used for phase shifting. The turns ratio here is 1.01.

Click '**Help**' to read instructions on data input.

You can also choose to display more information of the case in the one-line diagram. For example, the load parameters can be displayed according to the following steps:

1). Go to 'Edit Mode'.
2). Right Click on the load. Select 'Add New Fields Around Load'.
3). A dialog box appears asking you to choose the position of the new field. Choose the position as you wish.
4). A new dialog box named 'Bus Field Options' appears. From 'Type of Field', select 'Load MW'. The value of load MW then displays in the one-line diagram.

Similarly, the one-line diagram can be adjusted to display more information about generators, buses and branches. Once the case is solved, the load flow results (bus voltages, branch currents) can also be displayed, as shown below.
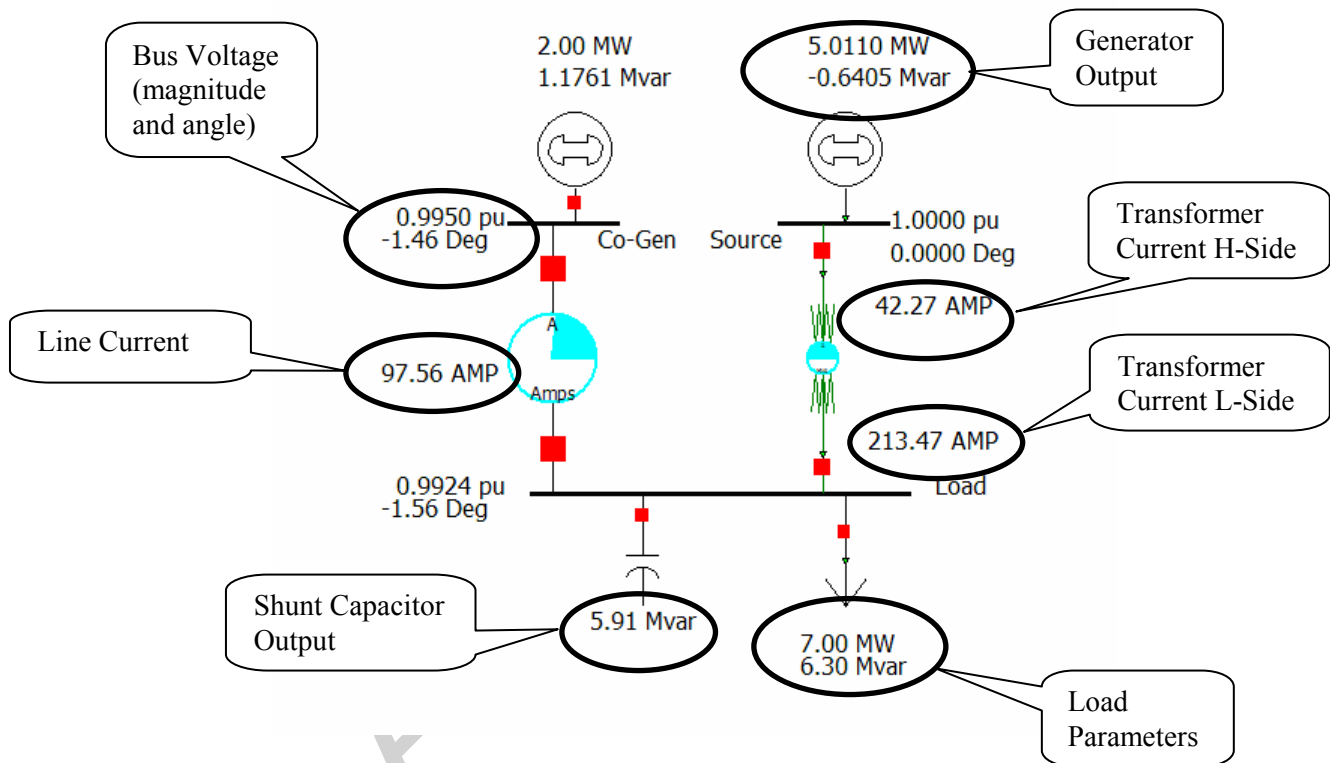
4. Analysis Tools

PowerWorld Simulator provides several tools for power system analysis. The tools used in EE433 labs include Power Flow Simulation, Fault Analysis and Scale Case. These tools are available from the 'Options/Tools' menu or 'Simulation' menu.

4.1 Power Flow

Power Flow is the most fundamental and commonly used tool for steady-state power system analysis. In the PW Simulator, power flow can be carried out by selecting 'Play' from the 'Simulation' menu. An animated power flow diagram is then displayed and helps you to have an intuitive feeling about power flow directions and relative values.

The options of the PW Simulator can be accessed by selecting 'Solution/Environment' from the 'Options/Tools' menu. The following diagram shows the general options for Power Flow Solution. Other options such as 'Automatic Controls', 'Area Interchange', 'Storage' are also available by clicking the buttons at the bottom of the dialog box. These options affect the results of power flow analysis. Make sure they have been set to the appropriate values before running the power flow simulation.
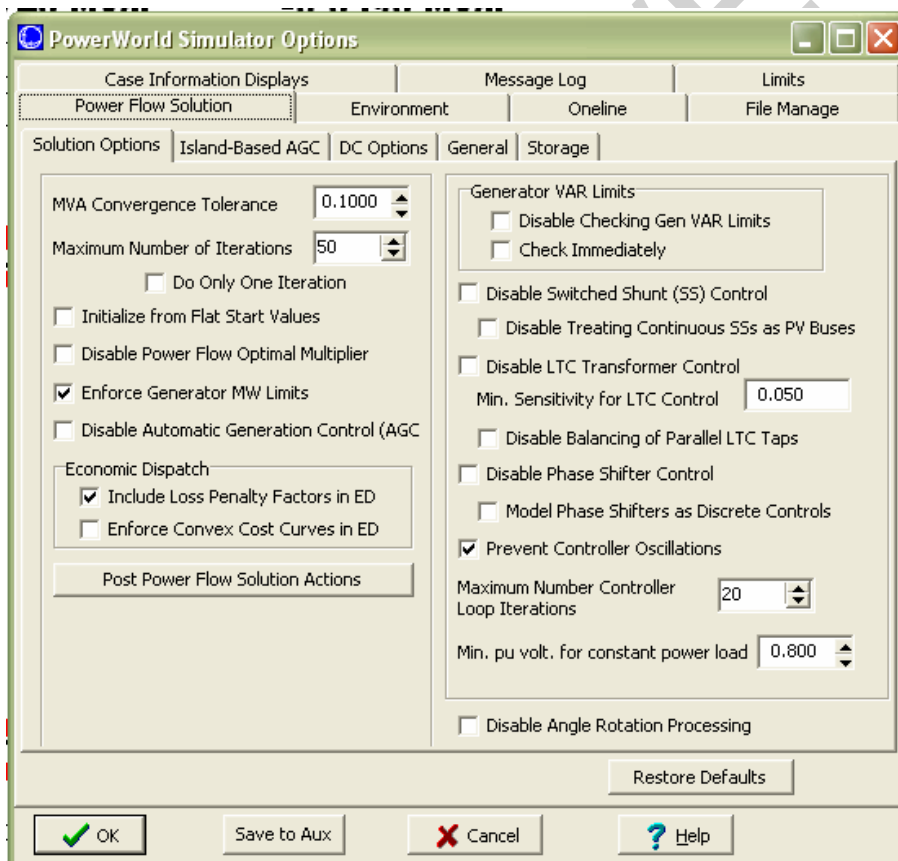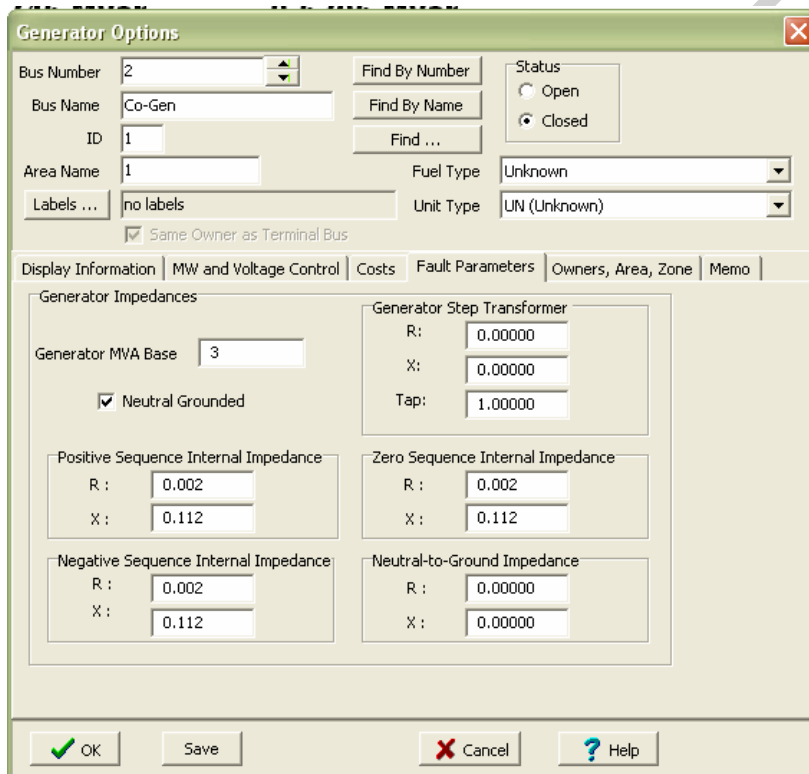
4.2 Fault Analysis

Fault analysis is also a commonly used tool for power system analysis. In PW Simulator, this tool can be activated by selecting 'Fault Analysis' from the 'Options/Tools' menu. Before running fault analysis, the fault parameters of all components need to be entered first.

Input Fault Parameters:

Fault parameters of power system components can be entered at the same time when the component records are created. Using a generator as an example, the following dialog box appears when the generator record is created. Click the button 'Fault Parameters', the parameters relating to fault analysis can be entered in the corresponding fields.

Run Fault Analysis:

When 'Fault Analysis' is activated, the following dialog box appears:
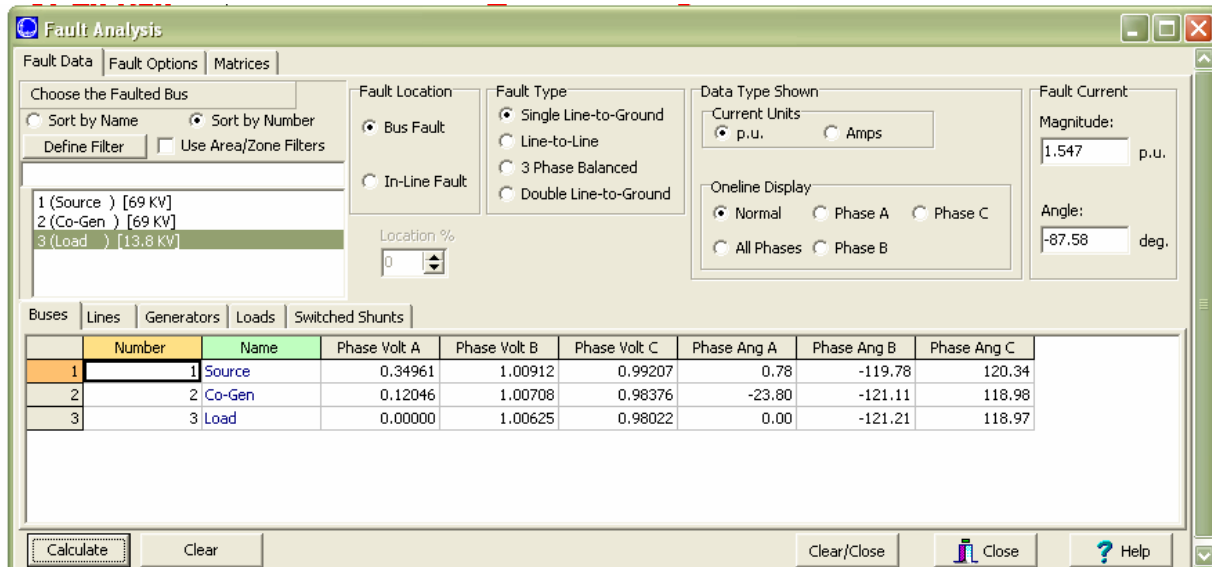
This box defines the faulted bus and the fault type. After entering these information, click the 'Calculate' button. The fault current is then displayed at the upper right corner and the detailed fault analysis results are shown in the bottom table.

4.3 Scale Case Tool

In some case studies, the load and/or generations of the power system need to be scaled (e.g. in voltage stability study). This can be carried out using the 'Scale Case' tool provided by PW Simulator. This tool will be further introduced in Lab 4 when voltage stability of a simple system is assessed.

This tutorial is only a brief introduction of the PowerWorld Simulator. You are encouraged to try and experience by yourself. Remember, you can always click the '? Help' button on each dialog page to get instructions on input and output.

Experiment No.: 10
Experiment Name : Load Flow Study Using PowerWorld Simulator

Objective

The objective of this experiment is to familiarize with the PowerWorld Simulator, which is an interactive power system simulation package. The simulator has a user-friendly graphical interface which facilitates the modeling of power systems in the oneline diagram form. Oneline diagrams are used in power system analysis to represent the actual three-phase power system using a single line to represent each three-phase device.

Procedure

We will create a simple power system model using PowerWorld Simulator. A simulation model is called a **Case**. To create a new case, select <u>**New Case**</u> from PowerWorld icon.

<u>**To insert a bus:**</u>

- Select **Network > Bus** from the **Individual Insert** group on the **Draw** tab. This prepares Simulator to insert a new bus.
- Left-click on the oneline background at the location where you want to place the new bus. This opens the **Bus Option** Dialog (below), which is used to specify various display properties, and the load and shunt compensation connected to the bus.
- The **Bus Number** field automatically displays '1'. Enter a suitable name to the **Bus Name** field, e.g. **One.**
- Next check the **System Slack Bus** field. Then, click OK to close the dialog box.
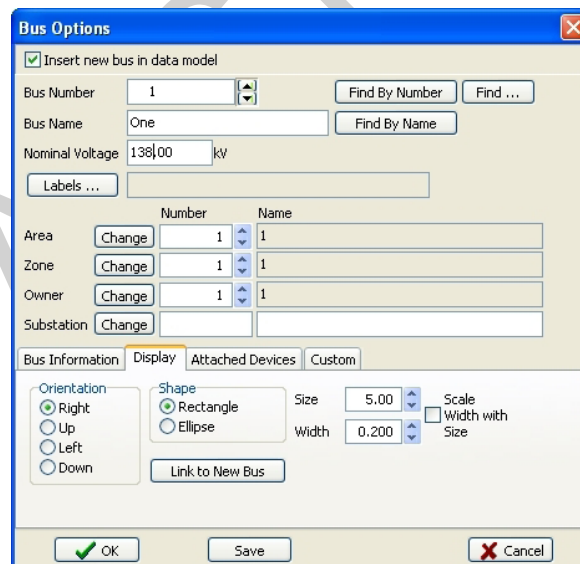
<u>**To connect a generator:**</u>

- Select **Network > Generator** from the **Individual Insert** group on the **Draw** tab.
- Left-click the bus on the oneline diagram to which you want to attach the generator (for this example, click on the slack bus – bus One.) The **Generator Option** Dialog

(below) will open. The dialog is used to specify the new generator's display properties and various power outputs.

- Click OK on the **Generator Option Dialog**. After the dialog box closes, the new generator will appear on the oneline attached to the previously selected bus.

To enter the second bus with load:

- Repeat the above procedure for entering the first bus. In the **Bus Options** Dialog (below) leave the bus number at the default value of **2**, and enter the name '**Two**' in the **Bus Name** field.
- Now we will connect a **200 MW**, **100 Mvar** load to this bus. Select the **Attached Devices** tab. Under the **Load Summary Information** heading enter '200' in the **Base MW** field and '100' in the **Base Mvar** field. Click OK to close the Bus Options Dialog and insert the bus.
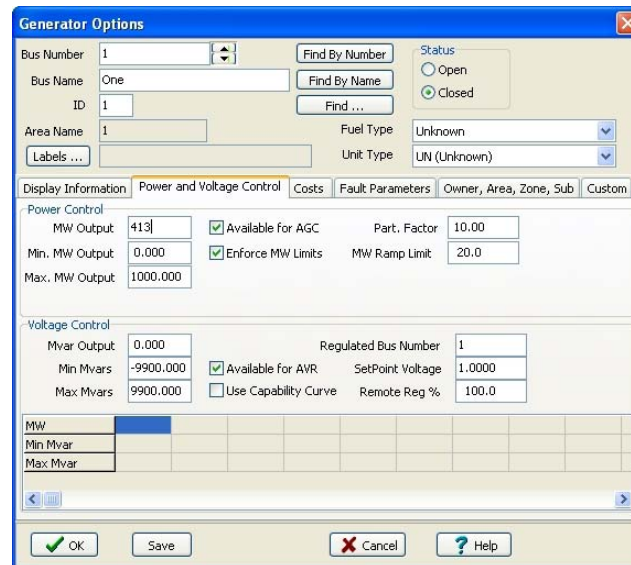- At this point the oneline diagram does not show the load at bus 2, even though it is represented in the power system model. To draw the load on the oneline diagram, select **Network > Load** from the **Individual Insert** group on the Draw tab.
- Left-click in the center of this bus. The **Load Options** Dialog box opens. The **Constant Power MW** and **Mvar** fields show that the load is 200 MW and 100 Mvar.
- Select **Up** in the **Orientation** field under the **Load Information** tab to make the load point upward. Verify that the **anchored** box is checked. This will force the load to move when the bus is moved.
- Click OK to close the Load Options dialog and insert the load. A circuit breaker symbol is automatically included with each load.

To insert a transmission line:

- Select **Network > Transmission Line** from the **Individual Insert** group on the **Draw** tab.
- Left-click at the point where you want the new line to originate. For this example, originate the line at bus **One**. Without holding down the mouse button, drag the mouse up. To terminate a line segment, click the left mouse button. Each time you click the mouse to terminate a line segment, a new vertex is defined for the line. To draw the next line segment, move the mouse to the desired location of the next vertex.

- To terminate the final line segment and conclude drawing the line, double click the left mouse button at the desired termination point (bus **Two** for this example).
- The **Transmission Line/Transformer Dialog** appears (below). The dialog should already contain a **1** in the **From Bus** Number field and a **2** in the **To Bus** Number Field.
- The **Series Resistance**, **Series Reactance**, and **Shunt Charging** fields are used to enter the per unit parameters of the line. The **Shunt Charging** field contains the total per unit charging capacitance for the line. Enter the values shown in the Dialog box.
- Click OK to close the Transmission Line/Transformer Dialog, and insert the new line.
- When the line is drawn it automatically has a **line flow pie chart** included. Additional line flow pie charts can be included by selecting **Pies/Gauges > Line Flow Pie Chart** from the Individual Insert group on the Draw tab, and then clicking near a line.

To insert a Transformer:

To insert a transformer we first need to insert a bus at a __different voltage level__. Insert a new bus in the bottom of the oneline, named **Three**, and enter **69 KV** for its nominal voltage in the **Bus Options** dialog box. To insert a transformer between buses 2 and 3:

- Either go to **Network > Transformer** from the **Individual Insert** group on the Draw tab. Click on bus 2, and then draw a line to bus 3 as you did for a transmission line. The **Transmission Line/Transformer Dialog** appears.
- On the **Parameters** tab, enter **0.02** for **Series Resistance**, **0.08** for **Series Reactance**, **0.1** for **Shunt Charging** and **1000** for **Limit A** (MVA).
- Select the **Transformer Control** tab. The **Off-nominal Turns Ratio** displays **1.000.** The true transformer turns ratio does not need to be specified as it is automatically determined by the ratio of nominal voltages between the **From Bus** and **To Bus**.
- Click OK to close the dialog and insert the transformer.
- Repeat this procedure to add a transformer between buses 1 and 3.

Add a Load and a Generator to bus 3:

- Repeat the procedures described above to add **400 MW, 200 Mvar** load, and a **300 MW** generator to bus 3.
- After these additions the oneline diagram should resemble the Figure-1.
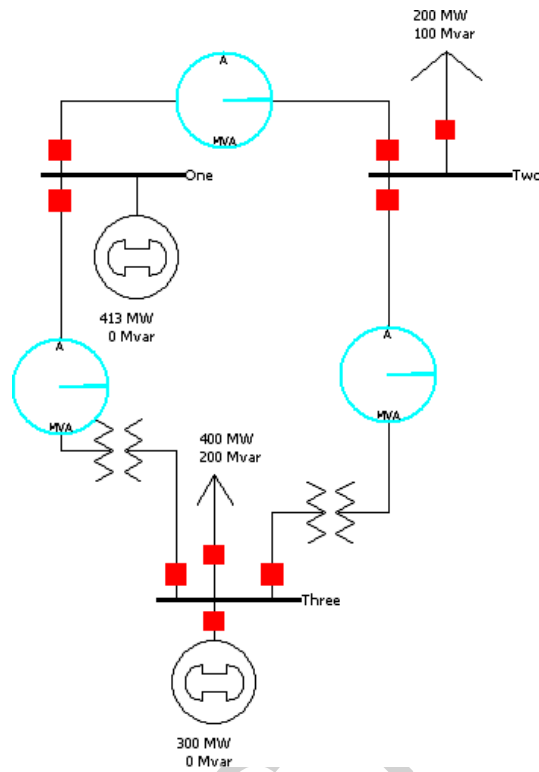
Figure-1

GENERATOR FEEDING A LOAD THROUGH A TRANSFORMER

Objective

The objective of this experiment is to simulate a simple power system, where a three-phase generator feeds a load through a three-phase transformer, using the PowerWorld Simulator.

Preliminary Work

The oneline diagram of the system is shown in Figure-2. The ratings of the components in the system are

Generator G: **120 MVA**, **20 kV**, synchronous impedance $Z_s = 0.1 + j\,0.2\ \Omega$ / phase Y.

Transformer T: **150 MVA, 20Δ / 138Y** kV, per phase winding resistance and leakage reactance of the high voltage side : $R = 2\ \Omega$, $X = 5\ \Omega$.

Load: **100 MW + j 40 Mvar** at **138 kV** (constant impedance load).
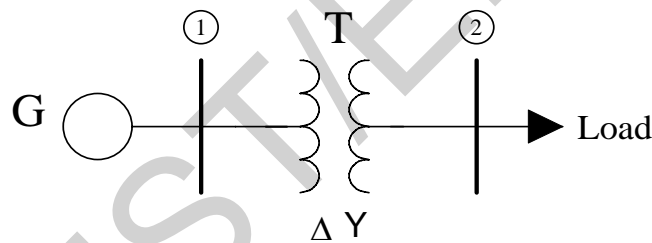
FIGURE -2

A system base of **150 MVA, 20 kV** is chosen on the low voltage side of the transformer.

   (a) Calculate the per unit impedances of all the components with respect to their own bases.
   (b) Calculate the per unit impedances of all the components with respect to the system base.
   (c) Keeping the voltage at **bus 1** at **1.0 pu**, calculate the following
       i.   The per unit load voltage.
       ii.   The real power in MW supplied to the load.
       iii. The reactive power in Mvar supplied to the load.
       iv.   The real power delivered by the generator at bus 1.
       v.   The reactive power delivered by the generator at bus 1.

Procedure

    (a) Draw the oneline diagram of the system in the PowerWorld Simulator, using the procedures described in Experiment 1. The system schematic should look like the one shown in Figure-3.

    (b) Enter all the per unit parameters of the devices calculated in the **Preliminary Work** using the appropriate dialog boxes.

    (c) Simulate the system using the Play icon under the Tools group.

    (d) From the solution given by the Simulator, note down all the variables that had been calculated in the Preliminary Work.
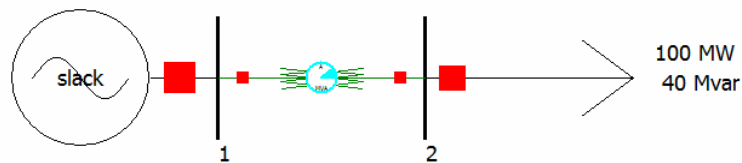
FIGURE -3

Results and Discussions

    (a) Compare the results from your calculation with those from the Simulator.

    (b) If the two results do not match, try to figure out how the discrepancy arises.

TRANSMİSSİON LİNE

Objective

The objective of this experiment is to simulate a simple power system, where a three-phase generator feeds a load through a transmission line and associated three-phase transformers, using the PowerWorld Simulator.

Preliminary Work

The oneline diagram of the system is shown in Figure-4. The ratings of the components in the system are

<u>Generator G</u>: **120 MVA**, **20 kV**, synchronous impedance $Z_s = 0.1 + j\,0.2\ \Omega$ / phase Y.

<u>Transformers</u>:
T1: 150 MVA, **20Δ / 138Y** kV, per phase winding resistance and leakage
    reactance of the high voltage side : $R = 2\ \Omega$, $X = 5\ \Omega$.
T2: 150 MVA, **138Y / 13.8 Y**kV, per phase winding resistance and leakage
    reactance of the high voltage side : $R = 1.8\ \Omega$, $X = 4\ \Omega$.
<u>Transmission line:</u>
$z = 0.04 + j\,0.1\ \Omega/\text{km}$, $y = j\,4\times10^{-6}\ \text{S/km}$, **length = 100 km**.

<u>Load</u>:   **100 MW** + j **40 Mvar** at **13.8 kV** (constant impedance load).
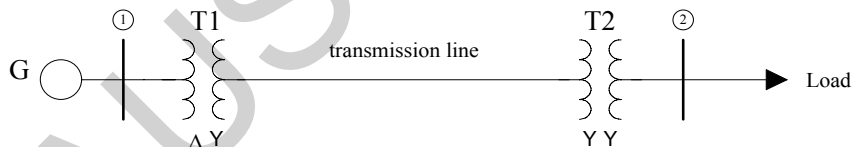
FIGURE-4

A system base of 1**00 MVA, 20 kV** is chosen on the low voltage side of transformer T1.

(a) Calculate the per unit impedances of all the components with respect to the their own bases.
(b) Calculate the per unit impedances of all the components with respect to the system base.
(c) Keeping the voltage at **bus 1** at **1.0 pu**, calculate the following
    i.   The voltages at the sending and receiving ends of the transmission line.
    ii.   The real and reactive power flow at the sending end of the transmission line.

iii. The real and reactive power flow at the receiving end of the transmission line.
iv. The real and reactive power supplied to the load.
v. The load voltage in per-unit and kV.

Procedure

(a) Draw the oneline diagram of the system in the PowerWorld Simulator, using the procedures described in Experiment 9 The system schematic should look like the one shown in Figure-5

(b) Enter all the per unit parameters of the devices calculated in the **Preliminary Work** using the appropriate dialog boxes.

(c) Simulate the system using the Play icon under the Tools group.

(d) From the solution given by the Simulator, note down all the variables that had been calculated in the Preliminary Work.

FIGURE -5

Results and Discussions

(a) Compare the results from your calculations with those from the Simulator.
(b) If the two results do not match, try to figure out how the discrepancy arises.
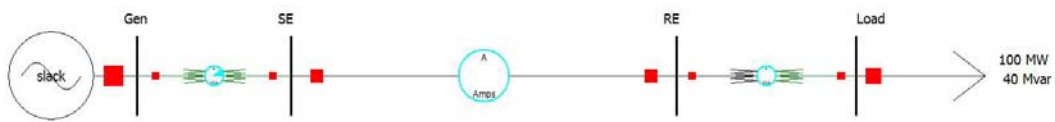
POWER FLOW 1

Objective

The objective of this experiment is to solve the power flow problem for a simple power system, which is the system in Figure 5, using the PowerWorld Simulator.

Preliminary Work

The oneline diagram of the system is shown in Figure-6. Bus 1 is the slack bus and bus 4 is the load bus. The ratings of the components in the system are

<u>Generator G</u>: **120 MVA**, **20 kV**, synchronous impedance $Z_s = 0.2 + j\, 1.2\ \Omega$ / phase Y.

<u>Transformers</u>:

T1: 150 MVA, **20Δ / 138Y** kV, per phase winding resistance and leakage
reactance of the high voltage side : **R = 2 Ω**, **X = 5 Ω.**

T2: 150 MVA, **138Y / 13.8 Y**kV, per phase winding resistance and leakage
reactance of the high voltage side : **R = 1.8 Ω**, **X = 4 Ω.**

<u>Transmission line:</u>

$z = 0.04 + j\, 0.1\ \Omega/km$, $y = j\, 4 \times 10^{-6}\ S/km$, **length = 100 km**.

<u>Load</u>:   **100 MW + j 40 Mvar** (<u>constant power load</u>).

FIGURE -6

A system base of **100 MVA, 20 kV** is chosen on the low voltage side of transformer T1. Use the nominal-π circuit model for the transmission line. Solve the power flow problem for this system and find the following for these cases: ***starting from 20% of the nominal value given above, load power is increased in steps of 20% up to the nominal value.***

1) The load (bus 4) voltage.
2) The transmission line currents at the sending and receiving ends.
3) The real and reactive power supplied by the generator at bus 1.

NOTE that the presence of transmission line shunt admittances complicates the problem. You may adopt one of the following two approaches:

Method 1:

  (a) Find the Thevenin equivalent of the system to the left of bus 4, thus eliminating buses 2 and 3.

(b) Write the Newton-Raphson equations for the unknown voltage of bus 4 in terms of the Thevenin voltage and impedance.

Method 2:

(a) Accept buses 2 and 3 as load buses with zero loads.
(b) Write the Newton-Raphson equations for the unknown voltages of buses 2,3 and 4 using $\mathbf{Y_{bus}}$ four the 4-bus system.

Procedure

(a) Use the oneline diagram of the system you have drawn for Figure 5.
(b) Change the type of the load from "**constant impedance**" to "**constant power**". For this, you enter zeros for load power values under "constant impedance" and enter the desired values under "constant power".
(c) Simulate the system using the Play icon under the Tools group.
(d) From the solution given by the Simulator, note down all the variables that had been calculated in the Preliminary Work.
(e) Compare the results from your calculation and those from the Simulator. If the two results do not match, try to figure out how the discrepancy arises. Then make the necessary corrections to your simulation model and repeat the procedure.
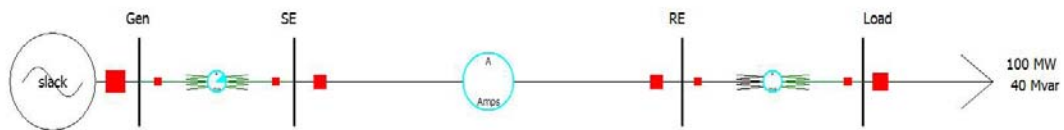
FIGURE -7

Results and Discussions

(a) Tabulate the results from the simulation, showing all values versus load, as in Table -1.
(b) Discuss what happens as the load is increased from 20% to 100%.

TABLE -1

Load (%)	Load voltage (pu)	Transmission line currents		Slack bus power	
		Sending end(A)	Receiving end(A)	P(MW)	Q(Mvar)
20					
40					
60					
80					
100					

POWER FLOW 2

Objective

The objective of this experiment is to analyze the power flow in a given power system using the PowerWorld Simulator. Power flow solutions will be obtained using the **Gauss-Seidel** and the **Newton-Raphson** methods, and the progress of the solutions through the iterations will be observed.

Preliminary Work

The oneline diagram of the system is shown in Figure-8. The data for the components in the system are given in per unit in Tables-2,3 and 4. The base values are **S_{base}=100 MVA**, **V_{base}=15 kV** at bus 1. The ratings of the devices are:

Generator G1:   400 MVA, 15 kV
Generator G2:   800 MVA, 15 kV
Transformer T1:   400 MVA, 15 Δ / 345 Y kV
Transformer T2:   800 MVA, 345 Y / 15 Δ kV
Lengths of transmission lines: L1=200 mi, L2=100 mi, L3=50 mi.
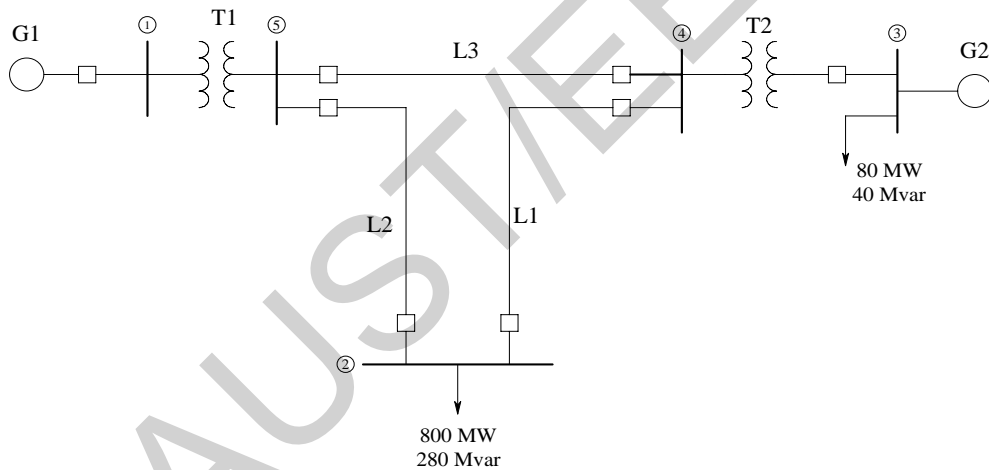
FIGURE -8

TABLE -2 Bus input data

Bus	Type	V p.u	δ degrees	P_G p.u.	Q_G p.u.	P_L p.u.	Q_L p.u.	Q_{Gmax} p.u.	Q_{Gmin} p.u.
1	Swing	1.0	0	-	-	0	0	-	-
2	Load	-	-	0	0	8.0	2.8	-	-
3	Voltage-controlled	1.05	-	5.2	-	0.8	0.4	4.0	-2.4
4	Load	-	-	0	0	0	0	0	-
5	Load	-	-	0	0	0	0	0	-

TABLE -3 Line input data

Bus-to-bus	R p.u.	X p.u.	G p.u.	B p.u.	Maximum MVA p.u.
2-4	0.009	0.1	0	1.72	12.0
2-5	0.0045	0.050	0	0.88	12.0
4-5	0.00225	0.025	0	0.44	12.0

TABLE -4 Transformer input data

Bus-to-bus	R p.u.	X p.u.	G_c p.u.	B_m p.u.	Maximum MVA p.u.
1-5	0.0015	0.02	0	1.72	6.0
2-5	0.00075	0.01	0	0.88	10.0

(a) Calculate $\mathbf{Y_{bus}}$ for the system using the data in the tables.

(b) Using the initial values given in Table 2, perform one **Gauss-Seidel** iteration for bus 2 and 3 voltages $V_2(1)$ and $V_3(1)$. Note that bus 3 is a voltage-controlled bus. Therefore, correction must be applied to the magnitude of $V_3(1)$ to force it to have the specified value ($|V_3| = 1.05$).

(c) In the **Newton-Raphson** method, calculate the initial power mismatches at all the buses 2-5. Also, calculate the Jacobian matrix elements of the partition $\mathbf{J_{11}}$. (NOTE: a power mismatch at a bus "k" is defined as $\Delta P_k(n) = P_{k,sch} - P_{k,calc}(n)$, where $P_{k,sch}$ is the scheduled real power and $P_{k,calc}(n)$ is the power calculated from the power flow equation after iteration n.

Procedure

(a) Draw the oneline diagram of the system in the PowerWorld Simulator, using the procedures described in the introduction section. The system schematic should look like the one in Figure-9.

(b) Enter all the per unit parameters of the devices given in the tables, using the appropriate dialog boxes.

(c) Under the "**Tools"** group, open the "**Simulator Options"** dialog. Under "**Power Flow Solution"** check the "**Do Only One Iteration**" box. Then, in the "**Run Mode"** open the **"Solve"** menu and choose "**Gauss-Seidel Power Flow**". The Simulator will perform one Gauss-Seidel iteration.

(d) Note down all bus voltages (magnitude and phase) and power mismatches at the end of the first iteration. For power mismatches, go to **Case Information → Network →Power Mismatches**.

(e) Proceed in single-steps through the solution by repeatedly selecting "**Gauss-Seidel Power Flow**". Perform 10 iterations and repeat step (d) at the end of each iteration. Arrange your results in the form of a table (Table A).

(f) Now, in your oneline diagram reset all voltages and power values to their initial values (In Edit Mode). Then, in the "**Run Mode"** open the **"Solve"** menu and choose "**Polar NR Power Flow**". The Simulator will perform one Newton-Raphson iteration.

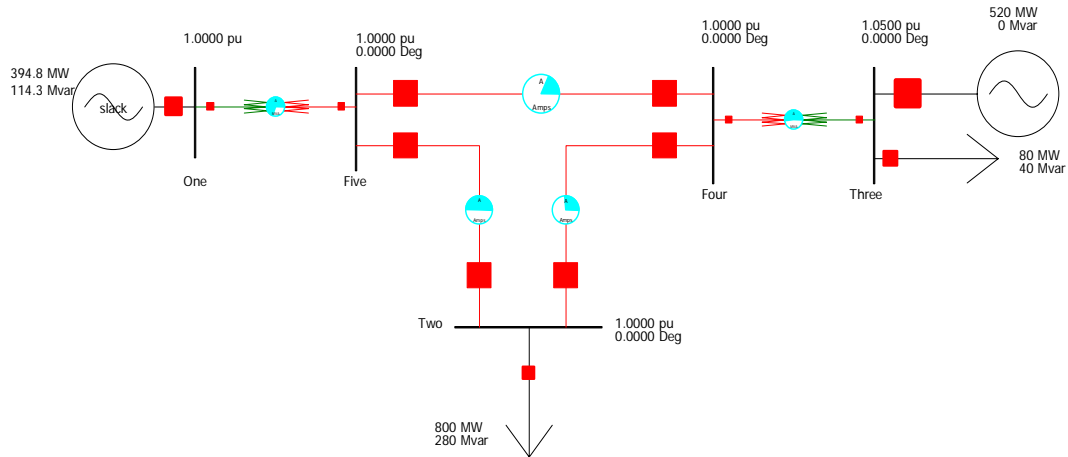(g) Repeat steps (d) and (e) for 5 iterations. Arrange your results in the form of a table (Table B).

FIGURE -9

Results and Discussions

(a) Compare the results from your calculations in the Preliminary Work and those from the Simulator.

(b) If the two results do not match, try to figure out how the discrepancy arises.

(c) Plot the power mismatches at all buses versus iteration number *n*, for both of the methods. Compare the convergence rates of the two power flow solution methods.

DESIGN PROJECT: POWER FLOW

Objective

The objective of this experiment is to analyze the power flow in a given power system using the PowerWorld Simulator, and design a different operating strategy to change certain system variables

Preliminary Work

The oneline diagram of the system is shown in Figure-9. The ratings of the components in the system are

Generator Ratings:
G1: 100 MVA, 13.8 kV, x = 0.12 pu.
G2: 200 MVA, 15 kV, x = 0.12 pu.

Transformer Ratings:
T1: 100 MVA, 13.8 kV Δ / 230 kV Y, X = 0.1 pu.
T2: 200 MVA, 15 kV Δ / 230 kV Y, X = 0.1 pu.

Transmission Lines:
All lines 230 kV, z = 0.08 +j 0.5 Ω/km, y = j 3.4×10^{-6} S/km
Maximum MVA = 400 MVA
Line lengths: L1 = 15 km, L2 = 25 km, L3 = 40 km, L4 = 15 km, L5 = 50 km,

Power Flow Data:
Bus 1: Swing bus, V_1 = 13.8 kV , $\delta_1 = 0°$.
Bus 2,3,4,5,6: Load buses.
Bus 7: Generator bus, $|V_7| = 15$ kV , P_{G7} = 180 MW, -87 Mvar < Q_{G7} < + 87 Mvar.

System base quantities:
S_{base} = 100 MVA
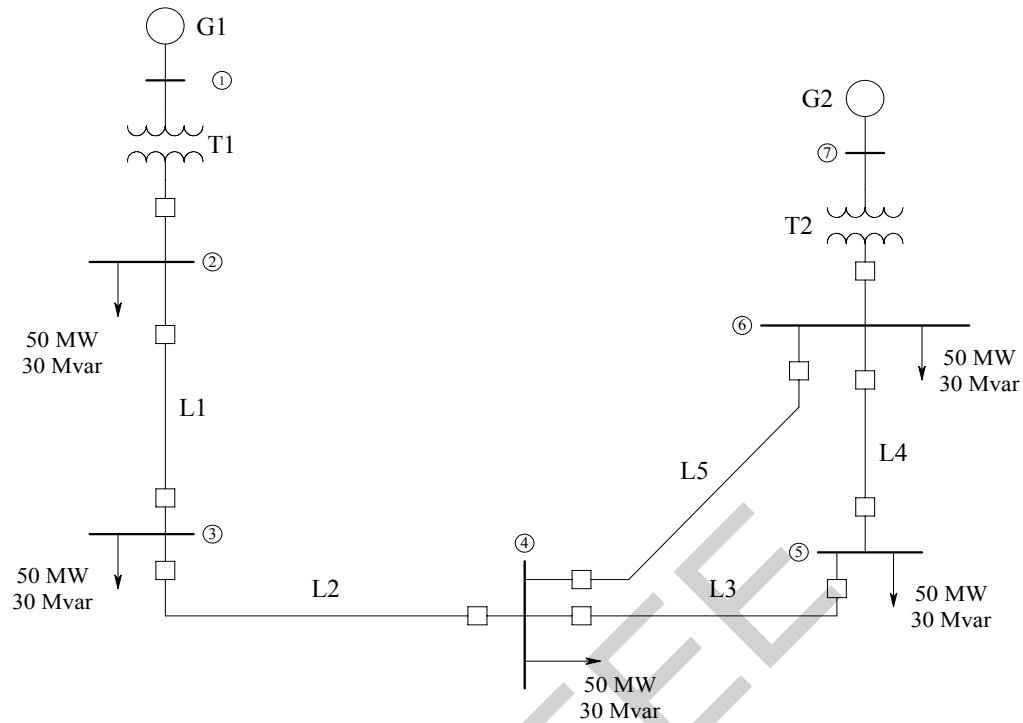V_{base} = 13.8 kV in the zone of G1.

FIGURE -9

(a) Convert all impedances, load and voltage data to per unit using the system base values.
(b) Prepare the following input data files for this system similar to the ones in Experiment 5: Bus input data, Line input data, Transformer input data.

Procedure

(a) Draw the oneline diagram of the system in the PowerWorld Simulator and verify that the input data files you prepared are the same as those given by the Simulator.
(b) Run the Simulator and obtain the voltages at all the buses.
(c) Suggest a method for increasing the voltage magnitude at bus 4 by 5%. Demostrate the effectiveness of your method by making appropriate changes to your model and solving the power flow problem. You may consider applying one or more of the following: generator excitation control, tap changing and regulating transformers, static capacitors, static var systems, and parallel transmission lines.

Results and Discussions

Discuss the effectiveness of your solution with respect to the achievement of the target and the cost of implementation.