Shri Ramdeobaba College of Engineering and Management, Nagpur

Shri Ramdeobaba College of Engineering and Management, Nagpur (MS)

(An Autonomous Institution Permanently affiliated to Rashtrasant Tukadoji Maharaj Nagpur University)
An ISO 9001:2015 Certified Institution. NAAC Certified 'A' Grade

Department of Electrical Engineering Laboratory Manual

Power Systems II Laboratory

EEP 371

(VI Semester Electrical)

Index

Vision

Department of Electrical Engineering endeavours to be one of the best departments in India having expertise to mould the students to cater the needs of society in the field of technology, leadership, administration, ethical and social.

Mission

To provide dynamic and scholarly environment for students to achieve excellence in core electrical and multidisciplinary fields by synergetic efforts of all stake holders of the Electrical Engineering Department and inculcate the ethical and social values.

Programme Educational Objectives (PEOs)

PEO 1. Our graduates will be able to plan, design, operate and practice in electrical and energy systems.
PEO 2. Our graduates will be able to work in multidisciplinary environments including IT applications and adapt themselves as per the emerging technological needs of Industry.
PEO 3. Our graduates will be able to progress in their career by demonstrating in practice the technical and communication skills effectively with understanding of ethical and social values

Program Outcomes and Program Specific Outcomes (UG)

Our electrical engineering graduates will be able to:

PO1. **Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals to the solution of engineering problems.
PO2. **Problem analysis**: Identify, formulate, review literature, and analyze complex engineering problems using first principles of mathematics, natural sciences, and engineering sciences.
PO3. **Design/development of solutions**: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public safety, societal and environmental considerations.
PO4. **Conduct problem investigations**: Use research-based knowledge including experimentation, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
PO5. **Modern tool usage**: Select, and apply appropriate techniques, resources, and modern engineering and IT tools for analyzing the engineering activities with an understanding of the limitations.
PO6. **The engineer, industry and society**: Apply contextual knowledge to assess industrial, societal and safety related issues and understand consequent relevance to the professional engineering practice.
PO7. **Environment and sustainability**: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
PO8. **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

PO9. **Individual and team work**: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
PO10. **Communication**: Communicate effectively on complex engineering activities such as, being able to understand and write effective reports, make effective presentations, and give and receive clear instructions.
PO11. **Project management and finance**: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team in multidisciplinary environments.
PO12. **Life-long learning**: 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.

Program Specific Outcomes

PSO 1. Analyse, design and develop electrical engineering systems considering green energy aspects in emerging applications like electric vehicles, renewable energy etc.
PSO 2. Apply the knowledge of modern IT tools to Electrical Engineering applications.

Course Objectives

The objective of the course is to:

1. Make students familiar with concepts and analysis of power systems
2. Make students familiar with prototype model of power system
3. Make students able for understanding, analyzing performance of power system
4. Make students able to understand and correlate the theory with experiments based on power system.

Course Outcomes

Upon successful completion of the course, the student shall be able to

1. Apply and analyze fundamental principles of power system Engineering with laboratory experimental work and programming work
2. Understand and perform the experiment, Analyze the observed data & make valid conclusion
3. Write Journal with effective presentation of diagrams and characteristics
4. Use the modern software like MATLAB for plotting and analyzing power system

Mapping of CO with PO and PSO

Course Outcome	PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	PO 8	PO 9	PO10	PO11	PO12	PSO 1	PSO 2
1	3	3											3	2
2	3	3											3	2
3	3	3											3	2
4	3	3											3	2

Rubrics for laboratory work evaluation and evaluation Scheme

Parameter=>	**Attendance and Performance**		**Journal Writing**		**Viva-Voce**	
COs Addressed	1,2,4		2,3		1,2	
Total Marks	10		10		5	
Marks Distribution (Sub-Parameters)	Present	2	Clarity of Aim	2	Understanding of Aim	1
	Proper simulation	2	Clarity of Circuit dig.and simulation diagram	2	Understanding of Theory Behind the Experiment and simulation	2
	Understanding of Experiment Performance	4	Clear Understanding of Calculations and simulation results	2	Understanding of practical Applications	2
	Correct Observations	2	Validity of Result	2		
			Conclusion	2		

Laboratory experiment index

1. Study of transmission Line Model
2. To study methods for load flow analysis.
3. Study of PSAT software for MATLAB
4. To simulate transmission line model and perform load flow analysis using PSAT
5. To simulate six bus system and perform load flow analysis using PSAT
6. To study Ferranti effect on long transmission line using PSAT
7. To study dynamic response of change in frequency of isolated single area system
8. Three phase fault analysis using Power World Simulator

Laboratory experiment details

All the experiments are to be performed on Simulation Softwares like MATLAB,PSAT and Power World Simulator

Experiment 1

Study of Transmission Line Model

The transmission line model used in the project is High Voltage Transmission Line Analyser

(VPST-100HV1). This model comprises of five sections, which are: -

a. Generating Station
b. Transmission Line Model c. Receiving Station
d. Compensator Section e. RLC Loading Section

a. Generating Station

The Generating Station is shown with a generator model from which the line is fed, the sending end is provided with a step up transformer from which different ranges of voltage ranging from 110/220V can be obtained. Figure 1 shows the generating station and dimmerstat attached with the generating station.

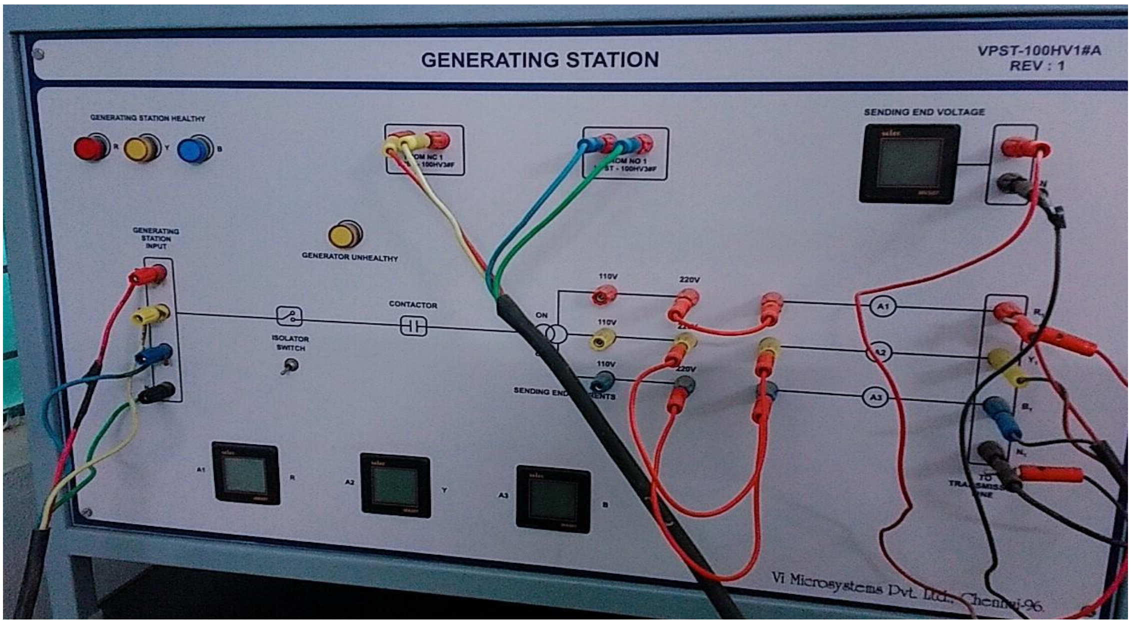


Figure 1 A. Generating Station

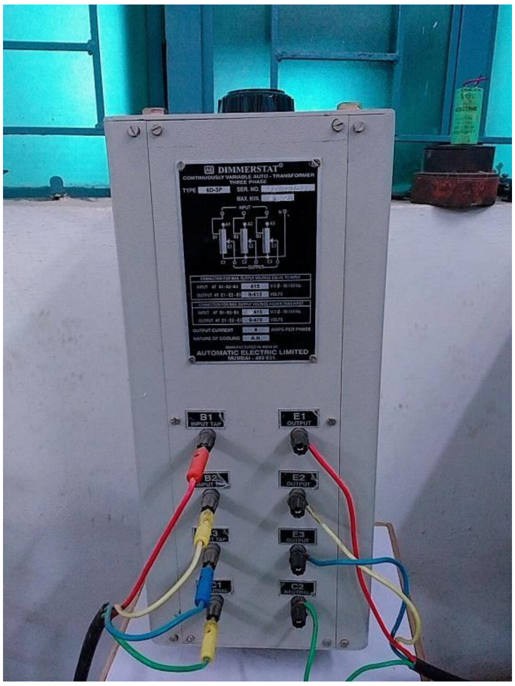


Figure 1 B. Dimmerstat attached generating station

b Transmission Line Model

The transmission line is considered for length of 180 km. The line may be used as 180 km, 3ϕ line or 540 km, 1ϕ line. The line inductance is taken for every 30 km and capacitance for every 15 km. The actual value of line parameters of 220 KV transmission line are 0.03333Ω/km,1.06mH/km and 7.33nF/km. Figure 2 shows the arrangement of transmission line model.

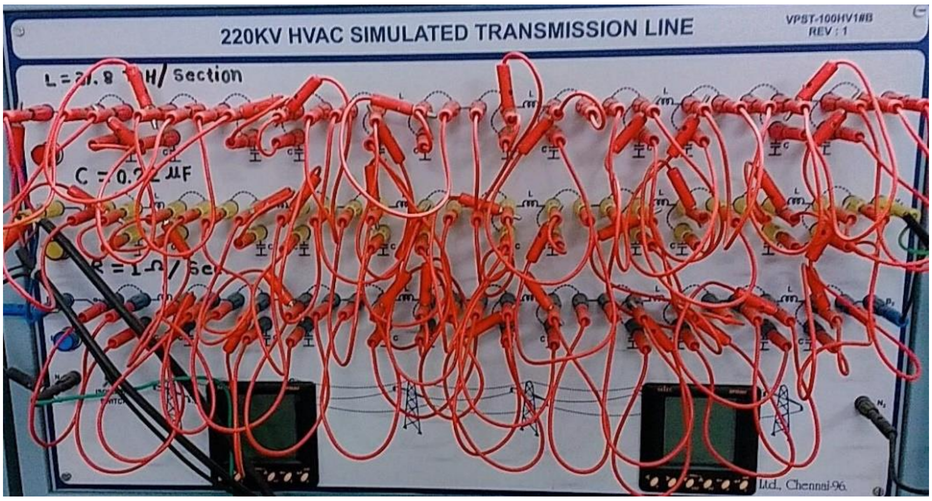


Figure 2 Transmission Line Model

c. Receiving Station

The receiving station is provided with a step down transformer from which different ranges of voltage ranging from 110/220V can be obtained. Figure 3 shows the Receiving Station.

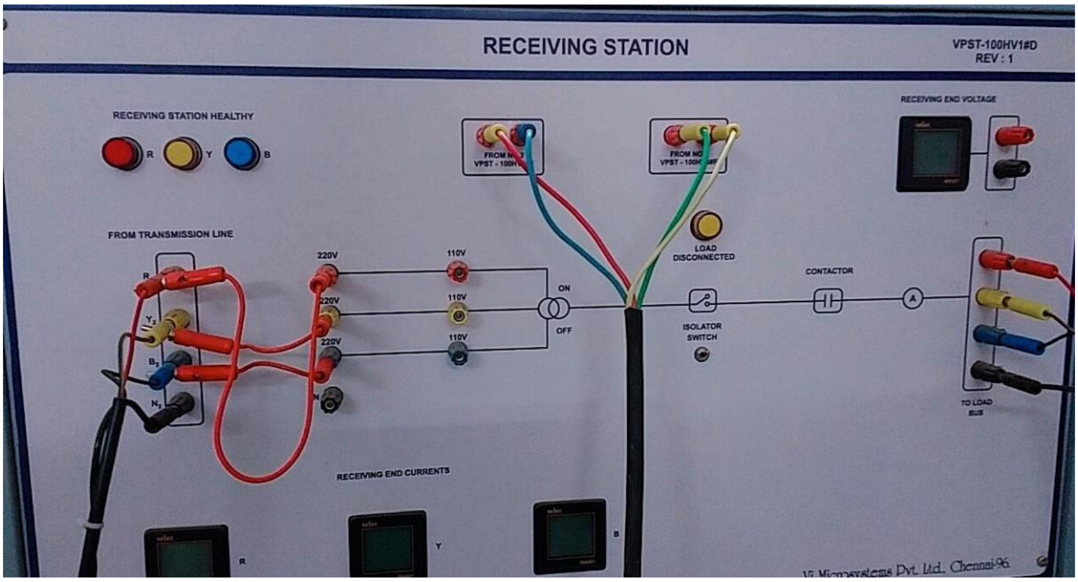


Figure 3 Receiving Station

d. Compensator Section

It consists of shunt capacitors for voltage control and series reactor to reduce the fault current during fault conditions.

- Shunt capacitor: 3 ϕ delta connected shunt capacitor of 1 KVAR – 4 numbers are available as independent units.
- Shunt reactor: A 3 numbers of 0 to 1700mH variable inductance available for compensation under no load condition.
- Series reactor: Series reactor with inductance 0mH to 120mH available in all the three phases for series compensation.

e. RLC Loading Section

The loading section is provided with resistive load, Inductive load. The loading section is also provided with an ammeter to measure the load current and a voltmeter to measure the load end voltage. Figure 4 shows the Compensator section and RLC loading section

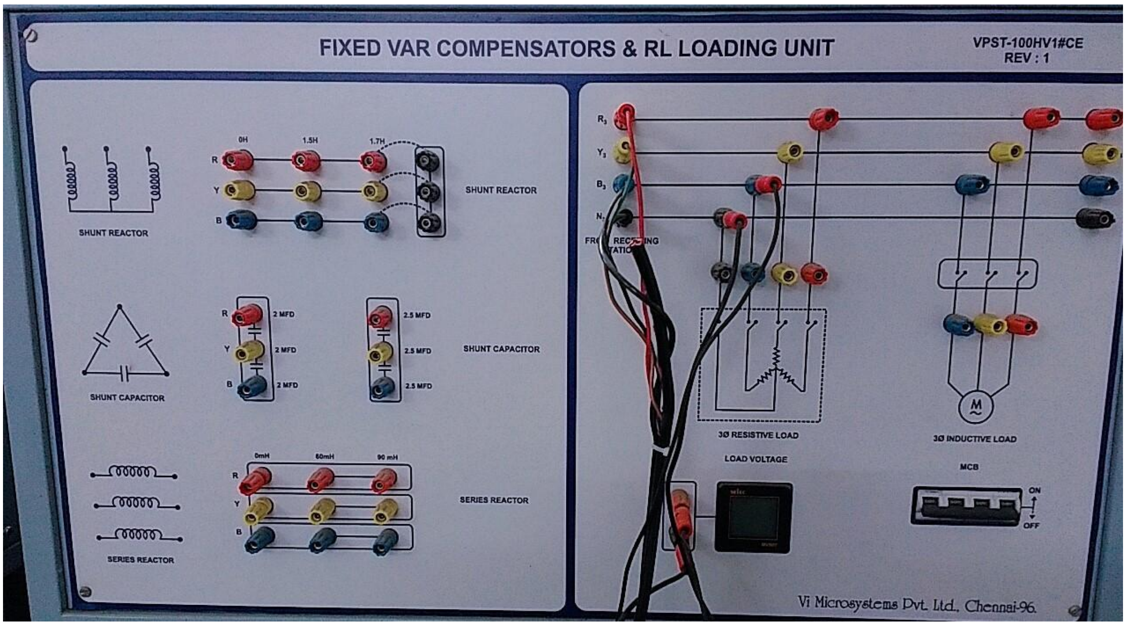


Figure 4 Compensator and RLC Loading Section

Experimentation work

The experiments can be conducted by connecting loads at different locations. The currents in various sections of transmission line, voltages on each bus, total powers consumed by the load can be obtained.

1. Resistive Load at the end
2. Induction Motor Load at the end
3. Resistive and Induction Motor Load at the end
4. Simultaneous Loading at the end with intermediate induction motor load

Experiment 2
Study of Load Flow Methods

What is “Load Flow”?

- Load flow is the steady state solution of the power system network.
- The main information obtained from the load flow study comprises of

  -The magnitudes and phase angles of bus voltages.

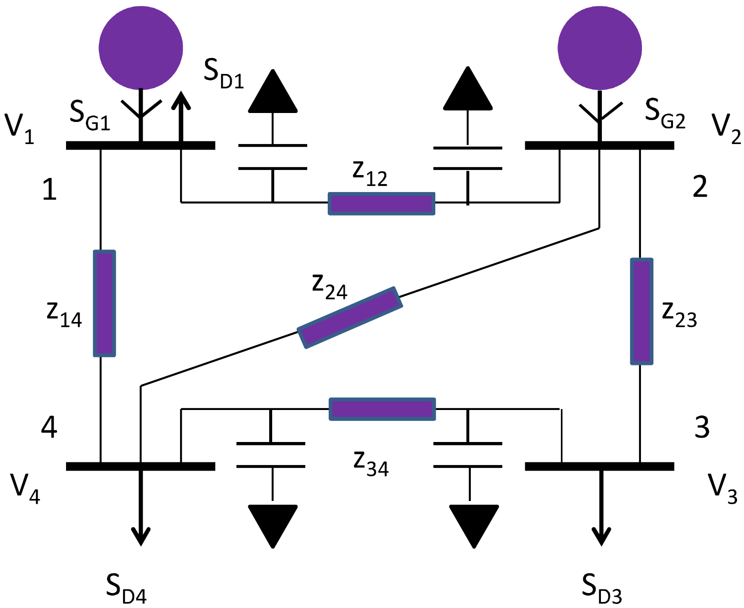
  -Power flows in transmission lines.

Need of Load Flow?

- Operation and control.
- planning.
- stability analysis.
- fault analysis.
- Security analysis.
  - System monitoring
  - Contingency analysis
  - System state classification

Bus Admittance Matrix

Consider a simple power system network



Complex power generated at i^{th} bus

$$S_{Gi}= P_{Gi}+jQ_{Gi}$$

Complex power demand at i^{th} bus

$$S_{Di}= P_{Di}+jQ_{Di}$$

Complex power injected into i^{th} bus

$$S_i= S_{Gi}-S_{Di}$$

Current injected into i^{th} bus

$$I_i= I_{Gi}-I_{Di}$$

V_i - Bus voltage

y_{i0}- self admittance of bus-i

$$I_1 = y_{10}V_1 + y_{12}[V_1 - V_2] + y_{14}[V_1 - V_4]$$

$$I_2 = y_{21}[V_2 - V_1] + y_{20}V_2 + y_{23}[V_2 - V_3] + y_{24}[V_2 - V_4]$$

$$I_3 = y_{32}[V_3 - V_2] + y_{30}V_3 + y_{34}[V_3 - V_4]$$

$$I_4 = y_{41}[V_4 - V_1] + y_{42}[V_4 - V_2] + y_{43}[V_4 - V_3] + y_{40}V_4$$

$$\Rightarrow \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} = \begin{bmatrix} y_{10}+y_{12}+y_{14} & -y_{12} & 0 & -y_{14} \\ -y_{21} & y_{20}+y_{21}+y_{23}+y_{24} & -y_{23} & -y_{24} \\ 0 & -y_{32} & y_{30}+y_{32}+y_{34} & -y_{34} \\ -y_{41} & -y_{42} & -y_{43} & y_{40}+y_{41}+y_{42}+y_{43} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix}$$

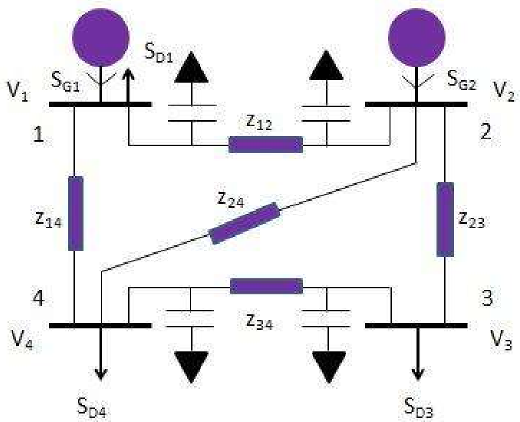
$$\Rightarrow \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} & Y_{14} \\ Y_{21} & Y_{22} & Y_{23} & Y_{24} \\ Y_{31} & Y_{32} & Y_{33} & Y_{34} \\ Y_{41} & Y_{42} & Y_{43} & Y_{44} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix}$$

$$I_{bus} = Y_{bus}V_{bus}$$

$$I_1 = Y_{11}V_1 + Y_{12}V_2 + Y_{13}V_3 + Y_{14}V_4$$

So we can write , $I_i = \sum_{k=1}^{n} Y_{ik}V_k$,

for i=1,2........n



Bus Admittance Matrix by Inspection

- Diagonal entries,

  $Y_{bus}(i,i)$ = Sum of the admittances of all components connected to node i.

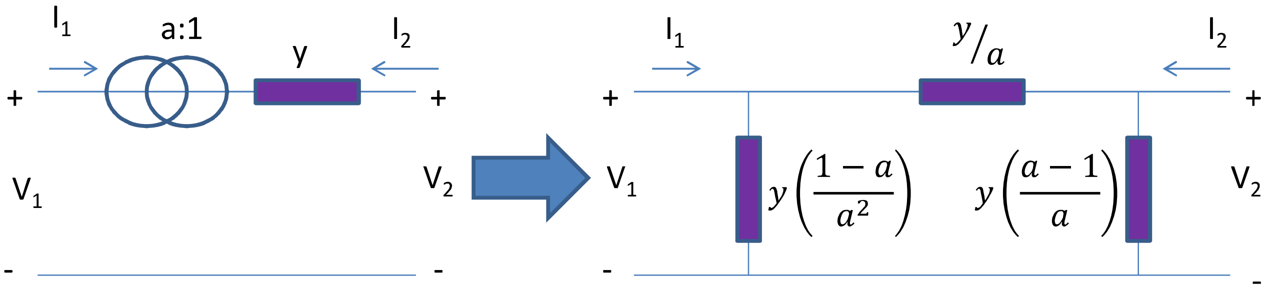
- Off-diagonal entries,

  $Y_{bus}(i,j)$ = Negative of sum of the admittance of all components connected between node i and j.

Is this method always applicable?

Effect of Tap changing Transformers

Let us consider a Tap-changing transformer with turns ratio ‘1/a’ whose admittance is ‘y’.



$$\begin{pmatrix} I_1 \\ I_2 \end{pmatrix} = \begin{pmatrix} y/|a|^2 & -y/a \\ -y/a & y \end{pmatrix} \begin{pmatrix} V_1 \\ V_2 \end{pmatrix}$$

What will happen if there is a Phase Shifting Transformer?

Inputs and outputs of load flow

- Inputs: real & reactive powers injected into the bus and network parameters
- Outputs: magnitude and phase angles of bus voltages

θ → real power
|V|→ reactive power

Power/load flow equations

Complex power at i[th] bus is given by

$$S_i = P_i + jQ_i = V_i I_i^*$$

$$= V_i \sum_{k=1}^{n} (Y_{ik} V_k)^*$$

for i= 1,2,..............n.

Note: here 'θ' is considered as bus voltage phase angle

let

$$V_i = |V_i| \angle \theta_i, V_k = |V_k| \angle \theta_k \ \& \ Y_{ik} = G_{ik} + jB_{ik}$$

$$P_i = \sum_{k=1}^{n} |V_i||V_k| (G_{ik} \cos \theta_{ik} + B_{ik} \sin \theta_{ik}) \longrightarrow \quad (1)$$

$$Q_i = \sum_{k=1}^{n} |V_i||V_k| (G_{ik} \sin \theta_{ik} - B_{ik} \cos \theta_{ik}) \longrightarrow \quad (2)$$

Are these equations linear?

- As these equations are non-linear we have to use iterative methods to solve them.
- For an n-bus system, there will be '2n' equations with '4n' unknowns (P_i,Q_i,$|V_i|$,θ_i at each bus).

How to solve these equations?

Is the solution unique?

Types of buses

1) Generator bus/voltage controlled bus
2) Load bus
3) Slack bus

among 4 variables (P, Q, |V| & θ) two will be specified and the remaining will be unspecified

Type of bus	Specified variables	Unspecified variables
Generator bus	P & |V|	Q & θ
Load bus	P & Q	|V| & θ
Slack bus	|V| & θ	P & Q

Need of slack bus

- Consider we are having ‘n’ buses ranging from 1 to n.
- If suppose all the given buses are load/generator buses, ‘P_i’ will be specified in both the cases, so “$P_L = \sum_{i=1}^{n} P_i = \sum_{i=1}^{n} P_{Gi} - \sum_{i=1}^{n} P_{Di}$” is known.
- The term P_L in the above equation is evidently the total I^2R loss in the transmission lines and transformers of the network.
- But the individual currents in the various transmission lines of the network cannot be calculated until after the voltage magnitude and angle are known at every bus of the system.

- There fore, P_L is initially unknown and it is not possible to prespecify all the quantities in the summations of the above eqn.
- In the formulation of the power flow problem we choose one bus ,as slack bus, at which P_i is not scheduled.
- After the power flow problem has been solved, the difference(slack) between the total specified ‘P’ going into the system at all the other buses and the total output power plus I^2R losses are assigned to the slack bus.
- For this reason a generator bus must be selected as the slack bus.
- The voltage angle of the slack bus serves as reference for the angles of all other bus voltages

Application of Gauss-Seidel method to Load Flow problem

As we know,

$$S_i^* = P_i - jQ_i = V_i^* I_i$$

$$\Longrightarrow \quad I_i = \frac{P_i - jQ_i}{V_i^*} \longrightarrow (3)$$

Also we know current injected into bus i,

$$I_i = \sum_{k=1}^{n} Y_{ik} V_k \longrightarrow (4)$$

From eqns. (3) & (4)

$$\frac{P_i - jQ_i}{V_i^*} = \sum_{k=1}^{n} Y_{ik} V_k$$

$$\Longrightarrow \quad \frac{P_i - jQ_i}{V_i^*} = Y_{ii} V_i + \sum_{\substack{k=1 \\ \neq i}}^{n} Y_{ik} V_k$$

$$\Longrightarrow \quad Y_{ii}V_i = \frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{k=1 \\ \neq i}}^{n} Y_{ik}V_k$$

$$\Longrightarrow \quad V_i = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{k=1 \\ \neq i}}^{n} Y_{ik}V_k\right] \longrightarrow \quad (5)$$

for all i=1,2........n.

eqn. (5) is non-linear because it contains 'v_i^*' term in denominator of the RHS term. In order to linearize eqn.(5) take 'v_i^*' from the previous iteration.

for pth iteration,

$$(V_i)^p = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ_i}{(V_i^*)^{p-1}} - \sum_{k=1}^{i-1} Y_{ik}(V_k)^p - \sum_{k=i+1}^{n} Y_{ik}(V_k)^{p-1}\right]$$

Algorithm for Gauss-Seidel Load Flow with only PQ_buses:

Step 1: make initial guesses for bus voltages as $V_i^{(0)}$
for all i=2,3………,n. and set iteration count p=1.

Step 2: calculate voltages at all buses(i=2,3……,n) by using the relation

$$(V_i)^p = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ_i}{(V_i^*)^{p-1}} - \sum_{k=1}^{i-1} Y_{ik}(V_k)^p - \sum_{k=i+1}^{n} Y_{ik}(V_k)^{p-1}\right]$$

Step 3: calculate the diff. b/w the voltages magnitudes of previous iteration and present iteration for all buses i=2,3,………,n.

$V_i(\text{diff.}) = |V_i^{(p)}| - |V_i^{(p-1)}|$

Step 4:

if

max(V_2(diff),V_3(diff)……,V_n(diff))≤ accuracy, stop iterations

else

set p=p+1 go to step_2.

Handling of PV_buses

We can't use the relation

$$(V_i)^p = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ_i}{(V_i^*)^{p-1}} - \sum_{k=1}^{i-1} Y_{ik}(V_k)^p - \sum_{k=i+1}^{n} Y_{ik}(V_k)^{p-1}\right]$$

In order to find the angle 'θ', because we don't know 'Q' value, but we can use the values of voltages to estimate the 'Q'.

So we first estimate the value of 'Q' for PV_bus

Using the relation

$$Q_i = \sum_{k=1}^{n} |V_i||V_k|(G_{ik}\sin\theta_{ik} - B_{ik}\cos\theta_{ik})$$

convergence properties

- whether the method will converge?
- how fast the method will converge?

For Newton-Raphson method, whether the method will converge or not depends on two things:

1) How close the guessed solution is to the correct solution.
2) The nature of the function close to the correct solution.

The NR-method converges “quadratically”.

Quadratic convergence means that each iteration increases the accuracy of the solution by two decimal places.

N-R Application to Power Flow

- Let **x** be the voltage angle and voltage magnitude, $\mathbf{x} = \begin{bmatrix} \boldsymbol{\theta} \\ |\mathbf{V}| \end{bmatrix}$

Why does the index start at 2?

- Power flow equations: f(**x**) = 0,

$$\overbrace{\sum_{k=1}^{n} |V_i||V_k|(G_{ik}\cos\theta_{ik} + B_{ik}\sin\theta_{ik})}^{\equiv P_i(\mathbf{x})} - P_i = 0$$

$$\overbrace{\sum_{k=1}^{n} |V_i||V_k|(G_{ik}\sin\theta_{ik} - B_{ik}\cos\theta_{ik})}^{\equiv Q_i(\mathbf{x})} - Q_i = 0$$

$$\Rightarrow \quad \mathbf{f}(\mathbf{x}) \equiv \begin{bmatrix} P_2(\mathbf{x}) - P_2 \\ \vdots \\ P_n(\mathbf{x}) - P_n \\ Q_2(\mathbf{x}) - Q_2 \\ \vdots \\ Q_n(\mathbf{x}) - Q_n \end{bmatrix}$$

Power Mismatch

- Defined by

$$\Delta\mathbf{P}(\mathbf{x}) \equiv \begin{bmatrix} P_2 - P_2(\mathbf{x}) \\ \vdots \\ P_n - P_n(\mathbf{x}) \end{bmatrix} \quad \Delta\mathbf{Q}(\mathbf{x}) \equiv \begin{bmatrix} Q_2 - Q_2(\mathbf{x}) \\ \vdots \\ Q_n - Q_n(\mathbf{x}) \end{bmatrix}$$

- We can express f(**x**) as,

$$\mathbf{f}(\mathbf{x}) \equiv -\begin{bmatrix} \Delta\mathbf{P}(\mathbf{x}) \\ \Delta\mathbf{Q}(\mathbf{x}) \end{bmatrix} = \mathbf{0}$$

- We use power mismatch to check convergence.

Jacobian matrix

- Jacobian matrix is the gradient of the power function with respect to voltage and angle.

$$\mathbf{J} = \begin{bmatrix} \mathbf{J}_{11} & \mathbf{J}_{12} \\ \mathbf{J}_{21} & \mathbf{J}_{22} \end{bmatrix}$$

$$\mathbf{J}_{11} = \frac{\partial \mathbf{P}(\mathbf{x})}{\partial \boldsymbol{\theta}} \quad \mathbf{J}_{12} = \frac{\partial \mathbf{P}(\mathbf{x})}{\partial |\mathbf{V}|} \quad \mathbf{J}_{21} = \frac{\partial \mathbf{Q}(\mathbf{x})}{\partial \boldsymbol{\theta}} \quad \mathbf{J}_{22} = \frac{\partial \mathbf{Q}(\mathbf{x})}{\partial |\mathbf{V}|}$$

Off-diagonal Elements of Jacobian Matrix

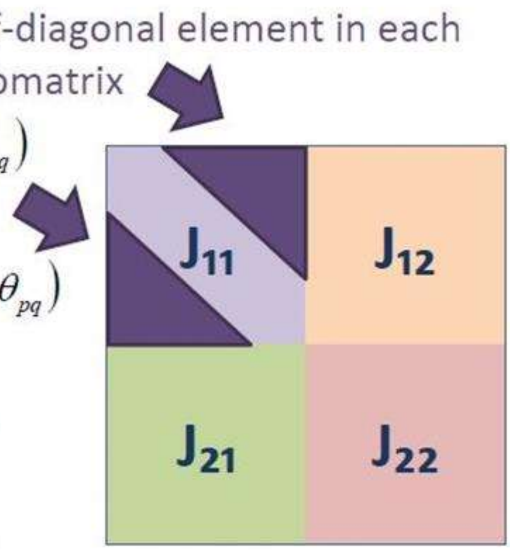
- For indices p ≠ q,

$$J_{pq}^{11} = \frac{\partial P_p(\mathbf{x})}{\partial \theta_q} = |V_p||V_q|\left(G_{pq}\sin\theta_{pq} - B_{pq}\cos\theta_{pq}\right)$$

$$J_{pq}^{21} = \frac{\partial Q_p(\mathbf{x})}{\partial \theta_q} = -|V_p||V_q|\left(G_{pq}\cos\theta_{pq} + B_{pq}\sin\theta_{pq}\right)$$

$$J_{pq}^{12} = \frac{\partial P_p(\mathbf{x})}{\partial |V_q|} = |V_p|\left(G_{pq}\cos\theta_{pq} + B_{pq}\sin\theta_{pq}\right)$$

$$J_{pq}^{22} = \frac{\partial Q_p(\mathbf{x})}{\partial |V_q|} = |V_p|\left(G_{pq}\sin\theta_{pq} - B_{pq}\cos\theta_{pq}\right)$$



Note that $J_{12} \neq J_{21}$ however, they look somewhat similar.

Diagonal Elements of Jacobian Matrix

- For indices p=q

$$J_{pp}^{11} = \frac{\partial P_p(X)}{\partial \theta_p} = \sum_{\substack{q=1\\ \neq p}}^{n} |V_p||V_q|(B_{pq}\cos\theta_{pq} - G_{pq}\sin\theta_{pq})$$

$$J_{pp}^{21} = \frac{\partial Q_p(X)}{\partial \theta_p} = \sum_{\substack{q=1\\ \neq p}}^{n} |V_p||V_q|(G_{pq}\cos\theta_{pq} + B_{pq}\sin\theta_{pq})$$

$$J_{pp}^{12} = \frac{\partial P_p(X)}{\partial |V_p|} = 2|V_p|G_{pp} + \sum_{\substack{q=1\\ \neq p}}^{n} |V_q|(G_{pq}\cos\theta_{pq} + B_{pq}\sin\theta_{pq})$$

$$J_{pp}^{22} = \frac{\partial Q_p(X)}{\partial |V_p|} = -2|V_p|B_{pp} + \sum_{\substack{q=1\\ \neq p}}^{n} |V_q|(G_{pq}\sin\theta_{pq} - B_{pq}\cos\theta_{pq})$$

Modified Diagonal Elements of Jacobian Matrix

- For indices p = q,

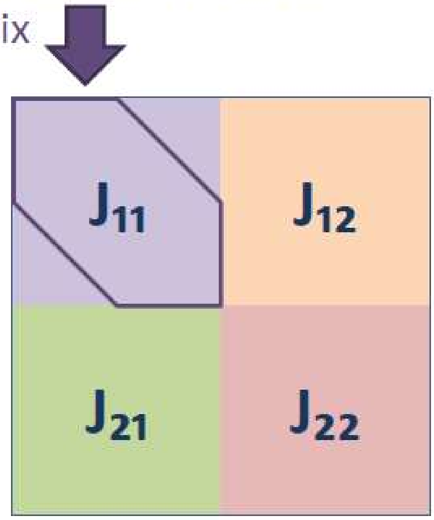
$$J_{pp}^{11} = \frac{\partial P_p(\mathbf{x})}{\partial \theta_p} = -Q_p - B_{pp}|V_p|^2$$

$$J_{pp}^{21} = \frac{\partial Q_p(\mathbf{x})}{\partial \theta_p} = P_p - G_{pp}|V_p|^2$$

$$J_{pp}^{12} = \frac{\partial P_p(\mathbf{x})}{\partial |V_p|} = \frac{P_p}{|V_p|} + G_{pp}|V_p|$$

$$J_{pp}^{22} = \frac{\partial Q_p(\mathbf{x})}{\partial |V_p|} = \frac{Q_p}{|V_p|} - B_{pp}|V_p|$$

Diagonal element in each submatrix



Note that $J_{12} \neq J_{21}$ however, they look somewhat similar.

Handling of PV_buses

- For PV-buses 'Q' is unspecified, so there will no equation corresponds to ΔQ, so the jacobian consists of only one row corresponds to ΔP.
- we first estimate the value of 'Q' for PV_bus

Using the relation

$$Q_i = \sum_{k=1}^{n} |V_i||V_k|(G_{ik} \sin \theta_{ik} - B_{ik} \cos \theta_{ik})$$

- We will proceed in the same as that of Gauss-seidel load flow.

Computational Challenges with N-R

- Large-Size of Jacobian matrix

  –For n-bus network, Jacobian matrix size may reach 2(n-1) by 2(n-1) matrix.

  –Sparse matrix.
- Need to re-evaluate and take inverse of the Jacobian matrix at every iteration.

Comparison of Load Flow Techniques

Gauss seidal method	**Newton-Raphson method**
1. Computer memory requirement is less.	1. Computer memory requirement is large, as the elements of jacobian matrix are to be computed in each iteration.
2. Time taken for each iteration is very less.	2. Time taken for each iteration is very high.
3. It takes more number of iterations.	3. It takes less number of iterations.

Experiment 3

Study of PSAT Software for MATLAB

PSAT SOFTWARE

1.1 Introduction

PSAT is a Matlab toolbox for electric power system analysis and control. The command line version of PSAT is also GNU Octave compatible. PSAT includes power flow, continuation power flow, optimal power flow, small signal stability analysis and time domain simulation. All operations can be assessed by means of graphical user interfaces (GUIs) and a Simulink-based library provides an user friendly tool for network design.

PSAT core is the power flow routine, which also takes care of state variable initialization. Once the power flow has been solved, further static and/or dynamic analysis can be performed. These routines are:

1. Continuation power flow;
2. Optimal power flow;
3. Small signal stability analysis;
4. Time domain simulations;
5. Phasor measurement unit (PMU) placement.

1.2 PSAT Software Structure

In order to perform accurate power system analysis, PSAT supports a variety of static and dynamic component models, as follows:

- Power Flow Data: Bus bars, transmission lines and transformers, slack buses, PV generators, constant power loads, and shunt admittances.
- CPF and OPF Data: Power supply bids and limits, generator power reserves, generator ramping data, and power demand bids and limits.
- Switching Operations: Transmission line faults and transmission line breakers.
- Measurements: Bus frequency and phasor measurement units (PMU).
- Loads: Voltage dependent loads, frequency dependent loads, ZIP (impedance, constant current and constant power) loads, exponential recovery loads [Hill 1993, Karlsson and Hill 1994], thermostatically controlled loads [Hirsch 1994], Jimma's loads [Jimma et al. 1991], and mixed loads.
- Machines: Synchronous machines (dynamic order from 2 to 8) and induction motors (dynamic order from 1 to 5).

- Controls: Turbine Governors, Automatic Voltage Regulators, Power System Stabilizer, Over-excitation limiters, Secondary Voltage Regulation (Central Area Controllers and Cluster Controllers), and a Supplementary Stabilizing Control Loop for SVCs.
- Regulating Transformers: Load tap changer with voltage or reactive power regulators and phase shifting transformers.
- FACTS: Static Var Compensators, Thyristor Controlled Series Capacitors, Static Synchronous Source Series Compensators, Unified Power Flow Controllers, and High Voltage DC transmission systems.
- Wind Turbines: Wind models, Constant speed wind turbine with squirrel cage induction motor, variable speed wind turbine with doubly fed induction generator, and variable speed wind turbine with direct drive synchronous generator.
- Other Models: Synchronous machine dynamic shaft, sub-synchronous resonance model, Solid Oxide Fuel Cell, and sub-transmission area equivalents.

Besides mathematical routines and models, PSAT includes a variety of utilities, as follows:

1. One-line network diagram editor (Simulink library);
2. GUIs for settings system and routine parameters;
3. User defined model construction and installation;
4. GUI for plotting results;
5. Filters for converting data to and from other formats;
6. Command logs.

Finally, PSAT includes bridges to GAMS and UWPFLOW programs, which highly extend PSAT ability of performing optimization and continuation power flow analysis. Figure 1 shows the Structure of PSAT.

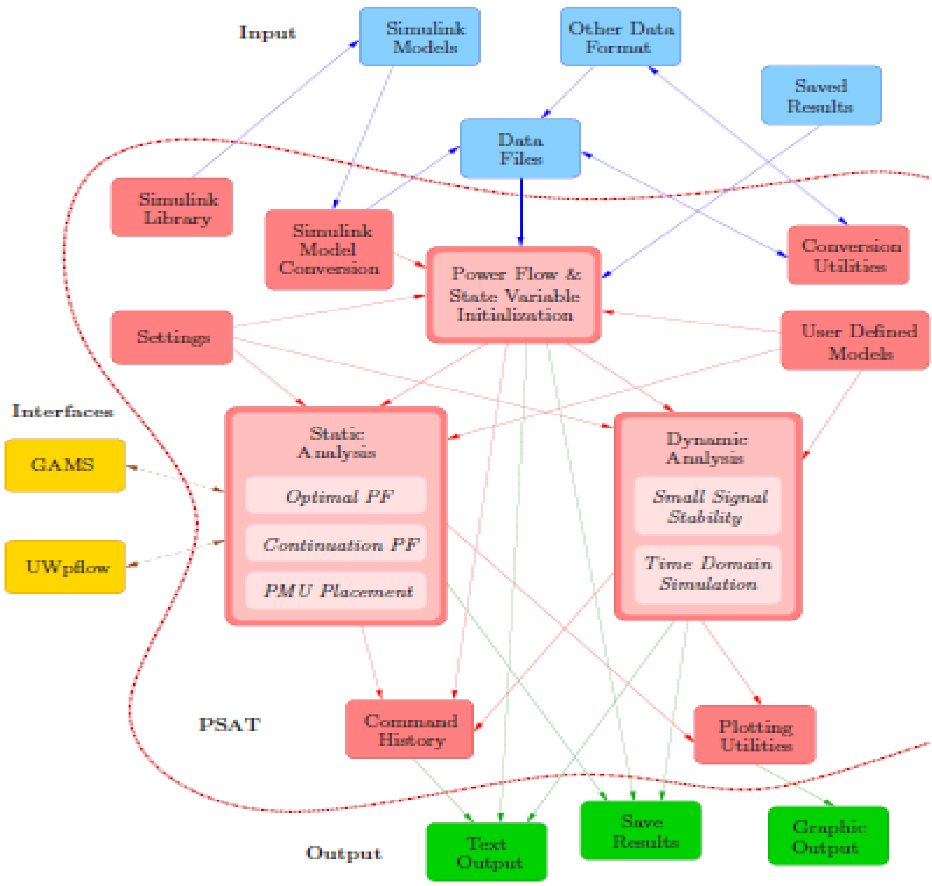


Figure 1 PSAT Structure

4.3 Graphical User Interface (GUI)

PSAT provides interfaces to GAMS and UWPFLOW, which highly extend PSAT ability to perform OPF and CPF analysis respectively. The General Algebraic Modeling System (GAMS) is a high-level modeling system for mathematical programming problems. It consists of a language compiler and a variety of integrated high-performance solvers. GAMS is specifically designed for large and complex scale problems, and allows creating and maintaining models for a wide variety of applications and disciplines [Brooke et al. 1998] and the GUI which interfaces PSAT to GAMS. UWPFLOW is an open source program for sophisticated continuation power flow analysis [Ca˜nizares and Alvarado 2000]. It consists of a set of C functions and libraries designed for voltage stability analysis of power systems, including voltage dependent loads, HVDC, FACTS and secondary voltage control. Figure 2 shows PSAT GUI interface.

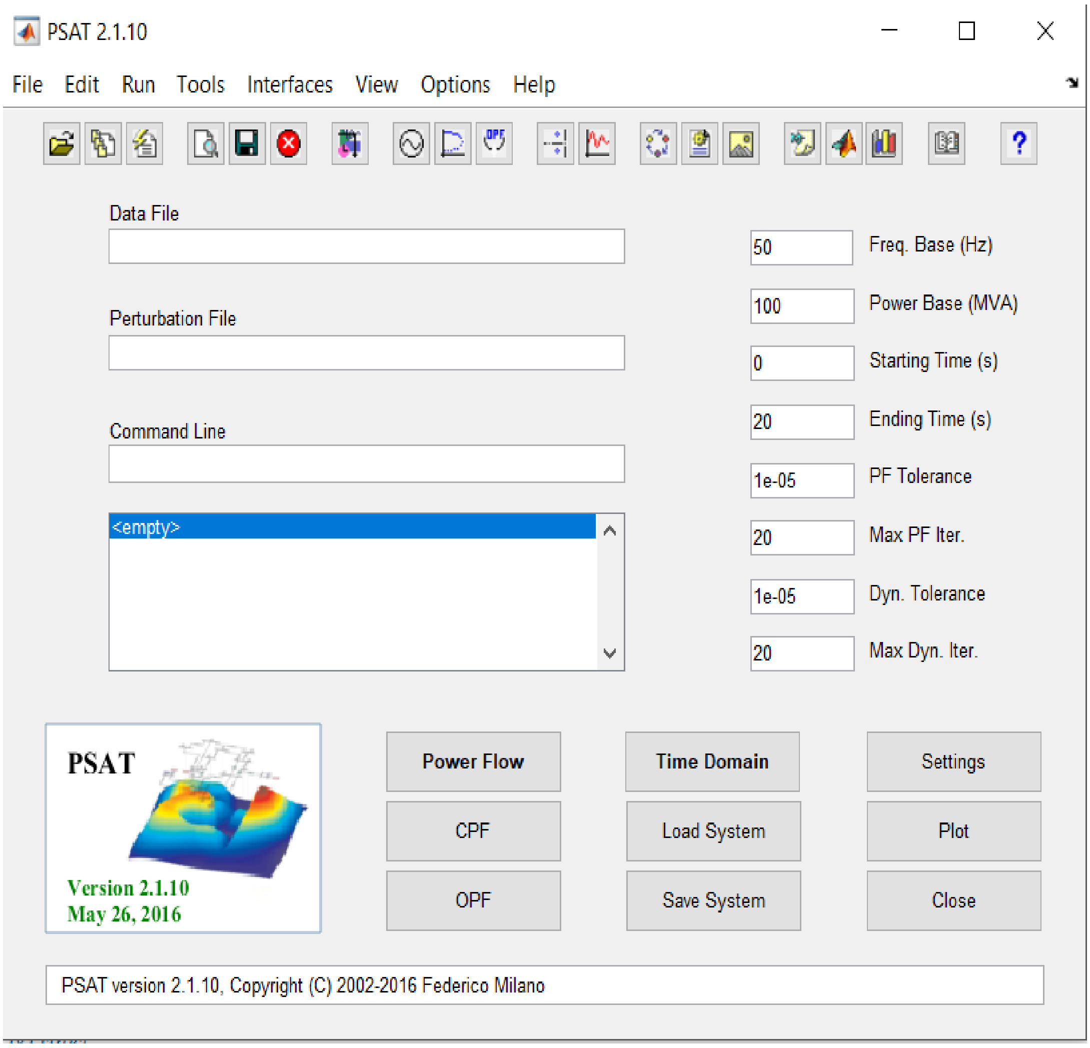


Figure 2 Main graphical user interface of PSAT

1.4 Loading of Data

PSAT has its own Simulink Library; loading of the data in each block is explained in this section.

- Bus : - The network topology is defined by the “bus” components, whose data format is depicted in Figure 3.

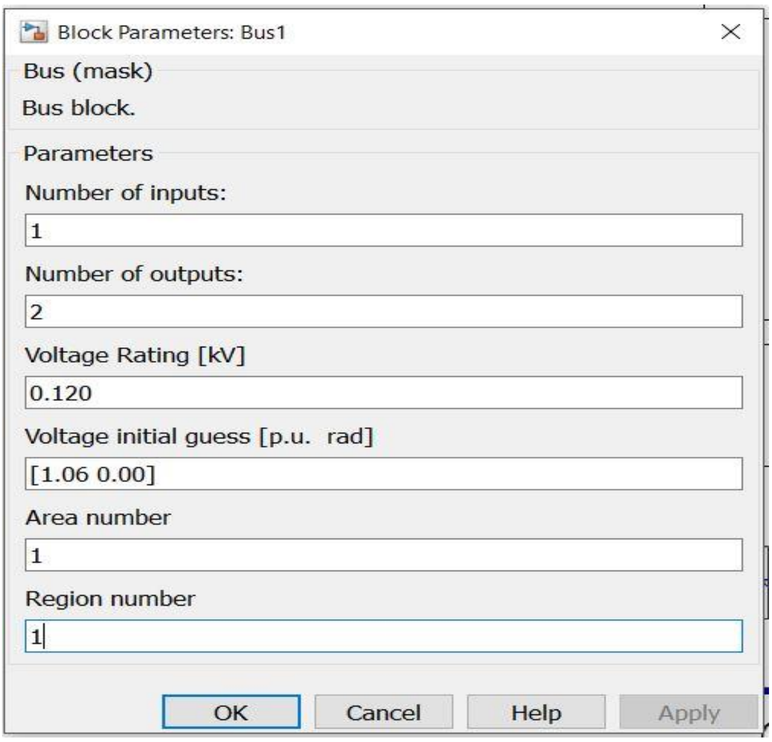


Figure 3 Bus parameter block

- Transmission Line: - Figure 4 depicts the block parameters used for defining the transmission line lumped model.

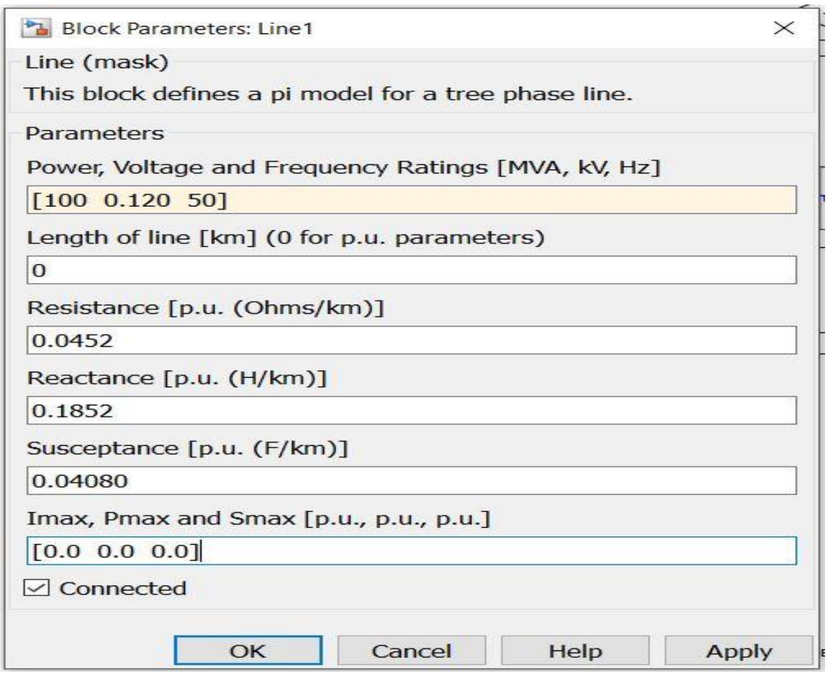


Figure 4Transmission line block parameter

- Slack Bus: - Slack bus parameters are shown in figure 5 given below.

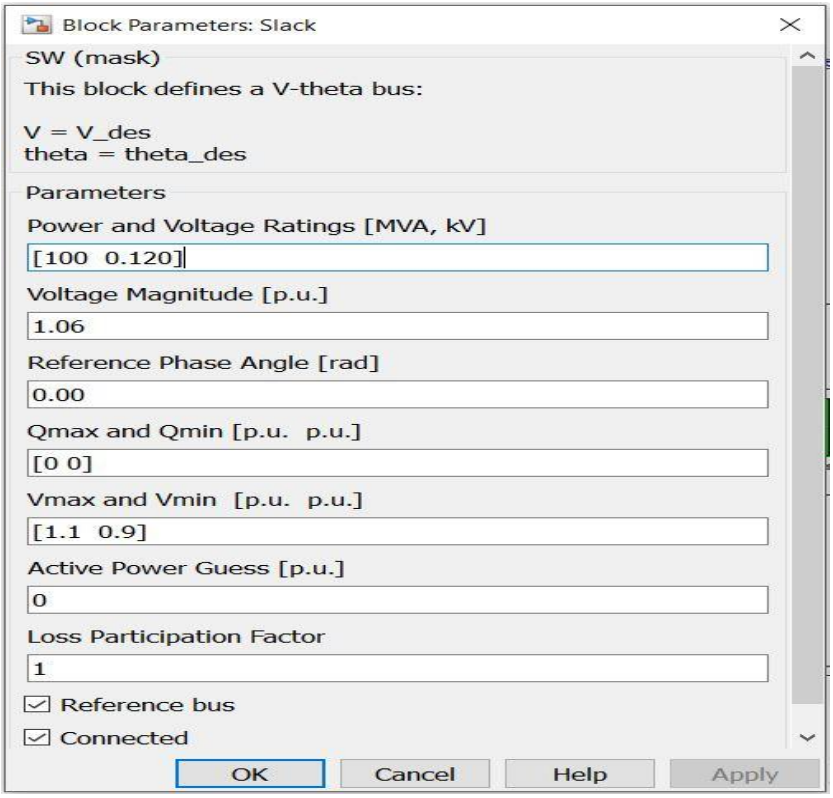


Figure 5 Slack bus block parameters

- PQ bus: - PQ bus or load bus is used to provide load in PSAT software. The block parameter of PQ bus is shown in figure 6.

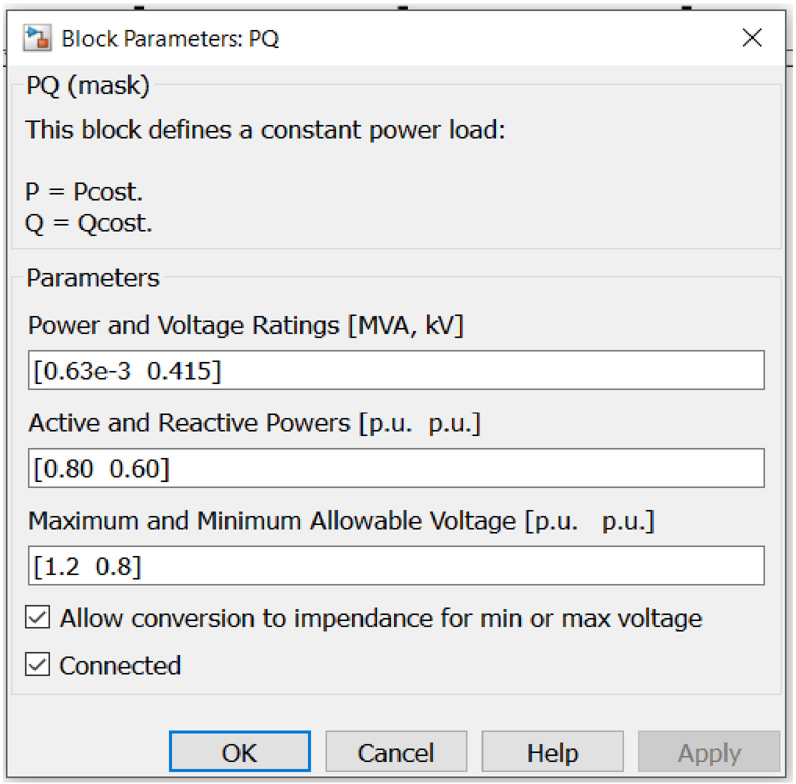


Figure 6 PQ bus parameters block

- PV Bus: - PV bus or Generator bus used to provide generator in PSAT software. The block parameter of PV bus is shown in figure 7.

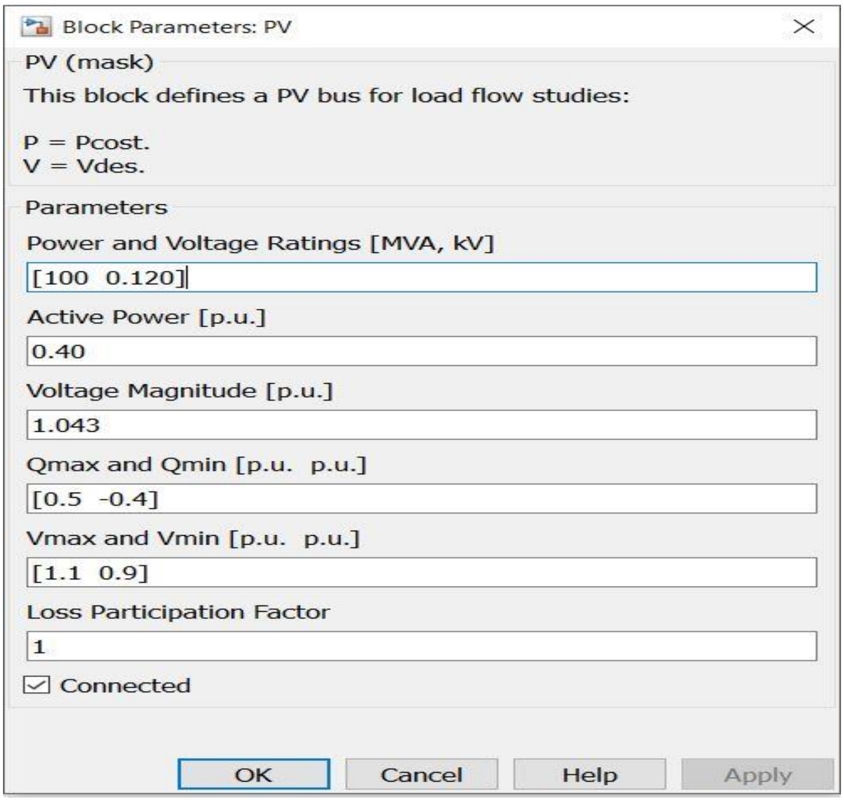


Figure 7 PV bus parameters block

- Shunt Compensator block: - It is basically a PV bus block which has active power (P) equals to 0. Figure 18 shows the Shunt Compensator Parameter Block.

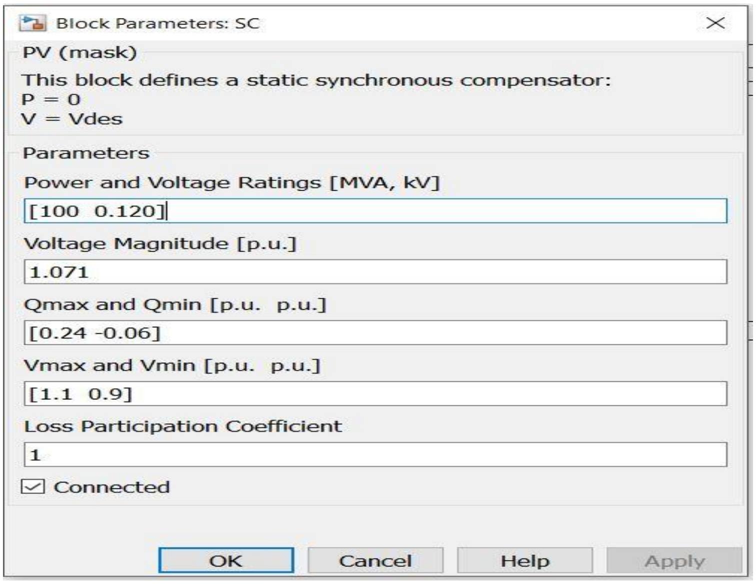


Figure 8 Shunt Compensator Parameter Block

- Transformer Block: - Transformer parameter block shown in figure 9.

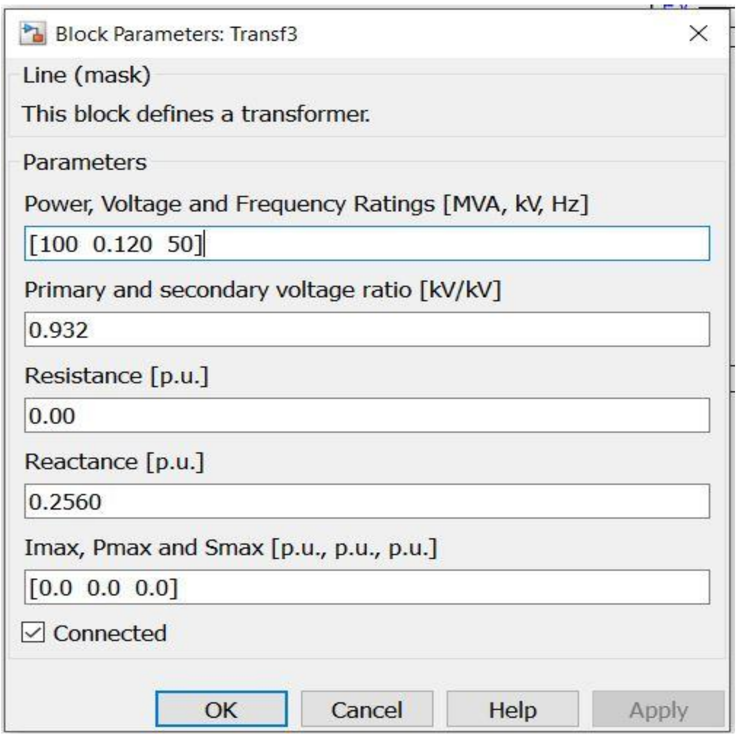


Figure 9 Transformer Parameter Block

- Three Winding Transformer: - Transformer block which has single input and two outputs. Parameters block for three winding transformer is shown in figure 10

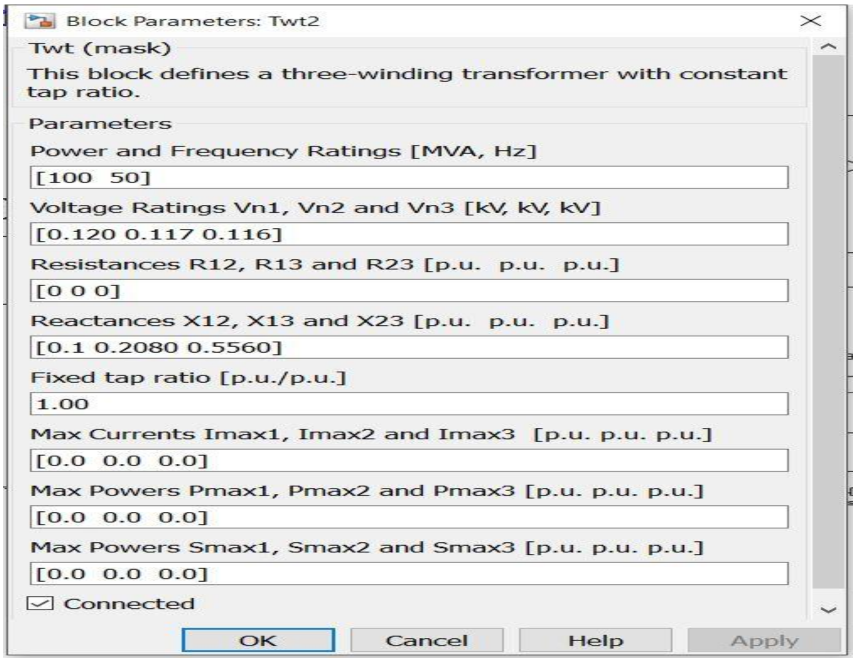


Figure 10 Three winding transformer parameter block

- Demand Parameter Block: - Block used to increase the load on the buses is known as the Demand Parameter Block. Figure 11 shows the Demand Block Parameter Block.

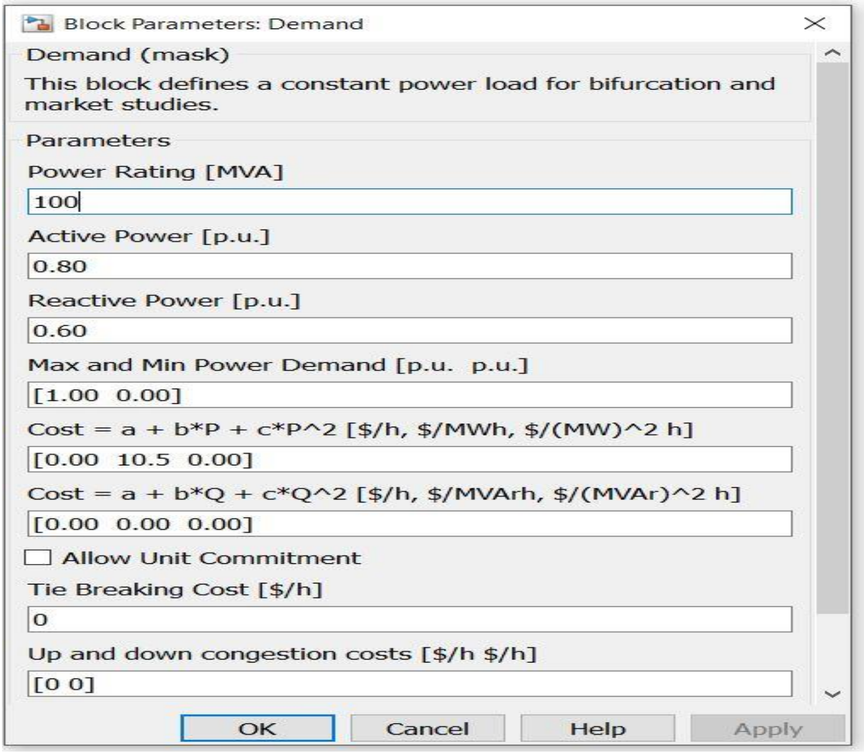


Figure 11 Demand Block Parameter Block

- Supply Parameter Block: - Block which defines a PV Bus for Bifurcation, is known Supply Block. Figure 12 shows Supply Block Parameter Block.

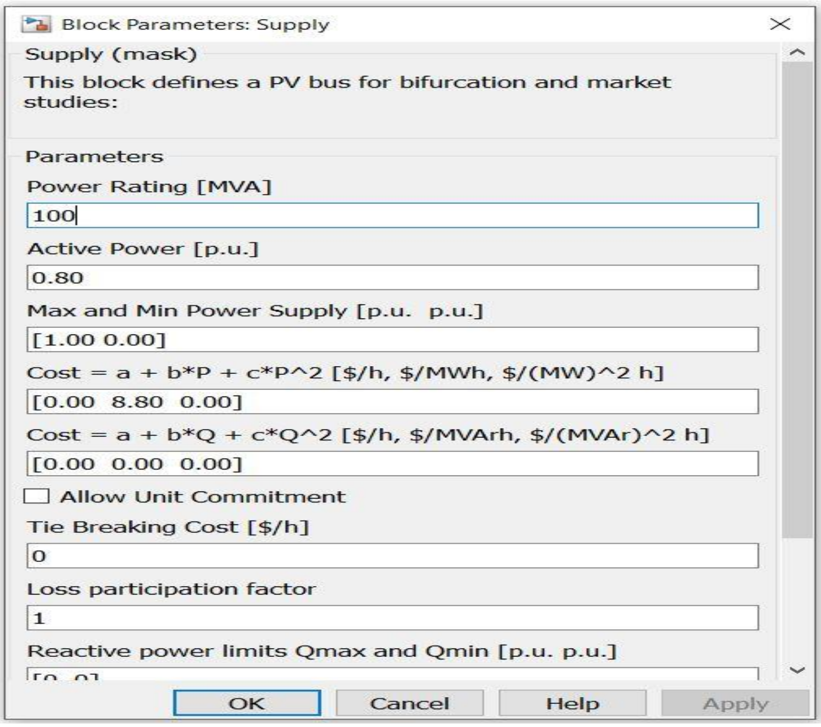


Figure 12 Supply Block Parameter Block

- SVC (Static VAR Compensator) Block: - The block assumes a time constant regulator, as depicted in Figure 13. In this model, a total reactance b_{SVC} is assumed and the following differential equation holds:

$$\hat{b}_{SVC} = \frac{K_r(V_{ref} + v_{POD} - V) - b_{SVC}}{T_r}$$

The model is completed by the algebraic equation expressing the reactive power injected at the SVC node:

$$Q = -b_{SVC} \times V^2$$

The regulator has an anti-windup limiter, thus the reactance b_{SVC} is locked if one of its limits is reached and the first derivative is set to zero.

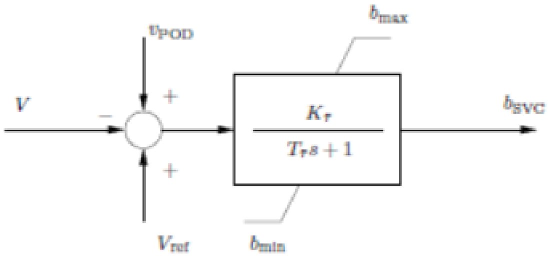


Figure 13 SVC Block

- STATCOM Block: - The STATCOM current is always kept in quadrature in relation to the bus voltage so that only reactive power is exchanged between the ac system and the STATCOM. The dynamic model is shown in Figure 14 where it can be seen that the STATCOM assumes a time constant regulator like SVC. The differential equation and the reactive power injected at the STATCOM node are given by:

$$\widehat{i_{SH}} = \frac{K_r(V_{ref} + v_{POD} - V) - i_{SH}}{T_r}$$

$$Q = -i_{SH} \times V$$

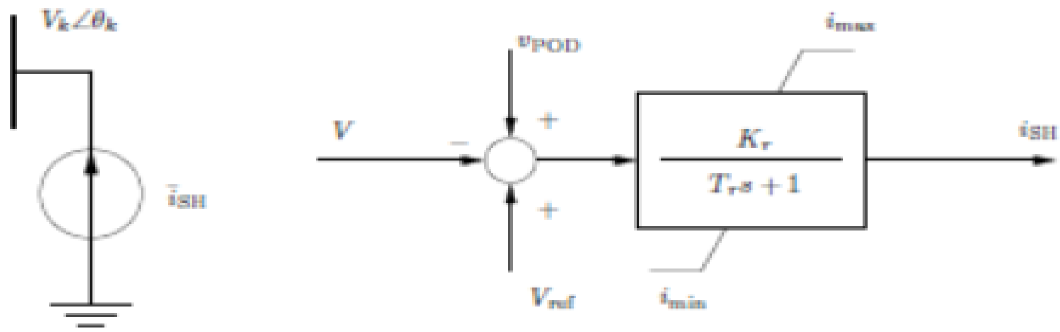


Figure 14 STATCOM Circuit and Control Block Diagram.

The regulator has an non-windup limiter, thus the current i_{SH} is locked if one of its limits is reached and the first derivative is set to zero.

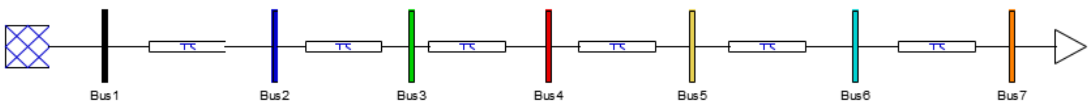
Experiment No.4

Aim: To simulate transmission line model and perform load flow analysis using PSAT

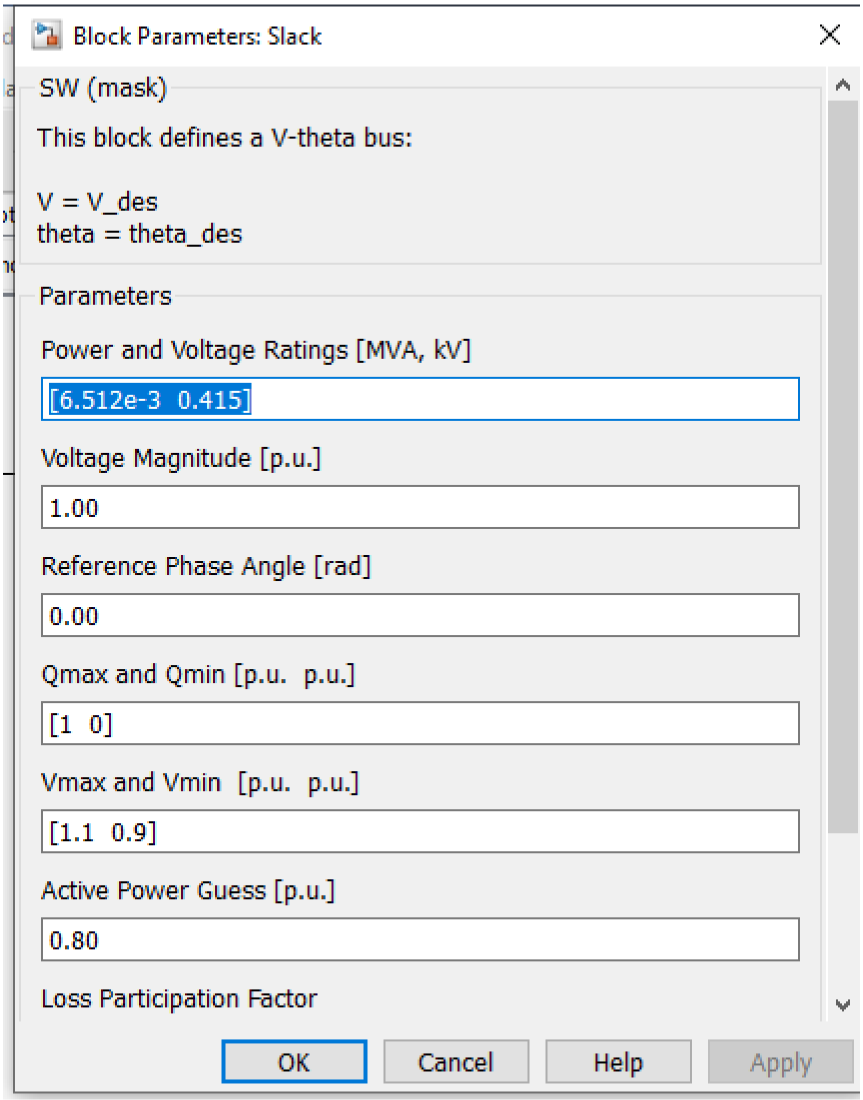
Appts: PSAT software, MATLAB software

PSAT Simulink blocks used: Bus, Slack bus, transmission line pi model load

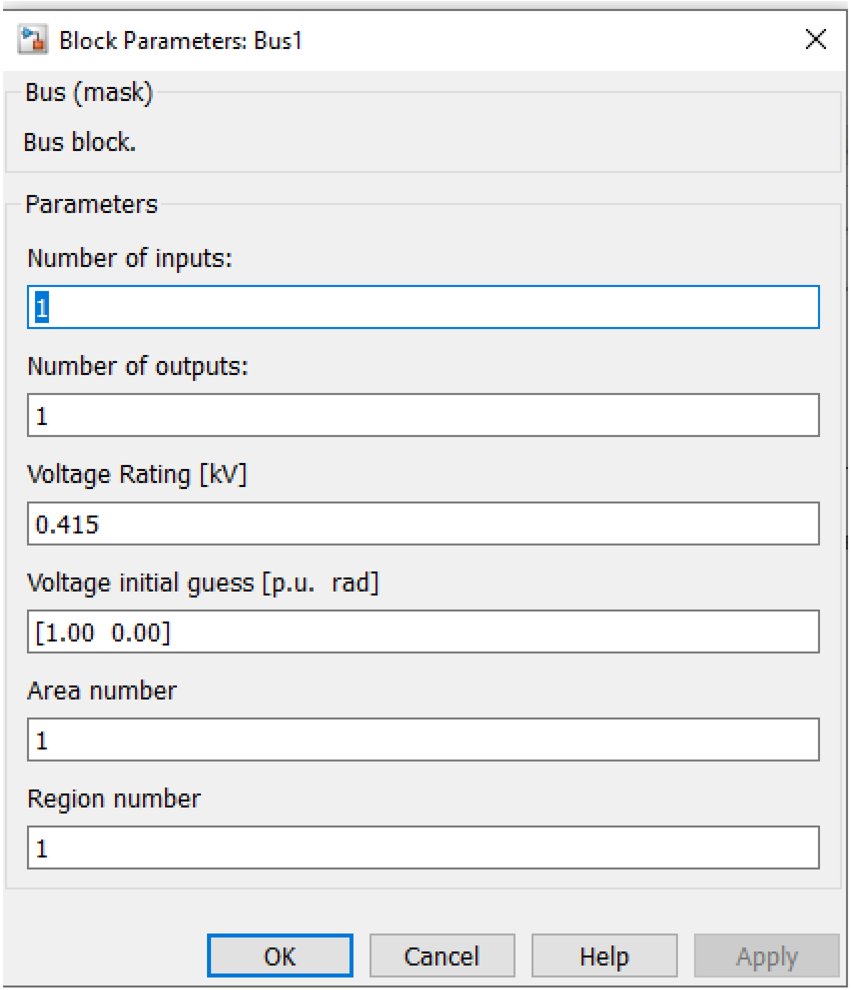
Circuit or simulation diagram:



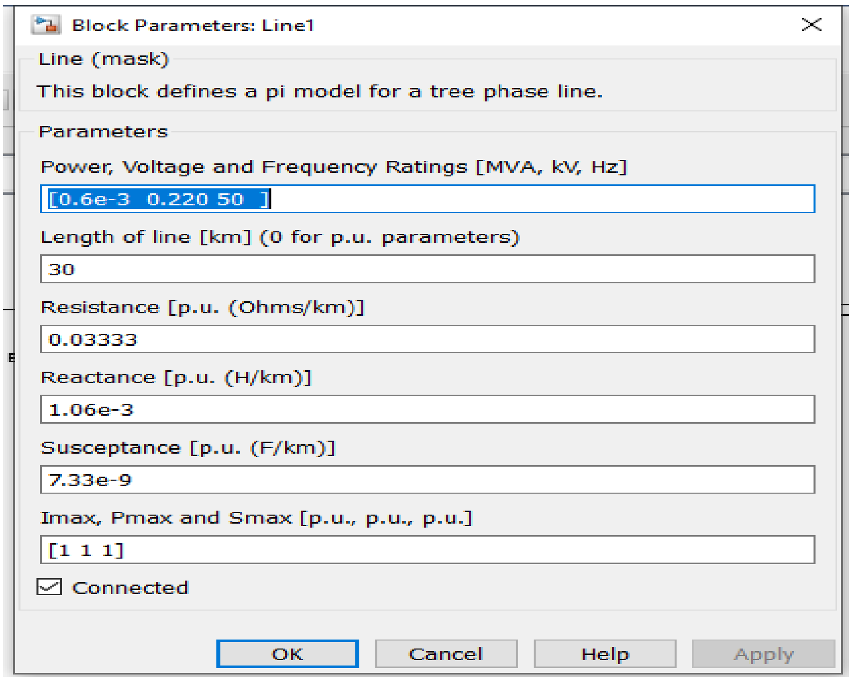
Slack bus data:



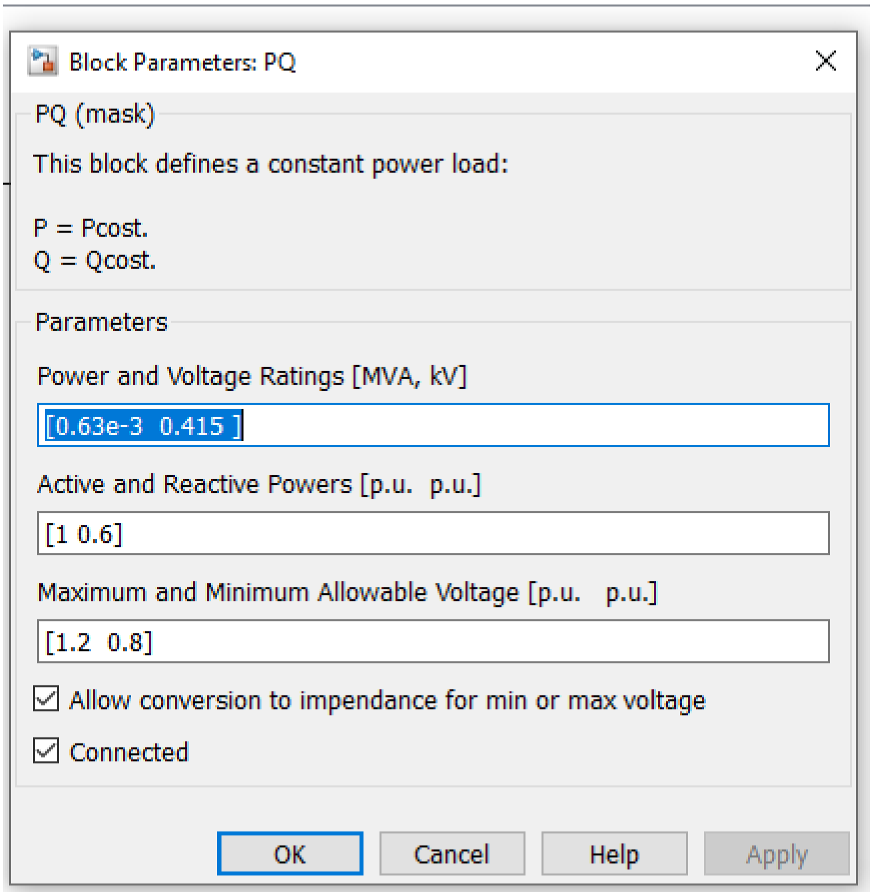
Bus Data:



Transmission line data:

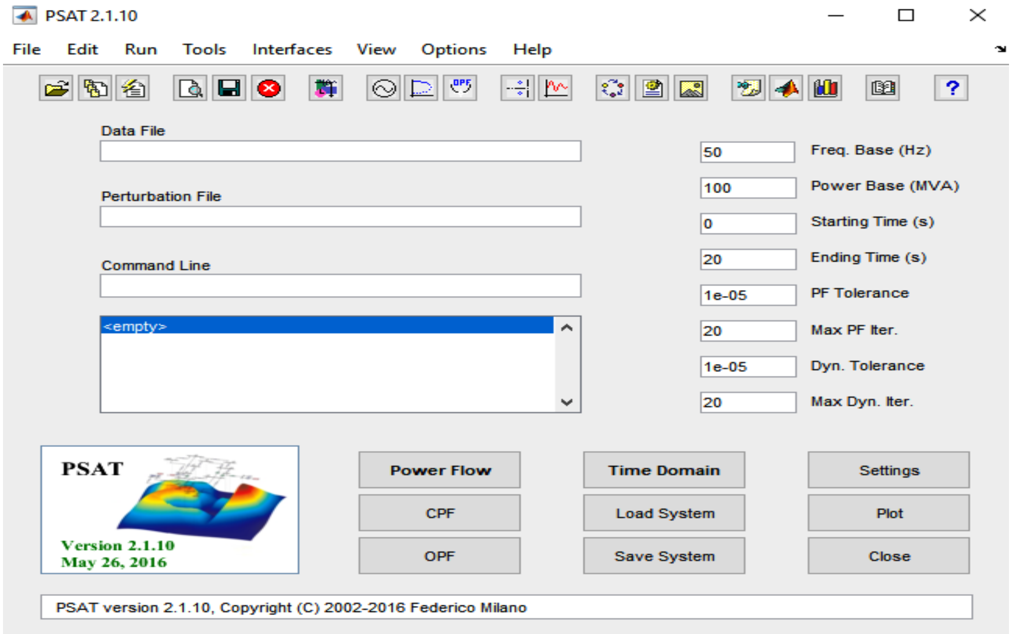


PQ load Data:



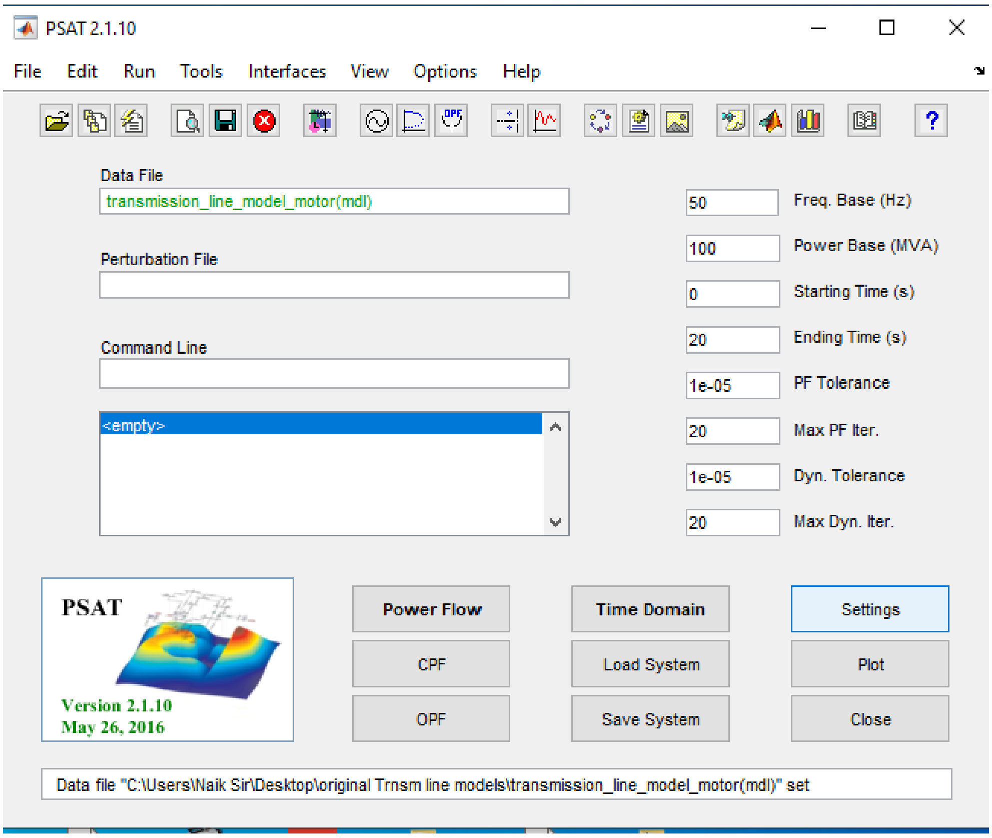
Procedure:

1) Open MATLAB
2) Browse for PSAT folder to give the path
3) Write PSAT in command prompt. This opens up PSAT GUI window.



4) Open New model in MATLAB and using PSAT Simulink create/draw the model.
5) Save the model with name in some folder.

6) Double click on data file
7) Select filters, PSAT model
8) In current path browse for the PSAT Simulink model created
9) Load the model



10) Click power flow
11) Click static report and then report
12) Open text file for report (Example: file: 'C:\Users\Naik Sir\Desktop\original Trnsm line models\transmission_line_model_motor_01.txt')

Load flow report

POWER FLOW REPORT

P S A T 2.1.10

NETWORK STATISTICS

Buses: 7
Lines: 6
Generators: 1
Loads: 1

SOLUTION STATISTICS

Number of Iterations: 1
Maximum P mismatch [p.u.] 0
Maximum Q mismatch [p.u.] 0
Power rate [MVA] 100

POWER FLOW RESULTS

Bus	V	phase	P gen	Q gen	P load	Q load
	[p.u.]	[rad]	[p.u.]	[p.u.]	[p.u.]	[p.u.]

Bus1	1	0	1e-05	1e-05	0	0
Bus2	0.96265	-0.03503	0	0	0	0
Bus3	0.92587	-0.07276	0	0	0	0
Bus4	0.88987	-0.1135	0	0	0	0
Bus5	0.85486	-0.15756	0	0	0	0
Bus6	0.82106	-0.20524	0	0	0	0
Bus7	0.78871	-0.25686	0	0	1e-05	0

LINE FLOWS

From Bus	To Bus	Line	P Flow [p.u.]	Q Flow [p.u.]	P Loss [p.u.]	Q Loss [p.u.]
Bus1	Bus2	1	1e-05	1e-05	0	0
Bus2	Bus3	2	1e-05	1e-05	0	0
Bus3	Bus4	3	1e-05	1e-05	0	0
Bus4	Bus5	4	1e-05	0	0	0
Bus5	Bus6	5	1e-05	0	0	0
Bus6	Bus7	6	1e-05	0	0	0

LINE FLOWS

From Bus	To Bus	Line	P Flow [p.u.]	Q Flow [p.u.]	P Loss [p.u.]	Q Loss [p.u.]
Bus2	Bus1	1	-1e-05	-1e-05	0	0
Bus3	Bus2	2	-1e-05	-1e-05	0	0
Bus4	Bus3	3	-1e-05	0	0	0
Bus5	Bus4	4	-1e-05	0	0	0
Bus6	Bus5	5	-1e-05	0	0	0
Bus7	Bus6	6	-1e-05	0	0	0

GLOBAL SUMMARY REPORT

TOTAL GENERATION
REAL POWER [p.u.] 1e-05
REACTIVE POWER [p.u.] 1e-05
TOTAL LOAD
REAL POWER [p.u.] 1e-05
REACTIVE POWER [p.u.] 0
TOTAL LOSSES
REAL POWER [p.u.] 0
REACTIVE POWER [p.u.] 0

Result and Conclusion:

Load flow using N-R method is performed on simulated transmission line model. Bus voltages and line flows are found.

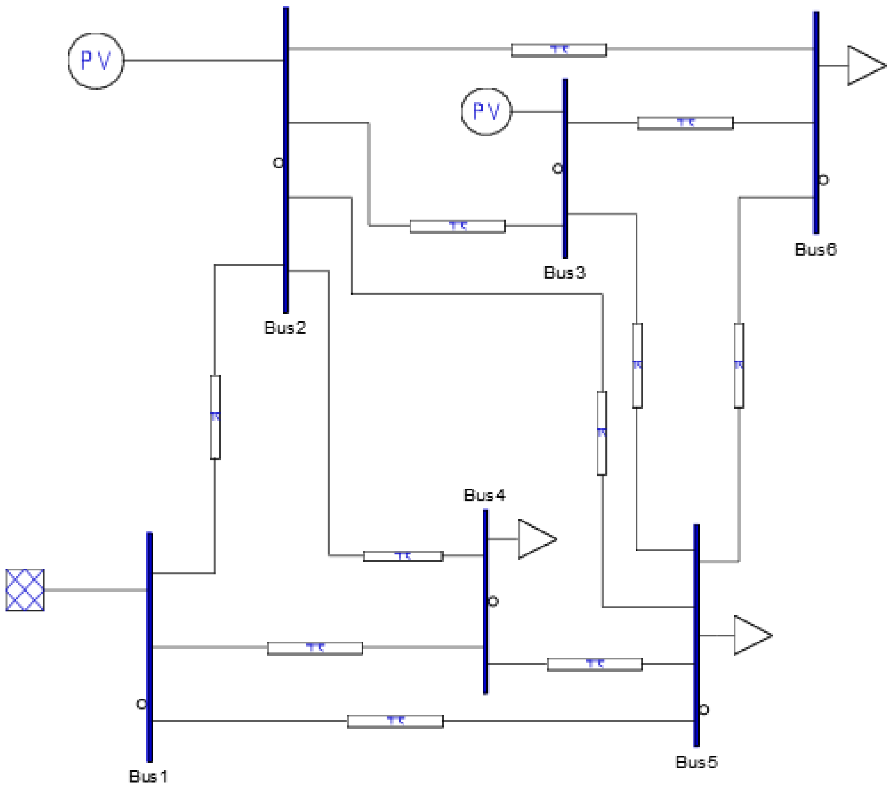
Experiment No.5

Aim: To simulate six bus system and perform load flow analysis using PSAT

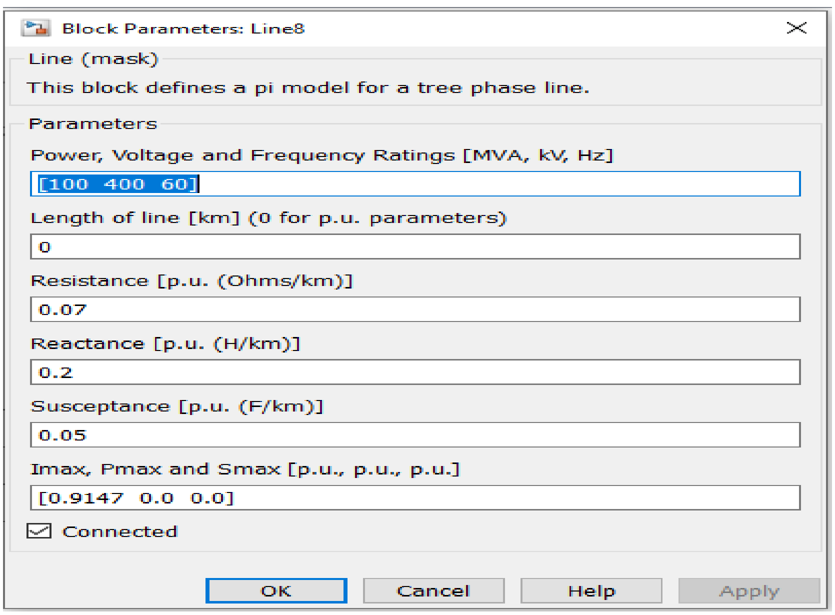
Appts: PSAT software, MATLAB software

PSAT Simulink blocks used: Bus, Slack bus, transmission line pi model load

Circuit or simulation diagram:



Line Data:



Block Parameters: Line8

Line (mask)

This block defines a pi model for a tree phase line.

Parameters

Power, Voltage and Frequency Ratings [MVA, kV, Hz]

[100 400 60]

Length of line [km] (0 for p.u. parameters)

0

Resistance [p.u. (Ohms/km)]

0.07

Reactance [p.u. (H/km)]

0.2

Susceptance [p.u. (F/km)]

0.05

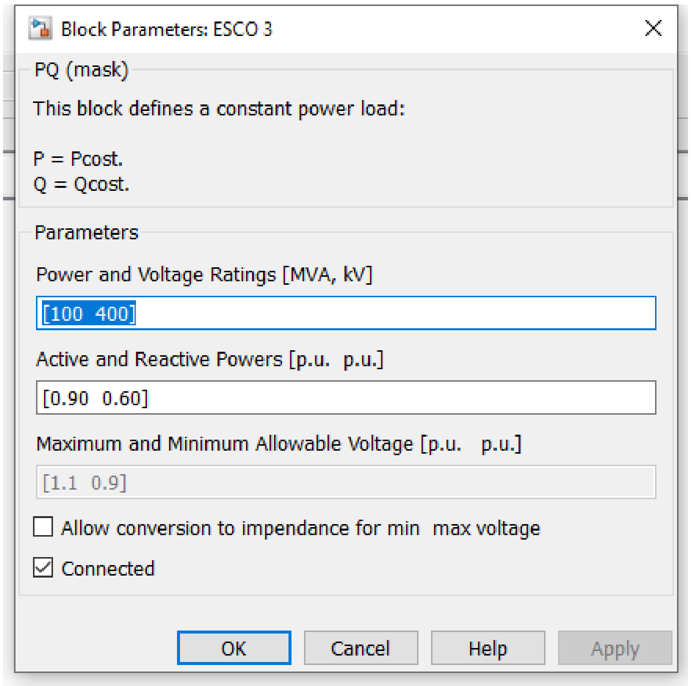
Imax, Pmax and Smax [p.u., p.u., p.u.]

[0.9147 0.0 0.0]

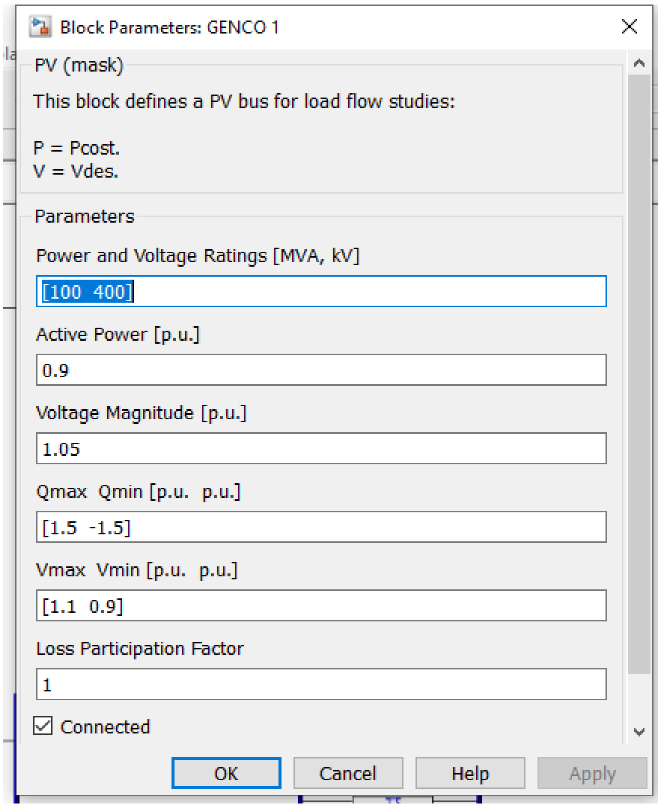
☑ Connected

OK | Cancel | Help | Apply

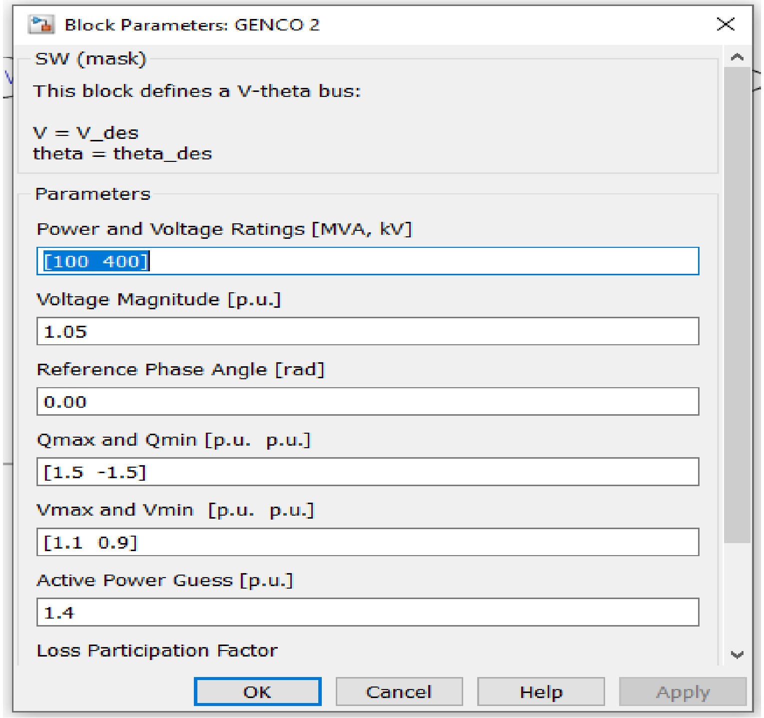
PQ Load Data:



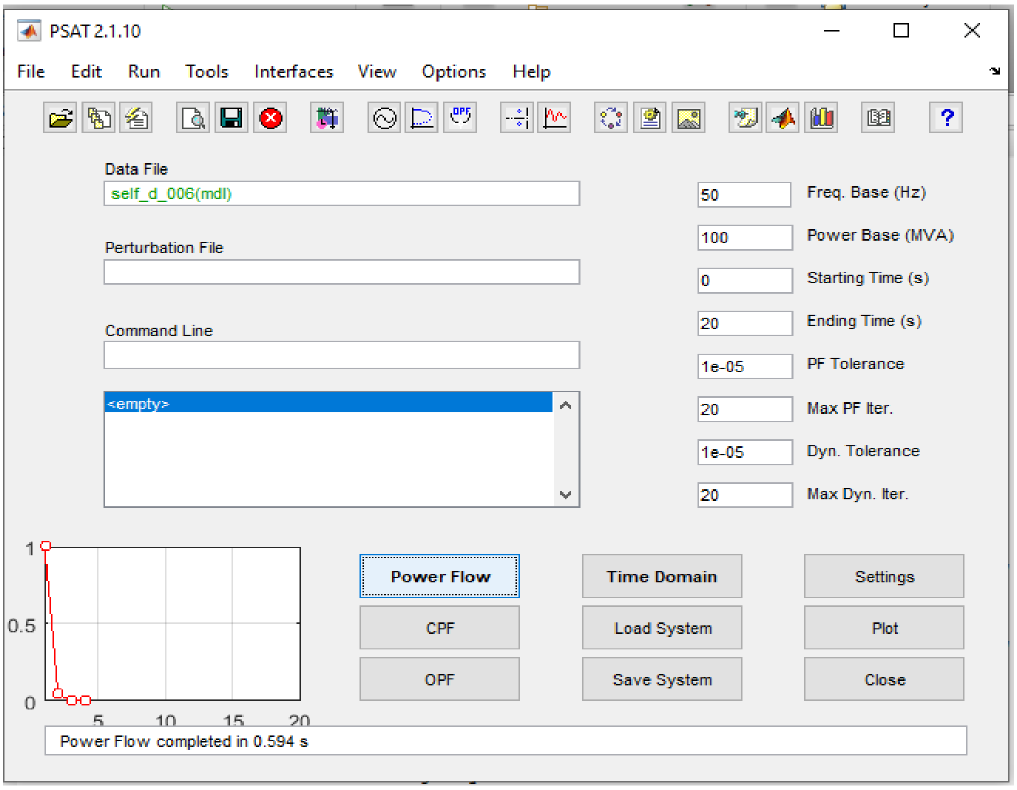
PV block data:



Slack bus data:



Power flow run:



Static load flow report:

POWER FLOW REPORT

P S A T 2.1.10

NETWORK STATISTICS

Buses:	6
Lines:	11
Generators:	3
Loads:	3

SOLUTION STATISTICS

Number of Iterations:	4
Maximum P mismatch [p.u.]	0
Maximum Q mismatch [p.u.]	0
Power rate [MVA]	100

POWER FLOW RESULTS

Bus	V [p.u.]	phase [rad]	P gen [p.u.]	Q gen [p.u.]	P load [p.u.]	Q load [p.u.]
Bus1	1.05	0	1.4129	0.15614	0	0
Bus2	1.05	-0.07717	0.9	0.85441	0	0
Bus3	1.05	-0.10533	0.6	0.70478	0	0
Bus4	0.98791	-0.09968	0	0	0.9	0.6
Bus5	0.96902	-0.13298	0	0	1	0.7
Bus6	0.99148	-0.14383	0	0	0.9	0.6

LINE FLOWS

From Bus	To Bus	Line	P Flow [p.u.]	Q Flow [p.u.]	P Loss [p.u.]	Q Loss [p.u.]
Bus2	Bus3	1	0.11973	-0.05527	0.00067	-0.06279
Bus3	Bus6	2	0.50489	0.51018	0.00955	0.02691
Bus4	Bus5	3	0.08293	-0.03252	0.00142	-0.07376
Bus3	Bus5	4	0.21417	0.20211	0.01073	-0.02778
Bus5	Bus6	5	0.00957	-0.10371	0.00062	-0.05581

Bus2	Bus4	6	0.44858	0.41924	0.01752	0.01426
Bus1	Bus2	7	0.34655	-0.17892	0.01313	-0.01785
Bus1	Bus4	8	0.56853	0.18753	0.01665	0.02503
Bus1	Bus5	9	0.49783	0.14754	0.02035	0.01507
Bus2	Bus6	10	0.40826	0.14834	0.01255	-0.01629
Bus2	Bus5	11	0.25686	0.18103	0.00973	-0.01165

LINE FLOWS

From Bus	To Bus	Line	P Flow [p.u.]	Q Flow [p.u.]	P Loss [p.u.]	Q Loss [p.u.]
Bus3	Bus2	1	-0.11906	-0.00752	0.00067	-0.06279
Bus6	Bus3	2	-0.49533	-0.48327	0.00955	0.02691
Bus5	Bus4	3	-0.08151	-0.04124	0.00142	-0.07376
Bus5	Bus3	4	-0.20344	-0.22989	0.01073	-0.02778
Bus6	Bus5	5	-0.00895	0.0479	0.00062	-0.05581
Bus4	Bus2	6	-0.43106	-0.40498	0.01752	0.01426
Bus2	Bus1	7	-0.33343	0.16107	0.01313	-0.01785
Bus4	Bus1	8	-0.55188	-0.16249	0.01665	0.02503
Bus5	Bus1	9	-0.47748	-0.13247	0.02035	0.01507
Bus6	Bus2	10	-0.39571	-0.16463	0.01255	-0.01629
Bus5	Bus2	11	-0.24713	-0.19269	0.00973	-0.01165

GLOBAL SUMMARY REPORT

TOTAL GENERATION

REAL POWER [p.u.] 2.9129

REACTIVE POWER [p.u.] 1.7153

TOTAL LOAD

REAL POWER [p.u.] 2.8

REACTIVE POWER [p.u.] 1.9

TOTAL LOSSES

REAL POWER [p.u.] 0.11292

REACTIVE POWER [p.u.] -0.18466

Result and conclusion:

Power flow is run by N-R method using PSAT simulated model of a six bus system.The bus voltages and line flows are found.

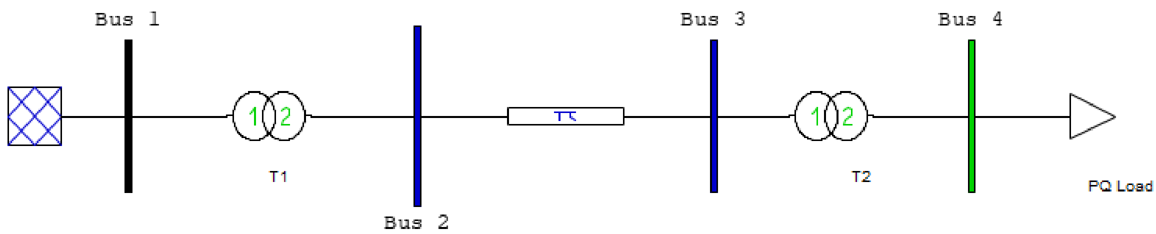
Expt.6

Aim: To study Ferranti effect on long transmission line using PSAT software

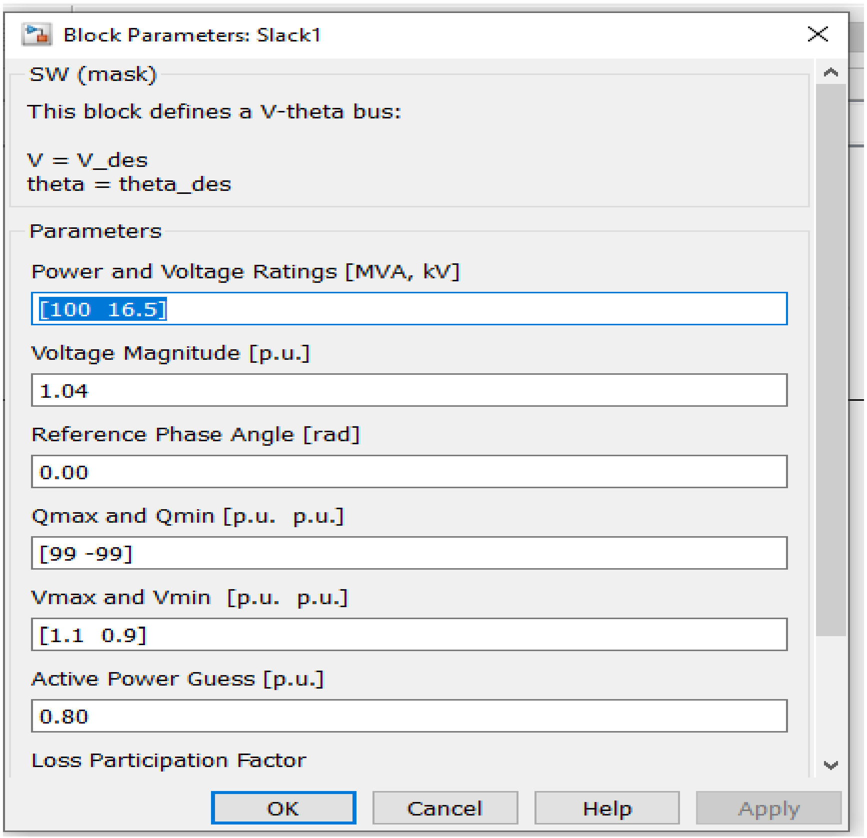
Appts: MATLAB software, PSAT software

PSAT Simulink blocks used: Bus, Slack bus, transmission line pi model load

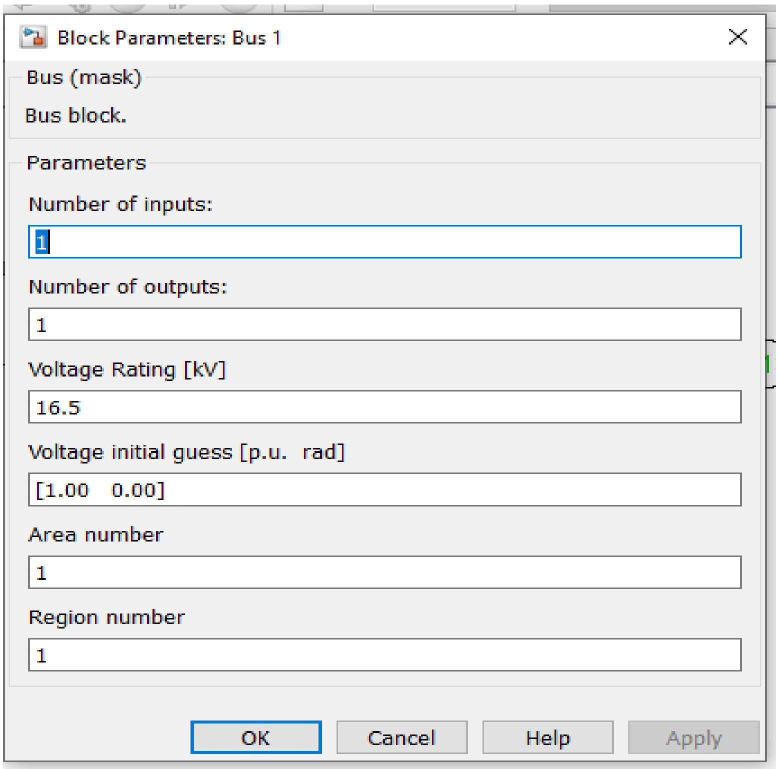
Circuit or simulation diagram:



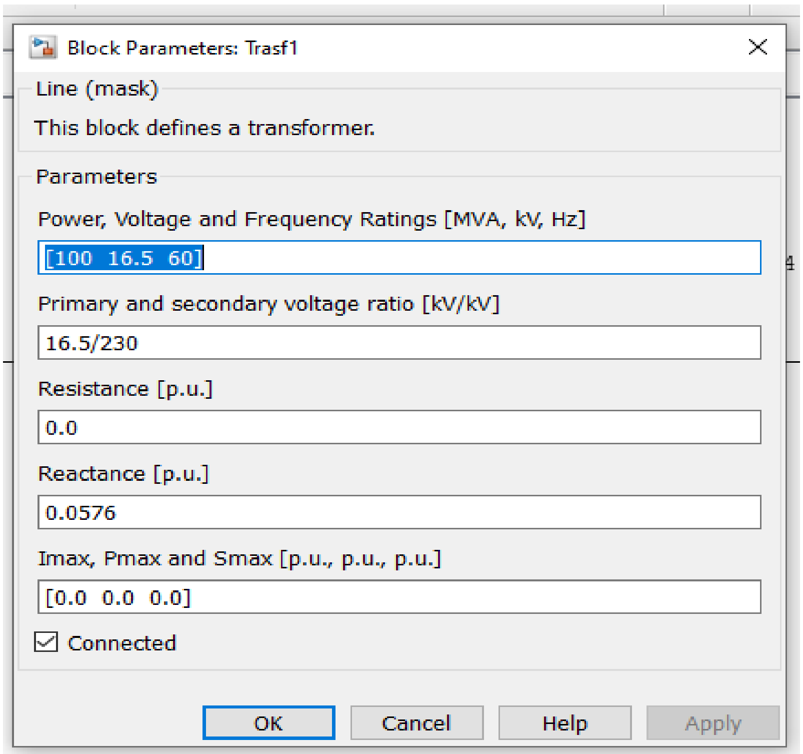
Slack bus



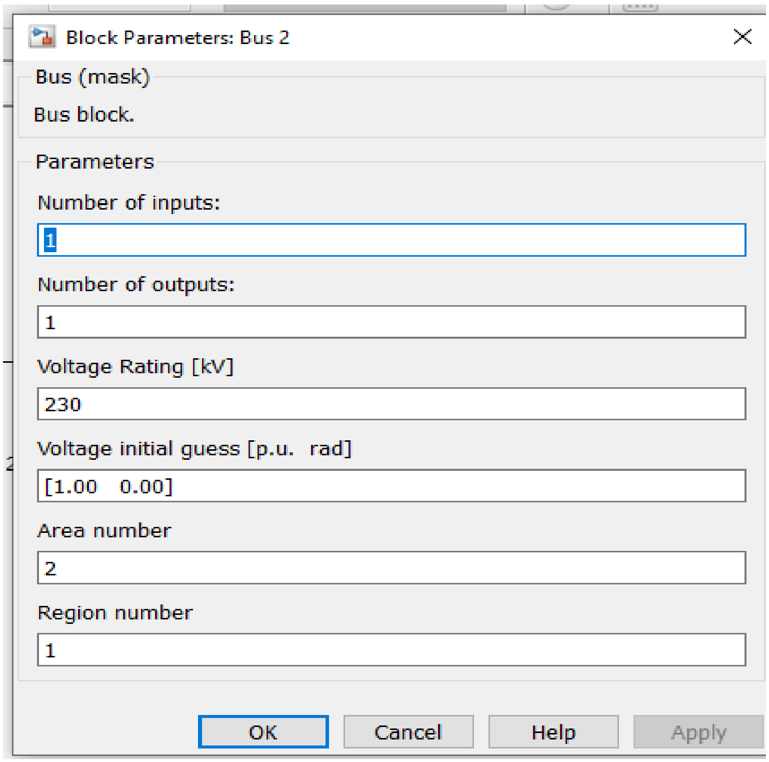
Bus 1



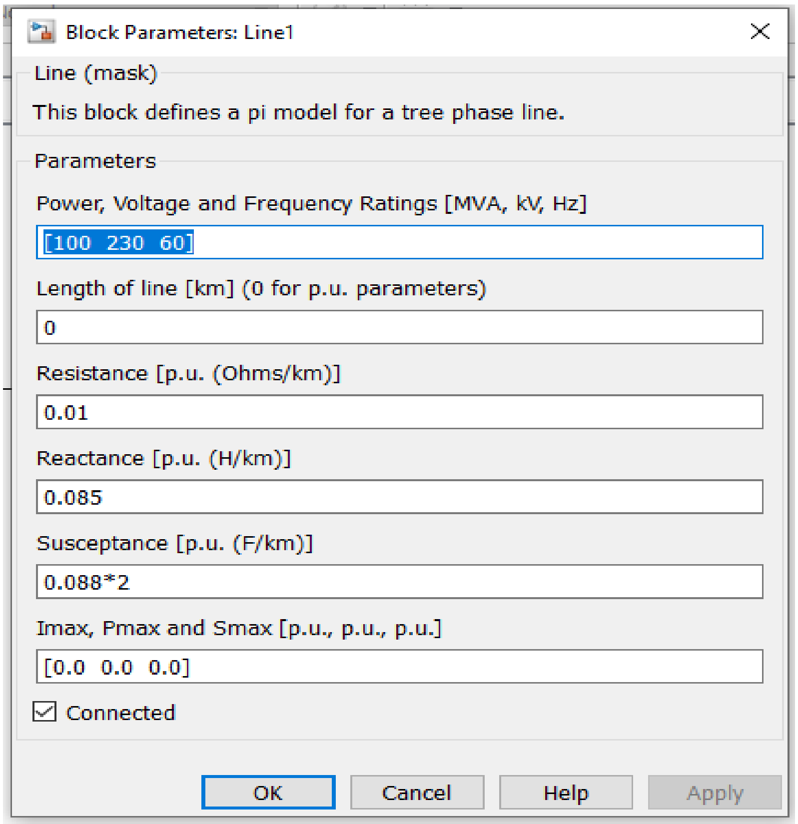
Transformer 1



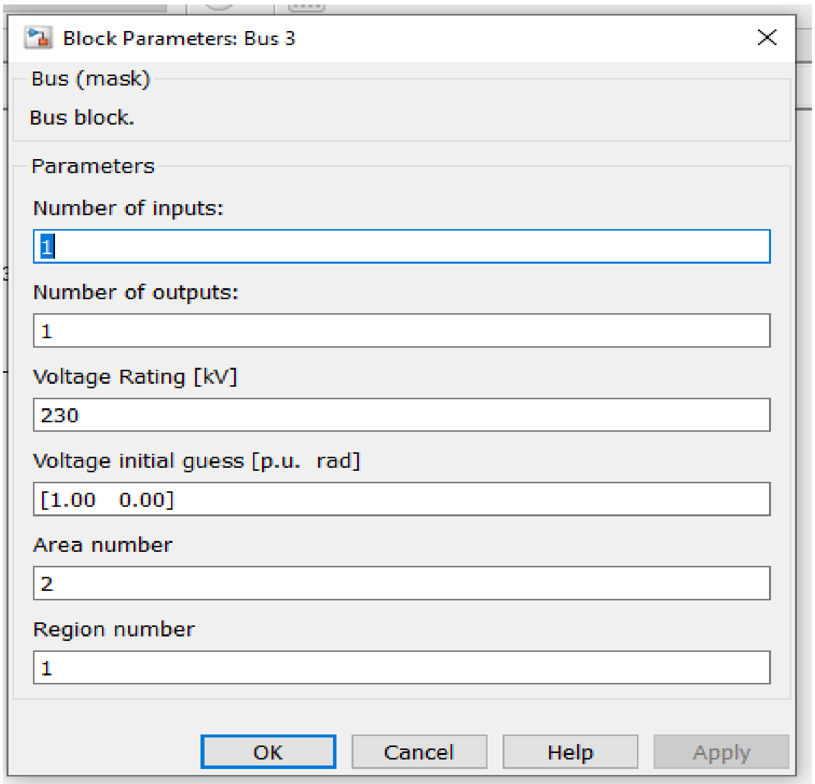
Bus 2



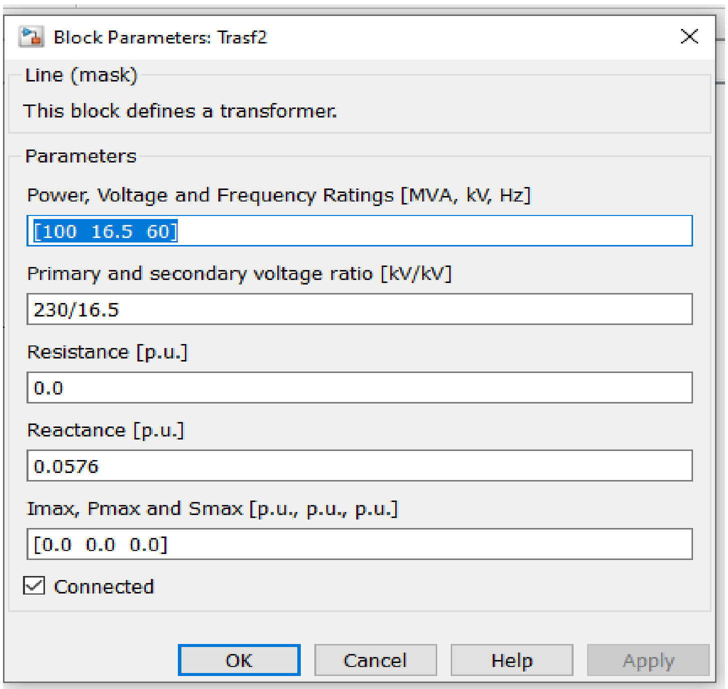
Transmission Line



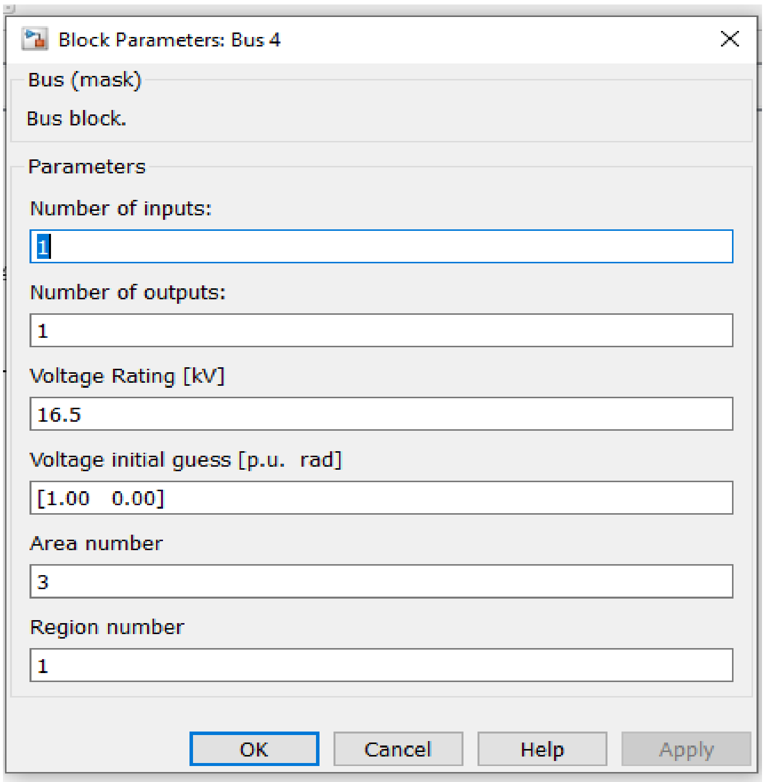
Bus 3



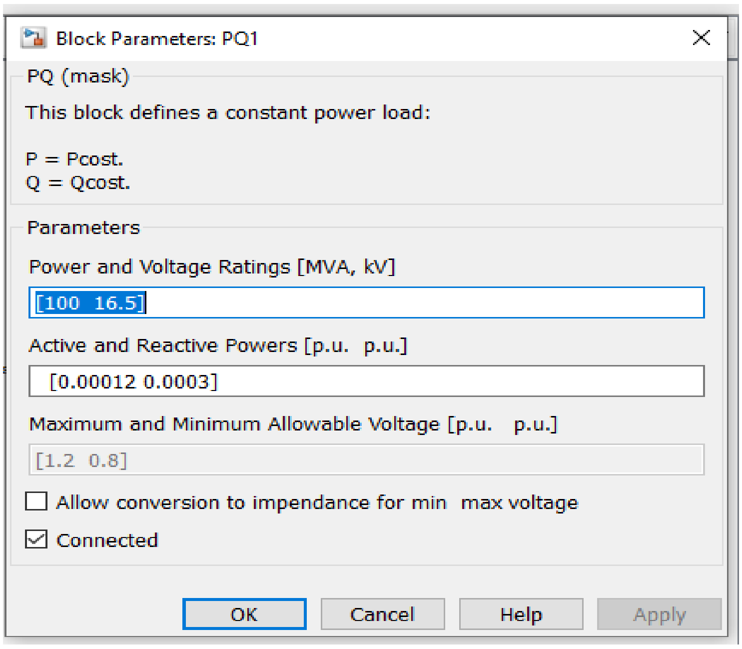
Transformer 2



Bus 4



Constant PQ Load



Procedure

1. Open MATLAB
2. Open PSAT
3. Create model using PSAT Simulink library
4. Set the block parameters.
5. Set load nearly zero
6. Perform Load flow
7. Take Report

Report

Buses:	4
Lines:	1
Transformers:	2
Generators:	1
Loads:	1

SOLUTION STATISTICS

Number of Iterations:	3
Maximum P mismatch [p.u.]	0
Maximum Q mismatch [p.u.]	0
Power rate [MVA]	100

POWER FLOW RESULTS

Bus	V [p.u.]	phase [rad]	P gen [p.u.]	Q gen [p.u.]	P load [p.u.]	Q load [p.u.]
Bus 1	1.04	0	0.00021	-0.19274	0	0
Bus 2	1.0507	-1e-05	0	0	0	0
Bus 3	1.0586	-0.0009	0	0	0	0
Bus 4	1.0586	-0.0009	0	0	0.00012	0.0003

LINE FLOWS

From Bus	To Bus	Line	P Flow [p.u.]	Q Flow [p.u.]	P Loss [p.u.]	Q Loss [p.u.]
Bus 3	Bus 2	1	-0.00012	-0.0003	9e-05	-0.19502
Bus 1	Bus 2	2	0.00021	-0.19274	0	0.00198
Bus 3	Bus 4	3	0.00012	0.0003	0	0

LINE FLOWS

From Bus	To Bus	Line	P Flow	Q Flow	P Loss	Q Loss

			[p.u.]	[p.u.]	[p.u.]	[p.u.]
Bus 2	Bus 3	1	0.00021	-0.19472	9e-05	-0.19502
Bus 2	Bus 1	2	-0.00021	0.19472	0	0.00198
Bus 4	Bus 3	3	-0.00012	-0.0003	0	0

GLOBAL SUMMARY REPORT

TOTAL GENERATION

REAL POWER [p.u.] 0.00021
REACTIVE POWER [p.u.] -0.19274

TOTAL LOAD

REAL POWER [p.u.] 0.00012
REACTIVE POWER [p.u.] 0.0003

TOTAL LOSSES

REAL POWER [p.u.] 9e-05
REACTIVE POWER [p.u.] -0.19304

Conclusion:

It is found that receiving end voltage is greater than sending end voltage. Ferranti effect is verified.

Expt.7

Aim: To study Dynamic response of change in frequency of isolated single area system.

Appts: MATLAB software

MATLAB Simulink blocks used: Transfer Function, summing/adder, scope

Data of single area system:

A 250 Mw Synchronous generator has following data.

R=Speed regulation of governor=3

Ksg=Gain of speed governor=1

Tsg=Time constant of speed governor=0.4 Sec

ΔPc=Speed governor setting (Commanded change in frequency).

Kt=Gain of turbine=1

Tt=Turbine time constant=0.5 Sec

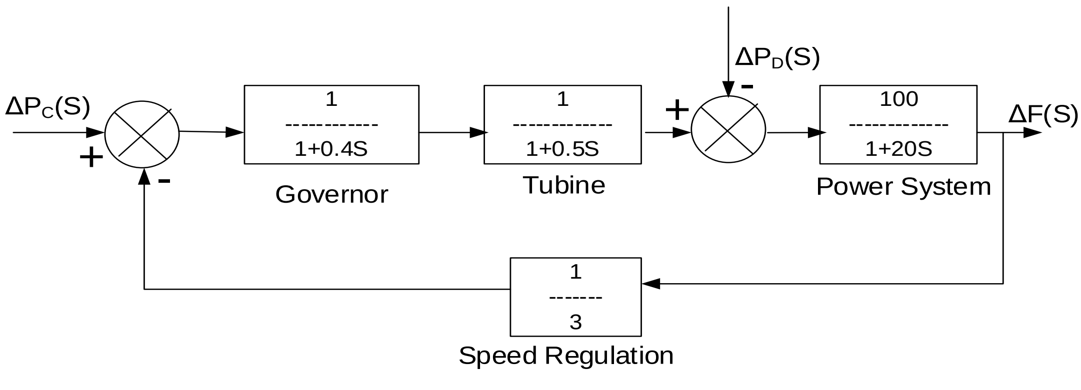
Tps=Power system time constant=20 Sec

Kps=Power system gain=100

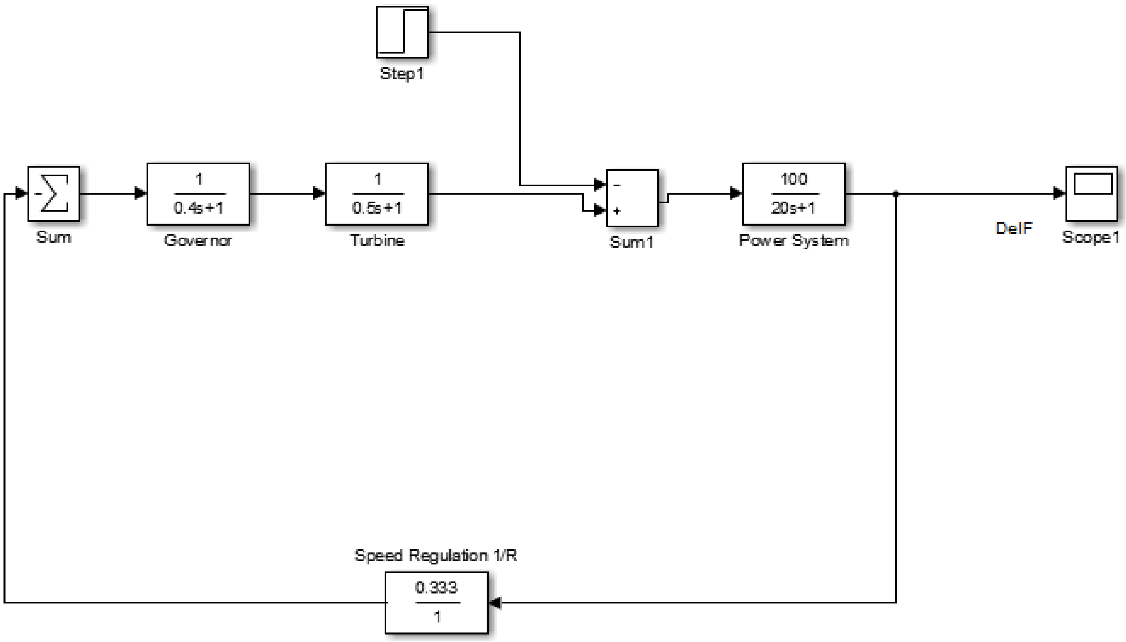
ΔP_D=Step load change =0.01 pu

Circuit Diagram/Block Diagram:

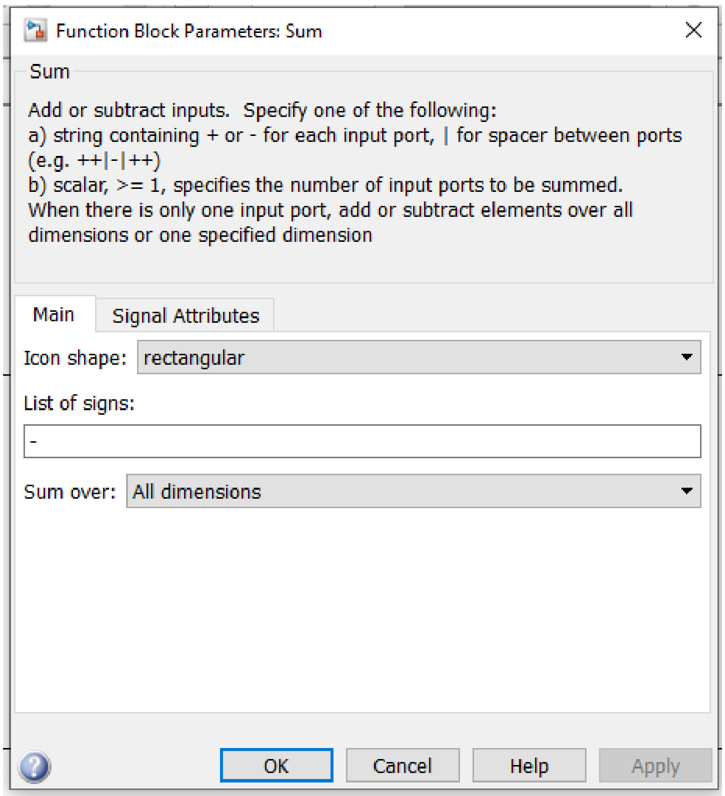
Speed Governing system of isolated single area system



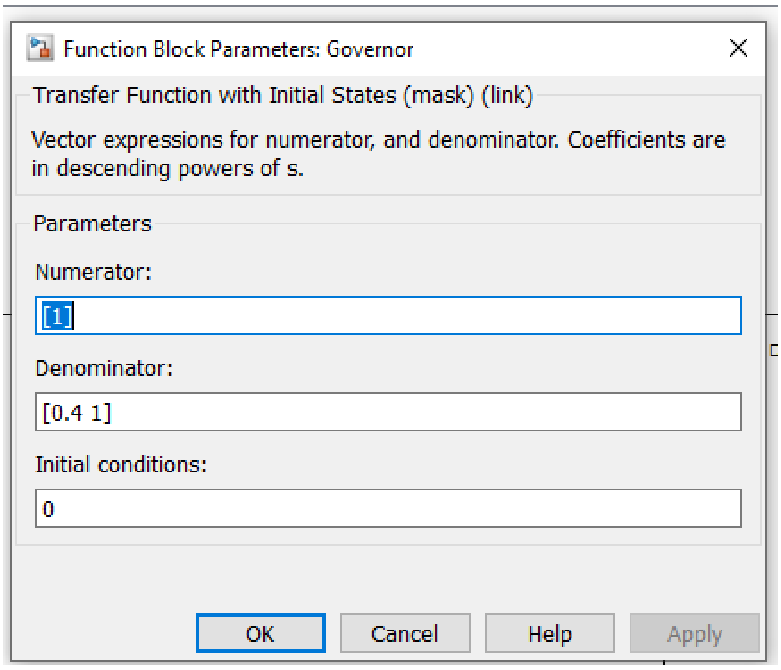
MATLAB Simulation Diagram:



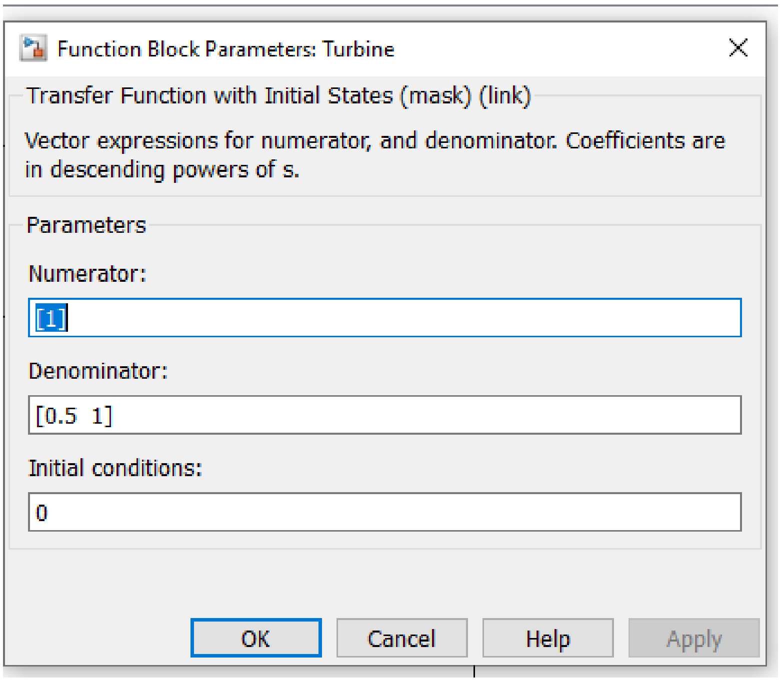
Sum:



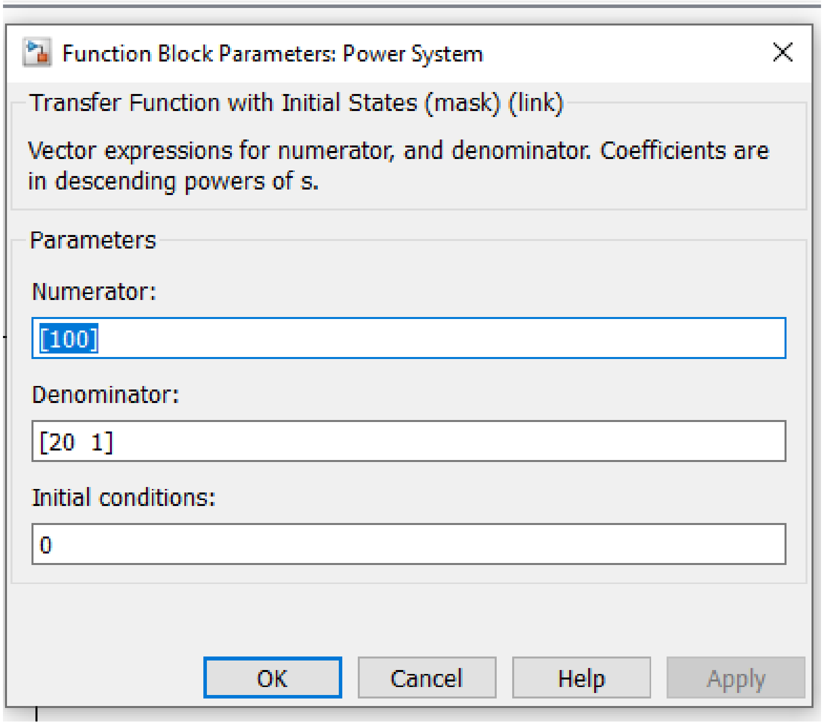
Governor Transfer Function:



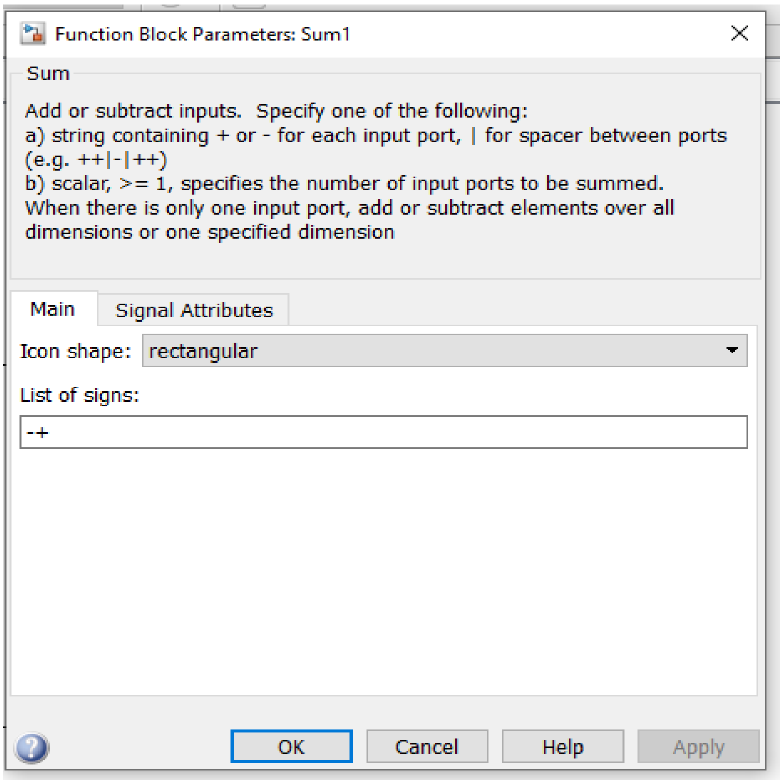
Turbine Transfer Function:



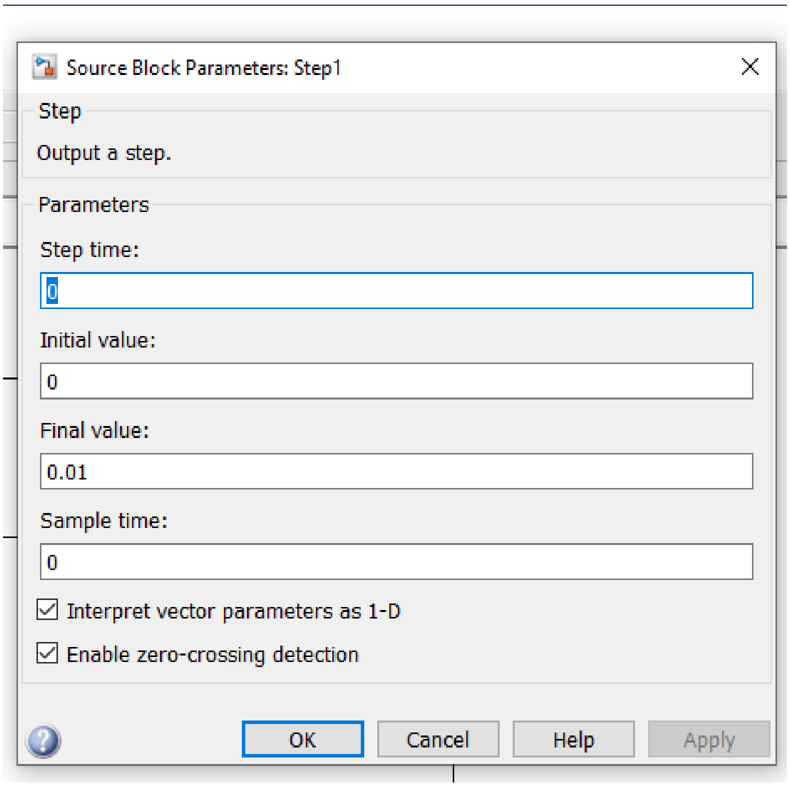
Power System transfer Function:



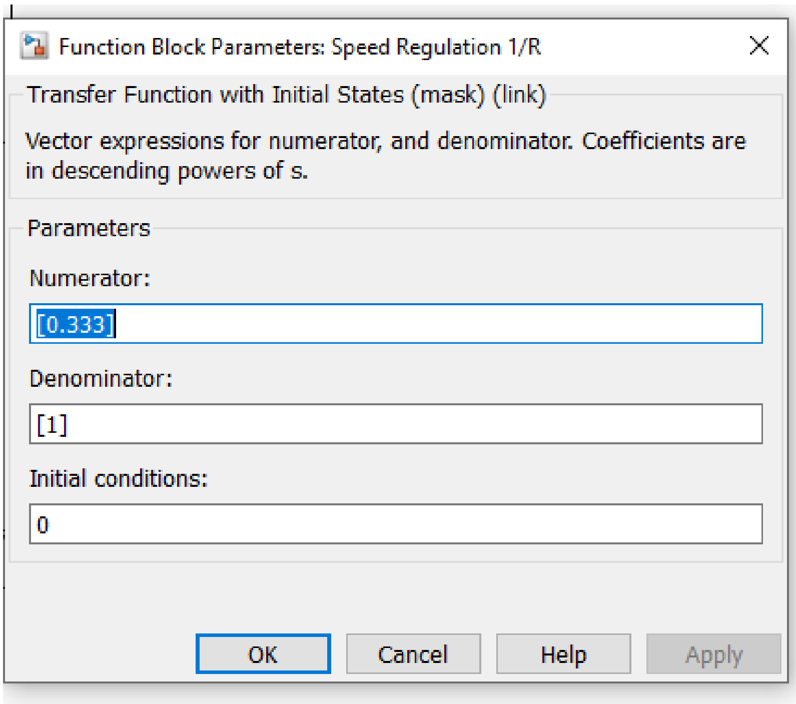
Sum 1:



Step:

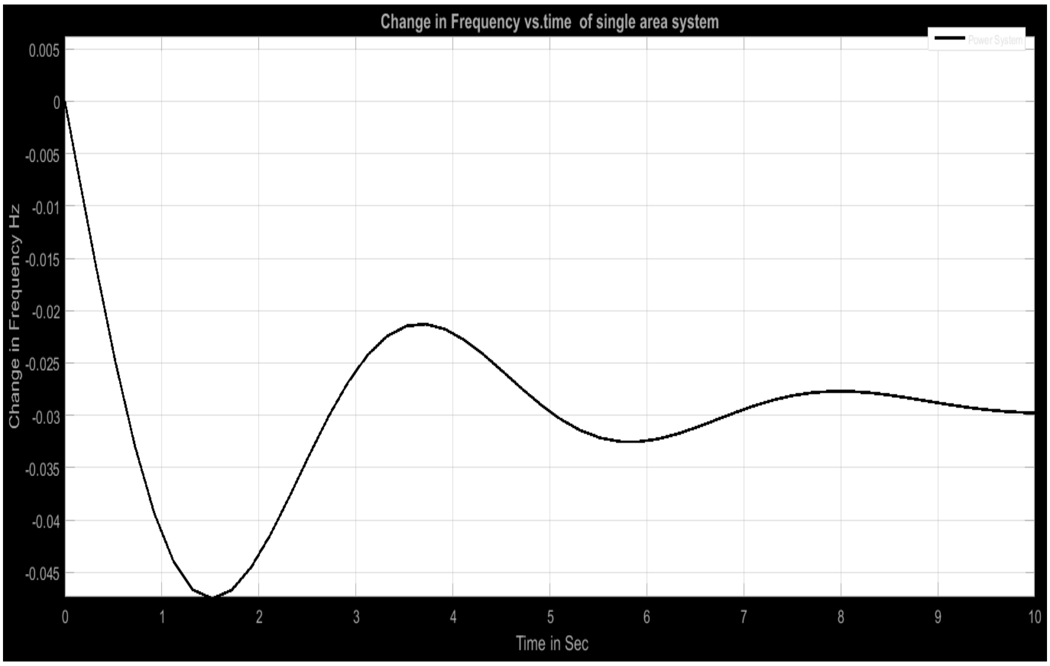


Speed Regulator Transfer Function:



Procedure;

1) Open MATLAB
2) Create Model using MATLAB Simulink library
3) Set all block parameters.
4) Perform simulation
5) Click on scope block
6) Convert the graph on scope to MATLAB figure
7) Name the axes of graph



Conclusion:

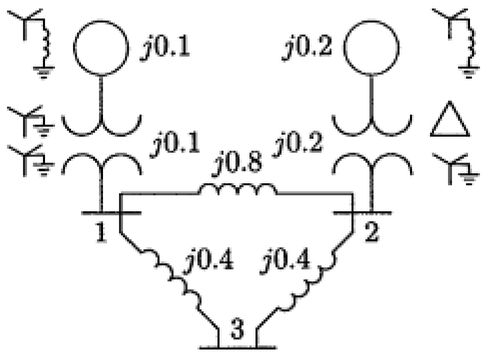
It is found that with free governor action frequency drops by 0.029 Hz in steady state for a step change of 0.01 Pu in load.

Expt.8

Aim: Three phase fault analysis using Power World Simulator

Appts: Power World Simulator software

Power System:



All impedances are expressed in Pu on common 100 MVA base.

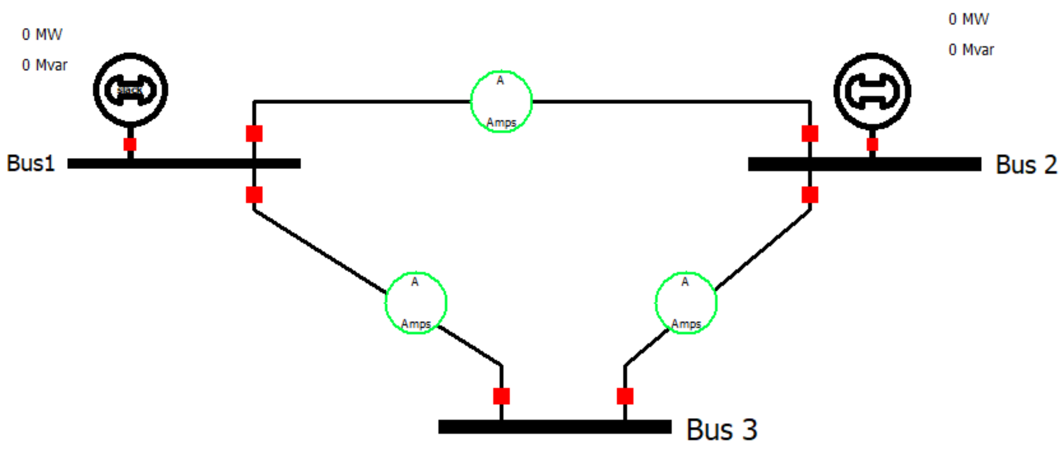
Determine fault current and bus voltages for three phase fault on bus 3 if

1. Fault impedance is zero
2. Fault impedance is $Z_f = 0.16$ pu

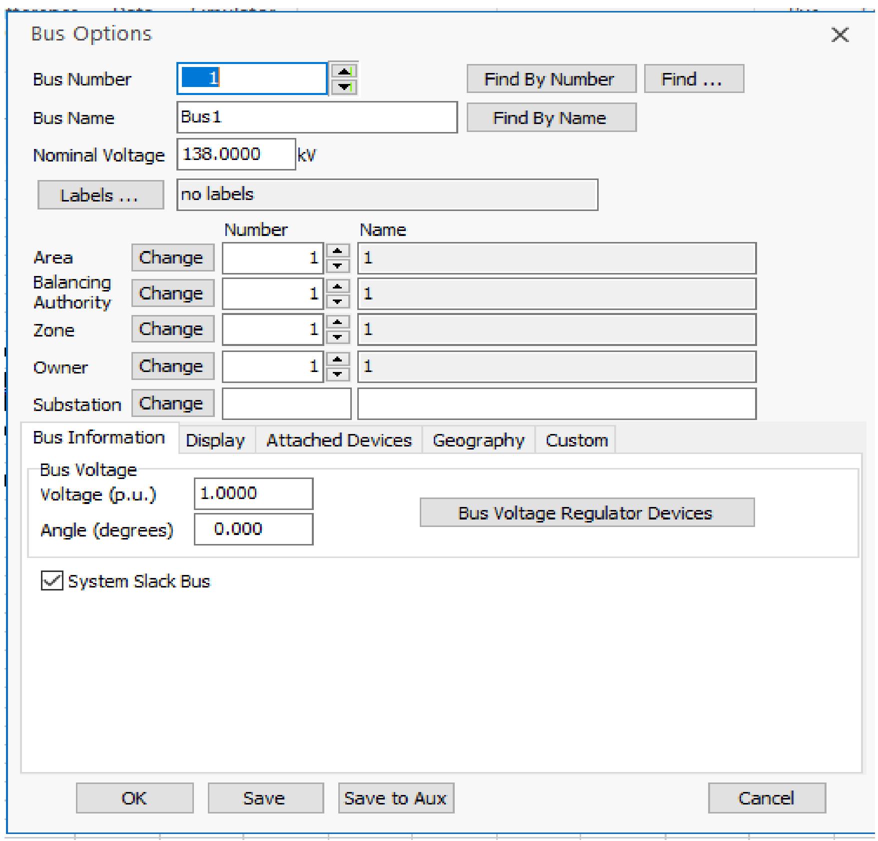
Procedure:

1. Open PW simulator
2. File>new case. For better visibility go to options>Draw Grid>Grid horizontal =4. Grid Lines.
3. In Edit mode,Network>Bus. Name it Bus 1. Change display size to 15. Select it as system slack bus
4. Similarly draw other two buses
5. Network>transmission line. Draw line between Bus 1 and Bus 2. Insert line reactance. Go to Display and increase line width to 3
6. Similarly draw other two lines
7. Network>Generator. Click on the Bus1.Select fault parameters and set generator and transformer reactances. You can set display size and thickness also. Go to Power and voltage control tab and set Mw set point to any arbitrary value or zero.
8. Similarly Connect other generator to bus 2
9. Run Mode>Tools>Play (Green Button)>Fault Analysis. A new window opens.
10. Click on Bus 3. Balanced three phase faults. Set fault impedance (Z_f if any)
11. Click on Calculate
12. Results will be displayed

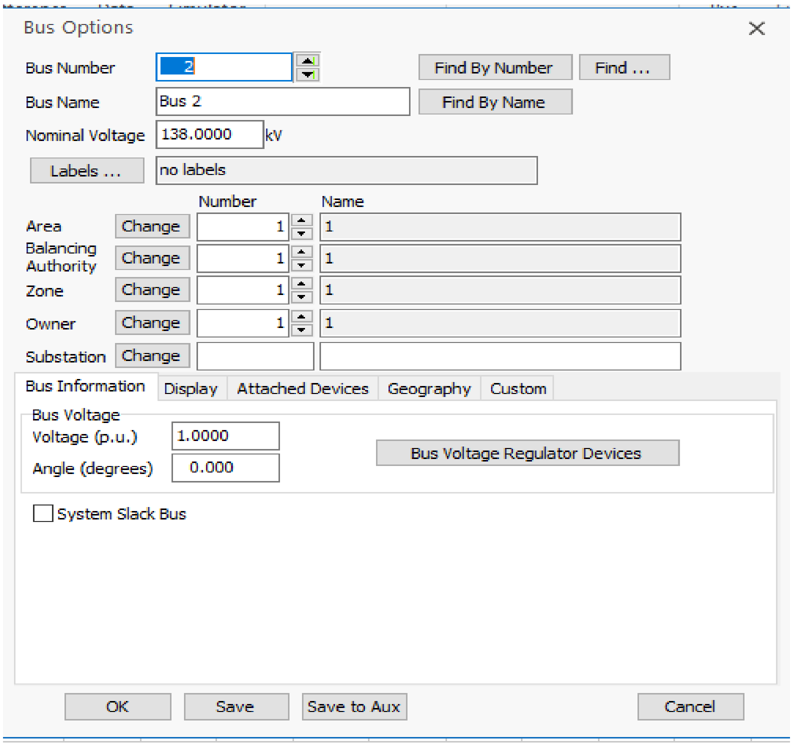
Simulation diagram:



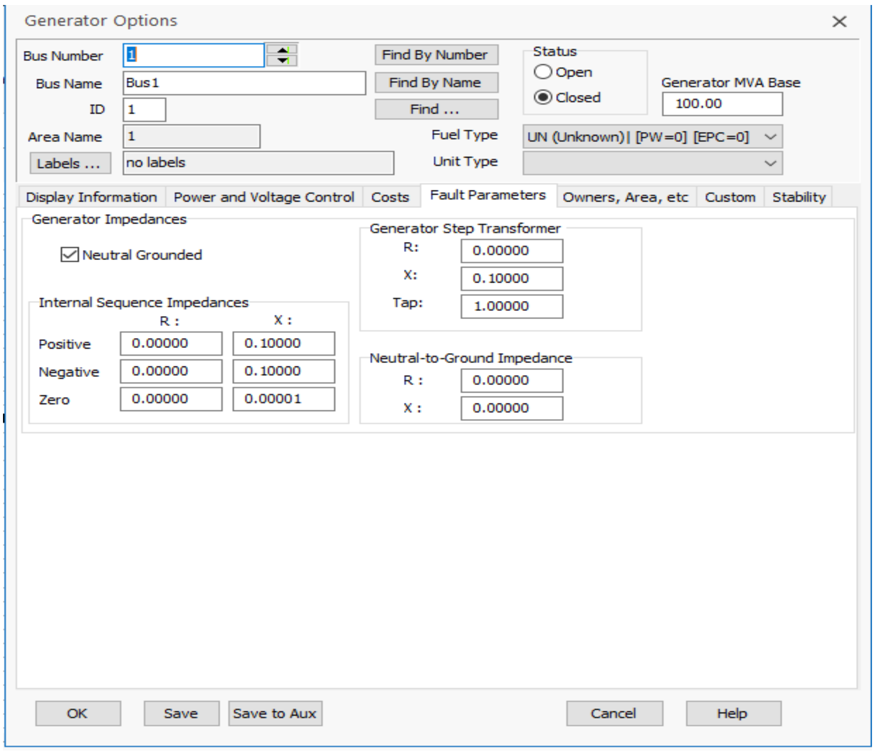
Bus 1:



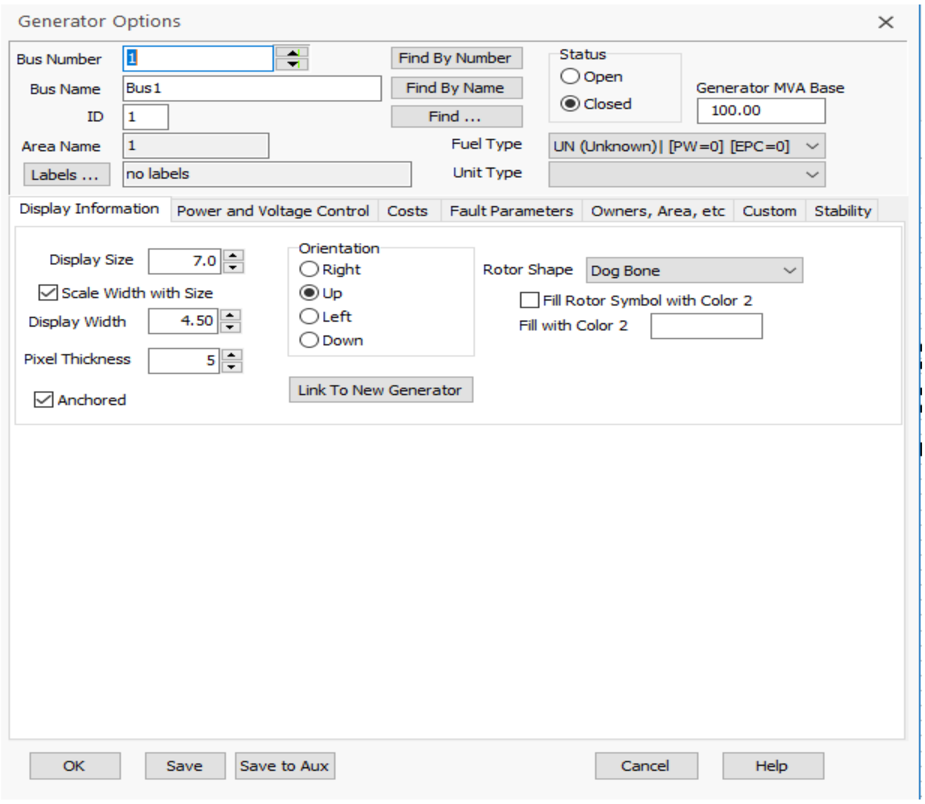
Bus 2:


Bus Options
Bus Number
2
Find By Number
Find ...
Bus Name
Bus 2
Find By Name
Nominal Voltage
138.0000
kV
Labels ...
no labels
Number
Name
Area
Change
1
1
Balancing Authority
Change
1
1
Zone
Change
1
1
Owner
Change
1
1
Substation
Change
Bus Information
Display
Attached Devices
Geography
Custom
Bus Voltage
Voltage (p.u.)
1.0000
Angle (degrees)
0.000
Bus Voltage Regulator Devices
System Slack Bus
OK
Save
Save to Aux
Cancel

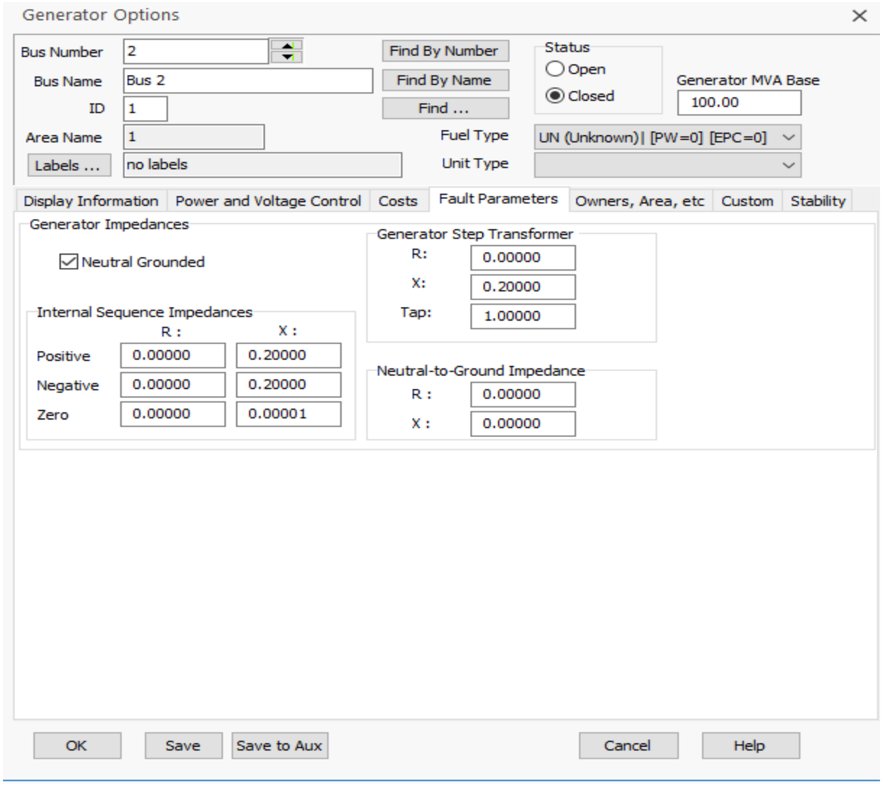
Gen. 1:


Generator Options
Bus Number
1
Find By Number
Status
Open
Closed
Bus Name
Bus1
Find By Name
Generator MVA Base
100.00
ID
1
Find ...
Area Name
1
Fuel Type
UN (Unknown)| [PW=0] [EPC=0]
Labels ...
no labels
Unit Type
Display Information
Power and Voltage Control
Costs
Fault Parameters
Owners, Area, etc
Custom
Stability
Generator Impedances
Neutral Grounded
Generator Step Transformer
R:
0.00000
X:
0.10000
Tap:
1.00000
Internal Sequence Impedances
R :
X :
Positive
0.00000
0.10000
Negative
0.00000
0.10000
Zero
0.00000
0.00001
Neutral-to-Ground Impedance
R :
0.00000
X :
0.00000
OK
Save
Save to Aux
Cancel
Help

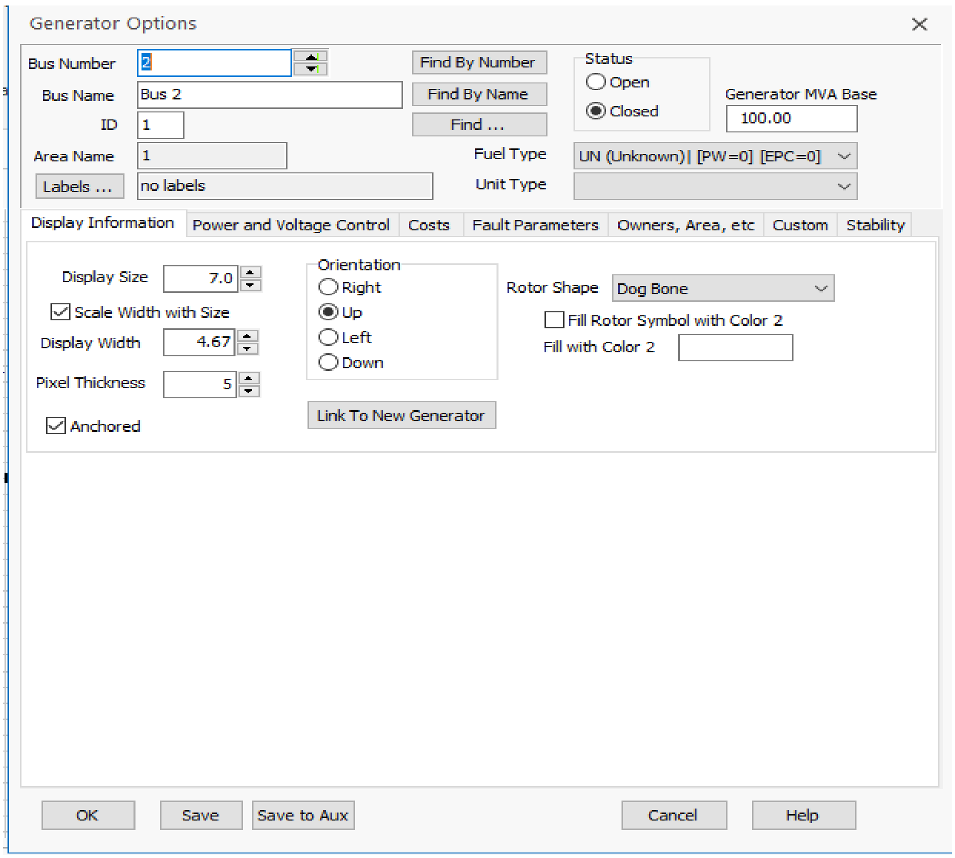
Gen. 1 Options:



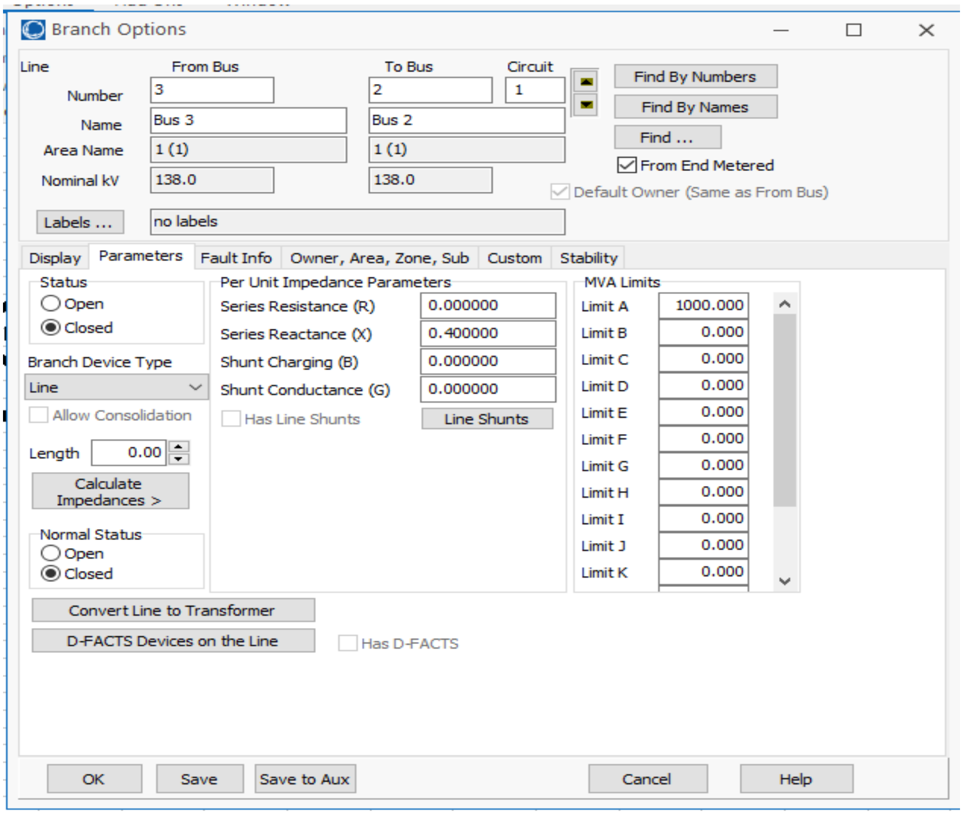
Gen. 2:



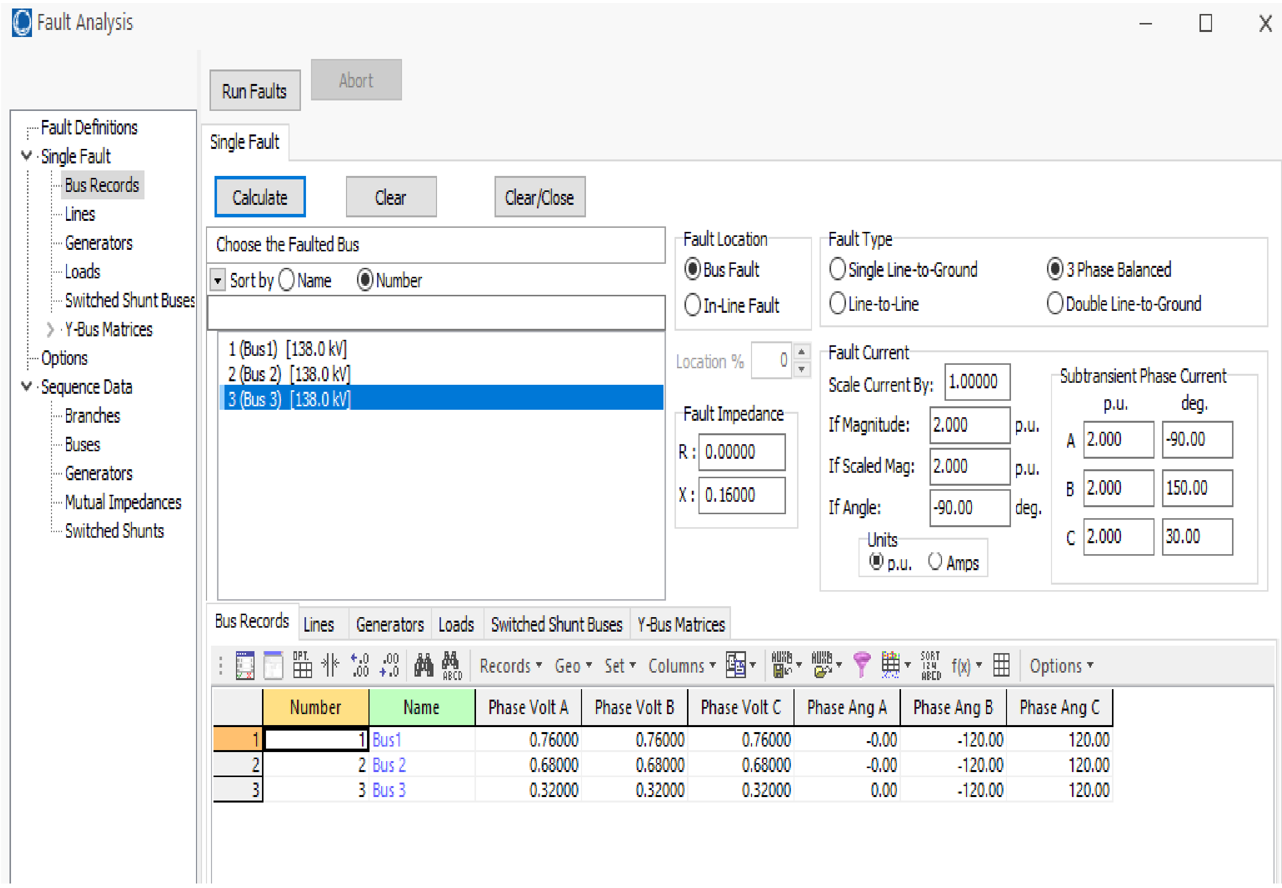
Gen. 2 Options



Line Parameters:



Results:



	Number	Name	Phase Volt A	Phase Volt B	Phase Volt C	Phase Ang A	Phase Ang B	Phase Ang C
1	1	Bus1	0.76000	0.76000	0.76000	-0.00	-120.00	120.00
2	2	Bus 2	0.68000	0.68000	0.68000	-0.00	-120.00	120.00
3	3	Bus 3	0.32000	0.32000	0.32000	0.00	-120.00	120.00

Conclusion: For a Three phase fault on bus 3 the fault current for fault impedance of 0.16 pu is found to be 2.0 Pu.