Advanced Power System Analysis
Lecture 6
Load Flow Study Using Power System Software and MATLAB source coding
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Lecture learning outcomes:

At the end of this lecture, you will be able to:

i. Determine the Y-bus matrix using direct method

ii. Identify the power flow simulation software

iii. Solve the Gauss–Seidel load Flow solution

iv. Develop the flowchart of MATLAB source code for power flow techniques

Outlines

1. Introduction
2. Common Power System Analysis Software
3. Gauss–Seidel Method Solved Problem
4. Load Flow Solution Using PSAT Simulator
5. Gauss–Seidel Iterative Algorithm Using MATLAB
6. Newton Raphson Algorithm (NRA)

Summary

References

1. Introduction

- Using power system software is essential to analyze large power system network, because it’s useful to:

- Analyze large-scale systems (1000+ buses) quickly.

- Avoid human error in tedious matrix calculations.

- Modify system data easily like changing loads or line impedances.

- Modeling, analyzing and determining the network parameter within short period of time is easily achieved

2. Common Power System Analysis Software

i. Electrical Transient Analyser Program (ETAP)[1]:

- Relay coordination, lightening, load flow, short circuit, and transient analysis are among its uses.
- Ideal for power utility planning, commercial and industrial power systems.

Advantages: Comprehensive analytical modules, integrated one-line graphic, and user-friendly GUI.

ii. PowerWorld Simulator [2].

- Used for the time-domain simulation, Voltage stability, OPF, load flow, and contingency analysis.
- Very good for utility grid simulation, education, and visualization.
- Highly interactive for simulation, excellent user-friendliness, and visible outcomes

Software Cont.…

iii. DIgSILENT PowerFactory

- Used for: Coordination of protection, dynamic simulation, and advanced power system analysis of load flow.
- Ideal for: Renewable energy integration, transmission networks, and utilities.
- Advantages: Detailed modeling, scripting support, and high degree of customization.

iv. The Siemens PSSE , Power System Simulator for Engineering

- Stability analysis, dynamic simulation, and load flow are among its uses.
- Ideal for the research use and transmission networks.
- Benefits include a large selection of plugins and industry ,and academic trust.

Software Cont.…

V. PSAT, MATLAB/Simulink

- Utilized for automation, dynamic systems, load flow, and custom simulation.
- Ideal for Power electronics, control systems, and research.
- Adaptability, large library, and simple code integration makes it more adaptable
- Better for GUI, continuation power flow analysis and the system network voltage stability analysis bas ed on the most fluctuating demands
- The maximum load multipliers can be determined
- Accordingly, the PSAT simulation software and MATLAB Simulink are used in

  this lecture

Software's Cont.…

2.1 PSAT software[3] : Without having to deal with lists of data directly, PSAT uses the Simulink environment and its graphical characteristics to provide a CAD tool that can construct power networks, visualize the topology, and modify the data contained within.

But simulink isn't the greatest technique to approach a power system network; it was designed for control diagrams with variables for inputs and outputs.

- Consequently, simulink's time domain functions and control block diagram-building capabilities are not used.
- PSAT just creates a data file after reading the data from the Simulink model.

Software's Cont.…

Steps to use PSAT simulation software are[4]:

- Step-1: Define bus data
- Step-2:Define the generator data
- Step-3:Define line/branch data
- Step-4: Define the iterative solution techniques to formulate problems
- Step-5: Model the network
- Step-6: Load and simulate the power flow results
- Step-7: Develop the results and record it.

3. Gauss–Seidel Method Solved Problem(GSMSP)

▪Example: The system data for a load flow solution are given in the following Tables. Determine the volta ges at the end of first iteration by Gauss–Seidel method. Take a = 1.2.

Table 1. Line parameter

Bus code	x
1-2	0.15
1-3	0.3
1-4	0.4
2-3	0.3
3-4	0.15

Table 2. Bus data

Bus	P	Q	V	Remarks
1	-	-	1.0	Swing bus
2	0.5	-0.2	-	PQ Bus
3	-1.0	0.5	-	PQ Bus
4	0.3	-0.1	-	PQ Bus

GSMSP Cont.…

Solution:

- First, we need to convert reactance (x) into admittance using Y=1/X as:

Table 3: Bus admittance conversion

Line	Reactance (X)	Y
1–2	0.15	−j6.67
1-3	0.3	−j3.33
1-4	0.4	−j2.5
2-3	0.3	−j3.33
3-4	0.15	−j6.67

GSMSP Cont.…

- **Step -1: Form bus admittance matrix for four bus network:** Y=4*4 matrix.
- The diagonal, Off-diagonal elements and Y-Bus matrix is given by:

$$Y_{11} = Y_{12} + Y_{13} + Y_{14}$$
$$= \text{j}(6.67 + 3.33 + 2.5) = \text{-j}12.5$$
$$Y_{22} = \text{j}(6.67 + 3.33) = \text{-j}10$$
$$Y_{33} = Y_{31} + Y_{32} + Y_{34}$$
$$= \text{j}(3.33 + 3.33 + 6.67) = \text{-j}13.33$$
$$Y_{44} = Y_{41} + Y_{43}$$
$$= \text{j}(2.5 + 6.67) = \text{-j}9.17$$

$$Y_{12} = Y_{21} = -\text{j}6.67$$
$$Y_{13} = Y_{31} = -\text{j}3.33$$
$$Y_{14} = Y_{41} = -\text{j}2.5$$
$$Y_{23} = Y_{32} = -j3.33$$
$$Y_{34} = Y_{43} = -\text{j}6.67$$
$$Y_{24} = Y_{42} = 0$$

$$Y = j\begin{bmatrix} -12.5 & 6.67 & 3.33 & 2.5 \\ 6.67 & -10 & 3.33 & 0 \\ 3.33 & 3.33 & -13.33 & 6.67 \\ 2.5 & 0 & 6.67 & -9.17 \end{bmatrix}$$

GSMSP Cont.…

- Step-2: select slack bus, which is bus-1 and its voltage and angle are: V=1.05 p.u, δ=0:
- Step 3. Assume initial values of voltages for all buses except the slack bus.

$$V_2^0 = V_3^0 = V_4^0 = 1pu$$
$$\delta_2^0 = \delta_3^0 = \delta_4^0 = 0$$

- Step 4. Set convergence criterion , ε=0.01
- **Step** 5. Set iteration count k = 0.
- **Step** 6. Bus count i = 1. If ‘i’ is the slack bus, then there will be an increment in the bus count.
- **Step** 7. Solve the voltage equation for bus i as we know that.

GSMSP Cont.…

- **Step** 7. Solve the voltage equation for load bus i as we know that.

$$V_2^{k+1} = \frac{\frac{P_2 - jQ_2}{(V_2^k)^*} - (\sum_{j=1, j\neq i}^{n} Y_{i,j} * V_j^k)}{Y_{2,2}}$$

$$V_3^{k+1} = \frac{\frac{P_3 - jQ_3}{(V_3^k)^*} - (\sum_{j=1, j\neq i}^{n} Y_{i,j} * V_j^k)}{Y_{3,3}}$$

$$V_4^{k+1} = \frac{\frac{P_4 - jQ_4}{(V_4^k)^*} - (\sum_{j=1, j\neq i}^{n} Y_{i,j} * V_j^k)}{Y_{4,4}}$$

- But, the load real and reactive power at each demand is given by:

$$P_2 = -0.5, Q_2 = 0.2$$
$$P_3 = 1,\ Q_3 = -0.5$$
$$P_4 = -0.3,\ Q_4 = 0.1$$

GSMSP Cont….

$$V_2^{k+1} = \frac{\frac{P_2 - jQ_2}{(V_2^k)^*} - (\sum_{j=1, j\neq i}^{n} Y_{i,j} * V_j^k)}{Y_{2,2}}$$

$$V_2^1 = \frac{(\frac{-0.5 - j0.2}{1} - [(1* j6.67) + 1* j3.33))}{-j10}$$

$$= 1.02 + j0.05 = 1.02\angle 2.8$$

$$V_4^{k+1} = \frac{\frac{P_4 - jQ_3}{(V_4^k)^*} - (\sum_{j=1, j\neq i}^{n} Y_{i,j} * V_j^k)}{Y_{4,4}}$$

$$V_4^1 = \frac{(\frac{-0.3 - j0.1}{1} - [(1* j2.5) + (0.963 - j0.001) * j6.67))}{-j9.17}$$

$$= -0.282 - j0.733$$

$$= 0.79\angle 68.89$$

$$V_3^{k+1} = \frac{\frac{P_3 - jQ_3}{(V_3^k)^*} - (\sum_{j=1, j\neq i}^{n} Y_{i,j} * V_j^k)}{Y_{2,2}}$$

$$V_3^1 = \frac{(\frac{1 + j0.5}{1} - [(1* j3.33) + 1.02\angle 2.8 * j3.33) + (1*6.67))}{-j13.33}$$

$$= j0.075 - j0.076 + 0.763$$

$$= 0.963 - j0.001 = 0.963\angle -0.059$$

4. Load Flow Solution Using PSAT Simulator

- PSAT is a free software downloaded for free, which is used for GUI, power flow simulation, stability analysis, contingency analysis and OPF.
- Accordingly, the above four bus problem can be also solved using PSAT simulation

Steps to use PSAT for power flow analysis are:

1. Open the PSAT from your storage and type >>psat in Matlab directory and then Fig.1 will be displaye d in the MATLAB.

PSAT Simulator Cont….

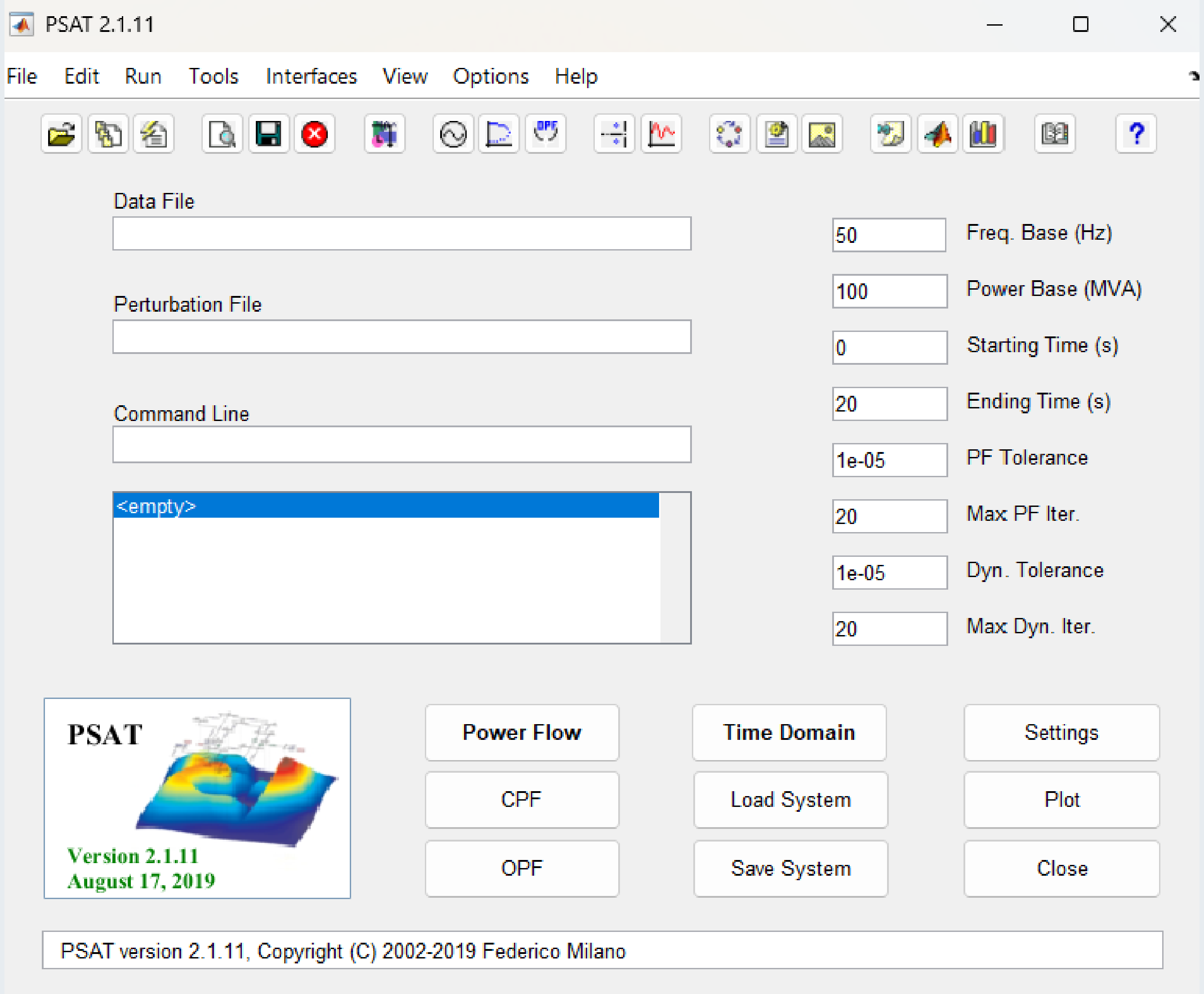

Figure 1. PSAT window for power flow simulation

PSAT Simulator Cont.…

2. Model the network using the data find in PSAT library based on your input file, which given in Fig.2.

3. Save the data using .mdl form.

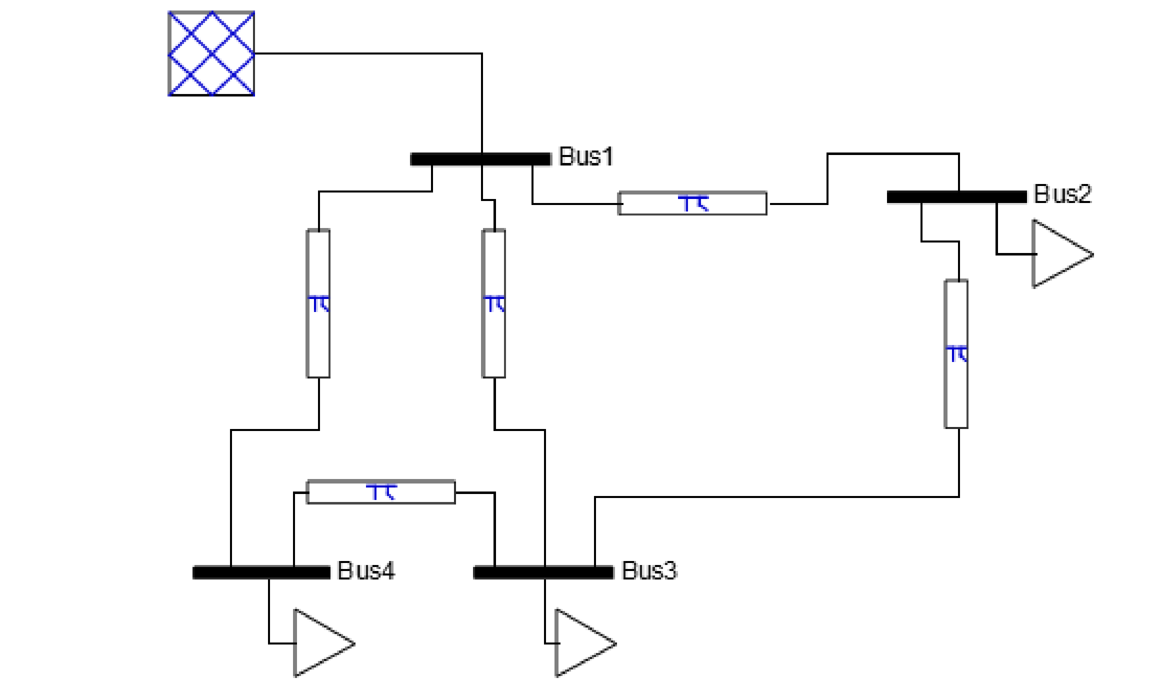

Figure 2. Four Bus PSAT Model

PSAT Simulator Cont.…

- 4. Load the saved model to MATLAB Simulink as provided in Fig.3

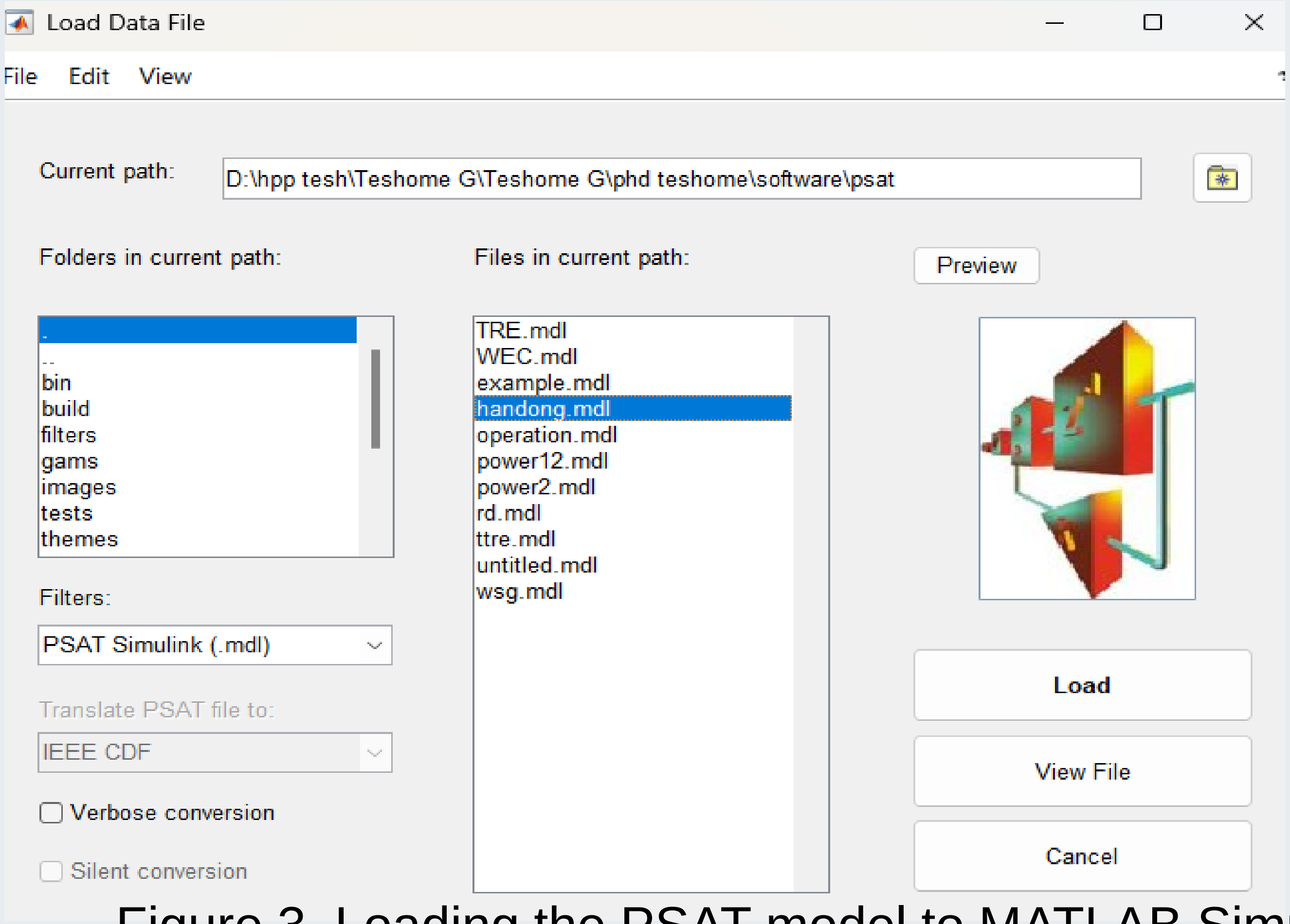

Figure 3. Loading the PSAT model to MATLAB Simulink library

PSAT Simulator Cont.…

- 5. Run the load flow analysis and develop the results based on Fig.4

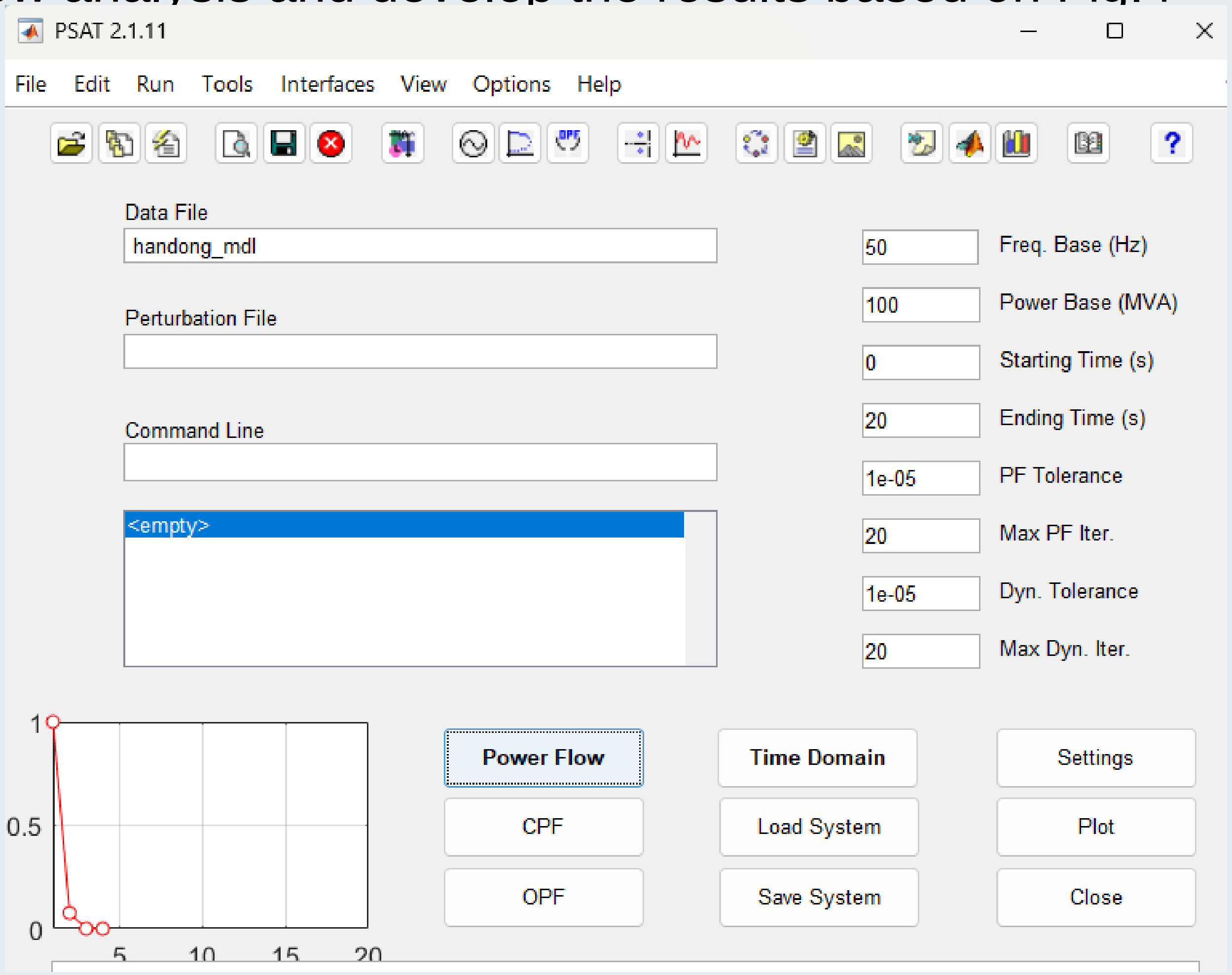

Figure 4. Four bus power network PSAT simulation

PSAT Simulator Cont.…

- Voltage of Line #3 from bus <Bus1> to bus <Bus4> differs more than 10% from the base defined at the connected bus <Bus1>

PF **solver: Newton-Raphson method**

- Single slack bus model
- Iteration = 1 Maximum Convergence Error = 0.070141
- Iteration = 2 Maximum Convergence Error = 0.0053507
- Iteration = 3 Maximum Convergence Error = 2.8229e-05
- Iteration = 4 Maximum Convergence Error = 8.035e-10
- Power Flow completed in 0.111 s

PSAT Simulator Cont.…

- PF solver: F**ast decoupled method**
- Single slack bus model
- Iteration = 1 Maximum Convergences Error = 0.46145
- Iteration = 2 Maximum Convergences Error = 0.014233
- Iteration = 3 Maximum Convergences Error = 0.00052403
- Iteration = 4 Maximum Convergences Error = 1.685e-05
- Iteration = 5 Maximum Convergences Error = 5.9762e-07
- Power Flow completed in 0.094 s

PSAT Simulator Cont.…

- Voltage of Line #3 from bus <Bus1> to bus <Bus4> differs more than 10% from the base defined at the connected bus <Bus1>
- **PF solver: Robust power flow method**
- Single slack bus model
- Iteration = 1 Maximum Convergence Error = 0.070141
- Iteration = 2 Maximum Convergence Error = 0.0053507
- Iteration = 3 Maximum Convergence Error = 2.8229e-05
- Iteration = 4 Maximum Convergence Error = 8.035e-10
- Power Flow completed in 0.08 s

PSAT Simulator Cont.…

- Number of Iterations:4
- Maximum P mismatch [MW] =2.22045E-14
- Maximum Q mismatch [MVar] =1.0783E-12

Table 4. Power flow results

Bus	V	phase	P gen	Q gen	P load	Q load
	[kV]	[rad]	[MW]	[MVar]	[MW]	[MVar]
Bus1	132	0	20	-10.30 E-14	0	0
Bus2	130.4924	0.026949	-5.6E-15	-7.2E-14	-50	20
Bus3	136.1981	-0.06802	-2.2E-14	-2E-13	100	-50
Bus4	132.2764	-0.00359	1.67E-14	1.08E-12	-30	10

PSAT Simulator Cont.…

Table 5. Line flows in forward direction

From Bus	To Bus	Line	P Flow	Q Flow	P Loss	Q Loss
			[MW]	[MVar]	[MW]	[MVar]
Bus1	Bus2	1	-17.7586	7.853683	0	0.565574
Bus1	Bus3	2	23.37621	-9.80605	-3.6E-15	1.927818
Bus1	Bus4	3	14.38242	-8.34898	0	0.06914
Bus2	Bus3	4	32.24136	-12.7119	0	3.687035
Bus3	Bus4	5	-44.3824	21.8672	0	3.449082

PSAT Simulator Cont.…

Table 6. Line flows in backward direction

From Bus	To Bus	Line	P Flow	Q Flow	P Loss	Q Loss
			[MW]	[MVar]	[MW]	[MVar]
Bus2	Bus1	1	17.75864	-7.28811	0	0.565574
Bus3	Bus1	2	-23.3762	11.73387	-3.6E-15	1.927818
Bus4	Bus1	3	-14.3824	8.418122	0	0.06914
Bus3	Bus2	4	-32.2414	16.39893	0	3.687035
Bus4	Bus3	5	44.38242	-18.4181	0	3.449082

PSAT Simulator Cont.…

Table 7. Global summary report

Total generation		
• Real power [mw]		20
• Reactive power [mvar]		-10.3014
Total load		
• Real power [mw]		20
• Reactive power [mvar]		-20
Total losses		
• Real power [mw]		-7.1e-15
• Reactive power [mvar]		9.69865
Limit violation statistics		
• all voltages except bus three are within limits.		
• all reactive power within limits.		
• all current flows within limits.		
• all real power flows within limits.		
• all apparent power flows within limits.		

PSAT Simulator Cont.…

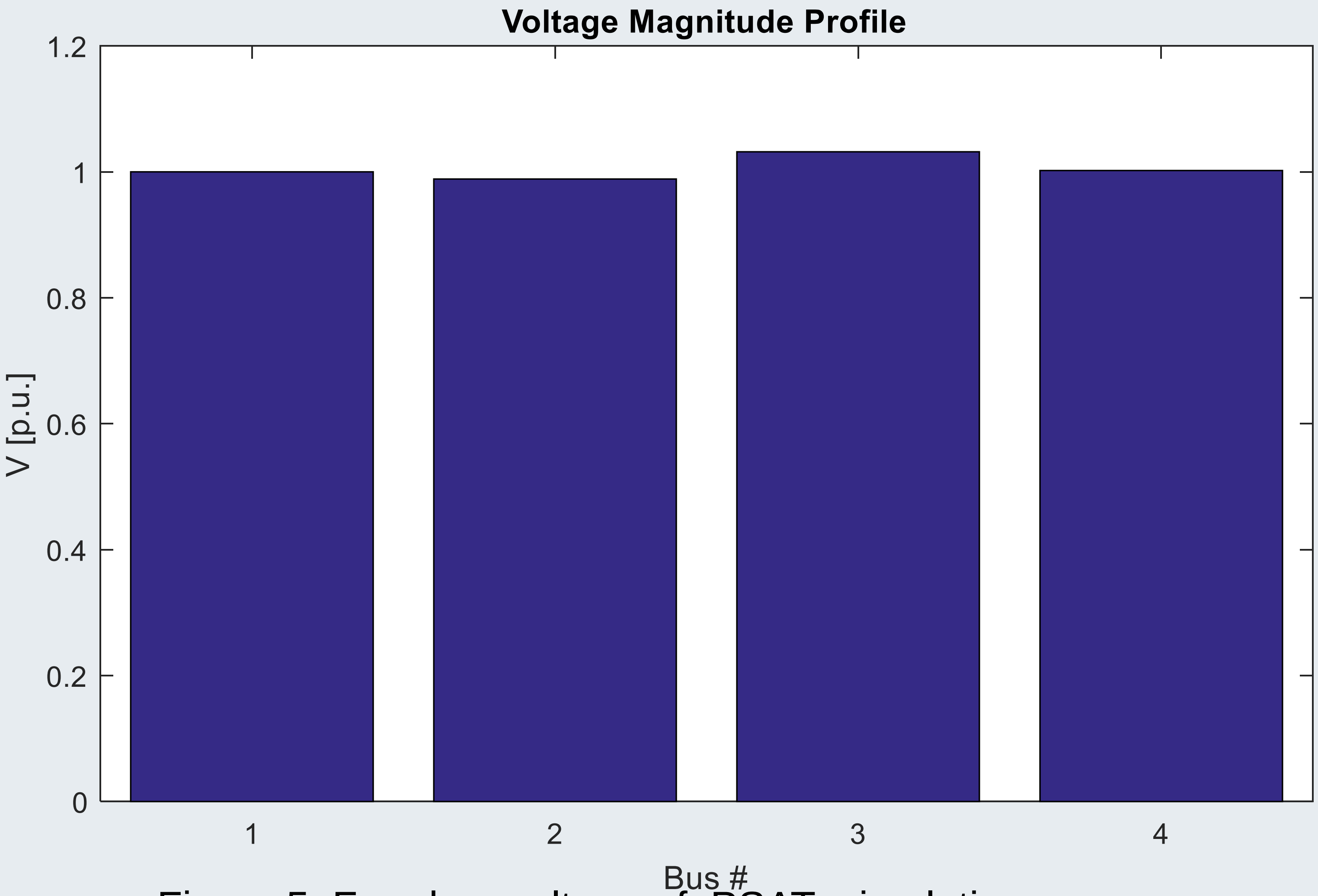

Figure 5. Four bus voltage of PSAT simulation

5. Gauss–Seidel Iterative Algorithm Using MATLAB

- The GS iterative solution using MATLAB source code applies for developing
- The y-bus matrix
- PV bus power flow solution
- PQ bus power flow solutions
- The power mismatch calculations
- The flowchart to develop GS based load flow solution is presented in Fig.6

GSIA Cont….

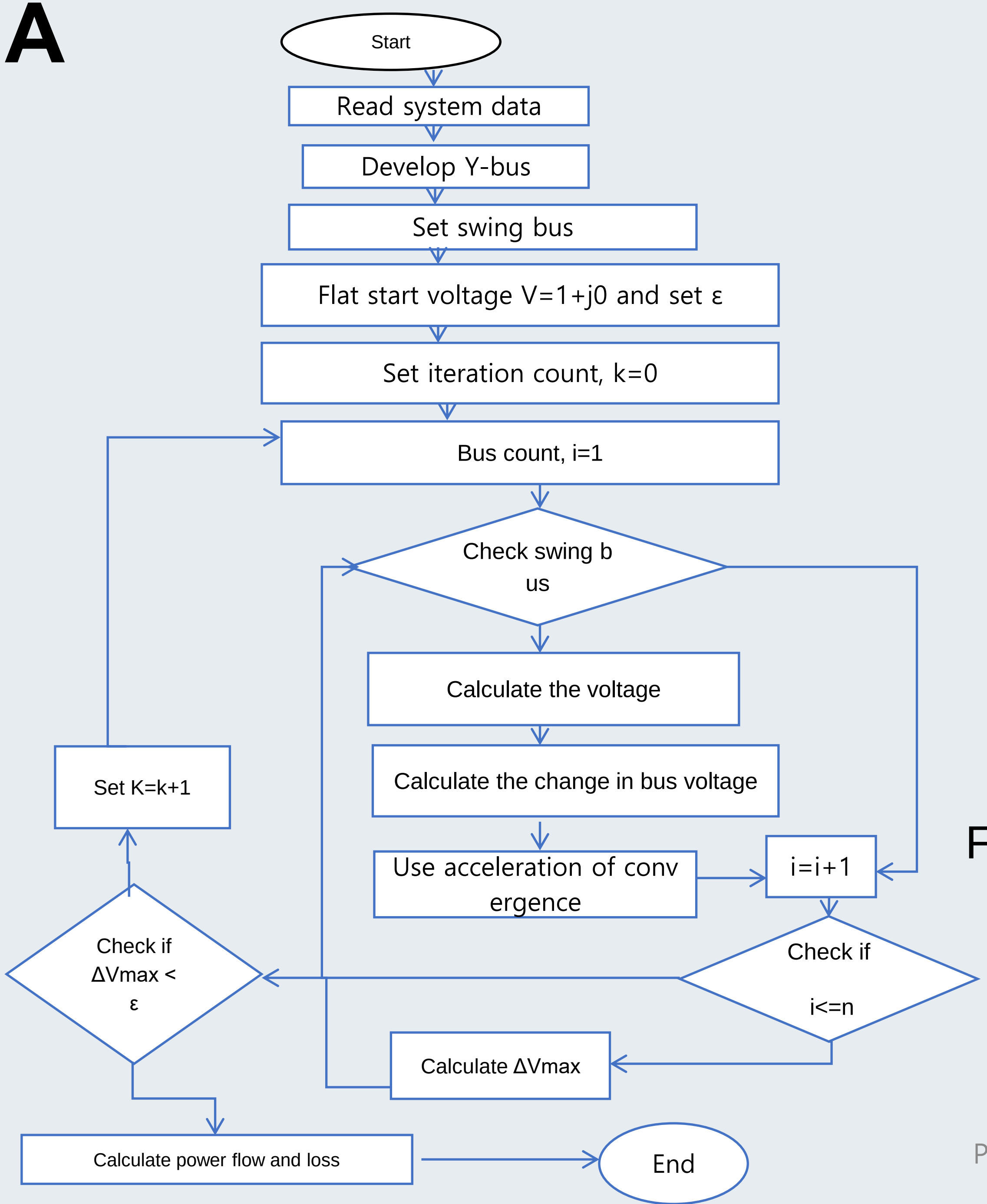

Figure 6. GS power flow source code flowchart.

6. Newton Raphson Algorithm (NRA)

- Determine
- Calculate Jacobean matrix
- Solve the following equation to find $\Delta\delta_{(i)}$ and $\Delta V_{(i)}$
- Power flows and losses on the network branches
- Lastly, determine the slack bus's real and reactive power

NRA Cont.…

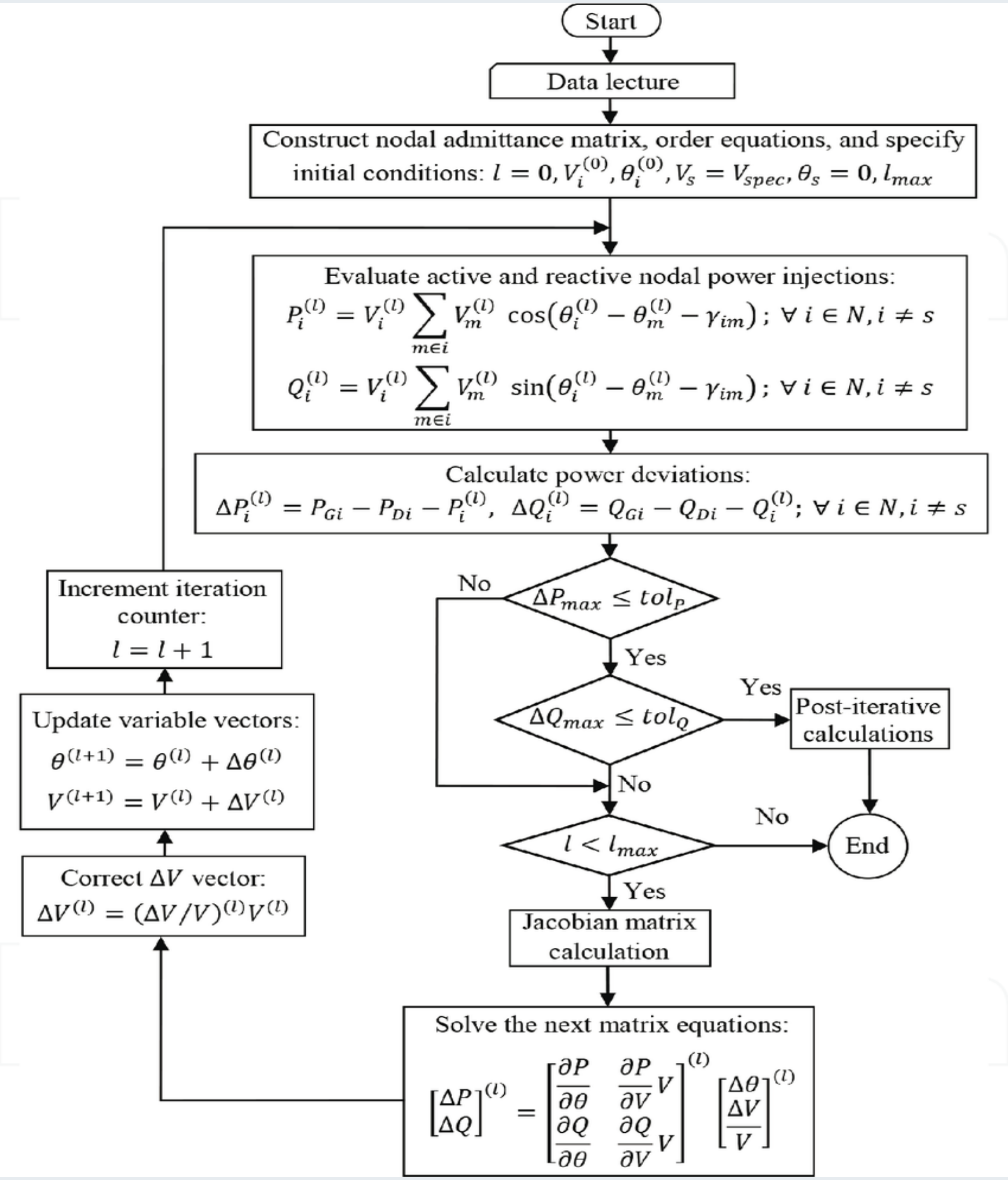

Figure 7 : NR load flow algorithm.

Url: https://www.researchgate.net/publication/367688833/figure/fig1/AS:11431281116672819@1675288548779/Flow-chart-for-solving-power-flow-problems-by-Newton-Raphson-method.png

NRA Cont.…

▪Example 2: The same system data for a load flow solution are given in the following Tables. Determine

a. the Y bus matrix using direct method

Table 7. Line parameter

Bus code	x
1-2	0.15
1-3	0.3
1-4	0.4
2-3	0.3
3-4	0.15

Table 8. Bus data

Bus	P	Q	V	Remarks
1	-	-	1.0	Swing bus
2	0.5	-0.2	-	PQ Bus
3	-1.0	0.5	-	PQ Bus
4	0.3	-0.1	-	PQ Bus

NRA Cont….

- The source code for Y-bus matrix using direct method is given as:

```
% Formation of admittance matrices Using  Direct  Method
clear all;
clc;
close all;
k=input('\n\n Give the number of buses n=');
B=input('\n\n enter your:\n>>1.for impedance 2.for admittance\n');
if (B==2)
fprintf('\n\n Enter the admittance value:');
end
if(B==1)
fprintf('\n\n Enter the impedance value:');
end
for i=1:k
for j=i+1:k
a(i,j)=0;
fprintf('\n write the bus %d to bus %d values:',i,j);
a(i,j)=input('');
if(B~=2&a(i,j)~=0)
a(i,j)=1/a(i,j);
end
a(j,i)=a(i,j);
end
end
d=input('\n\n for admittance value in source?\n Press “1” for yes and “0” for no:');
if (d==1)
for i=1:k
fprintf('\n Enter for bus %d:',i);a(i,i)=input('');
end
end
for i=1:k
for j=1:k
if(i~=j)
a(i,i)=a(i,i)+a(i,j);
y(i,j)=-a(i,j);
end
end
y(i,i)=a(i,i);
end
fprintf('\n\n Y bus=:>>\n\n');
display(y);
```

NRA Cont.…

y =

12.5000	-6.6667	-3.3333	-2.5000
-6.6667	10.0000	-3.3333	0
-3.3333	-3.3333	13.3333	-6.6667
-2.5000	0	-6.6667	9.1667

NRA Cont….

- Example 3. Using the flowchart presented in Fig.7 develop the MATLAB source code for NR load flow and Determine, the bus admittance matrix and line flow based on the following bus and line data of IEEE-6 bus test system[5].

```
% IEEE 6-BUS TEST SYSTEM
% Bus Bus Voltage Angle ---Load---- ----Generator-- Static Mvar
% No code Mag. Degree MW Mvar MW Mvar Qmin Qmax+Qc/ -Ql
busdata= [1 1 1.05 0.0 0.0 0.0 0.0 0.0 0 0 0
          2 2 1.05 0.0 0.0 0.0 50.0 0.0 -10 80 0
          3 2 1.07 0.0 0.0 0.0 60.0 0.0 -10 95 0
          4 0 0.0 0.0 70.0 70.0 0.0 0.0 0 0 0
          5 0 0.0 0.0 70.0 70.0 0.0 0.0 0 0 0
          6 0 0.0 0.0 70.0 70.0 0.0 0.0 0 0 0];
% Bus bus R X 1/2 B = 1 for lines
% nl nr p.u. p.u. p.u. > 1 or < 1 tr. tap at bus nl
linedata=[1 2 0.1 0.2 0.002 1
          1 4 0.05 0.2 0.02 1
          1 5 0.08 0.3 0.03 1
          2 3 0.05 0.25 0.03 1
          2 4 0.05 0.1 0.01 1
          2 5 0.1 0.3 0.02 1
          2 6 0.07 0.2 0.025 1
          3 5 0.12 0.26 0.025 1
          3 6 0.02 0.1 0.01 1
          4 5 0.2 0.4 0.04 1
          5 6 0.1 0.3 0.03 1];
```

NRA Cont.…

Y=

Columns 1	2	3	4	through 5
4.0063 -11.7659i	-2.0000 + 4.0000i	0.0000 + 0.0000i	-1.1765 + 4.7059i	-0.8299 + 3.1120i
-2.0000 + 4.0000i	9.3283 -23.2135i	-0.7692 + 3.8462i	-4.0000 + 8.0000i	-1.0000 + 3.0000i
0.0000 + 0.0000i	-0.7692 + 3.8462i	4.1557 -16.5673i	0.0000 + 0.0000i	-1.4634 + 3.1707i
-1.1765 + 4.7059i	-4.0000 + 8.0000i	0.0000 + 0.0000i	6.1765 -14.6359i	-1.0000 + 2.0000i
-0.8299 + 3.1120i	-1.0000 + 3.0000i	-1.4634 + 3.1707i	-1.0000 + 2.0000i	5.2933 -14.1378i
0.0000 + 0.0000i	-1.5590 + 4.4543i	-1.9231 + 9.6154i	0.0000 + 0.0000i	-1.0000 + 3.0000i

Column 6
0.0000 + 0.0000i
-1.5590 + 4.4543i
-1.9231 + 9.6154i
0.0000 + 0.0000i
-1.0000 + 3.0000i
4.4821 -17.0047i

NRA Cont.…

- Power Flow Solution by Newton-Raphson Method

Maximum Power Mismatch = 0.079723

No′. of Iterations = 2

Bus Voltage Angle ------Load------ ---Generation---Injected'No. Mag. Degree MW Mvar MW Mvar M var

1	1.050	0.000	0.000	0.000	-116.739	32.052	0.000
2	1.050	5.645	0.000	0.000	50.000	-71.815	0.000
3	1.070	7.706	0.000	0.000	60.000	-20.796	0.000
4	1.051	3.729	70.000	70.000	0.000	0.000	0.000
5	1.065	4.678	70.000	70.000	0.000	0.000	0.000
6	1.069	6.542	70.000	70.000	0.000	0.000	0.000

NRA Cont.…

Line- Power at bus & line -Line lossTransformer
from to MW Mvar MVA Mvar tap

from	to	MW	Mvar	MVA	Line loss MW	Line loss Mvar
1		-116.739	32.052	121.059		
	2	-42.307	23.606	48.447	2.138	3.836
	4	-33.582	6.986	34.301	0.550	-2.214
	5	-29.356	0.582	29.362	0.636	-4.323
2		50.000	-71.815	87.507		
	1	44.445	-19.770	48.644	2.138	3.836
	3	-17.106	-7.995	18.882	0.143	-6.029
	4	29.446	-15.955	33.491	0.493	-1.220
	5	4.121	-8.706	9.632	0.054	-4.311
	6	-10.883	-8.741	13.958	0.098	-5.332
3		60.000	-20.796	63.502		
	2	17.249	1.967	17.360	0.143	-6.029
	5	20.134	-9.403	22.221	0.470	-4.679
	6	22.641	-4.137	23.016	0.091	-1.832
4		0.000	0.000	0.000		
	1	34.132	-9.200	35.350	0.550	-2.214
	2	-28.953	14.735	32.486	0.493	-1.220
	5	-5.169	-5.494	7.543	0.051	-8.850
5		0.000	0.000	0.000		
	1	29.992	-4.905	30.391	0.636	-4.323
	2	-4.068	4.394	5.988	0.054	-4.311
	3	-19.664	4.723	20.223	0.470	-4.679
	4	5.219	-3.356	6.205	0.051	-8.850
	6	-11.470	-0.792	11.498	0.122	-6.462
6		0.000	0.000	0.000		
	2	10.980	3.409	11.497	0.098	-5.332
	3	-22.550	2.306	22.668	0.091	-1.832
	5	11.593	-5.670	12.905	0.122	-6.462

Total loss 4.845 -41.416

Project assignment : For example 2, develop the NR load flow solution.

Take acc = 1.2.

Summary

- In this lecture, the solved problem, Simulation and Source code of Power flow analysis are presented.
- Thus, using the simulation software and developing MATLAB source code is very important to solve la rge number of buses and equations within short period of time.
- It reduces the computational time and hence minimizes the error
- In addition, the types of power flow simulation software's with its brief example is presented

References

[1]. J., Prabhu; S., Sharma; M., Nataraj and D., Tripathi. ‘’Design of electrical system based on load flow analysis using ETAP for IEC projects’’. IEEE 6th International Conference on Power Systems (ICPS), 2016, pp. 1-6. doi: https://doi.org/10.1109/ICPES.2016.7584103.

[2]. S., Syafaruddin and S., Latief. "Lesson Learned from Power System Design with PoweWorld Simulator“. Conference on Power Engineering and Renewable Energy (ICPERE), Solo, Indonesia, 2018. pp. 1-6. doi: https://doi.org/10.1109/ICPERE.2018.8739687.

[3]. L., Vanfretti and F., Milano. "Application of the PSAT, an Open Source Software, for Educational and Research Purposes“. IEEE Power Engineering Society General Meeting, USA, 2007. pp. 1-7, doi: 10.1109/PES.2007.385952.

[4]. B., Ashutosh and B., Dhananjay. ‘’Power Flow Analysis using PSAT’’. International Journal of Enhanced Research in Science Technology & Engineering.V.2(4), 2013, pp:100-105.

[5]. P., Venkatesh; B., Manikandan, S., Charles and A., Srinivasan. ‘’Book:Electrical power systems: Analysis, Security and Deregulation’’. Asoke K. Ghosh, PHI Learning Private Limited

Thank you !