SCHULICH
School of Engineering

UNIVERSITY OF CALGARY

DEPARTMENT OF ELECTRICAL
AND COMPUTER ENGINEERING

ENEL 487
ELECTRICAL ENGINEERING ENERGY SYSTEMS

Lab Instructions

Lab 3: Power Flow Analysis with PowerWorld

SYSTEM DESCRIPTION

The system used in this lab consists of 5 buses and is representative of a small-sized power system. The purpose of this lab is to study and perform power flow analysis and to familiarize yourself with the tools available in PowerWorld to perform such analysis.

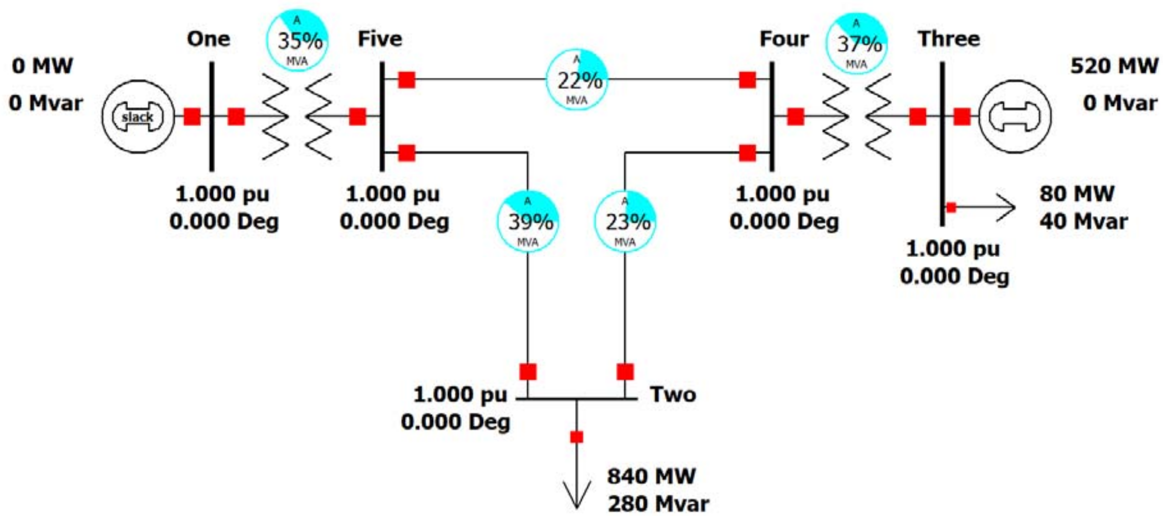


Figure 1-Network Single Line Diagram

To use this system, download the files ***Lab3.pwb*** and ***Lab3.pwd*** from the course D2L site. Start PowerWorld and open ***Lab3.pwb.*** The input data for this network is presented in Tables 1, 2 and 3.

Note: All the system data has already been incorporated into the model. You do not need to change the network data in the PowerWorld file.

Table 1 – Bus data

Bus	**V (pu)**	δ	**P_{Gen} (pu)**	**Q_{Gen} (pu)**	**P_{Load} (pu)**	**Q_{Load} (pu)**	**$Q_{Gen,max}$ (pu)**	**$Q_{Gen,min}$ (pu)**	**Bus Type**
1	1.0	0			0	0	---	---	
2			0	0	8.4	2.8	---	---	
3	1.05		5.2		0.8	0.4	4.0	-2.8	
4			0	0	0	0	---	---	
5			0	0	0	0	---	---	

Note: S_{base}= 100 MVA, V_{base}= 15 kV at buses 1 & 3, and 345 kV at buses 2, 4, and 5

Table 2 – Line data

Bus-to-Bus	R (pu)	X (pu)	G (pu)	B (pu)	Max. MVA (pu)
2-4	0.0090	0.1	0	1.72	12
2-5	0.0045	0.05	0	0.66	12
4-5	0.00225	0.025	0	0.44	12

Table 3 – Transformer data

Bus-to-Bus	R (pu)	X (pu)	G_C (pu)	B_m (pu)	Max. MVA (pu)
1-5	0.0015	0.02	0	0	6
3-4	0.00075	0.01	0	0	10

To view the input data for the system, switch to the **Edit Mode** first. Then click on the **Case Information** tab. Select **Network** followed by **Buses** to view the parameters for each bus. Select **Network** followed by **Lines and Transformers** to view the parameters for the transmission lines and transformers.

After accessing all the system parameters, you should see tables similar to Figures 2 and 3.

	Number	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar
1	1	One	1	15.00	1.00000	15.000	0.00			0.00	0.00
2	2	Two	1	345.00	1.00000	345.000	0.00	840.00	280.00		
3	3	Three	1	15.00	1.00000	15.000	0.00	80.00	40.00	520.00	0.00
4	4	Four	1	345.00	1.00000	345.000	0.00				
5	5	Five	1	345.00	1.00000	345.000	0.00				

Figure 2- Bus Parameters

	From Number	From Name	To Number	To Name	Circuit	Status	Branch Device Type	Xfrmr	R	X	B	Lim MVA A	Lim MVA B	Lim MVA C
1	1	One	5	Five	1	Closed	Transforme	YES	0.00150	0.02000	0.00000	600.0	600.0	600.0
2	4	Four	2	Two	1	Closed	Line	NO	0.00900	0.10000	1.72000	1200.0	1200.0	1200.0
3	5	Five	2	Two	1	Closed	Line	NO	0.00450	0.05000	0.66000	1200.0	1200.0	1200.0
4	3	Three	4	Four	1	Closed	Transforme	YES	0.00075	0.01000	0.00000	1000.0	1000.0	1000.0
5	5	Five	4	Four	1	Closed	Line	NO	0.00225	0.02500	0.44000	1200.0	1200.0	1200.0

Figure 3-Line and Transformer Parameters

Note: The fields shown in blue can be directly changed by double clicking on them.

To display the values of the **Y_{Bus}**, select **Solution Details** followed by **YBus.** Your YBus should look similar to Figure 4.

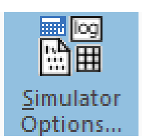
	Number	Name	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5
1	1	One	3.73 - j49.72				-3.73 + j49.72
2	2	Two		2.68 - j28.57		-0.89 + j9.92	-1.79 + j19.84
3	3	Three			7.46 - j99.44	-7.46 + j99.44	
4	4	Four		-0.89 + j9.92	-7.46 + j99.44	11.92 - j147.96	-3.57 + j39.68
5	5	Five	-3.73 + j49.72	-1.79 + j19.84		-3.57 + j39.68	9.09 - j108.69

Figure 4-YBus

Before starting the Newton-Raphson solution of this network, switch to Run Mode and:

- Select **Case Information** followed by **Network** followed by **Mismatches** to display the mismatch vector. This shows the real and reactive power flow equations evaluated at each bus based on the current values of V, δ, P_{gen}, Q_{gen}. As you can see, the mismatch vector is not zero at the first iteration.
- Select **Case Information** followed by **Solution Details** followed by **Power Flow Jacobian** to display the Jacobian matrix.

To perform the Newton-Raphson iterations, go to the **Tools** tab and then select **Solve-Single Solution-Full Newton.** In version 20 of the software, this option is not immediately visible. To activate single iteration solution, click on Simulator Options:



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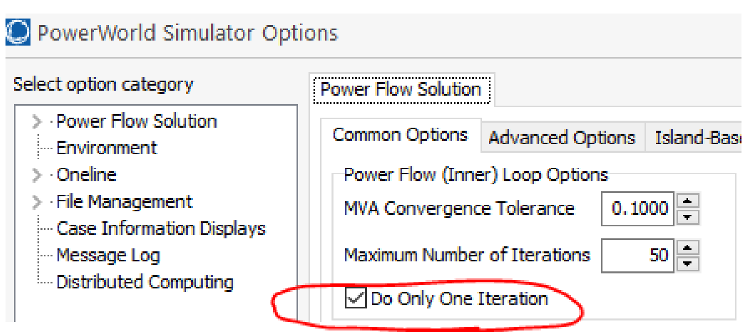
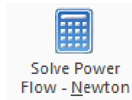
and make sure "Do Only One Iteration" box is checked.



This feature allows performing one iteration of NR at a time in order to see the progress towards the optimal solution. To continue the iterations, select **Solve-Single Solution-Full Newton**, (In version 20, click on 

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check the values in the mismatch vector and continue until the mismatch values are all 0. It should take about 4 iterations to bring the mismatches to 0.

After the Power Flow Analysis is performed your system should look similar to Figures 5, 6 and 7.

Note: PowerWorld (and the textbook) do not include the slack bus in the Newton-Raphson method, i.e. it is not incorporated into the Jacobian. So, for a 5-bus system, the Jacobian is 8x8 and the mismatch vector is 4x1. At the end of each iteration, after the unknowns for all other busses are estimated, the P_{gen} and Q_{gen} values at the slack bus are calculated based on the excess/deficient power of the entire system.

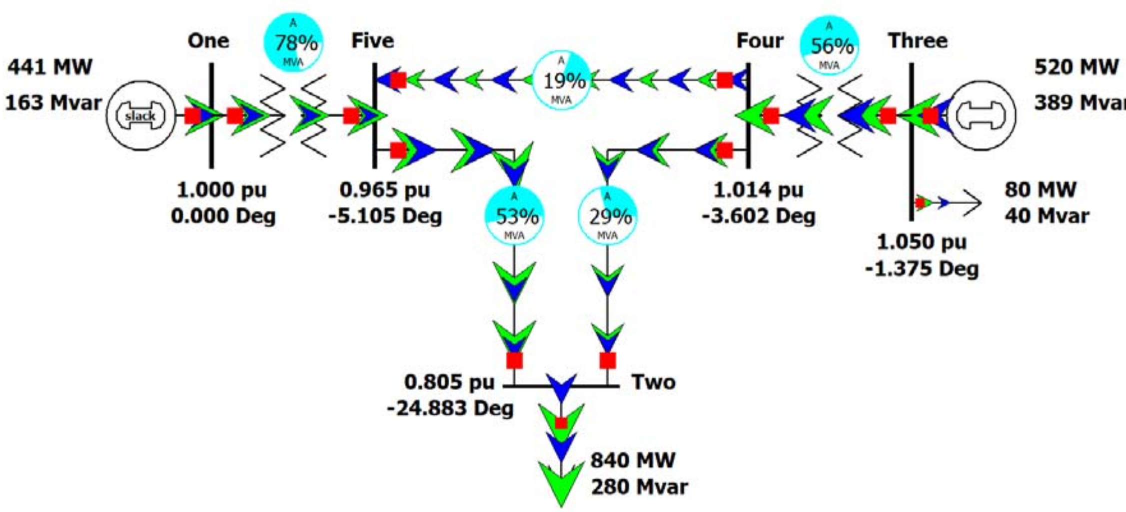


Figure 5-Power Flow Solution

	Number	Name	Area Name	Type	Mismatch MW	Mismatch Mvar	Mismatch M\
1	2	Two	1	PQ	0.00	-0.00	0.00
2	3	Three	1	PV	-0.00	-0.00	0.00
3	4	Four	1	PQ	-0.00	-0.00	0.00
4	5	Five	1	PQ	-0.00	-0.00	0.00
5	1	One	1	Slack	0.00	0.00	0.00

Figure 6-Mismatch Values

	Number	Name	Jacobian Equation	Angle Bus 2	Angle Bus 3	Angle Bus 4	Angle Bus 5	Volt Mag Bus 2	Volt Mag Bus 3	Volt Mag Bus 4	Volt Mag Bus 5
1	2	Two	Real Power	21.31		-7.28	-14.03	-8.28		-3.57	-6.76
2	3	Three	Real Power		106.14	-106.14			12.02	-3.77	
3	4	Four	Real Power	-7.81	-105.52	152.23	-38.90	2.81	-11.48	12.09	-2.57
4	5	Five	Real Power	-14.96		-38.72	101.13	4.85		-4.45	8.76
5	2	Two	Reactive Power	-10.13		3.62	6.52	19.52		-7.18	-14.54
6	3	Three	Voltage Magnitude						1.00		
7	4	Four	Reactive Power	-2.26	12.05	-12.27	2.47	-9.70	-100.50	150.08	-40.33
8	5	Five	Reactive Power	-3.91		4.51	-8.45	-18.59		-38.17	104.84

Figure 7-Jacobian Matrix Table

For questions 5 and 6, you need to change the Generation provided by Bus 3. In order to do this (from the Run Mode), right click on the "520 MW" field to the right of the Generator connected to Bus 3, then select **Generator Field Information Dialog** to display the **Generator Field Options**. Then, change the **Delta per Mouse Click** to "**10"** and select **Ok**. Now, small arrows will appear besides the "520 MW" field that will allow you to change the value of generation power provided by Bus 3, as shown in Figure 8.

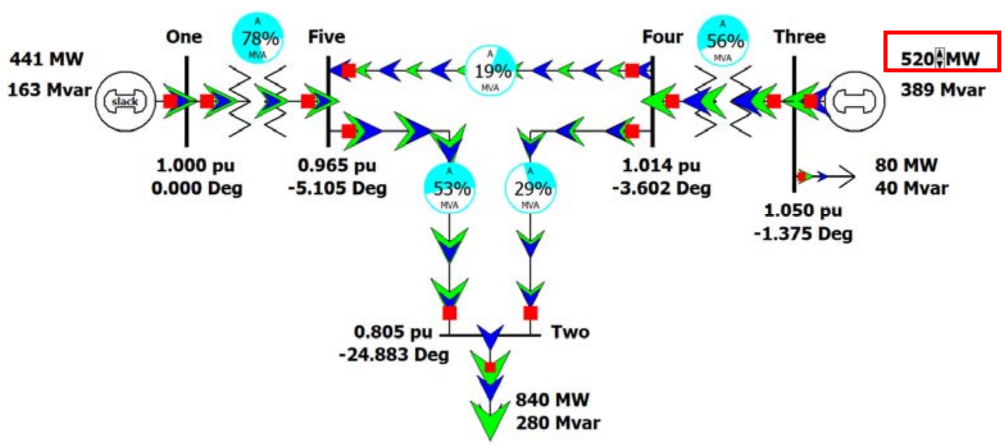
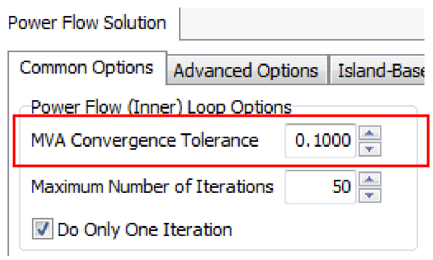


Figure 8-Power Flow Solution

Note: If the power generated at Bus 3 is changed, it is necessary to perform the Newton-Raphson solution again. To check this, after changing the value of generated power, perform the **Solve-Single Solution-Full Newton** and verify the value of the mismatch (it will likely not be 0). Perform iterations until the mismatches are 0 (or close enough to 0).

But what is "close enough to 0"? In the lectures, we mentioned that we keep iterating until $|| F(X) || < \varepsilon$ (i.e. the largest value in the mismatch vector is smaller than some threshold/tolerance ε.) You can define the value of ε in PowerWorld under **Simulator Option** > **Common Options**.



For this lab, ε is set to 0.1 MVA (This is a fairly large value for ε. For a more accurate power flow, you would set this a few orders of magnitude smaller.)

Questions:

In your lab report, please respond to the following questions. Use snapshots from the PowerWorld environment in your responses when applicable.

Q1) Why is Power Flow Analysis important and what parameters of the network can be obtained as a result of this study?

Q2) Draw the impedance diagram (per unit circuit) of the system using the information provided in Tables 1, 2 and 3.

Q3) Calculate all the elements of the Y_{Bus} matrix for this system and compare your results with the values presented in Figure 4.

Q4) Fill out the **Bus Type** column of table 1. You are not required to fill out any of the other blank cells in that table.

Recommendation: Bus type can be identified based on the known and unknown variables at that bus. A bus can be one of the following types:

- Slack bus [Type 3]
- Generator / P-V / Voltage Control bus [Type 2], or
- Non-generator / load / P-Q bus [Type 0]

Q5) Increase the active power generated at Bus 3 until the transformer connected from Bus 3 to 4 is loaded to 100% of its MVA rating. How much is the real power generated at Bus 3 and how much is the real power provided by the Swing/slack Bus during this condition? Record and take snapshots of your results.

Also, the real and reactive power flow equations at Bus 3 are:
$P_{gen,3} - P_{load,3} - P_{branch,3} = 0$ & $Q_{gen,3} - Q_{load,3} - Q_{branch,3} = 0$

P_{gen} and Q_{gen} are supplied by the generator at bus 3. P_{load} and Q_{load} are known (80 MW + 40 MVAr). The only branch connected to bus 3 is the transformer so $P_{branch,3}$ and $Q_{branch,3}$ represent the power flowing through that transformer. Using the $P_{gen,3}$ and $Q_{gen,3}$ values shown in PowerWorld, calculate the real and reactive power flowing through the transformer using the equations above. Do these values verify that the transformer is loaded to 100% of its rated MVA?

Note: Verify that the mismatches are 0 (or less than ε) after changing the power of Bus 3 before analyzing your results.

Q6) Decrease the active power generated at Bus 3 until the transformer connected from Bus 1 to 5 is loaded to 100% of its MVA rating. How much is the real power generated at Bus 3 and how much is the real power provided by the Swing Bus during this condition? Record and take snapshots of your results. What do you notice about the operation of the slack bus in Q5 and Q6?

Note: Verify that the mismatches are 0 (or less than ε) after changing the power of Bus 3 before analyzing your results.