SCHULICH
School of Engineering
UNIVERSITY OF CALGARY
DEPARTMENT OF ELECTRICAL
AND COMPUTER ENGINEERING

ENEL 487
ELECTRICAL ENGINEERING ENERGY SYSTEMS

Lab Instructions

Lab 1: One-Line Diagram and Introduction to POWERWORLD Simulator

INTRODUCTION

The objective of ENEL 487 is to provide the basics of electric energy generation and transmission systems and its analysis. For this, it is necessary to understand how the steady-state models of the main components of a power system are developed and how these models behave when interacting with one another. Among the major components of a power system that will be covered during the course are transformers, transmission lines, generators, and loads. After learning how to represent each component of a power system, analysis methods can be applied to determine the flow of active and reactive power from generation sites to load centers.

Power system analysis studies are crucial for the design and operation of a power system network. These studies allow the power system operator to predict how a network will operate under certain loading conditions or how a new component in the network will affect the performance of the whole system. Power system operators perform this analysis on a daily basis in order to ensure the reliable operation of a power system. These studies can be performed on a power network with as little as a few buses (nodes) or as many as hundreds and thousands of buses. This is only achievable with efficient software analysis tools with high degree of computational capability.

The purpose of ENEL 487 Laboratories is to familiarize the students with simulation of electrical power networks by using a commercial power system analysis package. PowerWorld Simulator Software offers various power network analysis applications and is widely used in the industry. This software will be used for all the laboratory studies in this course. PowerWorld has a comprehensive array of analysis tools to support power system analysis requirements.

For more information about PowerWorld, and to download the software, visit: www.powerworld.com/GloverSarmaOverbye

GETTING STARTED WITH POWERWORLD

First, open PowerWorld and create a new case. This is done by clicking on the "File" tab in the top left corner and selecting "New Case". PowerWorld has two main modes: *Edit Mode* and *Run Mode*. The Edit Mode is used to create and edit the systems you want to simulate and Run Mode is used for simulating them. The "create new case" window is shown in Figure 1.

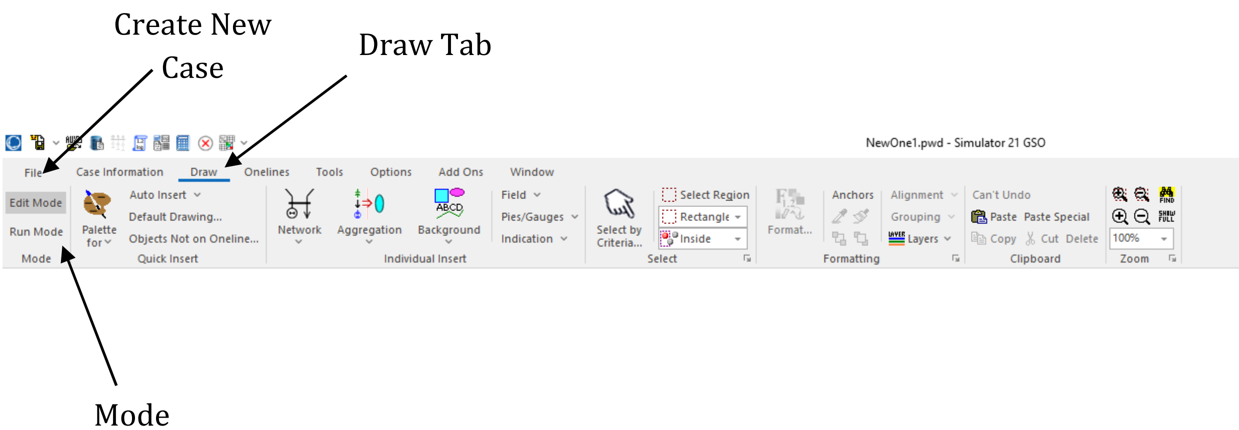


Figure 1-New Case Window for PowerWorld

In Edit Mode, you will be using the *Draw* tab to select and insert components and create your system, as seen in Figure 1. A preview of the available components for creating a One-Line-Diagram (OLD)[1] is shown in Figure 2.

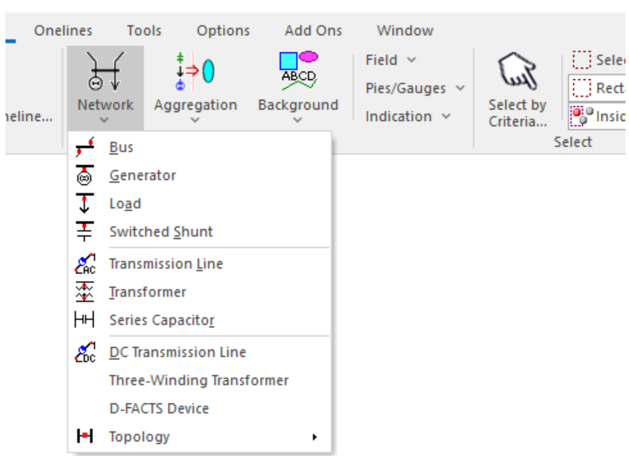


Figure 2-Power System Components available in the PowerWorld environment

[1] More on OLDs (also known as Single Line Diagrams –SLDs) later in the course. We use them to represent three phase systems while only drawing one phase. **Important: In OLD/SLD, the voltages are line-to-line, the currents are line currents, and the power values are the three phase quantities.**

CREATING A TYPICAL ONE LINE DIAGRAM

In order to insert components (Generators, Transmission Lines, Transformers, Loads, etc) you must first insert a bus since PowerWorld requires that all components are connected to a bus[2]. Let's start with a simple One-Line-Diagram:

The structure of the OLD that is going to be simulated in this lab is as follows:

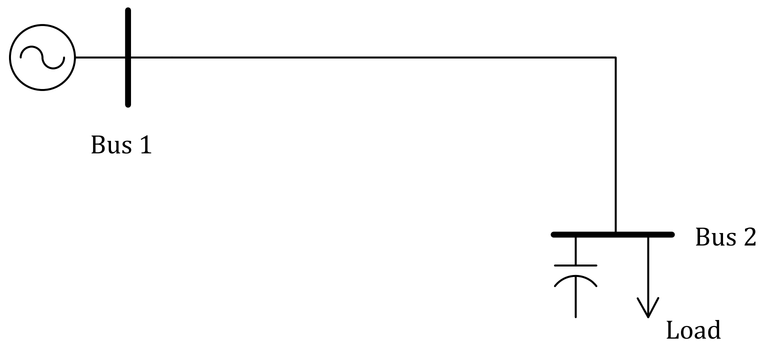


Figure 3-System OLD

In order to build the system shown in Figure 3, perform the following steps:

[2] A bus is another term for a node: connection point of 2 or more elements.

1) Insert Bus 1 by clicking on 

and then click anywhere on the screen to define the location of the bus. After that, define the bus name as "One" in the *Bus name* box, and enter 13.8 kV in the *Nominal Voltage* box voltage. Under the *display tab* in the lower section of the window, select "Down" in the *Orientation* box. After this, your window should look similar to Figure 4.

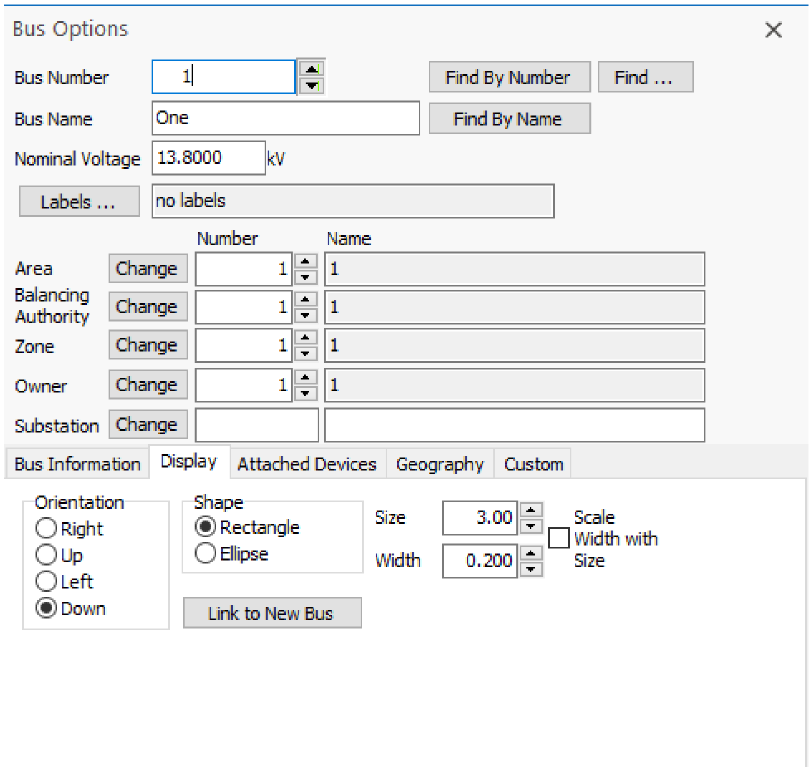
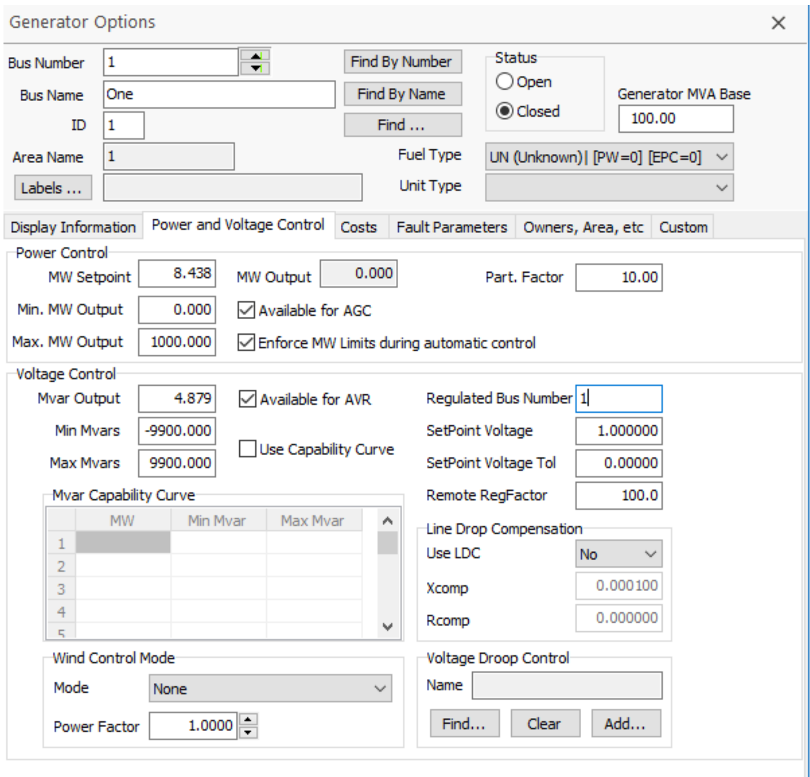


Figure 4-Bus Editor Window

2) Perform the same procedure for Bus 2, defining the name as "Two" and having a 13.8 kV Nominal Voltage. This time, select the orientation as "Left".

3) Insert the Generator in the system by clicking on 

and then clicking on Bus 1 to connect the generator to that bus. Then, click on the *Power and Voltage Control* tab and enter 8.438 MW in the *MW Setpoint* box and 4.879 MVAr in the *MVAr Output* box. Click on the *Display* tab and select "Left" in the *Orientation* box. Your windows should now look similar to Figure 5.



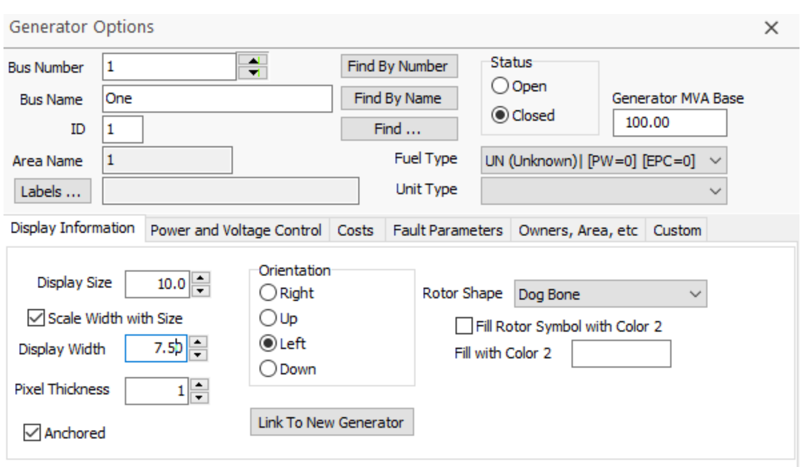
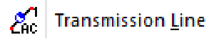


Figure 5-Generator Editor Window

4) Insert the Transmission Line by clicking on 

, clicking on bus 1 and then on Bus 2. Don't move your mouse from Bus 2 and press ENTER. Then, click on the *Parameters* tab and define the Series Resistance and Series Reactance as 0. For the first part of the lab, the transmission line is considered to be lossless. Your window should look similar to Figure 6.

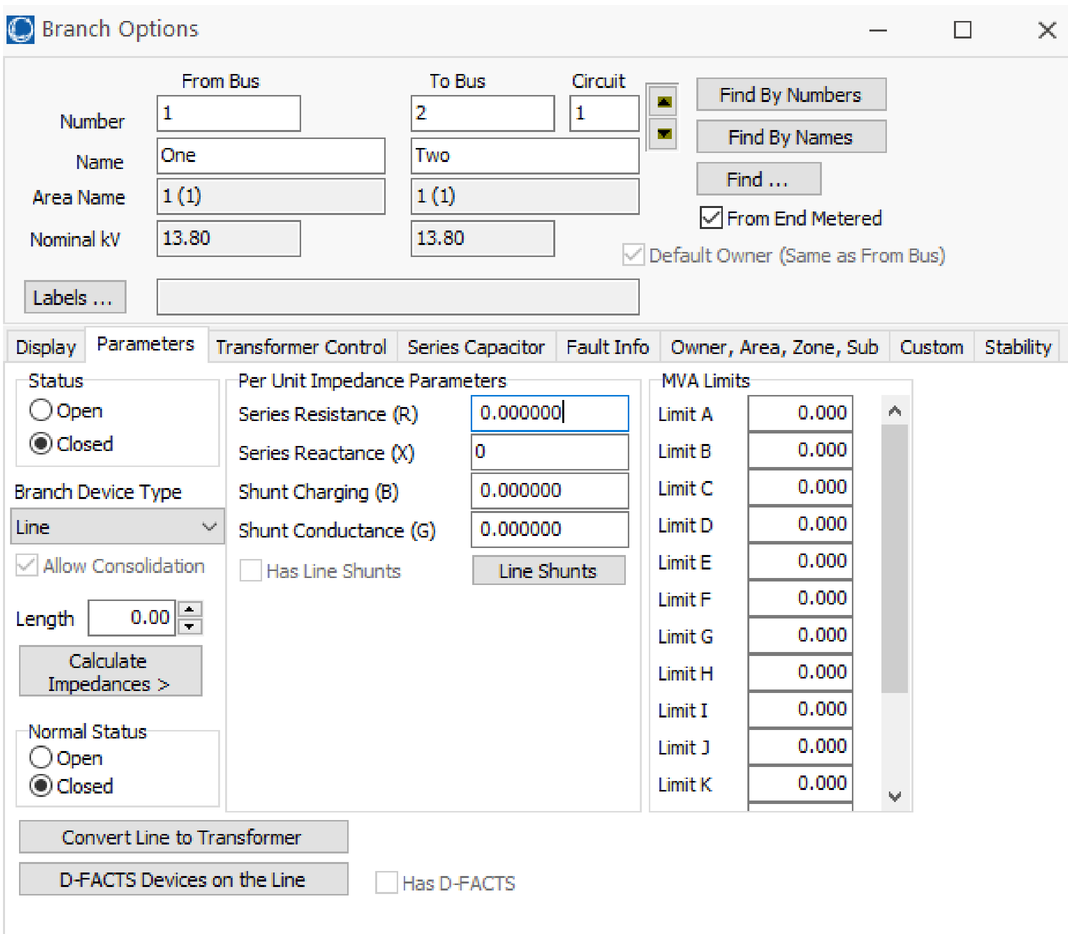


Figure 6-Transmission Line Editor Window

5) Insert the Load by clicking on  followed by Bus 2. In the *Load Information* tab, define the MW Value under the Constant Power column as 9 MW and the MVAr Value as 4. Also verify that the *Orientation* is selected as "Down". Your window should look similar to Figure 7.

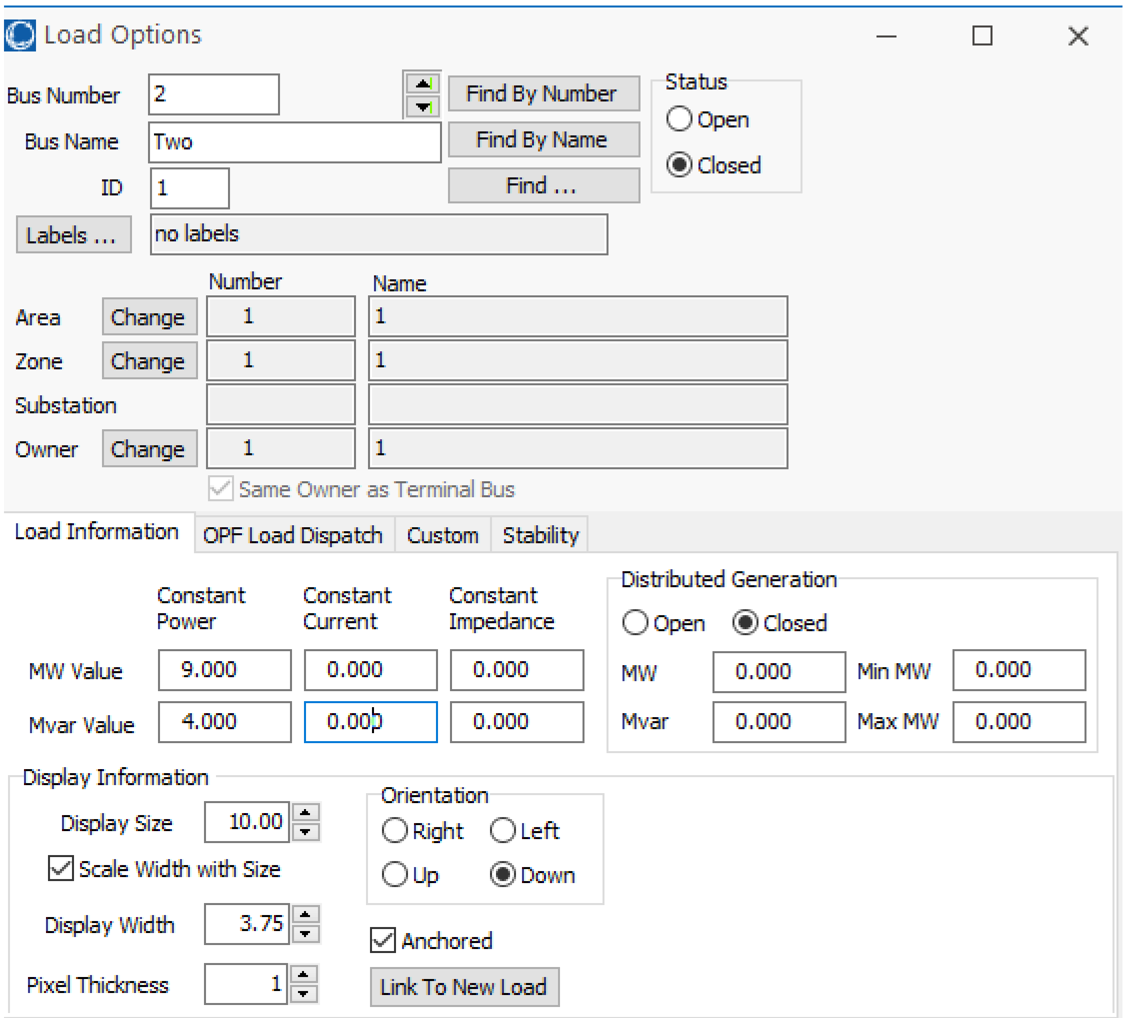


Figure 7- Load Editor Window

6) Insert the Capacitor by clicking on Switched Shunt followed by Bus 2. In the *Parameters* tab, define the Nominal MVAr as 0. After that, change the control mode to *Continuous*, double click on the cell below *Number of Steps* (at the right side of the window) and define it as 20, and define the *MVARS per Step* as 0.5. Click on the *Display* tab and select the Orientation as "Down". Now, change the control mode to *Fixed*. Your window should look similar to Figure 8.

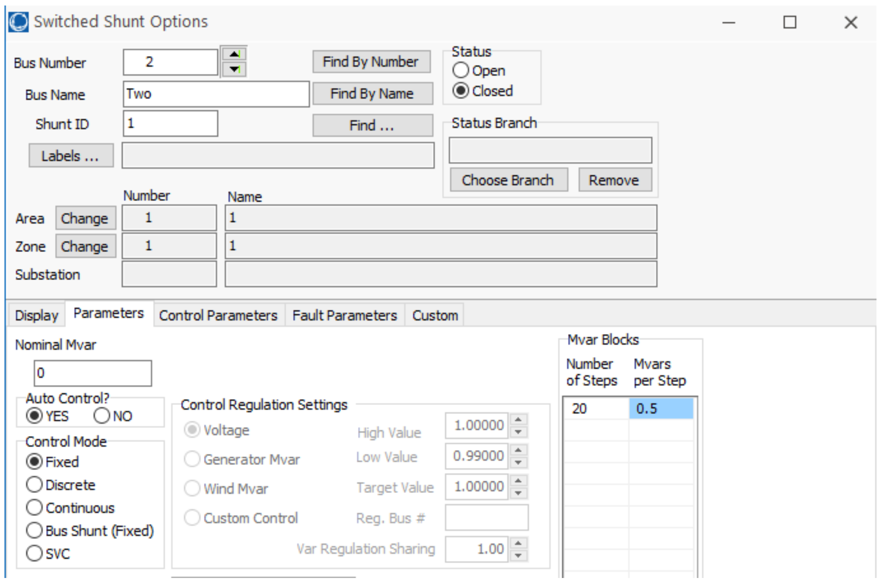


Figure 8- Switched Shunt Editor Window

7) Now, double click on the Capacitor value, i.e. on the label that indicates 0.0 MVAr, and set the *Delta per Mouse Click* value to 10. This allows you to change the value of the Capacitor by the defined steps during the Run Mode. (We are creating an adjustable capacitor bank for this simulation) If this step is performed correctly, you will see two arrows (up/down) next to the capacitor value. Your window should look similar to Figure 9.

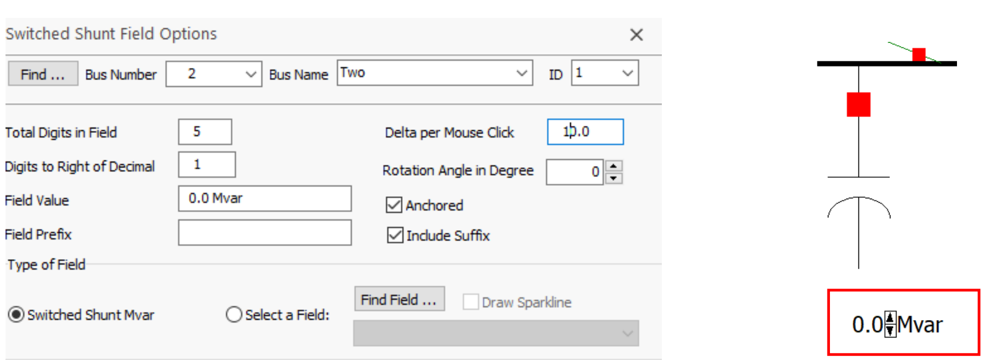


Figure 9- Switched Shunt Field Options Editor Window

8) At this point, the structure of the OLD is complete and your system should look similar to Figure 10.

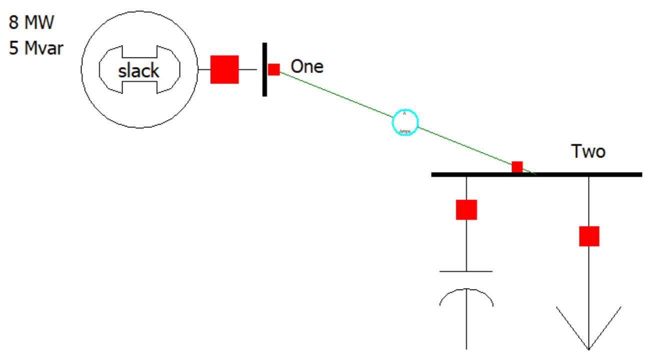


Figure 10- OLD Structure build in PowerWorld

9) In order to analyze the performance of our OLD under different conditions, it is necessary to add some measurements capabilities to our system. Let's begin with the busess: under the *Draw* tab, click on *Field* and then on *Bus Field*.

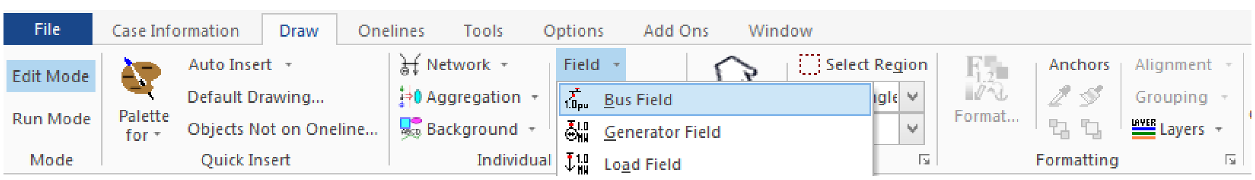


Figure 11-Field Selection

10) Now, click close to Bus 1 and Select '*Bus Voltage (kV)'* under the *Type of Field* box and click OK.

11) Repeat Step 10 for Bus 2

12) For Bus 2, define another field that shows the Bus Voltage in per unit (p.u.) by selecting the '*Bus Voltage (p.u.)'* option under the *Type of Field* box. The per unit value shows the bus voltage as a fraction/percentage of a *base value* (base value is 13.8 kV in this case).

13) Now define three fields for the Transmission Line: one Field for MW Flow, one field for MVAR Flow and another Field for MVA Flow. Make sure *Near Bus* is set to 1 and the *Far Bus* is set to 2. This would measure the power going from the generator (bus 1) to the load (bus 2). Also, set the *Digits to Right of Decimal* to 2.

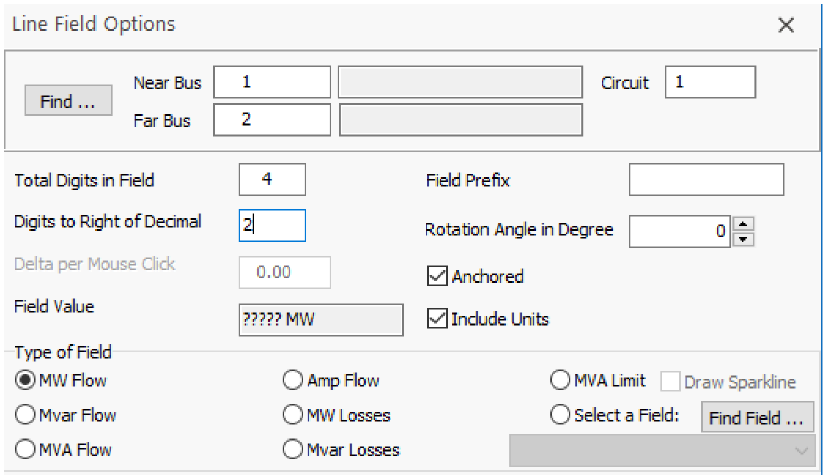


Figure 12- Line Field Options Editor Window

14) In a different location on the OLD, define two more fields for the Transmission Line: MW Losses and MVAR Losses.

15) In order to remember the measurements associated with each field, it is recommended to create a title to identify them. Under the *Draw* tab, click on *Background* and then on *Text*. Then, click close to the field that you would like to identify and type in a logical title for the field.

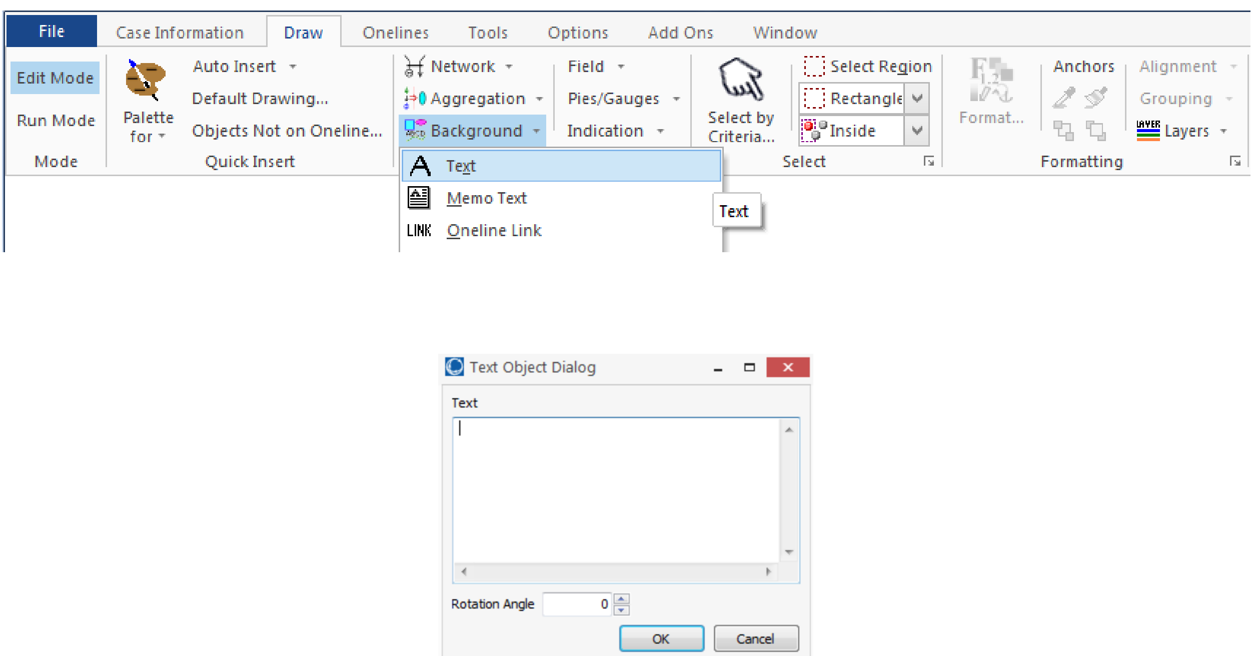


Figure 13- Text Editor Window

16) After inserting all the measurements fields and the respective titles, your system will look similar to Figure 14.

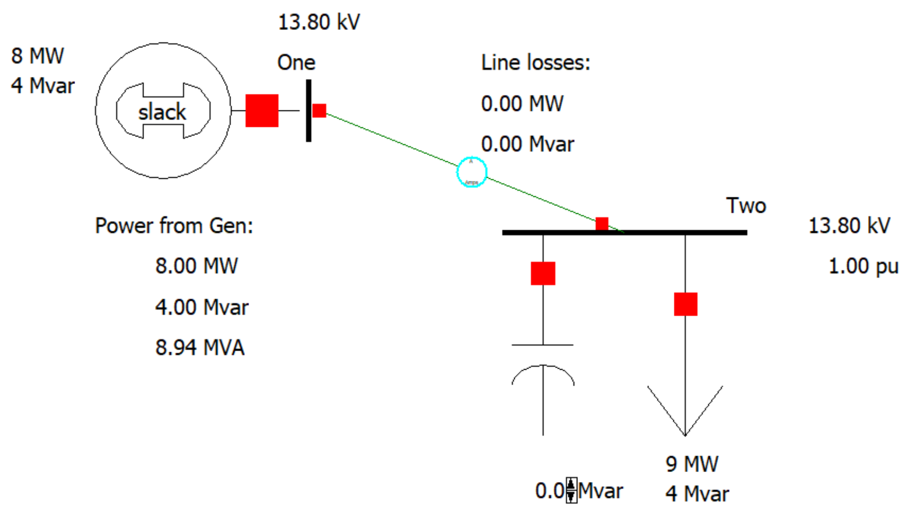


Figure 14- OLD including all Fields

17) Before running our simulation, it is necessary to define the visualization settings of our system. To do this, click on the *Options* tab and then click on *Animation*. The settings that have been changed are highlighted with a red box. Please refer to Figure 15 and make sure your settings match those in the figure.

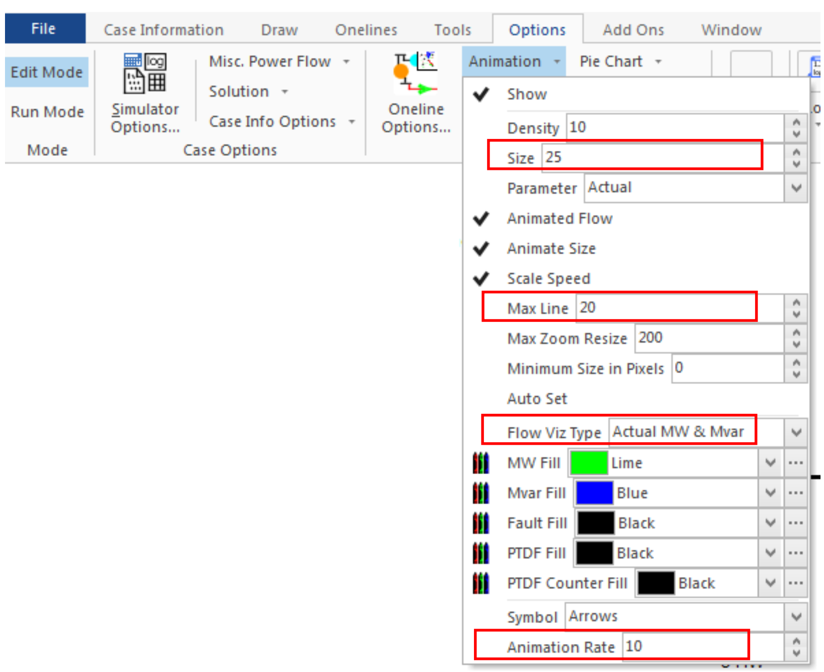


Figure 15- Animation Settings Window

18) After stablishing the animation settings, switch to *Run Mode*. Under the *Tools* tab, you will notice a green *Play* button in the *Power Flow Tools* box area. Press that button to begin your simulation.

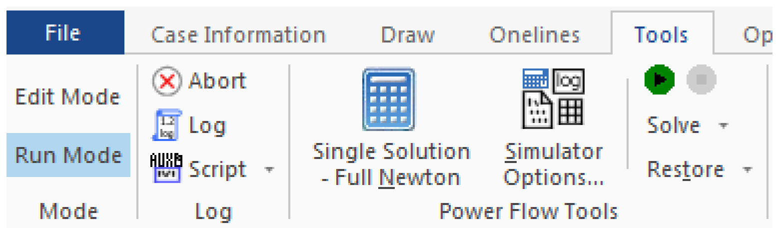


Figure 16- Run Mode and Solve Options

19) Once the animation starts, you will see a pair of Green and Blue arrows moving from the Generator trough the Transmission Line into the Load. The Green arrows represent the Active Power Flow (Watts) in the system and the Blue arrows represent the Reactive Power Flow (VARs) in the system. The size of the arrow is proportional to the amount of power. Your system should look similar to Figure 17.

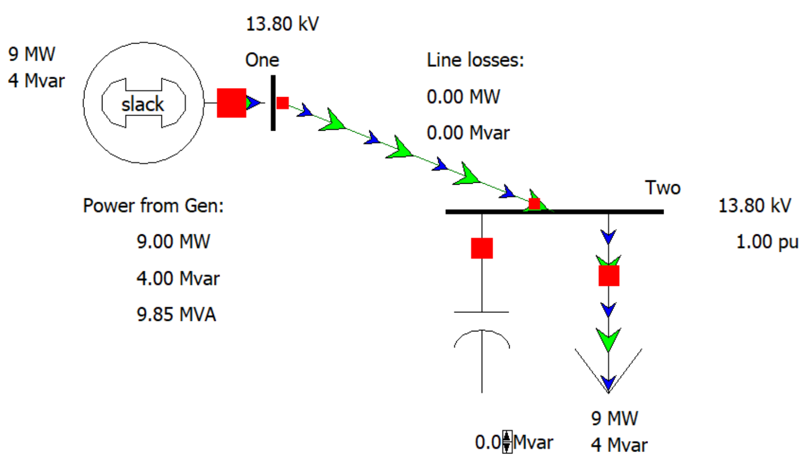


Figure 17- OLD Animation during Simulation

QUESTIONS

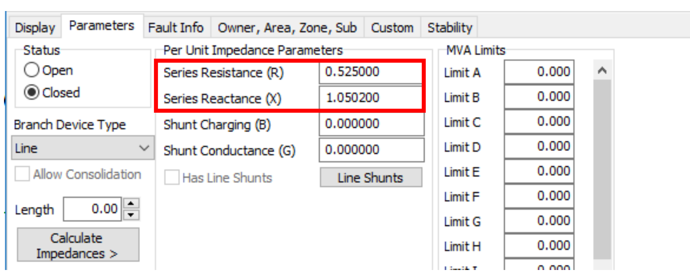
In your lab report, please respond to the following questions. Use snapshots from the PowerWorld environment in your responses when applicable.

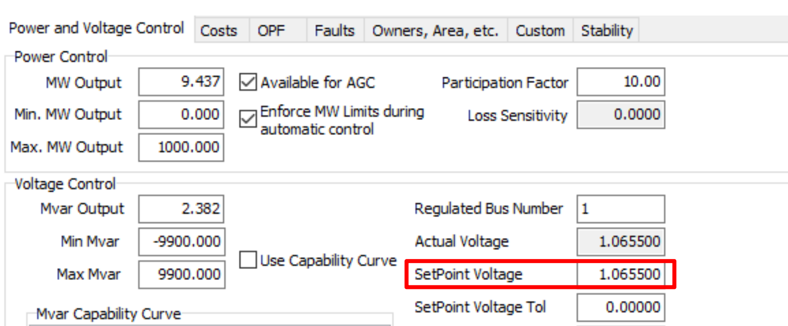
Q1) For the OLD of Step 19, calculate the Power Factor of the Load and the Power Angle (θ). Also, draw the power Triangle of the load.

Q2) For the OLD of Step 19, the Power System Operator is now requiring that the load power factor is at least 0.95 lagging. Calculate the value of the reactive power to be delivered by a capacitor bank connected in parallel to the load to comply with the Power System Operator requirements.

Q3) In the OLD, with the simulation running, increase the reactive power provided by the capacitor by using the arrows (up/down) right next to the MVAr label and bring this value as close as possible to the answer from Question 2. What is the Power Factor of the <u>source</u> during this condition?

Q4) Change the impedance of the Transmission Line to R=0.525 pu and X=1.0502 pu (This is 1+j2 Ω. More on per unit later in the course) and change the Setpoint Voltage in the Generator from 1pu to 1.0655pu (14.7 kV)[3]. Record the Voltage of Bus 2. Is this Voltage still 1 pu? If not, please explain why.





[3] We can typically control the real power output of a generator and the voltage magnitude. The voltage magnitude is controlled by adjusting the field (stator) current, i.e. the magnetic field in the generator.

Q5) Increase the capacitor value until the Voltage at Bus 2 is 1pu (13.8 kV) again. What is the amount of MVAr provided by the capacitor? What is the Power Factor of the combined load under this condition (i.e. the Power Factor for the load and capacitor bank together)?

Q6) It is requested to know the amount of current flowing through the Transmission Line when the Voltage at Bus 2 is 1pu. Find out how to take this measurement using PowerWorld and make the line current appear on the OLD during your simulation. Take a snapshot of your simulation. What is the current value provided by PowerWorld? Based on your system conditions (load power and voltage), calculate the value of this line current and compare it with the simulation value. Is the calculated current the same as the one displayed by PowerWorld? Reminder: this is a three phase system.

Q7) By changing the amount of MVAr supplied by the capacitor, determine what value of Qcap minimizes the Real Power Losses of the Transmission Line. What value of Qcap minimizes the MVA provided by the Generator? **Note:** It is recommended to increase the number of decimals shown by the power fields in order to gain more precision for this exercise.

Q8) In each Component Editor window (for example Load Editor Window in Figure 7 or Switched Shunt Editor Window in Figure 8), there is a *Status* box with *Open* or *Closed* condition. Can you explain the operation of this box?