University of California, Santa Cruz  
Baskin Engineering School  
Electrical Engineering Department  

Laboratory 2  
Introduction to POWERWORLD  

EE175L  
Power Systems Laboratory  

I. INTRODUCTION AND BACKGROUND  
The purpose of this lab is to become familiar with the PowerWorld software simulation tool by solving a variety of power flow problems. In addition, the concepts of per-unit notation, power-flow conventions and various bus types will be introduced as a requirement for using and understanding PowerWorld.  

Power-Flow Convention  
Unlike PSCAD, PowerWorld is not meant to solve anything directly in the time domain; rather, all system simulations are done in the phasor domain, and emphasizes use of only steady-state sinusoidal complex power flow quantities: voltage, apparent power (S in the power triangle), real power P, and reactive power Q. It may bother and frustrate you at times because PowerWorld will stubbornly show sources and loads only in terms of the power triangle and voltages. In classic circuit theory problems, we usually have to derive or calculate these power quantities from known voltages, currents and impedances. PowerWorld assumes voltage and complex power from the outset, so if instead you want impedance and current you will have to calculate them from known voltage and power quantities. This convention, of describing power systems in terms voltage and power variables, will rapidly become familiar with practice. PowerWorld allows us to visualize these parameters directly using very cool animated colored arrows to denote real and reactive power flows. The simplest problem begins with characterizing how power flows from a single generator to a single load, and quickly develops into a real power grid having many generators delivering power to many loads over a complex parallel network of interconnected transmission lines.  

Therefore, to keep track of things we need a clear convention about how to characterize what is actually sourcing or delivering power, as in the case of generators, and what is actually sinking or absorbing power, as in loads. Once this is understood, it may surprise you to learn that generators can be used for purposes other than just sourcing real power. They can also be used for VAR correction (a power flow concept aimed at making voltages and currents more closely in phase) by absorbing or delivering reactive power – keep in mind in developing your project.  

Hence, power systems engineers often describe major system blocks or components as either delivering or absorbing real or reactive power based on either the load or generator power flow conventions. Which one to use depends on the nature of the block being considered. Remember, these two apply only to the steady-state phasor domain and requires that we properly understand use of the classic power triangle relating S[VA], P[W] and Q[VAR]. If we’re working with a generator, then the generator convention will be assumed. If a load, then the load convention is assumed. You must know the context to handle these quantities correctly. Refer to fig. 1 for a summary reference on the power flow conventions used in PowerWorld.
System Bus Types

In order to understand and use PowerWorld to solve power flow problems, you must understand various types of buses and how they are used in power systems analysis. All buses used in PowerWorld must be specified before any simulation can be run. In power systems, a bus is essentially what we would call a node in electronics; it is simply the interconnection of two or more components. In physical systems, these points of common interconnection are often constructed differently. In high-voltage systems, these are called busbars, and are typically large separated metal tubing structures made of copper or aluminum. In low-voltage systems, like those in found in panel buses, they are typically closely spaced insulated wire used to connect circuit breakers.

In PowerWorld, buses are defined by their purpose. There are three basic types: (1) slack (or swing) bus; (2) load bus; (3) voltage controlled bus. Depending on the bus type, different variables must be given as input and different variables are then solved for during the simulation of power flow calculations.

**Slack Bus**

There is only one slack bus in a system. Consider why this is necessary. In a simulated power system, to successfully solve for a particular steady-state solution, some quantities must be allowed to vary or swing. This bus type has inputs of voltage and phase \( \phi \); these are generally set to 1.0 \( \pm 0.0^\circ \) (per-unit) – for per-unit system see next page and Chapter 3, Sec. 3.3, pages 108-116 of Power System Analysis & Design, 5th ed., Glover et al., Cengage 2012. P and Q become the swing variables, and because these are unknown, a slack bus must be connected to a generator since it must deliver P and Q to satisfy system constraints. Another way to look at this is to observe that loads can be dynamic, so one can think of a slack bus as a component delivering real and reactive power to the system based on the load it sees.

**Load Bus**

The load bus has real and reactive power, P and Q as inputs with voltage and phase \( V \) and \( \phi \), being calculated. This will be the most common type of bus in a system since few generators serve multiple loads.

**Voltage Controlled Bus**

---

Voltage controlled buses have inputs of real power and voltage, P and V, while reactive power and phase, Q and \( \phi \), are calculated. Generally, voltage controlled busses are connected to equipment used for voltage and VAR correction, such as shunt capacitors, generators and static VAR correction systems.

When setting up a PowerWorld simulation, a single slack bus connected to a generator must be included for the program to converge on a solution. All other generators will be connected to voltage controlled buses. Since it is a requirement of utilities to deliver power within a narrowly defined voltage range (±5% nominal), the reactive power output of a generator can be controlled to maintain buses voltage within this range. (If you don’t see how this is possible, draw the power triangle and consider how changing Q can change the voltage.) This range can be set within PowerWorld which will adjust a generator’s reactive power in order to meet the required bus voltage.

**Per-Unit Notation**

The idea behind *per-unit notation*\(^2\) is to make the many variables in a power system easy to quickly compare and proportionally understandable. Thus, it is a method of expressing the four system quantities, voltage, current, power, and impedance, as a percentage or “per-unit” of some specified proportional reference base. As you should know, if we chose any two quantities from this list, we can then define the others in terms of these two. Therefore, to express a system in per-unit notation, two independent base values must be chosen. The majority of the time, these will be a power base and a voltage base. For example, the simple system shown below in figure 1, the voltage base, V, can be chosen to be \( V_{LN} \) 115kV and the Complex Power base, S, can be chosen to be 100MVA.

Per-unit notation is especially useful when transformers exist in a power system to effectively eliminate the effects of turns ratios by normalizing them out. Note that in systems where there are transformers, the voltage base will change depending on the turns ratio of the transformer. For example, in figure 3 below, the voltage base for the generator (primary side of T1) will be 22kV while the voltage base on the secondary side of transformer T1 will be 220kV.

---

\(^2\) Ibid. refer to sec 3.3 for a more detailed treatment of per-unit notation.
II. ASSIGNMENT AND PROCEDURES

Part 1: Simulating a three-Phase AC Circuit in Steady State

Fig. 2 shows a simple three-phase power system consisting of three buses drawn and interconnected as a one-line diagram. Each interconnecting line between buses, loads and generators, represents one per-phase equivalent for a balanced three-phase system. PowerWorld uses this approach. The three short horizontal lines with multiple connections are each 3-phase buses. Bus #1 is shown in the upper left corner connected to generator G1. Bus #2 is connected to another generator, G2, and bus #3 to generator G3. See the attached pdf “Introduction to PowerWorld” for a tutorial on how to set up and get started using PowerWorld for this lab.

a. Use PowerWorld to simulate the system. Note that units for power in figure 2 are in per-unit notation. For the two base units, choose apparent power and line voltage: $S_{1b}=100$ MVA and $V_{1N}=132.7$ kV.

b. From the earlier discussion of bus types, which bus should be chosen as the slack bus? Why?

---

3 Ibid., Chapter 2, page 83.
c. Add transmission line fields to show real and reactive power flow at each end of the transmission lines. If we consider the transmission lines to be a load, does the power flow at each end of the transmission lines follow the power flow convention described above? Explain.

d. Notice that PowerWorld shows red boxes at each circuit element connection to a bus. These boxes represent switches and can be opened or closed while in run-mode. Explore what happens to the power flow solution as you open and close various circuit elements.

e. From the real and reactive power shown in PowerWorld, calculate the power factor for each transmission line at each end (2 per transmission line).

f. Add VAR correction to bring the power factor into unity by adding capacitive reactance to the system. Do this by adding a load with only reactive power consumption for each transmission line.
Part 2: Transformers in PowerWorld

a. Referencing figure 3, and using PowerWorld, solve for the complex power delivered by the generator from the single line diagram. Note that you will have to convert some values from nominal to Per-Unit depending on the input type in PowerWorld. Also, recall that the voltage base is set by the nominal bus voltage and changes on each side of a transformer.

**Figure 3.** One-Line Diagram for Part 2.

### III. WHAT TO TURN IN

Submit a well-written report (see the handout on reporting guidelines posted on our website) discussing the work done in this laboratory. Some of the tasks have questions, be sure to answer these in the flow of your treatment.