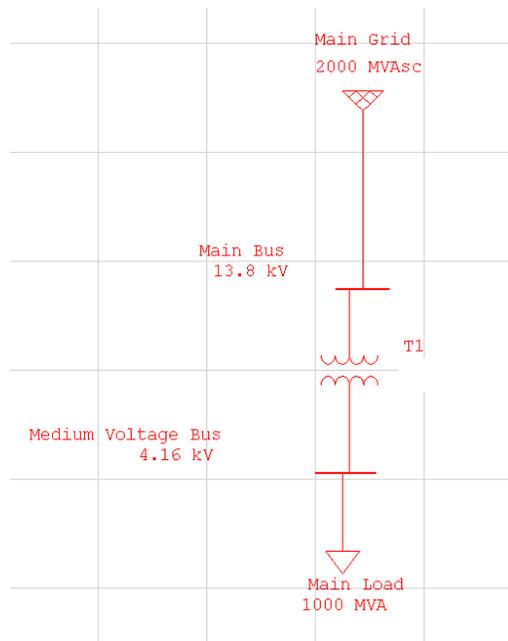


Problem 4: Sizing a Transformer For Use in A Power System

In this problem, we're going to consider a typical task performed by power-system designers: Transformer sizing. When selecting a transformer, we must consider a number of factors:

- The voltage at the primary
- The voltage at the secondary
- The magnitude of the APPARENT power that must be delivered to the secondary. Recall that apparent power is a complex vector defined as follows: $S = P + jQ$, where P is the real power delivered to the secondary, and Q is the reactive power delivered to the secondary.

Our system will look like the following:



Here is what we know:

- The rated apparent power of our load is 1000MVA at an 80% power factor.
- The voltage at our primary is 13.8kV. This is a phase-to-phase voltage.
- The voltage at our secondary is 4.16kV. This is a phase-to-phase voltage.

Before delving into ETAP, you must answer the following questions:

- a) If the phase-to-phase voltage at the secondary is 4.16kV, what is the magnitude of the phase-to-neutral voltage?

- b) If our load absorbs 1000MVA at an 80% power factor, how much real power P does it consume? How much reactive power Q does it consume? Clearly explain your calculations.
- c) If our transformer has some resistance and leakage inductance at its secondary, should the voltage at the secondary terminals be 4.16kV when the load is operating? Explain your answer. To answer this question, consider what we learned in the lecture on Power Systems on Tuesday September 23.
- d) Transformers are sized using apparent-power ratings. By comparison, motors are sized using real-power ratings. Why are apparent-power values used to size transformers? To answer this question, think about the fact that transformers cannot be allowed to get so hot that their winding insulation begins to deteriorate. Since losses cause temperature to rise, there is a certain upper bound on the losses in the transformer. These losses include the following components:
- Copper losses in the windings. These losses are given by I^2R .
 - Core losses due to the non-idealities of the core material. These losses will also increase as the current, and thus the field, increases.

To answer this question, note that losses are dependent on the magnitude of the current. and consider how overall current is affected by a higher Q .

- e) Now, let's choose an apparent power rating for our transformer. To do so, we'll consider a subset of specs that are commonly used by many companies.
- Efficiency spec:* Assume that the transformer is operating at 99% efficiency. This means that 99% of the power absorbed by the primary is delivered to the secondary. So, for example, if the secondary is absorbing 200MVA, it must be true that $200/.99 = 202$ MVA is flowing into the primary.
 - Load-growth spec:* Assume that we may eventually add loads to the secondary side of the transformer. Typically, we assume that we may have a 10% load growth. In other words, assume that we may eventually have to deliver 110% of 1000MVA.
 - We must choose a transformer that is commercially available. Typical transformer ratings are 1000, 1200, 1500, 2000, 2500, 3000, 4000, 5000, 7500 kVA, etc.

Choose the lowest rated transformer that meets the load-growth and efficiency requirements. In your write-up, you should clearly describe your calculations.

- f) Once a transformer rating has been selected, we must choose a real transformer and verify that it does not adversely affect system operation. In this simple system, this means that we need to verify that the impedance of the real transformer does not cause the voltage at the secondary bus to fall below 5% of its rated value. To verify this, we need to perform what's called a power-

flow or load-flow study. To do so, we will use ETAP. This will require you to follow the instructions shown below. **NOTE THAT STEP 13 AND STEP 18 CONTAIN QUESTIONS THAT NEED TO BE ANSWERED.**

What follows is a tutorial that should be straightforward and easy to follow. If it's not, please provide feedback. Also, additional Video and PDF format Tutorials about ETAP are available at the following web site: <http://www.etap.com/tutorials.htm>. You should not need these tutorials, but you may be interested in them.

Step 1: Log in to the Mosaic Computing System through your username and password. If you only have access from home, try the following link: http://www.coe.uncc.edu/mosaic/remote_desk

Step 2: Click on **Start** → **All Programs** → **MOSAIC XP** → **Engineering** → **Electrical** → **ETAP** → **ETAP 5.5.6**

Step 3: Click on **File** → **New Project**

Step 4: On the Create New Project File Dialogue box: Type the Project File Name in the Name box and then **Change the Directory to your personal folder system (i.e. My Documents, etc.) using the Browse button. Note that you can't save the project in the default directory C:\PROGRAM FILES\ETAP 556\ as it is blocked by the administrator.** Click Okay. ETAP will now load your project files. This may take some time. In the process, a few dialogue boxes may pop-up asking for user name, etc. Answer the questions appropriately and click either Okay or Cancel as needed.

Step 5: Once the new project is open, you should see several windows in your workspace. One of these is the Project Editor window. This box stores all the work you do with your project, such as short-circuit analysis results, load-flow analysis results, etc. You should also see a window entitled "OLV1 (Edit Mode)." This is the space where you can create your Single-Line Diagram (SLD).

Step 6: Now we're going to set some important standards to those that are commonly used in the United States. To do so, Click **Project** → **Standards** and set the standards to the following:

- Standard: ANSI
- Frequency: 60 Hz
- Unit System: English
- Date Format: MM-DD-YYYY.

Step 7: Now, we're going to start drawing the single-line diagram. First, click the icon that looks like so:



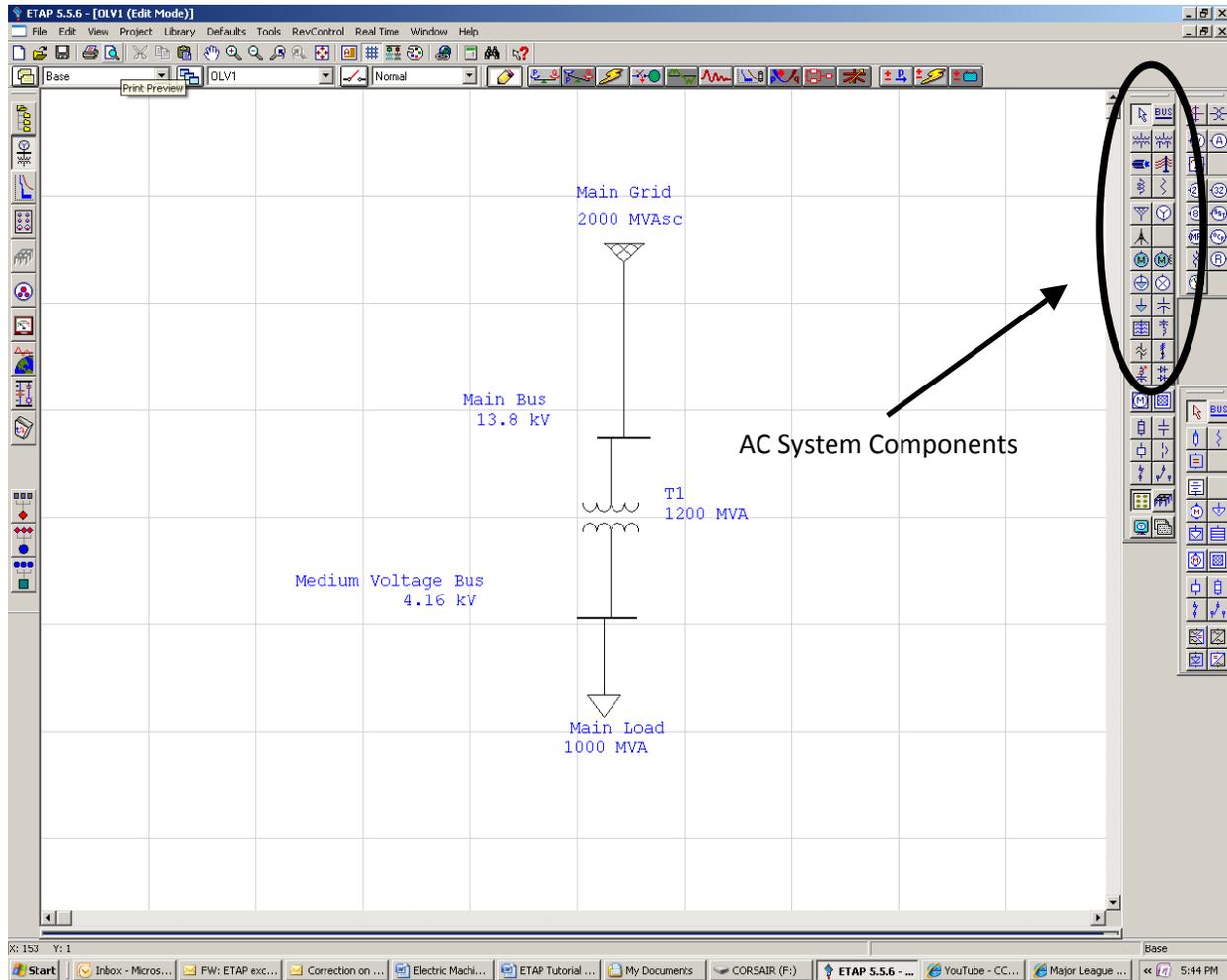
(Show Grid Lines). This icon is located just below the Real Time menu on the menu bar at the top of the screen.

Step 8: Enlarge the window OLV1 (Edit Mode) using the mouse so that we can fit the whole SLD in that window.

Step 9: The items that you'll need to draw the SLD are on the right-side of the screen. Let's begin by creating a power grid that will supply the primary of our transformer. First, click on the **Power Grid** icon.



Note that if you place your mouse pointer over an icon, a message bar will pop-up to tell you what the icon does. Once you've clicked on the power grid icon, place your mouse pointer somewhere in the OLV1 window and left click. A power grid should appear in your diagram. **Note that all of the items that we will place in our diagram must come from the AC-system components section. This section is shown in the figure below. DO NOT SELECT COMPONENTS FROM OUTSIDE OF THIS SYSTEM, AS YOU MAY BE SELECTED COMPONENTS FOR DC SYSTEMS.**



Step 10: Now we need to configure our power grid. To do so, double click on the power grid that you just placed in the OLV1 window. A dialogue box will appear with several tabs. Go first to the Info Tab. On that tab do the following:

- Name the grid "Main Grid" using the ID text box.

- Change the Mode to Swing.

Now, go to the Rating Tab. On that tab, do the following:

- Change Rated kV to **13.8**
- Set the short-circuit rating in the SC Rating section:
 - Set the 3 Phase MVA_{sc} to **2000**. This value gives the maximum apparent power that can be supplied by the grid.
 - Set the X/R ratio to **50**. This is the ratio of the reactive impedance of each phase to its resistance. We'll talk more about this later.
 - As you enter these values, you should see other values change. This is the result of calculations that ETAP is performing using your values. We'll talk about these more later.

Do not hit Enter after you enter individual values. If you do, the dialogue box will close. Once you've entered all of the information described above, click OK.

Step 11: Now click on the **BUS** icon . Note that you must choose the AC bus icon, which is the one nearest to the top of the window. (Note that there is another bus icon near the bottom of the window. That icon is for DC systems and it will not work here). Place the mouse pointer somewhere in the OLV1 window below the Main Grid and left click. A bus should appear, and its voltage should be 0kV.

Step 12: Let's now connect our bus to the main grid. Place your mouse pointer on the very bottom of the Main Grid icon in your OLV1 window. A little purple square should appear. If so, hold the left mouse button down and drag the mouse pointer down toward the bus that you just placed. When your mouse pointer is over the bus, the bus should eventually turn purple. When it does, go ahead and let go of the left mouse button. Notice that the bus voltage should change from 0 kV to 13.8 kV i.e. voltage of the grid. Now, double click the bus and change Bus ID to "Main Bus".

Step 13: Now click on the **2-Winding Transformer** icon . Place the 2-winding transformer in the same way that you placed the previous two components. Join the primary of the transformer to the Main Bus. Double click the transformer icon and set the following properties:

- On the Info Tab
 - Change the transformer ID to "Main Transformer".
- On Rating Tab
 - Notice that the primary voltage rating has been set to 13.8 kV.
 - Set the secondary voltage rating to **4.16 kV**

- Set the primary MVA rating to the value that you chose previously. Note that this should be placed under MVA, not Max. MVA.
- In the Impedance section of the Rating tab, click the **Typical Z and X/R** button. When you do, ETAP will choose a transformer from the ETAP library that matches your voltage and apparent power ratings. It will give you the %Z and X/R values for this transformer.
- Click OK to close the window.

Note that this transformer does not really have two windings – it has one primary winding for each phase, and one secondary winding for each phase. In reality, it thus has 6 windings. Since it connects two three-phase busses, we call this a two-winding transformer. By comparison, a three-winding transformer would have two sets of secondary windings.

ANSWER THE FOLLOWING: Note that ETAP calculates what’s known as the full-load ampacity (FLA) of both the primary and the secondary windings. This number is the maximum current than can flow into or out of any given phase winding. Calculate the FLA at the primary using the rated MVA and the rated primary voltage. Your number should match the FLA value calculated by ETAP.

Step 14: Now click on the **BUS** icon  and place a bus below the secondary of the two-winding transformer. Join the transformer secondary and the bus. Notice the voltage of the bus should change from 0 kV to 4.16 kV, i.e. the voltage of the transformer secondary. Double click the bus and change the Bus ID to “Medium Voltage Bus”.

Step 15: Click on the **Static Load** icon  and place a static load below the Medium Voltage Bus. Join the Medium Voltage Bus to the static load. Double click on the load.

- On the Info Tab
 - Change the ID to “Main Load”.
 - On the Loading Tab
 - Change the MVA value to **1 MVA**
 - Change power factor (%PF) to **80%**. The MW and MVar should change to the values that you calculated in Part b.
 - Click OK when you are done.

Step 16: Finally, we are done drawing our SLD. Click the **Load Flow Analysis** icon  at the top of the ETAP window. The single-line diagram icons on the right side of the screen should now disappear and be replaced with icons that are appropriate for performing load-flow analysis.



Step 17: Click on the **Run Load Flow** icon on the right side of the screen. A dialogue box should appear and ask you to choose a name for your results file. Use a name such as “LoadFlow1”. Click OK.

The result of your Load Flow Analysis should now appear on the screen. At each bus, you should see three different numbers:

- The actual P flowing into or out of the bus
- The actual Q flowing into or out of the bus
- A percentage which represents the actual voltage as a percentage of rated voltage. For example, if a 4.16kV bus yields a percentage equal to 90%, the actual voltage is 3744V.

Step 18: Change the display options of the load flow. Do so by clicking on the **Display Options** Icon



on the right side of the screen. Modify the results so that you can also see the angle of the voltage at each bus. Note that the angle of the voltage on the main bus is set as a 0 degree reference. One bus must always be selected as a reference. The angle at this bus will never change.

IN YOUR WRITE-UP, PROVIDE A READABLE SCREEN SHOT SHOWING YOUR FINAL LOAD FLOW RESULTS. ALSO INCLUDE A TABLE THAT INCLUDES THE FOLLOWING INFORMATION:

- The actual P flowing into or out of each bus
- The actual Q flowing into or out of each bus
- The magnitude of the voltage at each bus
- The angle of the voltage at each bus.

IN YOUR WRITE-UP, INDICATE WHETHER THE MAGNITUDE OF THE VOLTAGE AT THE SECONDARY BUS IS WITHIN 5% OF ITS RATED VALUE. IF IT'S NOT, A NEW TRANSFORMER WOULD NEED TO BE SELECTED.