*Wind*Lab^{TM}
Wind Turbine Power System

Sample Laboratory Procedure Manual

WindLab^{TM} is a scaled Wind Turbine Electrical Generation System, designed to function like a full-sized wind turbine system. It features a programmable, variable speed wind tunnel powering an industry standard configuration 3-blade wind turbine rotor system driving a fully functional three phase electrical power generator.

NOTE: Sample Lab Procedure does not replace Operator's Manual for proper operational procedures! Please refer to manual for detailed system operational and safety instructions.

Lab Session #1: System Familiarization

Purpose: To gain an understanding of the WindLab™ System as a whole and details of its components and controls. This will prepare you for operation of the system.

Wind Speed Anemometer

The operator's control panel consists of the following:

1. Master Power Switch for turning electrical power on or off to the unit.

2. Wind Speed Master Controller/Display: Controls/displays wind speed (wind fan).

3. Generator Excitation Controller/Display: Controls/displays excitation voltage to generator electro-magnetic rotor core.

4. Wind Turbine RPM Display

5. Wind Speed Display

AV. Voltage Display for Phase A

AA. Amperage Display for Phase A

AR. Adjustable Resistance for Phase A: rheostat provides individual phase loading for turbine's electrical generator (same for each phase).

BV. Voltage Display for Phase B

BA. Amperage Display for Phase B

BR. Adjustable Resistance for Phase B

CV. Voltage Display for Phase C

CA. Amperage Display for Phase C

CR. Adjustable Resistance for Phase C

Data Acquisition Computer
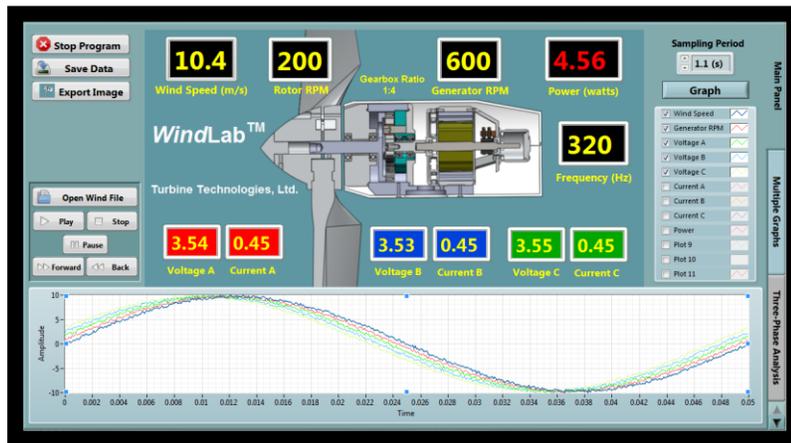
Computer connects to unit's on-board data acquisition system via a cabinet mounted USB port. Displays and captures data for operation and analysis. On Board Data Acquisition System which feeds a cabinet mounted USB Port. The computer features a Virtual Instrument Panel (VI) for the WindLab™ System.

System Operation

Purpose: Conduct pre-start, start-up, operation, data gathering and shut down of WindLab™ Wind Turbine Power System.

General Procedure: Utilize WindLab™ Operators Manual and follow Section 4 to perform system pre-start, start, operation, and shut down steps of system. Use Section 6.5 Virtual Instrument (VI) Display/Data Collection for data collection. **Data plotting is covered in detail in this sample lab.**

Specific Lab Procedure:

Run stepped wind speed programs and follow a specific loading test card to see the difference in generation capabilities as wind speeds change. The end result will be to generate plots of performance graphs throughout a specific wind speed range.

1. Verify that all load rheostats are set at no load (zero) for each phase and excitation (Phase C shown).
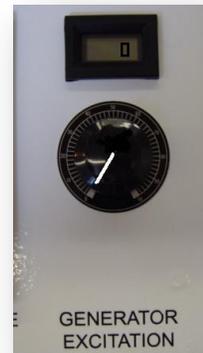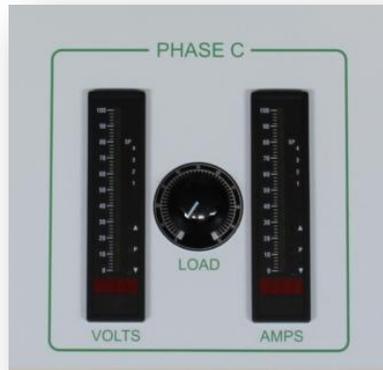
2. Turn MASTER Power Key to ON Position

3. Start system and chose a low wind speed. When wind anemometer starts to spin, the WIND SPEED Meter will start to display data.

4. You may wish to hand record this data as a means of keeping track of progress, however, for graphing purposes, the Data Acquisition system should be used to record that for you (Voltage/Current for each phase, Turbine RPM and Wind Speed).
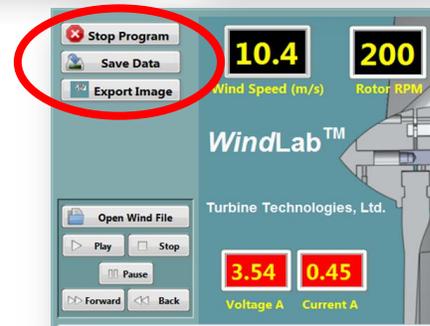
5. Set **GENERATOR EXCITATION** to any value you'd like to start the process. It is adjustable from 0 to 14V DC. <mark>Make sure you record this setting as the Data Acquisition system does not record it.</mark>

6. Adjust each **PHASE LOAD** rheostat (A, B, C) from 0 Ohms to 10 Ohms and let system stabilize (10 seconds). This is considered balanced loading. Again, performance data will be recorded by the data acquisition system. <mark>Make sure you record these settings as the Data Acquisition system does not record it.</mark>

7. Continue adjusting each **PHASE LOAD** rheostat (A, B, C) by 10 Ohm increments (and allow unit to stabilize for 10 seconds at each setting) all the way to 100 Ohms.

8. After waiting at least 10 seconds, return all load PHASE load rheostats (A, B, C) back to zero. You can leave GENERATOR EXCITATION value where it is set to finish this data gathering exercise.

9. Adjust wind speed up to the next incremental value (essentially one increase in the speed button on the wind speed controller, or whatever you would like it to be. We recommend incrementally increasing or decreasing wind speed to gain a good understanding of the WindLab operational envelope.

10. Repeat the process of adding balanced rheostat loads at 10 Ohm increments from 0-100 Ohms.

11. Repeat this process again for increasing wind speed values until the maximum allowable wind speed value is reached (the system automatically limits the maximum amperage level allowed for the wind fan motor.) Allow system to run for at least 10 seconds for stabilization and then push down arrow key on control to bring speed down. When nearly stopped, hit **STOP** button.

Lab Session #2: DATA COLLECTION

Utilize the data acquisition system to capture the operational values from startup to shutdown **(covered in Section 6.5.1 VI DATA Display and Collection in Operator's Manual and also covered in detail in next section of this sample lab).**

The following steps assume the use of the standard WindLab^TM Software and default settings as supplied with the WindLab^TM. Use of non-default setting or other software may necessitate alternative methods or procedures for data collection. Consult the LabView/National Instruments software specific information as required.

From Windows, OPEN the WindLab^TM Software by double-clicking on the WindLab 1.0 shortcut icon located on the Windows Desktop. WindLab 1.0 will start with the *Main Display/Control* and *Channel configuration Window* displayed.

WindLab^TM Launch Icon

NOTE: The computer must be connected to the WindLab^TM USB port prior to opening the WindLab^TM software.

The WindLab^TM configuration software is dependent upon the specific DAQ Module serial number as installed in the WindLab^TM and will not function properly if the DAQ Module cannot be found. If this was not done incorrectly, exit the program, attach the USB cable and start over.

To verify that the software is communicating with the DAQ Module, open **Measurement and Automation** from desktop. In menu tree, click on **Devices and Interfaces**, then, click on **NI DAQ 6218.** This provides and verifies the proper serial number for the on board DAQ system and also verifies that a proper connection to that device is being made.
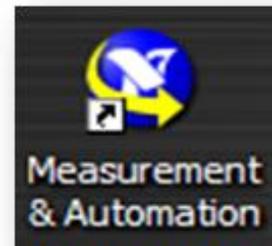
Measurement and Automation Icon

TO PERFORM THE FOLLOWING FUNCTIONS:

- **Virtual Instrument Panel Software Controls are shown on next page.**
- **Logging Data to File feature is shown on page 9.**
- **Importing Acquisition Data into MS-Excel Spreadsheet is shown on page 10.**
- **Graphing Spreadsheet Data is shown on page 11**

Virtual Instrument Panel Software Controls
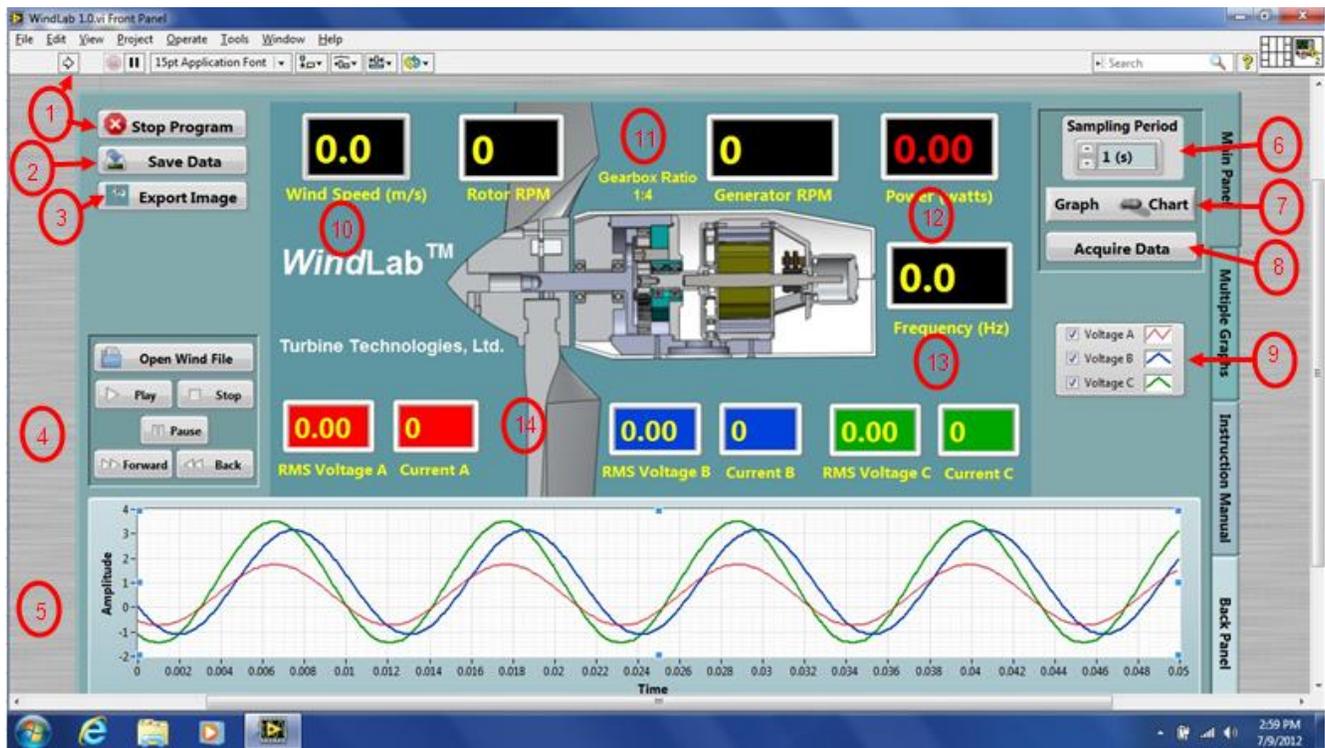
1. The program opens acquiring data and can be toggled on with the black arrow or off with the stop button.

2. Will save data to a text file (see below).

3. This will send an image of this VI (see saving data below).

4. Controls a pre recorded wind speed program.

5. A graph of the raw voltage from the generator.

6. Controls the rate data is taken press the up arrow for slower rate and down for faster.

7. Toggles the lower graphical display (5) between chart display or graph display.

LOGGING DATA TO FILE

When you want to save Data, you must hit "Stop Save" button, then:

1. Use the drop down menu to select a file path to save your data.

2. Give your data a file name, then select "OK". It is now saved in that file.

Importing Acquisition Data into MS-Excel Spreadsheet

A convenient way to analyze WindLab performance data is to graph the data points using a spreadsheet program such as Microsoft Excel. To accomplish this, Delimited data captured during the lab data acquisition must be imported into the Excel program. <u>Note: MS-Excel spreadsheet program will be illustrated. If using another spread sheet program, please review how to accomplish these same results with that particular program.</u>
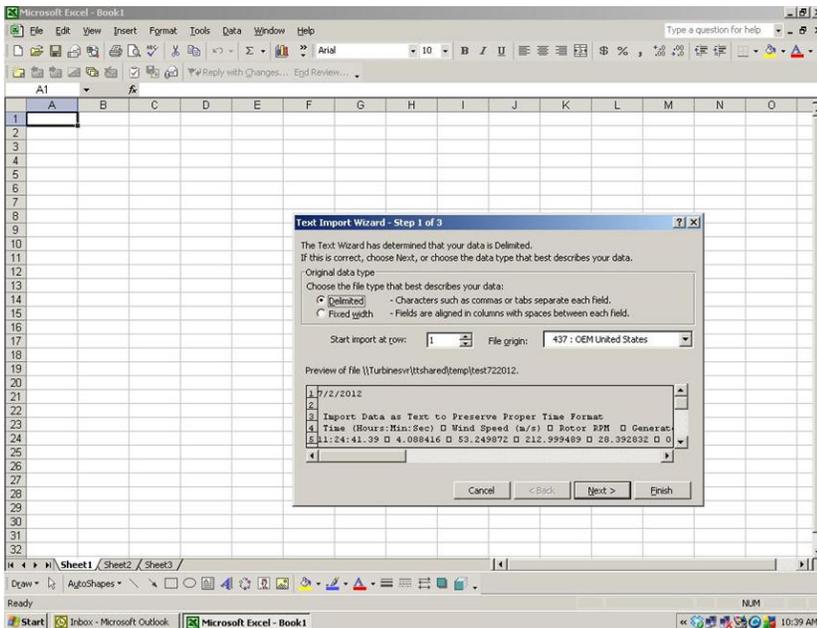
1. In Excel, Open your data file from where it is saved. You will see the attached screen come up with "Delimited" highlighted. Click "Next" and then click "Next" again when the next screen comes up.
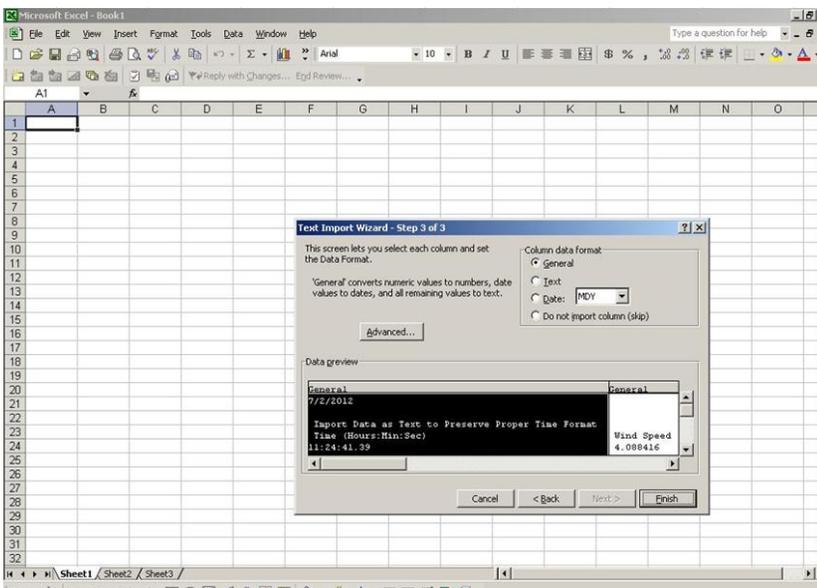
2. When this screen comes up, click "Finish"

3. Data is now in spreadsheet format.

Graphing Spreadsheet Data

1. Highlight the desired column or columns of data desired for graph. For this example, Rotor Speed and Generator RPM column data will be plotted (C&D).

2. Click "Insert" on the top menu bar.
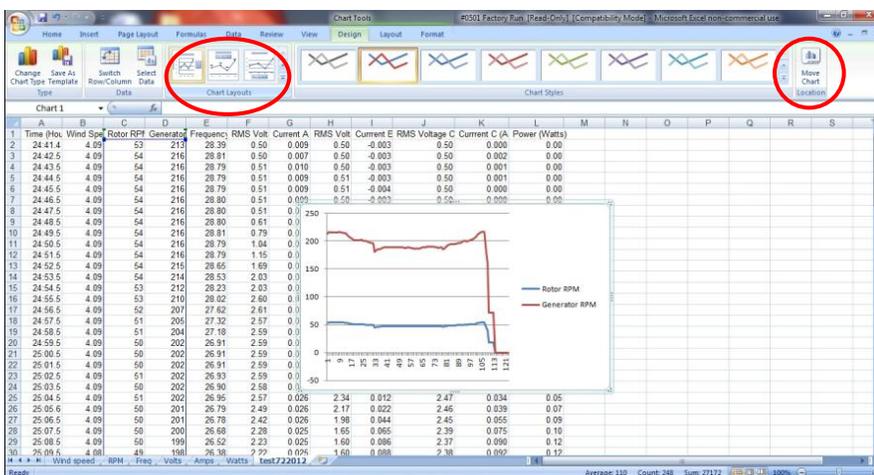
3. After clicking "Insert", click on "Chart Layouts". In this case, select no markers for data points and just lines.

4. Click "Move Chart"

5. Click on "New Sheet" bullet and "Chart 1" will be highlighted to name the chart, in this case call it "RPM".

6. Once named, click "OK". Chart will be moved to a separate sheet with a tab at the bottom labeled "RPM".
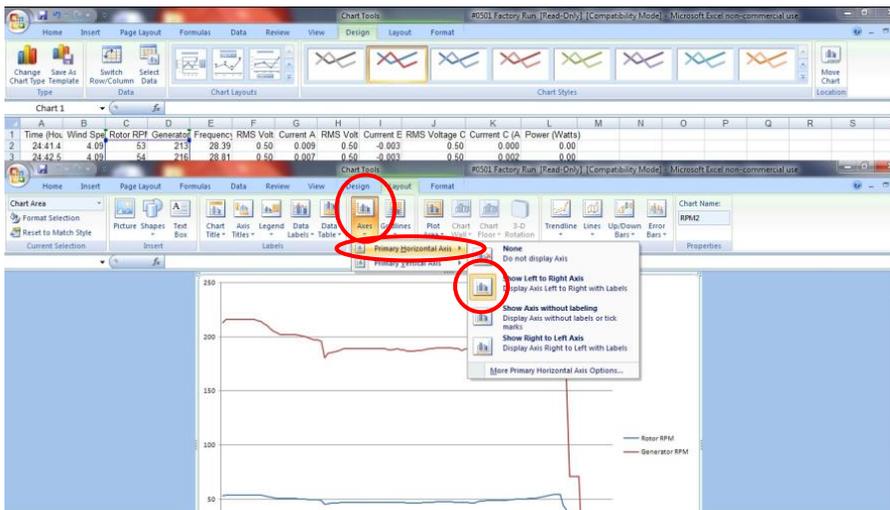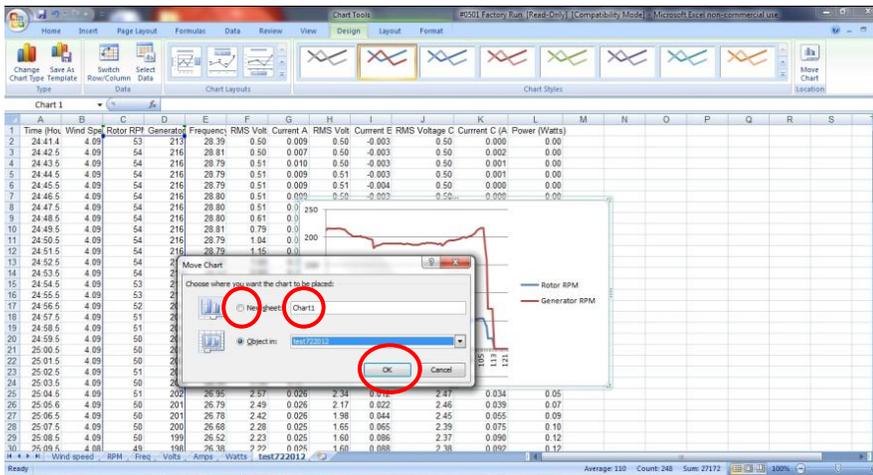
7. Click on:
 "Axes"
 "Primary Horizontal Axis"
 "Show Left to Right Axis"
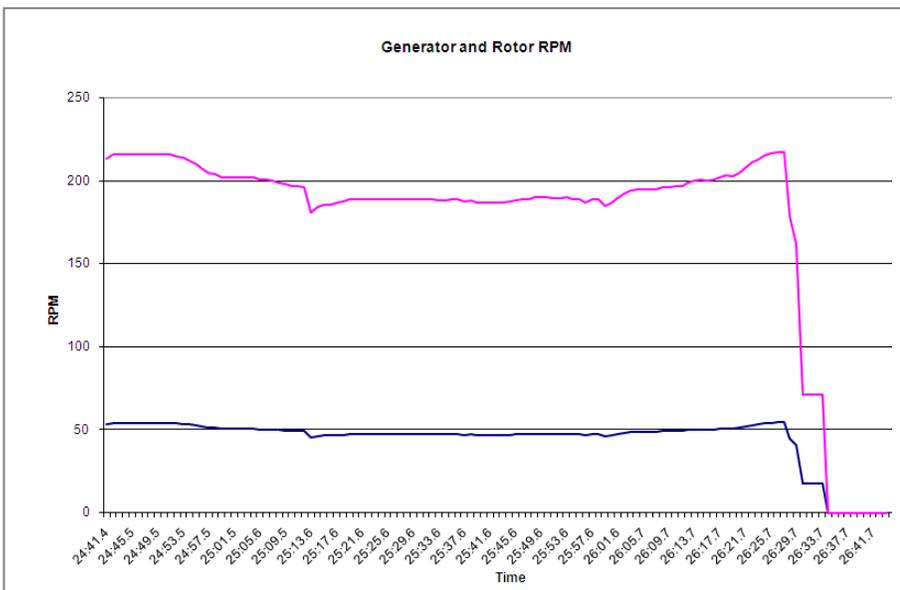
8. Final Graph
Generator and Rotor RPM
Comparison

Lab Session #3: System Analysis

Purpose: To review graphical data and answer performance questions

Procedure: Perform requested analysis

Using graphical information plotted for lesson 1 data run, answer the following questions;

1. For this system, where is the best generation output? Qualify with numbers.

2. Based upon your power curve wind generation graph and an average loading of 50%, what would be the total watt-hours of power generated for the 24 hour period if recorded wind data is as shown.

Midnight to 1:00 AM: CALM
1:00 to 2:00 AM: CALM
2:00 to 3:00 AM: Steady at 1 m/s
3:00 to 4:00 AM: Steady at 2 m/s
4:00 to 5:00 AM: Steady at 4 m/s
5:00 to 6:00 AM: Steady at 4 m/s
6:00 to 7:00 AM: Steady at 4 m/s
7:00 to 8:00 AM: Steady at 4 m/s
8:00 to 9:00 AM: Light Gusting, 4-6 m/s
9:00 to 10:00 AM: Light Gusting, 4-6 m/s
10:00 to 11:00 AM: Heavy Gusting, 6-7 m/s
11:00 to 12:00 Noon: Heavy Gusting, 6-7 m/s
12:00 Noon to 1:00 PM: Light Gusting, 4-6 m/s
1:00 to 2:00 PM: Light Gusting, 4-6 m/s
2:00 to 3:00 PM: Steady at 6 m/s
3:00 to 4:00 PM: Steady at 6 m/s
4:00 to 5:00 PM: Steady at 5 m/s
5:00 to 6:00 PM: Steady at 4 m/s
6:00 to 7:00 PM: Steady at 2 m/s
7:00 to 8:00 PM: CALM
8:00 to 9:00 PM: CALM
9:00 to 10:00 PM: CALM
10:00 to 11:00 PM: CALM
11:00 to Midnight: CALM

3. If your facilities have an average daily electric power consumption curve that looks like the following;
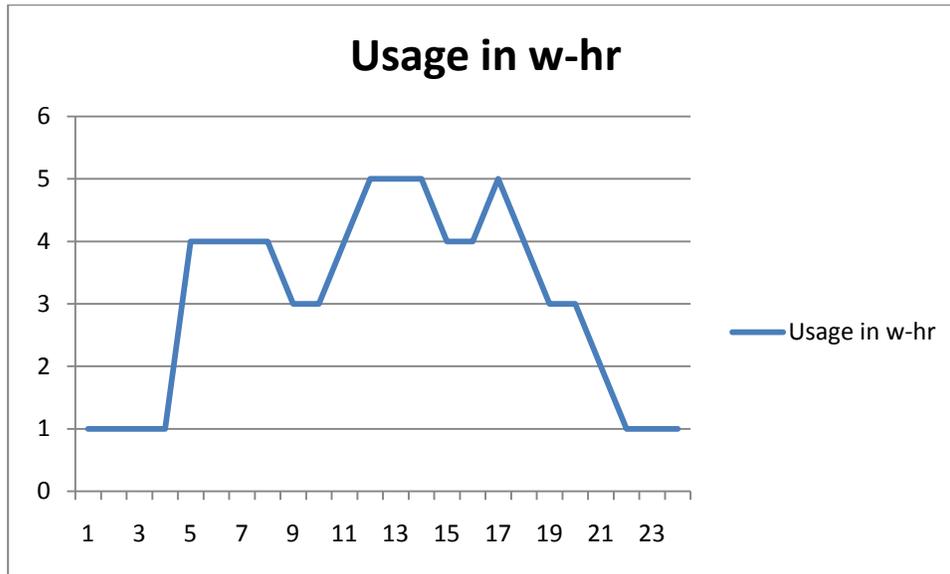
A. Based on the conditions cited earlier, what portion of that requirement will be handled by the wind turbine (if you have both wind turbine and commercial power distribution service connected to your facilities)? Show an overlay plot of wind turbine performance onto the typical usage curve for visual comparison purposes.

B. If billed electric service costs the facility property owner $0.10/wh, what savings will wind turbine owner realize for this day?

C. If this pattern of usage and generation were to be steady for a year, what is the savings for a year?

D. If the system being used had an acquisition cost of $10,000.00, what would be the calculated payback in years for the unit?

MORE LAB EXERCISE IDEAS!

As indicated, this is a sample lab procedure for the WindLab^TM Wind Turbine System. There are many exercises that can be run with the system. The following are ideas and basic outlines of some additional testing that can be done with WindLab^TM. The system offers some very wide-open exploration opportunities.

Exercises are basic and can include the following:

1. Run stepped wind speed programs and follow a specific loading test card to see the differences in performance for this type and size of machine. **Remember, generator rotor excitation voltage is adjustable from 0-14.5 VDC. This gives the operator a wide ranging capability to adjust excitation to help the turbine match wind conditions and get the most power generated. The more this is used, the better adjustable electro-magnetic verses permanent magnet capabilities will be understood.**

2. Run a programmed gust series and see what happens with supply integrity to load.
    NOTE: Programmable capabilities will be coming via a future software upgrade.

3. Conduct rotor blade pitch experiments and find the sweet spot for operation. Blade pitch angles are ground adjustable, so full system test cards can be conducted at various blade pitch angles.

4. Develop your own blade profiles and test them against the system's standard issue blades. CAD files are available from TTL with present blade geometry (please request the files when ready). Airfoil shape and twist can be modified in CAD and then sent to TTL for blade manufacture (or you can do it there if you have the capabilities).

5. Have students correlate these activities to the large HAWTs.

6. Once students have worked with WindLab^TM and have become knowledgeable with wind turbine generation, take them to a full-scale wind farm. They will know what they're looking for (after getting over how large they are) and may be inspired to get into the alternative energy field working with wind energy.

Here are some additional Lesson IDEAS with basic procedures that can be followed;

Lesson Idea #1: Run at a fixed wind speed and record what happens as load increases.
Procedure:
- Set and Record Blade Pitch Angle to _____ degrees.
- Turn on Power Key to electrically power up the system.
- Initiate Data Acquisition System to display and record data
- Choose a fixed wind speed of _____ m/s.
- Start wind speed fan and accelerate to chosen wind speed.
- Wind Turbine is unloaded and will start to spin. Upon stabilization, record unloaded RPM.
- Using load rheostat, slowly add load and watch the Voltage, Current, Power Output and Frequency change.

- Note WT RPM change as load is added.
- When this load scenario is stable, record:

  WT RPM _____
  Wind Speed_____
  Voltage_____
  Current_____
  Power_____
  Frequency_____

- Now, increase wind speed by 1 m/s and record your parameters.
- Adjust load until required frequency is made.
- Do 1 m/s increases and record each step along the way until you reach max wind speed allowed by the system.
- Analyze the performance along the way and determine best operating efficiency.
- What conclusions can you draw from the turbine with the twist angle set at _____ degrees.

Lesson Idea #2. Repeat lesson 2 while setting the WT blade pitch to a different angle
 Report performance comparison between original and new pitch

Lesson Idea #3. Gusty Wind Conditions
Goal: Gain an understanding of the power production problems wind turbines face with ever-changing gusty wind conditions.

Procedure:
- Turn on power key
- Start data acquisition recorder
- Start up wind fan and ramp up wind speed of 3 m/s.
- Adjust load to provide a Frequency, Voltage, Current and Power output.
- Ramp up wind speed to 6 m/squickly. WT system will respond.
- Adjust rheostat to add load to keep frequency within required range.
- Drop down to 3 m/s quickly. Respond with load reduction to maintain frequency.
- Note change in Voltage, Current and Power.

Lesson Idea #4
1. Using the wind data map supplied for the particular wind turbine siting region, please calculate total generation capacity for the year.

2. Provide an anemometer data set which could be programmed into the variable frequency drive. Somehow, students could scale the run time. The point we want to get across is average utilization verses designed capacity. (This can be accomplished when programmable portion becomes available).

3. If we scale this unit to a 5 MW system, let's calculate the ROI (return on investment) for this particular system.

4. Based on a buy back rate of _____ per kwh from the power utility grid, what is the revenue gained by this particular turbine.

5. Based on a sited cost of $20 million dollars and maintenance amount of 100,000.00 USD per year, how long will it take to pay off the WT and turn a profit? If the WT, has a 25 year life span, how much profit will it ultimately "generate" for its owners?

6. What is the average percentage utilization of the system (actual power being generated verses designed maximum power rating).