Wind Turbine Power Measurement Procedure

In this lab, we will determine the maximum electrical power that your wind turbine can generate. This involves the use of two key components: a power meter and a variable resistor (potentiometer). We first introduce these two components.

Power Meter

A power meter is a circuit that measures simultaneously both the voltage across and the current through a pair of wires. The circuit multiplies the values of voltage and current and produces a product which, of course, is the power flowing through this pair of wires. Figure 1 shows the structure of the power meter.

![Figure 1 Power meter functional diagram.](image)

Figure 1 Power meter functional diagram. The power meter consists of circuitry, which measures the voltage across and the current through a pair of wires, multiplies them together, and then displays the instantaneous power.

Figure 2 shows the top view of the power meter that will be used in this lab. The meter is built on a printed circuit board (PCB) without a chassis. As shown, there are two pairs of wiring connections near the front edge of the Power Meter board. One pair of the connections (on the left side) should be connected to the source of the energy and the other pair should be connected to the circuit that uses energy (the load side). The designation of ‘source’ and the ‘load’ is only for reference. The actual connections are not critical. If the power flow is from the left connections to the right connections, the display will show a positive power reading. If the power flow is in the other direction, it will show a negative number. In fact, in some applications, the power flow direction changes with time.

![Figure 2 Top view of the power meter.](image)

Figure 2 Top view of the power meter. Note that you must connect a DC adapter at the left side to power the meter.
As shown in Figure 2, the first digital display on the left shows the voltage across the wires (the connections) and the center display shows the current through the wires (from the left connections to the right connections). The one on the far right shows the power in mW (milliwatts, that is 0.001W). The switch (located between the connections) changes the metering range from 0.2 W maximum to 2 W maximum. Your wind turbine will most likely generate more than 200mW. If this is the case, the switch should be in the 2W maximum setting (down position) for this experiment.

The hardware for facilitating the wire connection is called a ‘binding post’ (see Figure 3).

![Figure 3 Binding Post](image)

**Figure 3 Binding Post.** A binding post has a hole through which you insert the wire you wish to connect and tighten the cylindrical knob to make good electrical contact.

To make a wire connection to the binding post, you first unscrew the top cylindrical knob to expose the hole on the post. You insert the wire through the hole (or you can loop the wire around the post). You then tighten the knob so that it presses down on the wire. Do not unscrew the knob so that it comes off the post and do not screw down too hard and cut off the wire.

**Potentiometer**

Figure 4 shows a picture and the circuit symbol of a potentiometer (called a ‘POT’ for short). As will be explained in the next section, the energy generated by the wind turbine will be ‘dumped’ into this variable resistor and turned into heat (probably too low to be felt in this case.)

![Figure 4 Potentiometer](image)

**Figure 4 Potentiometer.** A potentiometer (POT) is a variable resistor. The resistance between the center wiper terminal and either of the end terminals depends on the rotation angle of the shaft.

The internal structure of a typical potentiometer (POT) closely resembles its circuit symbol (as shown in Figure 4). Inside a POT, there is a strip of conducting material (or, more precisely, a resistive material). For a rotary POT, the kind we have in the lab, this conducting strip is in a
circular shape. Two ends of this conducting material are connected to two side terminals. The center terminal is connected to one end of a ‘wiper’. The other end of the wiper touches the conducting material. The position of the wiper tip can be adjusted by turning the shaft of the POT. As the wiper contact moves closer to one of the terminals (say, the left one), the resistance between this terminal and the center terminal (between the left terminal and the center wiper) becomes smaller. In fact, if you turn the shaft all the way clockwise to a stop, the resistance between these two terminals becomes zero.

A POT is rated by its end-to-end resistance and its power rating (the maximum power that it can dissipate without burning out). We have three types of POTs in the lab: 10Ω, 50Ω, and 250Ω. All three types are rated at 5W. Note that power rating of an electronic component is a rating of how much power the device can safely dissipate. The component does not (and, in fact, will rarely) dissipate this amount of power in a normal operating condition. Since your wind turbine will not generate more than 5W of power, it is safe to use these POTs as the load (where all the energy generated will be dissipated).

Wind Turbine Power Measurement

As mentioned above, we will use a POT as the load in our test setup. The resistance of the POT (loading resistor) affects how much power is extracted from the wind generator. At a certain wind speed, for a given turbine/generator design, there is a maximum power that the generator is capable of generating. Whether this maximum power is fully utilized or extracted from the generator depends on the loading condition. If, for example, the wires of the generator are left open (no current drawn from the generator, called the ‘no load condition’) or if the wires are shorted (high current, but zero voltage across the wire), even with best wind condition and the best design of the turbine, no power will be drawn from the generator. Why? (Hint: how is power defined for electrical devices?)

The goal of this experiment is to find the best loading condition (i.e., the loading resistance that draws the most power) for your wind generator. By varying the resistance of the POT (the load), we can experimentally find this ‘best loading condition’.

**Procedure 1**: (Resistance Measurement)

You will need to measure the resistance of the POT setting in this experiment. The following procedure will give you practice with measuring resistance using a multimeter. A multi-meter can measure voltage, current, and resistance. For this exercise, we will set the meter to the ‘resistance measurement’ mode.

1. Obtain a 50Ω POT from the instructor.
2. Turn on the multimeter and select the measurement mode to resistance measurement mode by pressing the button marked “Ω” (see Figure 5). Hold the multimeter probes so that they touch two terminals of the POT --- the center terminal and a side terminal (either side). Note that for resistance measurement, the polarity of the probe connections (red + and black -) is not important.
3. Turn the POT from end to end and observe the resistance variation with the turning
shaft angular position. Also verify that the maximum resistance is about the same
as the POT resistance marked on the back of the POT (50Ω).

![Multimeter Diagram]

**Figure 5  Multimeter.** The multimeter will be used to measure the resistance
of the POT

**Procedure 2:** (Wind Turbine Setup)

4. Take your wind turbine/generator to a ‘wind station’ setup in the lab, and connect it
to the power meter and a POT as shown in Figure 6. **DO NOT** TURN ON THE
BLOWER AT THIS TIME. Connect the POT to the ‘Load’ side of the power
meter, unless this has already been done. Connect your generator to the ‘Source’
side of the power meter by using two alligator clips as shown in Figure 6. The
polarity of either connection is not important. If, for example, you connect the
positive voltage from your turbine generator to the negative binding post, the
voltage and the current readings will simply be shown as a negative value. The
power reading in this case, however, will remain positive.

![Wind Turbine Wiring Diagram]

**Figure 6. Wiring diagram for wind turbine power testing.** Connect your
wind turbine generator leads to the alligator clips, and connect the POT the
binding posts for the load.

5. Stick a small piece of reflective tape (provided) on one of your turbine blades (on
the hub, where it is stronger). The blades are fragile. Be very careful not to put too
much pressure on them.
6. Before you turn on the fan, assign each team member to one of the following tasks:
   - One team member varies the POT resistance.
   - One team member records the experimental data (wind speed, RPM, voltage, current, and power readings)
   - One team member operates the non-contact tachometer.
   - One team member turns on/off the blower, measure wind speed, and secures your turbine during the experiment.

7. **BEFORE** you position your turbine in the path of the wind, the ‘blower operator’ can turn on the blower (set it to ‘high’), and use an anemometer to determine the distance away from the outlet of the blower where the wind speed is 20 MPH. Record this distance.

8. **TURN OFF THE BLOWER**, and then position your wind turbine at the distance determined in the previous step.

9. Turn on the blower (set the selection switch on the side of the blower to ‘high’). When the turbine reaches a steady state spinning speed, turn the POT from end to end at using small rotation increments (say, about 20 degrees). At each step, record the voltage, the current, the power, and the rotational speed of the turbine.

   To measure speed of the turbine, stand a foot or so behind your turbine, point the tachometer at the blades, and press the button on the side of the unit. You should see a red spot where the beam from the tachometer reflects off of the turbine blades. Note that you will need to divide the RPM reading shown on the tachometer display by the number of blades to get the rotational speed of the generator. If you have trouble getting a reading of the speed, you may need to stick a small piece of reflective tape (your instructor can provide) on one of your turbine blades. If you use the reflector tape, then you won’t have to divide the reading by the number of blades. The blades are fragile. Be very careful not to put too much pressure on them.)

   Reading fluctuation is normal. As you notice the power reading is approaching the maximum, use a smaller rotation angle of the POT shaft, and search for the maximum power point. In other words, the maximum power point must be one of your data points. (You will be graded based on this number). Note that the power reading should be the product of the voltage and current (verify this). Due to the measurement fluctuation, this relationship may not be exact according the readings. Wait for 10 seconds or so for the rotational speed to stabilize between changes in the POT resistance. Ask your lab instructor or lab assistant to certify the maximum power that your turbine can generate. **DO NOT** turn the POT after it is set to the maximum power load.

10. Disconnect the POT from the power meter, and use the multimeter to measure the resistance. This resistance reading is the ‘best’ loading condition for your turbine/generator design.

**Procedure 3:** (Four Different Loading Conditions)

   The following experiment allows us to visualize the power being generated by the turbine at four different loading conditions. There are four different types of light bulbs that will be used as the load in this experiment. They are marked as shown in Figure 7.
11. Connect one of the light bulbs to the load side of the power meter. Repeat the same procedure as described above and record all the readings for each type of the light bulbs.

Make sure that you include the results of your measurements in your final report and presentation. You are advised to make a graph summarizing the data that you took.

A modern wind turbine can generate 3 mega watts of power. For such a wind turbine, electronic equipment (called an ‘inverter’) is used to continuously track the maximum power point and, instead of dumping the energy into a resistor, it converts the power into an AC voltage that is compatible with the grid voltage and ‘pushes’ the energy onto the electrical supply grid.

Professor Hsu standing in front of a 750kw wind turbine. He is a member of the team that developed the power control system of the turbine.
Each turbine blade weights close to 2000lb (the person weights much less).