Experiments with 3-Phase Wind Turbines

For the PicAxe 28X2 Processor
Using the Whirlybird 3-Phase Wind Turbine

Experiment #3 – Adjusting The Load

A REEL Power tm (Renewable Energy Education Lab) Experiment

Purpose

This experiment is designed to show how the wind turbine can power a resistive load of varying value. You will see how the wind turbine slows down by adding more and more load (less and less resistance).

You will come to understand that:

1. The wind turbine generates power based on the load applied to it…and

2. The wind turbine generates power based on the wind speed.

PicAxe Background Information

If this is your first experiment or if you just need a refresher on some of the details please refer to the following background information guidelines:

- **Parts Assembly and Wiring Guidelines**
- **Coding Guidelines**
- **Resistor Color Codes**
- **Reprogramming the FTDI chip – very important!!**
- **Computing Current with Voltage Drop**
- **REEL Power Software Installation and Operation**
- **Safety Precautions**

Wind Turbine Information

This will give you supplemental information on the wind experiment.

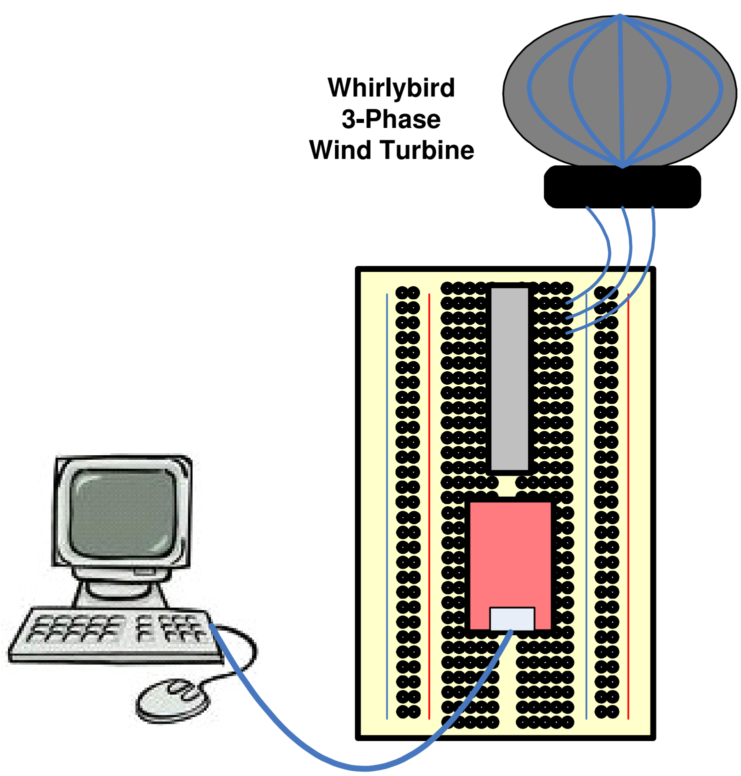
Equipment

Qty	Description
1	Whirlybird 3-Phase Wind Turbine
1	Solderless Breadboard (Radio Shack Model: 276WBU301)
1	PicAxe 28X2 microprocessor chip
1	SparkFun USB to Serial Board (Model BOB-00718)
1	USB cable
6	Diodes
1	1 ohm resistor
1	100 ohm potentiometer
1	10K resistor
10	Solid hookup wires (Radio Shack Model: 276-173)
4	Clip leads
1	Table fan
1	Windows PC computer with **REEL Power** tm software (MACs must have Parallel's "Desktop 3.0 for Windows")
1	Printer (optional)

General Hardware Hookup for Whirlybird Wind Turbine

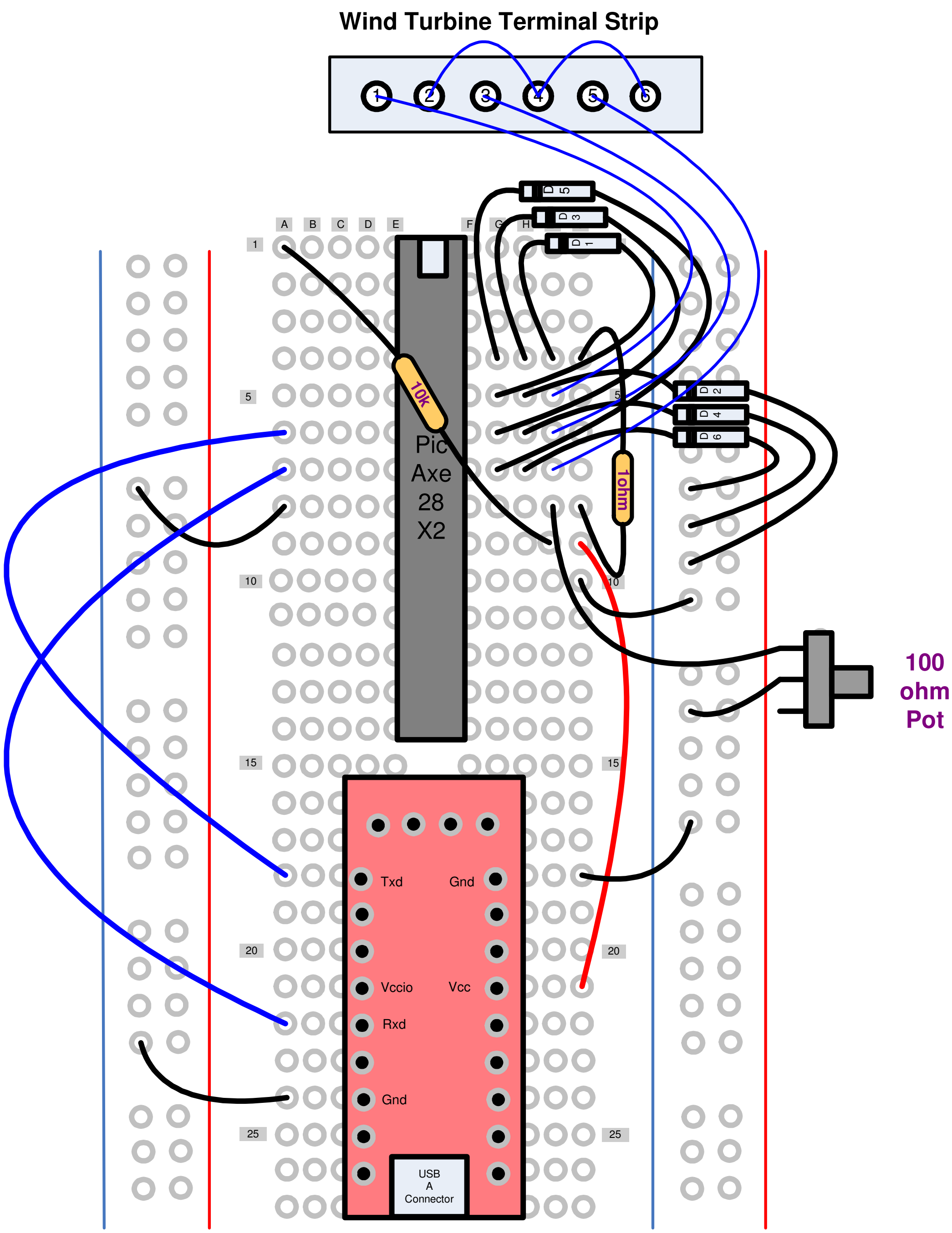
Setup the equipment as shown here, and then examine the **Jumper Board Hookup** (next) for specific details. .

Note: Your setup will <u>NOT WORK</u> unless the FTDI chip on the SparkFun USB to Serial Board is reprogrammed. See PicAxe Background Information for details

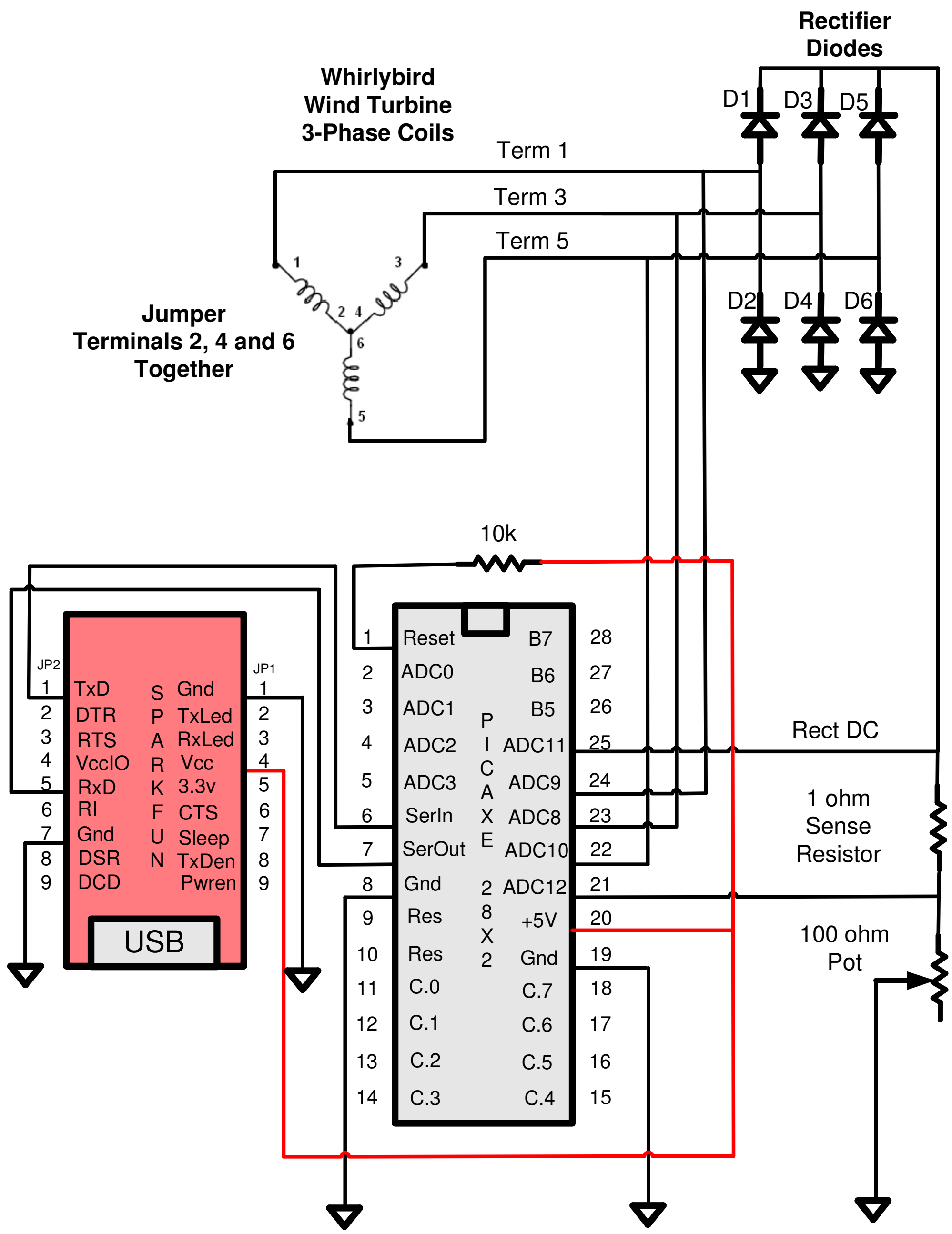


Jumper Board Hookup for Whirlybird Wind Turbine

Caution: This is a very dense hookup with many components whose leads can accidentally short together. Be careful in placing components so that they remain apart from one another.



Schematic for Whirlybird Wind Turbine



Code File

Download the following file to the PicAxe processor:

Picaxe_wind.bas

The code file can be found on the REEL Power CDROM that came with this lesson or on the LearnOnLine website at www.learnonline.com.

Note: Your setup will NOT WORK unless the FTDI chip on the SparkFun USB to Serial Board is reprogrammed. See PicAxe Background Information for details

Code Algorithm

Here's how the code works to acquire and display the 3-phase and rectified DC signals. For complete details refer to the above code file.

The Main loop looks like this…

```
Main:
      gosub Wait_For_Zero_Volts
      gosub Wait_For_Next_Peak
      pause delay
      gosub Acquire_Phase_Samples
      gosub Compute_RPM
      gosub Average_DC_Samples
      gosub Convert_To_Mv
      gosub Compute_Cksum
      gosub Transmit_Data
      delay = delay + 1
      goto  Main
```

The idea behind the Main loop is to synchronize the data gathering with the start of the phase1 voltage signal as it goes from zero volts and just starts to peak. This is what the first two subroutines do.

```
      GOSUB   Wait_For_Phase1_Zero_Volts
      GOSUB   Wait_For_Phase1_New_Peak
```

Following this the program delays from 0 to 255 milliseconds depending on the value of the delay.

```
       PAUSE   delay
```

After the delay, samples of all three phases and the rectified DC voltages are acquired by the A/D converter chip and averaged with the last readings.

```
GOSUB   Acquire_Phase_Samples
```

Following the phase samples the wind turbine RPM is computed when the phase1 voltage has reached the right level.

```
gosub Compute_RPM
```

Next, the rectified DC and 1 ohm voltage drop voltages are averaged to remove as much ripple as possible for better current and power computations.

```
gosub Average_DC_Samples
```

Then all the sampled data are converted from raw A/D counts to millivolts or milliamps

```
gosub Convert_To_Mv
```

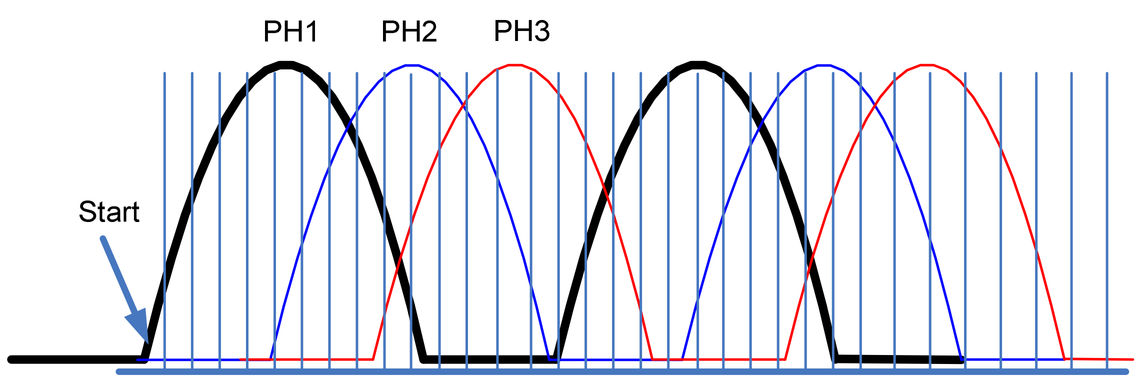
A checksum is computed and the samples are transmitted to the PC for display.

```
gosub Compute_Cksum
gosub Transmit_Data
```

The delay is incremented by 1 millisecond to advance the next sample and the process is repeated.

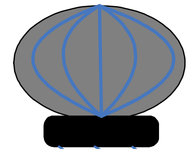
```
delay = delay + 1
GOTO  Main
```

The delay will eventually roll over to zero after 256 increments, but the idea is to take samples along the travel of the 3-phase waves in order to gain an understanding of how the nature of the wind turbine works. The diagram below shows the sampling process. Once again, the sequence is re-synched every time by detecting the start of phase1.

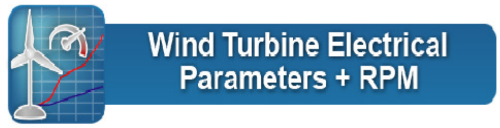


Progressive 1 ms delay samples after re-syncing to the start of Phase1

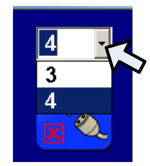
Procedure – Using the Whirlybird Wind Turbine



1. Click on the **REEL Power** tm icon to bring up the software menu. Then click on the **Wind Turbine Electrical Parameters + RPM** icon.



2. On the graphic display, click on the Connect button at the lower-left of the screen. Verify that the connected icon appears validating the Comm port selection. Make sure to click on the arrow and select the highest comm port number.



3. On the computer adjust the voltage (vertical) scale on the **REEL Power** tm software to 5.00 volts.

4. Adjust the potentiometer for maximum resistance – normally fully counter-clockwise. Temporarily remove the potentiometer from the circuit.

5. Set the fan to the highest speed setting and verify the following plot in Figure 1 below. This is a plot with no load applied. A small amount of current is displayed, but this is due to sampling the sense resistor after sampling the primary voltage, both of which are varying at different times.

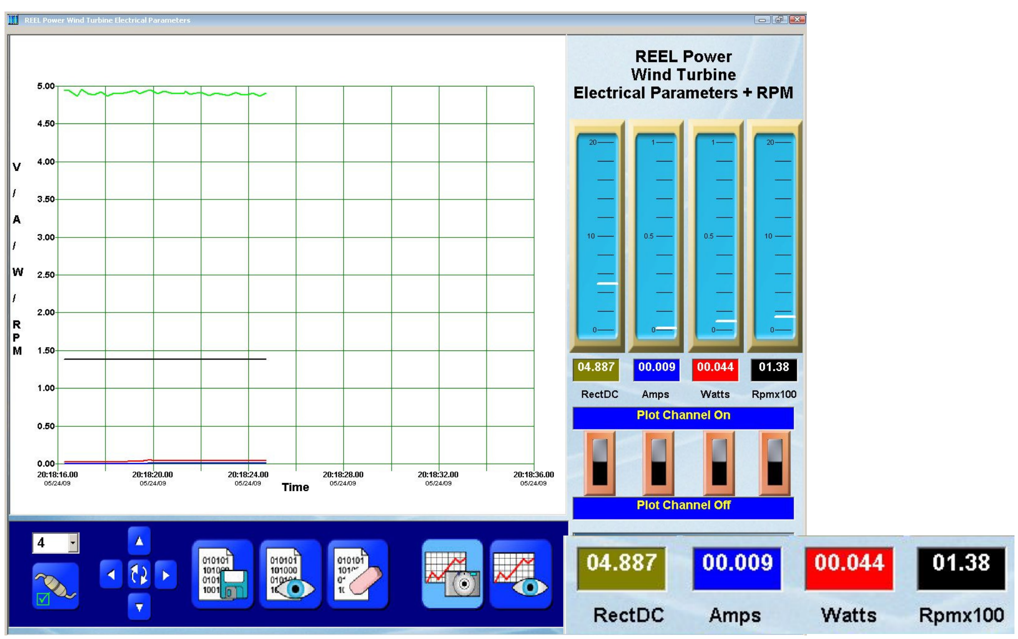


Figure 1– Filtered Rectified DC with No Load

6. Add the potentiometer back into the circuit and decrease the vertical range until the current and power plots are better visible. Your plot should like that in Figures 2. Note the drops in voltage and RPM.

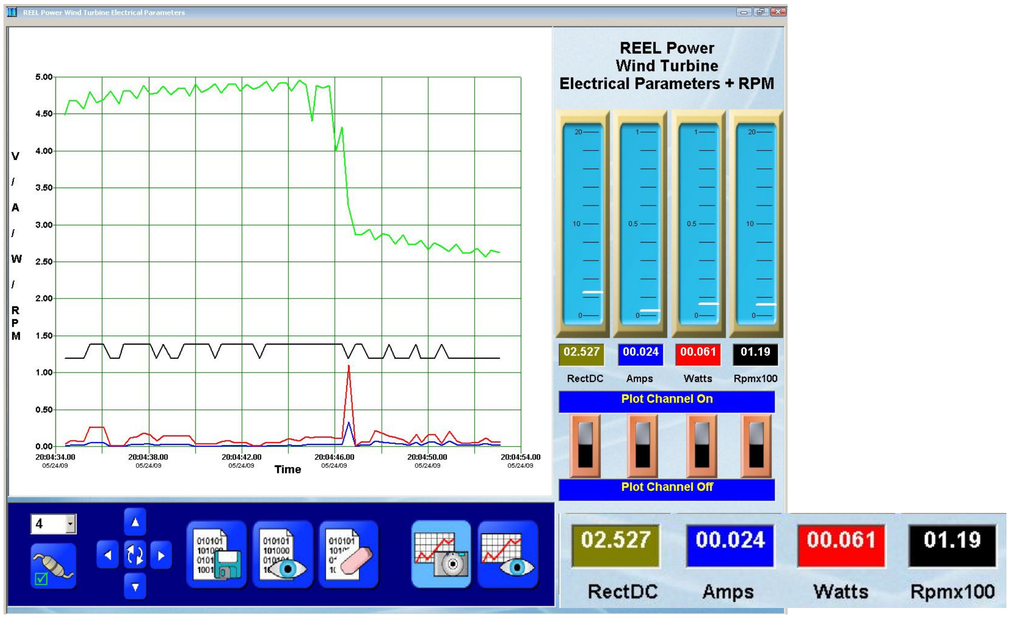
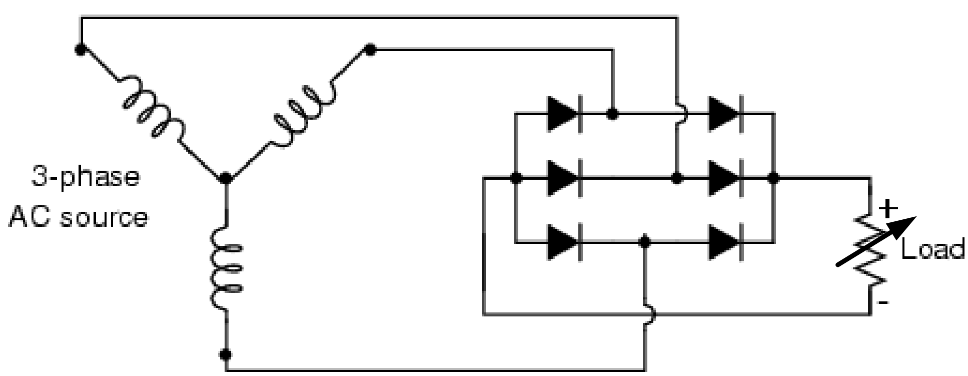


Figure 2 – Plot with 100 ohms as Load

Pre-Analysis

RPM and Corresponding Voltage Drop

The RPM drop is a result of applying the 100 ohm "Load" potentiometer across the rectifier diodes as illustrated below.



The wind turbine is now trying to supply power to the resistor load, but its' only source of power comes from the wind blowing across its rotor blades. If the fan's wind output stays constant, something has to give! In this case, it's the speed of the wind turbine rotation caused by the applied load, since it is working harder to supply power to the resistor load and not just spinning freely. The result is slower rotation.

For example, when you maintain the same peddling force riding a bicycle from a horizontal road to an up slope, the speed of the bicycle is reduced. The reduced speed is to compensate for the extra work load of climbing. The same analogy can be used here for the wind turbine's slower speed.

Current and Power Production

With a load attached, the wind turbine now has a path to deliver current and power. As an example take the readings from Figure 2 above and with Ohm's Law calculate the current generated by the alternator into the 100 ohm resistor load.

The equation for computing the association among voltage, current and resistance (load) is as follows:

$$V = I*R$$

Where V = Voltage in volts
I = Current in amps
R = Resistance in ohms

By algebraic substitution, current can be calculated as follows:

$I = V / R$
$I = 2.527 / 100$
$I = 0.025$ (actual is 0.024 amps)

With the current known, the power can be computed. The equation for power is shown below:

$$P = V * I$$

Where P = Power in watts
V = Voltage in volts
I = Current in amps

$P = 2.527 * 0.025$
$P = 0.063$ watts (actual is 0.061 watts based on 0.024 amps)

While the computed values in this example nearly match the displayed values, slight differences in actual versus computed current and power values are the result of rounding errors in software. In other words, you may not see the exact computed values displayed on the computer in every instance.

Because the wind turbine turns at slightly different rates while it spins, it generates slightly more, or less, voltage. This, in turn, produces more or less current and power. The wiggly lines of voltage, current and power represent both the 3-phase rectified DC signal along with the slight imbalance in the rotor blades plus any turbulence in the wind blowing across them. Wind is the result of the movement of air from the fan, and the movement of air is never steady – especially with a fan where the airflow is not laminar. Therefore, slight changes in wind speed will be reflected in the output voltage. You may have better results outdoors in natural wind.

7. Next, adjust the resistor for less resistance – about half of the entire rotation of the potentiometer. Now capture another plot of voltage, current and power as in Figure 3 below. Notice the increase in current but the drop in power and RPM.

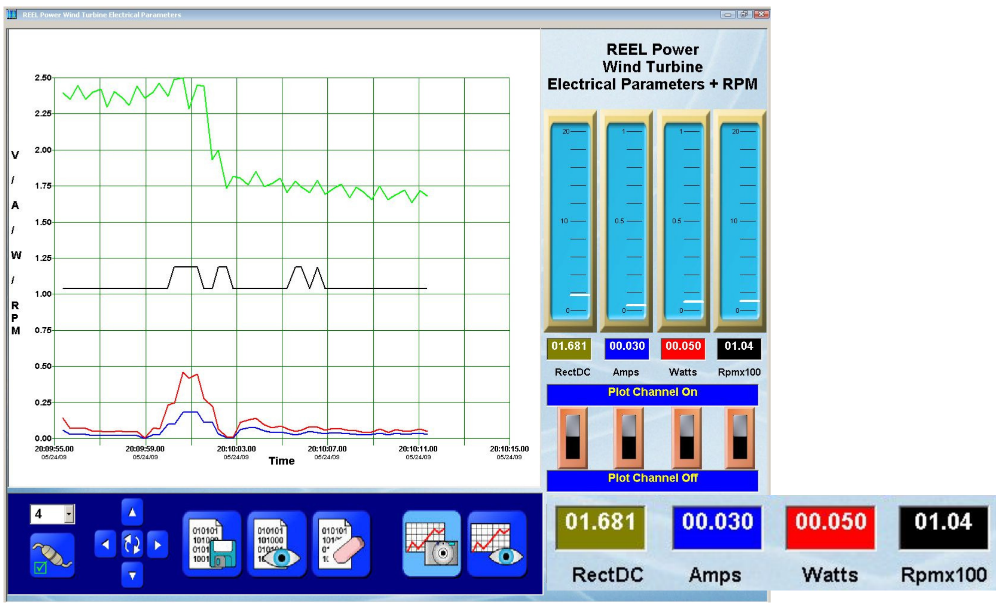


Figure 3 – Plot with 50 Ohm Load

Analysis

This experiment demonstrates that the wind turbine's ability to produce power is primarily dependent on the wind speed and the load. While the wind speed was kept constant, the load was reduced from 100 ohms to 50 ohms. While the current increased with the heaver load the resulting power levels decreased due to lower voltages since the wind turbine could not create enough power with the supplied wind speed. Wind turbine slowing or braking is done by dumping energy from the generator into a lower and lower resistance, thereby converting the kinetic energy of the turbine rotation into heat. This is what we did to make the turbine slow down. This is an alternative to mechanical breaking and is safe since the heat generated by the power dump is minimal.