Experiments with 3-Phase Wind Turbines

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

Experiment #5 – The Effects of Magnetic Coupling

A REEL Power tm (Renewable Energy Education Lab) Experiment

Purpose

This experiment will determine the power loss by adding a larger space between the rotating magnets and the coil stator. This is done by adding more washers to increase the space between the coils and rotating magnets.

You will come to understand and interesting paradox:

1. For electrical reasons the air gap must be as small as possible to generate the maximum power.

2. For mechanical reasons the air gap must be large enough to allow sufficient RPM without the effects of air resistance and to allow for the expansion of the rotating machinery due to heat caused by friction.

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.

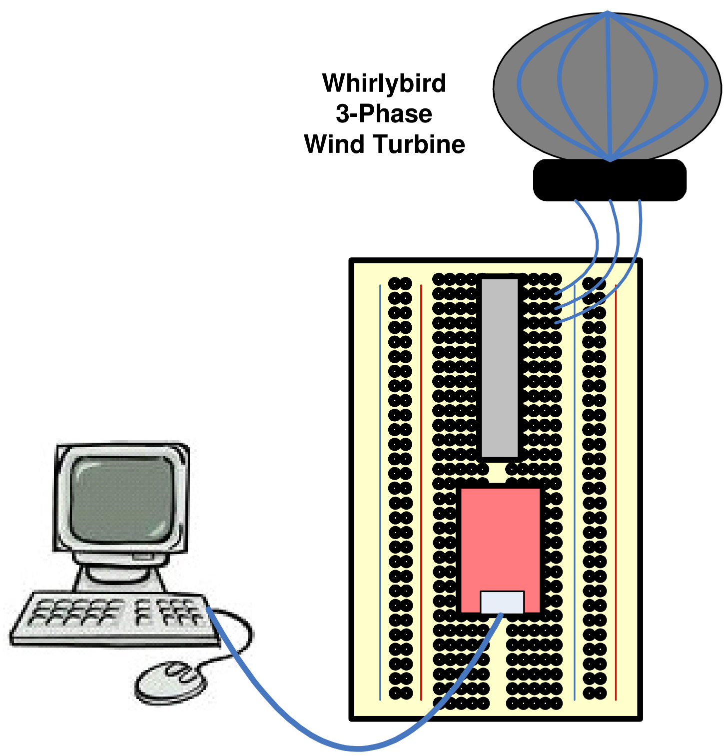
Equipment

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 (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

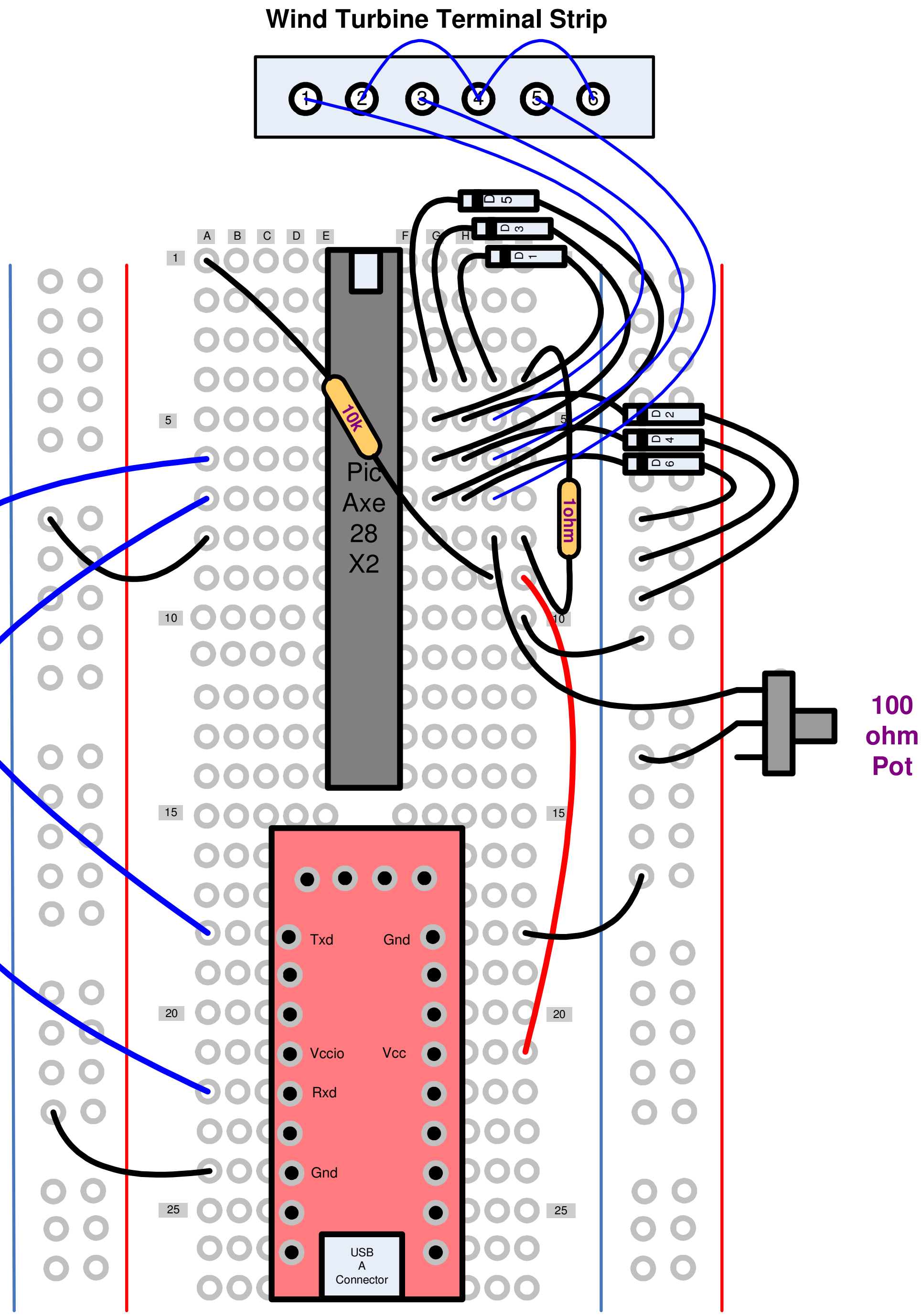
Setup the equipment as shown here, and then examine the **Jumper Board Hookup** (next) for specific details. .

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

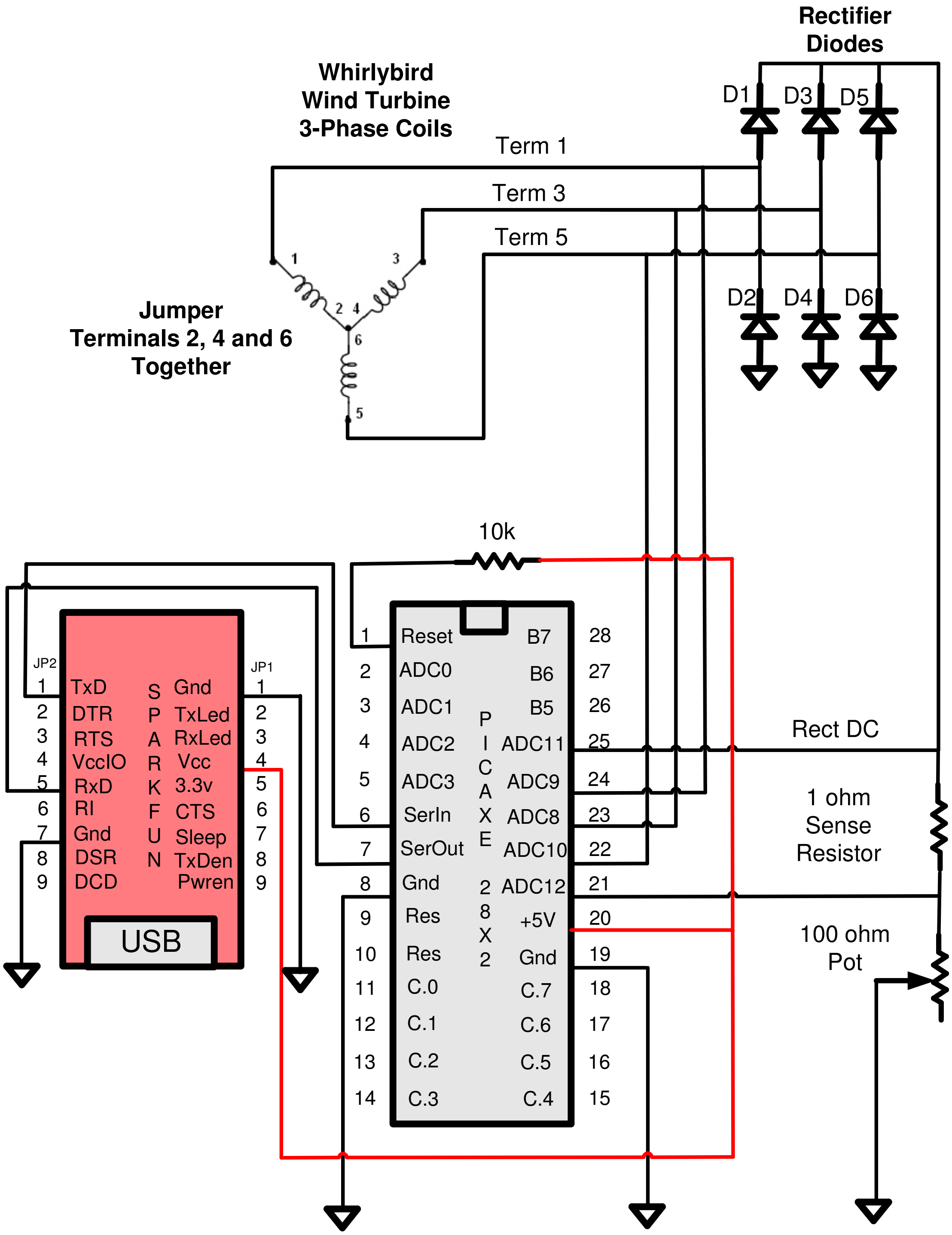


Jumper Board Hookup for Whirlybird Wind Turbine

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
```

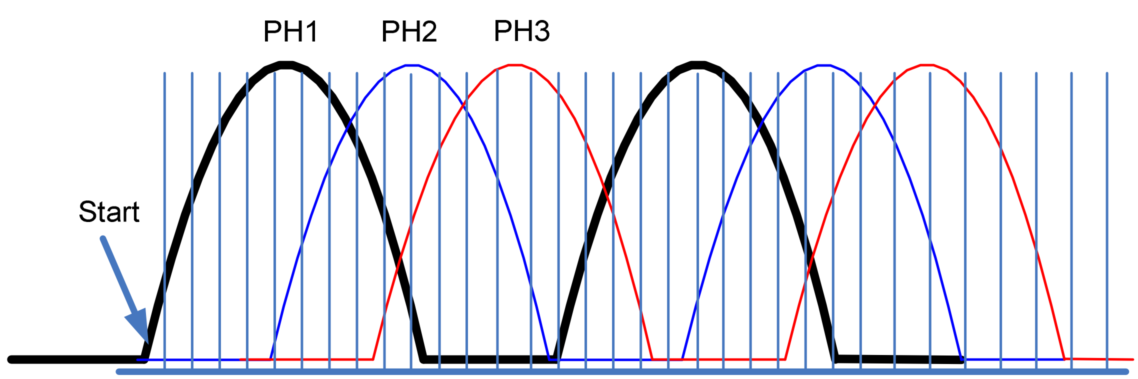
A checksum is computed and the samples are transmitted to the PC for display.

```
gosub Compute_Cksum
gosub Transmit_Data
```

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

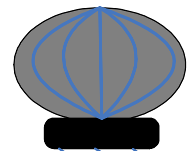
```
delay = delay + 1
GOTO  Main
```

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 10.00 volts.

4. Adjust the potentiometer for maximum resistance – normally fully counter-clockwise. Temporarily remove the 100 ohm pot from the circuit.

5. Set the fan to its highest speed setting. With the wind turbine spinning, verify the following plot in Figure 1 below. We will use this as a baseline setting.

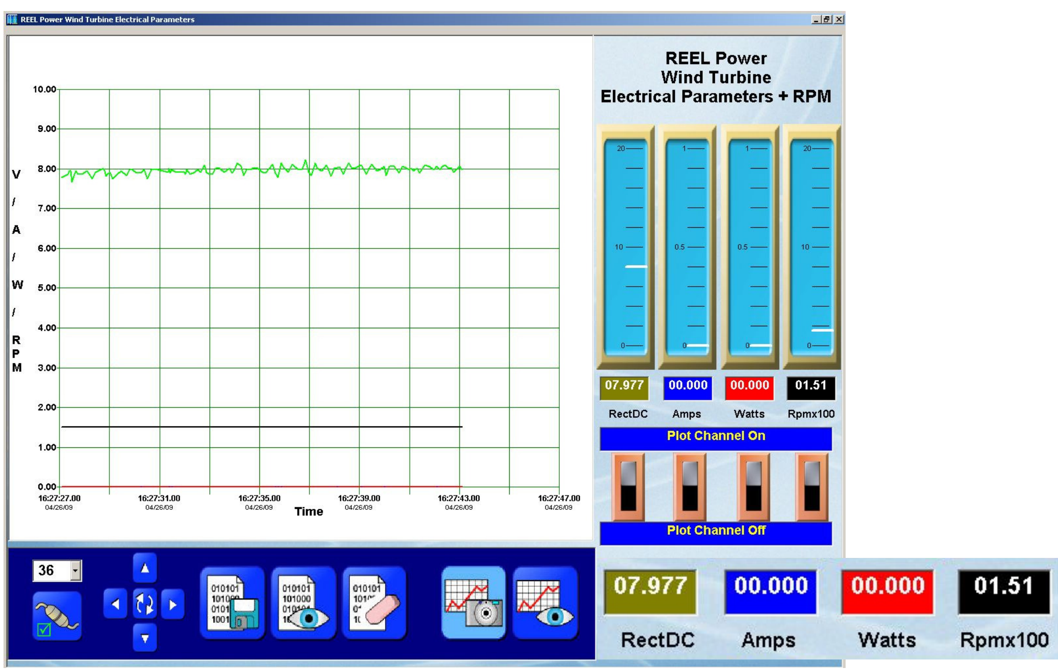


Figure 1 - Rectified DC under No Load

6. With the table fan at full speed and the wind turbine spinning, re-attach the 100 ohm potentiometer. Your plot should look similar to the one in Figure 2 below. Record the power.

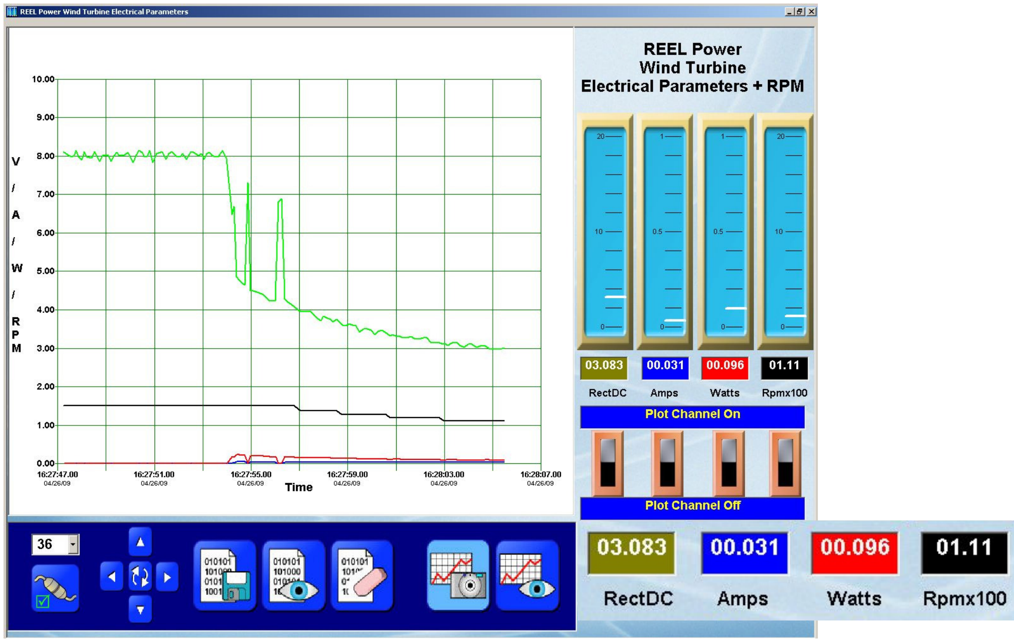


Figure 2 – Current and Power with 100 Ohm Load

7. Stop the table fan and disassemble the wind turbine by removing the bottom stator assembly from the top rotor assembly. Add a 3/8" washer to the bolt that holds the two assemblies together thus increasing the gap between the rotor and stator assemblies. Reassemble the turbine.

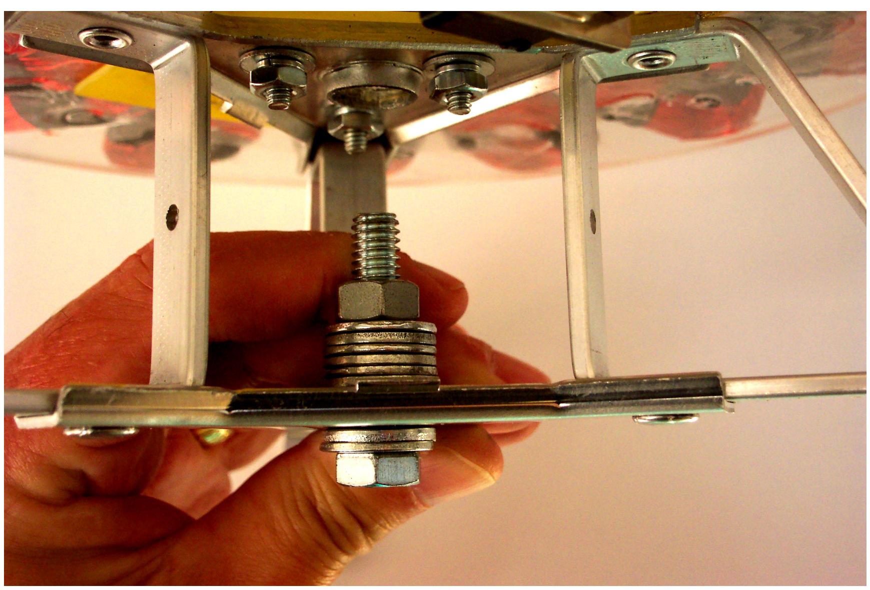


Figure 3 – Adding a Washer

8. **<u>With the turbine in the same place and rotating at the same RPM</u>**, repeat step 6 and record the power. Notice how much the power has decreased with the space of only one more washer – nearly by half!

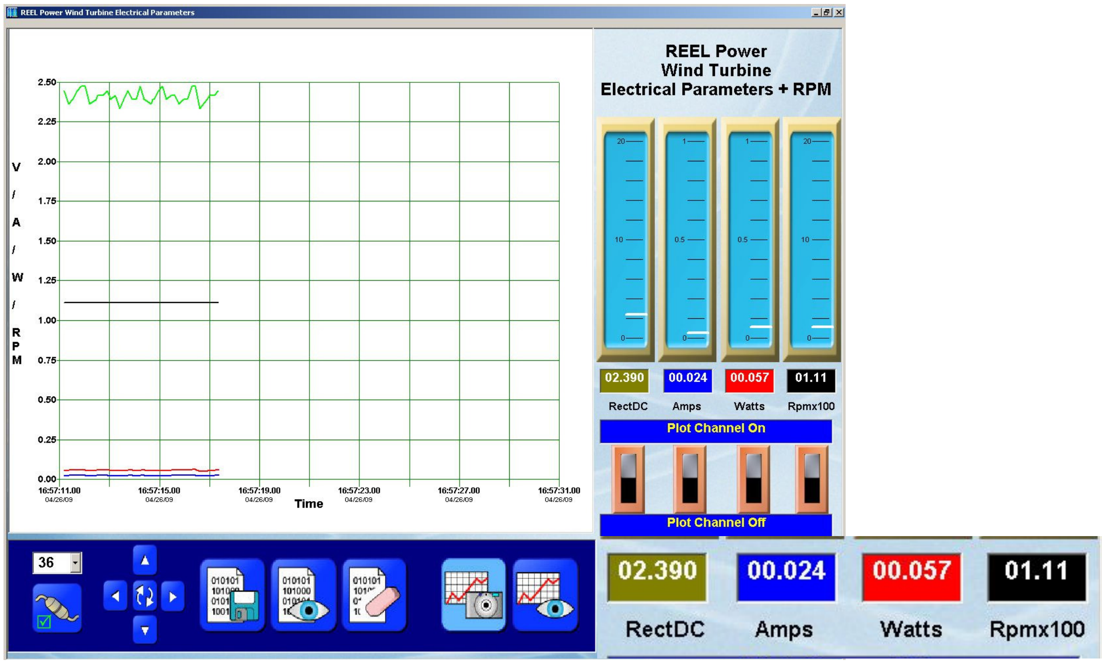


Figure 4 – Power Reduction with One Extra Washer

9. Repeat steps 7 and 8 again by adding a second washer. Notice, once again, the dramatic power decrease with the wind turbine spinning at the same RPM.

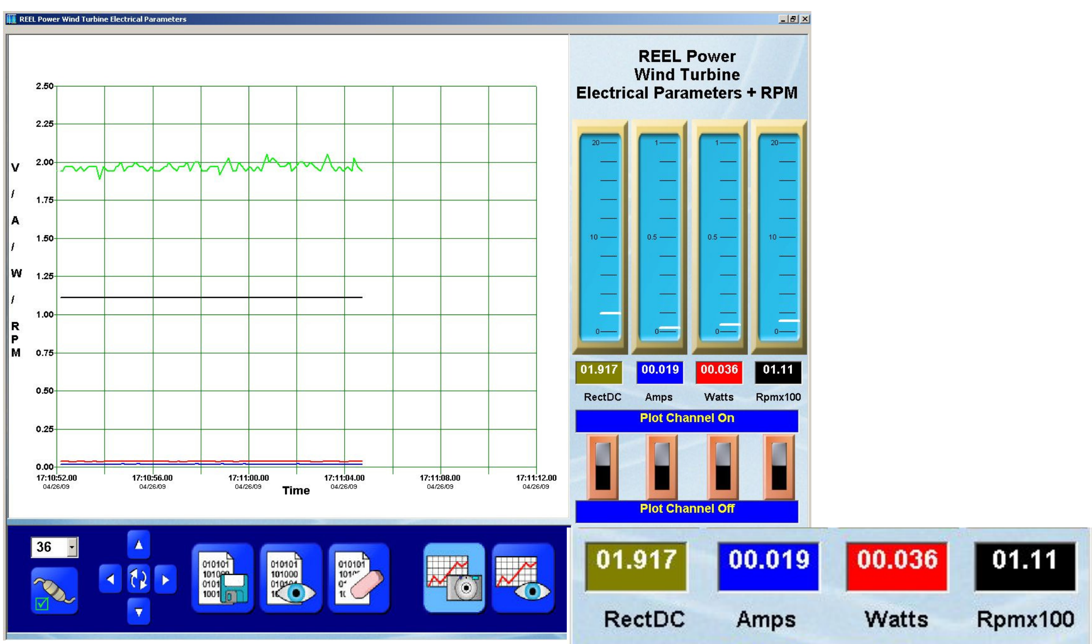


Figure 5 – Power Reduction with Two Extra Washers

Analysis

By adding just two washer spacers and increasing the air gap by about an 1/8" the effective power output dropped from 96 milliwatts to 36 milliwatts – a 62.5 % decrease!! This shows how dramatically magnetic flux affects power output.

Based on the results of the experiment we want to minimize the air gap in the magnetic field path. It can't be too small or the physical components will rub together, and it can't be too large or power will be reduced significantly.

Therefore, there are special demands of motors and generators with respect to air gap.

The electric motor (or alternator as we have here) presents the unique necessity for an air gap fully separating a rotating magnetic structure from a stationary one. Not only must the separation be complete; it must be large enough so that manufacturing tolerances will not allow the separated components to come into damaging contact during machine operation.

The high "reluctance" of air means that for every unit length of magnetic flux path, the mmf or magneto motive force, required to drive flux through the air portion of the path will far exceed (as much as tenfold) what's needed for the magnetic (steel) portion. he larger that gap in an induction motor, the lower the power factor.

That creates an unavoidable contradiction in the design process. For mechanical reasons, we want to avoid too small an air gap; for electrical reasons, we don't want it too large. Now you can appreciate why the coils and magnets should be as close together as possible without touching.

For example, the rotor (out for repair) in a typical Hoover Dam electrical turbine has a tolerance of less than 1/100 of an inch between the rotating magnets shown here and the stator coils. Imagine the task of removing and reinstalling this behemoth.

This makes the gap in our Whirlybird turbine far too large for commercial applications, so do your best to minimize it.

Photo courtesy Wikimedia.org.