My First Attempt at a Low-Cost Homemade Wind Turbine

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Abstract

I built a wind turbine using mostly salvaged materials in the hopes of using the homemade, off-grid power to charge my family's many hand-held electronic devices. We have a total of 16 rechargeable devices in regular use in our household, requiring an estimated 112 watt-hours of energy each day. I planned to mount a small wind turbine (4-foot blade diameter) on our roof and store the power in a 12V Duracell Powerpack. We would then use the built-in standard receptacles on the Powerpack to charge our electronics.

My wind turbine works successfully to produce power; however, the available wind at my location is not sufficient to produce the amount of energy required to meet the above needs. This is due to:

- A high cut-in speed (12.5 mph) caused by the weight of the blades/hub and the internal friction of the generator.
- The inefficiency of the homemade blades. The power coefficient, Cp, of my turbine was found to range from 0.12 to 0.16, as compared with typical Cp values of 0.4 for commercial wind turbines.

Once the cut-in speed is achieved, my turbine performs as predicted for a typical home-made unit. During testing it produced on the order of 200W when wind speeds of 25 to 30 mph were obtained, and data confirmed the exponential relationship of power to wind speed. My wind turbine would perform well in a location where average wind speeds are typically high such as ridge-top and coastal regions.

Problem

With four people in our household, including two teenage boys, we have a large number of handheld electronic devices that require frequent charging. The amount of energy that we use for this purpose on a daily basis is estimated in Table 1. I wish to find a way to take these devices off- grid using a green renewable energy source.

Table 1. Estimated Energy Usage to Charge Handheld Electronics On a Daily Basis

Item	Power Requirement (Watts)	Charging Habits (assume each device requires 3 hrs for a full charge)	Average Time Charged on a Daily Basis (hours)	Estimated Daily Energy Requirement (watt-hours)
Mom's Droid smart phone	0.7A @ 5.1V = 3.6W	Charged once per day.	3.0	10.8
Derek's cell phone	0.7A @ 5.1V = 3.6W	Charged every other day.	1.5	5.4
Ian's cell phone	0.7A @ 5.1V = 3.6W	Charged every other day.	1.5	5.4
Dad's iphone	1.0A @ 5.1V = 5.1W	Charged once per day.	3.0	15.3
Mom's ipod	1.0A @ 5.1V = 5.1W	N/A. Charges in car.	0.0	0.0
Dad's mini ipod shuffle	1.0A @ 5.1V = 5.1W	Charged every 3 days.	1.0	5.1
Derek's ipod	1.0A @ 5.1V = 5.1W	Charged every other day.	1.5	7.7
Ian's ipod	1.0A @ 5.1V = 5.1W	Charged every other day.	1.5	7.7
Dad's ipad	2.1A @ 5.1V = 10.7W	Charged once per day.	3.0	32.1
Rechargeable land-line phones (2 handsets)	0.35A @ 9V = 3.2W each = 6.4W	Each charged once per day.	3.0	19.2
Rechargeable batteries for Xbox controllers	One AA battery charger = 7.0W	Change out one set of batteries every 3 days.	1.0	7.0
Mom's laptop	3.95A @ 19V = 75W	Charged once per day.	3.0	225
Derek's laptop	3.95A @ 19V = 75W	Charged once per day.	3.0	225

OF NOTE FROM TABLE 1:

- Estimated daily energy requirement **without laptops: 116 watt-hours**
- Estimated daily energy requirement **with laptops: 566 watt-hours**
- A reasonable estimate of the maximum number of items that would be actively charging at any one time is: one laptop, the ipad, one ipod, 2 cell phones, one house phone, and the Xbox batteries. This would require a **max instantaneous power draw of 110 Watts.**

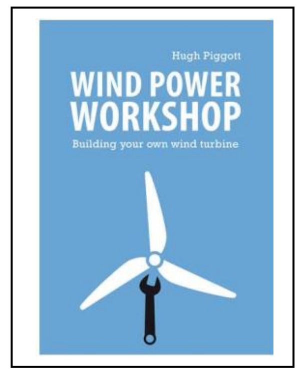
Proposed Solution and Initial Feasibility Research

My primary interest in the renewable energy field is wind turbines. I chose to use this project as a chance to work hands-on with wind power so that I could gain firsthand experience with its capabilities and limitations, and with the complexities of capturing wind to produce energy.

I proposed building a small homemade wind turbine using salvaged materials. I would mount the turbine to the roof of my house and use the energy to charge a 12V Duracel Powerpack (specifications show in Attachment 1). The Powerpack, which is equipped with built-in electrical outlets, would be conveniently located in our house and would provide a central charging station for our handheld electronic devices.

A web search revealed that others have successfully built small, low-cost wind turbines and used them to produce power that is sufficient to meet my requirements. A sampling of instructions, YouTube videos and websites is shown here:

1. http://scoraigwind.co.uk/
2. http://www.youtube.com/watch?v=1pfz25RbBwk
3. http://makeprojects.com/Project/Wind-Generator/9/1
4. http://make-guide-pdfs.s3.amazonaws.com/guide_9_en.pdf
5. http://www.youtube.com/watch?v=k8J9_yv2grM&feature=related
6. http://www.youtube.com/watch?v=hQ45G337I6k&feature=fvwrel
7. http://www.youtube.com/watch?v=clv_iLvTgRQ&feature=fvwrel
8. http://www.mdpub.com/Wind_Turbine/



Item 1 above is a wind power website maintained by Hugh Piggot. Hugh lives off-grid in Scotland and has extensive experience building wind turbines using salvaged materials. I used his book Wind Power Workshop to identify the baseline design and size for my turbine, and as a reference throughout my project.

Items 2 through 4 above are the video instructions, web instructions and PDF plans for the wind turbine that I chose to build. The video instructions were initially an episode of a do-it-yourself television series called The Maker Workshop. The plans are included here as Attachment 2.

Items 5 through 8 are simply examples of small homemade wind turbines built by others, and served to convince me that my proposed wind turbine could in fact be built inexpensively and in a reasonable amount of time.

Feasibility: Can I Expect to Get Enough Energy From A Reasonably Sized Homemade Wind Turbine?

Table 1.2 of Hugh Piggot's Wind Power Workshop, partially reproduced below, is presented as a quick guide for predicting power output at various average wind speeds and with various turbine blade diameters. The average wind speed in Falls Church, where my home is located, is 9 mph (online Wind Energy Atlas and www.City-Data.com). Extrapolating within Hugh's table shows that with a 1 meter diameter wind turbine I can expect an approximate power output of 10 watts. One meter is a reasonable rotor diameter for a do-it-yourself project, and it also is an appropriate size for the roof of my house.   In fact, a web search for free, downloadable, step by step instructions resulted in the plans for the 1.25-meter diameter turbine that I chose to build. Further extrapolation within Hugh's table shows that I can expect to produce on average 19 watts with this wind turbine at my location.

Table 2. Average Power Output in Watts
Reproduced from Hugh Piggot's Wind Power Workshop, Table 1.2, pg 6.
Info in black is from the original table. Info in red has been extrapolated.

Average Wind Speed	3 m/s 7 mph	4 m/s 9mph	4.5 m/s 10 mph	6 m/s 13 mph
Blade dia. 1 m	4	10	13	30
Blade dia. 1.25m		**19**		
Blade dia. 2 m	15	45	51	121
Blade dia. 3 m	34		115	272

Note that the values shown in this table assume a power coefficient (Cp) of 0.15. A typical Cp value for a commercial wind turbine is 0.4. The lower value of 0.15 used here is appropriate for homemade wind turbines such as mine since they will be significantly less efficient than commercial models.

I estimated earlier that my family's daily energy requirement for charging our electronics is 116 watt-hours (not including laptops). A turbine producing on average 19 watts would need to operate for 6 hours per day to produce that amount of energy. That means that the wind would need to blow on average 9 mph for 6 hours per day. That seems reasonable.

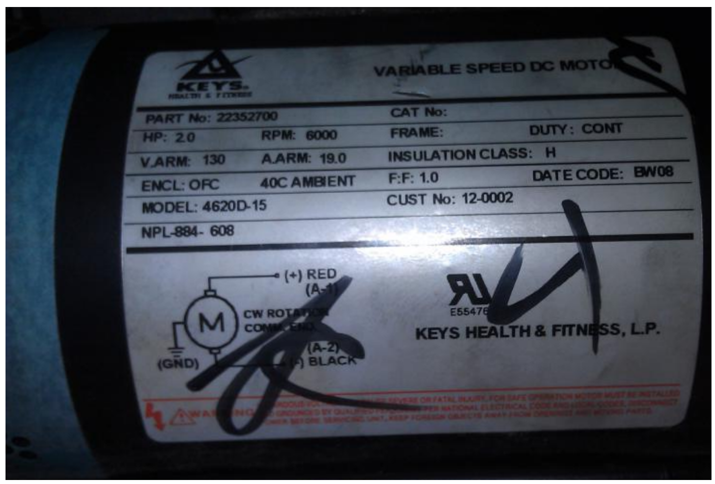
If we were to also charge one laptop using our homemade energy, it would add 225 watt-hours or almost 12 more hours of required wind turbine operation time. That doesn't sound quite as feasible. However, I determined that the project was still worthwhile even without the ability to charge our laptops.

Based on the above information, I decided to proceed.

Construction

The following photo history outlines my construction process:

Generator. Any permanent magnet DC motor driven in reverse can be used as a generator. A treadmill motor was specifically suggested by the Maker Workshop plans. I found a free used treadmill on www.freecycle.org and easily removed the motor.



It is a 2 HP motor rated at 6000 RPM, 130 Volts and 19 Amps, with an internal resistance of 6.8 ohms.

As I began working with the motor, I noticed significant friction in turning the shaft and became concerned that the amount of wind required to start the blades might be too high. I obtained a second treadmill thru Freecycle and removed that motor for comparison, thinking that something might have been wrong with the first. However, the amount of shaft friction was similar with the second motor, so I proceed as planned with the first.

Blades

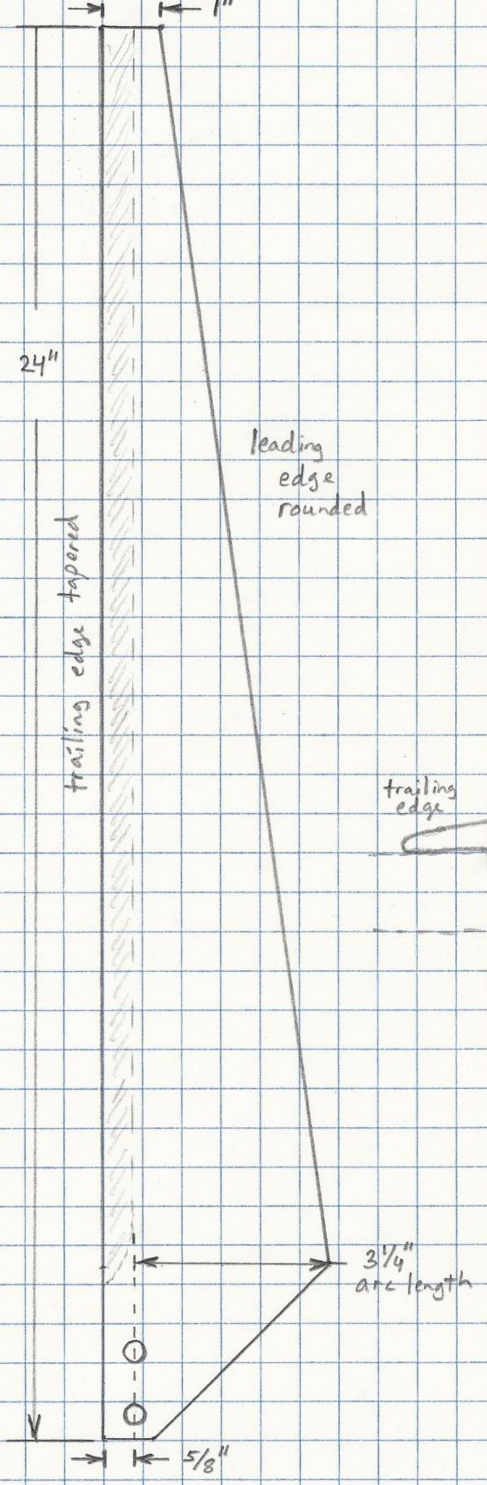
Eight-inch, schedule 80 PVC pipe was specified by the plans:

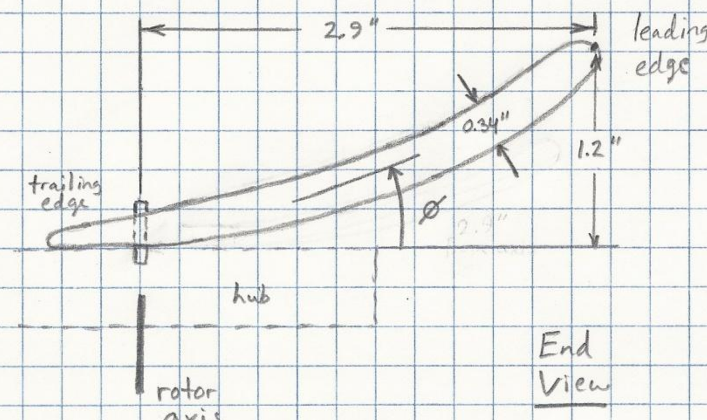
- 8-inch diameter to get the appropriate wing-shaped curvature
- Schedule 80 wall thickness (thicker than the standard schedule 40) so that the blades are strong and stiff

Eight-inch schedule 80 PVC pipe turned out to be very difficult to find. I could have purchased a 20-foot minimum length from a waterworks supply warehouse for over $200.00, but really didn't want to do that. Luckily, the local Falls Church City maintenance warehouse had a short length of 8-inch schedule 40 PVC pipe left over from a recent job. They were happy to give it to me for free. I decided to go ahead and use the thinner schedule 40 pipe even though some stiffness and strength of the blades would be sacrificed.

I used a jig saw as shown in the following photos to cut the PVC pipe. The final blade dimensions are shown in Figure 1.

Figure 1 - BLADE GEOMETRY





Pitch Angle Ø

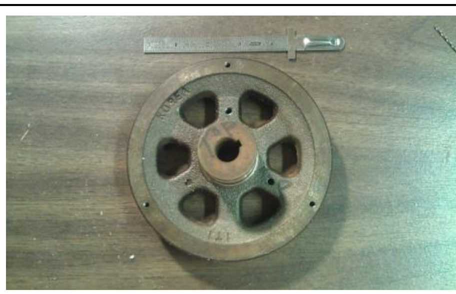
- At widest point of blade Ø = 22.5°
- At midpoint of blade Ø = 12.5°

Further Blade Shaping

I used a belt sander to round the leading edge and taper the trailing edge of each blade so that the shape would approach that of an airplane wing.

Rotor Hub and Blade Attachment

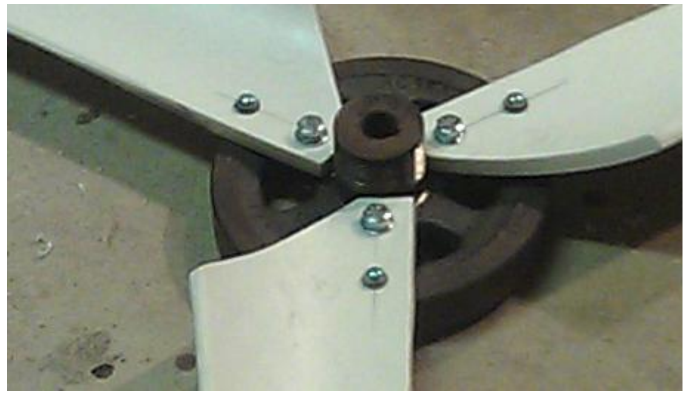
The treadmill motor's flywheel was easily removed and became the hub for the rotor. I did not have access to a drill press, so I chose to have the hub drilled and tapped (threaded) at a local machine shop. It is crucial that the blades be attached symmetrically, otherwise imbalances will cause oscillations which can lead to a blade tearing away from the hub.



The treadmill's flywheel, drilled and tapped for blade attachment

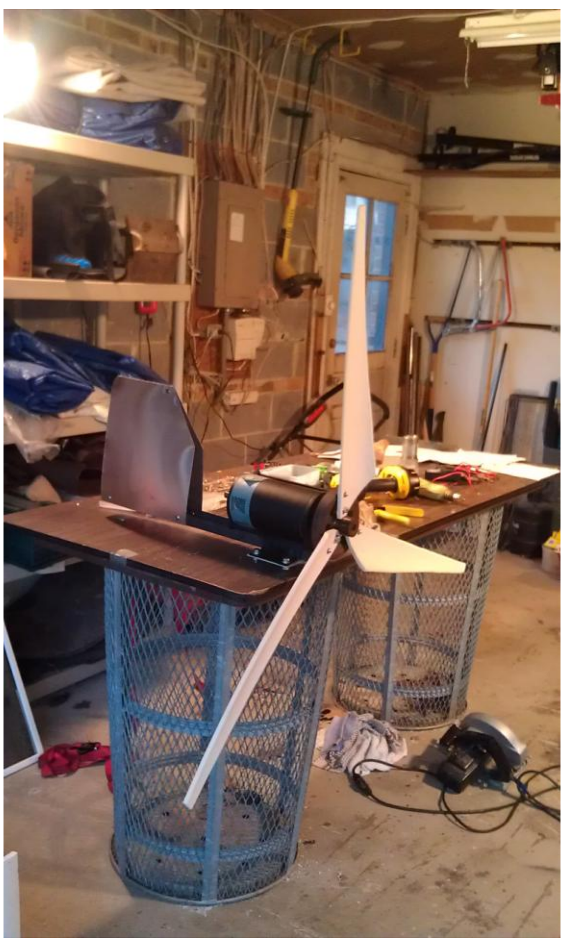
To ensure the blades were attached symmetrically, I used a tape measure to get the tip-to-tip spacing precise before drilling the final attachment holes through the blade.

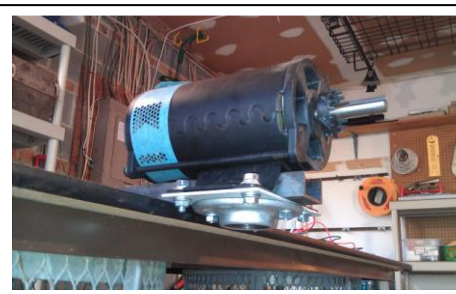
Final blade attachment to hub. The inner fasteners are through-bolts; the outer fasteners are machine screws threaded into the hub.



Tail and Mounting Hardware

I used aluminum sheeting for the tail, cut to approximately 1 square foot…a size suggested by The Maker Workshop and that looked reasonable for my turbine. The tail and generator are mounted on a 2-foot length of 2-inch by 1-inch steel channel. The channel is in turn mounted on a 1 ½ -inch pipe floor flange which provides the attachment point for the mounting pole. The rectangular plate shown here was an existing part of the generator's mounting system from inside the original treadmill.





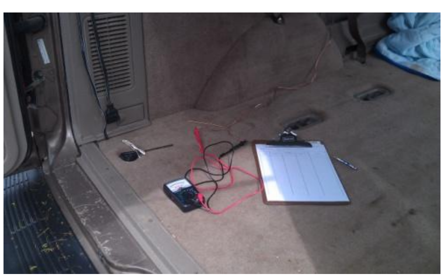
Testing

Initial testing in the workshop showed that the wind turbine did indeed generate power. When I spun the blades as fast as possible by hand the voltmeter read approximately 4 V.

My family helped me perform road tests to correlate wind speed with the voltage produced. We were hoping to find:

- A very low cut-in speed so that we could capture as much of our small quantities of available wind as possible.
- The ability to consistently produce at least 12 volts at around 9 mph. 12 volts are necessary to "push" the power into the 12 V Duracell Powerpack.

I salvaged an old coat rack, modified it to be the display stand for my wind turbine, and devised a way to attach the stand to the roof of my van for road testing. Note that the attachment between the turbine and the stand includes a pipe union joint. The joint is tightened enough to be secure, but left loose enough so that the turbine can turn to face the wind.



My husband drove and shouted "wind" speeds. My son monitored the instruments and shouted voltages. And I struggled to record it all in an understandable fashion.

Test Results

We first tested in a parking lot behind the local high school, and started very slowly. I was a bit concerned that a blade might fly off at high speeds, because during construction it had been difficult to attach the blades with precise symmetry on the hub. Gladly, it held together just fine. In fact, we eventually went out onto the road and my turbine successfully survived sustained wind speeds of 30 mph.

Our series of test runs is shown here:

Table 3. Test Runs (referenced video clips are included on a jump drive with this report)

Test #	**Purpose**	**Notes**
1	Short slow 5mph test to begin determining cut in speed and ensure structural integrity of test stand and blades.	Didn't cut in.
2	Same as above but 15 mph.	Cut in at 12.5 mph. Video clip.
3	Same as above but increased to 25 mph. Still kept a slow gradual acceleration. Straight run, no turns.	Cut in at 12.5 mph. Video clip. No voltage reading was taken bcs the meter was misread.
4	Same as above but increased to 27 mph.	Cut in at 13 mph. At 27 mph the voltage was above 10 V (pegged at upper end of scale).
5	Changed voltmeter scale to 0-25V. Fast start to 25mph, slowed to 10 mph around turn, proceeded to 32 mph after turn.	Cut in at 17.5 mph. At 32 mph the voltage was above 25 V (again pegged at upper end of scale).
6	Same as above. Focused specifically on finding the speed at which 12V was reached (9V rms on voltmeter scale).	Cut in at 16 mph. 9V rms produced at 12.5 mph. At 30 mph voltage was above 25V.
7	Changed voltmeter scale to 0-50V. Same test as above but looking specifically for max voltage reached.	Cut in at 15 mph. 9V rms reached at 12 mph. Max 28V rms at 33 mph.
8a and 8b	Two slow tests, one heading straight east, one heading straight west to determine if the slight ambient breeze was effecting test results.	Cut in at 12.5 mph both times. Determined that breeze was not effecting tests.
9 Graph of power vs speed attached.	Gun it to start, fast turn, fast acceleration out of turn to max possible speed.	Cut in at 23 mph. Video clip. 9V rms achieved at 15 mph. Max 35V rms at 33 mph.
10 Graph of power to time attached.	Slow consistent test. Twice around. Slow steady acceleration at start and out of turns. 15 mph straights. 10 mph turns.	Cut in at 15 mph. 9V rms achieved at 15 mph.
Road Test Graphs showing correlation of Cp attached.	Left the parking lot and drove home. Three full stops at stoplights. Max speed 30 mph.	Steady state Cp ranged from 0.12 to 0.16.

Analysis and Conclusions

Cut-in Speed

From Table 3 it can be seen that the cut-in speed is a function of how quickly the wind speed increases.

- For slow steady accelerations (simulating a steady wind), the cut in speed was consistently 12.5 mph.
- For fast accelerations (simulating a strong gust of wind), the cut in speed varied from 15 to 23 mph.

Sadly these high cut-in speeds will prevent my turbine from creating any appreciable amount of energy at my location. Remember that the average wind speed here in Falls Church is only 9mph. In fact, I left the wind turbine on top of my van and parked it in the street in front of my house for about 4 days. Two of those days were particularly windier than normal. Every now and then the blades would turn slightly with a strong gust of wind, but they were never able to make even one full revolution.

The high cut in speeds are a result of the weight of the blade/hub assembly (8 ½ lbs) and the high internal friction of the generator.

Wind Speed Required to Charge the 12V Duracell Powerpack

The wind turbine must produce 12V (peak) for power to flow into the battery. Note that the voltage read from the voltmeter is RMS, not peak. The RMS voltage is the value of DC voltage that would make a bulb glow with the same brightness as the AC peak voltage. Peak voltage is about 40% higher than RMS. Therefore our target reading on the voltmeter was 9V RMS, equivalent to 12.5V peak.

Table 3 shows that 9V RMS was consistently achieved at 12 to 15 mph. Again, this shows that the turbine will not be useful at my location, with average wind speeds of only 9 mph.

Exponential Correlation of Wind Speed to Power Generated

Data from Test #9 is shown tallied and plotted on attached sheets.

> Speed (mph): was read from the van speedometer
>
> RMS voltage: was read from an analog voltmeter
>
> Peak voltage: calculated as Peak = RMS * 1.4
>
> Power: calculated from $P = V^2/R$
>
> R = 6.8 ohms = generator resistance calculated using the voltage and amperage ratings on the treadmill motor housing

The plot shows the exponential correlation of power to wind speed.

Behavior of Blade Rotation vs Wind Speed Once Steady State is Reached

Data from Test #10, also tallied and plotted on attached sheets, shows the correlation between wind speed and power during a controlled speed test. During this test we proceeded slowly around the parking lot, making three turns at about 10mph, and keeping a steady 16 to 17 mph on the straightaways. Our goal was to determine the turbine's behavior in typical wind fluctuations.

The test showed that once the blades are spinning their weight provides good momentum. This allows them to continue spinning even as wind speed is reduced, and to ramp back up to faster speeds quickly without the cut-in or slow ramp-up periods associated with the initial start. Notice that coming out of each turn, the power peaked again quickly. Notice also that the blades continued spinning, producing about 30W, even when the vehicle speed went below the cut-in speed (turn #3 on the graph). Additionally, I noted that the blades continued to rotate for a significant amount of time after the vehicle had stopped at the end of each test.

Agreement of Power Coefficient to Initial Assumptions

During portions of the road test we were able to drive at faster speeds (25-30 mph) for a significant amount of time. This data, tallied and plotted on attached sheets, was used to determine the power coefficient of my wind turbine.

The power coefficient was calculated using the wind energy extraction equation:

> $P = 0.5 * Cp * rho * A * u^3$
>
> Where:
>
> u is the wind speed measured during testing.
>
> P is the associated power, calculated from recorded RMS voltages
>
> A is the swept area of the turbine blades = 1.2 m^2
>
> Rho is the density of air = 1.23 kg/m^3

Data shows that the power coefficient of my wind turbine at steady state ranges from 0.12 to 0.16. This agrees nicely with the assumptions made for homemade wind turbines during my initial feasibility research.

Conclusion

My wind turbine works successfully to produce power; however, the available wind at my location is not sufficient to produce the amount of energy required to meet the above needs. This is due to:

- A high cut-in speed (12.5 mph) caused by the weight of the blades/hub and the internal friction of the generator.
- The inefficiency of the homemade blades. The power coefficient, Cp, of my turbine was found to range from 0.12 to 0.16, as compared with typical Cp values of 0.4 for commercial wind turbines.

Once the cut-in speed is achieved, my turbine performs as predicted for a typical home-made unit. During testing it produced on the order of 200W when wind speeds of 25 to 30 mph were obtained, and data confirmed the exponential relationship of power to wind speed. My wind turbine would perform well in a location where average wind speeds are typically high such as ridge-top and coastal regions.