Harnessing Wind Energy with Recyclable Materials

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Engineering Analysis Report

Document

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Introduction

The "Harnessing Wind Energy with Recyclable Materials" (H-WERM) design project is a project initiated and sponsored by Srinivas Kosaraju, a Mechanical Engineering professor at Northern Arizona University (NAU), located in Flagstaff, Arizona.

The customer of the design project cannot be specifically identified as an organization or a corporation: the final project design is intended for citizens of third world countries who are in need of relatively small quantities of electrical energy. The energy is intended to be used to provide basic living "luxuries" such as lighting and the use of fan(s).

Goal

Goal Statement

To provide inexpensive electricity to third world country citizens who have limited access to electricity.

Scope

The scope of the design is to provide an inexpensive, portable wind turbine system to harness wind energy. The wind turbine system will include both a wind turbine to generate electricity, and a means of storing the electricity generated.

Requirements and Constraints

The wind turbine project must satisfy the following requirements:

- Made of recycled/recyclable materials
- Portable - easily transferred and moved
- Easily assembled and disassembled
- Withstand high wind speeds
- Produce 0.5 kWh of energy per day for powering small electronics

Additionally, the project may not exceed the following constraints:

- Total cost of design may not exceed $50
- Total weight of design may not exceed 45 kg

Final Design Concepts

For the final design concepts, both a vertical wind turbine and a horizontal wind turbine are considered. A vertical wind turbine has multiple advantages toward harnessing wind energy, but also has multiple disadvantages. A couple disadvantages of a vertical wind turbine are lift and drag. For every turbine blade facing into the wind, there is a corresponding blade facing the opposite direction. Since wind pushes against both blades, drag forces as well as wind turbulence are created, which decreases the efficiency of the turbine. A horizontal wind turbine can achieve greater revolutions per minute than a vertical wind turbine can, and has a smaller drag coefficient. However, one disadvantage to horizontal wind turbines comes with the direction of wind across the turbine. Wind direction significantly affects the operations of horizontal turbines, so a horizontal turbine may require additional components and assembly to allow the turbine to turn into the wind as the wind direction changes.

Two design concepts were chosen as the best options for the project. Figure 1 shows the first final design concept.

Figure 1 – Final Concept Design, Vertical Bike Wheel Turbine

The Vertical Bike Wheel Turbine consists of two recycled bike wheels, with halved PVC pipes attached between them in a circle. Developing cost effective wind turbine blades with a high rate of performance using recycled materials is not an easy process. Poly-vinyl Chloride, also known as PVC, can be cut in half and trimmed to form a swept helical curve resulting in an inexpensive wind turbine blade. As the wind blows and catches in the PVC turbine blades facing the direction of the flow, the shaft rotates and electrical power is generated through an alternator, dynamo, or generator.

Figure 2 shows the second final design concept.

Figure 2 – Final Design Concept, Horizontal Bike Wheel Turbine [1]

The Horizontal Bike Wheel Turbine, shown in Figure 2, is a simple horizontal wind turbine made from reusable materials, including a bike wheel. Turbine blades can easily be created using the geometric shape already laid out in the pattern of spokes. Having duct tape or fabric wrapped across the spokes in the pattern shown makes a wind blade, yet the blade length is limited to the radius of the wheel. To increase the blade length, and consequently the swept area of the turbine, PVC blades can be attached to the bike wheel, extending out past the rim. The PVC blades would be designed similarly to the blades for the Vertical Bike Wheel Turbine. Mounting these types of blades evenly across the bike wheel should be sufficient in harnessing wind energy due to the increase in swept area with the geometry of the spoke layout. Increasing the swept area increases the power that a turbine can generate, as shown in equation (2) in the Design Components section below.

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[1] http://3.cf.shn.m3cdn.net/wp-content/uploads/2012/03/3500bike-wheel-turbine.png.400x300_q85_crop-smart.jpg

Design Components

Flow diagram

The diagram shown in Figure 3 is the proposed circuit for the wind turbine system design. A battery connected in parallel with the appliances will enable the system to provide supplemental power to the load (appliances) when the power generated by the turbine is less than the load requirements. The battery will be charged when the appliances are turned off and when the power generated by the turbine exceeds the load requirements.

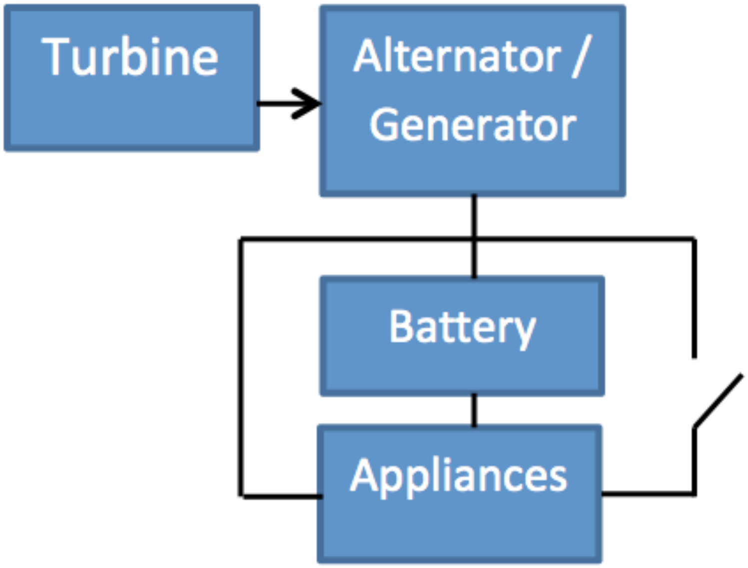

Figure 3 – Component Flow Diagram

Turbine

The equation for the power a wind turbine can generate is given by:

$$P = \frac{1}{2} C_p \rho A V^3 \tag{1}$$

Where:

- P = Power produced [W]
- C_p = Coefficient of performance for the turbine
- ρ = Density of air [kg/m^3]
- A = Swept area of turbine blades [m^2]
- V = Wind speed [m/s]

By rearranging equation (1), the swept area required for the wind turbine can be found as such:

$$A = \frac{2P}{C_p \rho V^3} \tag{2}$$

For the engineering analysis, the following assumptions were made:

- Air at standard temperature and pressure: ρ = 1.2 kg/m^3 [2]
- Average wind speed of V = 5 m/s
- Maximum coefficient of performance for a drag based turbine: C_p = .22

The following specifications were also included in the analysis:

- Required power: P = 100 W

Based on these values, the required swept area for a wind turbine is 6.06 m^2. Since this is an unrealistically large area, other options were considered. The client suggested reducing the power requirements by substituting a compact florescent light (CFL) for the incandescent light. CFLs that produce approximately the same amount of light as a 60W require only 15W. This reduces the total power requirements to 55W and 275 Wh. A recalculation the swept area with the revised power requirements shows that an area of 3.33 m^2 is required.

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[2] Twidell, Weir – *Renewable Energy Resources, 2nd Edition,* pp. 263, 2006.

Alternator/Generator

To generate electricity from the turbine, several generators were considered.

- Car alternator
- Bicycle dynamo
- Motorcycle dynamo

The first generator considered was a car alternator. While this generator would produce a large amount of power and would be relatively easy to find in a junkyard, the car alternator was ultimately ruled out because a minimum of 1000 rpms were required to generate constant power.

The second generator considered was a bicycle dynamo. These are connected to the wheel of a bicycle, and are generally used to power small lights. The most commonly available bicycle dynamos only produce 3W or 6W, and cost up to $30. Larger dynamos that produce at least 55W are much harder to find, and typically cost upwards of $200, however some used models may be less expensive.

The third generator considered was a motorcycle stator. These do not produce as much power as car alternators, and consequently have lower rpm requirements. Brand new, these usually cost more than bicycle dynamos. However, motorcycle stators can be salvaged from wrecked motorcycles for a reduced price. In addition, motorcycle stators are easier to find than high-powered bicycle dynamos. Both bicycle dynamos and motorcycle stators are currently being considered for the final design concepts.

Battery

To store the electricity generated by the turbine and alternator, a battery is required. The team considered using either a car or motorcycle battery, because these could be easily found, and are probably the least expensive option to store the required amount of energy. It may be possible to acquire a motorcycle battery that is already connected to a stator, reducing cost and assembly time. Otherwise, a car battery will most likely be chosen.

Electrical Component Specifications

Table 1 contains the specifications for the electrical components that are under consideration for the turbine design project.

Table 1 – Electrical Components

Component Type	Description	Specifications
Appliance	Incandescent Light Bulb	60 W
	CFL Bulb	~15 W
	Fan	40 W
Battery	Car Battery	12 V, 80Ah, 1 kWh
	Motorcycle Battery	12 V, 6 Ah, 72 Wh
Alternator / Generator	Bicycle Dynamo Generator	Varies Widely
	Motor Cycle Stator	12 V, 750 rpm, 60 – 90 W
	Car Alternator	~14 V, 2000 rpm

Initially, the team intended to use a modification of the electrical circuit depicted in Figure 3, above. This circuit included the turbine connected in series with a car alternator and a car battery, respectively. The intent of this system was to charge a car battery, which would then be removed from the turbine system to power the appliances. Although the design was plausible, and after a post-design proposal recommendation from the project sponsor, the team decided to modify the circuit described above to the one depicted in Figure 3.

The modified circuit contains a battery in parallel with the load (appliances) and the coupled turbine/generator system. The modifications require a generator or alternator that outputs energy at a minimum rate that satisfies the appliance load and the DC voltage required to charge the battery (12 V). Consequently, the team has considered using a bicycle dynamo generator or a motorcycle stator/alternator system, which meet the load requirements.

Current Project Timeline

Figure 4 contains an up-to-date timeline of the H-WERM project progression.

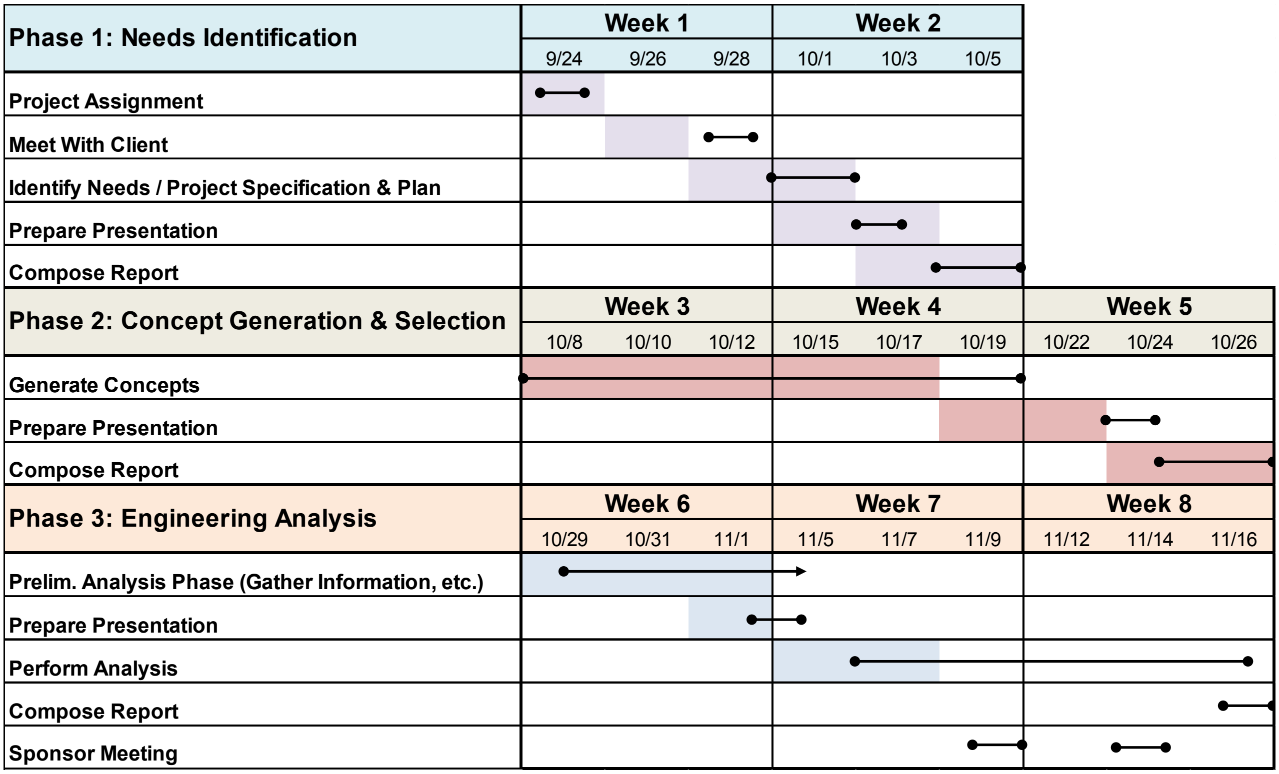

Figure 4 – Current Project Timeline

The span of the timeline ranges from the project assignment date, to the (current) date this Engineering Analysis Report was composed. Note that the color-shaded region indicates the pre-determined allotted timeslot for the associated task, while the bold lines with round endpoints indicate the actual date(s) the specific task occurred. Also, the bold line with the arrow on the right endpoint denotes the current progress to date.