Design of a Wind Mobile Phone Charger

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Abstract

A significant amount of people do not have grid electricity. For these people a simple task like charging a mobile phone is a serious issue. This paper deals with the harvesting of wind energy to help such people charge their mobile phone. A prototype has been developed and can also be used in an emergency when there is no nearby mobile phone charging port. Obtained results show the practicability and usefulness of the developed prototype.

Keywords

Wind energy, mobile phone charging, off grid electricity, prototype development

1. INTRODUCTION

There are 1.6 billion people without access to grid electricity in the world and about 500 million have access to a mobile phone but do not have their own means of charging it [1]. To charge a mobile phone for these individuals is costly. They either need to travel to a location with grid electricity or simply pay a local business to charge. According to a study done by GSMA in Kibera, Kenya the price of a single mobile charging is KES 20 (approximately R3.25) [1]. This is the same price as the cheapest airtime voucher. Consumers then have to choose between charging and loading airtime. In South African rural areas this is an issue as well. People pay about R5 per charge.

Sometimes people go on trips to places without grid electricity. Being from an 'urban' area they own smart mobile phones and are constantly either on social media, trading or simply making phone calls. Six hours after charging the battery runs flat and people then get stranded. Besides the entertainment that comes with mobile phones, important calls need to be made during emergencies. Without power this becomes impossible. A person might die or miss a business opportunity just because of a flat battery that could have been charged given an off-grid charging system.

The purpose of this paper is to review the literature around wind turbines and then present a design of a wind mobile phone charger. Furthermore, the results obtained during the experiments conducted on the wind mobile phone charger will be presented.

2. THEORY

2.1 TYPES OF WIND TURBINES

There are two types of wind turbines used to generate electricity and they are the horizontal axis wind turbine (HAWT) and the vertical axis wind turbine (VAWT) [2]. These are shown in Figure 1.

A horizontal axis wind turbine has its rotor rotating in an axis parallel to the wind stream and ground. A HAWT can either be upwind or downwind [2]. In An upwind HAWT, the rotor faces the wind and has an advantage that it avoids the wind shade behind the tower. However, its drawback is that the rotor needs to be inflexible and placed at a certain distance from the tower. Moreover, a yaw mechanism may be required to keep the rotor facing the wind. This increases the turbines complexity and cost [3]. On the other hand is a downwind HAWT, where the rotor is on the "downside" of the tower and the wind enters the blade from back. The advantage here, theoretically, is that a yaw mechanism is not necessary. Furthermore, the rotor may be flexible. The disadvantage, however, is the fluctuation in the wind power due to the rotor passing through the wind shade of the tower.

A vertical axis wind turbine has a rotor that rotates vertically around its axis. Different designs exist but the main ones are the Darrieus turbine and Savonius turbine The Darries turbine requires an externally powered motor to start its rotation. Once in motion the wind passing through the air foils generates torque and thus drives the rotor. Due to the blade arrangement this turbine can reach speeds that are higher than the wind speed making them ideal for generating electricity in turbulent winds. The

Savonius turbine is a drag-type device and consists of two to three curved scoops. The drag of the scoop is more when it moving with the wind than when it is moving against the wind. It is this deferential drag that causes the Savonius turbine to spin, however, the power it extracts is much less than the Darrieus type turbine.

Figure 1 HAWT (left) and VAWT (right) [2]

A HAWT is preferred for this application because it is:

- Self-staring. This eliminates the need of an externally powered motor to start the rotation of the blades a VAWT has.
- More stable because of its blade location being on the sides of its center of gravity.

The process undergone by a HAWT is detailed below:

2.2 ENERGY CONVERSION

Energy conversion in a wind turbine occurs in two stages. During the first stage wind energy is converted into mechanical energy, thus rotating the blades which in turn rotates the generator rotor. The second stage happens inside the generator, where the rotation of the rotor (mechanical energy) inside a magnetic field produces electricity. The electrical power, P, generated by the wind turbine depends on four factors:

- Air density, ρ.
- Area swept by the blades, A.
- Wind speed, v.
- Power coefficient, C_p.

The following equation shows how the net electrical power, after considering the aerodynamic efficiency of the rotor blades and the electrical system losses, is related to the above factors [4].

$$P = 0.5\rho C_P A v^3 \qquad \text{[Eq. 1]}$$

From the above equation it can be seen that power is directly proportional to the air density, power coefficient, the area swept by the blades and the cube of the wind speed. The wind speed is the one factor that contributes the most to the net electrical power as it is cubed in the equation.

The area swept by the blades is directly proportional to the square of the length of the blades. The long the blades are the more power generated [4]. However, longer blades may cause an unbalance in the system and make it bulkier.

The density of the wind varies from location to location. Coastal areas may have higher values because of higher moisture in the air while places like deserts may have lower values because of dry air. However, the average air density values is around 1.23Kg/m^3 [5].

Equation 1 can be written in terms of the tip-speed-ratio (TSR), rotor radius (R) and the rotational blade speed ω as follows:

$$P = 0.5\rho C_P A \left(\frac{R}{TSR}\right)^3 \omega^3 \qquad \text{[Eq. 2]}$$

Where:

$$TSR = \frac{\omega R}{v} \qquad \text{[Eq 3]}$$

The tip-speed-ratio (TSR) is a dimensionless parameter defined as the ratio between the rectilinear speed of the blade and the wind speed, as shown by equation 3.

2.3 BOOST CONVERTER

A boost converter can be employed when the output voltage needs to be greater than the input voltage generated by the wind turbine. Figure 2 shows the circuit diagram of a boost converter. The amount of output voltage boost depends on the duty cycle D as follows:

$$V_{out} = \frac{1}{1-D} V_{in}$$

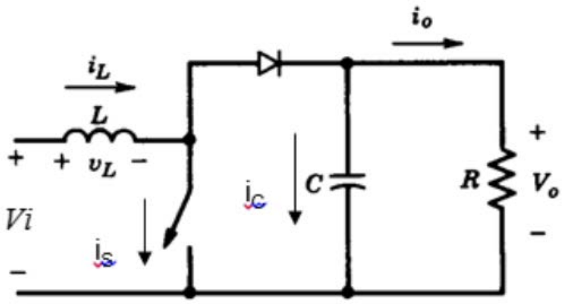

Figure 2 Boost converter circuit diagram

3 DESIGN

Figure 3 shows the block diagram of the design. The importance of each block is detailed below in Figure 3. Each block is described in subsections below:

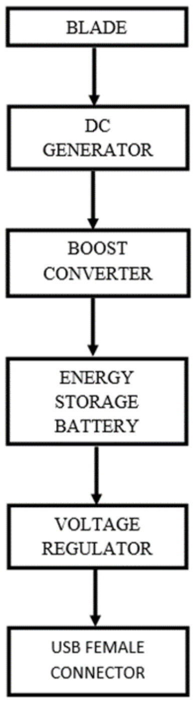

Figure 3 Block diagram of the design

3.1 BLADE

Blades are a crucial module of this design because they determine the amount of wind energy harvested. QBlade together with a computer aided design (CAD) software were used to design the blades. The blade (rotor) diameter, number of blades, tip-speed-ratio as well as airfoil properties were used in Qblade as input parameters to estimate the performance of the wind turbine. . A CAD software was then used to create the blade geometry with the data from Qblade.

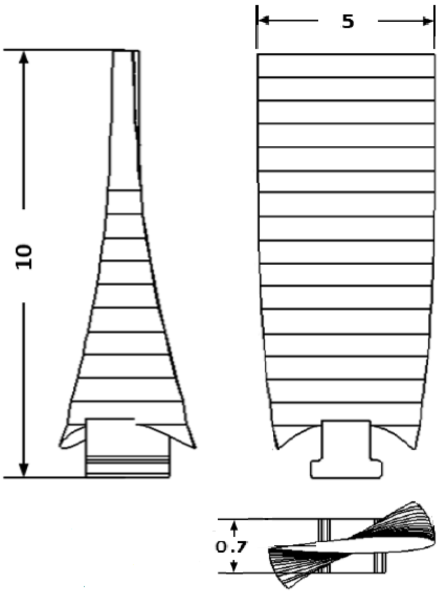

Figure 4 QBlade designed blade

Due to the cost of 3D printing this design a decision was made to purchase blades that closely met the design specifications. The purchased blades are shown in Figure 5.

Figure 5 Purchased blades

3.2 GENERATOR

Inside the generator, a rotor rotates a coil in a magnetic field and according to Faradays law, this results in an induced voltage. The induced voltage varies depending on the rotational speed of the rotor. The rotor has to rotate at an angular speed sufficient to produce an output of 1.5-3V. A DC generator has been chosen to eliminate a rectifier circuit that would be required if an AC generator is used. This makes the design less expensive and more compact.

3.3 BOOST CONVERTER

The boost converter was designed as follows:

The 5V output voltage is for charging a mobile phone and the 7.2V is for charging a storage battery in the case when there is not mobile phone connect to the system.

$$i_{max} = i_{inductor} = \frac{P_{out}}{V_{in\ (min)}} = \frac{5}{1.5} = 4.17\ A$$

$$i_{out\ (max)} = \frac{P_{out}}{V_{out}} = \frac{5}{5} = 1\ A$$

$$D_{max} = 1 - \frac{V_{in\ (min)}}{V_{out}} = 1 - \frac{1.5}{7.2} = 0.79166 \approx 79.17\%$$

MOSFET ratings:

$$V_{s\ (\max)} = V_{out} + \Delta V = 7.2 + 0.13 = 7.33\ (choose\ 10V)$$

$$i_{s\ (max)} = i_{max} + \Delta i = 4.17 + 0.1 = 4.27A$$

(choose 5A)

$$i_{s(rms)} = i_{max}\sqrt{D_{max}} = 1.33 \times \sqrt{0.7917} = 3.71\ A$$

Diode ratings:

$$V_{D\ (\max)} = -(V_{out} + \Delta V) = -(7.2 + 0.13) = -7.33\ (choose\ 10V)$$

$$i_{D\ (max)} = i_{max} + \Delta i = 4.17 + 0.1 = 4.27A$$

(choose 5A)

$$i_{D\ (rms)} = \frac{P_{out}}{\sqrt{V_{out} V_{in\ (\min)}}} = \frac{5}{\sqrt{13 \times 3}} = 1.52\ A$$

Inductor rating:

$$i_{inductor(max)} = i_{inductor} + \Delta i = 4.17 + 0.1 = 4.27A$$

(choose 5A)

$$L \geq \frac{V_{in}\ (V_{out} - V_{in})}{2\Delta i V_{out} f_s} \approx \frac{V_{out}}{8\Delta i f_s} = \frac{6}{8 \times 0.133 \times 190000} = 29.68\mu H$$

$$V_{inductor(max)} = \max\left(V_{in\ (\max)}, V_{out} - V_{in\ (\min)}\right) = (3V, 5.7V)$$

(Choose 10V)

Capacitor:

$$V_{Cap\ (\max)} = V_{out} + \Delta V = 7.2 + 0.13 = 7.33V$$

(choose 10V)

$$C \geq \frac{i_{out} D}{2 f_s \Delta V} \approx \frac{P_{out}\ D_{max}}{2V_{out}\ \Delta V\ f_s} = \frac{5 \times 0.75}{2 \times 6 \times 0.13 \times 190000} = 5.06\mu F$$

The design was then simulated. Figure 6 and 7 shows the boost converter simulation circuit and the simulation results respectively. From the simulation it can be soon that the converter boosts the voltage, but because the software uses ideal components, it boost the voltage to about 8.5V than 7.2V.

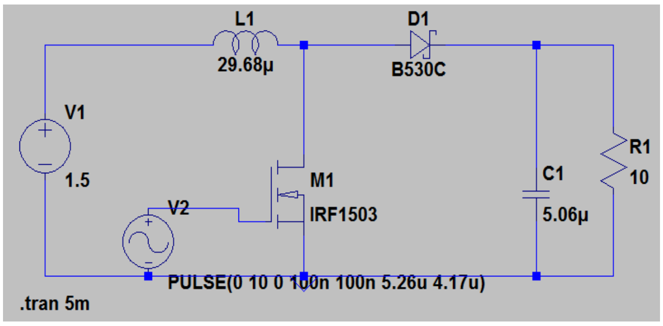

Figure 6 Boost converter simulation circuit

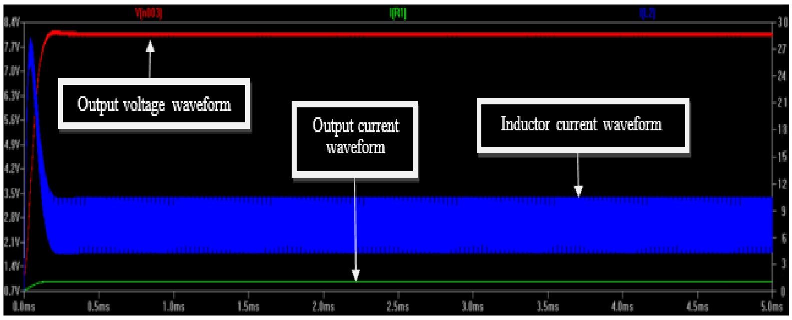

Figure 7 Simulation results**.**

3.4 Energy Storage Battery

This module will serve as an energy storage element. The stored energy will be used to charge a mobile phone even when there is no wind available. It is therefore a crucial module to ensure constant power supply for mobile phone charging.

3.5 Voltage Regulator

A typical mobile phone needs no more than 5V at 1A (5W) to charge, anything above this may damage it. Since a 6V battery is employed, the voltage regulator is then responsible for limiting the voltage and current to a constant 5V and a maximum of 1A. A 7805 voltage regulator has been chosen because it has built in current limiting, thermal shutdown, and safe area protection. This makes it virtually immune to damage from output overload. This serves as the protection module for a charging mobile phone.

3.6 USB Female Connector

Almost all mobile phones use a standard male USB connector to connect at the source and a male micro USB connector to connect in the phone. The USB female connector is then employed to easily connect a mobile phone to the wind energy charging system.

4. RESYULTS AND ANALYSIS

Table 1 Turbine output voltage at different wind speeds

%wind speed	Voltage (V)
30	1.2
35	1.8
40	2.32
45	2.92
50	3.73
55	4.52

60	5.1
65	5.25
70	6.12

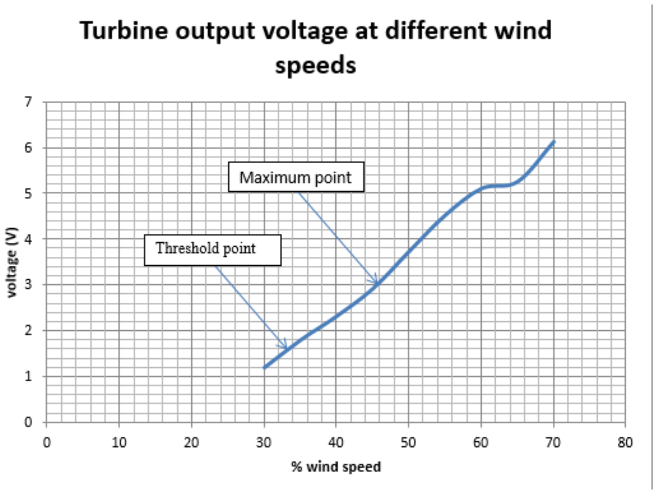

Figure 8: Voltage levels (Turbine) at different wind speeds

From the above results and plot it can be seen that at wind speed percentages of 35-45 the voltage generated is within the boost converter input range. The threshold wind speed resulting in 1.5V (minimum boost converter input) turbine output is 33%. The maximum point is where the wind speed result in a turbine voltage output of 3V (maximum boost converter input) and it is at a wind speed of 45.8%.

Figure 9 and 10 shows the results of the boost converter experiment. The DC power supply was used to input 1.6V and 0.11A, the multimeter was used to measure the output current and the oscilloscope was used to measure the output voltage (figure 7.3). The output current was measured to be 0.03A while the output voltage was 5.42V.

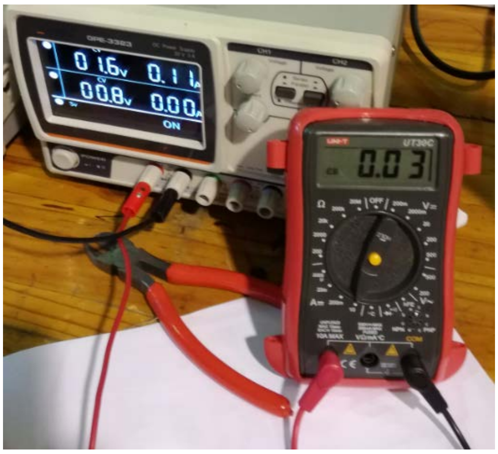

Figure 9 boost converter input voltage and current (power supply) and boost converter output current (multi-meter)

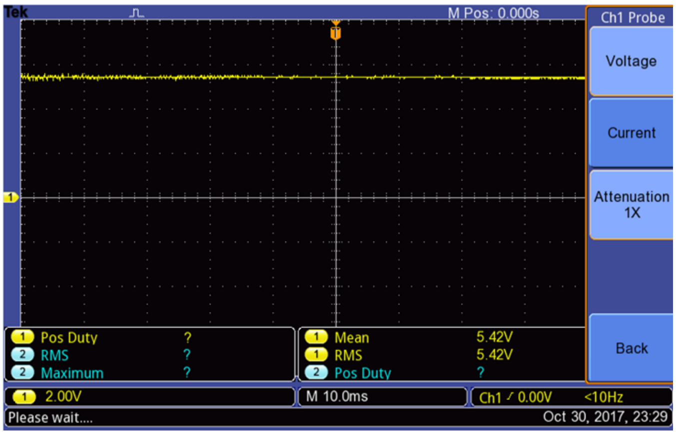

Figure 10 Boost converter output voltage (oscilloscope waveform)

Table 2 Results and efficiency calculation table

input voltage	1.6V
input current	0.11A
input power	(1.67)(0.17) = 0.184W
output voltage	5.42v
output current	0.03A
output power	(5.42)(0.03) = 0.163W
efficiency	1.63/0.184 = 0.8859 $\approx$ 88.59%

The efficiency of the boost converter is 88.59%. This means that 11.41% of the input power is lost in the MOSFET as switching losses and conduction losses as well as in the diode as conduction losses. The high efficiency is very important for this application as it allows for 88.59% of the power from the turbine to be used in charging a mobile phone and a 6V battery.

Table 3 Charging time and charge percentage table

Time (min)	charge percentage
10	1
20	1
30	2
40	3
50	4
60	5
70	7
80	9
90	11

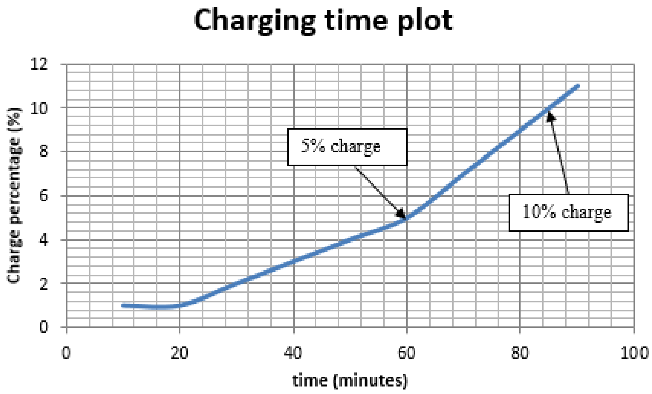

Figure 11 charging time plot

The above plot (figure 11) shows that the wind mobile phone charging system is able to charge a mobile phone from 0% charge to 5% in 60 minutes and 10% in about 85 minutes.

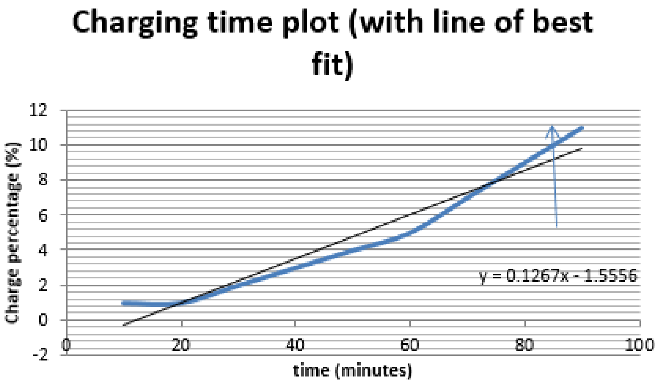

Figure 12 charging time plot with line of best fit

Using the line of best fit, drawn in figure 12 the time to reach 100% charge can be estimated as follows:

y = 0.1267x - 1.5556

$$x = \frac{y+1.5556}{0.1267} = \frac{100+1.5556}{0.1267} = 801.54$$

The estimated time to reach 100% charge from 0% on is estimated to be 801.54 minutes (13.36 hours). This charging time may vary depending on the time of phone being charged, for some phones the time might be shorter and for some it might be longer.

5. CONCLUSION.

After reviewing the literature it was found that there are two types of wind turbines, viz. VAWT and HAWT. A HAWT was chosen for this project mainly because it is self-staring. The blades were then designed using QBlade and CAD software. However due to 3D printing cost, blades that closely met the designed blades were purchased. The boost converter was then designed for the purpose of boosting the voltage to an output of 5V (for Mobile phone charging) of 7.2V for storage battery charging. The simulation shown that the design would function. The design was then implemented and after experimentation it was found that the boost converter is 88.59% efficient. Further experimentation took place to determine how long it would take to charge a mobile phone from 0% charge to 100% charge. This was determined to be 13.36 hours. With these results the system proves to be fully functional.

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