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WIND TURBINE DESIGN FOR HYBRID VEHICLES WITH THE BEST FEATURES TO OBTAIN OPTIMUM POWER

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Abstract

This paper presents full calculations needed for designing a small wind turbine to be used in hybrid vehicles. The industrial development and the demand for power caused the fossil fuel sources to drain with an increase in pollution and noise that harm both the environment and people alike. Using a small wind turbine (Micro Turbo) to get electric power considered as a permanent source of power that helps to reduce the consumption of fossil fuel and provides a clean operation to the hybrid vehicle with an efficiency in performance and minimum costs of investment. In this paper, we introduced a model for series hybrid vehicle and used Matlab Simulink to build a model for wind turbine calculations and test the results for different diameters values; finally, we designed the small wind turbine using Autodesk Inventor program.

Keywords: Hybrid Vehicles, Type of Hybrids, Small Wind Turbine, Micro Turbine, Hybrid Vehicles Batteries.

1. Introduction

Oil consumption by transportation has increased from 33% of total oil demand in 1971 to about 50% today according to (Raskin and Saurin, 2007). The emergence of hybrid vehicles may stop this increment of oil demand by vehicles. New technologies in hybrid vehicleshelp to improve fuel efficiency in near future.

1-1 Hybrid Basics

A hybrid vehicle is any vehicle combines two sources of power according to (Helms et al, 2010); normally hybrid vehicles combine an internal combustion engine with a generator, battery, and one or more electric motor. This combination helps to reduce the energy loss in theinternal combustion engine and mechanical processes. Since in the traditional engine, only 15% of the energy generated by fuel reaches the wheels and power accessories, such as air conditioning. The other 85% of the energy content of thefuel is lost to engine inefficiencies, idling and braking, nearly 62% is lost only in combustion (Raskin and Saurin, 2007), which is the process that converts chemical energy to mechanical energy. The main components of this loss are engine friction, air pumping into and out of the engine, and wasted heat. Hence, the potential to improve the fuel efficiency of traditional vehicles is enormous.

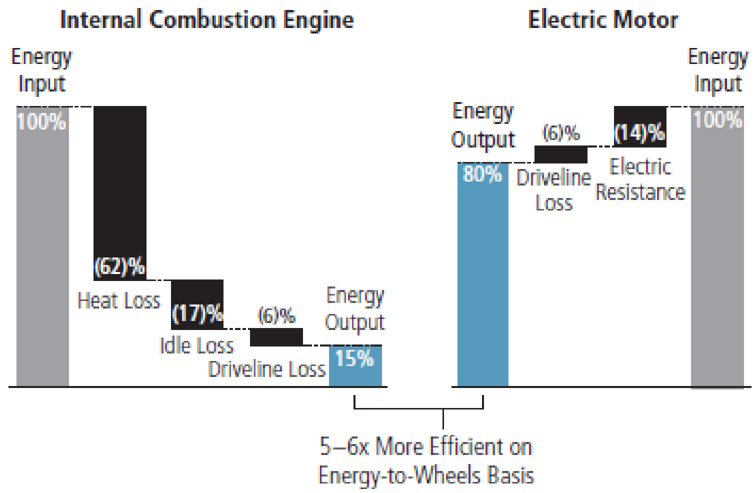

Figure 1. Electricity efficiency compared to combustion engines in powering cars.

1-2 Advantages of Hybrid Vehicles

Nowadays there are many technologies to power modern vehicles such as gasoline-electric vehicles (hybrid), biofuel (flex-fuel), battery only (all electric), natural gas, and fuel cell vehicles. According to (Raskin and Saurin, 2007) we can summarise the advantages of hybridvehicles over other power-technologies as following:

- Hybridsgive improved fuel efficiency and performance measured by acceleration and horsepower (hp).
- Hybrids provide lower emissions and greater convenience since many diesel vehicles sacrifice performance to gain fuel efficiency.
- Hybrids do not require special stations to refuel, unlike biofuel vehicles.
- Hybrids do not limit driving range, unlike all-electric vehicles.
- Hybrids make use of the improving technologies of engines, electrical components, and batteries.

1-3 Hybrid Configurations

The hybrid technology aims to improve the overall fuel efficiency by using a small internal combustion engine with an electric engine and electrical storage (battery bank) to balance the vehicle’s energy requirements. Normally there are two types of hybrid configurations (Chen, 2015), parallel hybrid and series hybrid.

- Parallel Hybrid:

  In this configuration, both combustion and electric engines can provide power directly to the wheels of the vehicle. When the power supplied by the combustion engine is excess to the requirements, the electric engine works as a generator to store additional energy in the battery bank. Whereas when the load is greater than the smaller combustion engine can provide the electrical engine helps to provide the additional power.

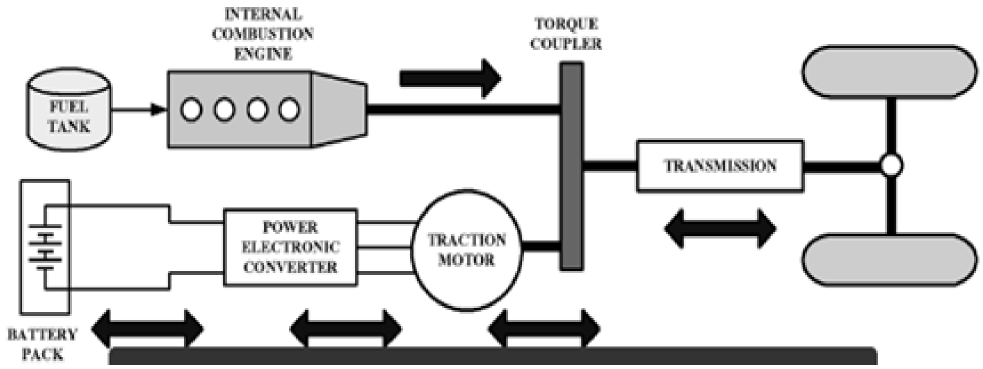

Figure 2. Parallel hybrid vehicles.

- Series Hybrid

  In this configuration, the vehicle has a much bigger and more powerful electric engine that provides all the power to the wheels. The combustion engine provides energy indirectly, operating continuously at peak efficiency to provide electrical power via a generator to the electric energy and to the battery bank.

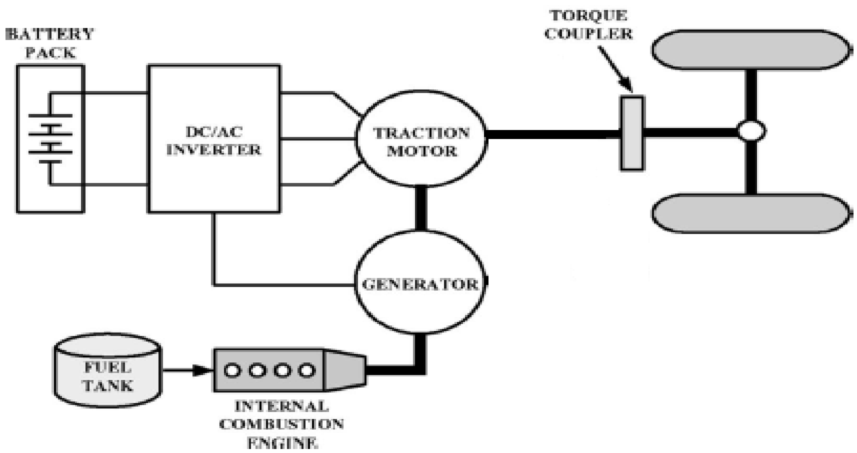

Figure 3. Series hybrid vehicles.

According to (Ireland, 2007), Hybrid vehicles can be sorted into three categories: full (strong) hybrids, mild hybrids, and weak hybrids.

- Full Hybrids:
  In this type of hybrids, the electric motor alone is capable of powering the vehicle for a period of time. This type has a ratio of electric to total power of 30% or higher. One of there presentative models of this type is Toyota Prius.
- Mild Hybrids:
  In this type of hybrids, the vehicle has a smaller electrical engine, which cannot run the vehicle alone, so this type needs to rely on their combustion engine continuously to provide the required power. This type has a ratio of electric to total power between 10% and 30%. One of there presentative models of this type is Honda Civic IMA.
- Weak Hybrids:
  This type normally called on hybrid pickup trucks, it is like mild hybrids but has a much lower ratio of electric power to total power because it is not designed to use electric power for propulsion. Their considerable battery power can be used to generate electricity on site for power tools and other accessories. One of there presentative models of this type is GMC Sierra

The following table shows the fuel efficiency and electric power ratio in the three previous hybrid types.

	Electric to Total Power	Fuel Economy Benefit	Representative Model
Conventional Vehicle	2%	Baseline	NA
Weak Hybrid	5–10%	5–20%	GMC Sierra
Mild Hybrid	10–30%	20–50%	Honda Civic Hybrid
Full Hybrid	30–50%	20–80%	Toyota Prius

Figure 4. Fuel efficiency with a ratio of electric to total power.

2. Wind Turbine Design Fro Hybrid Vehicle

In this paper, we have designed a wind turbine to convert the wind energy to electric energy that charges the battery bank in a hybrid vehicle model.

2-1 Hybrid Vehicle Model.

We have worked on a model of series hybrid vehicle that is shown in figure (5).

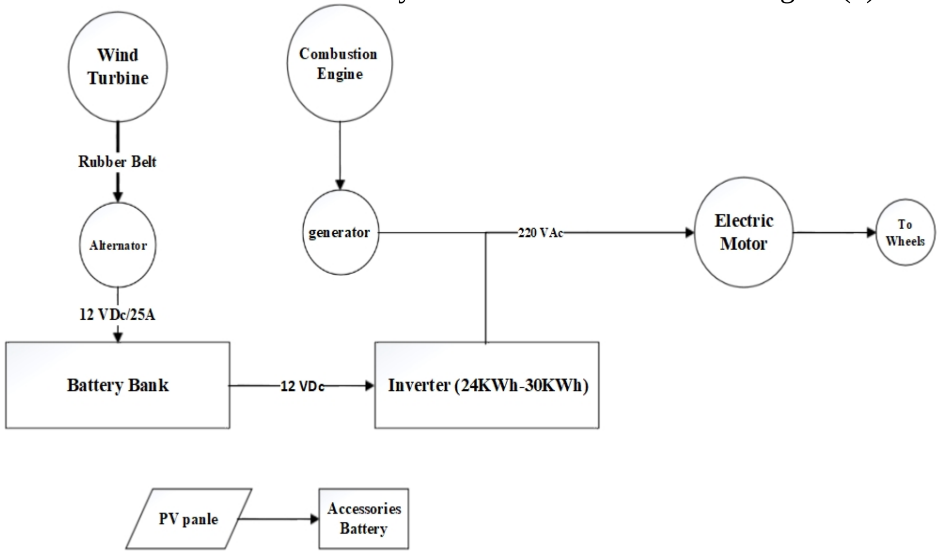

Figure 5. The studied model of hybrid vehicle.

The Hybrid vehicle model consists of the following:

- Electric Motor: 80 kW (110 hp), with 280 N.m torque.
- Inverter: 12V.Dc to 220 V.Ac (24kWh-30kWh).
- Battery Bank: 20 pack, each pack consists of 4 Li-ion batteries, each battery provides 3.6 V, 13Ah. The packs connected in parallel.
- Alternator: output voltage (13.4-14 V.Dc),output amperes 25 A,rotation speed (2500-6000 rpm), total power (335-340 W).
- Accessories Battery: 50 Ah, 12 V.Dc.
- PV panel: to charge the accessories battery.
- Generator.
- Small Combustion Engine: WL 739 cc.

In this model, the wind turbine is used to deliver the power needed to operate the alternator to charge the battery bank. The vehicle is powered by the electric motor that takes its power from a battery bank via an inverter that inverts the 12 V.Dc from the battery bank to 220 V.Ac. The combustion engine is used only when the power delivered by the inverter to the electric motor is not sufficient; in that case, the combustion engine delivers the needed electric power via agenerator to the electric motor.

<u>What is new in this approach (model)?</u>

- Exploiting wind energy by a small wind turbine to generate electrical power (via the alternator) gives a continuous source of power (as long as the vehicle is moving) to charge the battery bank, this means that there is no limit distance for driving the vehicle, unlike the traditional electric vehicles that need to stop for recharging.

- Enhanced fuel efficiency, since the combustion engine is small and runs only in extreme driving conditions that require instant power.
- Small losses while the vehicle is idling, only 14% of total power (as an electrical resistance) of the electric motor.
- No losses by accessories, since there is a battery for them and a PV panel charges it separately.

Key points for consideration:

- The turbine is placed under the front hood in front of the electric engine so the turbine diameter should be (45 -50 cm).
- The optimal wind speed to operate the turbine is between (11-25 m/sec) that meets a car speed of (40-90 km/h).
- According to (Patel, 2005), maximum power efficiency factor C_p for the turbine is 0.59.
- According to (Ingram, 2011), choosing the tip speed ratio for the turbine should match the following conditions:
  - For water pumping turbines which gives a high torque, tip speed ratio: $1 < \lambda < 3$.
  - For electric generating turbines, tip speed ratio: $4 < \lambda < 10$.

2-2 Selection of wind turbine features.

Considering the key points mentioned above, we start thewind turbine designing process by finding out the turbine parameters, so we start by calculating the turbine rotating speed that can be calculated from the tip speed ratio equation that is given as follows according to (Patel, 2005):

$$\lambda = \frac{\pi \times D \times n}{60 \times V} \qquad (1)$$

where:
D: turbine diameter [m].
n : rotation speed [rpm].
V: wind speed [m/sec].
λ: tip speed ratio.

From equation (1) we can calculate rotation speed as follows according to (Patel, 2005):

$$n = \frac{60 \times V \times \lambda}{\pi \times D} \qquad (2)$$

According to (Hansen, 2008), we can get tip speed ratio value from fig (6) that show the relation between wind speed ratio and power efficiency factor C_p.

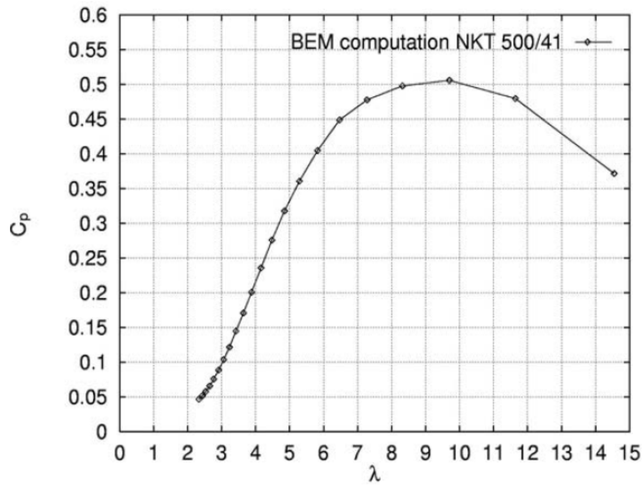

Figure 6. The relation between wind speed ratio and power efficiency factor.

Using MATLAB Simulink, we made a simulation for equation 2.The simulation model is shown in figure (7). Where figure (8) shows the turbine speed for 0.5 diameter and 4.4 tip speed ratio, from this figure we found that the turbine speed ranges between 1849.68 rpm when the wind speed is 11 m/sec and reaches 4203.82 rpm when wind speed is 25 m/sec.

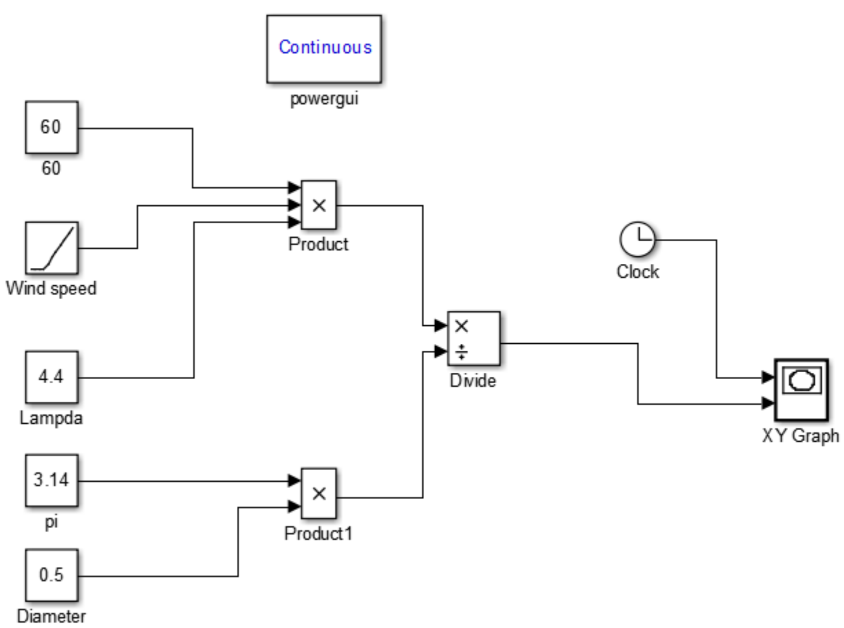

Figure 7.MATLAB Simulink model to calculate wind turbine rotation speed.

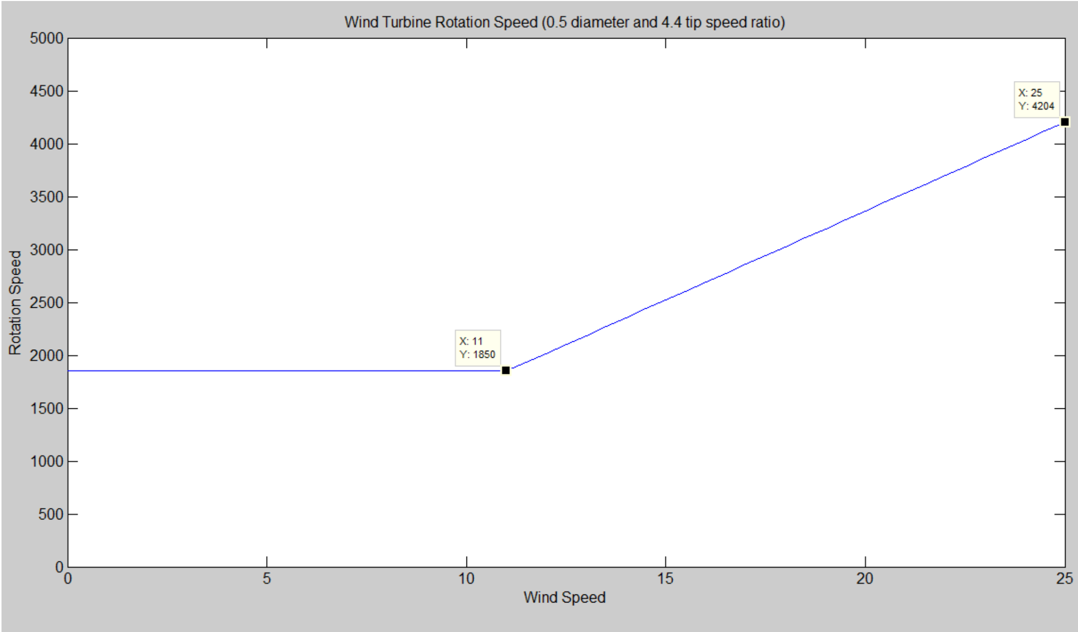

Figure 8. Wind turbine rotation speed for 0.5 diameter and 4.4 tip speed ratio.

Full results of equation 2 with different diameters and tip speed ratios are shown in table (1).

Table 1. Wind turbine rotation speed for different diameters and tip speed ratios.

$D(m)$	λ	$V_{min}(m/s)$	$V_{max}(m/s)$	$n_{min}(rpm)$	$n_{max}(rpm)$
0.5	4.4	11	25	1849.68	4203.82
0.45	4.4	11	25	2055.20	4670.91
0.4	4.4	11	25	2312.10	5254.77
0.5	4.8	11	25	2017.83	4585.98
0.45	4.8	11	25	2242.03	5095.54
0.4	4.8	11	25	2522.29	5732.48
0.5	6	11	25	2522.29	5732.48
0.45	6	11	25	2802.45	6369.42
0.4	6	11	25	3152.86	7165.60
0.5	6.8	11	25	2858.59	6496.81
0.45	6.8	11	25	3176.22	7218.68
0.4	6.8	11	25	3573.24	8121.01

After calculating turbine rotation speed, we calculate turbine output power (the power converted from the wind into rotational energy in the turbine) from the following equation according to (Patel, 2005):

$$P = \frac{1}{2} \rho \times A \times V^3 \times C_p \qquad (3)$$

Where:

A: The swept area which is given like this ($A = \frac{\pi \times D^2}{4}$ m^2).

C_p: The power coefficient, which is given in figure (6).

Using MATLAB Simulink, we made a simulation for equation 3. The simulation model is shown in figure (9)

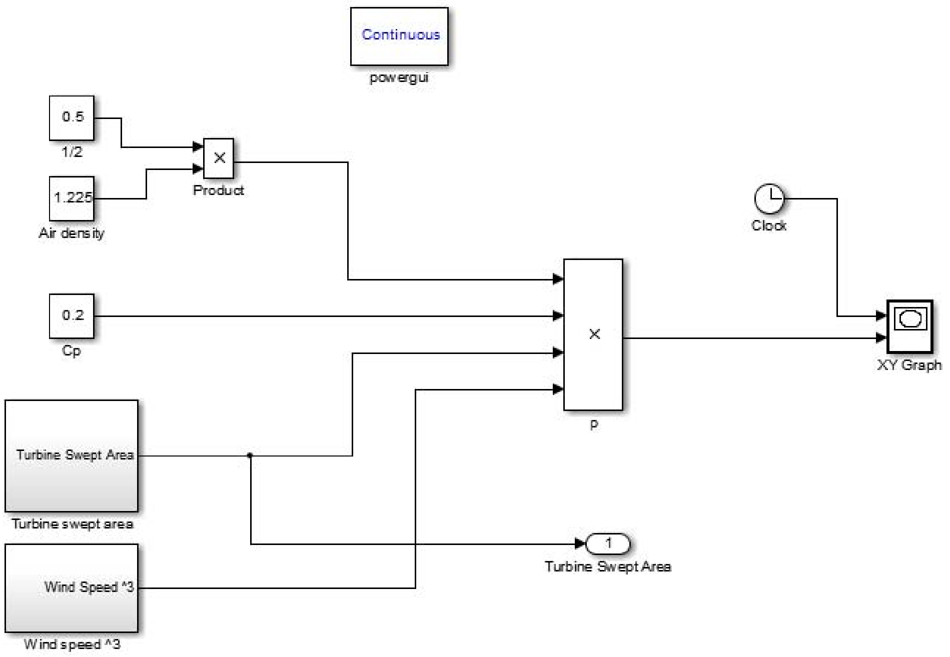

Figure 9.MATLAB Simulink model to calculate wind turbine output power.

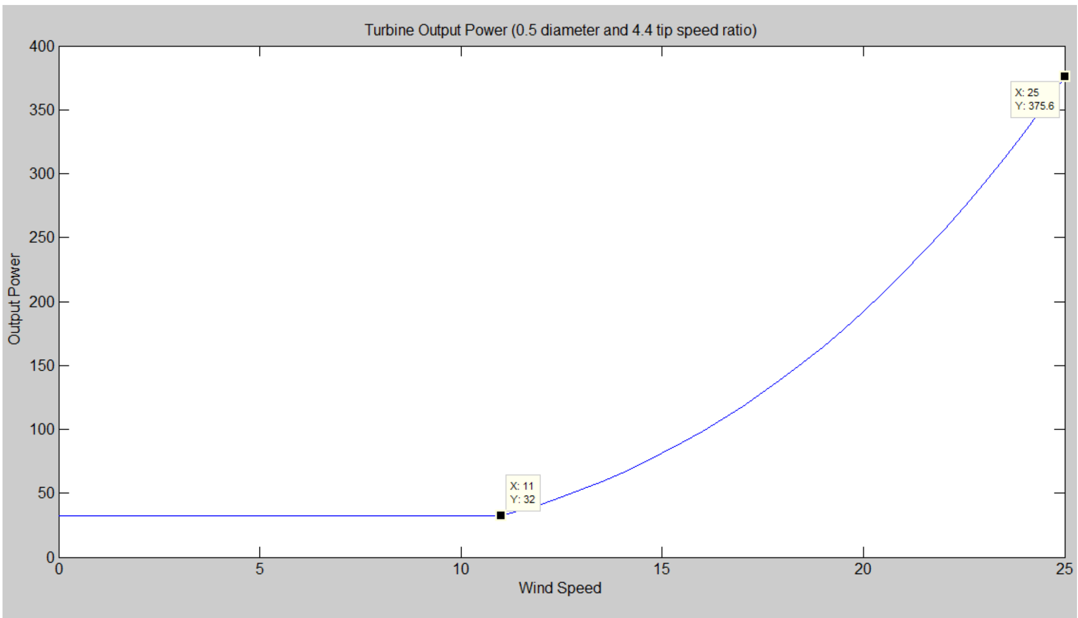

Figure 10. Wind turbine output power for 0.5 diameter and 4.4 tip speed ratio.

Full results of equation 3 with different diameters and power coefficient values are shown in table (2).

Table 2. Wind turbine output power for different diameters and power coefficient values.

$D(m)$	C_p	$V_{min}(m/s)$	$V_{max}(m/s)$	$A\ (m^2)$	$P_{min}(W)$	$P_{max}(W)$
0.5	0.2	11	25	0.19625	31.99	375.63
0.45	0.2	11	25	0.15896	25.91	304.26
0.4	0.2	11	25	0.1256	20.47	240.40
0.5	0.25	11	25	0.19625	39.99	469.54
0.45	0.25	11	25	0.15896	32.39	380.33
0.4	0.25	11	25	0.1256	25.59	300.50
0.5	0.35	11	25	0.19625	55.99	657.36
0.45	0.35	11	25	0.15896	45.35	532.46
0.4	0.35	11	25	0.1256	35.83	420.71
0.5	0.4	11	25	0.19625	63.99	751.26
0.45	0.4	11	25	0.15896	51.83	608.52
0.4	0.4	11	25	0.1256	40.95	480.81

After considering that the turbine needs to supply the needed power for the alternator that charges the battery bank. We found that the best features for the turbine are like shown in table (3), since the alternator rotates in a speed between (2500-6000 rpm), and needs a power between (335-340 W).

Table 3. Best features of the wind turbine.

$D(m)$	λ	C_p	$n_{min}(rpm)$	$n_{max}(rpm)$	$P_{min}(W)$	$P_{max}(W)$
0.45	6	0.35	2802.45	6369.42	45.35	532.46

The last parameter for the wind turbine is the number of blades, which is given related to tip speed ratio as shown in table (4) according to (Ingram, 2011).

All the parameters for the wind turbine are known, so we can design this turbine using Autodesk Inventor program. In figure (11) we show the designed wind turbine that is made of carbon fiber with a 45 cm diameter and 18˚ tilt angle, and 2 mm blade thickness.

Table 4. Frequency operation bands according to UCTE

λ	Blades Number
1	8-24
2	6-12
3	3-6
4	3-4
More than 4	1-3

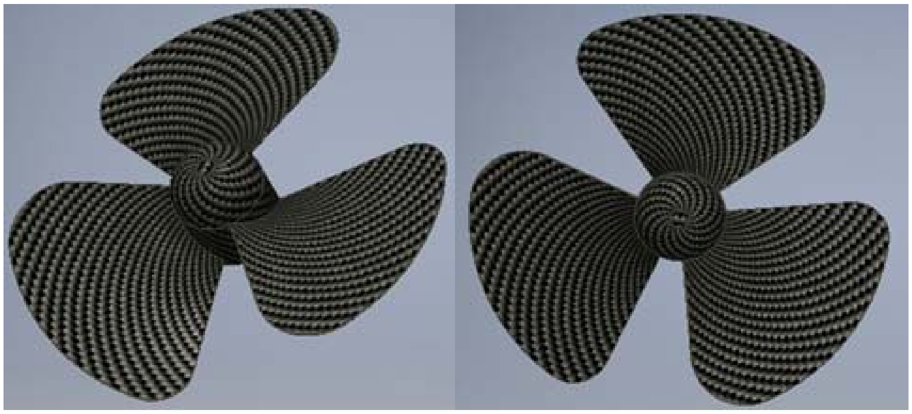

Figure 11. Wind Turbine Design using Autodesk Inventor.

3. DISCUSSION AND CONCLUSION

We found that the designed wind turbine gives the needed power to operate the alternator that charges the battery bank to supply the inverter with the electrical power needed to run the electric engine. We can put the designed turbine in a wind tunnel using Autodesk Flow Design program to test the turbine atdifferent wind speeds. We can enhance the model by putting sensors to stop the turbine from rotating when the wind speed exceeds 25 m/sec to protect the alternator. Using this wind turbine in hybrid vehicles provides a continuous source to charge the battery bank the thing that gives a long driving distancewithout the need to stop for recharging.

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