



Mathematical Modelling of a Wind Charging System for an Electric Automobile.

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Abstract

This study is centred on modelling a system for charging an electric vehicle that is safe to use and very economical. The problem of charging is the strongest limiting factor of making electric vehicles more attractive in the automobile market. Though the plug-in charging system has proven overtime to be the most reliant charging method, however, its availability has really shifted focus of design on many other alternatives. A wind turbine using aerodynamic drag force is modelled in this study as the power input source for battery charging. The system behaviour is designed and analysed for when the vehicle is in motion. Meanwhile, the system will keep charging and storing power in the batteries of the EV as long as the ambient wind has sufficient power to drive the rotor blade at rated speed when the vehicle is stationary. Results of the modelled system showed that an increase in velocity of the vehicle increases the power output, which invariably increases the charging rate of the battery. At the speed of 40 km/hr a designed blade diameter of 0.6 m shows the best performance. It is recommended for further study that the system can be improved by making the rotor blades adjustable (varying blade angle). This invariably gives a better control on power and torque and yields better efficiency for the system.

Keywords: Electric Vehicle Charging, Wind Turbine, Aerodynamic Drag, Battery Charging System, Renewable Energy Engineering

Introduction

Electric vehicles (EVs) have made a strong comeback after internal combustion engine (ICE) vehicles dominated the market for years. While ICE vehicles have long held a monopoly, their environmental impact, including emissions-related issues such as air pollution and greenhouse gas emissions, has driven global research into alternative solutions (Ljevaja, 2011; Torok, 2015; Nivas et al., 2022). EVs, along with hybrid electric vehicles (HEVs) and fuel cell technologies, offer a promising path to reducing or eliminating emissions. Historically, EVs were popular in the mid-19th century and even held speed records until 1900. However, their decline was due to high costs, limited range, and low speeds compared to ICE vehicles (Guarnieri, 2012). In the 21st century, renewed interest in EVs has emerged due to environmental concerns and the need for sustainable transportation. EVs rely on batteries and electric motors, while HEVs combine internal combustion engines with electric power sources to improve efficiency and reduce emissions. The future of automotive propulsion is shifting toward these cleaner alternatives (Burke, 1992). By 2016, the global electric vehicle (EV) fleet had surpassed one million units, with China accounting for more than 30% of this total (Boschert, 2006). While the accelerated deployment of EVs offers considerable environmental benefits, the resulting charging demand poses significant challenges to power grid reliability, including frequency deviations, voltage rise, increased peak loading, and network congestion (Burke, 1992; ElNozahy et al., 2014; Chandra-Mouli et al., 2016; Ipakchi & Albuayeh, 2009).

This study focuses on a fully electric vehicle with zero emissions, excluding hybrid electric vehicle options. All charging methods utilised are DC charging, either through constant current or constant voltage, depending on the battery configuration. Most research on electric vehicle charging has primarily covered the following areas: Solar-

powered charging, Hybridisation techniques, Regenerative braking and energy recovery systems, Inductive (wireless) charging, Installation of charging stations or grid-connected plug-in systems

Solar energy is a reliable and cost-effective source of thermal and electrical power, making it a key renewable energy option. Photovoltaic (PV) cells enable the conversion of sunlight into electricity by responding to electromagnetic radiation. A Solar Electric Vehicle (SEV) operates in dual modes, running on both battery power and solar energy independently. It consists of PV panels, a battery, an electric motor, a vehicle controller, and the vehicle body. PV panels are installed on the roof or sides of the vehicle, depending on the design. These panels connect to the vehicle's battery and motor through a controller, which manages power distribution. In sunny conditions, PV cells continuously generate electricity, which is either stored in the battery or used directly to power the motor (Su et al., 2010). In developing EVs, the appropriate battery configuration is an important subject to consider. The battery configuration is also dependent on the size and weight of the vehicle (Su et al., 2010). In order to achieve the required voltage, the Photovoltaic (PV) module may be configured as either parallel or series connection, but it is, however, costlier to use the PV module independently. Thus, to make it cost-effective, power converters and batteries are being used together with PV modules. The electrical charge is consolidated from the PV panel and directed to the output terminals to produce low voltage (Direct Current). The charge controllers direct this power acquired from the solar panel to the batteries, and modern technology has helped to eliminate the fear of overcharging. (Alphonse et al., 2012).

Hybridisation is the most common and widely available electric vehicle charging solution. A Hybrid Electric Vehicle (HEV) combines an internal combustion engine (ICE) with an electric propulsion system to improve fuel efficiency or performance. The extent to which an HEV functions as an electric vehicle varies based on its design. HEVs generate electricity using a motor-generator system, which either recharges the battery or powers the electric motor directly. Many HEVs use a start-stop system to reduce idle emissions by shutting down the ICE when the vehicle is idle. Since HEVs often have smaller, more efficient engines than conventional gasoline vehicles, they produce lower emissions. Hybridisation ranges from full hybrids, which can operate solely on the engine, battery, or both, to mild hybrids, which use a smaller electric motor that assists the ICE but cannot drive the vehicle independently. Mild hybrids typically support regenerative braking to improve energy efficiency (Boschert, 2006).

Regenerative braking is an energy recovery system that slows a vehicle by converting its kinetic energy into usable or storable electrical energy, unlike conventional brakes that dissipate energy as heat. This system improves vehicle efficiency and extends brake lifespan by reducing wear. The process works by reversing the motor's function, allowing it to act as a generator that sends power back to the battery. While regenerative braking increases efficiency, it cannot fully replace friction brakes, as it takes longer to stop a vehicle. A well-known application of regenerative braking is the Kinetic Energy Recovery System (KERS) used in Formula 1 racing (Eltaweel & Herfatmanesh, 2024). KERS captures braking energy and stores it in batteries, flywheels, or supercapacitors for later use. Formula 1 first introduced KERS in 2009 but temporarily discontinued it in 2011 due to racer agreements on standard vehicle weight.

Wireless energy transfer has become a key focus in recent research, with small electronic devices successfully using inductive and resonant energy transfer for wireless charging. Inductive charging works by placing two electrical coils close to each other, creating a low-power electrical field that enables energy transfer without direct contact. One coil (the sender) is constantly powered, transferring energy to the receiver until both have equal power (Rahulkumar et al., 2023). Resonance charging improves upon inductive charging by enabling energy transfer over longer distances (Van der Pijl, 2013). Wireless vehicle charging systems use ground-installed inductors to transfer power to a vehicle's battery automatically when the car is detected in a designated charging space, ensuring minimal energy loss (Panchal et al., 2018; Ramakrishnan et al., 2024)

Electric vehicles (EVs) are an effective solution for reducing gas emissions and oil dependence by using electricity instead of traditional fuels. As EV adoption grows, future oil demand is expected to decline. A key focus of recent research is charging infrastructure, which is essential for global EV adoption, particularly in areas with unstable electricity supply (Kumar et al., 2023). The increasing adoption of electric vehicles (EVs) has heightened the demand for charging infrastructure and efficient smart charging coordination. Alongside residential and public charging, destination charging plays a crucial role in meeting residual public charging needs (Yong et al., 2023). The plug-in charging method involves connecting a vehicle's rechargeable battery to an external power source using a cord. These power sources can include electrical sockets, battery packs, or solar energy (Chandra-Mouli et al., 2016). Vehicles

utilising this method are often referred to as grid-enabled or electrically chargeable vehicles. Nearly all electric vehicles incorporate plug-in charging to some extent, often in combination with other charging methods. However, a key challenge with this approach is its limited availability and reliability, particularly when travelling to remote or underdeveloped areas (Parks et al., 2007).

Electric Vehicles (EVs) rely entirely on electric power, making a constant power supply crucial for their widespread adoption. A major challenge preventing EVs from dominating the automobile market is the inconsistent availability of charging infrastructure. Without a reliable power source, EVs face limitations in travel distance, and environmental concerns linked to internal combustion engine (ICE) emissions remain unresolved. Yang et al. (2019) address the challenge of coordinating electric vehicle charging with building-integrated wind power by proposing centralised and decentralised real-time scheduling approaches that balance charging demand with volatile wind supply, demonstrating that the decentralised method achieves scalable, near-optimal performance while reducing grid impacts. Additionally, aerodynamic drag, a force opposing a vehicle's motion, plays a key role in automotive and aviation design. Since drag is always present when a vehicle is in motion, managing it effectively is essential for improving EV efficiency and performance.

Wang, (2018), proposes a highly efficient green energy-saving charging station designed for electric vehicles. Mohanasundaram (2018) designed a prototype system for charging an electric vehicle (EV) using renewable energy sources, specifically photovoltaic (PV) solar panels and wind energy. A vertical axis wind turbine (VAWT) with a 2kW, 24V capacity and a PV panel with 0.2kWp, 24V are integrated with separate 24V charge controllers to prevent voltage fluctuations and reverse conduction. The system provides a total renewable charging capacity of 2.2kW at 24V to charge an EV battery at 72V, 26Ah. Using three 24V battery strings connected in series to achieve 42Ah, the system enables a full charge in approximately 8 hours and 12 minutes. This setup allows for cost-free, pollution-free charging, reducing carbon emissions while meeting the growing energy demand for EVs with sustainable resources. This study focuses on developing an alternative power source to charge EV batteries and provide backup power during vehicle operation. By addressing this issue, the study aims to reduce dependence on fossil fuels, lower greenhouse gas emissions, and promote sustainable transportation.

Methodology

Modelling energy recovery systems from drag is the focus of this study. This study focuses on recovering energy from aerodynamic drag to generate electricity for an electric vehicle. A turbine, generator, and housing are installed on the vehicle to harness wind energy as the car moves. The housing includes a duct that directs and compresses airflow, increasing pressure energy before converting it into a high-speed jet through a nozzle. This jet drives a turbine, which rotates at high speed due to the aerodynamic drag. The turbine is connected to an alternator, which generates AC power, later converted to DC by a rectifier and stored in a battery (Figures 1 and 2).

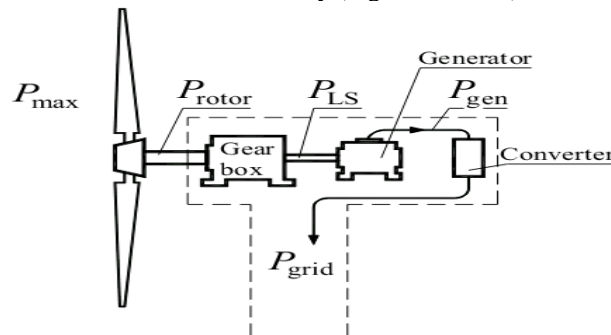


Figure 1. A Schematic Concept of the wind turbine energy recovery system

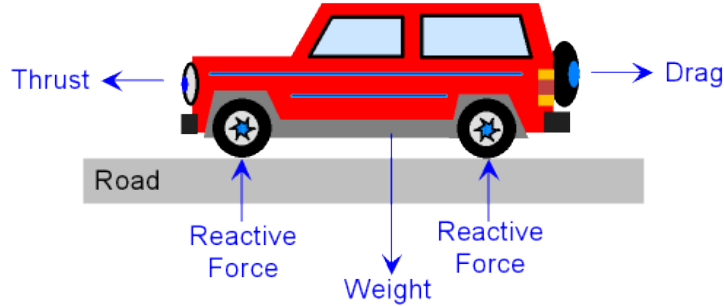


Figure 2. The different forces acting on a vehicle in motion

Thrust

$$\dot{m} = \rho A_v v$$

$$T = m \frac{dv}{dt} = ma = \dot{m}v = ma \tag{1}$$

Aerodynamic Drag

$$F_d = \frac{1}{2} C_d \rho A_v v^2 \tag{2}$$

$$P = F_d v \tag{3}$$

The power from drag transmitted to the interacting surface is always not efficient and thus drag coefficient is used to multiply the ideal power equation "C_d" to bring a better and more practical model of the drag force. Therefore,

$$P = C_d F_d v \tag{4}$$

Weight

$$W = mg \tag{5}$$

Reaction Force (Rolling Resistance)

Reaction forces are forces acting on the different wheels of the automobile. They are the forces acting at the point of contact between the vehicle and the surface.

$$F_r = C_r mg \tag{6}$$

Design Specifications

Battery Modelling

The total battery voltage $V_{battery}$ is obtained using equation (7) assuming that all cells have a uniform behaviour and where V_{el} is the voltage of a single cell

$$V_{batt} = n_{cell} V_{el} \tag{7}$$

Furthermore it is fundamental to calculate the battery SOC (where C_n is the rated capacity expressed in Ampere-Hours [Ah] and SOC_0 is the initial state of charge) to evaluate the amount of energy stored into the battery pack.

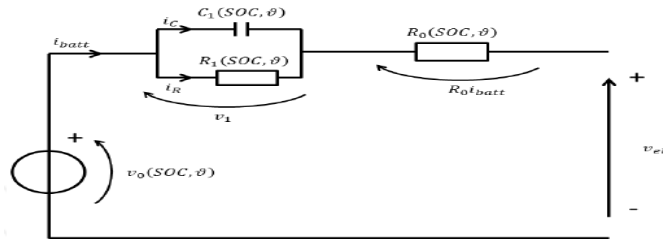


Figure 3. Randle Electrodynamic Model of a Cell

$$SOC(t) = SOC_0 - \int_0^t \frac{i_{batt}(t)}{3600.C_n} dt \tag{8}$$

Maximum power that could be generated from the battery (Figure 3);

Battery; $3 \times 12V, 62Ah$

For series connection of battery;

$$V_{total} = V1 + V2 + V3$$

$$V_{total} = 12 + 12 + 12 = 36V$$

$$I_{total} = I1 = I2 = I3 = 62Ah$$

$$P_{electrical} = I_{total} V_{total} \tag{9}$$

$$P = 36 \times 60 = 2232\text{Wh}$$

$$P = 2.332\text{KWh} = 2.9932\text{hph}$$

For parallel connection of battery;

$$V_{\text{total}} = V1 = V2 = V3$$

$$I_{\text{total}} = I1 + I2 + I3 = 186\text{Ah}$$

$$P = 12 \times 186 = 2232\text{Wh}$$

In either configuration, the power output is the same, and thus the choice of configuration will be dependent on if voltage or current is our target.

Motor Specifications

20 cm diameter 15cm length

2.5 cm shaft with 0.5 cm keyway by 4.5 cm long (threaded centre)

Torque constant: 1.14 in-lb/Amp (0.13 Nm/Amp)

12V to 36V due to turned rotor.

New Lithium/Graphite brushes work for either CW or CCW rotations.

Epoxy/Lam rotor efficiency = 94% (Brushed motors convert more electricity into usable horsepower)

Weighs only 22 lbs (10kg)

Dimensions: 20cm X 23cm X 23cm

The motor is a motor-generator (requires a 100-amp blocking diode)

Modelling the Turbine Rotor (Figure 4)

Some of the assumed design parameters for the design are as follows;

- Maximum acceptable blade diameter 60cm (0.6m) (considering vehicle size)
- Maximum vehicle velocity 40km/hr (11.11m/s) (the vehicle speed automatically assumes the value for the wind speed)
- The design calculation model will be for the maximum velocity.
- The angle of attack " α " for the design is 6°
- Density of air at sea level approximated as 1.22kg/m^3
- Due to the blade's relatively small size, the camber parameters are assumed to be negligible for our calculations

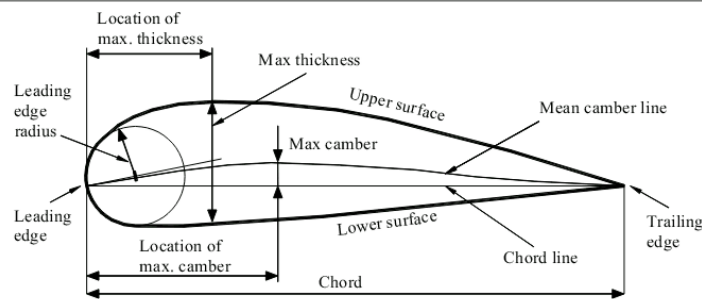


Figure 4. A typical aerofoil

Tip speed ratio (TSR) " λ " is very important in determining the turbine blade efficiency. It is dependent on turbine design, rotor aerofoil profile and number of blades (Figure 4).

$$\lambda = \omega R/v$$

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From observations, $s/R \approx 0.5$ (Ragheb and Ragheb, 2011). From equation 10

$$\omega_{\text{opt}} = \frac{2\pi \times 11.11}{3 \times 0.15} = 155.04622\text{rad/sec}$$

$$f = \omega/2\pi$$

$$f = \frac{155.1}{2\pi} = 24.68\text{Hz}$$

TSR could be determined from equation 3,

$$\lambda = \frac{155.1 \times 0.3}{11.11} = 4.19$$

The theoretical power that a wind carries is given by;

$$P = \frac{1}{2} \rho A v^3 \tag{11}$$

Because not all power from the wind is eventually collected by the turbine, it is essential to put a power coefficient into the model (Figure 5). Therefore, the turbine power P_t is given by;

$$P_t = \frac{1}{2} C_p \rho A v^3 \tag{12}$$

This infers that the maximum power that could be generated from a wind is nothing less than 60%. The power coefficient "C_p" is known as the Betz limit. Meanwhile, most wind turbine power is around 30%-45%.

$$P_t = \frac{1}{2} 0.5926 \times 1.2 \times \left(\frac{\pi 0.6^2}{4} \right) \times 11.11^3 =$$

$$P_t = 137.9W$$

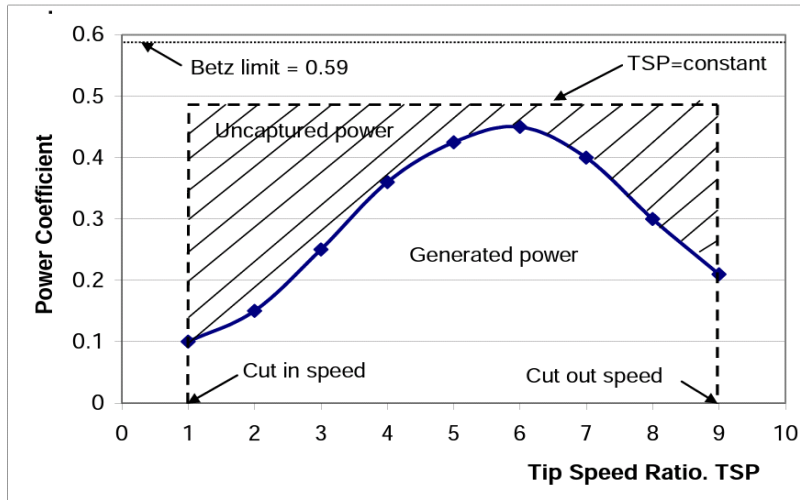


Figure 5. Power coefficient against TSR showing the Betz limit

Power is related to torque by the equation below;

$$\tau = \frac{P}{\omega} \tag{13}$$

From the above, the maximum torque supplied by the wind to the rotor is

$$\tau = \frac{137.2}{186.17} = 0.74Nm^{-1}$$

The most commonly used angle of attack ranges from 5°-10°. At 15°-25°, the turbine experiences stall.

$$c_{(r)} = \frac{1}{n} \left(\frac{16\pi r}{C_l} \right) \sin^2 \left(\frac{1}{3} \tan^{-1} \left(\frac{R}{\lambda r} \right) \right) \tag{14}$$

Referencing from the turbine tip and the outer hub, the chord lines are 0.04m and 0.09m, respectively.

The turbine blades need lift for good rotation so that the force acting in the axial direction is maximised. Lift is the force that acts perpendicularly to the wind direction. Lift is defined by the equation;

$$F_l = C_l \frac{1}{2} \rho v^2 A \tag{15}$$

C_l , C_d and GR is determined as 0.8, 7.3×10^{-3} and 110. The lift acts on the area of the blade defined by the chord line so therefore the area 'A' = bc.

$$F_l = 0.8 \times \frac{1}{2} (1.22 \times 11.11^2) (0.06 \times 0.22)$$

$$F_l = 0.795N$$

From the lift force, the weight of each blade can be assumed not to exceed 0.79kg.

Other important parameters in blade design are the blade pitch angle, angle of relative wind to rotor plane, angle of relative wind to rotor axis ($\beta_{(r)}$, $\varphi_{(r)}$ and $\gamma_{(r)}$) taken from a particular reference point 'r' on the blade.

$$\varphi_{(r)} = \tan^{-1} \left(\frac{2R}{3r\lambda} \right) \tag{16}$$

$$\beta_{(r)} = \tan^{-1} \left(\frac{2R}{3r\lambda} \right) - \alpha \tag{17}$$

$$\gamma_{(r)} = \tan^{-1}\left(\frac{3r\lambda}{2R}\right) \quad 18$$

At reference point 'r' given as 0.03m, we obtain; $\beta_{(r)} = -77.23^\circ$, $\gamma_{(r)} = 32.2^\circ$, $\varphi_{(r)} = 57.8^\circ$

If the reference point is the blade tip, the value of r will be the radius. Thus, the angles can be written as;

$$\varphi_{(r)} = \tan^{-1}\left(\frac{2}{3\lambda}\right) \quad 19$$

$$\beta_{(r)} = \tan^{-1}\left(\left(\frac{2}{3\lambda}\right) - \alpha\right) \quad 20$$

$$\gamma_{(r)} = \tan^{-1}\left(\frac{3\lambda}{2}\right) \quad 21$$

Slotting in values to the above equations;

$$\beta_{(r)} = -80.3^\circ, \gamma_{(r)} = 81^\circ, \varphi_{(r)} = 9.019^\circ$$

The transformation of drag and lift to torque and thrust is governed by the following equations;

$$dT = \frac{1}{2} \rho \omega^2 cr \quad 22$$

The rotor efficiency is given as $\eta_{rotor} = P_{rotor}/P_{max}$

$$\eta_{rotor} = \eta_{wake} \times \eta_{tip} \times \eta_{profile} \quad 23$$

From figure 3.6 $\eta_{rotor} = 0.79$

The maximum power available in the gearbox is the rotor power given as;

$$\eta_{generator} = \frac{P_{rotor}}{P_{generator}} \quad 24$$

$$\eta_{converted} = \frac{P_{generator}}{P_{grid}} \quad 25$$

$$P_{rotor} = \eta_{rotor} \times P_t \quad 26$$

$$P_{rotor} = 0.79 \times 137.9 = 108.9W$$

In the same vain, the maximum torque that gets into the rotor shaft can be given as;

$$\tau_{rotor} = \tau \times \eta_{rotor} \quad 27$$

$$\tau_{rotor} = 0.79 \times 0.74 = 0.59N/m$$

To minimize losses and cost, the rotor shaft serves as the alternator shaft. A single shaft connects the rotor to the alternator. The absence of a gear system reduces losses in the system and also gives design simplicity.

Generator Specifications

20 cm diameter 15cm length

2.5cm shaft with 0.5cm keyway by 4.5cm long (threaded centre)

Power 100W

Angular velocity 200rpm

Charges 12-36V battery

Weighs only 22 lbs (10kg)

Results

EV Charging System Evaluation

Charging the electric car battery is the one key factor that has limited the growth of electric vehicles in the automobile market. Using fuzzy logic, the different charging methods available are assessed as shown in Table 1.

Inference

The different charging methods come with their pros and cons. Choice was based on the following criteria;

1. Efficiency
2. Effects on the environment
3. Safety
4. Convenience/availability

Fuzzy logic style of selection gives room for degrees of exactness unlike the traditional Boolean method that uses just the YES OR NO (1&0) and does not give room for any degree of exactness. In Boolean, nothing is partially true. It is either yes or no. Fuzzy logic system gives room to select partially true or a near truth value.

Efficiency:

From the different laws of thermodynamics, the impossibility to attain 100% output is not farfetched. The different methods were judged based on minimal loss in the energy input

- Does the method have a minimal heat loss?
- Is the energy loss recovered in one way or the other?

- Are losses aside heating negligible?

Environmental Effect:

One of the reasons behind the resurgence of electric vehicle technology is the problems associated with emissions from ICEs. Each charging method will be rated based on the emission associated with them and how harmful or not they are

- Are emissions of greenhouse gasses minimized?
- Is pollution reduced?
- Is the method eco-friendly?

Availability/Convenience:

Availability is one criterion that must be considered in making choices on the type of method that is to be employed. The ease to charge is a big variable that affects the market if the electric vehicle as it births a big motivation to owning an electric vehicle. The convenience associated with charging is

- Is the method easy to use?
- Is it completely dependable?
- Can be battery be charged without parking?

Safety:

In engineering, safety is first. The most important thing to consider in selection is how safe the method selected will be. The safety behaviour of any method will determine how widely it will be accepted in the commercial market.

- Is hazard minimised with the use of this method?
- Are the accidents associated with this method threat free on individual's life?
- Is the method free of threats to the health of the individuals?

Size:

- Is the design light?
- Is the additional weight negligible?
- Will the design size of the vehicle be devoid of serious alteration if the method is employed?

For the different assessments, 'Y' represents yes, while 'N' is for no. For each criterion, yes for each question attracts a value of $1/n$ point, 'n' is the total number of questions in each assessment. The total points attainable is 'N', where $0 \leq N \leq 1$.

From Table 1, it could be inferred that the best EV battery charging approaches are the regenerative braking system, solar and the Plug-In charging method. Although, regenerative braking system proves to be best in all, its safety is below average. Solar on the other hand, is very much sunshine dependent and will be unavailable on a cloudy day. Before making our decision, there is need to consider why the regenerative braking system has the lowest score in its safety. If this can be improved, regenerative braking is simply an excellent solution. Most of the other methods combine the plug-in charging method.

The regenerative braking system is an energy recovery system which proves to be the most efficiency considerate method. The safety issue can be addressed by combining it with the traditional friction braking system. An energy recovery system will improve the efficiency thus allowing the vehicle to cover a longer distance.

However, the present study examines the feasibility of using a wind turbine connected to the moving vehicle for the purpose of charging the battery.

Design Behaviour

The design allows the car to continue charging while parked if the wind is strong enough to spin the rotor at a sufficient speed. However, the mathematical model is restricted to charging scenarios when the vehicle is in motion.

Table 1 Selection Grading Table

Charging type	Plug-In	Hybridization	Regenerative Braking	Solar	Inductive
Efficiency	NNN=0	NNN=0	NYN=0.33	YNN=0.33	NNN=0
Environmental Effect	YNY=0.66	NYN=0.33	YNY=0.66	YYY=1	YYY=1
Availability/Convenience	YYN=0.66	YYY=1	YYY=1	YNY=0.66	YYN=0.66
Safety	YYY=1	YYN=0.66	NNY=0.33	YYY=1	YYN=0.66
Size	YYY=1	YNN=0.33	YYY=1	YNN=0.33	YYN=0.66
TOTAL	3.32	2.32	3.32	3.32	2.98

Behaviour of Blade at Different Design Angle

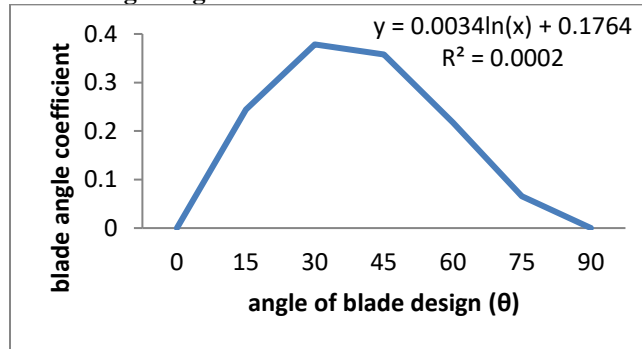


Figure 6. Graph of blade angle coefficient-angle of blade design

The graph above (Figure 6) explains the various behavioural effects of the wind acting on different configurations of the angle of the blade to the wind. At 30° the maximum blade angle coefficient is given. This implies that the force produced is maximal at that particular angle. With the graph, the braking and speed control of the turbine can take another innovative shape.

Power Behaviour and Rate of Charging at Different Vehicle Speed

The wind speed is assumed to take the value of the vehicle speed and the data recorded from mathematical modelling of the charging system is given by Figure 7.

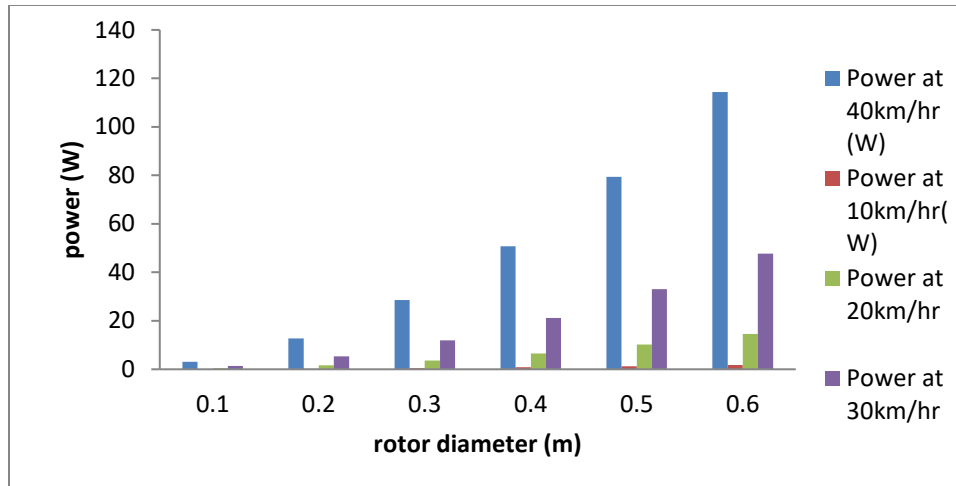


Figure 7. Performance characteristics of the design

The arithmetic increase in area (blade diameter) and vehicle speed tend to cause a geometric increase in power produced. Since the total battery voltage supplied is 36V, the power design limit will be at 40km/hr for a rotor with diameter of 0.3m. Any speed below 30km/hr will produce power that’s insufficient to charge the battery. Figures 8 to 10 show that the power output increases with increase in vehicle velocity and increase in blade diameter as expected. However, there is a limit at which an increase in the blade diameter with results in a decrease of power output due to increase in aerodynamic drag force and turbulence around the blade.

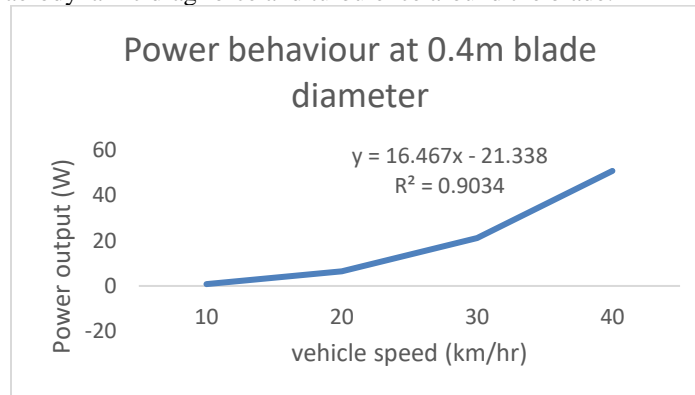


Figure 8. Power output at varying vehicle speed using the design rotor diameter of 0.4m

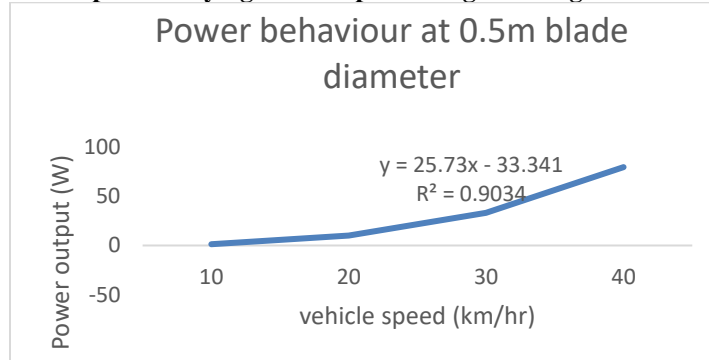


Figure 9. Power output at varying vehicle speed using the design rotor diameter of 0.5m

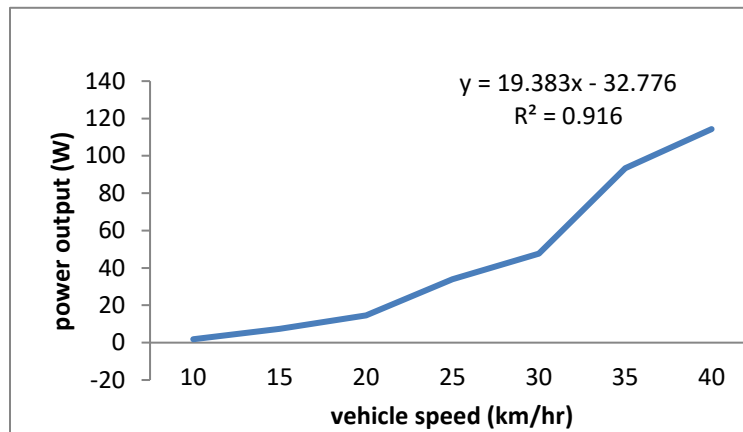


Figure 10. Power output at varying vehicle speed using the design rotor diameter of 0.6m

The rate of charging is dependent on the power produced thus it is trivial to say the rate will vary for each vehicle speed. Since the vehicle speed is a function of the driver’s decision, the rate of charging as a result will take a very complex analytical study and will be unique to a particular travel.

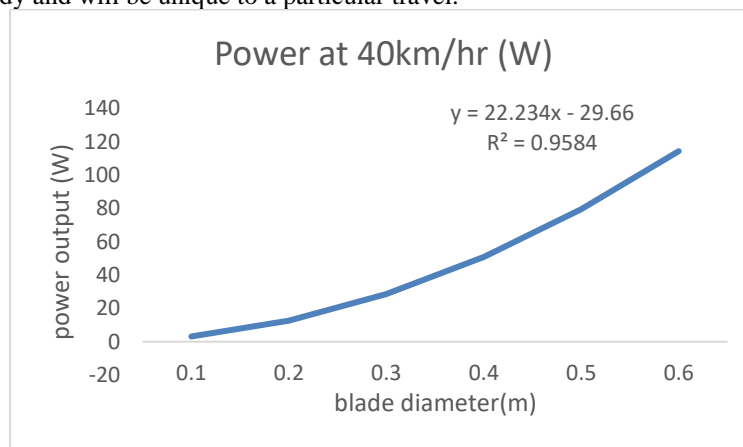


Figure 11. Behaviour of power at top speed

Figure 11 is a representation of the system behaviour at top speed. Power output increases as the blade diameter increases with the gradient, power output per blade diameter, between subsequent diameters changing and getting steeper. It is inferred that the best charging rate at top speed will be when the blade diameter is designed at 0.6m. Although, charging at very low battery and when battery is almost full is quite slow and require more power, it could also be modelled for a constant vehicle speed with little difficulties.

Conclusion

The problem of charging is the strongest limiting factor of making electric vehicles take over the automobile market. This project is centred on designing a system that charges the EV at any given time, is safe to use and also very economical. This has directed the study on the different charging methods available for EVs. Though the plug-in charging system has overtime proven to be the most reliant charging method however, its availability has really shifted focus of design on many other alternatives. A wind turbine using aerodynamic drag force is modelled in this study as the power input source for battery charging. The system behaviour is designed and analysed for when the vehicle is in motion. Meanwhile, the system will keep charging the EV as long as the ambient wind has sufficient power to drive the rotor blade at rated speed when the vehicle is stationary. Results showed that an increase in velocity of the vehicle increases the power output, which invariably increases the charging rate of the battery. At the speed of 40 km/hr a designed blade diameter of 0.6 m show the best performance. It is recommended for further study that the system can be improved by making the rotor blades adjustable (varying blade angle). This invariably gives a better control on power and torque and yields better efficiency for the system.

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