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Power Generation from a Moving Locomotive by Wind Turbine

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Abstract: Locomotive Mounted Wind Turbine (LMWT) is a mounted horizontal axis wind turbine system for heavy electric vehicles. This paper presents the design and implementation of LMWT to generate electricity from the vehicle. LMWT has several new advantages, including high RPM turbine, convenient weight, practical shape, direct storage and portability. And also, this paper evaluates the LMWT performance in terms of power generation. Here analyze that, with proper designing, LMWT can generate approximately 300W and above of power at vehicle speed of 80 km/hr which have a radius of 1m. A number of design considerations have taken into account specially for designing LMWT to ensure its proper functionality in practical heavy electrical locomotives.
Keywords: Hawt-Horizontal Axis Wind Turbine, Lmwt-Locomotive Mounted Wind Turbine, Pmdc-Permanent Magnet Dc, Tsr-Tip Speed RatioWt-Wind turbine.

1. INTRODUCTION

Green energy or wind energy which is the one of the most important sources of renewable energy that easily available in nature. At the end of this decade, most of the countries are moving towards to install more wind turbine around the world, because of the increasing need of electric power without any pollution. Wind energy is also known as green energy because it doesn't produce any pollution. According to statistics the electricity consumption is increasing largely due to the introduction of more electric vehicles. According to CEA (central electricity authority) in India 160 GW power is consumed in 2016-17. Around 10% of it only is produced by wind, which is the installed capacity, during the year 2016-17 about 46,011 million kWh generated, which is the 3% of overall generation. The latest consumption of energy is focused on electric locomotives, so to reduce the consumption of electric locomotive by combining electric locomotive and the wind turbine is used as an advanced technology.

1.1 ABOUT VEHICLE MOUNTED WIND TURBINE:

The commercial wind turbine is not suitable for small scale application as it requires more area, and cost of installation is large. Modern society is moving towards electric vehicles, so there needs an advanced technology of power production, here the concept of small portable wind turbine which can easily connected to electric heavy vehicles such as electric trucks, buses are introduced there by reducing the total consumption of electric power for electric locomotives. A fast moving locomotive such as train or long distance heavy and passenger vehicle that travels in good speed produce enough energy as a source for wind turbine and a moving locomotive to produce electric energy

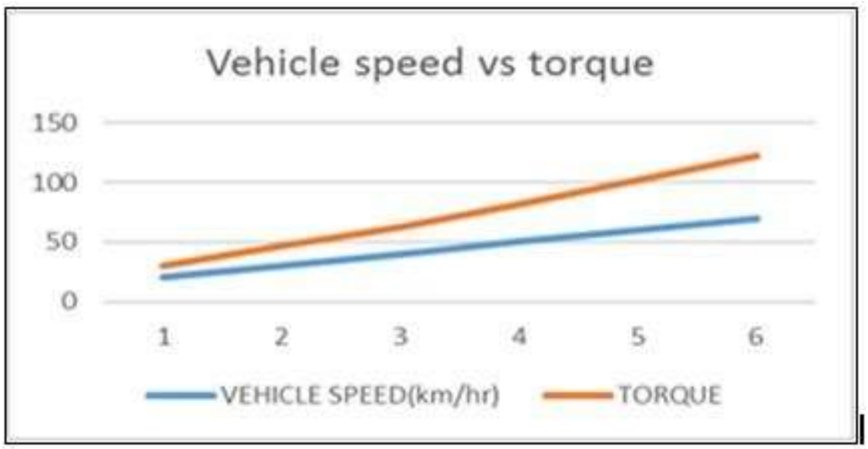
1.2 EXISTING SYSTEM

Many attempts done on this field to produce electric power by moving locomotives (Sham, 2011, Ferdous et al., 2011). The purposed systems not at all satisfying, because they don't meet the threshold of the practical implementation. These models are inefficient or directly affect the performance of vehicle (Jean, 1983; Jose, 2013; Cecil, 2012; Andrew, 2013; Peter, 2013; Keith, 1979; Tran,2011). So power generation from moving locomotive is still an active area to explore. As from above papers, this paper proposes a modern, portable wind generation and distributed system for vehicles. The introduction of these systems to an electric heavy vehicles helps us to achieve over target of producing wind energy and thereby reducing the running cost of future. The Blade Element Momentum (BEM) theory explains the factors related to the control of rotor blades rotating (Muller, Deicke, and Doncker, 2002).

Table No.1.1 Relation between speed of vehicle and wind produced

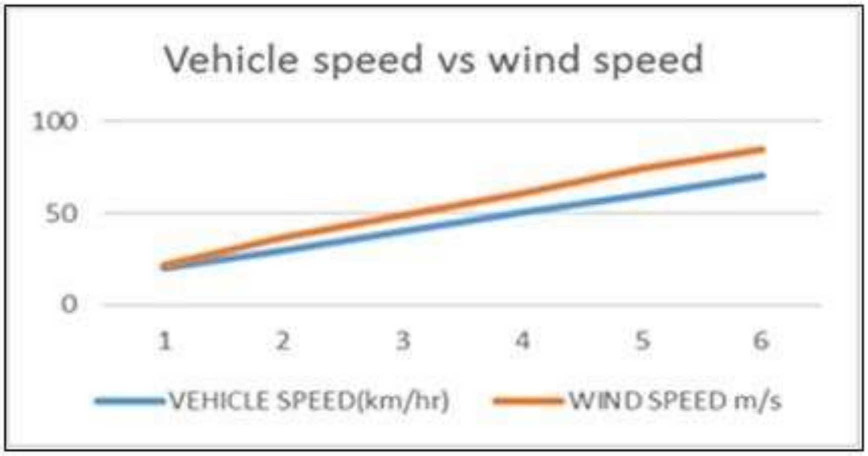
Sr. No	RELATION BETWEEN SPEED OF VEHICLE AND WIND PRODUCED		
	VEHICLE SPEED(km/h)	TORQUE	WIND SPEED (m/s)
1.	20	10	2
2.	30	17	7
3.	40	22	9
4.	50	32	11
5.	60	42	14
6.	70	52	15

Figure 1.1: Vehicle Speed versus Torque



- **Vehicle Speed Relation to Torque:**Vehicle speed and torque are directly proportional all. The speed rises from the minimum to the allowable limit the wind speed also rises up linearly to the torque.

Figure1.2: Vehicle speed versus wind speed

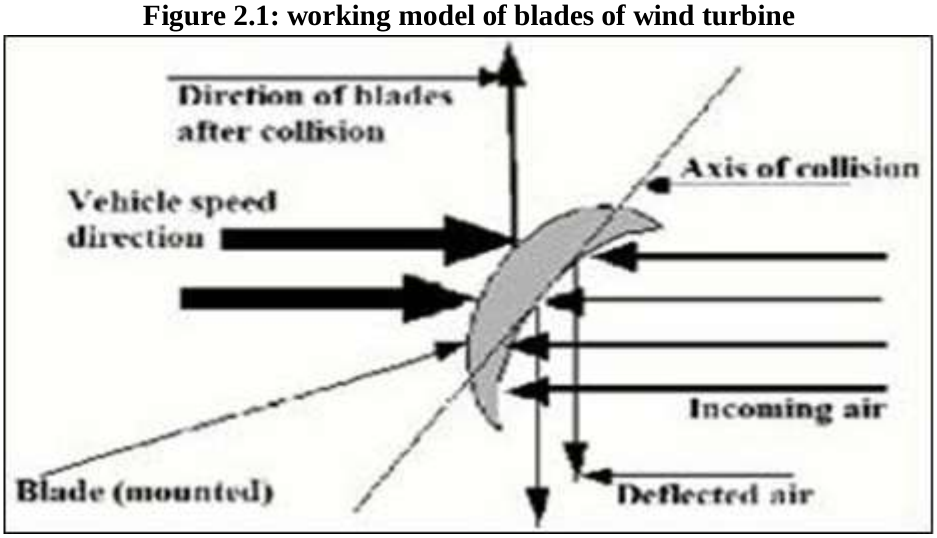


- **Vehicle Speed Relation to Wind Speed:** Speed of wind turbine directly related to wind speed, the speed of locomotive moves from first gear to next on smooth road then the speed directly changed to the next, by changing gear the speed increases up and there by sufficient amount of wind energy can be directly supplied to wind turbine.

2. SMALL WIND TURBINE FOR VEHICLE

Small wind turbine which individually produce power, which has less cost and efficient than big ones. And small space only needed for this type, their usual length varies from 1.5 to 3.5meters. Small lengthen of 0.8meter are also available which produces about 300W power to above depends on length and wind power. Small wind turbines protect themselves from high winds (governing) by tilting the rotor up or to the side, or by changing the pitch of the blades.

Figure 2.1: working model of blades of wind turbine



2.1 Conversion of Wind Energy:

Kinetic energy is the input form to turbines and KE done by Wind Power. Considering the fact that wind speed and wind direction are not independent random variables. Such kind of combined distribution can be obtained, Wind energy transformed into mechanical energy by turbines and to electrical energy by generators. Wind is the source which converted to electric and transmitted to battery. While, the availability of wind energy is different from conventional WT. Already existing systems are stationary but here it's moving. The kinetic energy available in wind is given by,

$$K.E = 0.5 \times \rho \times v \times A \times T \quad (1)$$

Where ρ is the density of the air, v is air velocity, A is the area of the air parcel and T is the time required for the air parcel to move through the plane.

Now, wind power can be expressed as follows,

$$PW = 0.5 \times \rho \times v \times A$$ Now, wind power density (WPD) can be stated as, (2)

$$W.P.D = 0.5 \times Pj \times Vj \quad (3)$$

Here, n is the number of wind speed reading, Pj, Vj are the jth (1st, 2nd, 3rd, etc.) readings of the air density and wind speed. Simplification of this gives,

$$WPD = 0.5 \times (\text{median of } \times \text{frequency of occurrence}) \quad (4)$$

$$WPD = 0.5 \times K \times \rho$$

Where K determined by the shape of the distribution pattern that the wind speed.

2.2 Aerodynamics:

Wind power changes at a wide range of time scales. In order to take the consideration of variability into the design of WTs, Aerodynamics determines precisely the right way to design rotor blades for WT (Wei and Feng, 2010). Now the rotor design lies on Bernoulli's law (Christoph, 1993), which is,

$$P.E + K.E = CONSTANT \quad (5)$$

$$P + 0.5\,Pv + \rho gh = constant \quad (6)$$

Where *P* is the static pressure (in *N/m2*), *ρ* is the fluid density(in *kg/m3*), *V* is the velocity of fluid flow (m/s),

h is elevation and *g* is the gravitational acceleration.

Equations leads to the maximum point of stress for WT and is called dynamic pressure equation. Equation A and deals with the basic aerodynamics of the WT rotor. Nevertheless, drag and lift force, tip speed ratio & solidity and

Betz limit directly affect the aerodynamic performance of WT rotor.

Relative wind velocity = wind velocity-blade velocity

The relative wind velocity determines the power input to wind turbine. Maximum extractable power:

$Pm = 0.5\ \rho \times v^3 \times A \times T$ (7)

Tip speed ratio and solidity: Tip Speed Ratio (TSR) is one of the important factors in WT design. TSR refers to the ratio between wind speed and speed of the tips of the WT blades. TSR maximizes power output and efficiency of WT.

$$TSR = (\text{Tip speed of blade})/\mathit{Wind}$$

2.2.1 Wind Rotor Profile:

Drag force and lift force: Lift force is considered as the force that works as perpendicular to the direction of motion. Lift force is very essential for a WT and should be as strong as possible. Lift force can be found as,

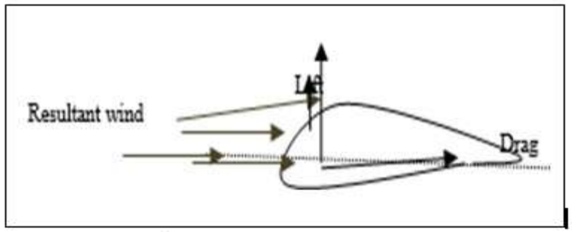


Figure 2.2: Aerodynamic forces on blades

2.2.2 Power and Wind Speed:

The concept is for Wind energy sources the minimum speed is required for WT is about 2m/s only there are many home based wind turbine producing electricity in developed countries and wind turbine blade is about 1 meter for moving locomotive so no need of height. Position of wind turbine should be the area where maximum wind can be captured but should not affect other machinery.

The moving locomotive runs at minimum of 60km/h can produce enough energy to run a small wind generator and that can produce up to several kilo watts. The converters and inverters are needed to use the energy storage and for the next generated vehicles are becoming electrified so it must be large possibility in coming era. According to WT available in market WT of 2m can produce 300W and more of power output when the speed of Wind is about 3.1m/s, which has weight of 200kg that can be easily carried by heavy electric vehicles such as bus and trucks, so energy production become easier.

Due to winds high uncertainty, with regards to small wind turbine installations as well as the power output being a cube function of wind speed. Part of the atmosphere in which all wind turbines operate is called the planetary boundary layer. It is an equivalent of the boundary layer defined in fluid mechanics.

2.2.3: Betz Limit:

The energy from the moving airfoil fall on the blades cannot be transformed to mechanical power. The theoretical maximum power efficiency of any design of WT is 0.59, not more than 59% of the energy carried by the wind can be extracted by a WT) (Martin, 2013). Hence, this factor needs to be addressed properly during the designing of the WT. The Blade Element Momentum (BEM) theory explains the factors related to the control of rotor blades rotating (Muller, Deicke, and Doncker, 2002).

3. SYSTEM DESIGN

The system designing of Locomotive Mounted Wind Turbine needs careful considerations. LMWT has the basic configuration of a Horizontal Axis WT. However, the field of application makes it different from conventional HAWT. LMWT has some additional design criteria over conventional HAWT. Namely, rotor, generator, gear box (optional) and storage system designs are different. Moreover, LMWT has to be light weight, high RPM, highly rigid, low cost unlike conventional designs for the reason that it should carry the WT. The LMWT has to be designed carefully to compromise with these aspects. The direction of the airfoil can either be natural or artificially directed to the rotor. They collide and make a resultant force in a modified direction. This event follows the Bernoulli's Law (Grant, 2005).

A generator is placed on roof of the vehicle and coupled with turbine shaft by a belt. Generator and turbine shaft are connected in parallel and belt is vertically coupled with two shafts. The output terminal of the generator is connected to a storage device (in this case battery). When the vehicle is in motion, the turbine rotates with a significant rpm and produces mechanical torque (i.e. mechanical input) to generator which produces electrical output and stored in the battery of the electric vehicle there by increasing the mileage leads to more use of electric locomotives.

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3.1 Converters and Inverters:

For use of AC generators Converter converts the electricity produced by your wind generator into the DC which can be stored in batteries. The mechanical input depends on the vehicle speed and wind speed. Therefore, a small, lightweight and low cost converter is required to regulate the output voltage level compatible with the storage. Therefore, a simple topology can be a best choice. A buck-boost DC-DC converter is recommended for regulated output (Rizzoli et al., 2014; Camara et al., 2010; Sivaprasad, Jijo, Kumaravel, and Ashok, 2015).

3.2 Storage of Power:

Storage of power can be done directly to the discharged battery in the electric locomotive by converting, by AC which is from the generator and to DC by the converter, then to storage cells. Charging of battery depend on wind speed and power production. When the bank is fully charged, the controller sends energy from the battery bank to a dump (diversion) load. Use only deep-cycle batteries in wind-electric systems. Lead-acid batteries are the most common battery type. Flooded lead-acid batteries are usually the least expensive, but require adding distilled water occasionally to replenish water lost during the normal charging process. Continuous monitoring is required at the control panel.

4. HARDWARE IMPLEMENTATION

Electric locomotive wind turbine installation is the most vital part, and are mainly classified for two types mainly for electric bus and electric trucks:

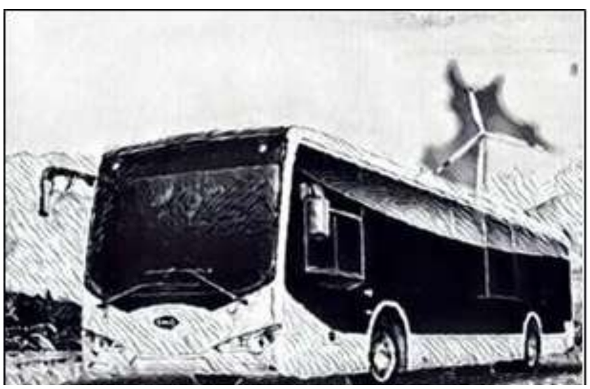

Figure 4.1: WT of front side of LMWTFigure 4.2: WT of back side of LMWT

(a)for bus this can be installed in back side or front side and there should be a support which comes from chassis of vehicle that can carry the WT thus the flow of wind can be adjusted, (b)for electric trucks the implementation is on the front cabin can be done. The output be directed to the battery storage, for the charging of the battery and also connected with a protective device to protect from over charged.

4.1 Blades and Turbine:

Blades have importance due to the width of the vehicle they cannot be inside vehicle limits. Materials such as glass fiber reinforced plastic (GFRP), carbon fiber reinforced plastic (CFRP), steel and aluminum is the new technology of manufacturing blades. The criteria for designing the blades are to provide high RPM, moderate torque, high tolerance and light weight. Hence, twisted blade is the first choice. However, twisted blades possess high cost. Therefore, modified half twisted blades are used to meet the requirements. The maximum diameter of WT should be 1.75m, and should be low weighted. Carbon fiber reinforced load-bearing spars can reduce weight and increase stiffness. Blades are assembled to form turbine, blades are connected to a disc and screwed. Disc is connected to shaft of the generator by metal pipes. According to design considerations, three blades are more efficient. The ratio of the rotating blade tip speed and the undisturbed wind velocity at hub height is one of the most important para- meters to be decided when designing the blades.

4.2 Mounted type Generator:

The mechanical output of a wind turbine can vary a lot, from 0 to a maximum based on maximum power point tracking (MPPT) method. Therefore, the choice of the generator is to be very efficient. Hence, a permanent magnet DC (PMDC) motor as generator is the best choice to capture the output of the turbine. This type of generator is very sensitive to rotation and able to give feedback at very low mechanical input.

Figure 4.3: Vehicle speed versus Power (w)

Generator	Blades	Turbine
PMDC Generator Input: 180V/5A	Length: 0.80 m Width: 0.24 m Total blades: 3 Orientation: Central	Swept area: 1.8 m Length: 0.65 m Type: HAWT Tail: No

Table 4.1: Different parameters

5. CONCLUSION

Every reaction has an equal and opposite reaction, here the wind energy that we can easily access while moving in a bus or truck at a faster speed is collecting and re-generation of power done to increase the efficiency of system by converting them into a small electric power without much losses. A suitable system for wind energy collection with a vehicle is proposed in this paper called vehicle mounted wind turbine (LMWT). Moreover, LMWT has a cheap installation cost and nearly zero maintenance cost. From theory it is conformed that, by LMWT up to 300 W of electricity is acquirable from a single vehicle (< 80 km/hr). With proper conversion technology, this power can be stored easily for its own use. Nevertheless, some drag force is originated evidently. Hence, it is recommended to follow the Betz limit of efficiency properly. In conclusion, with proper design LMWT can be an efficient source of small scale electricity for domestic and portable purposes. However, a hybrid energy harvesting system for vehicle is our future time.

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