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A Proposal for Implementation of Wind Energy Harvesting System in Trains

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Abstract **–Energy resources in our modern fast paced techno-world is fast depleting. Hence a renewable energy source is much required at the moment. Thus researching new and innovative systems in renewable energy sector is an indispensable prerequisite. This paper attempts to propose a model for generating clean energy by harnessing the power of wind in moving trains. The scope of this paper concentrates on a new approach to harvest wind power by installing a conical shaped ducted turbines on the roof of the trains which are coupled to a generating unit. Another auxiliary system is also installed that sucks in air through a tunnel like shroud and compresses it. The compressed air is stored in pressure conduits or an agitation tank that maintains the turbine speed at the desirable rate during fluctuations in train speed or wind potential at the inlet turbine. To complement this approach, CFD simulated results are used investigate the design profile of the proposed model. The conclusion thus obtained proves the efficiency of the system to harness large scale power in a sustainable manner.**

Key words-train power; clean energy; electricity; alternate energy; ducted turbines; wind energy etc.

I. INTRODUCTION

The world is a resident for about 7 billion people which will be 9 billion shortly.1/3rd of the population i.e., 2.3 billion people have no access to electricity. Moreover, world's fuel needs are largely met by fossil fuels that are costly, finite and non eco-friendly as it pollutes the environment and are exhausting at a very faster rate. Hence conservation and tapping of energy from new sources is much needed aspect all over the world. Renewable energy systems on a large scale are an important step for keeping national and international infrastructures intact, it's also important to understand the scalability of renewable energy solutions.

It is widely known and accepted that wind and solar power are the most sustainable energy sources that is available in abundance. New improved innovative methods to harness their power are much appreciated in the present decade. The major predicament in extracting the power from wind is its variations in velocity. This paper explains a novel concept plan that harvests the wind power from moving trains. The idea of large scale energy harvesting from trains is very fascinating. India has about 63000 route kilometers of railways and 14,300 trains running every day. Indian railways can generate 1,481,000 MW power every day according to calculations [2] when train runs, the alternative pattern of wind energy produces around the train is very unique, if the wind is properly directed towards the blades, optimum energy can be generated.

II. POWER POSSIBBLITIES IN TRAIN

The train is an entire hub of energy source that can be harvested to supply power to the grid, distributed systems, standalone load supply or to power up the supply head for local trains and to meet the daily power requirements of the railway system. Indian railways spend 17 percent revenue on the fuel head which is roughly 15000 Crores (150 billion) per annum. There are three possible methods to produce power in a moving train, namely wind, solar and human excreta. When the train runs at an average speed of 50-60 km/hr, it creates an air pressure in the opposite direction. It compresses the air in the front of it and pushes it to its sides, thereby creating a vacuum at its rear and sides as it moves forward. To fill up this vacuum a mass of air flow rushes into the sides and rear of the train. The kinetic energy thus created by the wind flow induced by the train can be effectively utilized to generate power on a large scale [1] [2]

Next method is to integrate solar modules into traditional roof materials of train in order to generate clean energy [2]. Although this method promotes effective use of roof space, it does have its own disadvantages like dust deposition, high capital investment, extensive maintenance etc. The third method is to utilize the vast quantity of human waste to produce energy instead of disposing it along the tracks. Bio degradable waste undergoes a process of anaerobic digestion after which they are subjected to induction heating. This produces methane gas which can power the methanol fuel cells. This paper technically concentrates on power production by utilizing the wind velocity in moving trains by using set of wind turbines and air suction system to complement their standby operation at varying speeds of wind.

TABLE I. LIST OF SYMBOLS USED

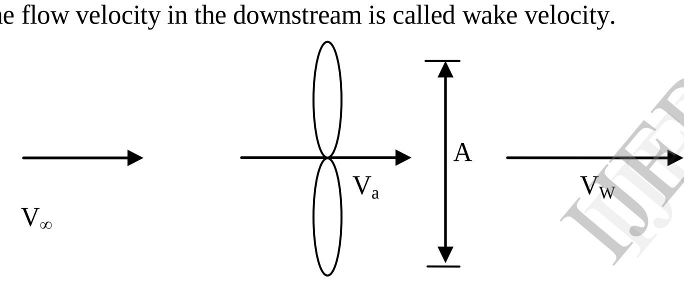
Symbol	Meaning	Unit
m	Mass of low rate of air	(kg/s)
V_w	Wake velocity	(m/s)
V_∞	Free stream velocity	(m/s)
V_a	Induced velocity	(m/s)
P_{max}	power	(watt)
W_T	Power output from air stream	(watt)
A	Swept area of rotor	(m^2)
R	Radius of the turbine	(m)
D	Diameter of the turbine	(m)

$K.E$	Kinetic energy	(J)
ρ	Density of air	(Kg/m^3)
λ	Tip speed ratio	
K	Turbine resistance coefficient	
δ	Pressure coefficient	
C_p	Power coefficient	
C_T	Torque coefficient	
C_V	Velocity coefficient	

III. BASIC THEORY OF WIND TURBINE

W.J.M. Rankine and W E Fraude established simple momentum theory for application in the shipped propeller. Later, A .Betz of the institute of Gottingen used their concept to the windmill [4].

When wind flows across a wind mill, the flow is retarded in the downstream side of the windmill. The flow velocity through the windmill is usually called induced velocity and the flow velocity in the downstream is called wake velocity.



According to Newton's second law of motion the thrust developed in the axial direction of the rotor is equal to the rate of change of momentum i.e.

Axial thrust = $m(V_\infty - V_w)$ (1)

Where m is the mass of the air flowing through the rotor in unit time.

Therefore the power produced is given by

$$P = m\,(V_\infty - V_w)\,V_a \quad (2)$$

The rate of kinetic energy change in the wind is,

$$\Delta K.E/\sec = \tfrac{1}{2}(V_\infty^2 - V_w^2) \quad (3)$$

Equating (2) and (3),

$$m\,(V_\infty - V_\omega)V_a = \tfrac{1}{2}\,m(V_\infty^2 - V_w^2) \quad (4)$$

After simplifying equation (4), we obtain

$$V_a = \frac{V_\infty - V_w}{2} \quad (5)$$

Gauert determined the identical expression in his actuator disc theory.

Here the flow is assumed to occur along axial direction of the rotor and velocity is uniform over the swept area, A of the rotor.

Since,

$$m = \rho A V_\infty$$

From the equation (2), Power extraction at the rotor,

$$P = \rho A V_a (V_\infty - V_w) V_a \quad (6)$$

Where, ρ is the density of air, substituting the value of V_a from equation (5) in the equation (6)

$$P = \rho A V_a^2 (V_\infty - V_w) = \rho A \left(\frac{V_\infty + V_w}{2}\right)^2 (V_\infty - V_w) \quad (8)$$

This can be rewritten as,

$$P = \rho A V_\infty^3 \left(1 + \frac{V_w}{V_\infty}\right)\left(1 - \left(\frac{V_w}{V_\infty}\right)^2\right) \quad (9)$$

$$let\ \frac{V_w}{V_\infty} = x$$

Therefore equation (9) becomes,

$$P = \frac{\rho A V_\infty^3}{4}(1 + x)(1 + x^2) \quad (10)$$

Now differentiating P of the equation (10) with respect to x and setting it to zero for maximum power, one obtains

$$x = \frac{V_w}{V_\infty} = \frac{1}{3} \quad (11)$$

By simplifying, the expression for maximum power is obtained as,

$$W_{Tmax} = \frac{8}{27}\rho A V_\infty^3$$

$$W_{Tmax} = \frac{1}{2}\rho A V_\infty^3 \cdot C_p$$

$$C_P = 0.59 \quad for\ ideal\ turbine$$

Here mass of air flowing through the blades has been assumed to be ideal.

A German physicist Albert Betz concluded in 1919 that no wind turbine can convert more than 59.3% of the kinetic energy of the wind into mechanical energy turning a rotor. This is known ad Betz limit [7].This is called power coefficient C_P.

The C_P value is unique to each turbine type and is a function of wind speed that the turbine is operated in. Hence we need to concentrate on improving the power efficiency or power coefficient factor to improve the available maximum power that can be converted into usable electricity.

A. WIND POWER CALCULATION WITHOUT SHROUDS

The energy available at the turbines at the cut in speed can be calculated as follows

$$W_{Tmax} = \frac{1}{2}\rho A V_\infty^3 \cdot C_p$$

Let's assume the density of air ρ at 20◦c at sea level, $\rho = 1.2\ Kg/m^3$

A= πR^2 =3.14×0.25^2= 0.19 m^2

When the train runs at an average speed of 60 Km/hr.

V_∞ = 16.7 m/sec

Hence by substituting the above values, we get the maximum work output as

$$W_{Tmax} = 314\ watts$$

By the time we take into account the other factors in a complete wind turbine system e.g. the gearbox, bearings, generator, and mechanical loading effect and so on, the power available is further reduced. In this paper we shall concentrate on improving the efficiency of the system by using ducted turbine, better gearbox system to reduce the mathematical loading effect on the turbine.

IV. SYSTEMATIC DIAGRAM OF THE PROPOSED MODEL

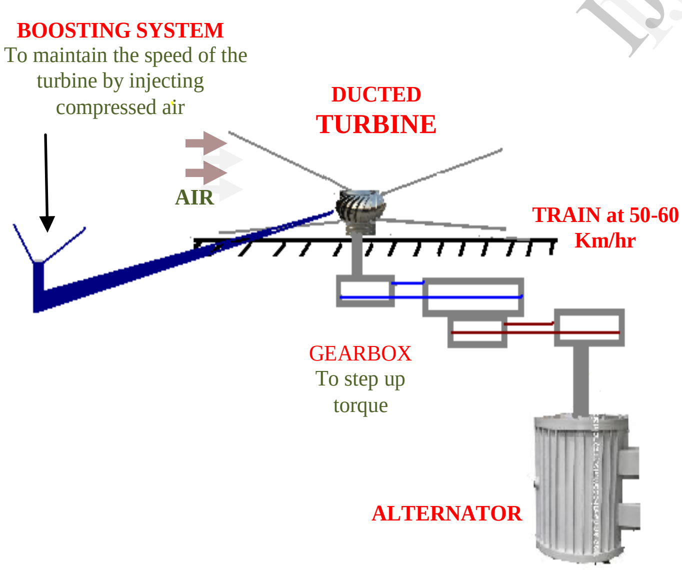


Figure 1. Proposed model

When the train starts to move, the turbine starts to rotate, the converging section of the conduit increases the actual induced velocity of the wind over the blades. With the additional wind velocity and improved turbine design, there is a significant increase in the power that can be extracted from the turbine from the suggested design. The ducted and multi-bladed turbine overcomes many difficulties that are faced by the conventional models. This rotation is then transferred to a specially designed gearbox system that steps down the speed and increases the mechanical torque of the system to avoid mechanical loading effect over the turbine. This is then coupled to the rotor shaft of the alternator. Another feature of the proposed model is the boosting system. The train speed is never a constant, it varies with places hence to have a constant input speed, and we use an auxiliary system that sucks the air, compresses it with a set of impellers and stores it in an agitation tank. When the speed of the train or the major input speed is below the desired level then a governor sets the boosting system to inject high pressure air through a gun nozzle over the turbine to maintain the speed of the turbine rotation. Hence large amount of power can be produced, which can be connected to the grid or power up local lads. In the next section, the ducted turbine design, gearbox designs are detailed.

V. WIND TURBINE DESIGN

The proposed model uses vertical axis wind turbine (VAWT). Reasons for selecting VAWT over horizontal axis turbine (HAWT) are given below.

- HAWT type turbines installed over the train obstructs the train's forward motion by exerting a force against their propelling.
- HAWT also loads the generating system and cannot easily function at high velocities of the moving train.
- High thrust developed over horizontal axis turbines develops fatigue loads.
- The wind energy developed excessively during train's propulsion is concentrated on the surface thrust of horizontal axis turbines, so the useful power input is lost.
- The self starting capability and starting torque of VAWT is high
- One of the major advantages of VAWT in train implementation is that it can work on wind force from any direction, even when the train goes on reverse direction. Whereas HAWT requires shifting blades according to the direction of the wind, hence a system needed for this direction change is excluded in case of VAWT.

Improvisation in technology has made VAWT designs much efficient and easy.

Figure 2. Different VAWT turbine types proposed.

We know that the total power obtained is governed by the C_P factor.

$$W_{Tmax} = C_P * P_{max}$$

C_P is the power coefficient that affects usable potential at the turbine. Hence the prime objective of this study is to improve this factor so as to increase the efficiency by using different turbine design. The remarkable feature of this paper is the use of encasing for the turbines called ducts or otherwise known as shrouds. A conical shaped duct is installed in the upstream inlet junction so as to obtain increased wind velocity at turbine inlet.

An optimum multi-bladed convergent inlet, divergent outlet shrouded wind turbine design has aerodynamic advantages than the conventional bladed ones. A converged inlet duct is used to accelerate wind speed, this high dynamic pressure is exerted over the turbine blades and the high cut in pressure is incorporated with a diverged tail section along the downstream for adjusting the turbine exit pressure to get high input.

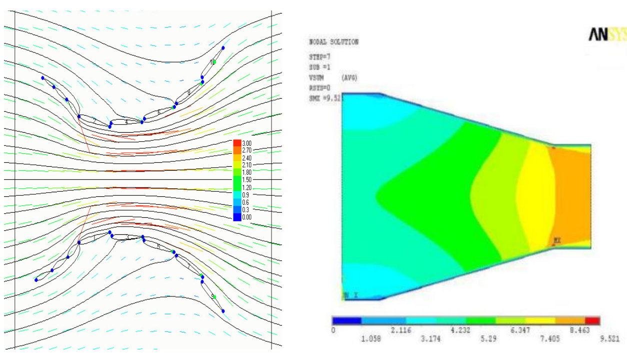


Figure 3. Simulation results of pressure variation and air flow dynamics inside a duct.

The numerical and experimental results have proved that ducting decreases torque fluctuation of the vertical axis turbine significantly, especially at high tip speed ratio [6]. Frankovic and vrsaloric estimated that the efficiency of the ducted wind turbine could be raised 3.5 times while the area of the inlet was 3 times of minimum section. Hence researches, experimental and stimulated analysis study have been made to improve the C_P [8].

Power extracted from the air stream is given by

$$W_T = \rho A V_W \left[\frac{\delta V_W^2}{2} - \frac{V_W^2}{2C_V^2}\right] \quad (1)$$

Differentiating equating (1) with respect to V_W gives the maximum conditions.

$$V_W = C_V \sqrt{\frac{\delta}{3}} V_\infty \quad (2)$$

Substituting in equation (1) gives maximum power output

$$W_{Tmax} = \frac{C_V}{3\sqrt{3}} \rho A \delta^{3/2} V_\infty^3 \quad (3)$$

We know

$$W_{Tmax} = C_P \cdot P_{max}$$

$$P_{max} = \frac{1}{2} \rho A V_\infty^3$$

Therefore the power coefficient is given by

$$C_P = \frac{2}{3\sqrt{3}} C_V \delta^{3/2}$$

The power output component is therefore a function of the duct velocity coefficient (C_V), the operating area and free stream velocity of the wind V_∞.Experimental analysis [9] has shown C_V to be close to 1.0

Hence we find that ducting the turbine significantly increases the C_P factor thus increasing the power output of the turbine.

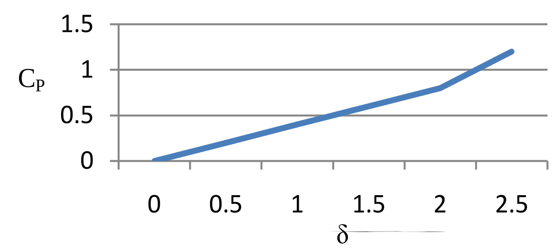


Figure 4. Variation of power coefficient with pressure coefficient

An optimum multi-bladed system is provided to increase the efficiency of the turbine effectively. It increases the starting torque, reduces cut in speed and provides better blade area to transfer the downstream wind [5]. Hydro dynamic experiments of ducting a vertical axis turbine shows that it can significantly increase the power output of the turbine by about 70% increase in power coefficient. Fluid dynamics remain same for hydro and aero dynamics. An important factor that contributes to the turbine design for implementing in train is the tip-speed ratio (λ). For any wind turbine, the tip-speed ratio is defined as the ratio of the speed at the tip of the turbine blade, to the wind speed. TSR is denoted by λ, in terms of rotational speed (ω) of the turbine blade, wind speed (V_∞) and rotor radius R.

$$\lambda = \frac{2\pi R\omega/60}{V_\infty}$$

Arifujjman calculated a model for C_P as a function of λ and generated a curve [10]. Statistical analysis showed that predicted model for C_P with fitted coefficient was acceptable. The resulting equation was found to be,

$$C(\lambda) = C_P = 0.00044\lambda^4 - 0.012\lambda^3 + 0.097\lambda^2 - 0.2\lambda + 0.11$$

Hence plotting the values of λ will result the following curve

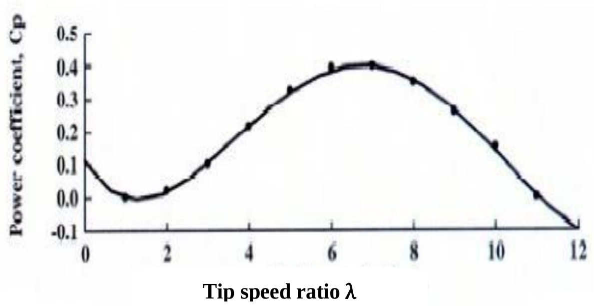


Figure 5. Variation of Power coefficient with TSR

Therefore to obtain higher power efficiency factor we chose the λ value for greater value of C_p to design the turbine, according to the generator's requirement.

Sheng-Huuan Wang and Shih-Hsiung Chen concluded in their study by computational fluid dynamics technique, that increasing the number of blades increases the torque coefficient but plays a reducing role over the power coefficient. Appropriate blade design is needed to match the generator performance and power requirement. Here the power coefficient is found to decrease because of the blockage and lowering of blade entrance velocity. As we use a ducted design it is possible to avoid the blockage by effective and efficient design process.

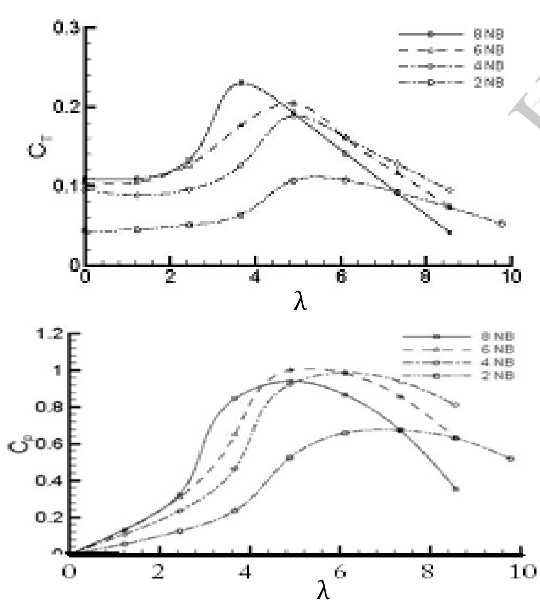


Figure 6. Variation of C_t and C_P with λ for differeent number of blades.

The incident and stragger angle of the fin can be varied by designing an optimum incident angle of the duct conduit and creating side space to allow more wind passing through the duct. Thus we can obtain maximum power coefficient and torque coefficient by intelligent designing of the ducted turbine.

VI. MAXIMUM POWER AVAILABLE AT THE DUCTED TURBINE

Shrouding the turbine increases the velocity and pressure of the incident induced velocity (V_1) at the blades. C.J Lawn in his study concludes that the pressure coefficient is high when the turbine resistance coefficient K is low [11].

$$K = \frac{P_a - P_W}{\frac{1}{2}\rho V_\infty^2}$$

$$C_t = \frac{P_\infty - P_W}{\frac{1}{2}\rho A V_\infty^2}$$

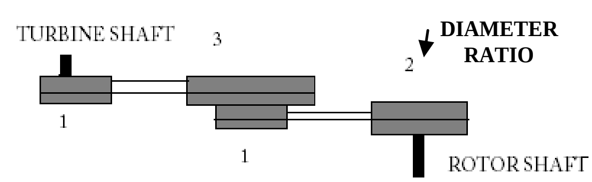
$$C_P = \frac{\eta K}{\left(K/_4 + 1\right)^3}$$

Therefore that the power output at the turbine is considerably increased.

We have increased the incident velocity at the turbine V_a and the power coefficient C_P by efficient design process, thus increasing the potential available.

VII. GEARBOX DESIGN

The proposed model uses a special gearbox system that is design to step down the available rotational speed and step up the mechanical torque. If the turbine is directly coupled to the generation system, the electrical loading on the generator will have a mechanical impact over the turbine in the reverse direction, a blocking torque will be produced so it is indispensible to design a gearbox system that steps up the torque input to the rotor shaft.



The design of the gearbox is very unique that steps up the torque. Let's assume that we obtain a high rpm prime input, this is given to a 4'' diameter gear and it is coupled to another gear that is three times its diameter. Hence three rotations made by gear 1 will induce one rotation in gear 2. As gear 2 is a heavier body it can drive gear 1 without much work, thus we step up the torque three times of that which is available. This system is directly coupled to a three times smaller gear or a similar gear as 1 to transfer the speed to that gear but with a higher torque. This gear 3 is again coupled to another gear that is twice its diameter; hence the torque is again increased doubly. Therefore a significantly increased torque-rotation is given as input to the rotor shaft of the generator with decreased speed. This can be varied according to the input requirement of the generator.

VIII. AUXILIARY BOOSTING SYSTEM

The proposed model consists of an auxiliary boosting or standby system. The speed of the input turbine is maintained at the desired level by using this model. Train speed is subjected to fluctuations and so is the prime mover input. To have a constant steady input we have the supporting unit attached with main system. This unit consist of a suction duct that sucks the air when the train moves, or it is positioned in such manner that the opposing wind flow is naturally forced into the duct which consist of a conduit with impellers under compression system. Then compressed air is stored in agitation tank or conduit. This high pressure air is injected at variable speeds as the turbine input by using a gun like mechanism to maintain the desired speed even during the slow motion of the train; this is carried out by using an electronic governing system. Thus we have a steady, high speed, fluctuation less high torque input to the generator to produce large scale power output.

IX. APPLICATIONS

This system can be installed in every compartment of the train. The proposed model is capable of producing five times more power than any traditional conventional system. Hence each unit step can produce up to 900 watts power. A train on an average has about 15 compartments; therefore every train is capable of producing 13.5KW power, where the speed of the train is considered to be average. Hence it is evident that the system is capable of producing very large power if implemented. This can be used to power up the local loads, to meet the power requirements in the train – to charge the batteries to run fans, lights etc. The harnessed energy is an uninterrupted form as it has an auxiliary boosting unit and so it can be connected to the grid. The produced power can also be supplied to the power heads of the suburban trains and to meet the private power requirements in offices, hospitals, stations, housings etc. Thus we see that the wind energy available in the train can be harvested on a very large scale.

X. DISADVANTAGES

Although the proposed model proves to work more efficiently to produce high power output, it has few disadvantages.

- It has more mechanical parts and may require space. Thus the design and positioning of the system has to be carried out to reduce the space requirement.
- This system requires high capital cost investment but once invested it can work on, and the output obtained thereafter has greater efficiency than the conventional self generation system used in trains.
- It does not require frequent maintenance but it has to be maintained once a while to assure proper working.
- The ducts installed on the train roof can obstruct trains forward propulsion and hence the train might require a higher fuel than it usually uses.

XI. CONCLUSION

Free accessible energy can be created with the help of this work, which can cater to the growing demands of power all over the world. Such a high power output from trains is really appreciated as it can significantly reduce the power shortage and light up numerous homes in the long run. Thus an alternate renewable green energy in a larger scale is provided by the proposed model. Although the idea of wind power from train persists, this research innovation presents a clean picture with adequate analysis and results to support the concept. India has one of the world's largest railway networks comprising 115,000 km of track over a route of 65,000 km and 7,500 stations and this system can bring about a positive and incredible change in India's power production. The effectiveness of the system has substantially a higher competency over any other conventional wind power system that can be used. This produces sustainable power and is environment friendly as it has no pollution consequences. Therefore positive ramification of this entire research is manifold and will tend to alleviate the major energy crisis problems faced all over the world.

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