Harnessing Wind Energy via Wind Generated on Moving Train

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Abstract— The aim of this work is to generate free electricity for general use, through wind energy which is created due to the motion of trains. This is achieved by using a dynamo with adjustments such that it can support a fan and then using it as a small wind turbine. By creating a closely developed arrangement of many such dynamos mounted on the roofs of each compartment of trains, supported by feeding the outputs of all these dynamos systematically to a central electrical transmission line, we can feed all the energy produced to a battery for further use. 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 project attempts to propose a model for generating clean energy by harnessing the power of wind on moving trains by installing a windmill on the top (roof) of train and then coupling it with a dynamo. The energy generated through the rotation of the blades is stored in a battery.

Key words: Dynamo, Harnessing, Electricity, Motion of trains, Battery, Depleting

I. INTRODUCTION

Wind energy has been used for several purposes throughout history. It has been used in such ways as food production, draining lakes and marshes, pumping water for farms and ranches, and eventually to generate electricity for homes and industry (U.S Department of Energy: Energy Efficiency and Renewable Energy). The purpose of using wind energy is because the human race is always looking for ways to become more efficient in energy production that minimizes cost and maximizes efficiency."

The aim of this work is to generate free electricity for general use, through wind energy which is created due to the motion of trains. This is achieved by using a low friction ball bearing sensitive dynamo (24V, 1500mA, 20W) with adjustments such that it can support a blade and using it practically as a small wind turbine. The vertical axis wind turbines are mounted on the roof of a train. By creating closely developed arrangements of many such dynamos on the roof of trains and, by feeding the outputs of all these dynamos systematically to a central electrical line of a train compartment, we can feed all the energy produced to the battery of the compartment.

Wind energy is one of the fastest growing source of electricity and also one of the fastest growing markets in the world today. The growth tends to be linked with the multi-dimensional benefits associated with wind energy such as green power, sustainable, affordable and economic development.

II. PROBLEM IDENTIFICATION

- Fast depletion of non-renewable energy sources.
- Excessive usage of non renewable energy fuel by the Indian Railways.
- Absence of an alternative source of clean energy to power trains.
- Conventional windmills creates excessive drag on trains.
- Indian Railways has a huge carbon footprint which needs to be reduced.

III. TYPES OF BLADES

A. *Horizontal Axis Wind Turbine:*

Horizontal-axis wind turbines (HAWT) have the main rotor shaft and electrical generator at the top of a tower, and must be pointed into the wind. Small turbines are pointed by a simple wind vane, while large turbines generally use a wind sensor coupled with a servo motor. Most have a gearbox, which turns the slow rotation of the blades into a quicker rotation that is more suitable to drive an electrical generator.

Any solid object produces a wake behind it, leading to fatigue failures, so the turbine is usually positioned upwind of its supporting tower. Downwind machines have been built, because they don't need an additional mechanism for keeping them in line with the wind. In high winds, the blades can also be allowed to bend which reduces their swept area and thus their wind resistance. In upwind designs, turbine blades must be made stiff to prevent the blades from being pushed into the tower by high winds. Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted forward into the wind a small amount.

Turbines used in wind farms for commercial production of electric power are usually three-bladed. These have low torque ripple, which contributes to good reliability. The blades are usually colored white for daytime visibility by aircraft and range in length from 20 to 80 meters (66 to 262 ft). The size and height of turbines increase year by year. Offshore wind turbines are built up to 8MW today and have a blade length up to 80m. Usual tubular steel towers of multi megawatt turbines have a height of 70 m to 120 m and in extremes up to 160 m.

The blades rotate at 10 to 22 revolutions per minute. At 22 rotations per minute the tip speed exceeds 90 meters per second (300 ft/s). A higher tip speed means more noise and blade erosion. A gear box is commonly used for stepping up the speed of the generator, although designs may also use direct drive of an annular generator. Some models operate at constant speed, but more energy can be collected by variable-speed turbines which use a solid-state power converter to interface to the transmission system. All turbines are equipped with protective features to avoid damage at high wind speeds, by feathering the blades into the wind which ceases their rotation, supplemented by brakes.

B. *Vertical Axis Wind Turbine:*

Vertical-axis wind turbines (or VAWTs) have the main rotor shaft arranged vertically. One advantage of this arrangement is that the turbine does not need to be pointed into the wind to be effective, which is an advantage on a site where the wind direction is highly variable. It is also an advantage when the turbine is integrated into a building because it is inherently less steerable. Also, the generator and gearbox can be placed near the ground, using a direct drive from the rotor assembly to the ground-based gearbox, improving accessibility for maintenance. However, these designs produce less energy averaged over time, which is one drawback.

The key disadvantages include the relatively low rotational speed with the consequential higher torque and hence higher cost of the drive train, the inherently lower power coefficient, the 360-degree rotation of the aerofoil within the wind flow during each cycle and hence the highly dynamic loading on the blade, the pulsating torque generated by some rotor designs on the drive train, and the difficulty of modeling the wind flow accurately and hence the challenges of analyzing and designing the rotor prior to fabricating a prototype.

When a turbine is mounted on a rooftop the building generally redirects wind over the roof and this can double the wind speed at the turbine. If the height of a rooftop mounted turbine tower is approximately 50% of the building height it is near the optimum for maximum wind energy and minimum wind turbulence. Wind speeds within the built environment are generally much lower than at exposed rural sites, noise may be a concern and an existing structure may not adequately resist the additional stress.

IV. BASIC CONCEPTS

The performance of the wind turbine can be explained according to the following three basic rules that are still applicable:

1) The speed of the blade tips is ideally proportional to the speed of wind.
2) The maximum torque is proportional to the speed of wind squared.
3) The maximum power is proportional to the speed of wind cubed.

The performance of any kind of wind turbine can be expressed in the form of torque coefficient (C_t) and the coefficient of power (C_p) versus the tip speed ratio (λ).

A. *The swept area (A_s):*

As the rotor turns, its blades generate an imaginary surface whose projection on a vertical plane to wind direction is called the swept area. The amount of energy produced by a wind turbine primarily depends on the rotor area, also referred to as cross-sectional area, swept area, or intercept area. The swept area for the wind turbine can be calculated from the dimensions of the rotor as shown in Fig (1).

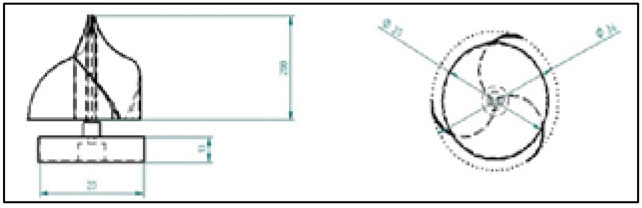


Fig. 1: Dimensions of the rotor.

Thus, the Savonius Area = Swept area = A_s = H * D

Where, H = the rotor height (m)

D = the rotor diameter (m).

B. *The Tip speed ratio (λ):*

The tip speed ratio is the ratio of the product of blade radius and angular speed of the rotor to the wind velocity. The tip peripheral velocity of the rotor (V_{rotor}) is defined as Fig(2)

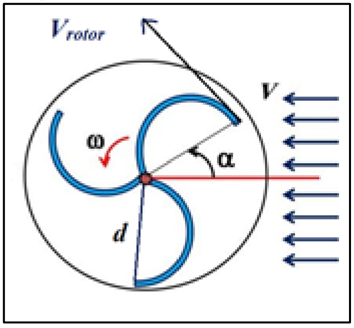


Fig. 2: Scheme of the rotor showing tip velocity.

Where, V_{rotor} = the tip speed (the peripheral velocity of rotor) (m/sec)

ω = the angular velocity of rotor (rad/sec)

d = the inner diameter of the rotor (m).

Now the Tip Speed Ratio (TSR) of a turbine is expressed as:

$$\text{The Tip Speed Ratio, TSR} = \boldsymbol{\lambda} = \boldsymbol{V_{rotor}}/\boldsymbol{V} = \boldsymbol{\omega * d}/\boldsymbol{V}$$

Where: V = the wind speed (m/sec)

The Torque Coefficient (C_t): It is defined as the ratio between the actual torque developed by the rotor (T) and the theoretical torque available in the wind (T_W).

Thus the torque coefficient (C_t) is given by:

$$C_t = \frac{\textit{The rotor torque}}{\textit{The wind torque}} = \frac{T}{T_w} = \frac{T}{\frac{1}{4} * \rho * A_s * d * V^2}$$

Where: Ct = the torque coefficient

T = the rotor torque (Nm)

T_w = the wind available torque (Nm)

ρ = the air density (kg/m3)

Another concept that can used to measure the wind turbine performance is the static torque (T_s), which measures the self-starting capability of the turbine. Static torque is defined as a maximum value of the torque when rotor is blocked i.e. without ability to rotate.

So, the static torque coefficient is given by:

$$C_{ts} == \frac{T_s}{T_w} = \frac{T_s}{\frac{1}{4} * \rho * A_s * d * V^2}$$

Where: C_{ts} = the static torque coefficient

T_s = the rotor static torque (Nm)

The static torque of different angle of attack (α) relative to the wind direction was measured at every (30°) to (360°). Fig. 3 shows angle of attack (α).

The torque is defined as the force acting tangentially over the rotor blade, operating at a distance of rotor radius (d) from the center, it is given as:

$$\boldsymbol{T = I \cdot \alpha}$$

Where: I = the rotor moment of inertia (kgm^2) or (Nms^2)

α = the rotor angular acceleration (s^{-2})

The moment of inertia tells us how much energy is stored in a rotating shaft or about how much energy it will take to accelerate the shaft to a particular velocity. This is called the second moment or moment of inertia and it is equal to:

$$\boldsymbol{dI = r^{2} * dm}$$

Referring to (figure 3), the moment of inertia for a semi-circular blade shape can be calculated according to the following equation:

$$\boldsymbol{Ib = r^{2} * dm}$$

Where: r = radius (the distance of the infinitesimal element of mass from the origin)(m)

= $d * cos\emptyset$ dm = the infinitesimal element of mass (kg)

= $\rho \,.\, H \,.t \,.\, d \,.\, cos\emptyset \; d\emptyset$ t = the blade thickness (m)

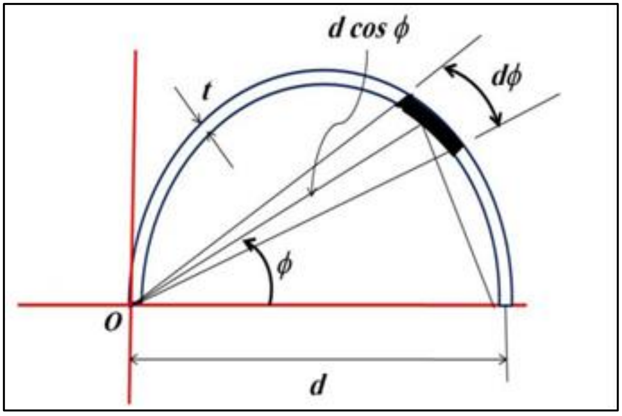


Fig. 3: Schematic drawing for the calculation of moment of inertia.

Therefore, the moment of inertia for one blade (I_{1b}) becomes equal to:

$$\boldsymbol{I_{1b} = \int_{0}^{\frac{\pi}{2}} \rho * H * t * d^{3} * (cos\,\emptyset)^{3} * d\emptyset}$$

$$\boldsymbol{= \frac{4}{3\pi} * m * d^{2}}$$

Where: $m = \pi/2 * \rho * H * t * d$ (kg)

Thus, the moment of inertia becomes:

$$\boldsymbol{I_{3b} = 4\pi m * d^{2}}$$

Thus, the total moment of inertia for the wind turbine is equal to:

$I = I_{3b} + 2I_p + I_s + I_d$

Where: I_b = blades moment of inertia (kgm^2)

I_p = the end plates moment of inertia (kgm^2)

I_s = the shaft moment of inertia (kgm^2)

I_d = the torque measuring disc moment of inertia (kgm^2)

The angular acceleration (α), is given as:

$$\boldsymbol{\alpha = \frac{\omega_2 - \omega_1}{T}}$$

Where: T = the time (sec)

ω_1 = the initial angular velocity (s^{-1})

$\omega 2$ = the final angular velocity (s^{-1})

Power Coefficient (C_p) Analysis: Power coefficient, (C_p) of a wind turbine is the ratio of maximum power obtained from the wind to the total power available in the wind.

This hypothesis shows the relationship between the power coefficient (C_p) and the wind speed (V), which expresses the basic theory of the wind turbine. Principally the power that the rotor can extract from the wind (P_w) is less than the actual available from the wind power (P_a).

The available power (Pa), which is also the kinetic energy (KE) of the wind, can be defined as:

$$\boldsymbol{KE = P_a = 1/2 * m_a * V^2} \text{ (Watt)}$$

$$\boldsymbol{P_a = 1/2 * \rho * A_s * V^3}$$

Where: m_a= wind mass flow rate striking the swept area of the wind turbine (kg/sec)

= $\rho * A_s * V$

But, the swept area,

$A_s = H*D$,

therefore the actual power becomes:

$$\boldsymbol{P_a = 1/2 * \rho * H * D * V^3}$$

The power that the rotor extracts from the wind is:

$\boldsymbol{Pw = T * \omega}$ (Watt)

Where: Pw = the power that the rotor extracts from the wind (Watt).

The power coefficient (C_p) is thus given by:

$$\boldsymbol{C_p = \frac{Extracted\ power\ from\ wind}{Available\ wind\ power} = \frac{P_w}{P_a}}$$

V. MATHEMATICAL CALCULATION OF BLADE PROFILE DESIGN

Let β1 and β2 be the inlet and outlet angles of this blade respectively. Selection of β2 is made generally for an optimum efficiency. An average value of 22.5° is called normal for all specific speeds. The limit of β2 followed in a good design is from 17.5° (minimum) to 27.5° (max). The values for β1 and β2 are selected as 10° and 30°. For smooth flow, the blade must be designed such that this angle increases smoothly from 10° to 30°.

The next step is to construct the blade shape. There are several methods to construct the blade shapes. The one used in practice consists of tangent circular arc.

The radius of the Circular arc contained between the rings R1 and R2 is given by,

$$\boldsymbol{R = \frac{R_2^2 - R_1^2}{2(R_2 \cos\beta_2 - R_1 \cos\beta_1)}} \dots \text{ (Eqn. 1)}$$

(Where, R1 and R2 is the radius of shaft and outer diameter of the blade)

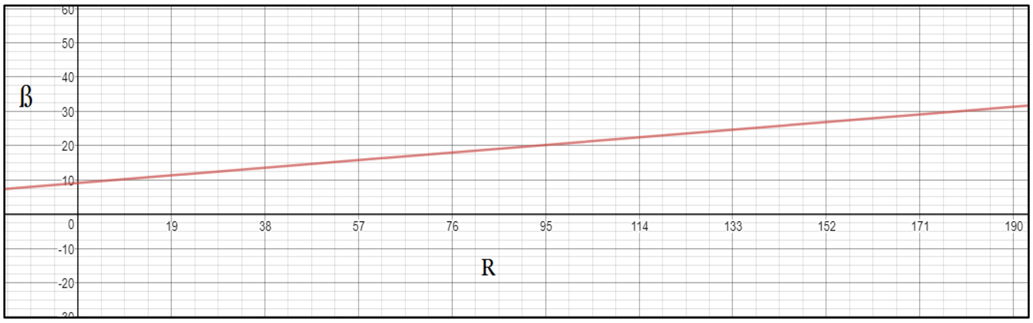
While using this method, the diameter of the blade is divided into a number of concentric rings, not necessarily equally spaced. The value of R for any two consecutive concentric rings is calculated using the equation 1 and blade shape is plotted which is actually an arc tangent to both the rings. An accurate vane shape can be obtained by joining the areas as shown in the proceeding part below:

The radius of shaft diameter (R1) is given by 16/2 = 8 mm.

The radius of outer diameter (R2) is given by 360/2 = 180 mm.

Now, the intermediate values of radius can be found out by (R2-R1)/n, (where, n = number of intermediate concentric rings required.)

For better resolution the value of n is taken as 9. The values thus obtained from eqn. 1 are: 8, 27, 46, 65, 84, 103, 122, 141, 160 mm. Similarly, the corresponding values for the blade angle β can be found out graphically using Graph (1)



Graph 1: R (mm) vs β

Table 1 is constructed showing the calculated values of R1, R2, β1 and β2 for various values of R.

R1 (mm)	R2 (mm)	β1	β2	R (mm)
8	27	10	12.22	17.96
27	46	12.22	14.45	38.20
46	65	14.45	16.67	59.49
65	84	16.67	18.89	82.25
84	103	18.89	21.12	106.99
103	122	21.12	23.34	134.14
122	141	23.34	25.56	164.54
141	160	25.56	27.78	199.13
160	179	27.78	30	239.26

Table 1: The calculated values of R1, R2, β1 and β2 for various values of R.

VI. ANALYSIS AND RESULT

The total numbers of passenger coaches are 70,241 on the end of December 2015.These huge number of passenger coaches can be used to generate electricity by mounting vertical axis wind turbine on the top of each coach. These vertical axis wind turbine can be 5 or more, depending on the area occupied by it. A brief tabulation of expected results is shown in Table 2 below:

Sl. No.	Description	Value
1.	Total number of coaches(2014)	70,241
2.	Number of VAWT on each coaches	6
3.	Total number of VAWT	4,21,446
4.	Power produced by each VAWT in an hour	18 W
5.	Time train is ideal in a day	5 hours
6.	Time train is operational in a day	19 hours
7.	Power produced by each VAWT in a day	342 W
8.	Power produced by 4,21,446 VAWTs in a day	143 MW
9.	Cost per VAWT (mass production)	Rs.1000
10.	Total cost of 4,21,446 VAWTs	Rs.42 Cr
11.	Cost of electricity bought by Indian railway(2014)	Rs.3.7 Cr
12.	Cost of 143MW of electricity	Rs.53 Cr
13.	Profit earned by Indian railway	~Rs.9 Cr

Table 2: Expected Outcome of the Wind turbine setup

VII. CONCLUSION

1) There is a huge potential for producing electricity from Wind.
2) Harnessing Waste Wind Energy from trains and converting them to useful electricity is one way to achieve the target of implementing green energy source.
3) From a single device we can obtain a daily power output of 342W.
4) Alternate source of power supply will help create a greener environment.

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