International Journal of Applied Engineering and Technology ISSN: 2277-212X (Online)
An Online International Journal Available at http://www.cibtech.org/jls.htm
2011 Vol. 1 (1) October-December, pp.119-126/Dwivedi et al.

Research Article

PROPOSED MODEL FOR THE WIND ENERGY HARNESSING SYSTEM IN TRAINS

Ravi Dwivedi[1], *Kshitiz Upadhyay[2], Ankur Kumar Singh[3] and Anant Kumar[4]
[1] *Department of Mechanical Engineering, Maulana Azad National Institute of Technology, Bhopal (M.P), India, 462051*
[2,3]*Department of Mechanical Engineering, Maulana Azad National Institute Of Technology, Bhopal*
[4]*Department of Electrical Engineering, Maulana Azad National Institute Of Technology, Bhopal*
**Author of Correspondence*

ABSTRACT

Wind Energy is a renewable source of energy. Today, the output power from wind turbines can be utilized in two ways, either by direct use of the mechanical shaft power (through a gearing ratio) or by letting the wind turbine power an electrical generator, and utilising the generated power as electrical power. Recent advances in the wind energy harnessing techniques have revealed many modern applications [*Anderson, 2007*]. Battery charging at remote telecommunication stations, domestic heating and lighting, hybrid systems, where a generator is run by diesel are few common examples in the present scenario. It is widely accepted fact that we need to switch on to the non-conventional energy sources. This paper brings a new possibility for the utilisation of the wind generated power, for various electrical components inside a typical railway train through the batteries charged by the wind energy harnessed by a series of wind turbines mounted at the top of the train coaches. This paper deals with the design and development of a wind turbine system with a concept of generation of electricity as an auxiliary source in the train.

Key Words: *Wind Energy, Wind Turbine, Railway Train*

INTRODUCTION

Wind energy is basically the kinetic energy of the moving wind. It is a renewable source and thus, is having far reaching economic value. The use of wind energy as an auxiliary source of energy is the utmost need of the modern society. Wind energy is harnessed by wind turbines, which may be Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT).

Wind turbine technology can be grouped in three applications *[Anderson, 2007]*:

1. Large grid connected wind turbines.
2. Hybrid energy systems combining intermediate size wind turbines with other energy sources such as photovoltaics, hydro and diesel and/or storage used in small remote grids or for special applications such as water pumping, battery charging or desalination.
3. Small “stand-alone” wind turbines for water pumping, battery charging, heating etc.

In this paper, Authors present a new idea of harnessing the wind energy from the moving trains. This can be used to run various electrical components, either simultaneously, or by charging DC batteries which can be used later as a source of electricity. The following sections give a detailed description of this idea along with the proposed blade profile, mathematical model with calculations, electric circuit and its components and the turbine system’s arrangement over the railway coach.

Wind Turbine Design

Turbine type

HAWT (Horizontal Axis Wind Turbine) is used in the proposed system. Reasons for selecting HAWT and not VAWT (Vertical Axis Wind Turbine) [*Tangler, 2000*]**:**

1. VAWT blades are constant chord type blades, which adversely affect blade efficiency and self-start capability.

2. Rotor wake-induced losses of the VAWTs are greater than those of HAWT's since VAWT's only operate at optimum lift-to-drag ratio over a small azimuth of the rotation. This leads to excessive wind energy going into rotor thrust loads rather than useful power output.
3. The highly cyclic power and thrust generated by VAWT rotors also results in higher fatigue loads.
4. VAWT tends to be a lower rpm machine that derives power more from torque than rpm, which results in greater machine weight and cost.

Blade number

Blade number is the number of blades in a given turbine. 3 blade system is proposed for the system. Two main parameters which play an important role in turbine design are solidity and blade number. The solidity is defined as,

$$\sigma = (B \times Blade\,Area)/\pi r^2 \quad ...(1)$$

More is the solidity of a turbine, more torque will be exerted on the blades, which makes the initial starting of the blades easier at low wind speeds. At the same time, the speed of the blades is comparatively less with high solidity design. In the system proposed, the wind speed is high enough. So lesser solidity is desired, which speeds up the turbine blades, increasing the power output. Although it appears that minimizing the number of blades leads to the best turbine design, still in the present day wind turbine community, three blades is preferred to two, to minimize the adverse yaw effects [*Duquette, 2003*].

Tip-Speed Ratio

For any wind turbine, the Tip-Speed Ratio is defined as the ratio of the speed of the tip of the turbine blade, to the wind speed. TSR, denoted by λ, in terms of rotational speed (ω) of the turbine blades, wind speed (v) and the rotor radius (R) is given by,

$$\lambda = \omega R/v \quad ...(2)$$

The relationship between C_p and λ is critical and can be approximated by a quadratic equation. Arifujjaman calculated a model for C_p as a function of λ and generated a curve [*Arifujjaman, 2006*]. Statistical analysis showed that the predicted model for C_p with the fitted coefficients was acceptable. The resulting equation was found to be,

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

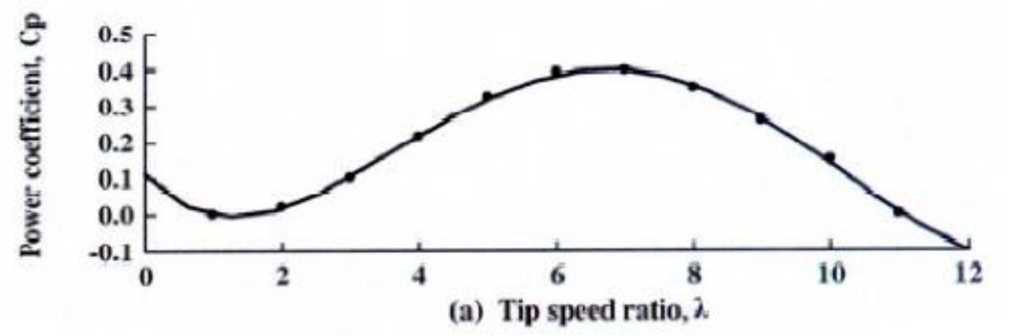

Figure1. Power Coefficient as a function of Tip Speed Ratio (TSR) [*Arifujjaman, 2006*].

Most 3 blade HAWTs operate at a TSR of 5-8.

Turbine Model

The different views of the proposed wind turbine model are shown in the diagrams below,

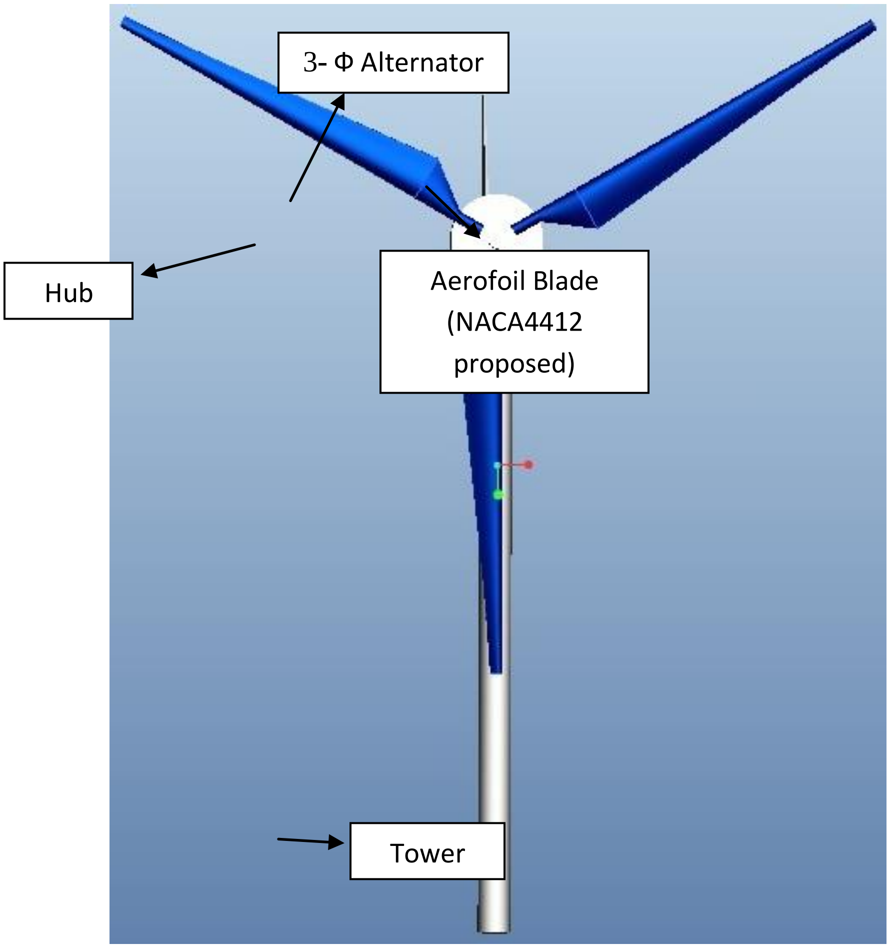

Figure 2. Wind Turbine - Front View.

The wind turbine proposed is basically a gearless turbine in which the turbine shaft is directly connected to the Alternator shaft without any gearbox in between. This type of system is generally preferred in case of small wind turbines. The blades used are aerofoil type with blade profile of NACA44 series, NACA 4412. NACA blade profiles were developed in around 1930s and have good all-round properties, giving a good power curve and a good stall [*Stiesdal, 1999*].

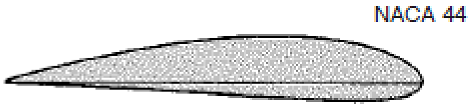

Fig 3. NACA44 Blade Profile. [*Stiesdal, 1999*]

Aerodynamic blades are always preferred over normal flat blades because of excellent aerodynamic properties and lift-drag ratio.

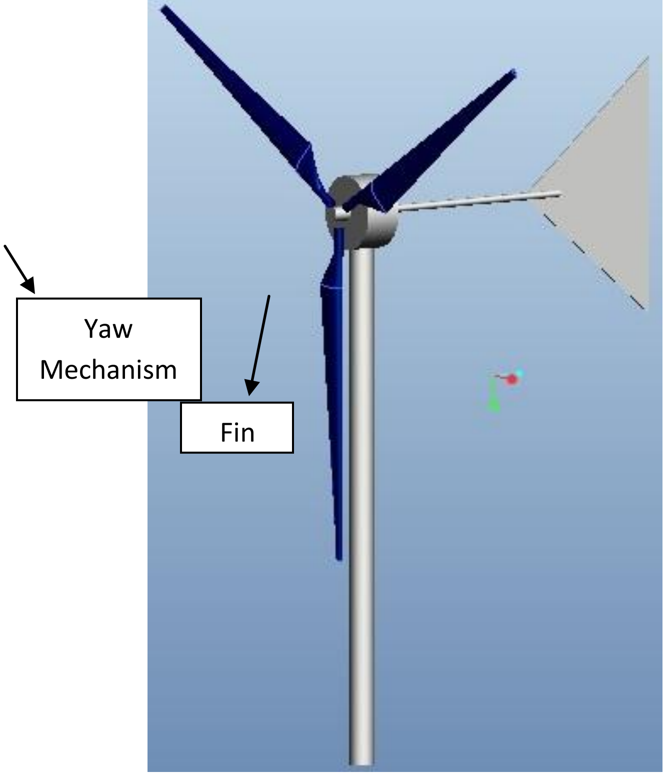

Figure 4. Wind Turbine- Axonometric View

A fin is installed behind every wind turbine to give it the proper direction in case of multidirectional wind flow, and in case, when the running direction of the train changes (when engine shifts its position). The turbine turns about it's axis through the yaw mechanism provided at the turbine-tower joint.

Mathematical Model

The definitions of various variables used in the given model are:

E = Kinetic Energy (J) of the Wind
m = Mass (Kg) of the Wind
v = Wind Speed (m/s)
A = Swept Area (m^2)
P = Power (W)
C_p = Power Coefficient
r = Radius (m)
ρ = Density of Air (Kg/m^3)
t = Time (s)
dm/dt = Mass flow rate (Kg/s)
dE/dt = Energy flow rate (J/s)
x = Distance (m)

Under constant acceleration, the kinetic energy of the wind is given by,

$$E = \frac{1}{2} m v^2 \quad \ldots (4)$$

The power in the wind is given by the rate of change of energy,
At a particular point of time when wind speed is v,

$$P = \frac{dE}{dt} = \frac{v^2 \left(\frac{dm}{dt}\right)}{2} \quad \ldots (5)$$

The mass flow rate of wind is given by,

$$\frac{dm}{dt} = \rho A \frac{dx}{dt} \quad \ldots (6)$$

And the rate of change of distance is given by,

$$\frac{dx}{dt} = v \quad \ldots (7)$$

We get,

$$\frac{dm}{dt} = \rho A v \quad \ldots (8)$$

Hence, from the equation, the power can be defined as,

$$P = \frac{1}{2} \rho A v^3 \quad \ldots (9)$$

A German physicist Albert Betz concluded in 1919 that no wind turbine can convert more than 16/27 (59.3%) of the kinetic energy of the wind into mechanical energy turning a rotor. This is known as the Betz Limit or Betz' Law [*Fink, 2005*]. The theoretical maximum power efficiency of any design of wind turbine is thus 59%, i.e. no more than 59% of the energy carried by the wind can be extracted by a wind turbine). This is called the Power Coefficient, and is defined as,

$C_{p_{max}} = 0.59$

Also, the wind turbine cannot operate at this maximum limit. So,

$C_{p_{max}} \leq 0.59$

The Cp value is unique to each turbine type and is a function of wind speed that the turbine is operating in. Once we incorporate various engineering requirements of a wind turbine – strength and durability in particular – the real world limit is well below the Betz limit with values of 0.35-0.45 common even in the best turbines. Hence the extractable power of the wind is,

$$P_{avail} = \frac{1}{2} \rho A v^3 C_p \quad \ldots (10)$$

If η_g be the efficiency of the generator, C_{pg} is the efficiency of the turbine-generator system.

$$P_{net} = \frac{1}{2} \rho A v^3 C_{pg} \quad \ldots (11)$$

Calculations Based on Proposed Data

For the real life running railway train, we take,

V_{avg} = 60 Km/hr = 16.67 m/s
r = Blade Length = 10 cm = 0.1 m

$A = \pi r^2 = \pi \times (0.1)^2 = 0.0314\ \text{m}^2$

ρ = Air Density = 1.23 Kg/m^3 at the sea level.

Taking efficiency, C_{pg} = 0.20, for a typical 3 blade wind turbine (From Fig 1.)

$$P_{net} = \frac{1}{2}(1.23 \times 0.0314 \times 16.67^3 \times 0.20)$$

$$P_{net} = 17.89\ Watts \quad \ldots (12)$$

The power output predicted is 17.89 Watts from one turbine.

In the proposed model, for a typical railway coach of 21.3 m length and 3.25 m, the turbine blades are arranged in 9 rows, in groups of 3. The figure below shows the arrangement of turbines in the proposed model.

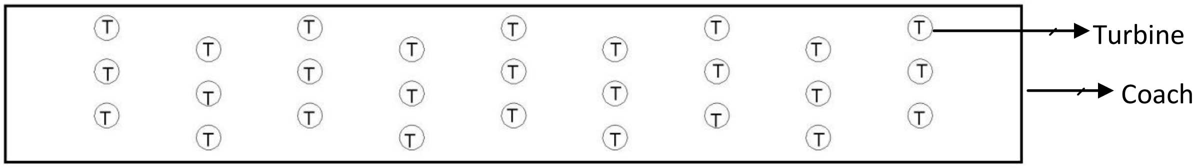

Figure 5. Arrangement of Wind Turbines over the coach - Top view (27 Turbines).

Using the net power output from a single turbine, we can calculate the power output from a system of 27 turbines, as proposed in the system. The net power output from a coach will be,

$P_{Total} = 17.89 \times 27$

$$P_{Total} = 483\ Watts \quad \ldots (13)$$

Electrical System

The electrical system is the system of electrical devices which will generate the electricity from the rotational energy of the turbine shaft. The system consists of a 3 phase Alternator, which produces a 3- Φ AC current of voltage rating between 13.5-14.8 V [Masters]. This 3- Φ AC current is rectified by a 3- Φ Rectifier in series with the alternator. The rectifier produces DC current which is fed into the 12V battery through a switch. The battery is then connected with an Inverter which converts 12V DC supply to 110V AC current which will run the electric components inside the train. Given below is the block diagram of the proposed system,

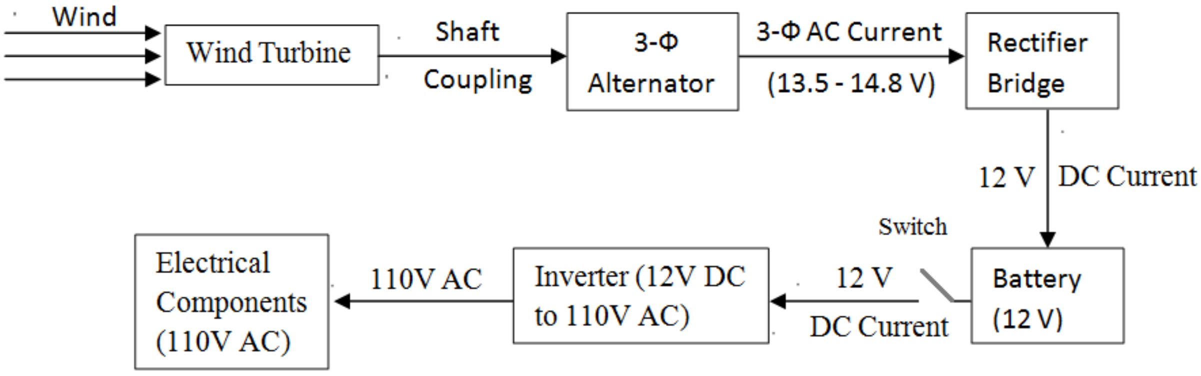

Figure 6. Block Diagram of the Proposed System.

The electric circuit for the alternator and rectifier bridge circuit is given below

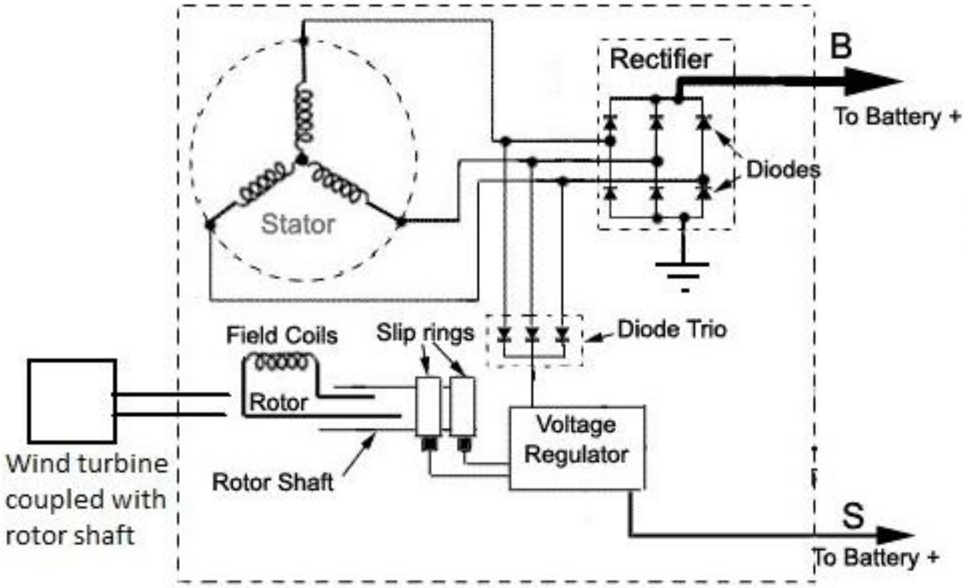

Fig 7. Electric Circuit diagram of the Alternator-Rectifier circuit.

RESULTS AND DISCUSSION

The proposed idea has got the following applications:

1. The estimated power output from the alternator is 483 Watts (Eq. 11.). For a typical railway SL coach, we generally have 9 compartments. The proposed design (Fig 2.) shows that 27 turbines are to be installed over one coach, 3 over each compartment to cater the need of internal electrical system in the coach. Since the ratings of a typical tube-light installed inside the railway coach are 110V AC-20W. So, for a single tube-light, we require,

$P_{tube} = 20\ Watts$

For a typical SL coach, 2 tube-lights are installed for each compartment, thereby making a sum of 18 tube-lights over the entire coach. So, the total power required by the tube-lights to run properly is,

$P_{req,tube} = 20 \times 18\ Watts = 360\ Watts$

For a typical SL coach, 3 ceiling fans are installed for each compartment, thereby making a sum of 27 fans for the entire coach. The ratings of a typical railway ceiling fan is 110V AC-60W. So, the total power required by the fans to run is,

$P_{req,fan} = 60 \times 27\ Watts = 1620\ Watts$

The power made available by the wind turbine system is,

$P_{avail} = 483\ Watts$

After the detailed calculations, the results show that even after lightening up all the tube-lights inside the coach, an additional 123 Watts of harnessed energy is left, which can be utilised for running two fans (60W-110V AC), or providing with some extra facility for mobile chargers, which has become an utmost need of a contemporary passenger.

The first application is thus, the running of the electrical components inside the railway coaches through the simultaneous charging and supply from the battery installed.

The turbine system is an auxiliary source of energy in addition to the conventional battery charging system from diesel, which will run the remaining components. When the battery charging is complete, the charging circuit will automatically disconnect from the battery.

2. Apart from simultaneous charging and supplying the electricity from the battery, the battery can be charged only, when the train is stationary at the yard, or at some point where electricity in the coaches is not needed. This energy can be stored in the battery and used further. This charging will be due to the wind flowing at the stationary train site. This extra energy can be used to run other electrical machines like cleaning machines at the yard.
3. The turbine system may also be installed over the roof-top of the loco. The batteries below the loco are used to start the loco engine, to provide the initial ignition. The battery rating is 12V-500Amp-hr. Usually 8 batteries are installed. The turbine system is used as an auxiliary source of energy. These batteries can be charged and used in the next run, to provide ignition.

Conclusion

1. The wind energy harnessed from the proposed wind-turbine system can be used for lightening up all the tube-lights, leaving an additional calculated 123W energy, which can be used to run the fans, or as an input to other devices like mobile chargers and night lamps.
2. The harnessed energy is an un-interrupted supply of energy which continues to work even when the diesel-battery system fails.
3. The proposed system as an auxiliary source of energy proves to be important at the times of emergency and accidental hazards when the main supply cuts off. This will add to the safety of the passengers, as well as the property of the railways.
4. The charged batteries from the stationary coaches at the time of cleaning of the train, can be used to run the cleaning devices.

ACKNOWLEDGEMENTS

We would also like to thank Pradeep Yadav and Prateek Sharma, MANIT Bhopal for their helpful inputs on the topic.

REFERENCES

Anderson P.D.(2007). *Review of Historical and Modern Utilization of Wind Power,* Wind Energy Department, RISØ DTU, Denmark. Available: http://www.risoe.dk/rispubl/VEA/dannemand.htm.

Arifujjaman M.D.(2006). *Maximum Power Extraction from a Small Wind Turbine Emulator Using a DC-DC Converter Controlled By a Microcontroller,* ICECE ’06, Dhaka, Bangladesh, December 2006.

Duquette M.M.(2003). *Numerical Implications of Solidity and Blade Number on Rotor Performance of Horizontal-Axis Wind Turbines,* Journal of Solar Energy Engineering, ASME, November 2003.

Fink D.(2005). *Small Wind Turbine Basics,* Energy Self Sufficiency Newsletter, July 2005. Available: www.otherpower.com/windbasics1.html .

Masters D. *Understanding Alternators-An Overview,* Quick Start Automotive Electric, Available: http://www.alternatorparts.com/understanding_alternators.htm

Stiesdal H. (1999). *Wind Turbine- Components and Operation.* Bonus Info Newsletter, Autumn.

Tangler J.L. (2000). *The Evolution of Rotor and Blade Design,* AWEA ‘00, California, April-May 2000.