Feasibility Study of Conversion of Wind Energy to Electrical Energy at Delhi Metro Stations using Light Rotor Turbines

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Abstract— To reduce dependence on fossil fuels and such non-renewable energy sources for generation of electricity, people worldwide are now leaning towards the 'clean and green' renewable sources of energy. Wind is one such resource which can reduce harmful environmental emissions when used instead of electricity generated from fossil fuels. The idea of extracting energy from the wind ushered in by high velocity metro trains using turbines is an effort made in the direction of converting wind energy, abundantly available all along metro trains which otherwise is going waste, to generate and to supplement the ever increasing demands of clean, green and cheap electricity and to support of nation's economy. Theoretically the power generated (based on the data collected by power predictor) by such small turbines is small, but with an innovative design such as multiple turbines on a single axis or as an array will gradually lead towards the ultimate goal of self-reliance for energy needs. Designing such turbines which would be tailor made according to the requirements of each station will improve the energy generation and will help to meet the national need for energy diversification. Although this project started as an innovative project sponsored by University of Delhi, the students who have worked under it are continuing to contribute towards it even after moving on to different universities all over India for their post-graduation. Thus the project based learning is spreading its roots amongst a larger number of students and universities through them.

Keywords: Light Rotor Turbines, Wind Energy, Electrical Energy

I. INTRODUCTION

It is well known that the resources of the world are depleting with expeditious speed. This has prompted an interest in protractible, protected and non-polluting varied power provisions reminiscent of wind energy. Wind energy is undoubtedly one of the cleanest forms of producing power from a renewable source. In the last decades, a growing interest in renewable energy resources has been observed. Unlike other renewable energy sources, wind energy has become competitive with conventional power generation sources and therefore the application of wind turbine generators has the highest growth amongst other sources.

One of the sources of wind energy is the wind blowing in underground metro stations. Here, we sometimes experience a huge gush of wind hitting us. This strong wind current arises due to the pressure difference at the ends of the tunnel because of the high speeding metro trains. The resulting wind has a high kinetic energy and can be converted into an appreciable amount of electrical energy by means of a wind turbine. Wind turbines work by converting the kinetic energy in the wind into rotational energy and then electrical energy. Therefore, it is important to know the expected power and energy output of each wind turbine to calculate its economic viability.

For an optimum generation of electricity, the type of wind turbine to be used further depends upon various parameters. A wind turbine should always extract the highest possible power from the wind and energy generation should be more than the energy loss due to air drag.

II. THEORETICAL CALCULATIONS OF WIND VELOCITY AND POWER GENERATION

Wind energy is the kinetic energy of air in motion. Total wind energy flowing through an imaginary surface with area A during time 't' is,

$$E = \frac{1}{2}(mv^2) \qquad \ldots\ldots\ldots\ldots(1)$$

where, v = velocity of air (m/sec^2) and m = mass of the air /object passing through A (kg)
Now,
Mass (m) = Density * Volume
m = ρ* (Area *Distance)
m = ρ*A*vt

m =ρAvt …………….(2)
Substituting value of 'm' from equation (2) in equation (1)

$$E = \frac{1}{2}(\rho Avt)v^2$$
$$E = \frac{1}{2}\rho Atv^3$$

Where,
ρ = Density of air (kg/m^3)
v = speed of wind (m/s)
Avt= volume of air passing through area 'A' (m^3)
Now, as power is defined as rate of doing work
So,

$$P = E/t = \frac{1}{2}A\rho v^3 \qquad …………….(3)$$

According to law of conservation of mass and energy, not more than 16/27 i.e., 59.3% of the kinetic energy of wind can be captured. (Stated by Albert Betz, known as the Betz law/ Betz limit [1]). Hence, the theoretical maximum power efficiency of any wind turbine is 59%. This is called the power coefficient.

The C_p value is a function of the wind speed that the turbine is operating in. The real world limit for C_p is 0.35 - 0.45. Therefore the power coefficient needs to be factored in (3).

$$P_{avail} = \frac{1}{2}\rho Av^3 C_p$$

where, P_{avail}= Power generated (W)
A = Swept area by turbine blades (m^2)
v = Wind velocity (m/s)
ρ = Air density (kg/m^3)
C_p = Power coefficient
This relation, however does not account for the power losses due to friction, air drag, etc.
It can also be observed that P α v^3, i.e. the power generated increases as the wind velocity increases.

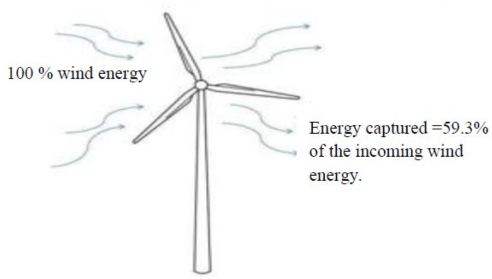


Fig. 1: Maximum power efficiency

A. Air Drag Factor / Aerodynamics

In a layman's language, air drag is "air resistance". Wind blows in a direction opposite to the motion of the moving vehicle and exerts an opposing friction force. The greater this air friction, the greater the vehicle's fuel consumption to maintain a constant velocity. Air drag force is directly proportional to the square of the free stream velocity. Thus, as the speed of the vehicle increases air drag also increases. The vehicle should have minimum drag to achieve fuel efficiency. It is therefore important to reduce the air resistance on a vehicle as much as possible. If the energy loss due to fitting a turbine is less than the energy gain from the turbine, then it is useful to use an auxiliary turbine.

An experimental investigation[2] has been carried out in a wind tunnel to investigate the above. Various aerodynamic data from the models were collected with and without auxiliary wind turbine. The power loss was calculated using the drag coefficient.

$$F_d = \frac{1}{2}C_d\,\rho v^2 A_{frontal}$$

Where,
F_d = Drag force
$A_{frontal}$ = Front projected area
C_d = Drag coefficient
v =Free stream velocity
ρ = Air density
Thus, power loss can be determined by,
P_{loss} = Fd * v
Or

$$P_{loss} = \frac{1}{2}C_d\,\rho v^3 A_{frontal}$$

Fig. 2: Model of Wind Tunnel

III. METHODOLOGY

A. Initial Steps

After completion of a literature survey and our survey of metro platforms and tracks, some positions were shortlisted for the installation of wind turbines. A 3 bladed HAWT (Horizontal Axis Wind Turbine) with blade length of 30 cm was installed at one of the proposed site (given by DMRC). It was found that the blade length was too small to catch sufficient wind to make the rotor move. Thus the three bladed systems which is the most efficient configuration in an open area for large wind turbines are not suitable for the place. So a 5 bladed HAWT with light rotor was taken for further measurements.

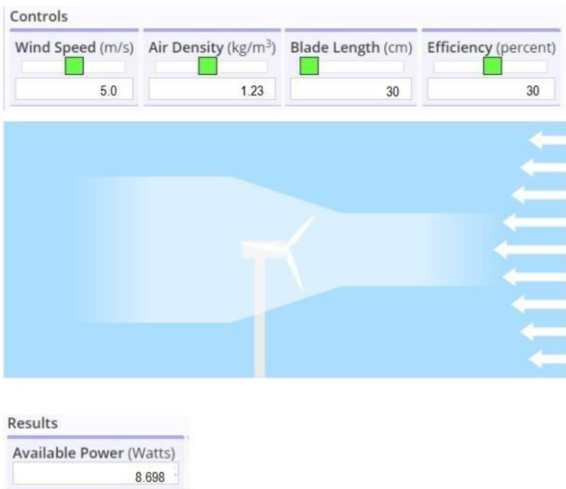
Fig. 3: A 3 bladed HAWT

Fig. 4: A 5 bladed HAWT

B. Outcomes with 5 bladed HAWT

When the five bladed turbines with cut in speed of less than 1.5 m/s was tested at different metro stations, it yielded results and it was estimated that we might be able to generate about 0.346kWh of energy by one turbine per day. The multi-blade turbine is expected to give better results with more RPM (Rotation per Minute) and less loss of energy. It was surveyed and experimented at 3 different metro stations, namely Kashmere gate, Chawri bazaar and Chandni Chowk in December 2014 and it was observed that the wind jetting in due to fast moving metro trains made multibladed fans to rotate with a good speed at a height of about 5 feet. Estimated energy that can be harnessed with 5 bladed HAWT at a wind velocity of approximately 5 m/sec will be 0.36 KWh and about 0.02608 kWh for 2.5 m/s wind speed.

C. Computer Simulation by Software ANYLOGIC



A simulation has been done for the estimated power calculation with the available wind velocity for the 5 bladed HAWT.

IV. CHALLENGES

For the periodic assessment and availability of wind velocity, we installed a wind data logger kit with sensor analysis software at chawri bazar metro station in the month of July 2015. As per the data collected we concluded that average available wind velocity is only 2.5 m/s. Although our present 5 bladed turbine is able to work there yet it is not compatible enough with such a low wind speed to generate more power than power loss due to air drag. Theoretical calculations reveal that power generation for a turbine of blade length 30 cm (assumed that the turbine is able to rotate) at this velocity is quite low. We still need a turbine with a lighter rotor which can generate higher power at such a low wind velocity.

V. LIGHT ROTOR TURBINES[3]

Researchers at Hong Kong University and Lucien Gambarota of Motor wave Ltd. have developed Motor wind, a micro-wind turbine technology small enough for private use in both rural and urban environments. Unlike large-scale wind turbines, Motor wave's micro-wind turbines are light, compact (25 cm rotor diameter), and can generate power with wind speeds as low as 2 meters/second. The gear-like turbines can be linked to fit just about anywhere in a row. According to tests, turbines arranged within a surface area of one square meter and a wind speed of 5 m/sec generate 131 kWh/yr.

Fig. 5: Set of Micro wind Turbines in Hongkong by Motor wave group

Fig. 6 : MACE's wind turbine

VI. RECOGNITION TO THE PROJECT

When the project started, it had no global precedent. However, in2013, metro officials at Los Angeles Metro department (Metro Environmental Compliance Services) [4] developed a similar project called "MACE" in the US and were able to generate an average of 77.7 kilowatt hours (kWh) per day with the train running at the speed of 70mph.This project has cited our work and is thus a testimonial to the potential of our concepts. Given that the Delhi metro airport line runs at the maximum speed of 65mph,we too can generate a huge amount of electricity.

VII. RESULTS

A. Data collection & presentation from power predictor's site

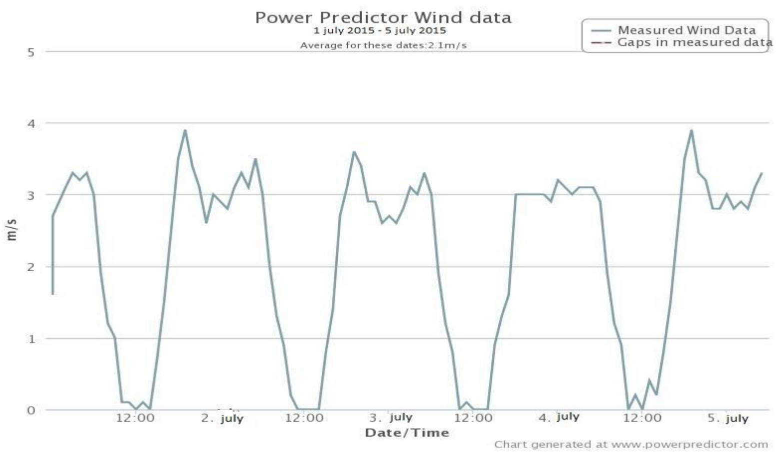


Fig. 7: Graph of wind velocity vs. time for 1-5 July

Expected graph of power generated vs. wind velocity for 5 bladed HAWT has been plotted with blade length of 30 cm.

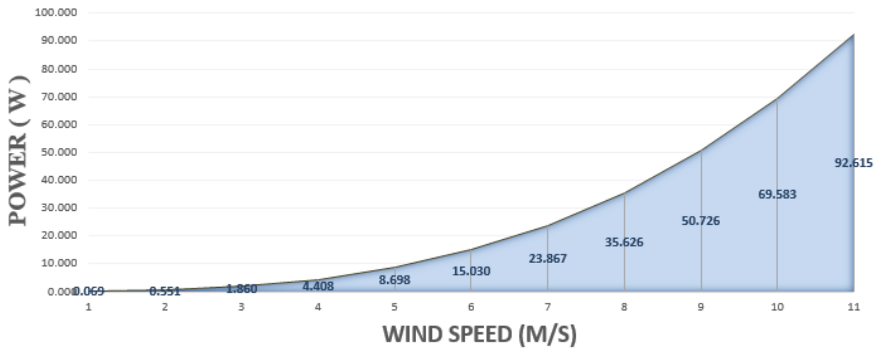


Fig. 8: Graph of Power Generated vs. wind speed

B. Data from Data Logger (power predictor) system

Wind Velocity	Air Density	Blade length	Area swept by blades	Power coefficient	Power
V	ρ	(L) = r	$A = \pi r^2$	C_p	$P_{avail} = \rho A v^3 C_p/2$
(m/s)	(kg/m^3)	(m)	(m^2)		(Watts)
0.4	1.23	0.3	0.283	0.4	0.004
1.4	1.23	0.3	0.283	0.4	0.191
2.4	1.23	0.3	0.283	0.4	0.962
3.4	1.23	0.3	0.283	0.4	2.736
4.4	1.23	0.3	0.283	0.4	5.930

Table 1: For Power generated and wind velocity (data taken by Power predictor)

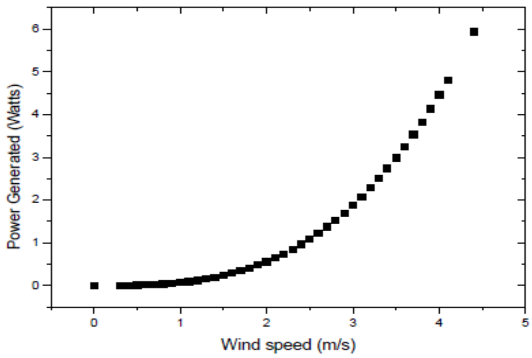


Fig. 9: Graph of Power vs. wind speed based on above Data

A graph drawn on the basis of data taken from power predictor has been shown in Figure 9 and 10.

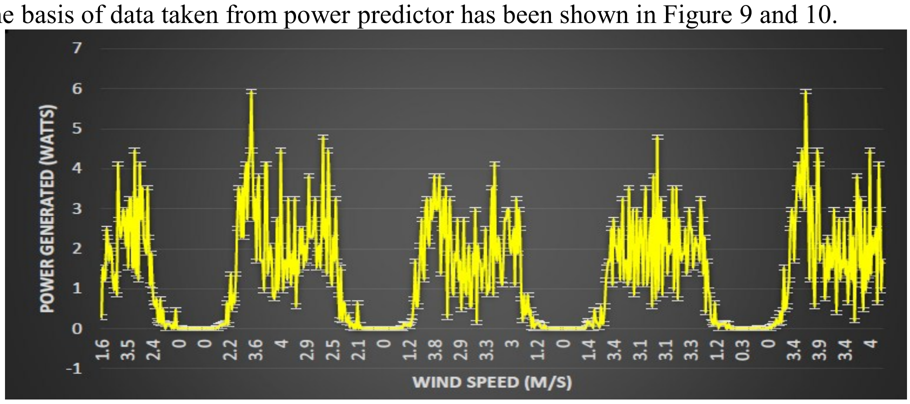


Fig. 10: Actual graph of power vs. wind speed showing the dependence on metro cycle

VIII. CONCLUSION

Earlier, the experiments have been done with a single turbine due to insufficiency of space available (presently the turbine is installed at the mouth of the tunnel with an area of less than 6*6 feet where the wind speed is much less than the speed available inside the tunnel). Further experiments were conducted with the 5 bladed horizontal axis wind turbine at different underground metro stations. We came out with exciting results. It was moving at a high RPM (rotation per minute). It appeared that it will be able to generate energy of about 0.36 kWh of power (theoretical calculation) by one turbine per day.

Now, we are waiting for DMRC's permission to install the new turbine. We will connect it to a battery and measure how much power it generates and try to come up with a design which will reduce air drag and friction..

Simulations and calculations are under progress for the appropriate angle at which the turbine must be installed. Discussions with experts from the field of mechanical, electrical and aerodynamically engineering are also under progress to come up with a design of a wind turbine appropriate for the Delhi Metro. Now, further studies and theoretical calculation show that, the best results can be obtained by installing numbers of small turbines with multiple blades in series by an axle inside the tunnel. The designs of metro tunnels are different from each other hence different types of turbines are required for different tunnels.

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