DU Journal of Undergraduate Research and Innovation
Volume 2, Issue 1 pp 116-, 2016

Wind Energy Generation from Traffic Movement

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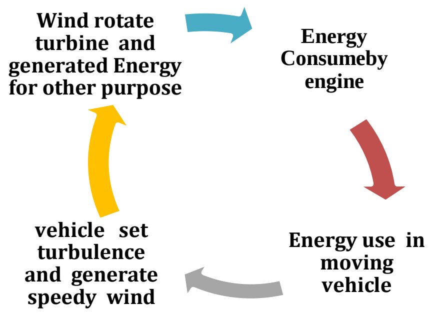
ABSTRACT

Round the clock speedy transport of heavily loaded vehicle on our highways is the glaring evidence of inferno desires of today's consumer society. This speedy transport of heavy vehicle drags and generates subsequent speedy wind over the highway surface. These speedy wind so generated over highways can be trapped and subsequently harnessed into another possible form of energy just as kinetic energy of naturally high-speed wind across over high altitude coastal regions is trapped through wind turbines and utilized to generate electricity on a larger scale. This study provides an estimation and possibilities of such wind power generation.

Keywords: Energy harvesting, Wind Energy, Traffic movement

INTRODUCTION

Recently, every section of society has seen leaps and bounds rise in the energy needs due to increased demand of luxurious lifestyles. With increasing luxuries, not only the numbers of the vehicle are increasing on road but also their speed. The most cities like Delhi have got busy highways and good quality connecting roads, this causes continuous and speedy road air turbulence. This generated air turbulence magnitude depends on velocity and momentum of moving vehicles. If this turbulence or generated wind is captured tactfully under suitable conditions energy can be harnessed. In this energy conversion process, the kinetic energy of the wind and road surface vibration (2) can be used for generating electricity. The kinetic energy available for conversion mainly depends on the wind speed approaching at the turbine and swept area of the turbine. Till now, the wind has been transferred to energy only in regions of high altitudes and coastal regions, where there is natural speedy wind. In this work our approach is to extend wind energy generation for those region having low wind speed. The generating high and continuous turbulence at high-speed vehicles on the highways can have an optimum potential to rotate a turbine. So a vehicle kinetic motion after consumption of fuel creates air turbulence on the road which can be captured by using wind turbines and electric energy can be generated.



In this work, we do some theoretical analysis about such possibilities of traffic driven wind energy generation from different angles. The existing well proved laws like - the law of conservation of energy and Bernoulli's theorem can play a major role in this direction. If we place turbine or set-up of series of the turbine at proper place it can generate a significant amount of electricity. The generated amount can depend on the location of the turbine, vehicle speed, volume available for expansion etc. This idea looks something strange because so far we hear that vehicles need energy in the form of petrol, CNG, diesel but here we are talking about the generation of energy not the consumption of energy.

Few experimental work has been done around world to harvest this wind energy generation by traffic speed like Tommaso Marbiato and his group (2,4,6) in 2010, Sinisa S *et al*. (7) in 2009 and Royal academy of Engineering (5), but have empty handed. This theoretical study shows that amount of generation energy will be less as compared to consumed, but have a significant amount enough for lighten up the road during the night. The only thing required is to increase the amount of generation. This would involve some vertically and Horizontally turbines set-up in series at a certain distance from each other, locations like depressions on roads, overpasses, tunnels etc where the probable speed of the vehicle will be comparatively maximum.

Traffic Driven Wind Energy Generation

From the previous windmill studies (1,3,6) it is very well known that for wind energy power P harnessed by wind turbine is related to wind velocity v_w and is given by

$$P = \frac{1}{2} C_p \rho A v_w^3 \qquad (1)$$

Here A = Cross-section area of the Turbine; ρ = Density of Wind; C_p= Betz Limit.

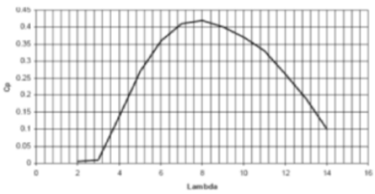


Fig. 1 : Lambda Vs Cp Variation

The Betz Limit Cp gives by Betz' Law (5-7) which is related to Power Coefficient and it varies with the tip speed ratio λ of the turbine in honor of scientist Albert Betz. Tip speed ratio is the ratio of blade tip speed to wind speed. The variation of Cp with tip speed ratio λ is shown in fig. 1 [5]. This law concluded 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. The qualitative behavior of air can be understood by using the law of conservation of energy and Bernoulli theorem for air fluid. This is done by lowering air fluid pressure in regions where the air flow velocity is increased. In order to calculate "real pressure variation, let assume a cylindrical air tube of height h and radius R (= Radius of the turbine) across the turbine which absorbs the kinetic energy of wind turbulence generated. The model calculation here assumes velocity profile follows laminar flow having no viscous losses and turbulence. Specifically, this involves assuming that the effective flow velocity is one-half of the maximum velocity.

If there is no wind profile variation perpendicular to the direction of motion of the vehicle, then all air turbulence goes directly or indirectly along the column height h. Under this ideal condition, all air turbulence reaches the wind turbine. This turbulence absorption results in rotational kinetic energy to the blades of the turbine.
This follows in accordance with the Bernoulli theorem for the fluid motion i.e.

$$P1 + \frac{1}{2}\rho_1 v_1^2 = P2 + \frac{1}{2}\rho_2 v_2^2 \qquad (2)$$

The air turbulence speed change for v_1 to v_2 creates a pressure difference dP = P_2 - P_1 at two face of the imaginary cylinder. It has significance value before of velocity variation and it also depends on size of air column. This pressure variation produced a drag force. The net drag force on the wind turbine is easily correlated with air column pressures difference as

$$F = dP\, \pi R_2$$
$$or \quad F \; = \; ½\, d\rho\, v_a^2\, \pi R^2 (3)$$

This drag force actually does work in displacing air column or setting vibration in air column. There will be more air horizontal propagation as compared to vertical as vehicle having horizontal motion. Indirectly drag forces work done is equal to the decrease in kinetic energy of wind column between two end of imaginary cylinder i.e.

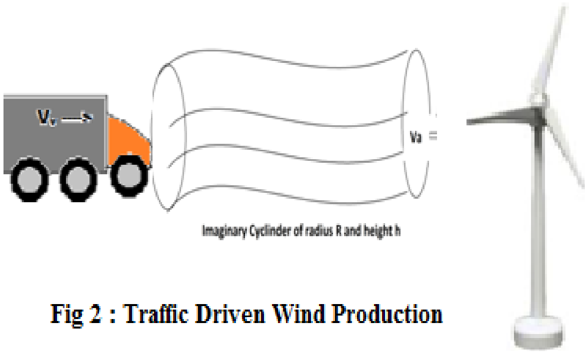


Fig 2 : Traffic Driven Wind Production

$$F.h \; = \frac{1}{2}\, (m_v v_v^2 - \, m_w v_w^2) \quad (4)$$

where h is high of air column.

From law of conservation of energy in situation of no wind energy loss , we have

$$\frac{1}{2}(m_v v_v^2 - \, m_w v_w^2) = \frac{1}{2}\, d\rho v_w^2\, \pi R^2\, .h$$

$$\text{or } v_w = \left[\frac{m_v}{m_{w+dp\, \pi R^2 h}}\right]^{\frac{1}{2}} v_v \qquad (5)$$

The multiplying factor $M = \frac{m_v}{\left(m_w + d\rho\pi R^2 h\right)} > 1$ because an increase of mass ratio is counter cannot balance by larger value of cylinder volume and so almost all the vehicle velocity is transferred to air velocity near wind turbine in ideal situations. But in the real situation there exist an another dynamical correlation, coefficient K related to various loss factors like loss of wind motion or energy due to diffusion, collision loss, air resistance, the location of the turbine, vehicle size & shape and volume available for expansion etc. The value of the dynamical correlation constant K lie between 0 to 1 and have a different value for different vehicle or wind turbine. The K=0 value corresponds to no velocity transfer and 1 for 100% velocity transfer. Therefore, wind turbulence speed is related to vehicle speed as

$$or\ v_w \; = \; K\, [\frac{m_v}{(m_w + d\rho\pi R^2 h}]^{\frac{1}{2}} v_v \quad (6)$$

The resultant wind velocity v_w can rotate turbine or kinetic energy of wind is transfer to rotational energy of turbine. The rotational speed of turbine having radius R is given by

$$\omega = \frac{MK\, v_w}{R}$$

So from eq (1) and (6) wind power P harnessed by wind turbine is given by related to wind velocity v_w and is given by

$$P = \frac{1}{2} K C_p \rho A \left[\frac{m_v}{(m_w + d\rho\pi R^2 h)}\right]^{\frac{3}{2}} v_w^3 \qquad (7)$$

The cubic variation of equation (7) guarantee the generation of wind power from vehicle speed.

RESULTS AND DISCUSSION

The previous section shows that vehicle motion induced some velocity to air-mass which can rotate wind turbine and generate wind power P given by eq. (7). The eq. (6) show that wind speed approaches at turbine are directly proportional to square root of vehicle mass and velocity of the vehicle. If we assume the following data:

R =0.5m , m_v=1200 kg, m_w=1.3 kg /m^3, $d\rho = 0.01\ kg\ /m^3$ and h=3 m

The value of multiplying factor M is found to be an order of 389. The variation of wind velocity approaches at turbine for different values of R is shown in Table 1.

The wind power P harnessed by wind turbine due to wind velocity v_w with same set of data can be calculated with the help of eq. (7) . It is found to be vary cubically with wind speed but limited by the value of Betz limit Cp and correlation constant K as shown in fig 3 & value in Table 1.

Table 1 : Table for Vehicle Speed vs Wind speed & Power generated

v_v (Km/h)	v_w (Km/h)	Power (kW)	v_w (Km/h)	Power (kW)	v_w (Km/h)	Power (kW)
Value of K→ **K=0.1**		**K=0.01**	**K=0.001**			
0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.00	19.72	232.09	1.97	23.21	0.20	2.32
20.00	39.44	1856.69	3.94	185.67	0.39	18.57
30.00	59.17	6266.33	5.92	626.63	0.59	62.66
40.00	78.89	14853.53	7.89	1485.35	0.79	148.54
50.00	98.61	29010.81	9.86	2901.08	0.99	290.11
60.00	118.33	50130.67	11.83	5013.07	1.18	501.31
70.00	138.05	79605.65	13.81	7960.57	1.38	796.06
80.00	157.78	118828.26	15.78	11882.83	1.58	1188.28
90.00	177.50	169191.02	17.75	16919.10	1.77	1691.91
100.00	197.22	232086.45	19.72	23208.64	1.97	2320.86

This is maximum power value as we have assumed that no wind variation along the column height and complete air turbulence effect the wind turbine. But in actual practice most of wind variation go useless due to wide angle as shown in Fig 2. If one can use and does not include energy loss factors like air resistance, friction factor etc and a minimum of 0.1 % of maximum value is available for power generation then still some significance value can be generated as shown in Table 1.

This can be increased if we place of small circular turbines or a series of small circular turbines at proper placed or at regular intervals , reduces mass and friction of wind turbine and use of high-quality piezo sensor (6) .

SCOPE AND DISCUSSION

These energy harvesters can help in satisfying the unending greed of humans encountering energy problems in their day-to-day life. This power generation through vehicle driven wind energy generation is low because the non-availability of any device which can trap adequate wind kinetic energy. It can be increased if we take care of location, shape of turbine and one locates turbine near to heavily accelerates traffic such as at flyovers, slip downs, tunnels etc. Table 1 shows that at the vehicle speed 60 km/h and for correlation value k =0.001 a power of few kW can be generated but no experiment have been designed so far to trap this power. The replacement of windmills by modern sensors like piezo sensor can help in this direction. Such sensor use minimizes Benz limit Cp loss, so more wind power can be generated. The energy generation will be at least sufficient for lightening roadside and this save electricity can be used for some other purpose.

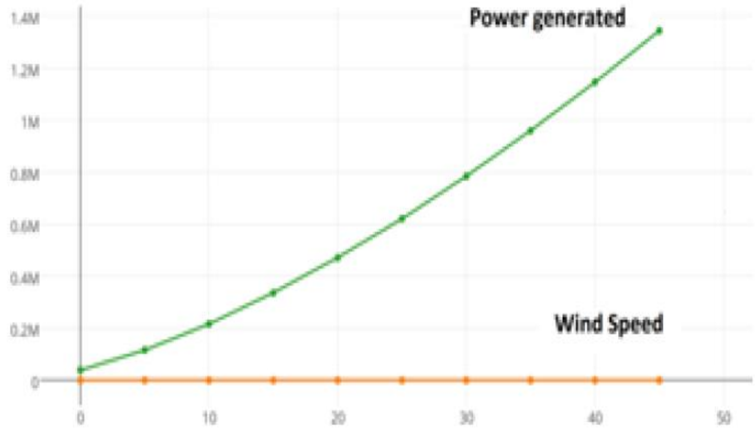


Fig 3 : Wind speed vs Power generated

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