DESIGN AND SIMULATION OF A VERTICAL AXIS WIND TURBINE FOR HIGHWAY WIND POWER GENERATION

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ABSTRACT

A considerable amount of wind energy is produced due to the pressure difference created by the moving vehicles on the highways. This wind energy can be utilized for the generation of electrical energy with the help of vertical axis wind turbines. This project aims to extract this energy in the most efficient manner. Vertical axis wind turbine can be installed on the median of the roads so that the wind from both sides of the median will act tangentially in opposite direction on both sides of the turbine thereby increasing effective wind speed acting on the turbine. This wind flow will depend on the velocity of the vehicle, size of the vehicle and intensity of the traffic. So a detailed survey has to be done for studying these distributions. Based on the studies made an optimal wind turbine design has to be made. The wind power harnessed through this technique can be used for street lighting, traffic signal lighting, toll gates etc.

Keywords: Blade Aerodynamics, Permanent Magnet Synchronous Generator, Renewable Energy, Vertical Axis Wind Turbine, Wind Power.

I. INTRODUCTION

In today's life the demand on electricity is much higher than that of its production. One of the biggest issues ever since men realized is that natural resources are going to be finished one day and a replacement is to be found. Apart from that fossil fuels play a major role in pollution, global warming and greenhouse gas. In order to overcome such problems incorporation of more renewable energy sources such as sunlight, wind and biomass is essential in the current century. Energy is very much essential for development of any nation. The global demand for energy is increasing in a rapid rate due to rapid rise in population and industrialization, while the energy sources are depleting in a very fast manner. Currently, more than 68 percent of electrical energy is produced by thermal power plants where fossil fuels such as coal, diesel etc. are used. As we realize that fossil fuels are going to be exhausted, we're trying to develop other means of power generation.

Wind energy is considered the fastest growing source of clean energy. However, it is limited by its variable nature. Highways can provide a considerable amount of wind to drive a turbine due to high vehicle traffic. Due to the pressure difference in the air adjoining the vehicle wind will be generated [1]. This project aims to extract this energy in the most efficient manner. Small vertical axis wind turbines can be installed in these areas to extract this

power. The wind turbines will be placed on the road dividers so that wind flow from both sides of the highway will be acting tangentially in opposite directions on both sides of the turbine [2]. These types of turbines can be installed on express highways and other high speed traffic areas to generate electricity. Ideally, the turbine can be used globally as an unlimited power source for street lights and other public amenities. Also this system can be connected to the grid to supply the increased power demand.

1.1   Current Scenario

As of 31 March 2014, total installed capacity in India is 255.012 GW. Most of the energy requirement is served by the conventional sources, a major part of which is contributed by thermal power plants. In India almost 177.742 GW of energy is generated by thermal plants, 40.799 through hydroelectric power plants, 4.78 GW through Nuclear power plants and remaining 31.692 GW through other renewable source. India's electricity sector is amongst the world's most active players in renewable energy utilization. India stands 5th in wind power generation with an installed capacity of 21.136 GW. Even though, we are facing a deficit of electrical energy due to lack of resources as well as the increased power demand. Currently, we are trying to incorporate more renewable sources into the grid to support the increased power demand. As a part of it a lot of researches are going on in the field of wind power generation and the researchers are trying to exploit the field of highway wind power generation as highway is one of the potential source of wind energy.

1.2   Significance/Importance of the Project

Since we are depending mostly on non-renewable sources, and they are depleting in a very fast manner, currently there is a shortage of electric power in the world. Also, pollution due to conventional sources like coal, diesel etc. is also a major problem. Because of these above mentioned reasons, we are trying for incorporation of more renewable energy resources (like solar, wind etc.) into the grid to support the increasing power demand. These renewable sources are long term sources of energy and only capital cost is significant for its implementation.

Nowadays, the vehicle density is increasing by a very fast rate and because of the development in road transportation facilities such as the development of express highways and national highways, where vehicles move in immense speed, large amount of wind energy will be generated by the moving vehicles on these highways.

1.3   Objective Of The Project

- Incorporation of more renewable energy to the power system.
- Design of a new method of generation of electricity using the wind energy generated by the moving vehicles on the highways.
- Development Stand-alone system for providing the power to the highways.

II.   DESIGN METHODOLOGY

Optimum design of the turbine is very important in the development of this project. Dessign of the vertical axis turbine for the highway wind power generation is explained in the following sections.

2.1   Data Collection

Before starting the design of the wind turbine, it should be made sure that sufficient wind energy is generated by the moving vehicles on the highways for the operation of the turbine. So, wind readings (peak values) were taken from different places in Salem highway at different intervals. The graphical representation of wind readings from a highway is shown in fig. 1. The natural wind speed is not considered here.

From the readings taken, it was found that average wind speed available on highway median is around 6 m/s. Also, it is found that wind speed is higher during the night time. From the readings taken from the highways, it was noticed that wind speed is varying with respect to the height from the ground and maximum wind speed is obtained between 1 metre and 2 metres from the ground level.
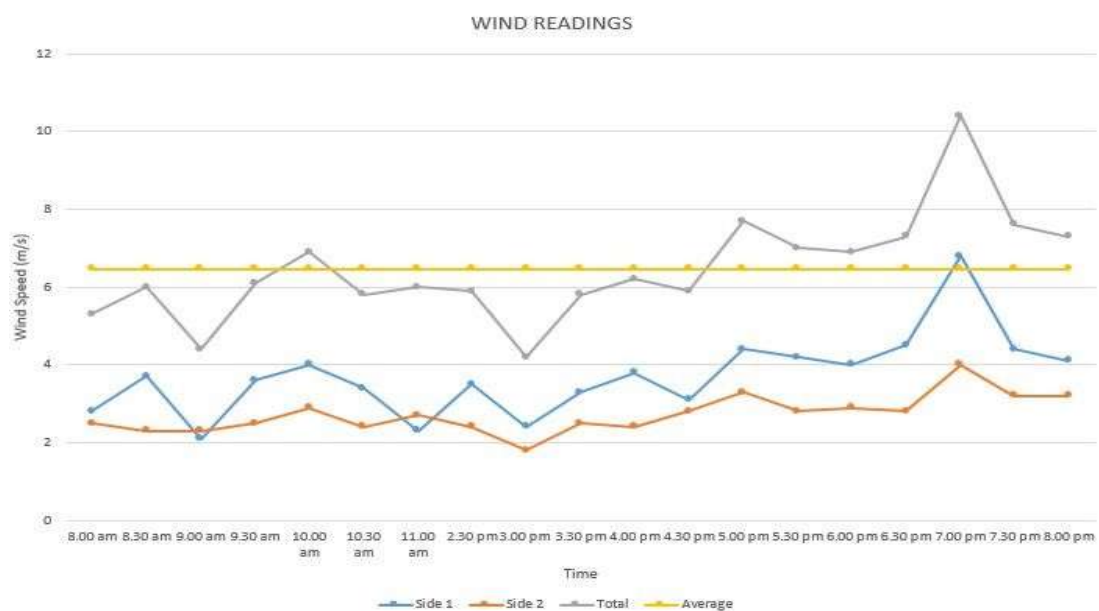
Fig. 1: Wind readings from Salem highway

2.2   Schematic Diagram

Schematic diagram of the proposed project is given in fig. 2. The kinetic energy of the wind is converted into rotational energy using vertical axis wind turbine which is either coupled directly or through gear. Rotational energy from the turbine is converted into electrical energy by the permanent magnet synchronous generator whose output is fed to an IGBT based chopper. Since the wind speed is not constant, the output of the generator will be varying frequently. Chopper regulates the output of the generator and charges the battery. Stored energy in the battery can be used to light LED based street lights using an LED driver circuit.
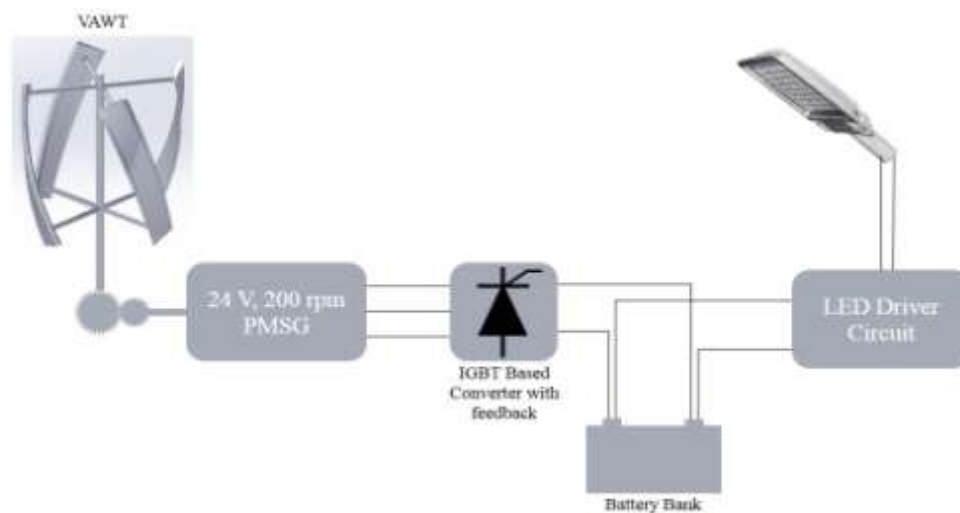
Fig. 2: Schematic Diagram of the Project

2.3   Blade Selection

Blade selection is one of the major step in the design of a wind turbine. Blades convert kinetic energy from the wind into rotational energy in the turbine shaft.

Vertical axis wind turbines are of generally two types- drag machines and lift machines. Drag machines move slower than the wind, have low efficiency and are self-starting, while in case of lift machines blade speeds are greater than the wind speed and are more favourable from an energy production view point but they are not self-starting [3]. Wind energy generated by moving vehicles may not be continuous as there may be idle time with no vehicle traffic and the turbine may need to stop and start frequently. Therefore, self-starting property is one of the very crucial parameter in case of highway wind turbines.

Two or three blades are the standard but four blades were chosen because it resolves a few issues with vibrations, noise and starting. Also, when four blades are used, atleast one blade will be always in direct contact with the wind [4].

To maximise power extraction, the use of cambered or angled blades is beneficial because such profiles will significantly increase the performance in the upwind where most of the power is produced. Thicker aerofoils are desirable in gusty conditions because turbines operating at lower tip speed ratios will experience smaller fluctuations in λ during the gusts and the drop in C_P is also reduced

Helically twisting the blades have been shown to produce smoother torque output that can increase the life of the mechanical components of the VAWT [5] Also, helically twisted turbine yields a steady power output and a higher mean C_P.

From the readings taken from the highways, it was noticed that maximum wind speed is obtained between 1 metre and 2 metres from the ground level. Therefore, the height of the turbine is decided as 1 m. Also, since the median width is 1 metre, the diameter of the turbine is taken as 0.8 m.

2.4   Mathematical Model

Mechanical work is a form of energy, which is given by force multiplied by distance

$$E = W = Fs$$

Force is given by mass multiplied by acceleration

$$F = ma$$

$$E = mas \qquad (1)$$

From kinematics of solid motion, $v^2 = u^2 + 2as$

$$a = \frac{v^2 - u^2}{2s}$$

Assuming the initial velocity of the object is zero,

$$a = \frac{v^2}{2s} \qquad (2)$$

Substituting (2) in (1), we get $E = \frac{1}{2}mv^2$

The power P in the wind is given by the rate of change of kinetic energy

$$P = \frac{dE}{dt} = \frac{1}{2}\frac{dm}{dt}v^2$$

Mass flow rate $\frac{dm}{dt}$ is given by

$$\frac{dm}{dt} = \rho A v$$

Therefore, $P = \frac{1}{2}\rho A v^3$

The actual mechanical power P_w extracted by the rotor blades in watts is the difference between the upstream and the downstream wind powers

$$P = \frac{1}{2}\rho A v (v_u{}^2 - v_d{}^2) \qquad (3)$$

From the mass flow rate, $\rho A v = \frac{\rho A (v_u + v_d)}{2} \qquad (4)$

Substituting (4) in (3), we get $P_w = \dfrac{1}{2}\rho A (v_u^2 - v_d^2)\dfrac{(v_u + v_d)}{2}$

$$P_w = \frac{1}{2}\rho A \left\{ \frac{v_u}{2}(v_u^2 - v_d^2) + \frac{v_d}{2}(v_u^2 - v_d^2) \right\}$$

$$P_w = \frac{1}{2}\rho A \left\{ \frac{v_u^3}{2} - \frac{v_u v_d^2}{2} + \frac{v_u^2 v_d}{2} - \frac{v_d^3}{2} \right\}$$

$$P_w = \frac{1}{2}\rho A v_u^3 \left\{ \frac{1}{2}\left(1 - \frac{v_d^2}{v_u^2} + \frac{v_d}{v_u} - \frac{v_d^3}{v_u^3} \right) \right\}$$

$$P_w = \frac{1}{2}\rho A v_u C_p$$

Where, coefficient of performance $C_p = \dfrac{1}{2}\left(1 - \dfrac{v_d^2}{v_u^2} + \dfrac{v_d}{v_u} - \dfrac{v_d^3}{v_u^3} \right)$

2.5   Generator Design

Generator is required to convert the mechanical energy generated by the turbine into electrical energy. In this application, since the wind speed is not constant, the rotational speed of the turbine will be varying frequently. Therefore variable speed generators should be used here. In wind turbine applications the commonly used generators are DC generators or permanent magnet synchronous generators [6] [7]. Also, since the rotational speed of the turbine will be low, the generator should be of low rpm rating.

Here, a three phase PMSG of ratings 100 VA, 24 V, 200 rpm is used for conversion of electrical energy into mechanical energy.

III. SIMULATION AND ANALYSIS

A Simulink model [8] with permanent magnet synchronous generator and uncontrolled bridge rectifier was developed for the proposed system, which is shown in fig. 3. The wind turbine model was realized using the generic equation of C_p developed by Heier, which is given below:

$$C_p = 0.22\left(\frac{116}{\lambda_i} - 4v - 5\right)e^{\frac{12.5}{\lambda_i}} + 0.0068\lambda_i$$

Where, $\dfrac{1}{\lambda_i} = \dfrac{1}{\lambda + 0.08\vartheta} - \dfrac{0.035}{1 + \vartheta^3}$

A variable wind speed block is created to obtain time varying wind output as per the wind readings obtained from the survey on highway. The block-set gives variable amplitude signal as its output. This variable wind is given as the input to the wind turbine block-set which is coupled to the permanent magnet synchronous generator. Output of the generator is rectified using an uncontrolled bridge rectifier. The variable wind input applied to the turbine
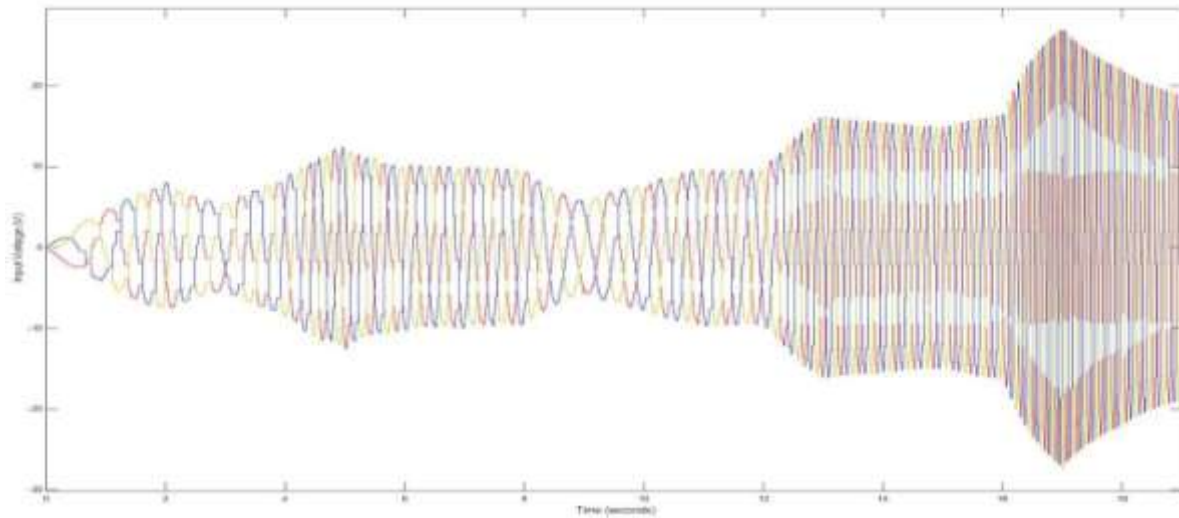
is shown in fig. 4. The three phase AC output of the permanent magnet synchronous generator and the rectified output voltage of the uncontrolled bridge rectifier are shown in fig. 5 and fig. 6.
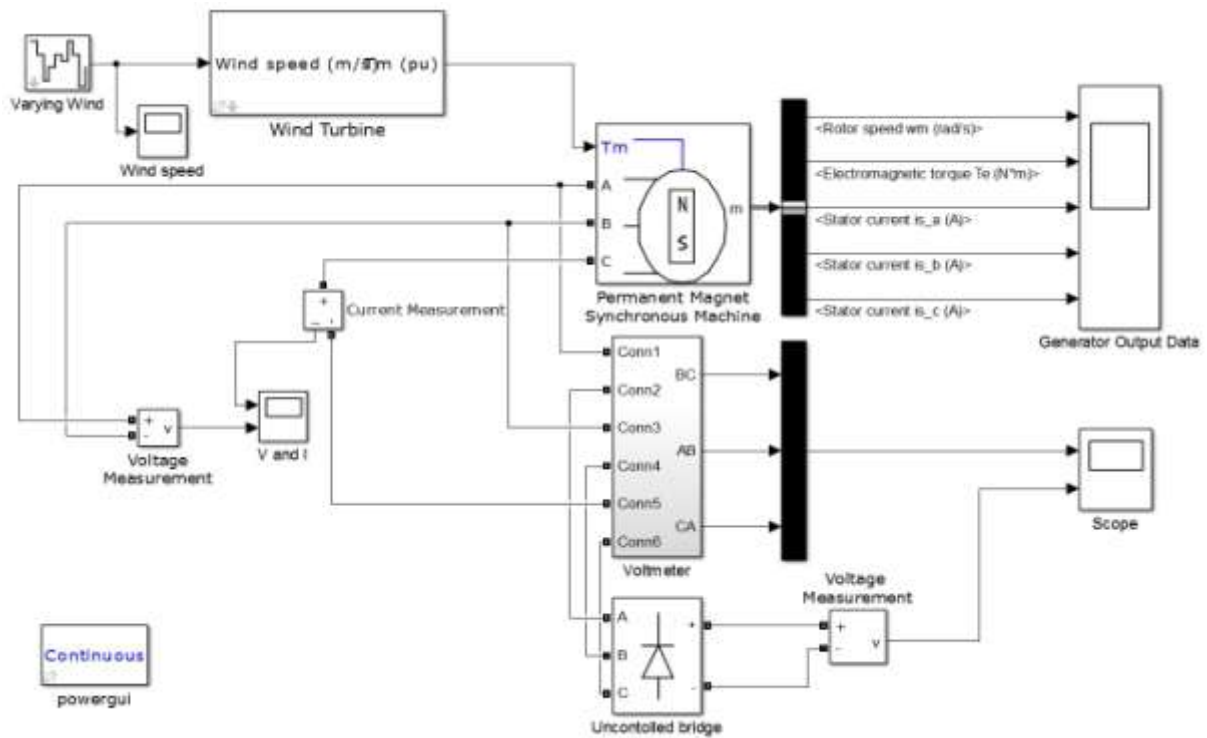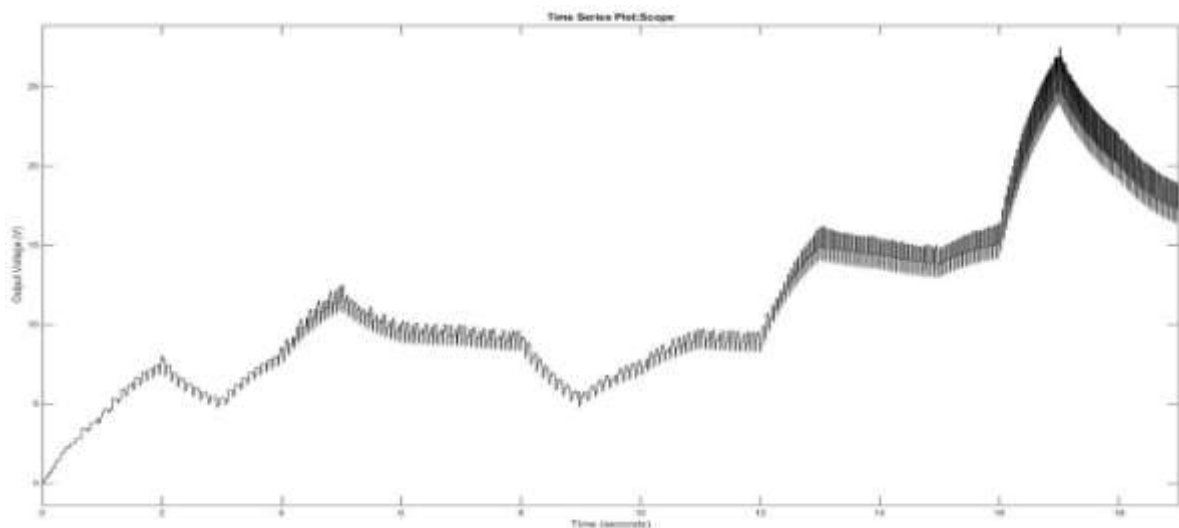

Fig. 3: Simulink model of the windmill
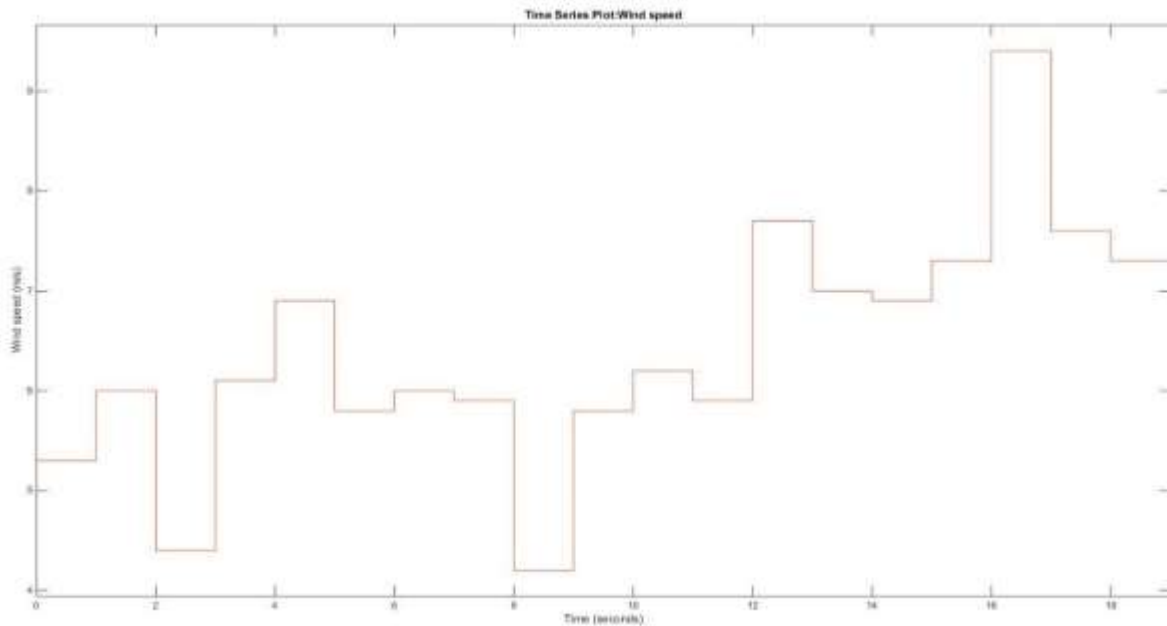
Fig. 4: Fluctuating wind input to the turbine

Fig. 5: Three phase output voltage of PMSG

Fig. 6: Rectified output of bridge rectifier

Since the wind speed is fluctuating, the mechanical torque generated by the turbine will also be fluctuating. The turbine shaft is coupled to the rotor of the generator. Because of the fluctuating torque input of the generator the rotational speed of the generator will be varying thus the output voltage of the generator will also be fluctuating rapidly. Here only an uncontrolled bridge rectifier is used at the output of the generator. But in order to keep the output voltage constant for battery charging, a closed loop converter should be used.

IV. CONCLUSION

The proposed model of helical vertical axis wind mill will be a good source of renewable energy on highways. The wind energy generated by the moving vehicles on highways can be utilized to generate electrical energy which can be stored in a battery and used for purposes like street lighting, traffic signals, road studs etc. This design concept is meant to be sustainable and environmentally friendly. If these types of turbines can be installed

on long high speed express highways like golden quadrilateral, a considerable amount of electrical energy can be generated, which can solve the issue of energy crisis to a large extend.

NOMENCLATURE

ρ	Density of air (kg/m^3)
A	Frontal sweep area of turbine (m^2)
v_u	Upwind velocity (m/s)
v_d	Downwind velocity (m/s)

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