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Wind Energy Conversion System for a Moving Vehicle

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Abstract : India has the second largest road network in the world, since the highway is wide open space there will not be any obstruction for the wind flow. When the vehicle is moving at a faster rate on a highway, the velocity of the wind on top of the vehicle will be high, which can be used to produce electricity. In this work, the possibility of harnessing wind energy on the top of a moving vehicle is proposed. According to the statistics, in India approximately 0.2 million buses & even more number of trucks will be plying on any given day. These vehicles can be used for generation of electricity by using a Wind Energy Conversion System .The vehicle is fitted with a chamber for airflow, chamber is further divided into channels. Each channel has a Vertical Axis Wind Turbine (VAWT) coupled to a Permanent Magnet Synchronous Generator (PMSG), generating electricity and charging the battery bank. This stored energy can be used to run local loads such as the Air conditioner, instantaneously improving the fuel economy of the vehicle in turn reducing the carbon emission. For a non air conditioned vehicle, upon reaching the destination energy stored in the battery bank can be converted to AC and fed to the grid or can be used to run an e-scooter as plug & play battery thus promoting the use of e-vehicles.

Keywords—Wind energy, Moving vehicle, Highway, Battery bank, Air conditioner, Grid

I. INTRODUCTION

India has the second largest road network in the world of about 5.4 million km [1] .As the vehicle will be travelling at a high speed there will be substantial amount of wind blowing around and on top of the vehicle which can used to generate electricity. Since wind is available 24*7 it can be harnessed to produce electricity which is stored in the battery bank [2]. This design not only proposes the use of untapped energy available but also promotes the use of EVs which will further help in reducing the carbon footprint of the country.

II. BASIC DESIGN

The proposed plan as shown in Figure 1 is to have a chamber on top of the vehicle for airflow.

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As the vehicle moves air enters the chamber from the opening at the front. The chamber is split into channels, each having a VAWT, which will be coupled to a PMSG. Towards the rear of the vehicle there will be an opening to allow the air out. Electricity thus produced is stored in the battery bank through a boost converter [3].

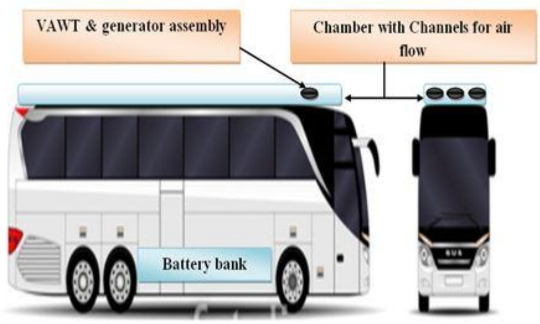

Figure. 1. Wind Energy Conversion System for a moving vehicle

III. COMPONENTS OF WIND ENERGY CONVERSION SYSTEM

The implementation of this system requires the following major components,

A. Vertical Axis Wind Turbine
B. Permanent Magnet Synchronous Generator
C. Boost Converter
D. Battery Bank

A. Vertical Axis Wind Turbine (VAWT)

The VAWT has several advantages over Horizontal Axis Wind Turbine (HAWT) such as; Accepts wind from all directions. Doesn't require yaw mechanism or constant wind velocity. Perfectly suits rooftop applications. Works with low start-up wind speed and has low noise signature [4].The type of rotor selected is an H-type rotor as shown in Figure 2 with diameter as 0.25m and height as 0.3m. Since the width of the Volvo B9R bus is 2.6m [5] , nine number of such VAWTs can be placed side by side facing the wind at the front of the vehicle.

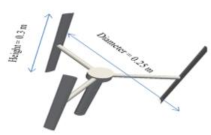

Figure. 2. H Type VAWT rotor

The mechanical power of turbine is expressed in terms of the following equation 1:

$$Pm = \frac{1}{2} \times Cp \times \rho \times A \times v3\ Watts \qquad (1)$$

Where Pm is the mechanical power of the turbine (W), Cp is the wind power coefficient, A is the swept area of turbine (m^2), ρ is the density of air (kg/m3), and v is wind speed (m/s).

Substituting values of C_p=0.35 , ρ = 1.225 kg/m^3, A = 0.3*0.25 m , v = 21.74 m/sec , the value of mechanical power is arrived at 165.2 Watts.

B. Permanent Magnet Synchronous Generator

In order to get realistic values as output a PMSG with a rating of 200W, 600 RPM, 24Volts which is readily available in the market is chosen for simulation

C. Boost Converter

The voltage rating of the generator is 24V and that of the Battery is 48V. Hence a boost converter is employed [6].

D. Battery Bank

Batteries selected are the ones used in an e-Scooter (Lithium Ion) with a specification of 48V, 24Ah.

This will store the energy as and when it is generated.

IV. RELATIONSHIP BETWEEN VEHICLE SPEED & WIND SPEED

In order to find out the relationship between vehicle speed and wind speed, a car was driven on the highway on five different days recording the vehicle and the wind speeds, later the values were averaged out to find the mean wind speed for a particular vehicle speed as shown in table 01.

Table 1 : Relationship between vehicle speed and wind speed

Vehicle Speed in kmph	Corresponding wind speed in m/sec					
	Day 01	Day 02	Day 01	Day 04	Day 01	Average
20	2.84	2.21	2.6	3.51	4.71	**3.17**
30	3.6	6.6	7.81	4.51	5.77	**5.65**
40	7.5	11.9	11.58	7.92	8.61	**9.50**
50	9.14	12.2	14.42	11.94	11.35	**11.81**
60	15.49	15.31	15.12	13.78	16.25	**15.19**
70	20	19.66	15.46	14.77	19.36	**17.85**
80	21.21	20.66	21.56	23.32	21.97	**21.74**

V. MATLAB SIMULINK MODELS

The Matlab simulink model for Wind Energy Conversion System is as shown in Figure 3.

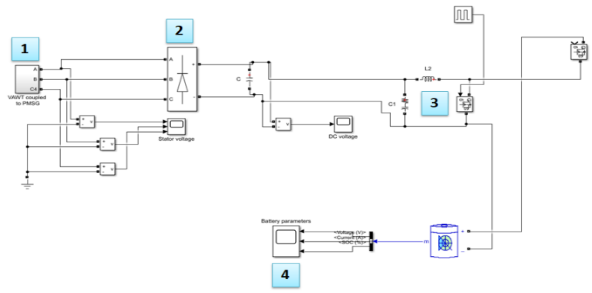

Figure 3 : MATLAB Simulink model for Wind Energy Conversion System

Model is sub divided into,

1. VAWT coupled to PMSG
2. 3 Phase rectifier
3. Boost converter
4. Battery

1. **VAWT coupled to PMSG**

The VAWT coupled to PMSG block is as shown in Figure 4. Which is further divided into,

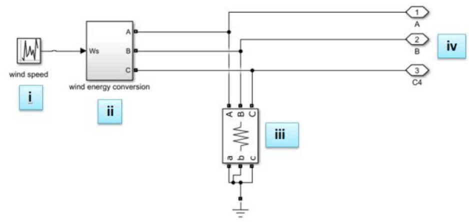

Figure 4 : VAWT coupled to PMSG

i. **Wind speed block**

In order to simulate real time vehicle movement on the highway and real time traffic, a random number generator block is used, which generates a random number between the set minimum and maximum values and each value holds for the specified sample time. In order to have realistic values the minimum vehicle speed considered is 60 kmph and maximum vehicle speed as 80 kmph. The corresponding wind speed is 15.19 m/sec and 21.74 m/sec respectively.

ii. **Wind energy conversion**

The wind energy conversion block is as shown in Figure 5 and has following blocks,

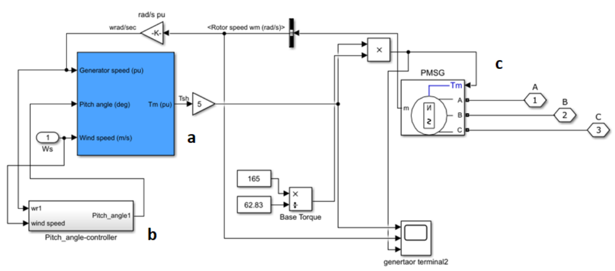

Figure 5 : Wind energy conversion

a. VAWT block

This block has 3 inputs. Wind speed, Pitch angle, Feedback from generator. And the output is torque. Wind speed is given as an input from wind speed block which generates random number between minimum and maximum values to simulate vehicle movement. Pitch angle is given as an input from pitch angle generator which varies the pitch angle of the blades in accordance to extract maximum power. Generator speed is given as a feedback from PMSG. The output from this block is torque which is fed as an input to the generator block [7].

b. Pitch angle controller

This block accepts generator speed as input and compares it with reference value, produces an output which gives the reference value of the pitch angle for extracting maximum possible power from the wind.The pitch controller block is as shown in Figure 6.

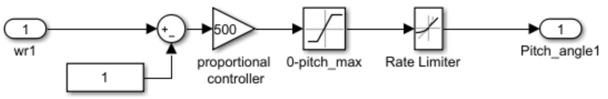

Figure 6 : Pitch angle controller

c. PMSG block

This block has torque as input and 3 Phase AC power as output.

iii. Dump load

The dump load comes into picture when the battery is full and disconnected from the source. If the load is disconnected then the wind turbine will spin out of control and damage the blades and the generator coupled to it. Dump load is used to dump the excess power through resistors when not needed as shown in Fig 4.

iv. Input to 3 Phase rectifier

The output from the generator is given as the input to a 3 Phase rectifier which converts 3 phase AC to DC as shown in Fig 4.

1. Three Phase rectifier

A 3 phase rectifier circuit is used to convert 3 Phase AC to DC. The circuit has 6 diodes and 3 diode bridge arms.

2. Boost converter

The boost converter block consists of a Capacitor, Inductor, and MOSFET as a switch and a pulse generator to control the converter operation. The voltage rating of the generator is 24V, but that of the battery is 48V so a boost converter is used to match the generator voltage with that of the battery. The duty ratio is given by the equation 2:

$$D = \frac{Vo-Vin}{Vo} \quad (2)$$

Substituting the values of V_O as 48 and V_{in} as 24. The value of duty ratio D is arrived at 0.5.

The inductor ripple current is calculated from the following equation 3:

$$\Delta I_L = 0.2 * \frac{V_o}{V_{in}} * I_o = 1.52 \text{ A.} \quad (3)$$

The inductor value can be calculated with the following equation 4:

$$L = \frac{(V_{in}-V_o)*V_o}{\Delta I_L * F_s * V_{in}} = 875\mu\text{H} \quad (4)$$

The output capacitor value can be calculated with the following equation 5:

$$C = \frac{I_o * D}{\Delta V_c * F_s} = 5800\mu\text{F} \quad (5)$$

Where ΔV_c=0.03275.

3. Battery

The power generated during the journey is stored in the battery. In order to use the battery as plug and play, the type chosen is a Lithium Ion battery.
The specification of the battery is 48V, 24Ah.

VI. RESULTS AND DISCUSSION

Matlab simulation of the wind energy conversion system is run for a sample time of 60 secs. The wind speed is varied between 15 to 21 m/sec corresponding to vehicle movements on the highway with speed of 60 to 80 kmph as shown in Figure 7.

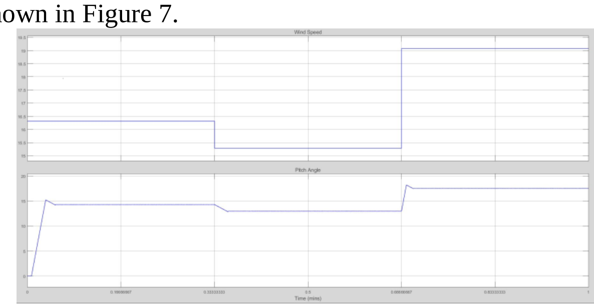

Figure 7 : Wind speed and Pitch angle

Out of a total of 60 sample seconds the wind speed is chosen to be constant for 20 secs .After twenty seconds wind speed will vary randomly between the upper and lower limits specified. The corresponding variation in rotor speed, torque is as shown in Figure 8. Accordingly the pitch angle is varied to extract maximum possible power from the wind which is evident in Figure 7.

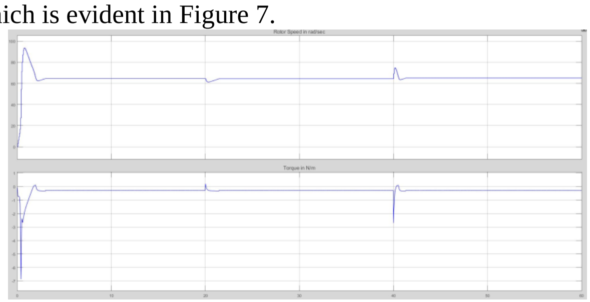

Figure 8 : Rotor speed and Torque

The generated stator voltage for all the 3 phases is as shown in the Figure 9.

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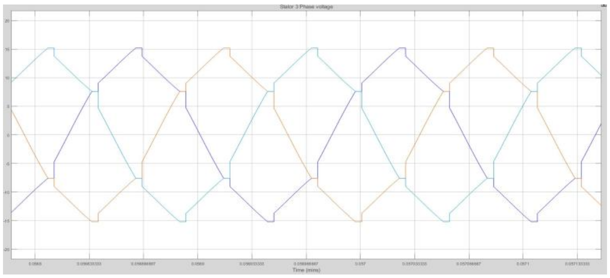

Figure 9 : Stator 3 phase Voltage

The DC output voltage from the 3 Phase rectifier is as shown in Figure 10.

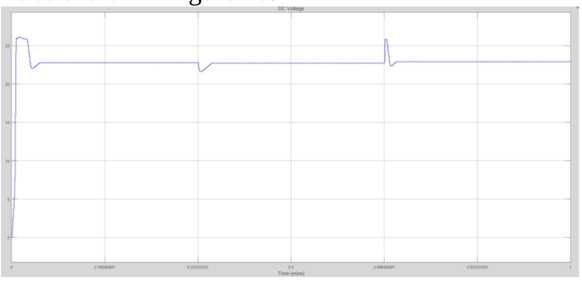

Figure 10 : DC output from three phase rectifier

The voltage, current and the SoC (State of Charge) curve of the battery is as shown in Figure 11. As seen the SOC% is steadily increasing as the battery gets charged.

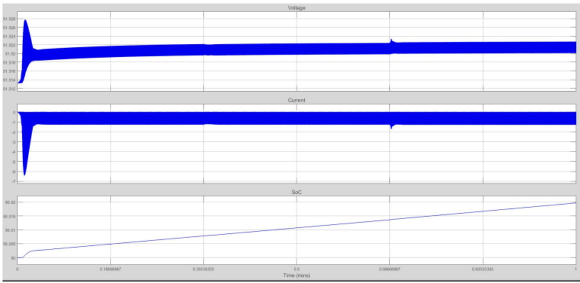

Figure 11 : Battery Voltage , Current and SoC curves

VII. CONCLUSION

It is clear from the waveform in Figure 11, that the battery voltage and current remain almost constant regardless of variation in wind speed. Voltage is around 51.5 volts and current is around 1.35 A.. So with nine number of such PMSGs connected in parallel the total current will add up to 1.35*9 = 12.15 A. Hence if 12.15 A of current is supplied continuously to Lithium Ion battery of 48A, 24Ah specification, then at the end of an hour the battery will be half charged and by the end of the second hour the battery will be fully charged.

If the vehicle is an Air Conditioned bus, then the generated power can be used to share load of the Air Conditioner (assuming rating as 2.5KW), the load of the Air Conditioner shared by WECS is 0.576 KW / 2.5 KW = 0.23. Hence the load of the Air Conditioner on the engine is reduced by 23% which will result in improvement of fuel economy of the vehicle. If the load of the Air Conditioner is completely taken off then fuel economy of the vehicle will improve by 25% [8]. The mileage of a Volvo Air Conditioned bus is around 3.5 km per litre. Since the Wind Energy Conversion System is able to share 23% of the Air Conditioner's load, the improvement in fuel economy will be 0.20 km per litre. Hence for a full tank capacity of 600 liters instead of travelling for 2100 km (without Wind Energy Conversion System), now the bus will travel for 2220 km (With Wind Energy Conversion System) resulting in additional 120 kilometers travelled for the same fuel consumption.

. If the vehicle is a truck or a non AC bus and travels for 12 hours then it can charge a minimum 06 number of 48V , 24Ah batteries. This can be used to run e-scooters. If each e-scooter can run for 50 kms with a fully charged battery then the total distance travelled is 06 * 50 = 300 km. Thereby promoting the use of electric vehicles and reducing the carbon footprint.

From the analysis of simulation results, it is clear that Wind Energy Conversion System can be installed on top of moving vehicle to produce electricity. In the future, this System can be realized on top of a bus with all the components mentioned to produce electricity. Wind tunnel tests can be carried out to optimize the blade design for this specific application. The structure housing the VAWT and PMSG should be sturdy enough to withstand high wind speed, vibrations and mechanical stress.

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