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A study on the rotational behaviour of a Savonius Wind turbine in low rise highways during different monsoons

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ABSTRACT

This work describes the behaviour of a vertical axis Savonius Wind Turbine (SWT) in Four-way lane highways during South-West and North-East monsoons. A vertical axis SWT was designed and fabricated using low-cost materials. Starting behaviour of the SWT was studied by measuring and calculating the starting torque coefficient. The proposed SWT's cut-in speed was achieved at a velocity of 3.5 m/s. Experiments were carried out on a four-way lane highway through the placement of turbine at two different positions (middle and sides of the highway). Also, the experiments were repeated during different monsoons to understand the behaviour under different wind directions. Error analysis was performed on the data obtained by considering possible measurement errors and instrument accuracies. The obtained experimental data clearly illustrates that the SWT's nominal rotational speed varies at different monsoons, when located at the sides of the road. From the data analysis, it can be understood that the wind directions play a key role for harnessing maximum amount of energy in highway wind-energy generation. Maximum augmented rotational speed of around 64% was achieved by placing the SWT at the median of Four-way lane highways in different monsoons.

Introduction

In the last few decades, numerous patents were filed with an aim to harness wind energy from the aerodynamic forces created by the moving vehicle traffic in motorways (Wiegel and Stevens, 2005; Chen, 2006). A simple and efficient device to harness the wind energy in highways has not been devised yet (Morbiato et al., 2014). When considering the horizontal axis wind turbine, the efficiency is higher than vertical axis wind turbines due to high surface and body forces (Bagus et al., 2015). On the other hand, from the economic point of view, the initial and maintenance costs are too high and the design is more complicated when compared to the vertical axis wind turbines. A simple difference in working principle is that the horizontal axis wind turbine rotates based on the lift force and the vertical axis wind turbines rotates from the drag forces that occur in the wind movement. These drag based wind machines are more suitable for harnessing the wind energy from the vehicle traffic in motorways due to its better torque generation in low wind speed speeds (Goh et al., 2016). Further, the drag based wind machines are classified into different types. They are Savonius, Darrious and Giromill wind turbines. Among these, the Darrious wind turbines do not have the ability to self-start. In the case of Giromill turbines, the rotational speeds vary even due to a small wind fluctuations that occur in the wind speeds at unsteady pulsating wind speeds. This is because of the issues in moment of inertia when the Giromill rotates due to unsteady wind speeds (Hara et al., 2012). But in the SWT, end plates have some considerable amount of weight to give good inertial force to provide stable rotational speeds when there are small wind fluctuations that occur on the flow. SWT is most economical compared to other vertical axis wind turbines due to its simple design and good starting behaviour (Belabes et al., 2016). Due to better aerodynamic behaviour at low running speeds and low cost, the SWT was selected and used in applications like pumping water, low and high-rise applications for generating electrical energy by means of coupling an electric generator or alternators. The major challenge in this project was for the selection of a wind based machine that can be accommodated in the available spaces in highways. SWT's shape and size makes it suitable for highway applications; it can be placed at the side shoulders and the centre median of the highways. Most researchers have focused their attention towards increasing the SWT's performance and behavioural characteristics by varying the wind velocities at steady state speeds at both numerical studies and wind tunnel tests. But in real time applications the behaviour of SWT may vary. So in this paper, an experimental study was carried out on the high-way low rise applications to know the rotational behaviour of the SWT at different wind speeds.

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Nomenclature

SW	South-West
NE	North-East
T	torque
C_t	coefficient of torque
ρ	density of air (Kg/m^3)
D	diameter of the semi-cylindrical Savonius rotor (m)
A	swept Area (m^2)
v	velocity of air (m/s)
N_{SW}	rotational speed of SWT in South-West monsoon
N_{NE}	rotational speed of SWT in North-East monsoon
v_{SW}	velocity of the wind in South-West monsoon (m/s)
v_{NE}	velocity of the wind in North-East monsoon (m/s)

India has one of the largest road networks in the world. It is one among the top five largest road networks in the world (NHAI, 2016). In the state of Tamil Nadu, India, the projected daily electricity peak electricity demand is 15,191 MW. But the installed capacity is 10,371.7 MW (CEA, 2016), which leads to power cuts lasting 6 h in rural areas. For this electricity demand, an alternate way must be found to overcome the issue. As cited earlier, Wind energy generation is the most attractive renewable energy source. In India, the horizontal axis wind plants are already installed for 26,915 MW (NIWE, 2016) capacity to produce electricity. The present cumulative installed capacity for wind energy generation 432GW. In the global wind energy market, India is the fourth largest wind energy producer after China, USA and Germany (Roy and Ducoin, 2016). But the cost of the electricity per unit that generated from the horizontal axis wind turbines is high when compared with other methods due to several economic reasons discussed earlier. So, by installing the SWT in the motorways, electrical energy can be predominately generated at lower costs than horizontal axis wind machines. A study suggests that the aerodynamic losses from the moving vehicles in the tunnel exits and urban canyons at motorways are enough to rotate the drag type wind turbines (Morbiato et al., 2014). Another study gives an overview of the flow field induced by the moving vehicle on the road at higher speeds was high for high energy generation (Mattana et al., 2014). When a vehicle passes through the road; it produces drag force and load on either sides. This drag force is used to accelerate the wind velocity on the sides of the roads to rotate the SWT to produce electrical energy (Mithun Raj and Ashok, 2015; Milius, 2004; Musa et al., 2012; Saqr and Musa, 2011; Lichtneger and Ruck, 2015). But when the wind fluctuations occur, the performance of SWT will decrease significantly (Wekesa et al., 2015). The correlation between the results of steady and unsteady wind speed is poor. The rotational behaviour of a variable speed vertical axis wind turbine strongly depends on unsteady wind speeds (wind gusts) (Battisti et al., 2016). This leads to consider the selection of the place and region in a careful way before installing the turbine for energy generation. Thus before installing the SWT farms on highways, the behaviour of the turbine at different wind speeds due to vehicle traffic and monsoons needs to be studied.

Left-hand traffic is being practiced in India. The motorways are constructed as single way, two-way, four-way and six-way lanes. But the state of Tamil Nadu which is located in South India, has mostly two-way and four-way lane roads. In this paper, the experimental data was collected at four-way lanes. In this paper, two-way lanes are not discussed due to the absence of centre median to keep the SWT in the middle of the road to conduct the test. The glossaries of four-way lane terms are shown in the Fig. 1.

South Asian Countries like India receive two monsoons. They are 1) SW monsoon from May to September (Summer Monsoon), 2) NE monsoon from November to March (Winter Monsoon) and transient monsoon during the month of October (Loo et al., 2015). Due to these monsoon variations, the generated flow field from the moving vehicle traffic also changes because the generated flow field is a function of the wind direction (Kalthoff et al., 2005). Few numerical studies have been conducted for the vehicle turbulence energy generated on the road traffic using realistic highway applications, vehicle shapes and different vehicle compositions in the lanes (Kim et al., 2016; Wang and Zhang, 2009). A numerical study states that there is a complexity in creating the sliding mesh mode for the opposite vehicle lane traffic to simulate and calculate the turbulent kinetic energy which is created by the vehicles (Kim et al., 2016). Earlier, the sliding mesh model was tried and generated to study the effect of energy created by the opposite vehicle traffic, but the model created was not matched to the real-time experimental tests (Wang and Zhang, 2009). Taking into account these difficulties in numerical studies, the real time study must necessarily know the actual rotational behaviour of the SWT in the highways for varying aerodynamic effects created by moving vehicles.

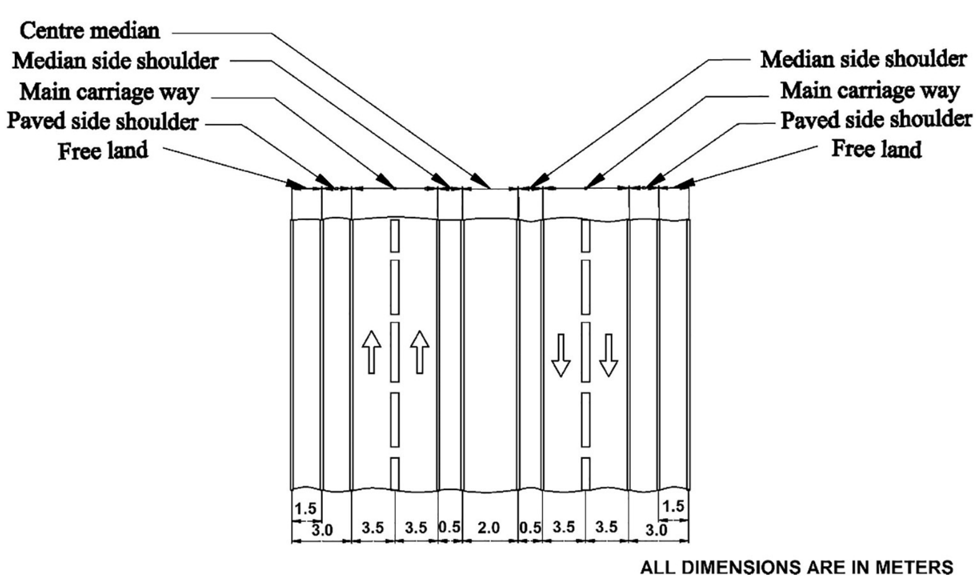


Fig. 1. Glossary of four-way lane terms.

So the behaviour of SWT must be studied before installing it on highways. An experimental setup was created and placed at both the middle of the highways and the sides of the highway to find out the location where maximum amount of energy can be harnessed. The experiments were conducted in four different conditions. The following conditions remain same for all monsoons.

Condition I: SWT placed in free land, vehicle passing in lane L1 as shown in Fig. 9(a).

Condition II: SWT placed in the median, vehicle passing in Lane L2 as shown in Fig. 9(c).

Condition III: SWT placed in the median, vehicle passing in Lane L3 as shown in Fig. 9(e).

Condition IV: SWT placed in the median, vehicle passing in Lane L2 & L3 as shown in Fig. 9(g).

Experimental details

Economic SWT design and alternator

It is necessary that the fabrication of the SWT must be more economical and low cost. A 55 gal steel oil drum was used to make the turbine blades more economically. The drum has a height of 880 mm, width of 610 mm and a thickness of 2 mm. From the literature study, a geometrically optimized configuration (Kamoji et al., 2009) was selected and applied on the oil drum for achieving the best performances. The configurations and geometrical details are shown in the Fig. 2 and Table 1 for more precision. The results for choosing the optimized configuration was given with the results of maximum coefficient of power, C_p and coefficient of torque, C_t were 0.21 and 0.30 at Tip speed ratio of 0.69 for the Reynolds Number 150,000. The maximum coefficient of starting torque was obtained at a rotor angle of 30°.

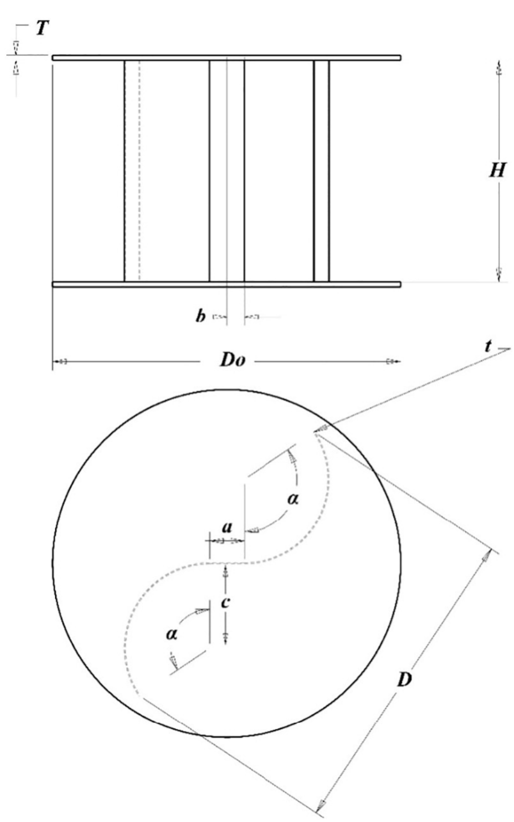


Fig. 2. Geometrical configuration of SWT.

Table 1
Geometrical details of SWT.

S.N.	Geometrical parameters	Values
1	Blade shape factor (b/c)	0.2
2	Blade are angle (α)	124°
3	Blade diameter (D)	610 mm
4	End plate diameter ($Do = 1.1D$)	671 mm
5	End plate thickness (T)	10 mm
6	Blade thickness (t)	2 mm
7	Blade height (H)	427 mm

The fabricated prototype has an increased scaling factor of 1.9 from the optimized design as reported in literature (Kamoji et al., 2009). The end plates are replaced with teak wood and coated with varnish to avoid corrosion. Ball bearings were used for supporting the shafts on both the ends.

A used car alternator (Maruti Suzuki alto) was employed to generate the electrical power from SWT. The selected automobile alternator functions from a rotational speed of 1400 RPM. But the SWT's nominal rotational speed will be 200 RPM. The windings were customized by increasing the number of turns and decreasing the thickness of the winding coil by separating the coil into two sections. The reason for modifying the windings of alternator is to generate electrical power without any gear arrangements. If engaged with gears for speed reduction, the self-starting will become complicated (Menet, 2004). In order to avoid these complications, the alternator output shaft is directly coupled with the SWT's output shaft through mechanical couplings. The specification of the alternator is 40 A, 12 V and it is connected with a resistive load bank. The alternator has an inbuilt rectifier unit in its casing to convert AC to DC power. The resistive load bank helps in the measurement of output power through application of load.

The angular speed of SWT was measured using a non-contact type laser tachometer and reflective strip. The reflective strip was pasted on the top side of the turbine shaft. The starting torque is measured by digital balance and fishing nylon string. The string has 0.4 mm diameter and has been winded in the tiny pulley which is fitted in the top side of the SWT's shaft. In the state of Tamil Nadu, the legal speed rules in city limit is 40 mph for four-way Highways. The data was collected only for the vehicles crossing within the speed limits. Vehicle speeds were measured using a radar gun. A simple windsock prepared manually with cloth and nylon thread was used for measuring the wind direction. The list of measuring devices and its specifications are specified in Table 2.

Error analysis

Instrument accuracies have been considered for the error analysis study. Possible measurement uncertainties in wind speed and turbine rotational speed were considered for calculating the error percentage. Simple statistical analysis was performed and the maximum error percentage was found to be 0.8%. All the results listed in this paper (percentage increase in SWT rotational speeds) can have a percentage variation of 0.8%.

Table 2
Specifications of measuring instruments.

S.N.	Measuring instruments	Range	Accuracy
1	Non-contact tachometer	2.5–99,999 RPM	±0.05%
2	Radar gun	16–322 km/h	±2 km/h
3	Cup type pocket wind meter	0.7–42 m/s	±4%
4	Digital multi-meter (Fluke 15B)	1000 V, 10 A	±5%
5	Digital weighing scale	40 kg	±20 g

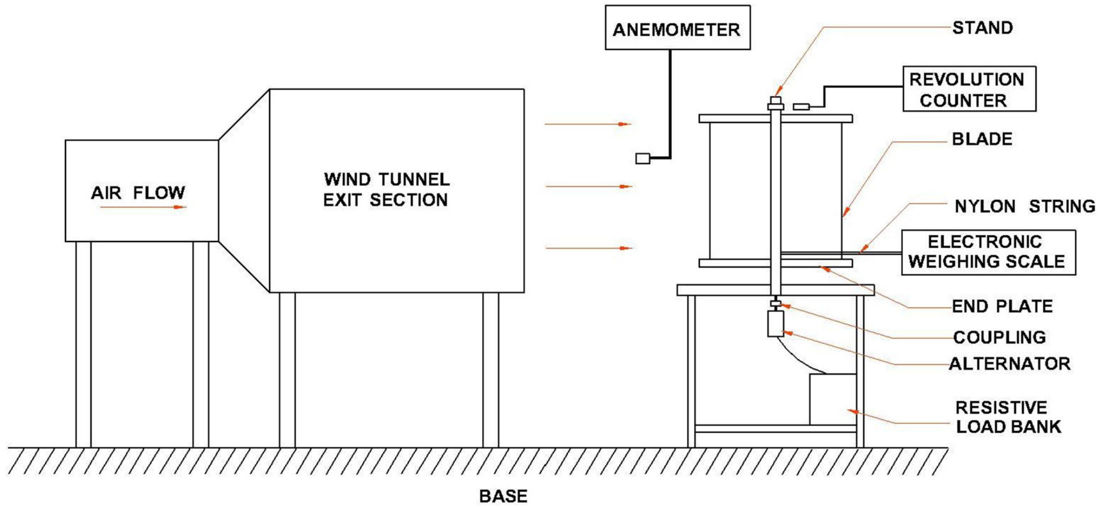


Fig. 3. Schematic view of the wind tunnel setup.

Analysis

Wind tunnel test and results

The experimental setup was fabricated and tested in a wind tunnel to determine the behaviour at uniform wind speeds. The schematic view of the wind tunnel setup is shown in Fig. 3. The self-starting potential was tested by measuring the starting torque at constant wind velocities. During starting torque measurement, the alternator was coupled with the SWT's shaft. The torque coefficient is calculated using Eq. (1). The starting torque coefficient at different rotor angles is depicted in the Fig. 4. The starting torque coefficient value was highest when the angle of attack was 30°. From the obtained wind tunnel data, the torque coefficient does not fall below the negative values. Thus, from the Fig. 4 it is inferred that the proposed SWT has good self-starting capability. From better starting capability and angular stability, better dynamic torque of the rotor is also expected. The cut-in speed of SWT is 3.5 m/s.

$$T = 0.25\, C_t \rho D A v^2 \quad (1)$$

The proposed alternator will produce a charging voltage of nearly 13.5 V (output terminal voltage of the alternator) when the turbine speeds reach above 160 RPM. The behaviour of SWT at varying wind speeds are shown in Fig. 6. The angular speeds and electrical power outputs were calculated at different uniform wind velocities. This test is conducted in an axial flow open wind tunnel with an exit section diameter of 800 mm and the wind tunnel is driven by variable speed DC motor with a specification of 440 V, 15 A and 8000 RPM. The distance between the wind tunnel exit section and SWT set up is maintained nearly at 1 m to get stable and uniform wind velocities (Lignarolo et al., 2014).

Peak power output of 108 W was generated at a wind speed of 13 m/s. When the wind velocity reaches higher than 13 m/s, the rotational speeds and power output did not increase linearly, due to vibrations in the experimental setup. For 10 m/s, the SWT generated a power of 69 W as shown in the Fig. 6. Whenever the rotational speeds are less than 150 RPM, the alternator cannot generate charging voltage of 13.5 V (A 12 V battery is considered). The electrical behaviour of modified alternator is presented in the Fig. 5.

Placing SWT on the roads

The drag force generated by moving vehicles strongly differs from the direction of the roads and monsoon. SW to NE directional road or vice-versa in four-way lane was considered for this analysis to achieve the maximum wind velocities and SWT's angular speeds compared to other directional roads in the highways. This is because the direction of road is identical as that of wind direction during different monsoons. The location selected for the study is about 16 miles from the Coimbatore city, Tamil Nadu, India. The highway comprises two-lanes in each

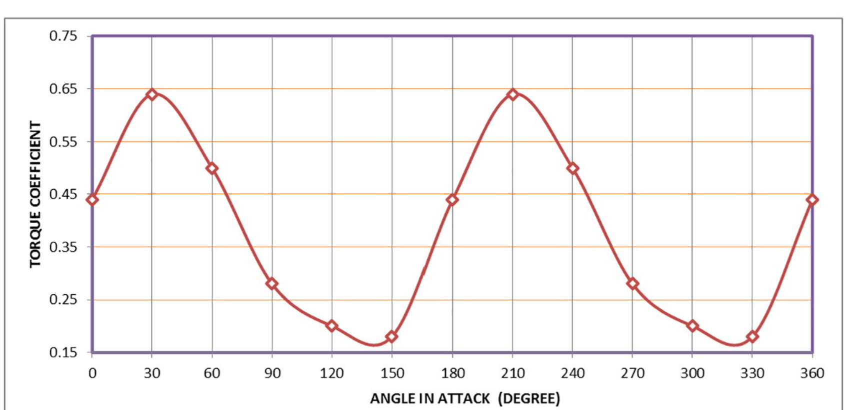


Fig. 4. Self-starting behaviour of proposed SWT.

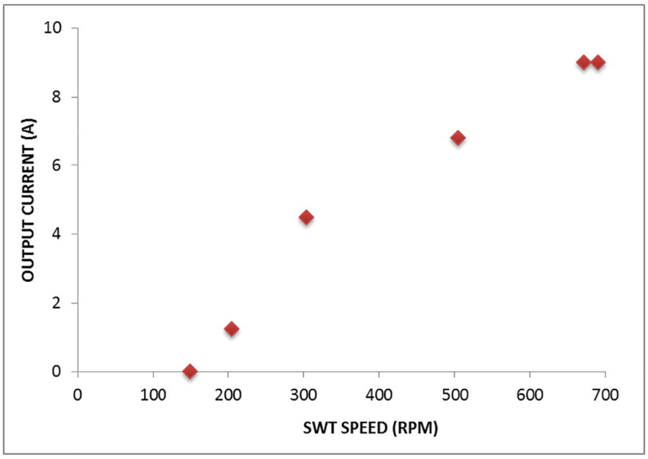


Fig. 5. Electrical behaviour of alternator.

direction. The lane numbers have been marked as shown in the Fig. 7(a) and (b). The selected highway is geometrically located at SW to NE direction. The turbine was positioned at the middle and at the side of the road as shown in the Fig. 7(a) and (b). A chassis was designed and kept at a height of 800 mm due to the centre median configuration of height 800 mm and width 1150 mm. Also, the force acting on the sides of the roads, created by moving vehicles will be considerably higher at heights between 750 mm and 1500 mm ranges (Quinna et al., 2001). The dimensions of the median may substantially vary depending on the geographical location where the highways are laid (Planning commission manual government of India, 2009).

SWT with two configurations A&B were used in this analysis as shown in Fig. 8. Configuration-A was used in the SWT when the readings were taken at the side of the road. In this configuration, blade-1 will act as advancing blade and the blade-2 will act as returning blade.

While keeping the SWT at the middle of the road, Configuration-B was used. Here both the blades 1 & 2 act as advancing blades because on both sides, the vehicles will be crossing in opposite directions in lanes L2 & L3. The SWT must be placed appropriately on the highway based on the advancing blade angle as shown in Fig. 7(b). Initially, the SWT was kept at the side of the highway and lane L1 was considered (condition I). The adjacent lane L2 was left unaccounted as referred in Fig. 7(a). Similarly, while collecting the data at the middle (condition II, III and IV), the adjacent lanes L1 and L4 were left unconsidered as referred in Fig. 7(b). In condition II, III and IV, Lanes L1 and L4 are located more than 2.5 m from the SWT. It is understood from previous studies

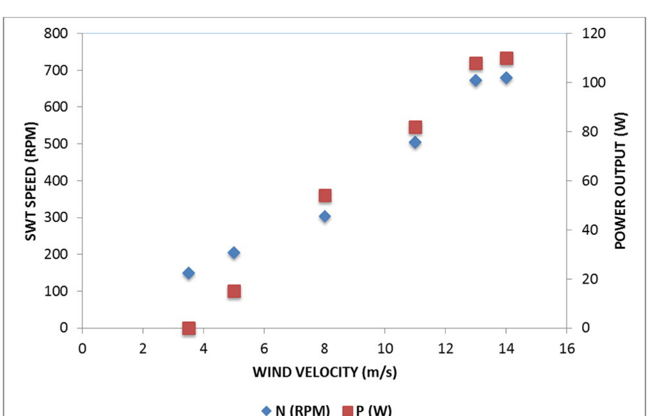


Fig. 6. Behaviour of SWT in a wind tunnel.

that the optimum distance between the SWT and moving vehicle should be less than 2.5 m (Quinna et al., 2001).

The type of vehicles, vehicle intensity, its aerodynamics and its varying speeds will make variations in the generated turbulence and drag force from the moving vehicle traffic (Bhautmage and Gokhale, 2016). It will affect the changes in the SWT's rotational speed. The crossing vehicle distance in the respective lane from experimental setup may create considerable deviations in final velocity and turbine rotational speeds. These factors were not accounted during data collection. Two wheelers, three wheelers, earth movers and road trains have not been considered for this data collection. Lorries and articulated vehicles generate more drag when compared with passenger cars and vans (Alonso-Estebanez et al., 2012). The variations in the size and shape of an articulated vehicle will cause a variation in the drag force created during its movement. So, articulated vehicles with similar containers were accounted. Also, the articulated vehicles have higher turbulence and drag on the top side of the articulated truck than on the sides of the moving truck (Kim et al., 2016). When the long coach buses pass in the adjacent lane, it creates slight variations in wind speeds and those data have been accounted in this analysis. Lane changing vehicles, vehicles traffic in paved side shoulders and median shoulders have not been considered in this data collection. Due to this reason the vehicle passing in the adjacent lanes at the same time was not accounted due to the minimal drag force created (Kim et al., 2016).

Results and discussion

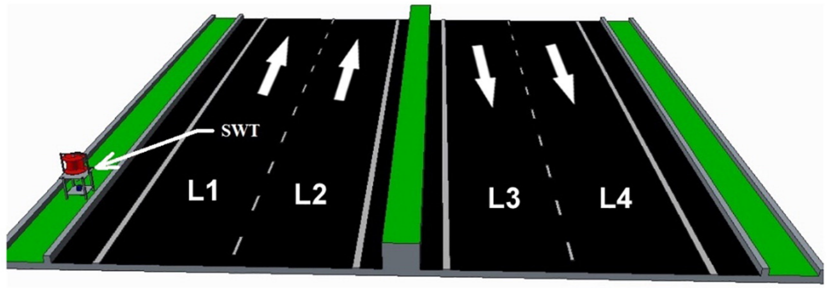
SWT placed as per condition I during SW and NE monsoons

The setup was placed on the side of the road and configuration-A was chosen as shown in Fig. 7(a) and the measurement was taken during SW and NE monsoons. The experimental setup was exactly placed in the free land (175 mm distance from shoulder of the road) of the road which is located adjacent to the paved side shoulders. During SW monsoon the wind blows in the same direction as of the direction of the selected road. Initially the wind blows and initiates the turbine to rotate at the corresponding angular speeds. In lane L1 (condition 1), the vehicles will be passing parallel to the wind direction. When the vehicle passes the turbine, the vehicle creates a wake effect and drag force from its sides (Quinna et al., 2001; Sanz-Andres et al., 2003). This drag force created from the left side of the vehicle was used to accelerate the normal wind speed and will make the turbine to rotate in higher angular speeds with respect to the increased wind velocities. An increase in the turbine speeds of up to 56% was observed during the SW monsoon. The wind velocity and the angular speed changes are graphically plotted in the Fig. 10(a) and (b). From the data obtained, it is observed that an increase in the wind speed causes an almost linear increase in the turbine speed.

Similar experiments were repeated during the NE monsoon. From the data obtained, it was observed that the average angular speeds of SWT increased by 44% from the nominal SWT speeds. This is because of the wind flow and vehicle movements are bidirectional as shown in Fig. 9(b). But in SW monsoon, the wind and vehicle traffic direction were unidirectional as shown in Fig. 9(a). Even though the SWT is independent of wind direction (Wekesa et al., 2016) the wake effect created by the crossing vehicles disturbs the normal wind speed and flow. This has caused the reduction in SWT angular speeds from 56% to 44%, when compared with the SW monsoon. From the obtained data, the regression equations, Eqs. (2), (3) were formulated using Microsoft Excel. The vehicle traffic in lanes L3 and L4 did not create negative drag force due to the huge distance (more than 4 m) between the experimental setup and the vehicles.

$$N_{SW} = 65.044 v_{SW} + 0.6882; \quad R^2 = 0.93 \tag{2}$$

$$N_{NE} = 63.016 v_{NE} + 30.459; \quad R^2 = 0.99 \tag{3}$$



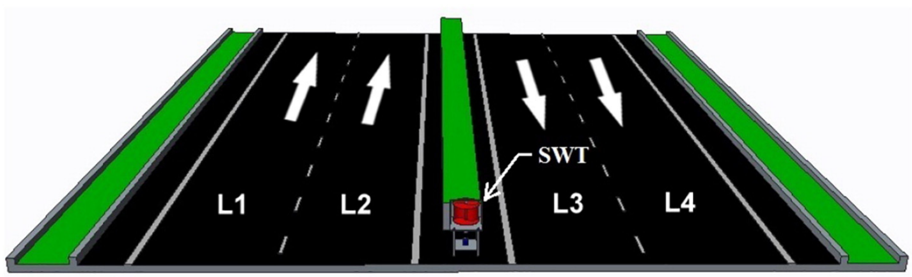


Fig. 7. (a) SWT placed in the side of the 4-way lane; (b) SWT placed in the middle of the 4-way lane.

SWT placed as per the conditions II, III and IV during SW and NE monsoon

The configuration-B was chosen and kept on the median of the highways. Initially, vehicles passing in lane L2 (condition II) alone were considered for the study. During SW monsoon, the vehicle and the wind direction are unidirectional, Fig. 9(c). So the created drag force from the right side of the vehicle resulted in an average increase of the rotational speeds of the experimental setup to 53% from the normal rotational speeds. In Fig. 11(a) and (b), the deviations in data from the linear line have been identified. These variations were observed due to vehicle aerodynamics, size and cruising speeds (between 60 and 65 km/h). The angular speeds of the turbine increased only 23% during NE monsoon. This variation is because of the monsoon wind direction. During NE monsoon, the traffic flow and the wind flow were bidirectional as shown in Fig. 9(d). So the induced drag force has not been accelerating the wind as much, compared with the unidirectional of traffic and wind flow in SW monsoon. From the condition II data at different monsoon seasons, the Eqs. (4), (5) was formulated.

$$N_{SW} = 59.668 v_{SW} - 5.6407; \quad R^2 = 0.98 \tag{4}$$

$$N_{NE} = 68.805 v_{NE} - 119.2; \quad R^2 = 0.97 \tag{5}$$

During SW Monsoon, from the condition III, the wind and vehicle direction are bidirectional as shown in Fig. 9(e). The increase in rotational speed of the turbine due to the vehicle crossing is about 24%.

During NE monsoon, the vehicle and wind direction are unidirectional in condition III, Fig. 9(f). The induced drag force from vehicles has accelerated the wind speed and increased the SWT's rotational speed higher up to 52%. The obtained data from the lane L3 were plotted in the graph as shown in Fig. 12(a) and (b) and the Eqs. (6), (7) were formulated.

$$N_{SW} = 64.007 v_{SW} - 88.659; \quad R^2 = 0.97 \tag{6}$$

$$N_{NE} = 52.007 v_{NE} + 37.436; \quad R^2 = 0.99 \tag{7}$$

In Fig. 13(a) and (b), the turbine speed vs. wind speed during both monsoons are shown. The highest average increase in rotational speed of SWT is around 66% for condition IV during SW monsoon. During NE monsoon, for condition IV, the average increase in SWT rotational

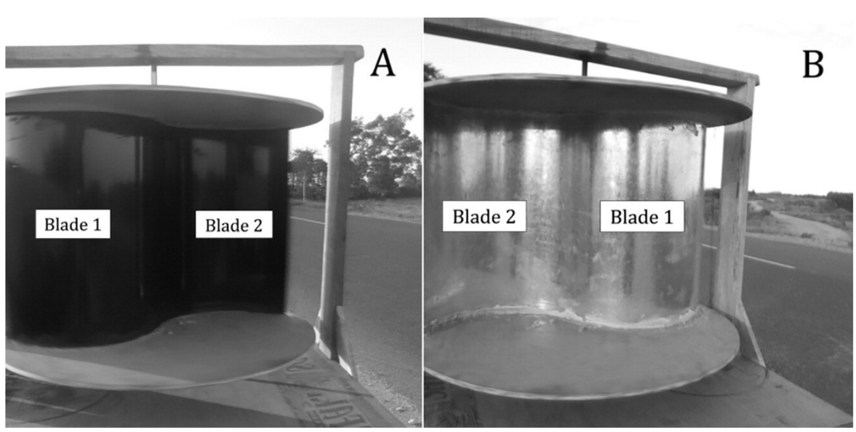


Fig. 8. Different configurations of SWT used in highways.

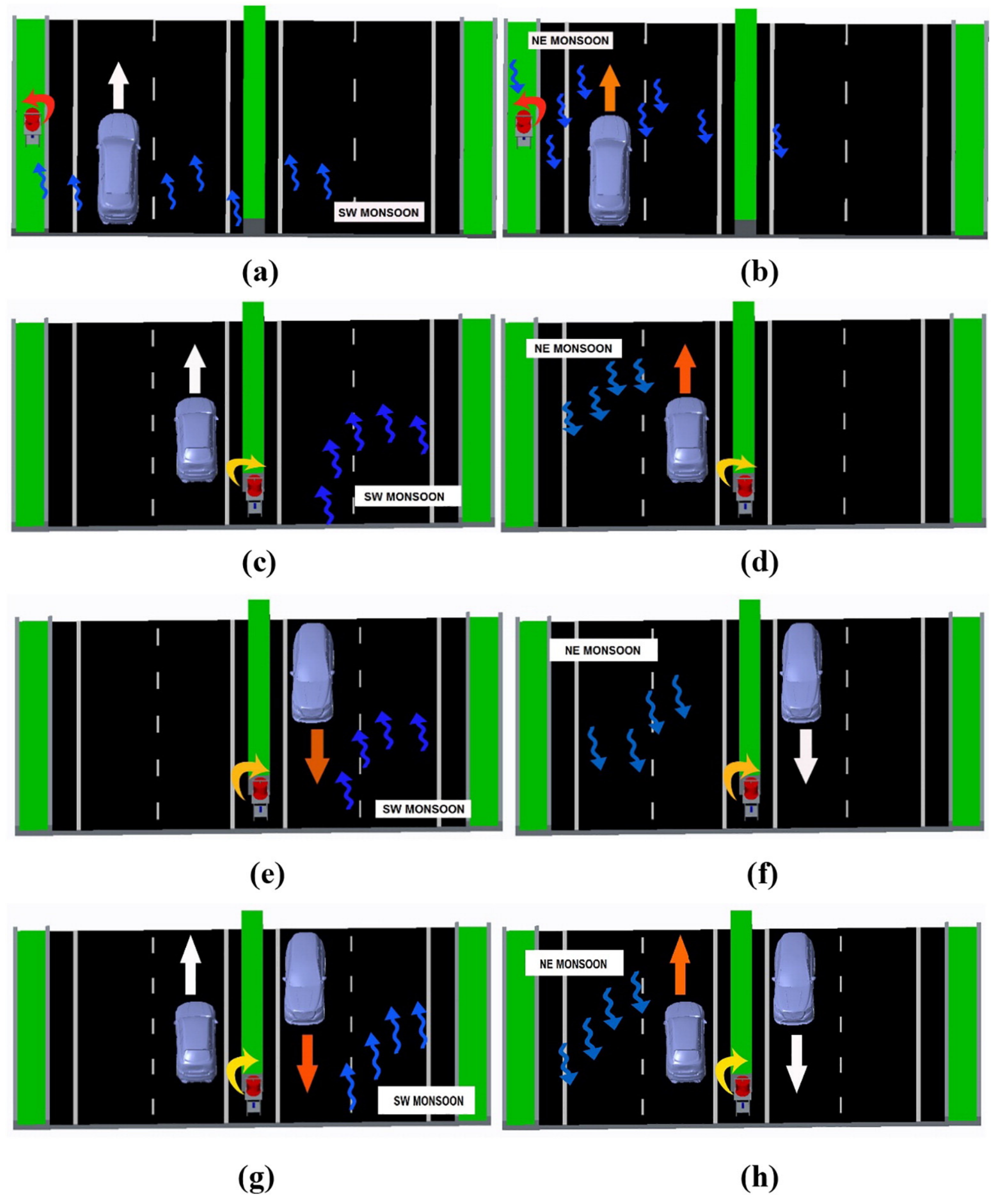


Fig. 9. (a) Wind flow and vehicle traffic in same direction at lane L1 (condition I); (b) Wind flow and vehicle traffic in opposite direction at lane L1 (condition I); (c) Wind flow and vehicle traffic in same direction at lane L2 (condition II); (d) Wind flow and vehicle traffic in opposite direction at lane L2 (condition II); (e) Wind flow and vehicle traffic in opposite direction at lane L3 (condition III); (f) Wind flow and vehicle traffic in same direction at lane L3 (condition III); (g) Wind flow and traffic in same direction at lane L2 & Wind flow and vehicle traffic in opposite direction at lane L3 (condition IV); (h) Wind flow and traffic in opposite direction at lane L2 & Wind flow and vehicle traffic in same direction at lane L3 (condition IV).

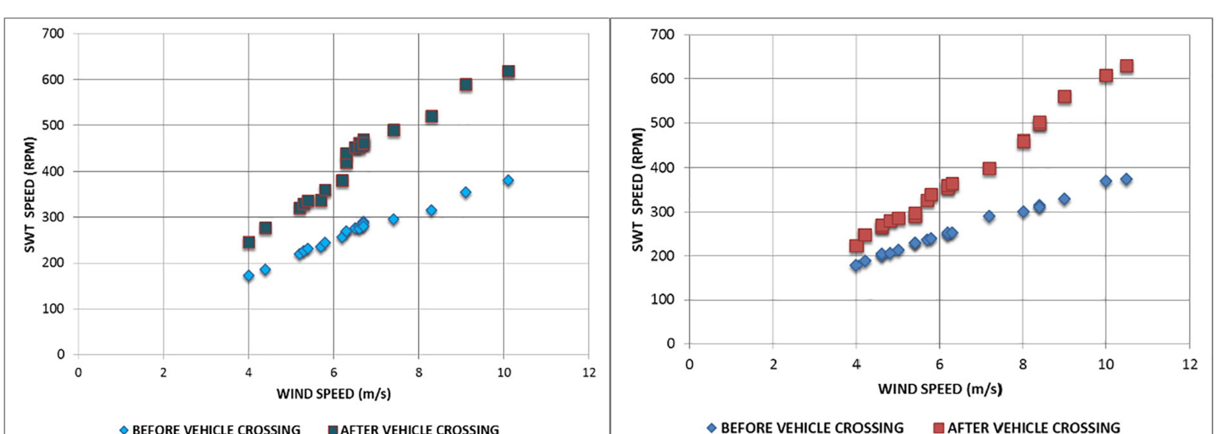


Fig. 10. (a) SWT behaviour at condition I during SW monsoon; (b) SWT behaviour at condition I during NE monsoon.

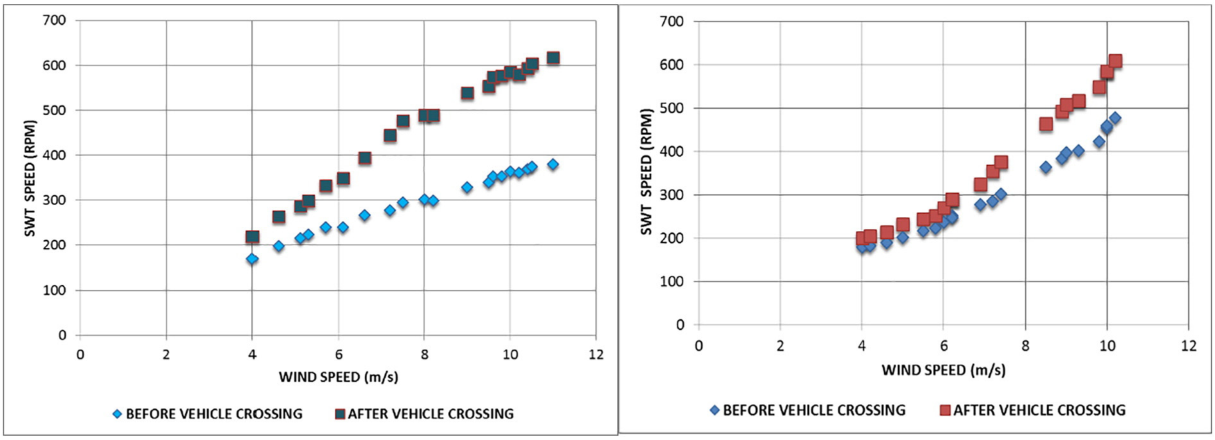


Fig. 11. (a) SWT behaviour at condition II during SW monsoon; (b) SWT behaviour at condition II during NE monsoon.

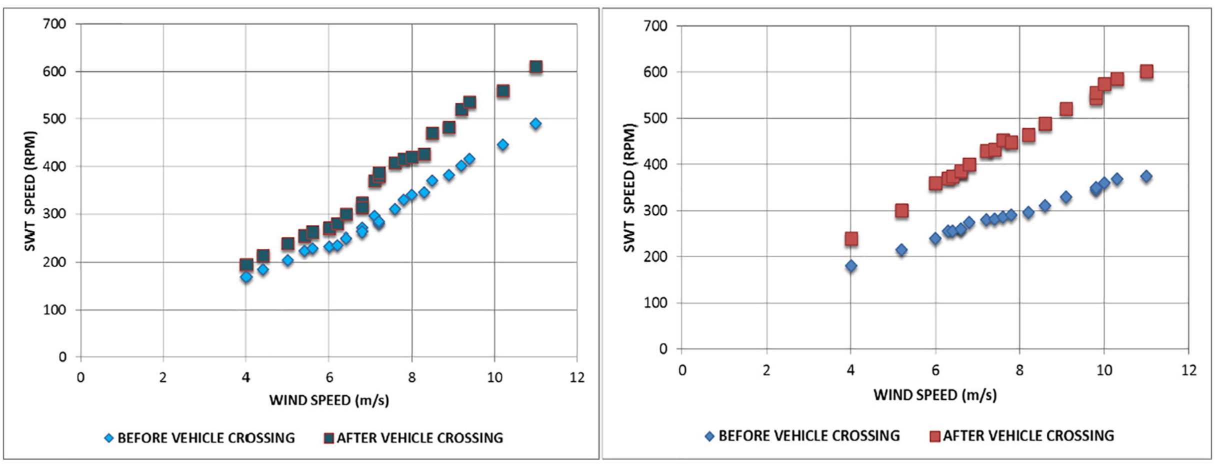


Fig. 12. (a) SWT behaviour at condition III during SW monsoon; (b) SWT behaviour at condition III during NE monsoon.

speed was observed to be 62%. Higher increase in SWT speeds were observed in the above mentioned conditions. This is due to vehicles crossing both sides of SWT in opposite directions at the same instant. Eqs. (8), (9) is used to predict the rotational speeds of SWT for unknown wind speeds during the vehicles crossing the lanes L2 and L3 (condition VI) at the same time.

$$N_{SW} = 76.128 v_{SW} - 49.417; \;\; R^2 = 0.97 \tag{8}$$

$$N_{NE} = 78.421 v_{NE} - 77.525; \;\; R^2 = 0.97 \tag{9}$$

In condition IV, the vehicles passing on lanes L2&L3 are not consistently unidirectional with respect to the wind direction due to changes in monsoons, as in Fig. 9(g) and (h). The movement of vehicles in any one of the lanes will become unidirectional. Vehicular movement in that lane causes an increase in wind turbine's rotational speed due to its unidirectional nature. The alternate lane (where the vehicular

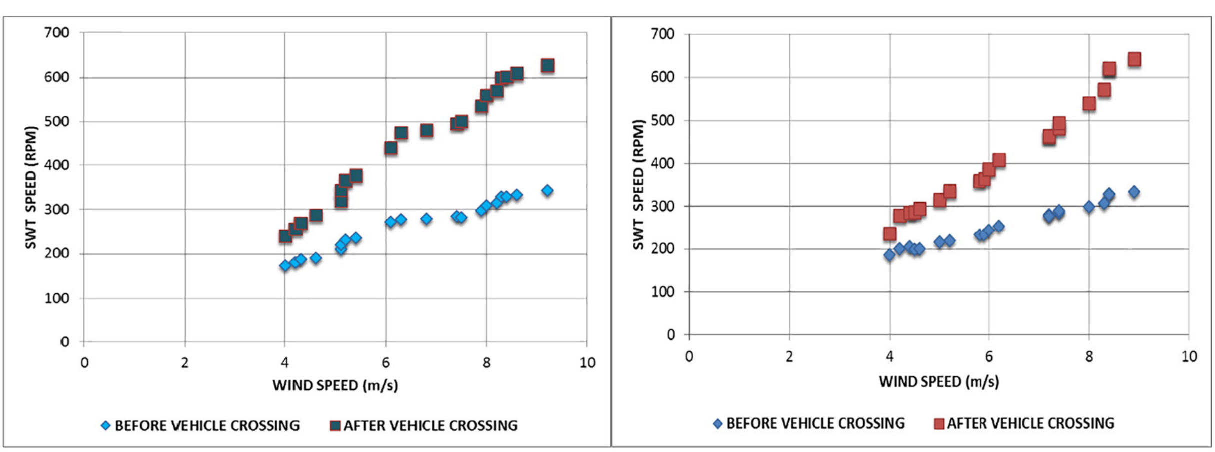


Fig. 13. (a) SWT behaviour at condition IV during SW monsoon; (b) SWT behaviour at condition IV during NE monsoon.

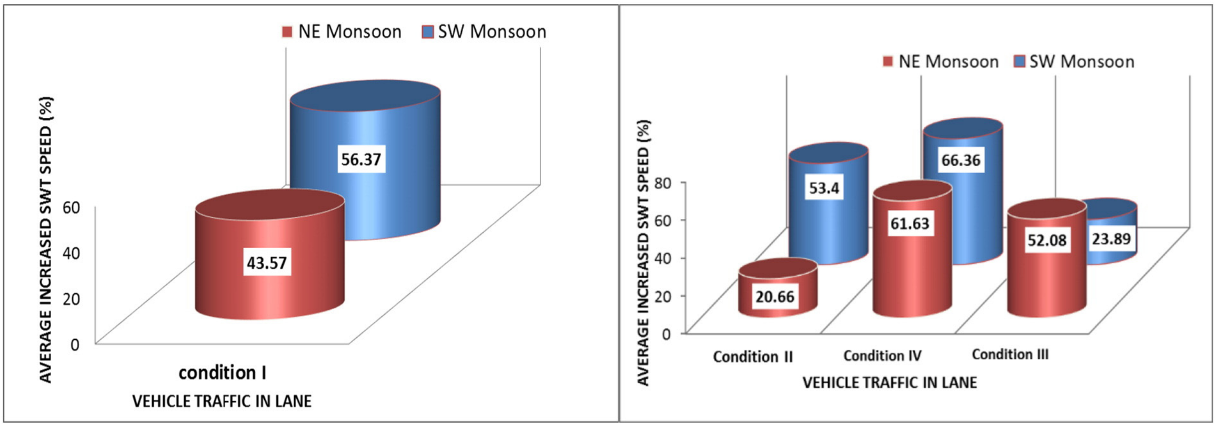


Fig. 14. (a) The increased rotational speeds of SWT at condition I; (b) The increased rotational speeds of SWT at the condition II, III and IV.

movement is opposite to wind direction) contributes to an increase in SWT speed only by 20%.

The average percentage variations of increased final SWT speeds are shown in Fig. 14(a) and (b). The maximum average rotational speeds obtained for condition IV when the turbine is kept at the median of the road is 66% in SW monsoon and 62% during NE monsoon. The minimum average SWT speeds obtained in the condition IV and condition III is 21% at NE monsoon and 24% at SW monsoon. Low variations in SWT speeds are observed when the vehicular movement is opposite to the wind direction.

Initially, the experimental setup generated vibrations whenever the speed increased above 600 RPM, due to the lack of sufficient rigidity in the turbine mountings. The issue was resolved by increasing the structural stiffness of the system. The cost of this set-up is less than \$150 which is nearly six times lesser when compared to the market price of SWT. The future idea of this work is to generate uninterrupted electricity using SWT on the highways in order to store, provide and distribute electricity for the lightings in highways and other applications in surrounding rural areas.

Conclusion

A low cost, vertical axis SWT was designed and fabricated at a cost of \$150. Operating characteristics of the SWT were studied in a wind tunnel. The SWT was placed at different lanes in the highways and the starting and rotational behaviours were studied. The experiments were repeated at different monsoons.

Comparison based on the percentage increase in SWT's average speeds with respect to its nominal speed yields the following conclusions.

In SW monsoon, the average increase in SWT speeds are as follows; condition I - 56.37%; condition II - 53.4%; condition III - 23.89%; and condition IV - 66.36%.

In NE monsoon, the average increase in SWT speeds are as follows; condition I - 43.57%; condition II - 20.66%; condition III - 52.08%; and condition IV - 61.63%.

In both SW and NE monsoons, the condition IV shows highest increase in SWT speeds of 66.36% and 61.63% respectively. Thus, making it the most suitable option for harnessing maximum amount of wind energy from the highways.

This analysis was done at a particular location in southern part of India at varying monsoons. Before installing SWT farms for highway applications, the direction of the road, position of the turbine on highways, vehicle speed limits and the behaviour of SWT at different monsoons must be thoroughly studied to harness maximum amount of wind energy.

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