Experimental investigations on modified Savonius wind turbine with curtain arrangements in the middle of the highway

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ABSTRACT. *The paper presents the design and experimental analysis of highway wind mill using Savonius wind turbine. The highway wind mill is nothing but the wind mill kept in the mid of the road so that, this wind mill utilizes the fast moving wind which is produced from fast moving vehicles travels in the high way. In this work the required wind data have been collected in highways and based on these values the design and fabrication have been made. The output of the wind turbine has been given to the power converter in order to get the constant power output and test has been done on the wind tunnel before implementing in the real application and the results obtained in the wind tunnel test is shown in this paper.*

RÉSUMÉ. *Cet article présente la conception et l'analyse expérimentale d'une éolienne d'autoroute utilisant une turbine de Savonius. L'éolienne d'autoroute n'est autre que l'éolienne maintenue au milieu de la route, de sorte que cette éolienne utilise le vent rapide généré par les véhicules en marche rapide sur l'autoroute pour se déplacer à grande vitesse. Dans ce travail, les données de vent requises ont été collectées sur les autoroutes, et sur la base de ces valeurs la conception et la fabrication ont été réalisées. La sortie de l'éolienne a été transmise au convertisseur de puissance afin d'obtenir une puissance constante. Un test a été effectué en soufflerie avant d'être mis en œuvre dans l'application réelle. Les résultats obtenus lors de l'essai en soufflerie sont présentés dans cet article.*

KEYWORDS: *modified savonius wind turbine, boost power converter, highway wind mill, computational fluid dynamics, curtain.*

MOTS-CLÉS: *éolienne de savonius modifiée, convertisseur de puissance boost, éolienne d'autoroute, dynamique des fluides numérique, rideau.*

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1. Introduction

In this work the required wind data have been collected in highways and based on these values the design and fabrication have been made. The output of the wind turbine has been given to the power converter in order to get the constant power output and test has been done on the wind tunnel as described by (Fujisawa *et al.*, 1994), before implementing in the real application and the results obtained in the wind tunnel test is shown in this paper. This energy source has drawbacks related to economics and pollution. To overcome these drawbacks and to improve the power accessibility, generate electricity from the Renewable Energy Sources (RESs) as suggested by (Ganesh *et al.,* 2015; Cannistraro *et al.,* 2017), which are preferably available locally and environmentally friendly such as wind, solar and hydropower. Owing to the specific advantages, particularly clean, sustainability, the solar energy and wind energy are promising renewable energies among all other renewable energy sources. This research work mainly concentrates on unused energy which is generated by vehicles running at high speed in the high way. By placing the modified savonius wind turbine in the middle of the high way it acquires wind from all the direction so the wasted energy can be utilized in the effective way. The advantage of modified savonius wind turbine as specified by (Bedri *et al.*, 2015) is that, it is an Omni-directional wind turbine, low cost. This system consists of two curtain arrangements to focus wind on one direction. The modified savonius wind turbine which converts wind energy into mechanical energy. Wind velocity with and without vehicle movement is measured using wind anemometer, Vehicle velocity is measured (for both heavy and light vehicle), Wind sustain time is measured. The simplest possible wind-energy turbine consists of two crucial parts as reminded by (Kamoji *et al.,* 2011), there are, Rotor blade and Shaft. The blades are basically the sails of the system; in their simplest form, they act has barriers to the wind (more modern blade designs go beyond the barrier method). When the wind forces the blades to move, it has transferred some of its energy to the rotor as reminded by (Savonius *et al.*, 1931). The wind shaft is connected to the centre of the rotor. When the rotor spins**,** the shaft spins as well. In this way, the rotor transfers its mechanical, rotational energy to the shaft, which enters an electrical generator on the other end as explained by (Manwell *et al.,* 2002). The simplest possible wind-energy turbine consists of two crucial parts there are, Rotor blade and Shaft as described by (Sheldahl *et al.,* 1978). The blades are basically the sails of the system; in their simplest form, they act has barriers to the wind (more modern blade designs go beyond the barrier method). When the wind forces the blades to move, it has transferred some of its energy to the rotor. The wind shaft is connected to the centre of the rotor. When the rotor spins**,** the shaft spins as well. In this way, the rotor transfers its mechanical, rotational energy to the shaft, which enters an electrical generator on the other end. From the collected data the optimum wind velocity is obtained between above half meter from the ground and below one and half meter from the ground. Based on the above constrain the height of the blade is taken as 1m. The breadth of the road divider is 1.5m hence from this constrain the radius is taken as 0.5m and Area =1× 0.5 m2. The basic parameters required in the present study are aspect ratio (H/D), overlap ratio (m/D), blade arc angle (w) and blade shape factor (p/q). Modified Savonius rotors are fabricated from mild steel sheet whose thickness is 2 mm. Rotors are covered at the top and bottom by an acrylic plate of 10 mm thickness. Stainless steel flanges housing the two end shafts are bolted to the two acrylic sheets. In this paper, implementation of vertical axis wind turbine on road dividers which provides effective output operation were analyzed. It can be installed on any highway with the width being the only constraint. The electrical energy conversion system consists of a unidirectional boost converter operates different modes in boost operation and one mode in a buck operation. Simulink model of whole system including unidirectional DC-DC boost converter, bidirectional DC-DC converters were developed for wind energy electrical system and design results were obtained in CFD. A variety of operating conditions from different inputs were analyzed. The system has a robust performance under mode changing while input wind speed changes. The hardware results of the proposed model were verified with design results. The mode changing operation is effectively done in both design and real-time platforms.

In the beginning of 21st century we are in the search of non renewable energy since fast depletion of fossil fuels and pollution as reminded by (Modi *et al.*, 1989). In the highway areas, energy consumers are getting power from only diesel generators as an energy source. This energy source has drawbacks related to economics and pollution. To overcome these drawbacks and to improve the power accessibility, generate electricity from the Renewable Energy Sources (RESs), which are preferably available locally and environmentally friendly such as wind, solar and hydropower. Owing to the specific advantages, particularly clean, sustainability, the solar energy and wind energy are promising renewable energies among all other renewable energy sources. This research work mainly concentrates on unused energy which is generated by vehicles running at high speed in the high way. By placing the modified savonius wind turbine proposed by (Moutsoglou *et al.,* 1995) in the middle of the high way it acquires wind from all the direction so the wasted energy can be utilized in the effective way. The advantage of modified savonius wind turbine is that, it is a Omni-directional wind turbine, low cost. This system consists of two curtain arrangements to focus wind on one direction. The modified savonius wind turbine which converts wind energy into mechanical energy. Then the output from turbine is converted into to electrical energy with help of Generator and it is stored in the battery with the help of bidirectional converter.

2. Wind data collection

Wind velocity with and without vehicle movement is measured using wind anemometer, Vehicle velocity is measured (for both heavy and light vehicle), Wind sustain time is measured. From the collected data the optimum wind velocity is obtained between above half meter from the ground and below one and half meter from the ground. Based on the above constrain the height of the blade is taken as 1m. The breadth of the road divider is 1.5m hence from this constrain the radius is taken as 0.5m and Area $=1\times0.5\ m^2$.

Table 1. Wind data collection

S. No	Actual wind velocity without vehicle	Light vehicles			Heavy vehicles		
		Wind speed (m/s)	Wind sustain time (sec)	Vehicle velocity (km/hr)	Wind speed (m/s)	Wind sustain time (sec)	Vehicle velocity (m/s)
1	4.7	5.4	15	60	7.4	30	50
2	6.2	8.8	12	90	8.0	35	65
3	4.5	5.0	15	50	8.2	25	70
4	6	9.2	20	95	7.7	30	60
5	5.1	7.4	18	70	7.5	27	58
6	6.5	7.8	10	80	9.5	32	75
7	9	11	17	110	10.2	29	80

3. Calculation of power at various stages

The output power of a wind energy system is directly proportional to swept area of the rotor and the output power is directly proportional to triple the velocity of wind.

The basic calculations of wind energy conversion system are as follows

$$\text{Kinetic Energy} = 0.5 \times \text{Mass} \times \text{Velocity}^2 \quad (1)$$

$$\text{Mass} = \text{Velocity} \times \text{Area} \times \text{Density} \quad (2)$$

$$P = 0.5 \times \rho \times A \times C_P \times V^3 \quad (3)$$

Where,

P=Mechanical power in watts.

ρ=Air density (about 1.225 kg/m^3 at sea level)

A=Rotor striking area, exposed to the wind (m^2)

C_P=Coefficient of performance

V=Wind speed (m/s)

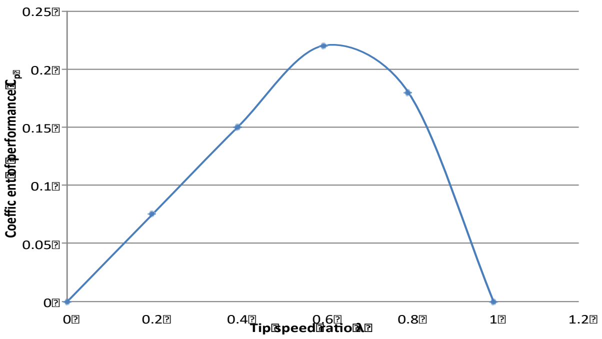

Figure 1. Tip speed v/s Cp

From the above graph for TSR = 0.35 coefficient of performance Cp = 0. (4)

From power equation $P = (1/2) \times (\rho) \times (A) \times (C_P) \times (V^3)$ (5)

$P = (0.5) \times (1.225) \times (0.5 \times l) \times (0.11) \times (9^3) = 25W$ (6)

Table 2. Calculation of theoretical wind power at various wind velocity

Wind speed (km/hr)	Wind speed (m/s)	Calculated mechanical power in watt	Electrical power = 0. 4×mech.power watt
0	0	0	0
5	1.385	0.089	0.035
10	2.770	0.715	0.286
15	4.155	2.410	0.966
20	5.540	5.720	2.290
25	6.925	11.180	4.470
30	8.310	19.320	7.730
35	9.695	30.690	12.270
40	11.080	45.810	18.320
45	12.465	65.230	26.090

Assume 40% efficiency to convert mechanical power in to electrical power.

So, Electrical power = 0.4 x mechanical power

=0.4 x 25 = 10 W.

4. Power converter circuit

The output voltage from the generator is varying according to variable wind velocity but constant input of 12V is given to the battery. For giving constant input to the battery power converter circuit is required. The power converter circuit which is used here is boost converter for step up the voltage.

4.1. Design of DC to dc power converter circuit

According to design the DC-DC power converter is modelled in MATLAB.

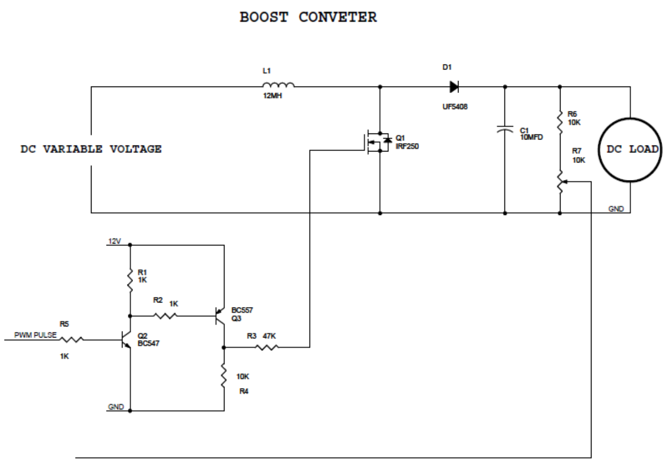

Figure 2. DC to DC power converter

4.2. Design of savonius blade and curtain

The simplest possible wind-energy turbine consists of two crucial parts there are, Rotor blade and Shaft). The blades are basically the sails of the system; in their simplest form, they act has barriers to the wind (more modern blade designs go beyond the barrier method). When the wind forces the blades to move, it has transferred some of its energy to the rotor. The wind shaft is connected to the centre of the rotor. When the rotor spins**,** the shaft spins as well. In this way, the rotor transfers its mechanical, rotational energy to the shaft, which enters an electrical generator on the other end.

4.3. 2D View of the savonius blade

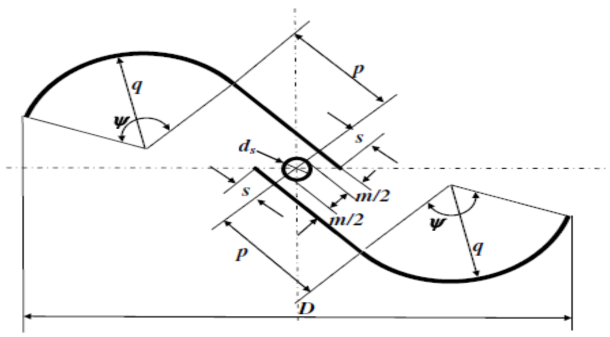

Figure 3. 2D view of savonius blade

4.4. Savonius blade design geometrical parameters

The basic parameters required in the present study are aspect ratio (H/D), overlap ratio (m/D), blade arc angle (w) and blade shape factor (p/q). Modified Savonius rotors are fabricated from mild steel sheet whose thickness is 2 mm. Rotors are covered at the top and bottom by an acrylic plate of 10 mm thickness. Stainless steel flanges housing the two end shafts are bolted to the two acrylic sheets.

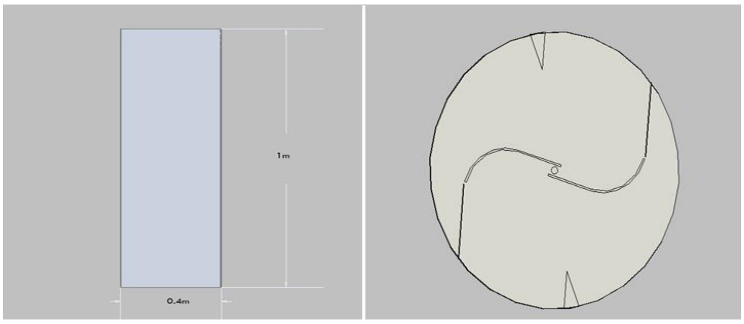

Figure 4. Modified savonius wind turbine with curtain arrangements

5. Analysis of the blade design with and without curtain

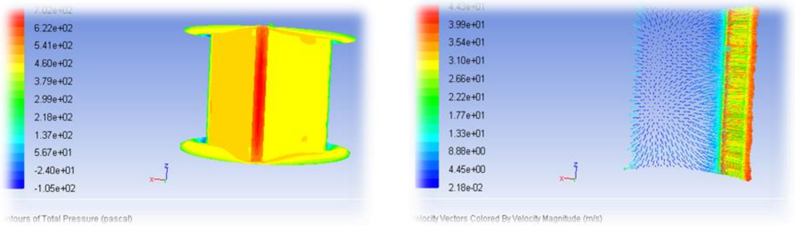

Figure 5. Pressure and velocity acting on MSWT without curtain

The designed normal (semi-circular) savonius wind turbine (NSWT) and the modified savonius wind turbine (MSWT) with and without curtain is subjected to CFD analysis in Fluent Software. The Wind velocity acting on the blade for both normal and modified savonius blade is 9m/s, for normal savonius blade the outlet wind velocity is 9.92 m/s and for modified savonius blade the outlet wind velocity is 11.813. The outlet velocity increases by approximately 2 m/s for modified savonius wind turbine. Hence the modified savonius blade is suitable for the available wind velocity. The velocity and pressure diagrams are given below.

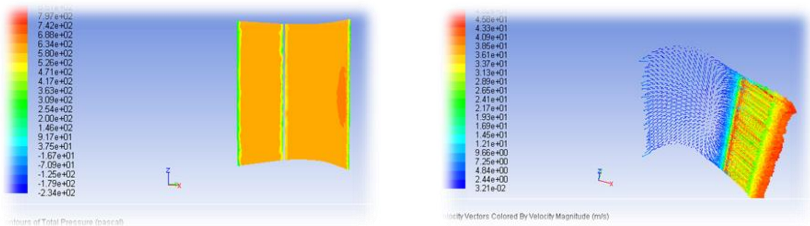

Figure 6. Pressure and Velocity acting on MSWT with curtain

The Wind velocity acting on the blade for both normal and modified savonius blade is 9m/s, for normal savonius blade the outlet wind velocity is 9.92 m/s and for modified savonius blade the outlet wind velocity is 11.813. The outlet velocity increases by approximately 2 m/s for modified savonius wind turbine. Hence the modified savonius blade is suitable for the available wind velocity. The velocity and pressure diagrams are given. By placing a curtain, the inlet wind velocity acting on the blade is 9 m/s. The pressure acting on the blade without curtain is 477.96 pascal and the outlet velocity is 11.183 m/s. The pressure acting on the blade with curtain is 614.734 pascal and outlet velocity is12.06 m/s. comparing the modified savonius wind turbine with and without curtain the pressure acting on the blade increases by 136.767pascal and velocity outlet increases by 1m/s.

6. Power converter & blade fabrication

Figure 7. Power converter circuit board

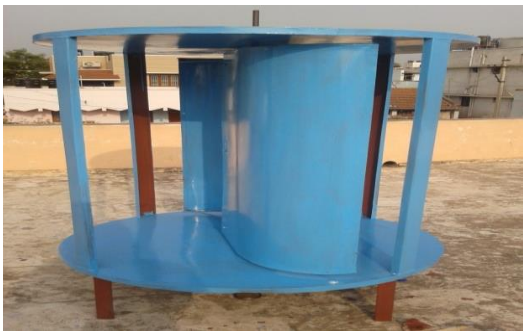

Figure 8. Vertical axis wind turbine

7. Experimental results

The output load performance of the wind turbine has been measured by using multimeter. The anemometer is used to measure the velocity of the wind and the corresponding open-end voltage to be generated by the PMDC motor is measured and the readings are tabulated. The output voltage from the PMDC motor is varying according to the varying wind velocity. So the output is directly given to the boost converter to give constant input to the battery. The battery which is used here is the lead acid battery.

Table 3. Calculation of experimental wind power at various wind velocity

Wind speed (km/hr)	Wind speed (m/s)	Electrical power output in watt
0	0	0
5	1.385	4.5264
10	2.770	8.0532
15	4.155	12.5036
20	5.540	17.976
25	6.925	26.898
30	8.310	35.426
35	9.695	46.872
40	11.080	60.120
45	12.465	78.136

Then the speed of the rotor has been measured using torque transducer. The speed of the normal savonius blade which is taken as rpm 1 and the speed of the modified savonius blade which is taken as rpm 2 which is shown in the table below.

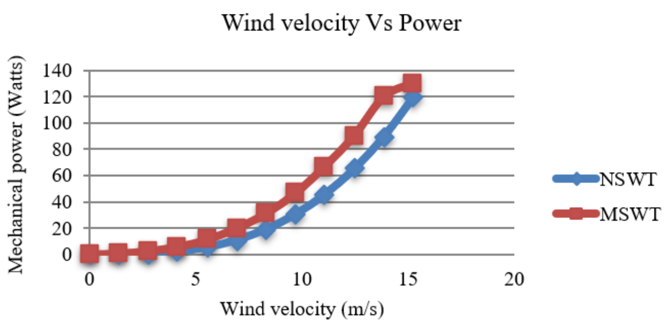

Figure 9. Graph shows the mechanical power vs wind velocity

Table 4. Calculation of experimental wind power at various wind velocity

V(m/s)	RPM 1	RPM 2
6	46	62
6.5	50	73
7.5	55	80
8.5	60	90
9.2	71	99
9.8	80	110
10.2	87	121

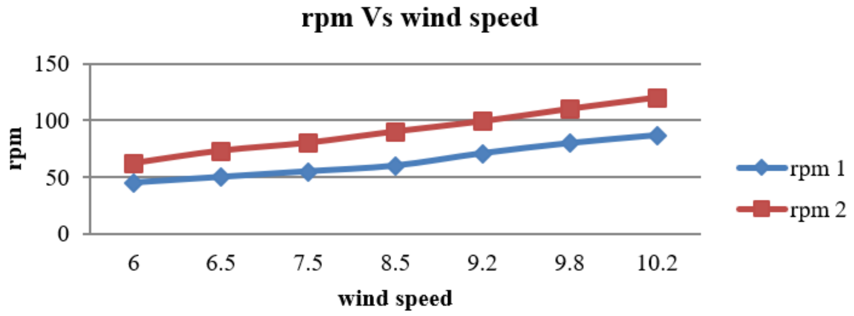

Figure 10. Graph showing the wind speed Vs rpm

8. Conclusion

In this paper, implementation of vertical axis wind turbine on road dividers which provides effective output operation were analyzed. It can be installed on any highway with the width being the only constraint. The electrical energy conversion system consists of a unidirectional boost converter operates different modes in boost operation and one mode in a buck operation. Simulink model of whole system including unidirectional DC-DC boost converter, bidirectional DC-DC converters were developed for wind energy electrical system and design results were obtained in CFD. A variety of operating conditions from different inputs were analyzed. The system has a robust performance under mode changing while input wind speed changes. The hardware results of the proposed model were verified with design results. The mode changing operation is effectively done in both design and real-time platforms. Since the battery is portable, we can use it in some other location for any low voltage purpose. It will provide effective solution for the boom of the electrical energy by the society.

Reference

Bedri K., Muğdeşem T., Ali E. (2015). Wind tunnel performance data for two and three bucket Savonius rotors. *J Acta Polytechnica Hungarica*, Vol. 12, No. 3, pp. 199-211.

Cannistraro G., Cannistraro M., Trovato G. (2017). Islands "Smart Energy" for eco-sustainable energy a case study "Favignana Island". *International Journal of Heat and Technology*, Vol. 35, No. 1, pp. S87-S95. https://doi.org/10.18280/ijht.35Sp0112

Fujisawa N., Gotoh F. (1994). Experimental study on the aerodynamic performance of a savonius rotor. *Journal of Solar Energy Engineering*, Vol. 116, No. 3, pp. 148-152. https://doi.org/10.1115/1.2930074

Ganesh G., Kumar G. V., Babu A. R. V., Rao G. S., Tagore Y. R. (2015). Performance analysis and MPPT control of a standalone hybrid power generation system. *J Electrical Engg*, Vol. 15, No. 1, pp. 334-343.

Kamoji M. A., Kedare S. B., Prabhu S. V. (2011). Experimental investigations on modified Savonius rotor. *Wind Engineering*, Vol. 35, pp. 483-510. https://doi.org/10.1260/0309-524X.35.4.483

Manwell J. F., McGowan J. G., Rogers A. L. (2002). *Wind Energy Explained: Theory, Design and Application*. https://doi.org/10.1002/0470846127

Modi V. J., Fernando M. (1989). On the performance of the Savonius wind turbine. *Journal of Solar Energy Engineering*, Vol. 111, No. 1, pp. 71-81. https://doi.org/10.1115/1.3268289

Moutsoglou A., Weng Y. (1995). Performance tests of a benesh wind turbine rotor and a Savonius rotor. *Wind Engineering*, Vol. 19, No. 6, pp. 349-362.

Savonius S. J. (1931). The S-rotor and its applications. *Mech Engg*, Vol. 53, No. 5, pp. 333-338.

Sheldahl R. E., Blackwell B. F., Feltz L. V. (1978). Wind tunnel performance data for two and three bucket Savonius rotors. *Journal of Energy*, Vol. 2, No. 3, pp. 160-164. https://doi.org/10.2514/3.47966