A Novel Approach Concerning Wind Power Enhancement

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Abstract

Being a tropical country, Bangladesh does have wind flow throughout the year. However, the prospect for wind energy in Bangladesh is not at satisfactory level due to low average wind velocities at different regions of the country. The field survey data indicated that the wind velocities are relatively higher from the month of May to August, whereas, it is not so for the rest of the year. Therefore, exploiting the wind energy at low wind velocities is a major predicament in creating a sustainable energy resource for a country with inauspicious forthcoming energy crisis. The scope of this paper concentrates on an innovative approach to harness wind power by installing an auxiliary unit which would only assist the primary turbine unit in case the wind velocity falls under the required value. The auxiliary unit would comprise a secondary turbine, which would be operated by a DC motor connected to a battery system that is charged by a solar panel. A specially designed conduit would encompass both the primary and auxiliary turbine units. A CFD simulation utilizing ANSYS FLOTRAN was carried out to investigate the velocity profiles for different pressure differences at different regions of the prototype conduit. A feasibility analysis of the modified system was eventually carried out for the preferred conduit design.

Keywords: Wind Energy, Solar Energy, CFD, FEM, Wind Power Enhancement.

1. INTRODUCTION

It is well known that the main drawback of wind power is the inherent variable behavior. Significant research has been carried out to improve the performance of the wind turbines to enhance the performance and establish the power system stability. Novel and significant designs of the wind turbines were developed during last few years. From the scientific literature survey it was found that a wind turbine system was developed which consists of a diffuser shroud with a broad-ring flange at the exit periphery and a wind turbine inside it for obtaining a higher power output [1]. Also for the optimization of the wind turbine energy as well as power factor an evolutionary computation algorithm was established. This evolutionary strategy algorithm solves the data-derived optimization model and also determines optimal control settings for the wind turbine [2]. To obtain a reliable and steady output of power, wind turbines are generally integrated with conventional solar panel or biomass energy or hydro power systems. From the previous research works hybrid photovoltaic wind energy system was analyzed to provide better electricity output to the grid [3]. From the literature survey it was also found that the Hybrid Solar-Wind System Optimization Sizing (HSWSO) model was developed to optimize the capacity sizes of different components of hybrid solar-wind power generation systems that employ a battery bank. A case study was reported in that paper to show the importance of the HSWSO model for sizing the capacities of wind turbines, PV panel and battery banks of a hybrid solar-wind renewable energy system [4]. Wind power was also complemented by hydropower to obtain firm power output. For getting constant power output in a hybrid power station without the intermittent fluctuations inherent when using wind power a conceptual framework was provided [5]. Wind power could be also integrated with bio energy. An innovative system combining a biomass gasification power plant, a gas storage system and stand-by generators to stabilize a generic 40 MW wind park was proposed and evaluated with real data [6]. In this current study, a novel design is proposed to enhance the wind power. A primary turbine is placed in a conduit inlet which would be governed by a secondary turbine at low wind speed placed in the conduit outlet. The secondary turbine would be coupled with a DC motor where the motor would be directly connected to the battery bank. The battery would be charged by the solar panel. This design mainly encompasses the scenario where the wind speed fluctuates in a significant manner. For example, the prospect for wind energy in Bangladesh is not at satisfactory level due to low average wind velocities at different regions of the country. However, there are some places in Bangladesh like coastal areas where wind speed is relatively higher for harnessing power but is not constant for all the time during power extraction. So the primary concentration would be to extract power at relatively low wind speed. In this paper, an innovative approach is shown with clear description to enhance the wind power and simulation of the design is also provided. Finally a comparative feasibility analysis of the modified system with the conventional wind turbine is given with elaborate mathematical explanations.

The following table gives information about the monthly variation of wind speed in some places of Bangladesh. It is clear that the wind speed is not constant for power extraction at promising level during a certain year, rather, it fluctuates in a significant manner. It shows that during few months for certain regions in the country power extraction from the wind turbine is not at all possible.

Locations	Months												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Mean
Barisal	2.90	2.57	2.57	3.56	3.23	2.90	2.71	2.64	2.57	2.11	2.07	2.05	2.66
Bogra	1.95	2.20	3.05	4.03	4.15	3.66	3.42	3.05	2.56	2.20	1.83	1.71	2.82
Chittagong	3.64	2.88	4.95	5.01	5.51	6.89	7.09	6.83	4.64	2.82	3.39	2.20	4.65
Comilla	2.26	2.70	2.57	5.45	3.83	3.20	2.88	2.95	1.82	2.38	1.63	1.70	2.78
Cox'sBazar	3.76	3.83	4.51	5.58	3.83	4.14	3.83	3.95	3.20	3.26	2.57	3.26	3.81
Dhaka	3.39	3.26	4.39	5.77	6.33	5.71	6.01	5.89	4.39	3.45	2.64	2.95	4.52
Dinajpur	2.68	2.44	4.88	2.44	2.93	2.68	2.56	2.44	2.44	3.54	2.44	2.44	2.83
Hatiya	3.04	2.64	4.16	3.97	4.82	6.47	5.75	2.64	2.96	2.77	3.06	2.57	3.74
Jessore	2.88	2.95	4.95	8.34	8.34	6.27	6.15	4.95	4.33	3.45	3.32	3.20	4.93
Khepupara	4.20	4.39	3.83	7.09	5.83	4.71	4.14	3.95	3.57	3.70	2.95	2.57	4.24
Khulna	2.96	1.65	3.04	3.05	4.16	3.89	3.31	2.44	2.51	1.98	3.31	2.38	2.89
Kutubdia	1.77	1.82	2.32	2.70	2.77	3.65	3.61	3.14	2.11	1.45	1.19	1.29	2.32
Mongla	1.07	1.25	1.72	2.51	2.92	2.63	2.48	2.35	1.83	1.27	1.02	1.01	2.20
Rangamati	1.45	1.65	4.42	3.10	2.11	3.23	1.72	2.24	1.45	1.45	1.39	1.59	2.15
Sandip	2.32	3.01	3.20	4.83	2.44	3.83	3.39	2.70	2.32	1.63	1.70	1.70	2.76
Sylhet	2.20	2.93	3.29	3.17	2.44	2.68	2.44	2.07	1.71	1.95	1.89	1.83	2.38
Teknaf	3.70	4.01	4.39	4.01	3.32	3.89	3.83	2.88	2.44	2.20	1.57	1.76	3.17
Patenga	6.22	6.34	7.37	7.92	8.47	8.69	9.20	8.54	7.48	6.93	6.71	5.91	7.48
Sathkhira	4.21	4.40	3.84	7.10	6.11	4.76	4.27	4.03	3.62	3.78	3.54	2.81	4.37
Thakurgaon	4.15	5.06	7.93	8.43	8.66	8.05	7.93	6.59	6.34	5.98	5.25	4.76	6.59

TABLE 1: Average Wind Speed (m/s) at 20 Meters Height at Different Locations in Bangladesh [7].

2. Basic Theory

W. J. M. Rankine and W. E. Froude established the simple momentum theory for application in the ship's propeller. Later, A. Betz of the Institute of Gotingen used their concept to the windmill.

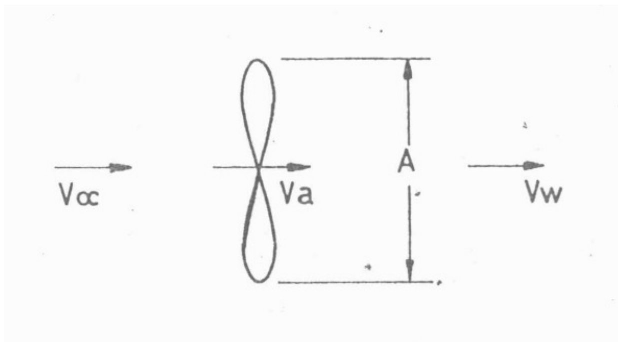

FIGURE 1: Flow velocities through a windmill.

As shown in the fig.1, the symbols, and respectively are the free stream wind velocity, induced velocity and wake velocity. When the flow occurs through the windmill, the flow is retarded and it is further retarded in the downstream side of the windmill. The flow velocity through the windmill is usually called the induced velocity, while the flow velocity in the downstream side is called the wake velocity because wake is formed there. According to the Newton's Second law of motion the thrust developed in the axial direction of the rotor is equal to the rate of change of momentum i.e.

$$\text{Axial Thrust} = m(V_\infty - V_w) \tag{1}$$

Where m is the mass of air flowing through the rotor in unit time.

Therefore, the power produced is given by,

$$P = m(V_\infty - V_w)V_a \tag{2}$$

The rate of kinetic energy change in the wind is,

$$\Delta K.E/\sec = \frac{1}{2}m(V_\infty^2 - V_w^2) \tag{3}$$

Now balancing the equations (2) and (3),

$$m(V_\infty - V_w)V_a = \frac{1}{2}m(V_\infty^2 - V_w^2) \tag{4}$$

After simplifying the equation (4), one obtains

$$V_a = \frac{V_\infty + V_w}{2} \tag{5}$$

Glauert determined the identical expression in his actuator disc theory. Here the flow is assumed to occur along the axial direction of the rotor and the velocity is uniform over the swept area, A of the rotor.

Since, $m = A\rho V_a$, from the equation (2), one finds the expression of power extraction through the rotor,

$$P = \rho A V_a (V_\infty - V_w) V_a \tag{6}$$

Where, ρ is the density of air. Substituting the value of V_a from the equation (5) in the equation (6),

$$P = \rho A V_a^2 (V_\infty - V_w) = \rho A (\frac{V_\infty + V_w}{2})^2 (V_\infty - V_w)$$

which can be rewritten as,

$$P = \frac{\rho A V_\infty^3}{4}(1 + \frac{V_w}{V_\infty})[1 - (\frac{V_w}{V_\infty})^2] \tag{7}$$

Inserting $x = V_w / V_\infty$ in the equation (7),

$$P = \frac{\rho A V_\infty^3}{4}(1 + x)(1 - x^2) \tag{8}$$

Now differentiating P of the equation (8) with respect to x and setting it to zero for maximum power, one obtains,

$$x = \frac{V_w}{V_\infty} = \frac{1}{3} \tag{9}$$

Substituting $V_w = \frac{V_\infty}{3}$ in the equation (7) and simplifying, the expression of maximum power extraction is obtained as,

$$P_{\max} = \frac{8}{27} \rho A V_\infty^3 \tag{10}$$

The available energy in the wind is the kinetic energy per unit time,

$$K.E / \sec = \frac{1}{2} m_i V_\infty^2 = \frac{1}{2} \rho A V_\infty^3 \tag{11}$$

Here mass of air (m_i) flowing through the rotor has been considered to be ideal i.e. full air flows through the rotor, as such $m_i = A\rho V_\infty$.

3. Modification and Design for Wind Power Enhancement

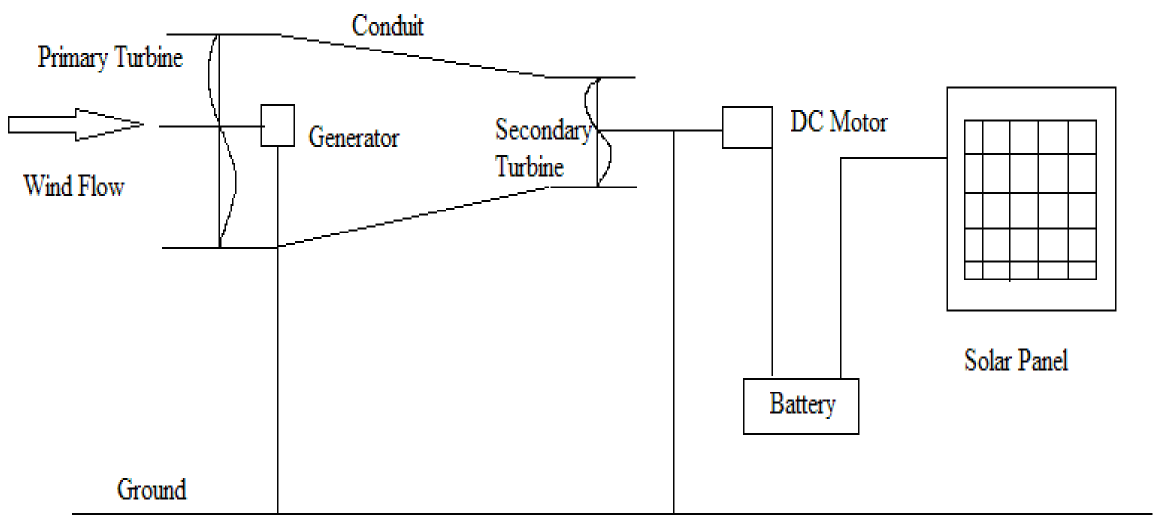

FIGURE 2: Schematic of the proposed modified design of the system.

As shown in fig.2, the primary turbine and the secondary turbine would be set at the inlet and the outlet of the taper shaped conduit consecutively. The primary turbine would comprise a generator which would be installed inside the conduit. The secondary turbine would run by a DC motor which would be connected to the battery system that would be charged by the solar panel. A PV solar panel would be used as a back up source for the DC motor.

When the wind speed would reach the desired level for power extraction the primary turbine would start to rotate and would give a certain power output. The wind would then pass through the conduit striking the blades of the auxiliary turbine with a relatively low energy compared with the inlet wind energy. The converging section of the conduit is helpful in increasing the air velocity that could be utilized to run the auxiliary unit effectively. Therefore power would also be produced by the auxiliary unit where the DC motor will act as a generator. Next when the wind speed goes down below the desired level then the secondary turbine will run with the help of DC motor to assist the primary turbine to rotate. In this case the primary turbine delivers the electrical power whereas the secondary unit gets the power from the DC motor connected to the battery bank. When the wind speed again reaches at the desired level then the DC motor will stop and act as a generator because of the natural wind flow through the secondary turbine. The overall power extraction as well as system efficiency is enhanced with the help of this proposed design. In the next two sections the feasibility of this proposed system is justified with simulation and mathematical calculations.

4. SIMULATION RESULTS

ANSYS FLOTRAN simulations were carried out with steady state, standard κ-ε turbulent model for varying downstream diameters of the conduit with varying pressure differences. From the simulations results depicted in fig.3, downstream diameter of 0.6 meter with upstream and downstream pressure difference of 30 Pa was selected to be the preferred parameters as this would provide the cut-in velocity of 5 m/s in the upstream region of the conduit. Fig.4 depicts the air velocity profile with the selected parameters.

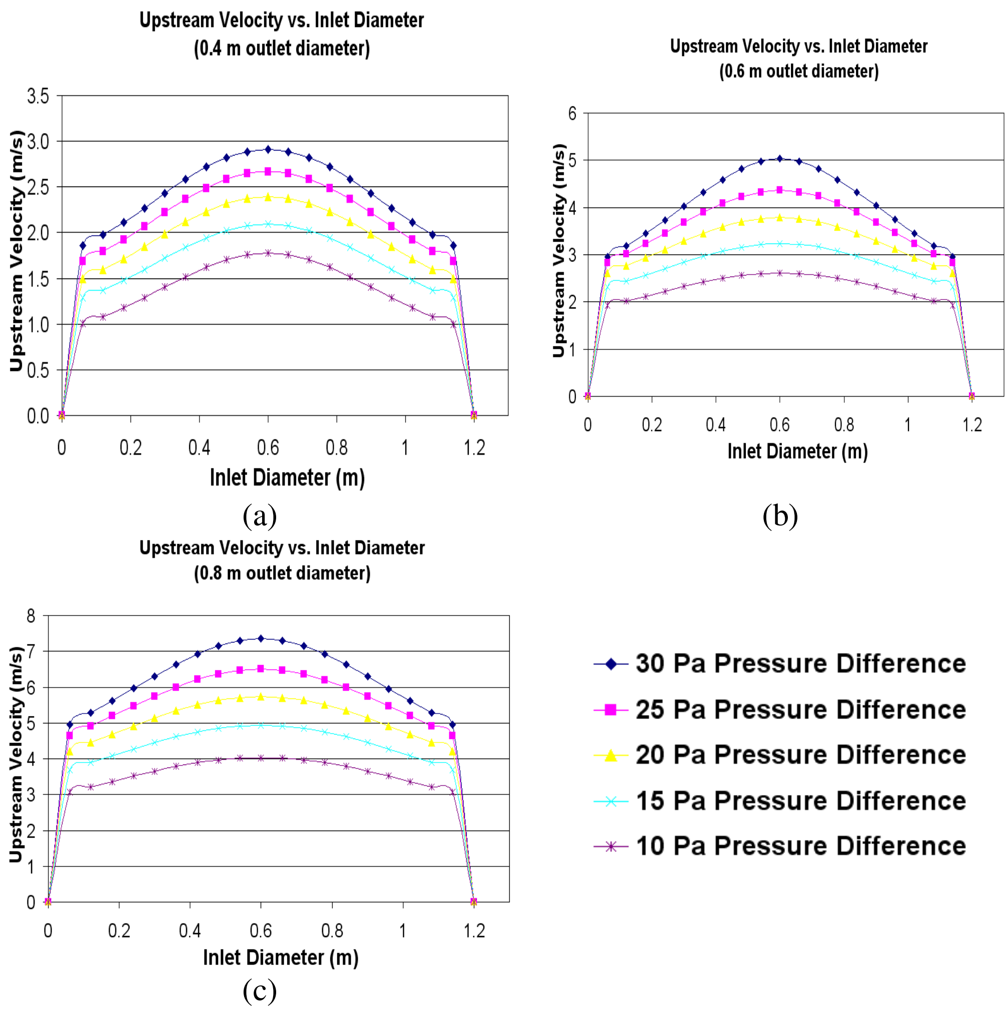

FIGURE 3: Upstream velocity vs. inlet diameter of the conduit for the outlet diameter of (a) 0.4m, (b) 0.6m, and (c) 0.8m.

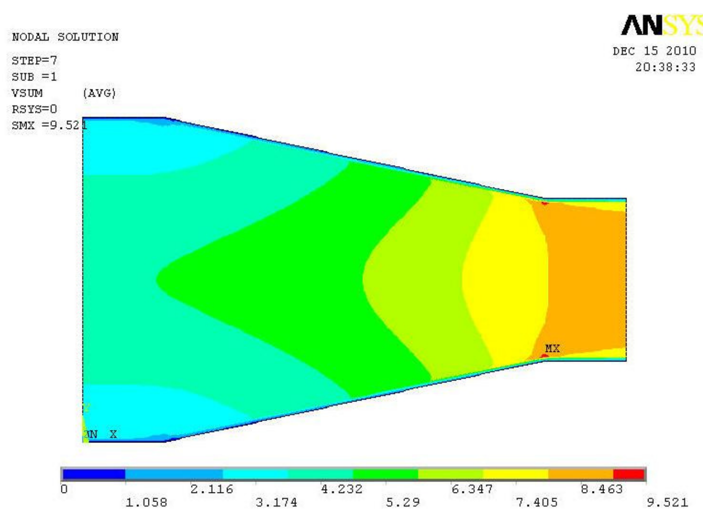

FIGURE 4: Velocity profile of air through the conduit (0.6m outlet diameter, pressure difference 30 Pa).

5. FEASIBILITY ANALYSIS OF THE MODIFIED SYSTEM

The feasibility analysis of the modified system is based on theoretical calculations. Here all conditions are assumed ideal.

Assumptions:
Diameter of the primary wind turbine = 1.1m
Diameter of the secondary wind turbine = 0.5m
Cut-in speed for 1.1m diameter turbine = 5m/s (approximated)
Inlet velocity at the primary turbine, $V_1 = 5m/s$
Inlet velocity at the secondary turbine, $V_2 = 8m/s$
The velocity variations were considered from the simulation results.

From fig.5, considering a specific scenario for the Cox's Bazar region, the theoretical calculation for feasibility analysis was carried out. From the figure it can be seen that, in the Cox's Bazar region cut-in speed could be achieved for the period of 12 hours for power extraction. However, for the remaining 12 hours, the wind speed is below the cut-in speed. Here, an analytical solution was attempted considering the cut-in speed as the maximum tolerance limit of 5 m/s.

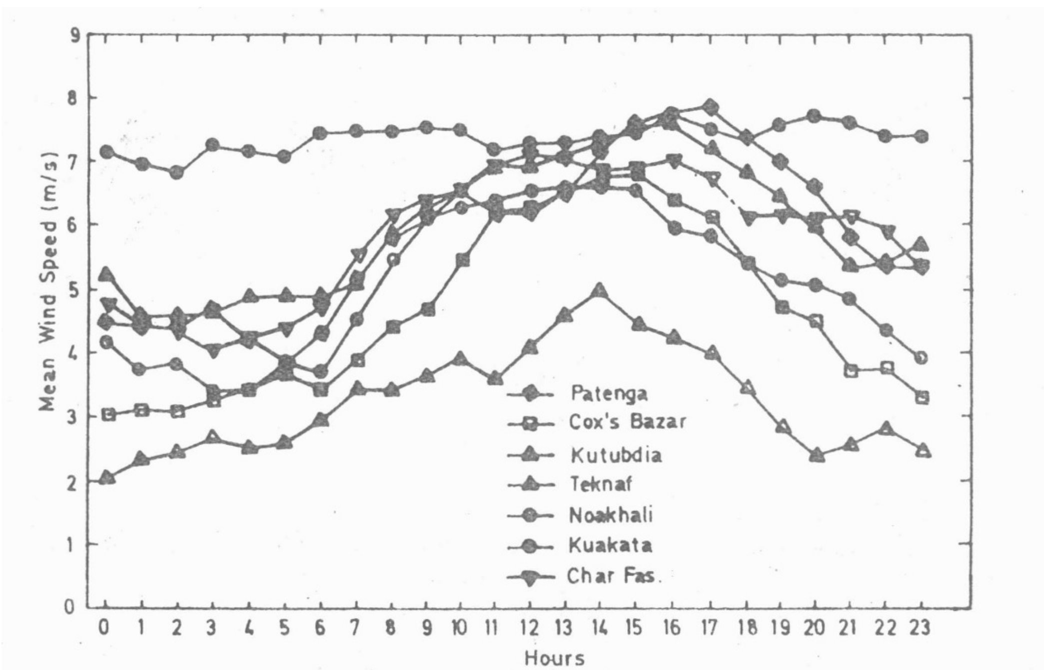

FIGURE 5: Diurnal Variation of Wind Speed in Some Places of Bangladesh [8].

For 12 hours when wind speed is at the cut-in speed of primary turbine the energy output from the primary turbine is $E_1 = \frac{8}{27}\rho A V_\infty^3 \times t$ =1824.64 KJ (Considering equation 10)
And for 12 hours the energy output also from the secondary turbine is $E_2 = 1544.16KJ$
Now for the rest of the 12 hours period when wind speed is below the cut-in speed of the primary turbine energy output from the primary turbine is $E_3 = 1824.64KJ$

And for 12 hours period energy input to the secondary turbine is $E_4 = \frac{1}{2}\rho Q(V_2^2 - V_1^2) \times t = 1587.89KJ$

The net energy output from the system is $E = E_1 + E_2 + E_3 - E_4 = 3605.55KJ$

Energy output from the same conventional wind turbine which would only work for 12 hours period is theoretically, $E_5 = 1824.64KJ$

Thus, during 24 hours, the amount of energy enhanced from the modified system was $(E - E_5) = 1780.91KJ$ or 20.61W. Here minimum energy has been gained considering the cut-in velocity. More energy could be harnessed when the wind flows at relatively higher speeds.

6. CONCLUSION AND FUTURE WORK

In this current research work a conceptual design has been proposed which was validated by the ideal theoretical formulations. Simulation results showed the wind speed variations through the conduit. Wind power could be enhanced by a certain amount by implementing this novel design. This feasible design could be implemented where wind speed is not at satisfactory level like Bangladesh. It would be beneficial if energy of the wind can be extracted at relatively low speed. Further research is currently being held regarding the prototype manufacturing and testing. Subsequently, the economical viability of the overall system would also be analyzed.

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