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Theoretical Results for Utilizing Nozzle Between the Wind-Way and Wind Turbine in Roof of the Buildings - Wind Speed Increase for Wind Turbine to Produce Electricity

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Abstract

In order to increase the electrical power of the wind turbines, the velocity of the wind blowing on the wind turbine, is the most important factor that has to increase. In this paper it has been recommended that Contraction Nozzles could be applied between Wind Turbines and wind-way to provide the wind through themselves with more velocity. For all cases analysed in this paper, a three dimensional contraction nozzle with the same length (3 meters) but different input (in which wind blows through it) and output segment areas is considered. In the presented calculations, the inlet mean velocity is considered a constant value of $3\frac{m}{s}$ in a windward area. Numerical solutions and CFD results have been the same for increased wind velocity in each Nozzle outlet or wind turbine's inlet. Furthermore, the electrical power of related wind turbines has been numerically calculated in the presence and absence of the nozzles between wind turbines and wind flow and it shows a dramatic increase in wind turbines power.

Keywords: Wind energy; Wind turbines; Contraction nozzle; Electrical power; Increasing wind velocity

Introduction

It has been inventing different machinery devices which can convert different kind of energies to each other. Using all energy resources make humanity's life more comfortable. The electricity is a secondary energy source, which we can obtain it from the conversion of different kind of primary sources like oil, nuclear power, natural gas, coal and other natural sources.

As we know, the flows, which without any limitation are produced in the nature and on the buildings (External Flows), blow abundantly especially in the windward areas. It is also common for homeowner to install Wind Turbine near their home to make use of wind energy. In this case, the velocity of wind is so important because every wind turbine needs an appropriate and specific amount of velocity to be turned by wind.

Almost in all over the world, most of the electrical power of the buildings is made in power stations. Turbines, that are turned very quickly, are large machines used in power stations to produce electricity by conversion of mechanical energy into electrical power (electrical current is made by the relative movement between magnetic field and conductor) so that a large amount of energy is needed to turn the turbines for producing electrical energy in power stations for household uses.

In other side, according to overt researches, nowadays the consumption of all sorts of energy has been increased. As a matter of fact, with daily development of science and technology and decreasing of natural and non-renewable resources, the optimal use of all sorts of energy is so important to human. Due to huge amount of energy for power stations to start electric energy, the governments tend to optimally use renewable energy sources. There is no doubt that Wind Energy, which is renewable energy, has obvious role in different energy supply such as Electrical power. Due to the fact that wind does not emit greenhouse gases and utilizes no fossil fuel, it has been known as one of the greenest forms of energy. Most homes that uses wind turbine's electrical power are still tied into the power grid when the wind blows slowly [1]. Recently with the development of making of the wind turbines, it has been easier to install wind turbines in a residential area, on the ground or on the roof of the buildings [2].

As it has been said Wind Turbines are one of the most significant electrical energy resources, it may be practical that, in the windward areas, each building to provide its required electrical energy by installing wind turbines on the buildings or close the building where wind blows (especially in rural regions).

Providing the electricity energy of buildings by wind turbine is practical but the main problem of this kind of source energy is that it is only useable for wind-ward areas and therefore the main problem for areas with low speed-blowing wind is the velocity of the wind to spin a wind turbine. According to aerodynamic principles, there must be methods to increase the wind speed. In the windward areas, even low-wind-speed areas, some contraction nozzle can be horizontally installed in a roof of a building, located between wind turbines and wind-way to increase the velocity of incoming wind and then increase the overall electrical power of the wind turbines. It is the aim of this project to bring increased wind energy, caused by contraction nozzle, to household us even in low-speed wind-ward areas.

Calculations and Results

As we know the external flows, which without any limitation are produced in the nature and on the buildings, blow repeatedly in the

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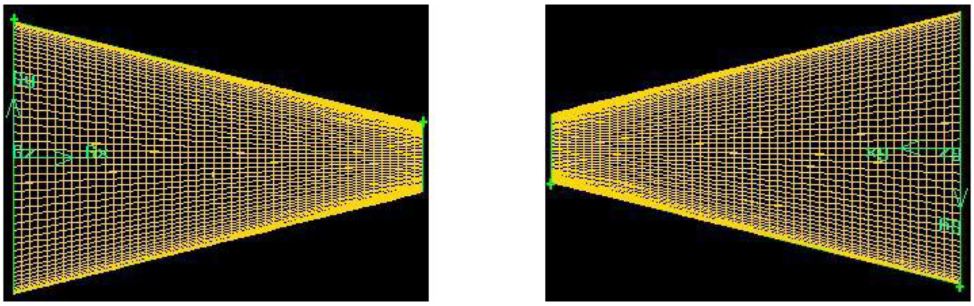

Figure 1: (A) Converging nozzle, (B) diverging nozzle.

windward areas. Low-velocity wind flow commonly blows on some wind-ward regions in the world. Although the wind blows non-stopped in these wind-ward areas but the produced wind in such a wind-ward areas is known to be exceedingly small, and it is not the most effective way to generate energy for our purposes. According to the power equation of wind turbines, the velocity is the most effective factor for spinning a wind turbine and then producing electric energy. There must be another effective ways to increase the velocity of the wind but here we numerically demonstrate that a contraction nozzle or converging duct can easily increase the flow velocity so that if we install such a nozzle between wind stream and wind turbine, the wind turbine will spin faster and as a consequence the power of wind turbine can be increased.

According to the following assumptions, we derive the inlet velocity for starting the wind turbine (in the real design, the numerical amounts can be easily changed):

1. Temperature is constant (= 25°C). Otherwise, we would add heat transfer equations in radial systems to obtain temperature in each section.

2. The material, which is used for creating of contraction nozzle, is steel.

3. The wind flow throughout the contraction nozzle should be maintained as incompressible and low-speed flow to be prevented from noises. Moreover, the compressibility affects on flow characteristics and the contraction nozzle only increase the velocity of the flow for velocities less than velocity of the sound.

4. Regardless of the calculations of boundary layer in the converging nozzle, we have calculated the velocity of the air at the output of the nozzle. It is because of the fact that calculation of boundary layer is not important in converging nozzles. For example, the ratio of boundary layer to the length of converging nozzle can be any amount.

5. In this study, we only propose that such a method for increasing the wind velocity in wind-ward areas can be practical in future applications to install wind turbines in low-velocity areas. Considering different factors for optimal design of a wind turbine with more efficiency is outside the scope of this study.

6. This method can be practical in both small wind turbines in roof of the buildings or near the buildings and big wind turbines in deserts.

7. For all the following calculations, the density of the incoming air and power efficiency of the wind turbine is considered to be constant amounts of = 1.169/3 and = 0.4 respectively.

In aerodynamic applications, converging and diverging nozzles are used to, corresponding to velocity needs, increase or decrease the velocity of incoming flows.

Figure 1 shows two kinds of nozzle that are used to increase or decrease the velocity of incoming flow. First of all, we need the Mach number, equation (1), to determine the kind of flow which approaches to the entrance of the nozzles. Therefore the Mach number would be given as:

$$M = \frac{v}{c} \qquad (1)$$

Where c and v and are respectively the velocity of sound and the velocity of incoming air [3]. The velocity of sound can be given by:

$$C = F(\mathrm{T}) \rightarrow \mathrm{C} = \sqrt{KRT} = \sqrt{1.4 \times 287 \times (273 + 25)} = 346.02$$

Where *K, R, T* are ratio of special heat, gas constant and temperature respectively [4]. For subsonic wind velocities (M< 1), an increase in area of the nozzle causes wind velocity to reduce but for supersonic wind velocities (M>1), an increase in area causes wind velocity to increase. We can use the equation (2) to understand better why a supersonic wind flow accelerates through the divergent nozzle while a subsonic wind flow decelerates through a divergent nozzle [5].

$$\frac{dA}{A}\left(\frac{1}{M^2 - 1}\right) = -\frac{d\rho}{\rho V^2} \qquad (2)$$

According to equation (2), for subsonic wind (incompressible) flows, the density of the wind flow remains constant, so when area of the nozzle increases, the velocity of the wind flow tends to reduce but for supersonic wind (compressible) flows, ρ and v are changing as we change the area.

Now we can suppose that we are applying this project in a windward area that the velocity of incoming wind blowing on wind turbine is less than the velocity of sound, therefore, according to aerodynamics principles for subsonic wind velocities, we have to use a converging nozzle, which increase the wind velocity by reducing the segment area of the nozzle, to increase the velocity of the incoming wind blowing on wind turbine. For all cases analyzed below, a three dimensional contraction nozzle (which converts the compressive energy to kinetic energy) with the same length (3 meters) but different input and output segment areas is considered. In these presented calculations, the inlet mean velocity is considered a constant value of $3\frac{m}{s}$ in a windward area.

The simulations of (Figure 2) are carried out by FLUENT software to show the changes of wind speed caused by nozzle. From the Figure 2 it has been found out that, for all cases, by decreasing the segment area of the nozzle, the wind speed obviously gets increase and it reaches peak at nozzle output or wind turbine inlet.

So it is showed that the velocity of the incoming wind blowing on the wind turbine blades can be easily increased by utilizing a well-designed contraction nozzle in the path of the wind used in the roof of

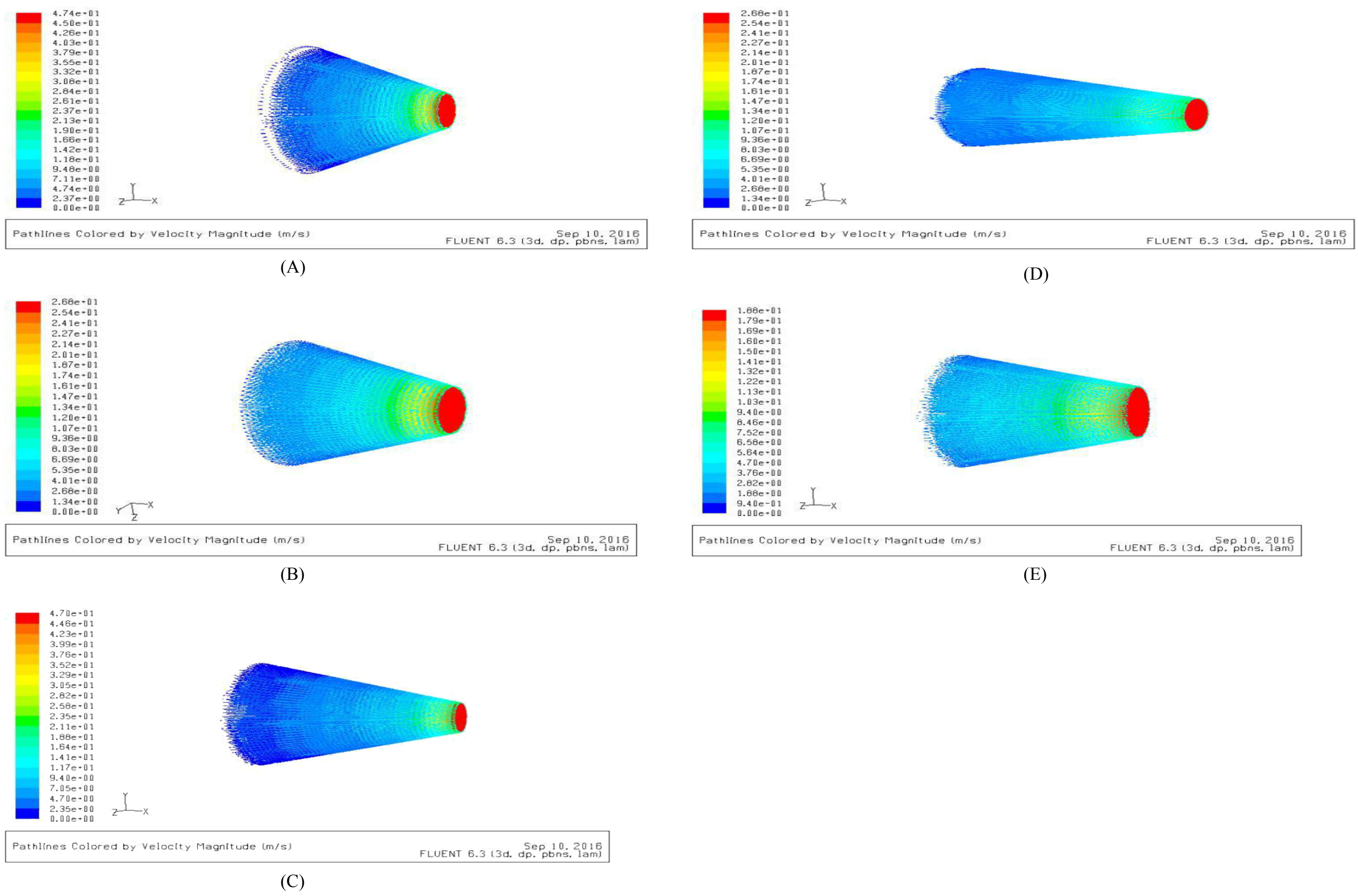

Figure 2: Comparison of increasing of inlet velocity for a wind turbine after passing through different nozzles with different segment areas.

a building or anywhere else that there is turbine. Now it is of critical economic importance to know the power and hence energy produced by different types of Wind Turbine that are located after the small area segment of contraction nozzle. Each wind turbine produces a specific power depending on the speed, mass and amount of the incoming wind hence the power of the wind turbine, which has been converted from mechanical energy to the electrical power, can be calculated by using the following equation [6]:

$$P=\frac{1}{2}\rho AV^{3}C_{p} \quad (3)$$

Where P, V, ρ, A, and CP are total produced power, the speed of the wind blowing on wind turbine, the incoming air density, the swept area of the wind turbine that can be calculated by A= πr^2 (where is the blade length of the wind turbine), and power coefficient. The ratio of power extracted by the wind turbine to the total contained in the wind resource is called the power coefficient. Albert Betz calculated that it is impossible that a wind turbine convert more than 59.3 % of the kinetic energy of the blowing wind into mechanical energy turning a rotor. This coefficient, which is known as the Betz Limit [6,7], is used for the theoretical maximum coefficient of electrical power for any wind turbine.

According to velocity calculations for incompressible flows, the continuity equation has been utilized [4] to obtain the velocity of the flow in the small diameter of the contraction nozzle (small segment area of the nozzle) or inlet velocity of wind turbine, which is given by:

$$\dot{m}_{in}=\dot{m}_{out}\rightarrow\rho V_{in}A_{in}=\rho V_{out}A_{out}\rightarrow V_{out}=\frac{V_{in}A_{in}}{A_{out}} \quad (4)$$

The equation (3) and the continuity equation (mass flow rate) $\dot{m} = \rho VA$= constant (where ρ, V and A are density of the air, velocity of the incoming wind and segment area respectively) have been utilized to get some information of Table 1. Moreover, the FLUENT Software calculations has been taken to account to obtain the wind velocity at outlet of the contraction nozzles or wind velocity that blows on wind turbines and as we see, there is no important difference between numerical calculations and FLUENT results for wind amount.

Some results of (Table 1) performed by FLUENT software. For example, the wind turbine inlet velocity calculated by continuity equation is approximately the same as CFD results. The power converted from the wind into rotational energy (electrical power of wind turbines) with different inlets wind speed and different lengths of wind turbine's blade have been numerically calculated by applying equation (3). This is the main result of this paper that shows we can install some nozzle in a building's roof between the wind turbines and wind-way and then produce the electrical power for household consumption. Figure 3 shows the main above results in a graph. It has been found that the power converted from the wind into rotational energy clearly depends on the wind velocity and blade length of the wind turbine (short diameter of the nozzle) (Figure 4).

The graph shows that a well-designed nozzle, for increasing the wind speed, and along with suitable blade length of the wind turbine can be practically designed and performed in a roof of a building to produce the electrical power of a house, of course more efficiently rather than installing wind turbine without nozzle, independent from

Nozzle Number	Height(L)	Large Diameter (M)	Short Diameter (M)	Inlet Velocity (M/S)	Outlet Velocity (Wind Turbine Inlet) (M/S) (Numerical)	Outlet Velocity (M/S)(Cfd)	Maximum Pressure(Pascal) (Cfd)	Electrical Power (Kw)
A	3	4	1	3	48	47.38	1490.84	20.297
B	3	3	1	3	27	26.75	458.27	3.618
C	3	2.5	1	3	18.75	18.7	218.64	1.209
D	3	2	0.5	3	48	46.99	1419.17	5.074
E	3	1.5	0.5	3	27	26.75	445.69	0.903

Table 1: Comparison of the growth of wind speed caused by different nozzles and electrical power produced by different wind turbines.

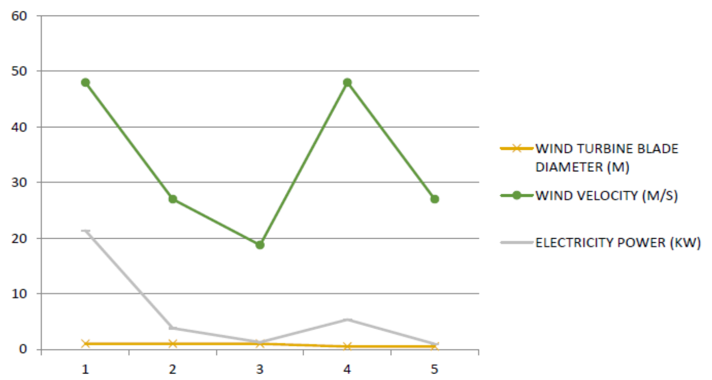

Figure 3: Comparison of effect of different wind speeds and blade length of wind turbines on electrical power.

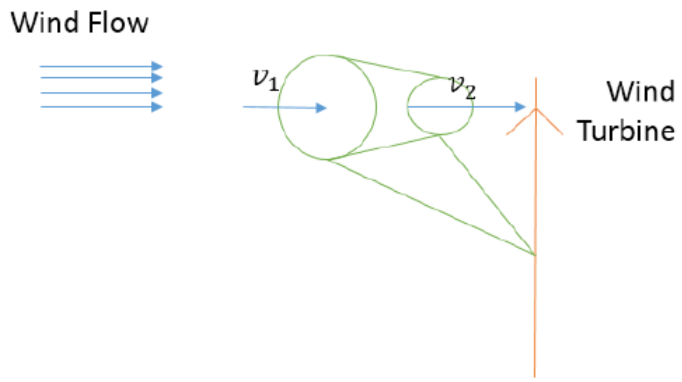

Figure 4: Schematic of the proposed method for increasing the velocity of the wind, where V1 < V2.

electrical power plants. That is, it is only needed to design suitable blade length for wind turbine corresponds to design of nozzle for increasing the wind speed, afterward, to put the nozzle between the wind-way and wind turbine and then it could be used of the electrical power of the wind turbines more efficiently which can be economically critical for many urban and rural householders.

Table 2 shows the electrical power for both common wind turbines and nozzle-attached wind turbines. By relying on the results obtained numerically for utilizing such a method for increasing of the incoming wind velocity, it could be found out that there will be more efficiency to apply such a method for using wind turbines electrical power. As it has been shown, nozzles with different diameters alter the amount of velocity of the wind and according to equation (3), the velocity is the most effective factor for increasing the electrical power of the wind turbines. The optimal design of wind turbines and nozzles for getting the most efficiency design is not in the scope of this study but according to the increased velocities caused by different nozzles, it could certainly be expected to experimentally apply such a method therefore wind turbine's producer factories can optimally design wind turbines with more efficiency even for low-speed wind-ward areas.

Conclusion

In this study it has been recommended that contraction nozzle can be installed between wind turbine and wind-way to increase the velocity of the wind blowing on wind turbine blades. From the CFD and Numerical analyses, it was found out that by decreasing the segment area of the nozzle, the wind speed gets increase through the nozzle and it reaches peak at nozzle output or wind turbine inlet. The power calculations for typical wind turbines in the presence and absence of the contraction nozzle demonstrated that power of the wind turbines will dramatically increase if a well-designed nozzle was used for wind speed increase. Since the power of the wind turbine can be increased by such a method, it would provide a basis for making the buildings self-sufficient from the electrical power plants even in low speed wind-ward areas. Although a single wind turbine is not enough for electrical power.

Wind Turbine Numbers	Electrical Power without Nozzle(KW)	Electrical Powerwith Nozzle(KW)
A	0.005	20.297
B	0.005	3.618
C	0.005	1.209
D	0.0012	5.074
E	0.0012	0.903

Table 2: Comparison the electrical power of wind turbines in the same conditions of common wind and increased wind velocity by nozzle.

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