Theoretical Concepts 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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Ever since humanity discovered various energy resources available in nature, it has been inventing devices, known as machines, which make life more comfortable by using energy resources. We get electricity, which is a secondary energy source, from the conversion of other sources of energy, like coal, natural gas, oil, nuclear power and other natural sources, which are called primary sources.

As we know, the flows, which without any limitation are produced in the nature and on the buildings (External Flows), blow aboundancely 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.

Electricity for powering our home is made in power stations. A power station contains large machines called turbines, which are turned very quickly. Power stations need large amount of energy to turn the turbines.

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. There is no doubt that Wind Energy, which is renewable energy, has obvious role in different energy supply such as Electrical power. Wind is one of the greenest forms of energy, as it uses no fossil fuel and does not emit greenhouse gases. Most homes that have residential wind installation are still tied into the power grid, both to use electricity when the wind is not blowing and to sell excess power to the grid when it is. A typical residential wind system can offset 1.2 tons of air pollutants and 200 tons of greenhouse gases. New home wind options make it easier to install a wind turbine in a residential footprint, on the roof or on the ground on the home’s lot [1].

As it has been said Wind Turbines are one of the most significant electrical energy resources, it may be practical, in the windward areas, each building to supply its electricity energy by installing turbines in the buildings.

But the main problem is the velocity of wind to spin a wind turbine. It has been proposed to capture low-velocity wind in a contraction nozzle and then increase its velocity to spin a wind turbine. It is the aim of this project to bring distributed wind energy to life by making it a natural part of the power infrastructure. In the windward 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 electricity power of the wind turbines.

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:

$$M = \frac{V}{C} \quad (1)$$

Where C and V are respectively the velocity of sound and the velocity of incoming air [2]. The velocity of sound can be given by:

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

Where K, R, T are ratio of special heat, gas constant and temperature respectively [3]. For subsonic flows ($M < 1$), an increase in area causes flow velocity to decrease but for supersonic flows ($M > 1$), an increase in area causes flow velocity to increase. We can use the equation (2) to find out why a supersonic flow accelerates in the divergent nozzle while a subsonic flow decelerates in a divergent nozzle [4].

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

According to equation (2), for subsonic (incompressible) flows, the density remains constant, so when area increase, the velocity decrease but for supersonic (compressible) flows, ρ and V are changing as we change the area.

Now we can suppose that we are doing this project in a windward area that the velocity of incoming air is less than the velocity of sound so that we should use a converging nozzle to calculate when the area decreases, the velocity of incoming flow increases. 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 Fig.2 are carried out by FLUENT software to show the changes of wind speed caused by nozzle. From the Fig.2 it has been found 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 air of 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 a building. Now it is of critical economic importance to know the power and therefore energy produced by different types of Wind Turbine in different conditions of wind velocity. Wind power depends on the amount, speed and mass of the air therefore we can calculate the power converted from the wind into rotational energy in the turbine using the following equation [5]:

$$P = \frac{1}{2}\rho A V^3 C_P \quad (3)$$

Where P, ρ, A, V and C_P are produced power, the air density, the swept area of the turbine that can be calculated by $A = \pi r^2$ (where r is the blade length of the wind turbine), wind speed and power coefficient. The power coefficient is the ratio of power extracted by the turbine to the total contained in the in the wind resource. Albert Betz calculated that no wind turbine could convert more than 59.3 % of the kinetic energy of the wind into mechanical energy turning a rotor. This is known as the Betz Limit [6, 7], and is the theoretical maximum coefficient of 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 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, velocity of the flow 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 outlet velocity of contraction nozzles or inlet velocity of wind turbines and as we see, there is no important difference between numerical calculations and FLUENT results.

Nozzle number	**Height (l)**	**Large diameter (m)**	**Short diameter (m)**	**Inlet velocity ($\frac{M}{S}$)**	**Outlet velocity (wind turbine inlet) ($\frac{M}{S}$) (numerical)**	**Outlet velocity ($\frac{M}{S}$) (cfd)**	**Maximum pressure (pascal) (cfd)**	**Electricity power (kw)**
A	3	4	1	3	48	47.38	1490.84	21.356
B	3	3	1	3	27	26.75	458.27	3.8
C	3	2.5	1	3	18.75	18.7	218.64	1.272
D	3	2	0.5	3	48	46.99	1419.17	5.339

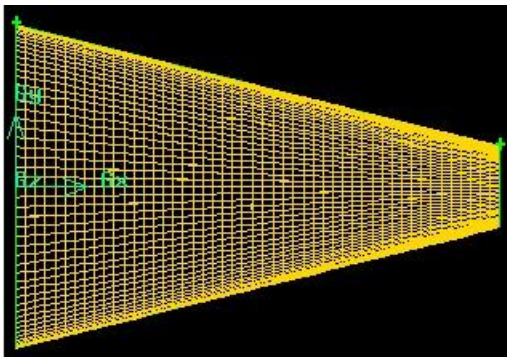
E	3	1.5	0.5	3	27	26.75	445.69	0.95

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

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 (electricity 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 wind turbines in a building roof between the nozzle and wind-way and then produce the electricity power for household consumption. Fig.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).

The graph shows that a well-designed nozzle for increasing the wind speed and a suitable blade length can be practically designed and performed in a roof of a building to produce the electricity power of a house independent from electricity 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, put the nozzle between the wind-way and wind turbine and then make use of electricity power which can be economically critical for many urban and rural householders.

The result of this study provides a basis for producing energy from external flows blowig on the buildings. It suggests that each building would be self-sufficient of electricity power plants. It has been recommended that some wind turbines to be installed in a roof of a building, located between nozzle and windway. From the CFD and Numerical analyses, it was found that by decreasing the segment area of the nozzle, the wind speed gets increase and it reaches peak at nozzle output or wind turbine inlet. So the electricity for powering our home would be practically made in the process of amplified-velocity wind in a duct and contraction nozzle to initiate a wind turbine. Although this study involves assumptions but the experimental concepts and software simulations shows that wind velocity would be enough increased in an isolated pattern to spin a wind turbine and then the required electricity power can be produced by wind turbine in the buildings, which is economically of advantages for saving energy.



(A)

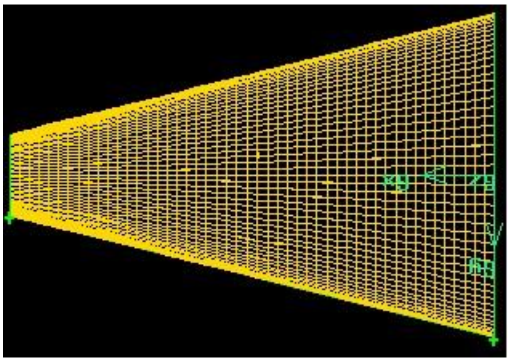


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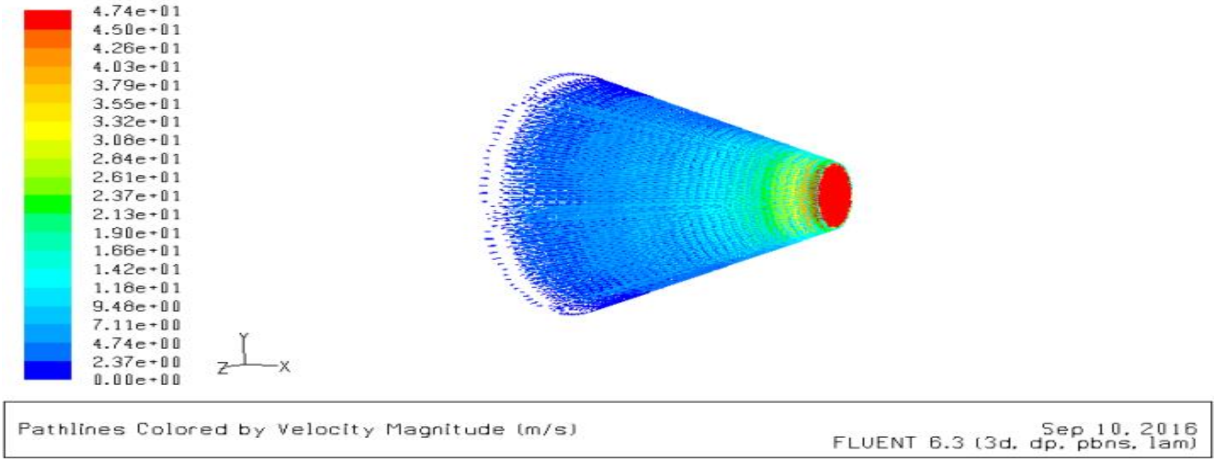
Figure 1. (A) converging nozzle, (B) diverging nozzle.



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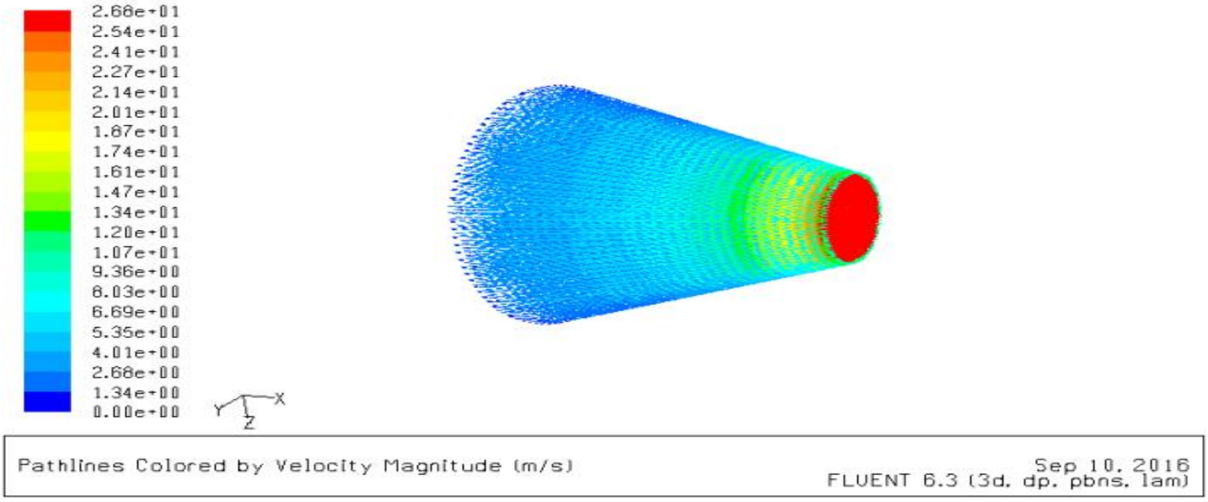

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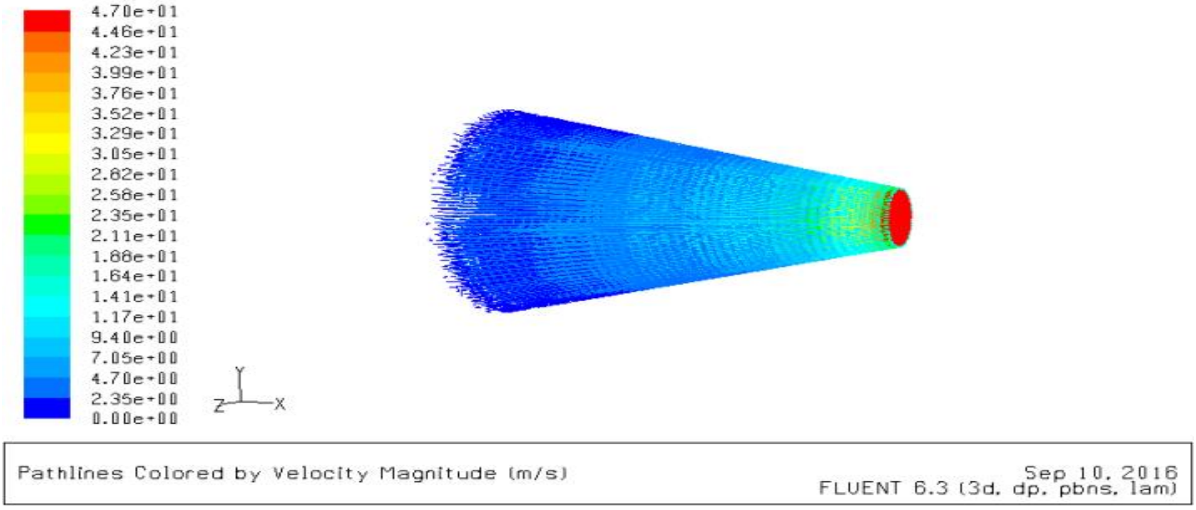
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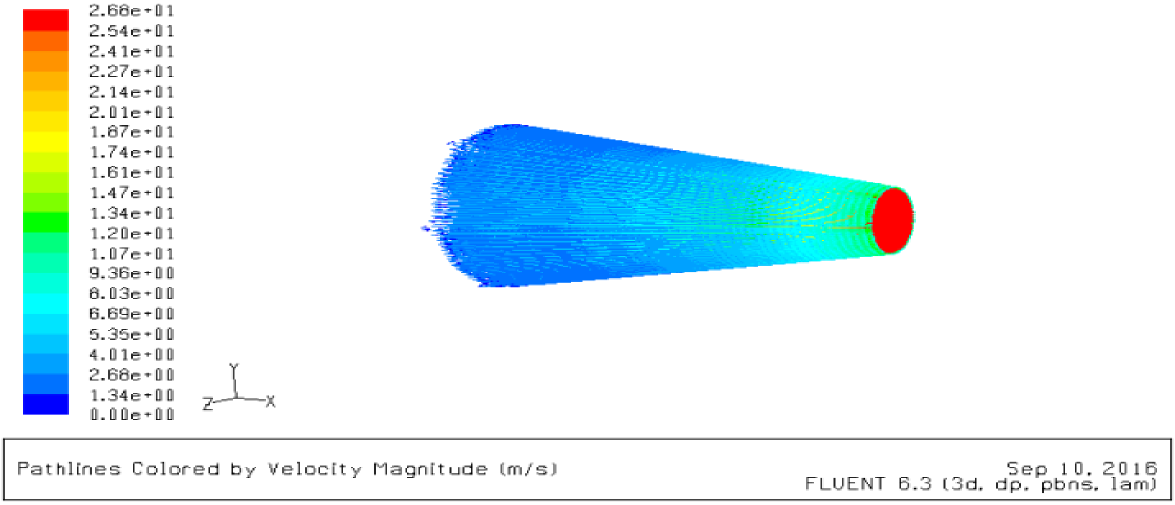
(C)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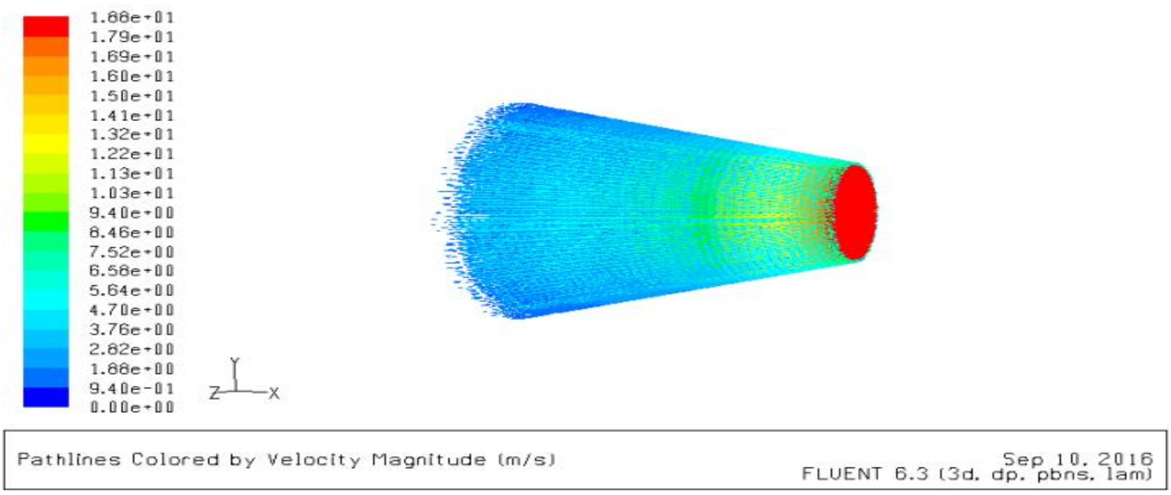
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Pathlines Colored by Velocity Magnitude (m/s)
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(E)

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

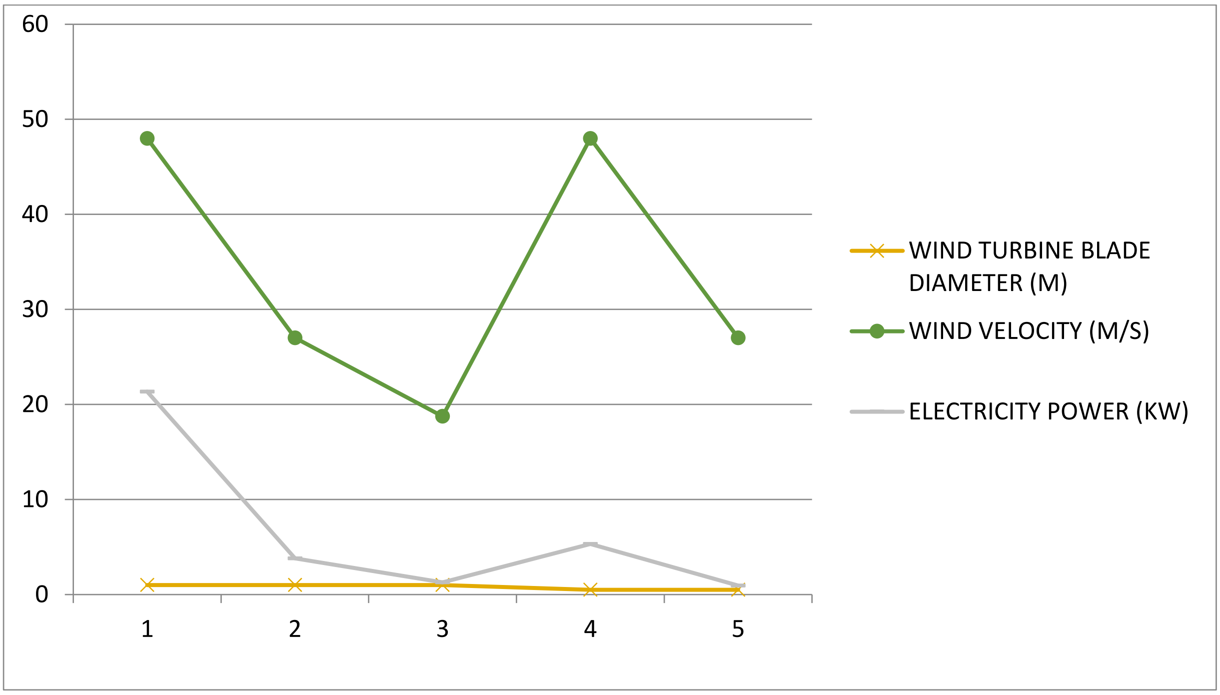

Figure 3. Comparison of effect of different wind speeds and blade length of wind turbines on electricity power.

References

1. John Bird, "Basic Engineering Mathematics", Published by Elsevier LTD (2007).
2. Victor Lyle Streeter. "Fluid Mechanics", McGraw-Hill (1951).
3. Claus Borgnakke, Richard E. Sonntag. "Fundamentals of Thermodynamics", Wiley, sixth edition.
4. Irving H. Shames. "Mechanics of Fluids", McGraw-Hill, fourth edition.
5. Alex Kalmikov and Katherine Dykes, "Wind Power Fundamentals", Published by MIT Wind Energy Group & Renewable Energy Projects in Action.
6. John Bird, "Basic Engineering Mathematics", Published by Elsevier LTD (2007).
7. Alex Kalmikov and Katherine Dykes, "Wind Power Fundamentals", Published by MIT Wind Energy Group & Renewable Energy Projects in Action.
8. Wind Turbines. Http://www.energysolve.ie/index.php/sustainable-world-1/domestic-application/wind-turbines/.