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Design of Direct and Indirect Wind Energy Harvest Systems

Yung Ting, Hariyanto Gunawan, Amelia Sugondo, Kun-Lin Hsu
Department of Mechanical Engineering, Chung Yuan Christian University
No. 200, Chung Pei Rd.,Chung Li 32023, Taiwan
yung@cycu.edu.tw

***Abstract*—Developing wind energy by using wind collector and electroactive materials are proposed and investigated in this article. Two systems will be considered to harvest energy: direct and indirect system. In direct system, wind induced drag force directly blow and vibrate the electroactive materials in the duct for generating electricity. Wind flow-guided mechanism is designed to collect arbitrarily blowing wind in environment and guide the flow direction perpendicular to the cross section of the nozzle as much as possible so that more uniform velocity distribution profile is achieved. Nozzle accelerator is designed for the purpose of increasing wind velocity. Indirect system uses gear as additional mechanism to impact and vibrate the electroactive materials. Two types of indirect system integrating the wind collector with fan and roof turbine ventilator to impact and vibrate electroactive materials are proposed.**

Key words: energy harvest, nozzle, electroactive materials

I. INTRODUCTION

Various kinds of electroactive materials such as piezoelectric ceramics, piezoelectric polymer, electrostrictive ceramics, are likely candidates of generating electricity by using piezoelectric direct effect. Piezoelectric unimorph basically consists of a piece of ceramics attached to a metal beam is selected as an example in this study. Piezoelectric ceramics has the property of electromechanical energy conversion, and can convert vibration energy into electrical energy, thus achieving the objective of recycling useless energy [1]. By using piezoelectric direct effect, mechanical deformation, for example generated by wind force, can be transformed into electricity. Wind is one of energy source that easily to get, but ambient wind velocity and wind direction are unpredictable. To efficiently harvest ambient wind energy needs specific devices to improve the performance of such as wind velocity and wind flow distribution. Nozzle and duct are integrated to increase wind velocity and direct the wind to vibrate the electroactive material. The wind output velocity could improve, but the distribution of wind may not be uniformly distributed in the cross section area of the duct. Hence, the electroactive materials employed around the duct are likely not effectively vibrated. It is necessary to design a wind flow-guided mechanism in front of the nozzle inlet so that the wind is directed into the nozzle nearly perpendicular to the cross section area. Besides, concerning indirect vibrating implementation, composite design such as combining the above wind nozzle collector with a roof turbine ventilator or an axial fan in the inside of duct coupled with gear mechanism to impact the electroactive materials is proposed [2].

II. WIND COLLECTOR

Wind-induced drag force is gained as the output of the wind collector can be used to vibrate the electroactive materials directly or drive a fan or ventilator to impact the electroactive materials indirectly. By means of the piezoelectric direct effect, electricity is generated eventually. Drag force that produced by wind can be calculated by [3]

$$F_D = 0.5 \cdot \rho \cdot C_d \cdot A_d \cdot U^2 \qquad (1)$$

where F_D is drag force, A_d is cross section area of a duct, C_d is drag coefficient. It is seen that the square of velocity will influence the force produced by the wind. How to increase the wind velocity is significant for improving the efficiency of vibrating the electroactive materials.

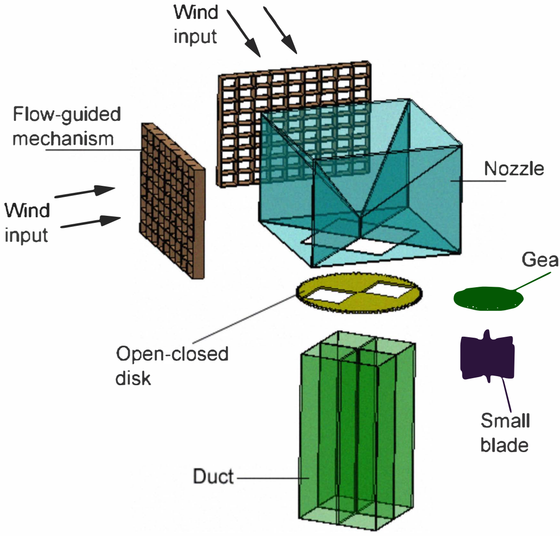


Fig. 1. Wind Collector with open-closed mechanism

A wind collector consisting of flow-guided mechanism, nozzle, duct, and open-closed mechanism is developed as illustrated in Figure 1. Flow-guided mechanism is able to effectively direct the wind flow from any angle with respect to the cross section of the nozzle to become perpendicular as possible and obtain uniform velocity to enter the nozzle. Nozzle is used to increase the wind flow velocity. In connection with the nozzle, duct is designed to implement electroactive materials or to lead the wind blowing the impact mechanism. Note that, wind flow must be discontinuous enter the duct, so generate vibration of electroactive materials. Open-closed mechanism as in figure 1 is used to make wind flow discontinuously enter the duct. Wind from environment blow small blades and rotate them. The rotation is transferred between gear and open-closed disk. When the disk in open condition, the wind flow enter duct and directly blow electroactive materials. Vice versa in closed condition, the wind can not enter the duct and during this condition allow electroactive materials bounce back automatically because of its own spring effect.

A. Nozzle Accelerator

Configuration of nozzle can be categorized into converging and diverging. On the converging section, gas flows from chamber will pass the throat, so the fluid will receive acceleration as a result of pressure drop. On the diverging section, fluid passes from the diverging portion and drains away to the ambient. Diverging section can be treated as a diffuser that has the reverse result of the converging section [4]. In this study, nozzle with converging section as shown in Figure 2 is used to increase wind velocity. As depicted in Figure 3, wind velocity is increased while wind flows through a nozzle.

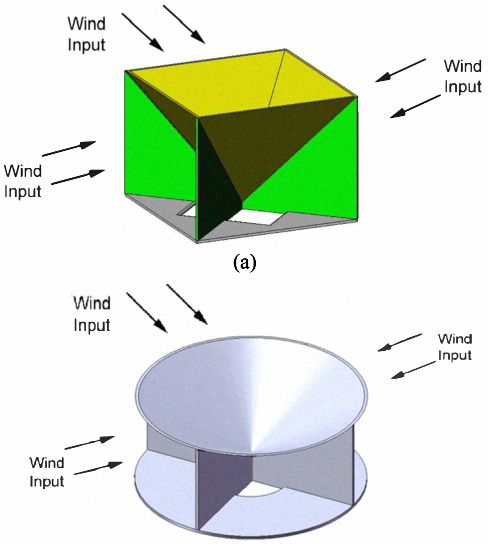


Fig.2. Nozzle accelerator (a) Rectangular (b) Circular

Nozzle accelerator is designed to increase wind velocity and direct the wind into the subsequent (e.g., rectangle) duct. The wind collector is designed of several equivalent sections with the same shape to capture wind from different directions. For instance, an example of four equivalent sections is used for presentation. The nozzle angle is the key design parameter of a nozzle wind collector. Nozzle angle determines the ratio of the inlet area to outlet area.

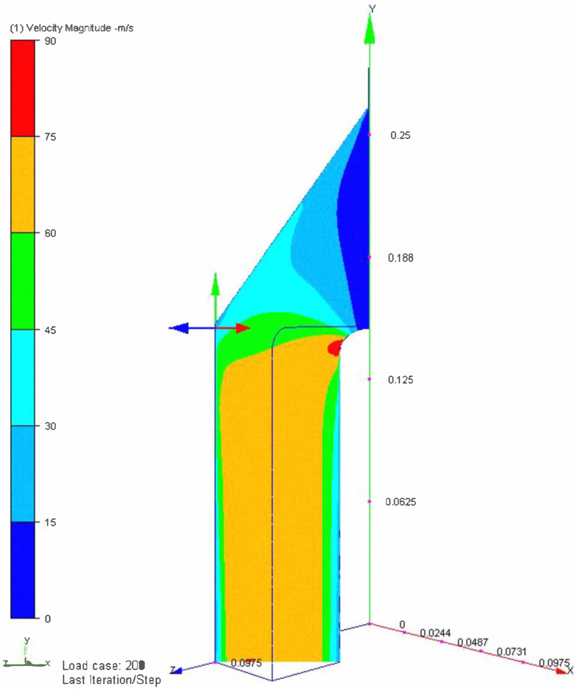


Fig. 3. Wind flow vector distribution

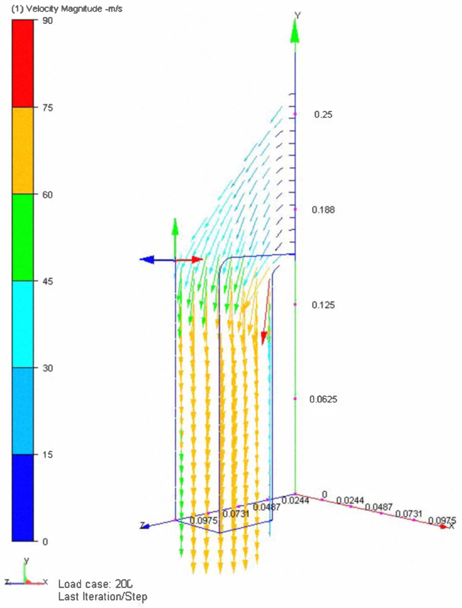


Fig. 4. Velocity vector distribution for nozzle angle α= 54°

Optimum design of the nozzle angle, which can collect more wind and increase wind velocity to vibrate the electroactive materials in order to produce more electricity is an important goal. Assuming the input nozzle area is $0.0137m^2$, various combinations of nozzle angle, α= 30^o, 40^o, 50^o, and 60^o are chosen to examine the performance. The condition of simulation is assumed that the system is steady and incompressible. SIMPLE (Semi-Implicit Method Pressure Linked Equation) method is used for solving pressure-velocity coupling. According to continuity equation, momentum equation, and turbulence factor equation of the wind output velocity, the CFD simulation result show the maximum velocity is calculated 65.6m/s, 68.5m/s, 73.3m/s, and 68.2m/s with respect to the nozzle angle of $\alpha = 30^{\circ}$, 40°, 50°, and 60° respectively. It shows maximum velocity occurs for the nozzle angle α is in the range of $50^{\circ}\sim60^{\circ}$. Further study is examined and found the optimal angle is $\alpha=54^{\circ}$, which agrees with the results in [5]. Figure 4 shows the wind velocity for the case of nozzle angle of $\alpha = 54^{\circ}$. The wind velocities are measured at different height of the duct for different nozzle angle is shown in Figure 5.

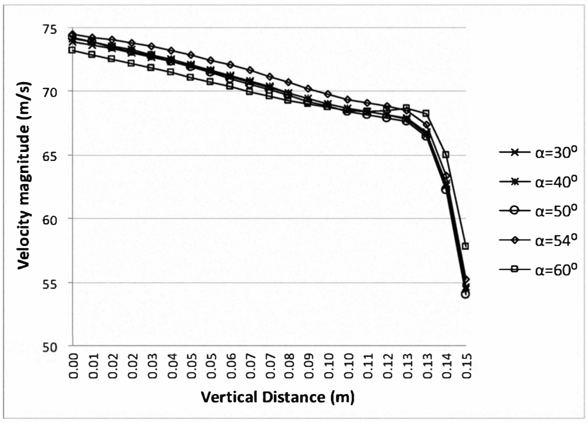


Fig. 5. Wind velocity distribution vs. height

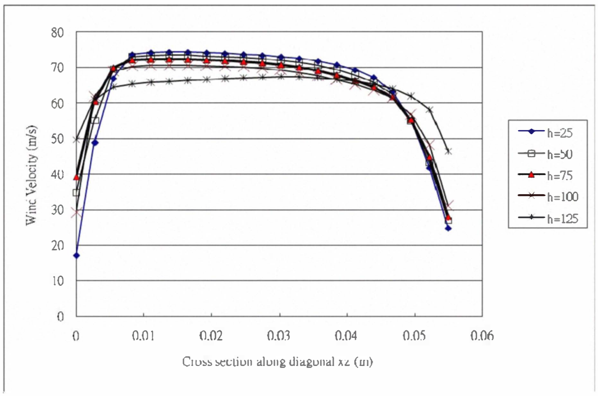


Fig. 6. Output wind velocity vs. heights

Increasing wind velocities are directed to enter the subsequent duct employed with static blades to blow and vibrate electroactive materials for generating electricity. Assuming the uniform wind flow passes through the XZ cross section, for the case of nozzle angle 54°, the wind velocity distributions are measured at the point along the bisection line of the XZ cross section in different height of 0.025m, 0.05m, 0.075m, 0.1m and 0.125m with respect to the reference base is shown in Fig. 6. Note that the wind velocity is low near the corner of the quarter section in the duct. Therefore, electroactive materials should not be employed in these regions. Also, for instance, the highest wind velocity is measured about 74.28m/s in the height of 0.025m from the reference base for input wind velocity 5m/s. It indicates wind velocity can be increased about 14 times by using a nozzle wind collector.

B. Wind Flow-guided Mechanism

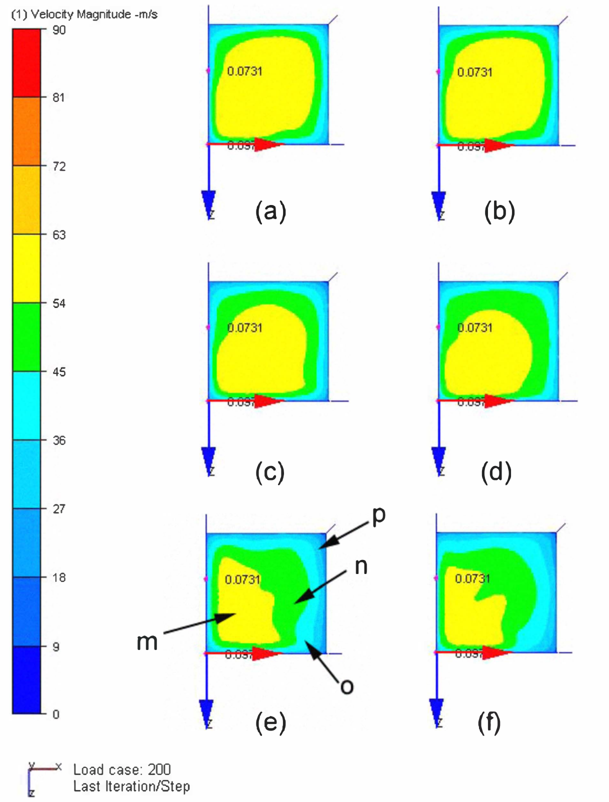


Fig. 7(i). Wind velocity distribution through XZ cross section of rectangular duct at (a) h=0.025m, $\gamma=90^{\circ}$ (b) h=0.075m, $\gamma=90^{\circ}$ (c) h=0.025m, $\gamma=40^{\circ}$ (d) h=0.075m, $\gamma=40^{\circ}$ (e) h=0.025m, $\gamma=70^{\circ}$ (f) h=0.075m, $\gamma=70^{\circ}$

Figure 7(i) and 7(ii) show the velocity vector of the wind flowing from ambient environment into the nozzle perpendicular to the cross section of the nozzle (i.e., input wind angle $\gamma=90^{\circ}$) and then into the rectangular or round duct. It is seen that the velocity vector almost uniformly passing the cross section of the duct. Nonetheless, while inlet wind flow is not perpendicular to the cross section of the nozzle, the distribution of velocity vector is changed as shown in Figure 7(i)(c)-(f) and 7(ii)(c)-(f). It is seen that velocity ranking of the color areas from high to low are yellow color (area *m*), green color (area *n*), light blue color (area *o*), and dark color (area *p*) for each figure of wind velocity distribution. It is desired to employ the electroactive materials in the area of larger velocity, that is, the area *m*. For instance, in Figure 7(i)(e), the area *m* is relatively small. It indicates very low efficiency of energy harvest happens in this case for only the electroactive materials located in this area can be vibrated efficiently with large wind speed.

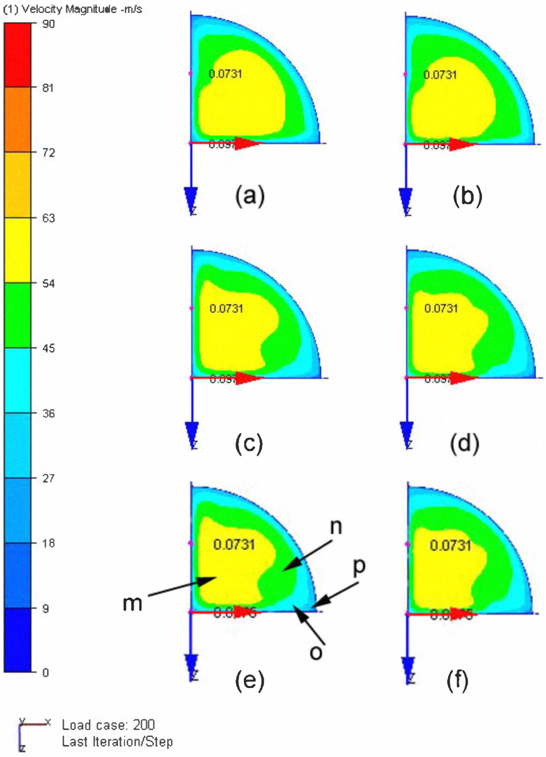
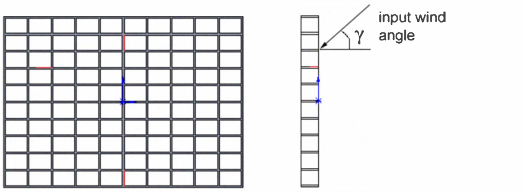


Fig. 7(ii). Wind velocity distribution through XZ cross section of round duct at (a) h=0.025m, γ=90° (b) h=0.075m, γ=90° (c) h=0.025m, γ=40° (d) h=0.075m, γ=40° (e) h=0.025m, γ=70° (f) h=0.075m, γ=70°



(a) Front view (b) Right view

Fig. 8. Wind flow-guided mechanism

Associated with such inlet wind flow condition, the electroactive materials need to deploy on the area where the wind flow passes in order to preserve vibration performance. Hence, both the wind velocity and its distribution profile are significant and instrumental to determine the location of electroactive materials. Since the wind flow is not predictable and the arrangement of electroactive materials is not automatically adjustable (waste energy), design of wind flow-guided mechanism as shown in Figure 8 is required. For examples, when the input wind angles γ=40° and γ=70°, are not perpendicular to the cross section area ideally. CFDesign software is used to simulate the efficiency of flow-guided mechanism and distribution of wind output velocity as shown in Figure 9. By using the wind flow-guided mechanism, the wind flow direction becomes almost perpendicular as shown in Figure 9(a) and 9(b).

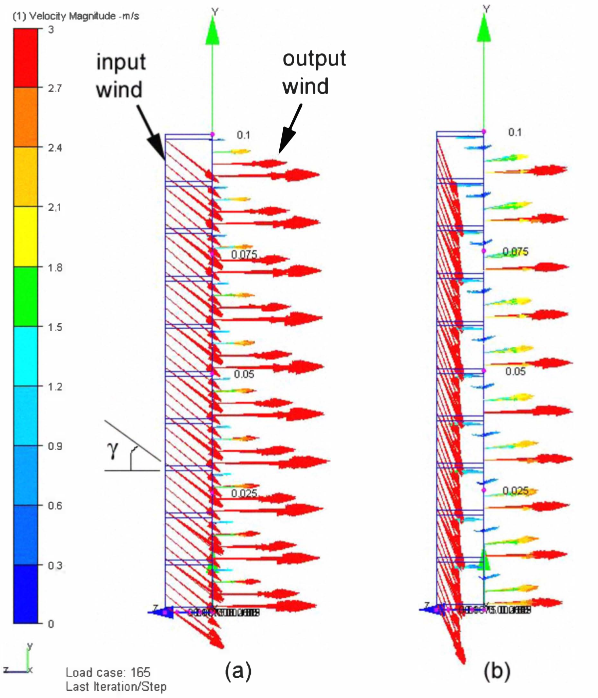
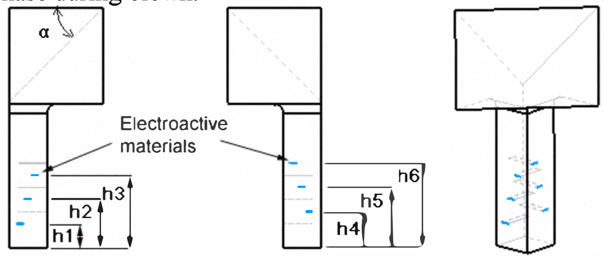


Fig. 9. Wind flow vector through guided-mechanism (a) γ=40° (b) γ=70°

III. DIRECT ENERGY HARVEST SYSTEM

For direct energy harvest system, number of electroactive materials employed in the duct will affect the design of nozzle wind collector. For example, there are 6 pieces of electroactive materials arranged in one section of duct as shown in Figure 10. It is assumed that with appropriate arrangement, the wind will equally flow into one of the four sections. Since multiple electroactive materials are employed and the AC volt is generated. The electroactive materials must have the same phase so that the voltage can be sum up. Wire is used to connect each electroactive materials and make them have almost same phase during blown.



(A) Front View (B) Right View (C) 3D View

Fig. 10. Arrangement of electroactive materials in the duct

IV. INDIRECT WIND ENERGY HARVEST SYSTEM

Two types of indirect wind energy harvest system in combination a fan or a roof turbine ventilator with the wind collector are proposed.

A. Wind Collector and Fan

As illustrated in Figure 11, a wind collector is connected with a fan. The velocity-increased wind will drive the fan to rotate. A gear mechanism that attached on the shaft of fan will rotate and impact the electroactive materials.

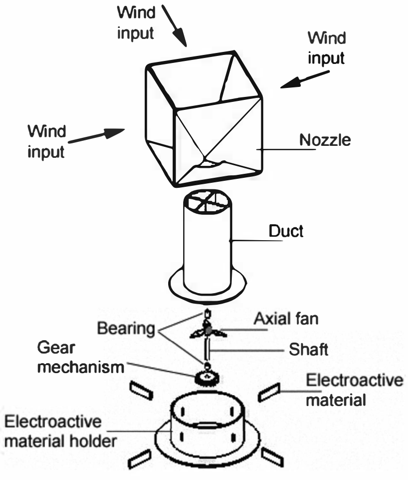


Fig. 11. Wind collector with fan

B. Wind Collector and Roof Turbine Ventilator

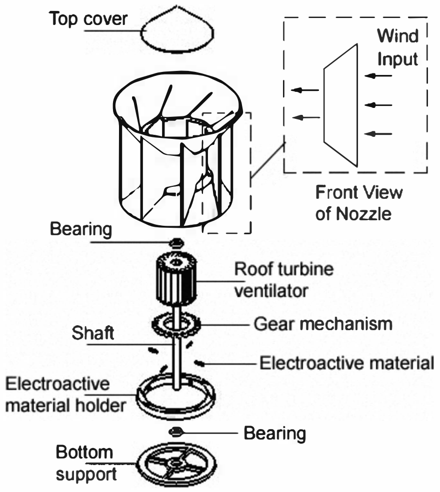


Fig. 12(a). Roof turbine ventilator with wind collector

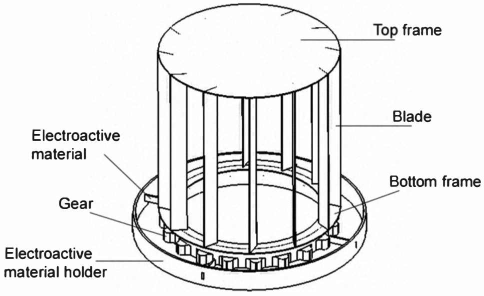


Fig. 12(b). Roof turbine ventilator

As illustrated in Figure 12(a), a wind collector is connected with a roof turbine ventilator, which is a specific type of aerator used for air ventilation. Preserving such purpose is an advantage of using roof turbine ventilator for energy harvest.

Increasing wind velocity will drive and rotate the roof turbine ventilator. As depicted in Figure 12(b), a gear mechanism associated with the roof turbine ventilator rotates and impact the electroactive materials. Figure 13 shows at higher wind speed, blade angle 90° and number of blade 18 can obtain larger driving force.

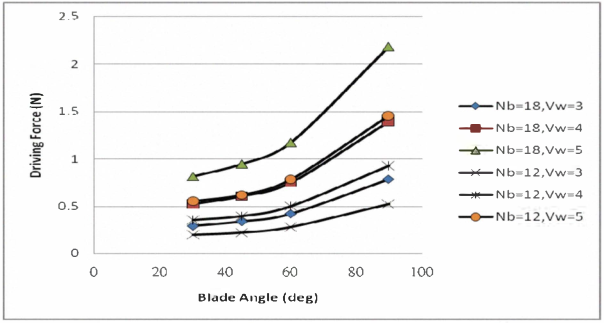


Fig. 13. Driving drag force F_D vs. blade angle β

V. CONCLUSIONS

A wind collector including nozzle accelerator and flow-guided mechanism is designed to collect the wind in the ambient environment and to increase its velocity. From simulation results, it indicates the proposed wind collector is quite efficient to directly vibrate the electroactive materials. Two types of indirect energy harvest system are proposed. Nozzle accelerator is combined with the fan or the roof turbine ventilator construction becomes the composite system. The wind flow-guided mechanisms instrumental to the composite systems need further comprehensive study and experiment to verify the performances. More discussions will be addressed in other articles in the near future.

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