

The Techno-Economic Analysis of an Exhaust Fan-Based Wind-Powered Micro-Generation Electricity System

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Abstract—

Researchers have been motivated to identify and develop alternative energy based producing systems by two factors: the rising electrical energy demand and the increasing costs of electricity units globally during the last two decades. Wind power is one of several renewable energy sources since it uses a non-traditional and, arguably, ancient technique of producing electricity: harnessing the wind. The exhaust fan in your home is a great way to harness the power of the wind while also venting out the steamy air that builds up when you cook, shower, or watch TV. The exhaust fan maintains a steady flow of fast-moving air. This paper explores the concept of using a wind turbine to convert the kinetic energy of a rotating exhaust fan into usable electricity. Accordingly, this paper provides the full development of a wind power based micro-generation electric system based on an exhaust fan, including the design layout, mathematical calculation to estimate the available power from an exhaust fan, system description, and the hardware implementation to validate its working by considering various parameters and installation factors, as well as its techno-economic evaluation. More than 70 percent of Pakistanis use exhaust fans for home ventilation, making the suggested device particularly useful for storing energy for later use and lowering power expenses.

Keywords—

Microgeneration, micro wind, home exhaust fan, air, and technological and economic development I.

INTRODUCTION

As an alternative to the conventional grid-connected power, micro-generation energy consists of the small-scale production of power by people to fulfil their own requirements [1]. Distributed generation is a subgroup that focuses on serving the local community rather than contributing to the larger electric grid [2]. Furthermore, it is environmentally beneficial technology since it relies on renewable energy sources rather than fossil fuels. In most cases, it does not emit carbon dioxide into the atmosphere, one of the primary drivers of global warming and climate change [3]. Because of its inherent power availability, wind is one of the most used renewable energy sources for electricity generating [4]. The use of wind turbines to generate energy has skyrocketed in the recent decade. Microgeneration using wind is a low-capacity technology; its rated power output is less than 50 kW for a small town and less than 3 kW for a residential installation [5]. Therefore, wind based

micro generation electricity systems, also known as micro-wind turbine generators or micro-wind energy conversion systems, are one of the simplest, cleanest, and inexhaustible ways to use the wind energy at home or household level to meet their electrical demands. So, in this study, we discuss the research and development of a wind-powered micro-generation electrical system that uses a common home appliance, the exhaust fan. Exhaust fans are often used to improve ventilation in homes, especially during the warmer months. From the outside of the ventilation exhaust fan, the propelled air from inside to outside of the house can be considered as a high velocity wind source, keeping the indoor environment cool and comfortable [6]. Power generation from such a high-speed wind may match or exceed that from atmospheric wind for a given wind turbine size. This paper details the schematic and hardware prototype of a micro-wind power production system that harnesses the wasted wind from a domestic ventilation exhaust fan to generate energy.

The paper's structure is as follows: Section II provides an overview of the project's context and goals, and Section III explains the fundamentals of how wind energy works. In Section IV, we go through the details of the proposed system development, including the system structure, air speed measurement of the exhaust fan, power calculation, and a description of the system's implementation and components. The techno-economic analysis of the proposed power conversion system is presented in section V. In section VI, we provide our last thoughts, followed by a list of references.

Context and Goals

In developing nations like Pakistan, the usage of exhaust fans has become the most frequent, easy, and economical approach for domestic ventilation. A research published in the Proceedings of the Pakistan Academy of Sciences found that 77.5% of individuals in Pakistan use exhaust fans to cool their houses during the summer [7]. Continuous or intermittent usage of exhaust fans is used in bedrooms, baths, living rooms, and kitchens to

remove hot, damp air. In Fig. 1 we see a kitchen exhaust fan in action.



Fig. 1. Example of exhaust fan use in a kitchen.

The percentage usage of exhaust fan in the different areas of home along with the average time of use in these areas are indicated in the graph of Fig. 2. This graph is compiled using the data collected from a survey of 500 homes as a part of this study. The survey form is given in Appendix I.

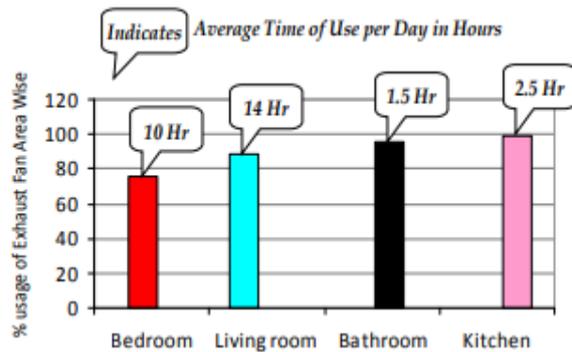


Fig. 2. Graph of a survey for exhaust fan usage in household.

The exhaust fan is generally installed inside at the wall top near the ceiling of a room. It throws the stale air outside of the room and allows the fresh air to be entered inside the room through the doors, windows and other air gaps. The thrown or propelled air outside the room by exhaust fan has high velocity and can be used as a wind power source to drive the wind turbine to generate electricity. Therefore, the purpose of the proposed work is to develop a micro-wind turbine-based power conversion system that is placed adjacent to or in front of the exhaust fan to recover the wasted wind energy during the ventilation process. The installation of the proposed system will be useful in providing energy particularly to lightening loads and will be helpful for reduction in the household electricity bills in Pakistan.

THEORY OF WIND POWER

The wind is a great source of free energy which has been used since ancient times in windmills for pumping water or grinding flour. With the appearance of electricity at the end of the nineteenth century, this trend had shifted towards the electrical energy production and the modern wind turbines were begun to build using classical windmill technology for the generation of electricity. The power available in wind is mathematically expressed as [8, 9];

$$P_w = \frac{1}{2} \rho A v^3 \tag{1}$$

Where: P_w is the power in the wind (watts), A is the cross-sectional area through which the wind passes (m^2), v is the wind speed normal to A (m/s) and ρ is the air density (kg/m^3). The wind turbine cannot extract all the power in wind. Thus, the extracted mechanical power (P_m) by a turbine from wind is mathematically described as [4, 8, 9, 10, 11];

$$P_m = P_w C_p = \frac{1}{2} \rho A v^3 C_p \tag{2}$$

Where: C_p represents the rotor efficiency of wind turbine which is included in (2) to account for the losses during the power conversion process by a wind turbine. The value of rotor efficiency cannot be greater than 59.3% that is its maximum theoretical value which is concluded by a German physicist Albert Betz and known upon his name as Betz efficiency or Betz' law [8, 10]. However, the mathematical relationship to calculate the practical value of rotor efficiency is given as follow [8].

$$C_p = \frac{1}{2} \left(1 + \frac{v_d}{v}\right) \left(1 - \frac{v_d^2}{v^2}\right) \tag{3}$$

The v_d in (3) represents the downwind speed. The Fig. 4 illustrates the upwind speed (v), cross sectional or sweep area of wind turbine rotor (A) and downwind speed (v_d).

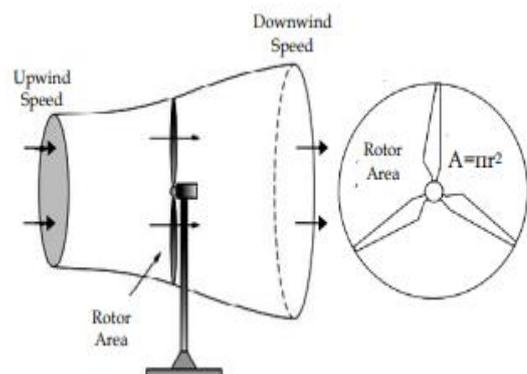


Fig. 3. Illustration of rotor area, upwind and downwind speed.

DEVELOPMENT OF PROPOSED SYSTEM

Layout of System

The layout of the proposed wind power based microgeneration electricity system using an exhaust fan is shown in Fig. 4. The system is equipped with an exhaust fan as a wind power source, a horizontal axis micro-wind turbine, a DC generator, a charge controller and a battery. The microwind turbine transforms the wastage wind power of exhaust fan into mechanical power. The produced mechanical power by micro-wind turbine is then used to drive a DC generator that converts the mechanical power into electrical power. The generated electrical power is then used to charge the battery through a charge controller that manages the charging of the battery. The stored energy in battery is used at any time to power the lightening or other suitable load.

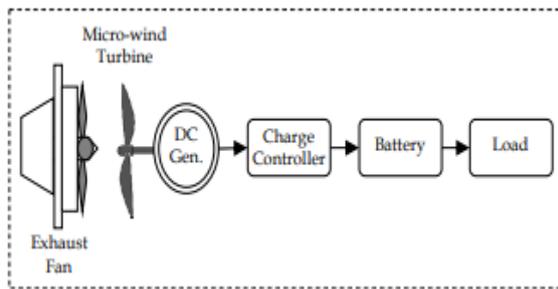


Fig. 4. Layout of the proposed wind power conversion system.

Air Speed Measurement of Exhaust Fan

For the development of proposed wind power conversion system, an exhaust fan of metal body in round shape form is used that is shown in Fig. 5. The technical specification of the used exhaust fan is given in Table I.



Fig. 5. Shape of the exhaust fan used for the proposed system.

TABLE I. TECHNICAL SPECIFICATIONS

Sweep Size (Diameter)		Rated Volt	Power	Speed	Air Delivery		Service Value
Inch	mm	VAC	Watts	RPM	m ³ /min	ft ³ /min	ft ³ /min/watt
14	355	230	90	1350	42	1500	16.67

To estimate the power available from the wind of the chosen exhaust fan, we need the air speed/velocity of that exhaust fan. Mathematically, it is calculated using the following relationship as [12, 13]:

$$V = \frac{Q}{A} \quad (4)$$

Where: V represents the average air speed of exhaust fan, Q is the air flow rate or air delivery, A is the area of the fan face. By replacing the fan area, A with its radius r or diameter d, the (4) becomes as:

$$V = \frac{Q}{\pi r^2} = \frac{4Q}{\pi d^2} \quad (5)$$

Thus, for the selected exhaust fan having air delivery of 42 m³ /min or 0.7 m³ /sec and sweep diameter of 355 mm or 0.355 m, using (5) the computed value of its air speed is 7.07 m/sec. This is the average air speed of exhaust fan. But as we know that the air speed close to fan surface is very high and it slows down as we go away from the fan surface due to friction. Therefore, the measured air/wind speed/velocity of the chosen exhaust fan using anemometer at different distances away from its surface area (perpendicular to its sweep area) are summarized in

Table II. TABLE II. AIR SPPEED/VELOCITY AT DIFFERENT DISTANCES FROM EXHAUST FAN

Distance from Exhaust Fan		Air Velocity/Speed
in feet	in meter	in m/sec
0.5	0.1524	8.30
1.0	0.3048	8.15
2.0	0.6096	6.50
3.0	0.9144	5.10
4.0	1.2192	3.20
5.0	1.5240	2.65

Power Estimation

The (2) indicates that the mechanical power available from the wind turbine mainly depends upon the speed of wind v and the swept area A of the wind turbine. For the development of proposed system, a three blades horizontal axis wind turbine (HAWT) is used to install at the front surface/face of exhaust fan at a distance of 1.0 foot where the

measured speed of air is 8.15 m/s as indicated in Table II. The blade length l of selected micro-wind turbine is 7 inches or 0.1778 m. The swept area of wind turbine is 0.0993 m² which is calculated using the following relationship.

$$A = \pi r^2. \quad (6)$$

Where: r is the radius of swept area and is taken equal to the value of blade length l . While the other parameters such as rotor efficiency C_p and air density ρ in (2) appear as constant. The value of C_p is unique to each turbine type and is a function of wind speed. The C_p value cannot be greater than 59.3% as discussed earlier however its common value lies within 0.35-0.45 range [10, 14]. Therefore, the average of these values i.e., 0.4, is considered for C_p to estimate the power of the proposed system. Whereas, the value of ρ changes with variation in atmospheric pressure, temperature and humidity [15]. At 101.325 kPa (abs) and 15 °C, air has a density of approximately 1.225 kg/m³ according to International Standard Atmosphere (ISA). The Table III illustrates the air density–temperature relationship at 1 ATM or 101.325 kPa. Normally, in summer, the room temperature in Pakistan lies in the range of 30-40 °C. This is because the Pakistan is largely a warmest country and the most parts of the country are experienced hot summer. The highest temperature ever recorded in Pakistan is 53.5 °C [16]. Therefore, the value of 1.1455 kg/m³ for ρ at 35 °C is taken to estimate the power of the proposed system. Thus, to estimate the power converted from the wind/air of exhaust fan into rotational/mechanical power in the turbine, the following values are used in (2) for different parameters.

- $\rho = 1.1455 \text{ kg/m}^3$
- $A = 0.0993 \text{ m}^2$
- $v = 8.15 \text{ m/s}$
- $C_p = 0.4$

The computed value of available mechanical power (P_m) at the rotor of the micro-wind turbine is given as follows.

- $P_m = 12.32 \text{ Watt.}$

TABLE III. AIR DENSITIES AT DIFFERENT TEMPERATURES [15]

Temperature in °C	Density of Air in kg/m ³
40	1.1270
35	1.1455
30	1.1644
25	1.1839
20	1.2041
15	1.2250
10	1.2466
5	1.2690
0	1.2922

-5	1.3163
-10	1.3413
-15	1.3673

CONCLUSIONS

The exhaust fan in your home may be used to generate wind energy. Exhaust fan output air/wind is much faster than that of natural air, and may thus create even more electrical power than that of natural air. Therefore, a micro-wind power conversion strategy with battery storage is proposed in this work to make use of the otherwise wasted wind energy generated by exhaust fans. Rachna College of Engineering and Technology in Gujranwala has a Department of Electrical Engineering where the suggested system may be simply developed and evaluated. The system works and gives decent results despite having to utilise a DC generator with a greater rating than necessary owing to its unavailability on the market. The cheap cost of this wind-based micro-generation system is another factor encouraging exhaust fan manufacturers in Pakistan to develop this technology commercially as an integral element of exhaust fan to preserve energy. For this reason, the suggested method will be useful to both producers and consumers.

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