Experimental Investigation and Performance Simulation of Kit Horizontal Axis Wind Turbine

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ABSTRACT
The present study explores the performance of the small horizontal axis wind turbine. NACA-44 profile for wind Education Kit at different wind velocity range of (3.5 to 5.5 m/s) is used to achieve this study. The effects of changing the pitch angles (10°, 30°, and 45°) of the blade on the power performance of small wind turbine rotor models were investigated experimentally. (3, 4 and 6 blades) have been used to compare the results at each pitch angle for the different wind velocity. A computer program code was built to simulate the mathematical model. The axial induction factor indicates the degree to which the wind velocity at the upstream of the rotor is slowed down by the turbine; the power coefficient and the thrust coefficient for a range of axial induction factor have been evaluated and compared for different blades pitch angles. The maximum power coefficient obtained is about 0.51 occurs at 10° pitch angle for the 3 blades. Furthermore, it has been shown that the increase of wind velocity at a certain point will drop the overall efficiency down.

Keywords
Small horizontal axis wind turbine, axial induction factor, simulates the performance, pitch angles, power coefficient.

1. INTRODUCTION
In order to ensure the stable operation of wind turbines using non-grid-connected wind power, as well as the efficient utilization of wind resources, a study of condition monitoring of wind turbines is necessary. A test system of wind turbines under laboratory conditions based on a Lab View platform has been designed [1]. In order to extract the maximum possible power, it is important that the blades of small wind turbines start rotating at the lowest possible wind speed [2]. Large Scale Wind Turbines have been extensively examined for decades but only a few studies have been conducted on the small-scale wind turbines especially for low wind speed applications, the wind tunnel experiments revealed that SWEPT has rated power output of 1W and is capable of producing power output up to 2.2W at wind speed of 5.5 m/s [3].

Ali M. Rasham et al., [4] investigated experimentally the performance for a small horizontal portable wind turbine (SHPWT) of different blades profiles under laboratory conditions at different wind velocity range of (3.7-5.8 m/s).

The possibility of increasing the efficiency of the small horizontal axis wind turbine rotor by adding winglets at the tip of the blade was presented. The effects of changing the winglet configuration with the blade on the power performance of small wind turbine rotor models were investigated experimentally [5].

Nitin Tenguria et al., [6] evaluated the performance of horizontal axis wind turbine blades based on optimal rotor theory, a method for the determination of the aerodynamic performance characteristics using NACA airfoils is given for three bladed horizontal axis wind turbine. Ozcan Atlam [7] used a small scale education experiment kit with wind generator-PEM electrolyzer system and modeling, performance characteristics of the wind system are defined for different wind speeds. Three different horizontal axis wind turbine (HAWT) blade geometries with the same diameter of 0.72 m using the same NACA4418 airfoil profile have been investigated both experimentally and numerically [8].

A developed methodology is used to predict the optimal performance of the horizontal axis wind turbine in terms of the most critical parameters such as tip speed ratio, pitch angle, blade number and wind speed. Interesting generalized performance maps were conducted. Results show that low pitch is recommended for low wind speed regime [9].

The performance of a horizontal axis wind turbine continuously operating at its maximum power coefficient was evaluated by a calculation code based on Blade Element Momentum (BEM) theory. The mathematical code produced a power co-efficiency curve which showed that notwithstanding further increases in rotational velocity a constant maximum power value was reached even as wind velocity increased [10].

2. EXPERIMENTAL WORK
In this experimental work, Wind Education Kit with NACA-44 blade profile is used. Figure (1) shows the general aspect of the experimental setup. The kit horizontal wind turbine extracts the kinetic energy stored in the wind and converted it into electrical energy. Three cases in the present work were used to make a comparison between the power coefficient, thrust coefficient, output power, and overall efficiency of three, four and blades for different pitch angles (10°, 30°, and 45°) and different wind velocity. The fan is placed in line with the wind turbine as an appropriate wind source range of (3.5 to 5.5 m/s) to exert wind toward the wind turbine device in order to spin the blades of the kit horizontal wind turbine to produces power. Spark sensor is used to measure a voltage and current produced after the rotation of wind turbine blades. A digital anemometer is used to measure the wind velocity at the upwind region of the wind turbine. Also, it was used to measure the wind velocity ahead of the blades of the wind turbine.

3. MATHEMATICAL MODEL
The kinetic energy of an air mass (m) moving at a velocity (v) can be expressed as:

$$\mathrm{K.E} = \frac{1}{2}\mathrm{mv}^2 \quad (1)$$

The power P that the wind contains is calculated by differentiating the energy with respect to time. For a constant wind speed v the power is:

$$P = \frac{1}{2}\dot{m}{v_1}^2 \quad (2)$$

The air mass flow rare with density (ρ) flows through an area (A) with speed (v_1) is:

$$\dot{m} = \rho A v_1 \quad (3)$$

The power of the wind becomes:

$$P_w = \frac{1}{2}\rho {v_1}^3 A \quad (4)$$

The axial induction factor which is the functional reduction of the wind velocity at the rotor calculated as:

$$a = \frac{v_1 - v_r}{v_1} \quad (5)$$

The power coefficient C_p and is given by:

$$C_p = 4a(1-a)^2 \quad (6)$$

The thrust coefficient C_T of a wind is defined as:

$$C_T = 4a(1-a) \quad (7)$$

The electrical output power can be estimated from the output voltage and current experimentally calculated which can be written as:

$$P_e = VI \quad (8)$$

The ratio of electrical power P_e of the turbine to the power of the wind P_w defines the efficiency for the power utilization of the wind:

$$\eta = \frac{P_e}{P_w} \quad (9)$$

4. RESULTS AND DISCUSSION

In order to study horizontal axis wind turbine performance, a laboratory kit wind turbine has been used. It has been investigated under different wind velocity range of (3.5 to 5.5 m/s) and checking the effect of changing the blades pitch angles and the number of blades for each angle. The representation of power coefficient and thrust coefficient with axial induction factor for a different number of blades is shown in figure (2, 3 and 4) respectively. It has been experimentally observed that changing the pitch angle has sufficient effect on measuring and calculated coefficients, C_p, and C_T of three blades were better than the case of (4 and 6) blades. Also, it has been shown that C_p and C_T record better results for 10°pitch angle of(3 and 4) blades, while there was no significant difference of the determined coefficients in the case of 6 blades wind turbine.

Figure (5, 6 and 7) shows the evolution of the wind power and the overall generated power of the wind turbine for different wind speeds range (3.5 to 5.5 m/s). The measurements were compared for (3, 4 and 6 blades), each case was tested to three different pitch angle (10°, 30°, and 45°). The wind power for all cases was the same since there is no change in the upwind speed range. It can be seen that P_w is always greater than P_e, because of the reduction of the rotor speed. A maximum power of 4.1 W at a wind speed of 5.5 m/s was obtained for the four blade wind turbine at 10° pitch angle.

The overall efficiency behavior by the changing influence of blades number and blade pitch angles is illustrated in figure (8, 9 and 10) respectively. The Maximum efficiency achieved was 70.97% at 10° pitch angle of 3 blade wind turbine. It can be shown that the overall efficiency of 3 and 4 bladed rotors is better than the use of 6 bladed rotors. As it can be seen from the figures, the efficiency distributions show little changes after the upwind speed of 5m/s for each of the cases. It is evident that efficiencies at the speed of 4m/s, 4.5m/s, and 5m/s are the best. Not only can the values of efficiency provide important information for the power generated, but also give the motivation for developing the simulation code.

5. CONCLUSIONS

A small-scale wind turbine generator has been used in this paper to investigate the performance. Simulation by generated a computer program code has been made to compare the results. The results of the present work lead to the following conclusions:

- The performance of three-bladed profile kit wind turbine is better than that calculated for the kit wind turbine with four and six-bladed. There is a significant effect of changing the blade pitch angle on both three and four-bladed rotor, the best results were at 10° pitch angle.
- The results indicate that for a small horizontal wind turbine with four blades at 5.5 m/s, the energy production reaches its maximum value (4.1 watts).
- The best overall efficiency obtained for three blades profile at 10° pitch angle reach about 70%.
- In general, the optimal performance of small horizontal wind turbine occurs for the three blades profile at 10° and 30° pitch angle for the velocity range of (4m/s to 5m/s).

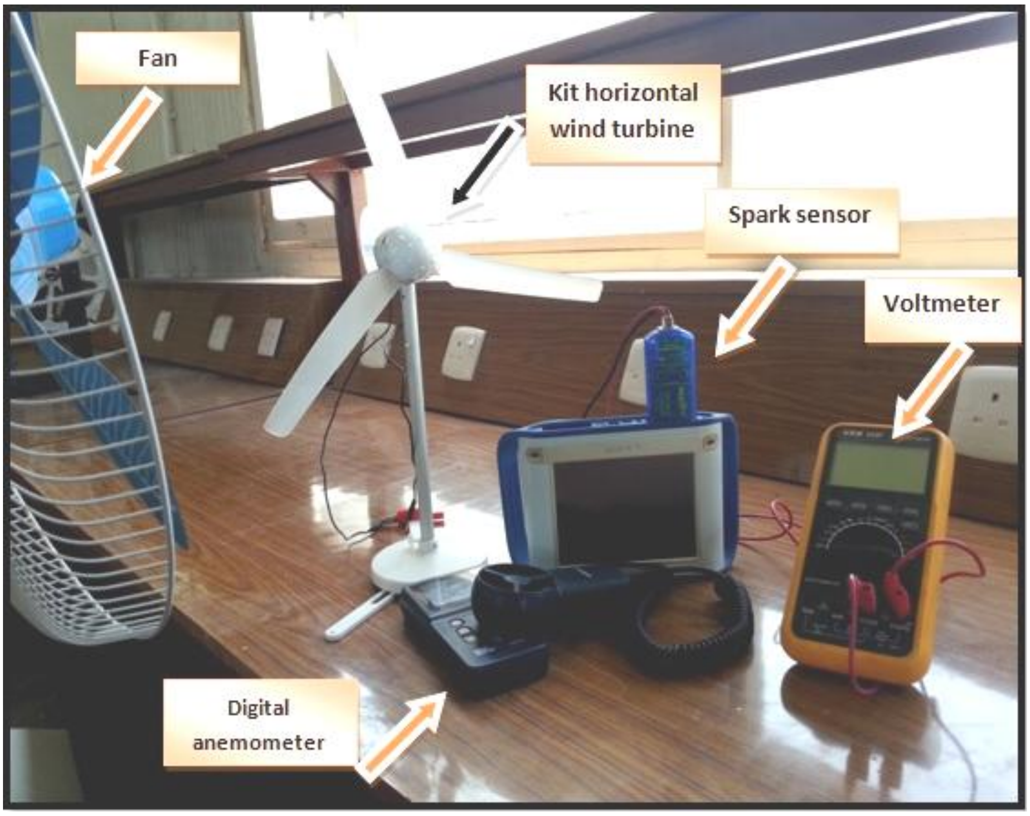

Fig 1: General aspect of the experimental setup.

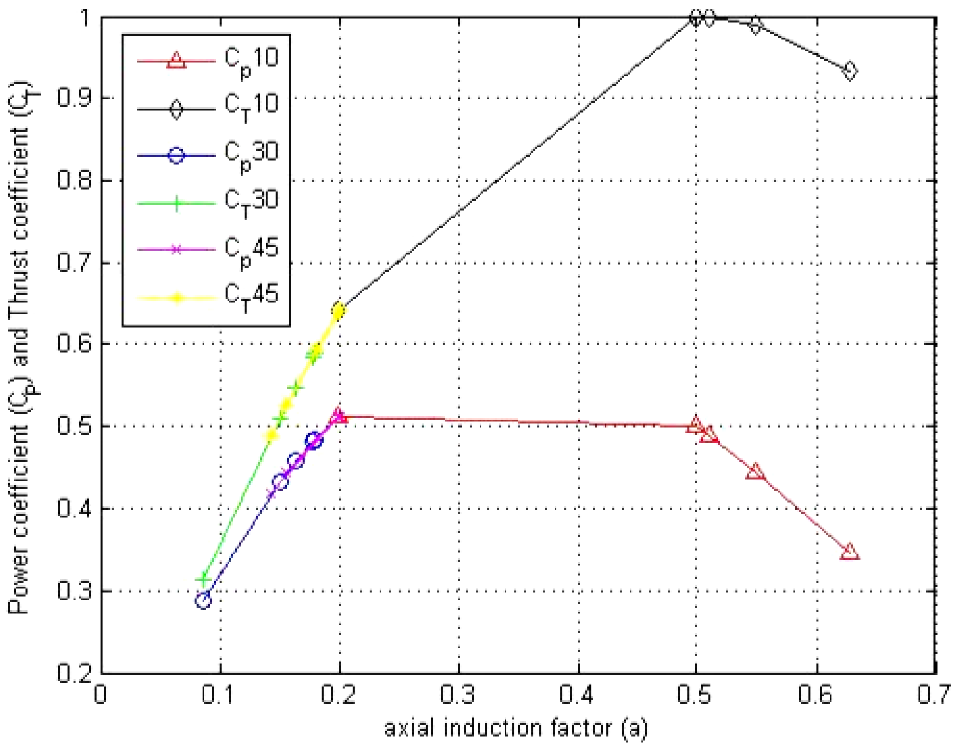

Fig 2: The relationship between (Cp, Ct) and axial induction factor (a) for three blades and (10°, 30°, and 45°) pitch angle.

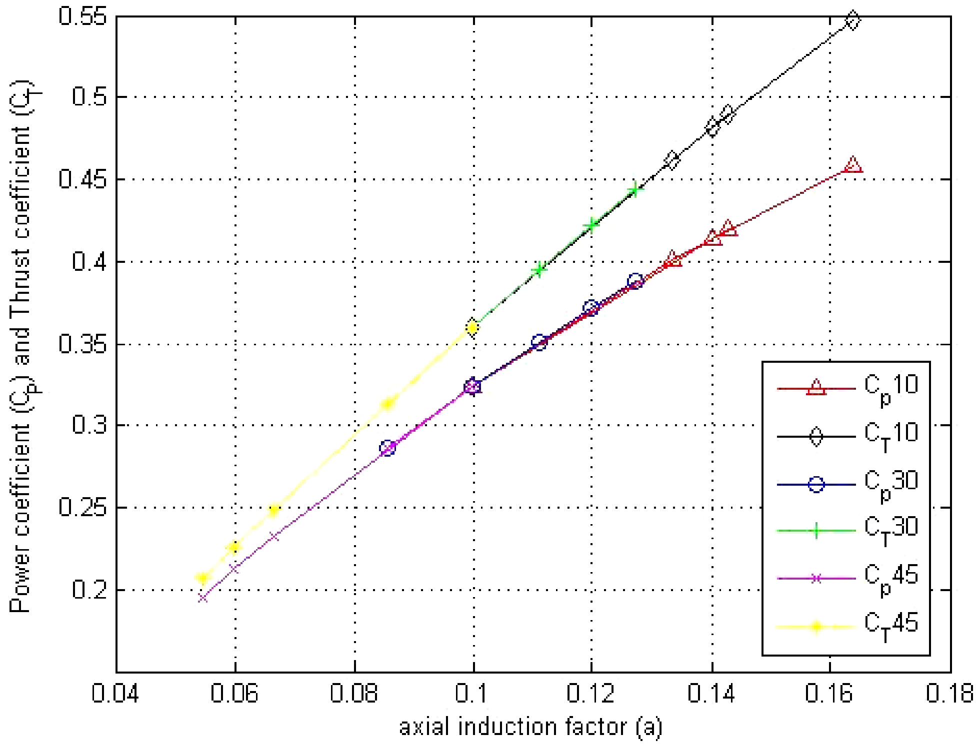

Fig 3: The relationship between (Cp, CT) and axial induction factor (a) for four blades and (10°, 30°, and 45°) pitch angle

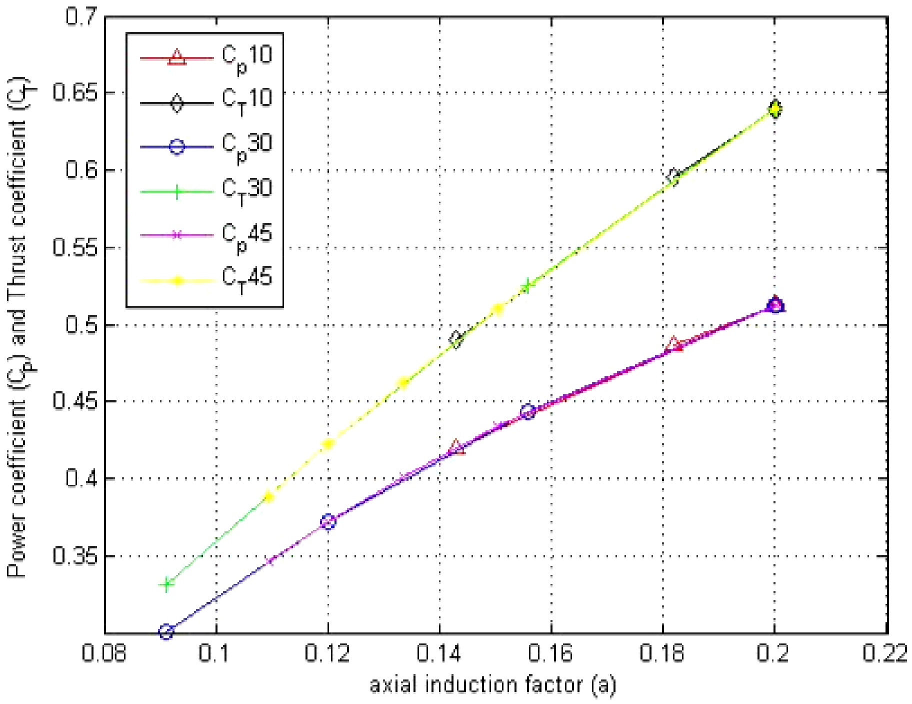

Fig 4: The relationship between (Cp, C_T) and axial induction factor (a) for six blades and (10°, 30°, and 45°) pitch angle.

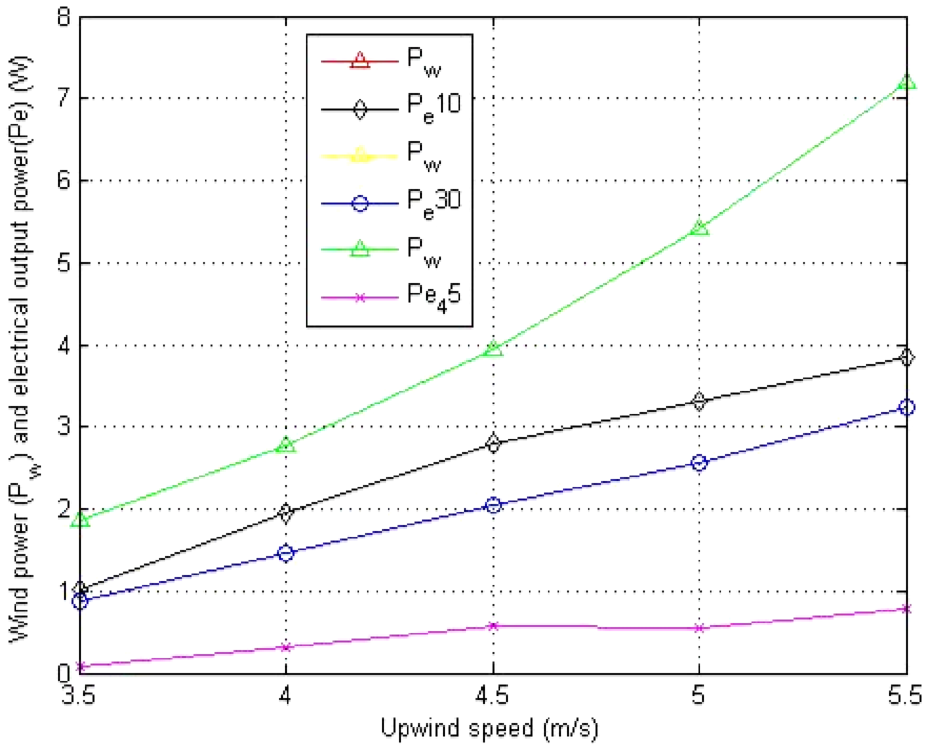

Fig 5: Variation of wind power and output electrical power with upwind speed for three blades and (10°, 30°, and 45°) pitch angle.

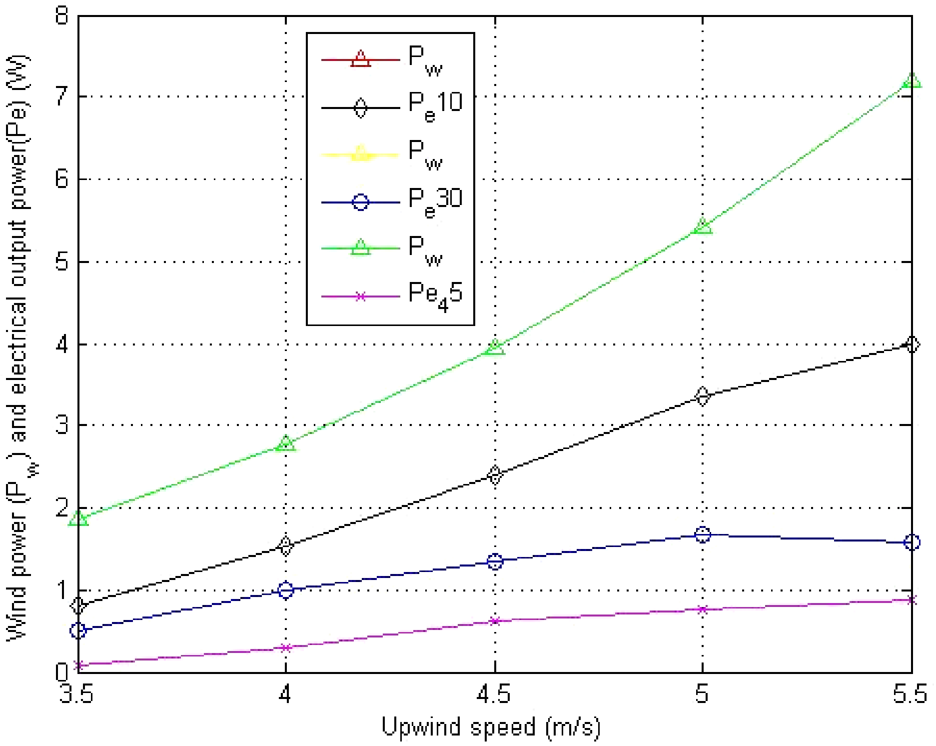

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Fig 6: Variation of wind power and output electrical power with upwind speed for four blades and (10°, 30°, and 45°) pitch angle.

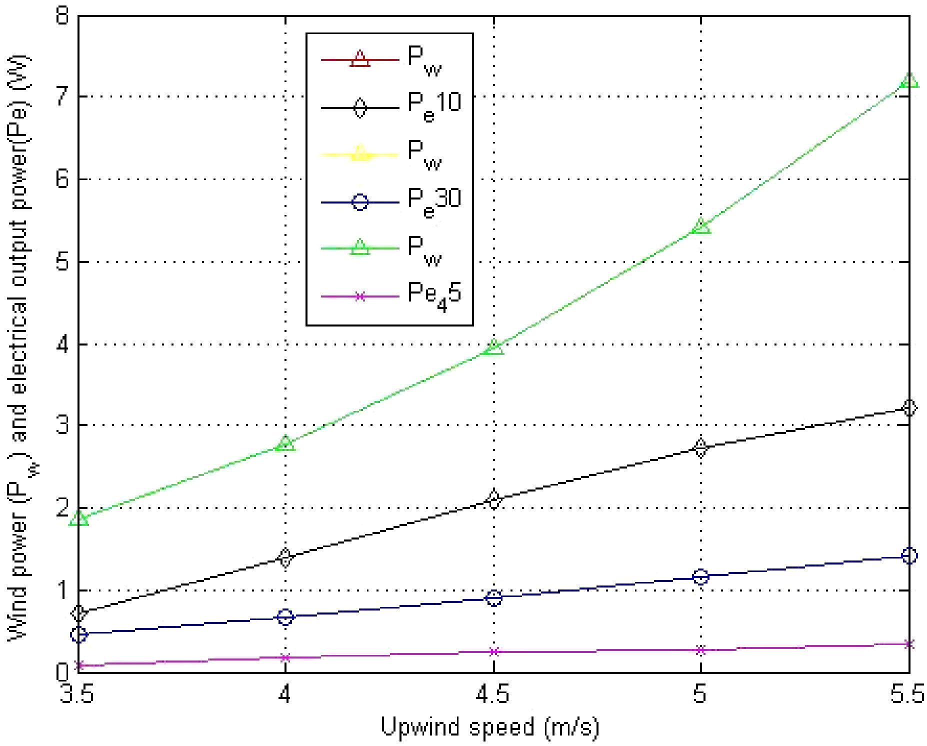

Fig 7: Variation of wind power and output electrical power with upwind speed for six blades and (10°, 30°, and 45°) pitch angle.

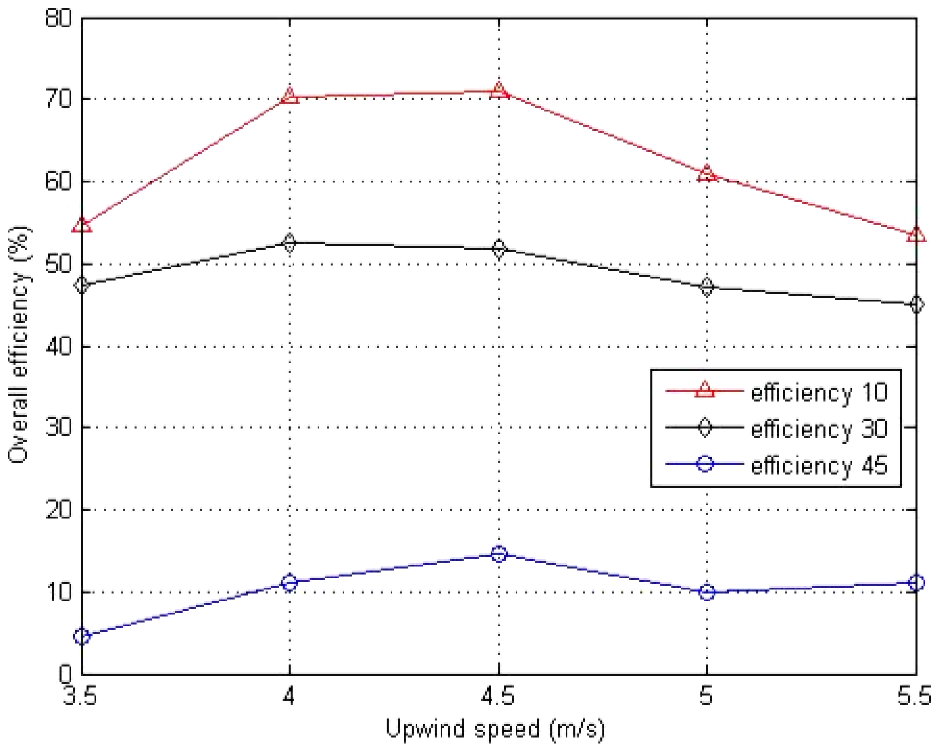

Fig 8: Overall Efficiency of the three-bladed rotor at (10°, 30°, and 45°) pitch angle.

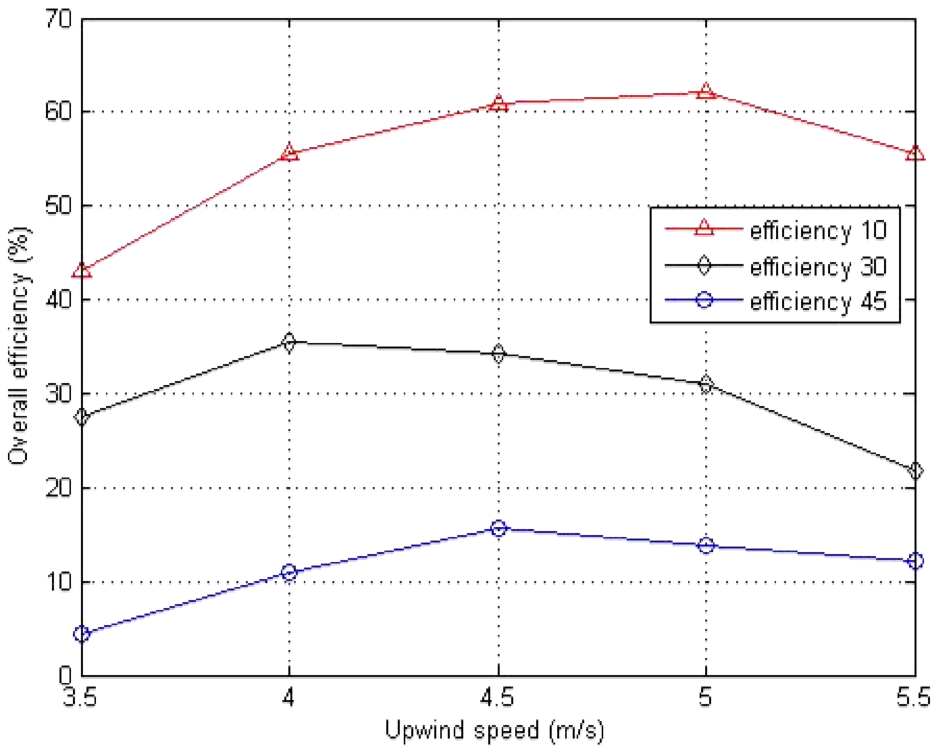

Fig 9: Overall Efficiency of the four-bladed rotor at (10°, 30°, and 45°) pitch angle.

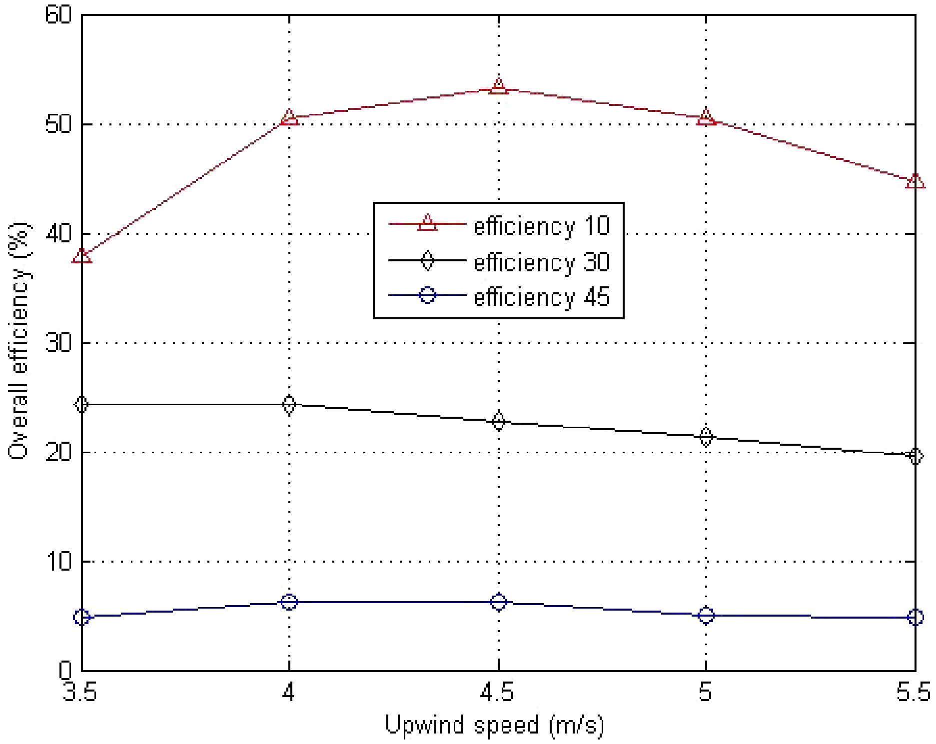

Fig 10: Overall Efficiency of the six-bladed rotor at (10°, 30°, and 45°) pitch angle.

6. NOMENCLATURES

Symbols	Description
m	Air mass(Kg)
v	Air velocity (m/s)
v_1	Upwind velocity (m/s)
v_r	Rotor velocity (m/s)
$\dot{m}$	Air mass flow rate (kg/s)
A	Rotor blade area (m^2)
a	Axial induction factor
C_p	Power coefficient
C_T	Thrust coefficient
P_w	Power of the wind (watt)
P_e	Electrical output power(watt)
V	Voltage (volt)
I	Current (Ampere)
Greek symbols	
ρ	Air density (1.24 kg/m3)
ɳ	Overall efficiency (%)
Abbreviations	
K.E	Kinetic energy
SHPWT	Small horizontal portable wind turbine
HAWT	horizontal axis wind turbine
BEM	Blade Element Momentum
NACA	National Advisory Committee for Aeronautics

7. REFERENCES

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