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Performance of Harris Hawks Optimization on Optimum Wind Cube Design

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A B S T R A C T

Renewable energy is a safe and boundless energy source that can be exploited for heating, cooling, and other applications. Wind energy is one of the most significant renewable energy types. Power variation of wind turbines happens due to wind velocity fluctuation. A wind cube is applied to decrease power variation and increase the power of wind turbine. The design of optimum wind cube is the main involvement of this work. The parameters applied to optimize the wind cube are its outer and inner radius, the hub height of the wind turbine and the roughness factor. A Harris Hawks Optimization (HHO) is used as a new metaheuristic algorithm in this problem. The objective function of this research includes two parts: the first part is to minimize the probability of loss in generated energy, and the second is to minimize the cost of the wind cube and wind turbine. The Red Sea governorate of Egypt metrological data is used as a case for this work.

Keywords: Wind turbine, Wind cube, Harris hawk's optimization.

I. INTRODUCTION

Improvements to quality of life are required when an economy and society grow. Reduced environmental contamination is one of the corresponding challenges. One of the key strategies for reducing environmental pollution is substituting clean energy for fossil fuels. Large-scale use of renewable energy can assist meet everyday energy needs [1, 2]. The development of power from renewable and clean energy sources is of interest to both businesses and academic institutions, and these considerations, combined with the development of already-existing technology, help to explain the significance of wind energy in recent years [3, 4]. A wind cube is a new type of wind turbine designed to capture and magnify more kWh of wind. Wind concentrates and develops speed when it strikes the wind cube, increasing power output. To optimize the performance of a wind turbine, it is important to consider the design and placement of the wind cube. The wind cube, also known as the rotor or blades, is responsible for capturing the wind energy and converting it into rotational energy that can be used to generate electricity. The contemporary wind cube technology was created to address issues with low wind speeds and gather wind energy in these conditions [5]. Wind cubes increase wind turbine productivity by increasing their effectiveness [5]. The nonlinear character of the wind necessitates the application of optimisation techniques. Soft computing technology is used to optimise the arrangement [6]. The best answer to many problems is derived using meta-heuristic optimisation techniques. The estimation of parameters in photovoltaic models like the Marine Predators Algorithm [7], the Multi-Strategy Success-History-Based Adaptive Differential Evolution [8], the Bacterial Foraging Algorithm [9], the Differential Evolution Algorithms [10], and the Shuffled Frog Leaping Algorithm [11] is one of these problems. One of the key methods for choosing the best location for a wind farm and maximising the power produced is to apply meta-heuristic optimisation to the layout of the wind farm. Modified genetic algorithms based on a Boolean code [12], the Monte Carlo method [13], a genetic algorithm-based local search [14], a novel pseudo-random number generation method [15], and a multi-level extended pattern search algorithm [16] are the optimisation algorithms that were employed for these.

II. Problem Formulation

Wind Turbine Analysis

The key element impacting the amount of power produced by a wind turbine is the fluctuation in wind speed. According to the following equation [17], the features of wind turbine output power rely on the limits of wind speed (cut-in speed V_{ci}, rated speed V_r and cut-off speed V_{co}) as in the following equation [17]:

$$P_{wind}=\begin{cases} P_r\left(\dfrac{V^3-V_{ci}^3}{V_r^3-V_{ci}^3}\right) & V_{ci}\le V\le V_r \\ P_r & V_r\le V\le V_{co} \\ 0 & V_{co}\le V \text{ or } V\le V_{ci} \end{cases} \quad (1)$$

where the rated power and speed, respectively, are P_r and V_r. Since the stream speed to the wind turbine is influenced by the hub height, the stream velocity can be modified in accordance with the hub height using the following equation [18]:

$$\frac{V_{h.2}}{V_{h.1}}=\left(\frac{h_2}{h_1}\right)^{\propto} \qquad (2)$$

where Vh.1 is the reference speed at the height of the wind turbine's reference hub, h1, and Vh.2 is the velocity at the new hub height, h2. The roughness ingredient factor, or, has a range of 0.14 to 0.25 under the neutral stability condition [19]. Utilizing the wind cube, the power produced by the wind turbine is improved. The Bernoulli hypothesis serves as the foundational theory for wind cube design. To get the best design, the size of the wind cube is modified. Fig. 1 explains how the wind cube is configured.

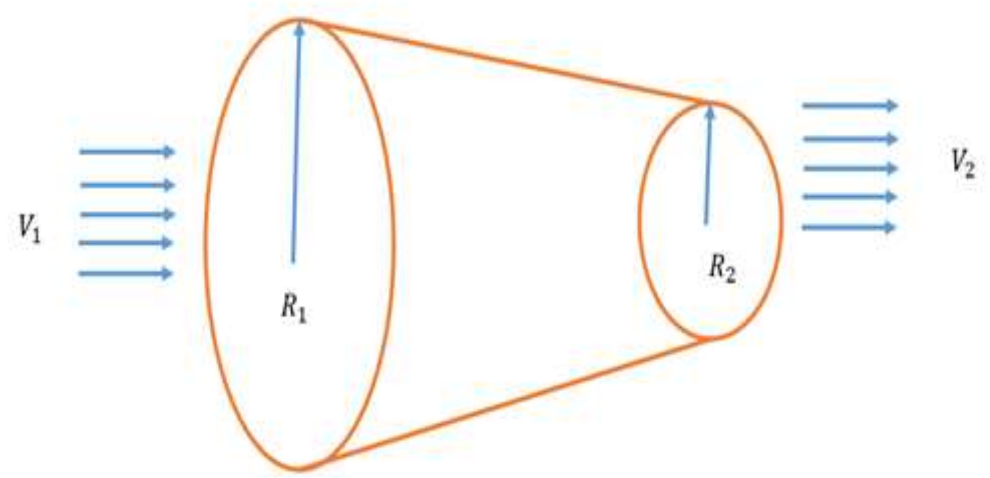

Figure 1: Wind cube configuration

The primary equation for the wind cube is represented as follows using Bernoulli's theory:

$$A_1V_1=A_2V_2 \qquad (3)$$

where A_1 is the area of the wind cube from the air side and A_2 is the area of the wind cube from the wind turbine side, and V_1 and V_2 are the wind speeds input and output from the wind cube, respectively. This equation represents the power produced by the wind cube-powered wind turbine:

$$P_{wind}=\begin{cases} P_r\left(\dfrac{\left(\dfrac{R_1^2\,V_1}{R_2^2}\right)^3-V_{ci}^3}{V_r^3-V_{ci}^3}\right) & V_{ci}\le V_1\le V_r \\ P_r & V_r\le V_1\le V_{co} \\ 0 & V_{co}\le V_1 \text{ or } V_1\le V_{ci} \end{cases} \qquad (4)$$

where R_1 is the wind cube's input radius from the air side and R_2 is the wind cube's output radius from the side of the wind turbine.

Metrological Data

Hurghada City in the Red Sea governate of Egypt is the site used in this work to simulate the power output improvement. The latitude is 27° 15' 26.57" N and the longitude is 33° 48' 46.48" E. The metrological data of the average wind speed for each month is explained in Fig. 2, and the average wind speed over the year is shown in Fig.3.

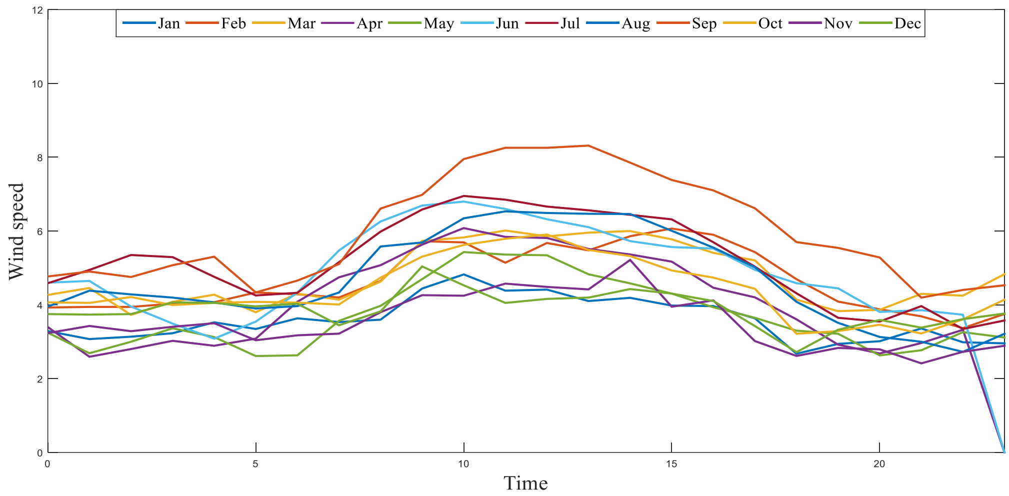

Figure 2: the profile of wind speed

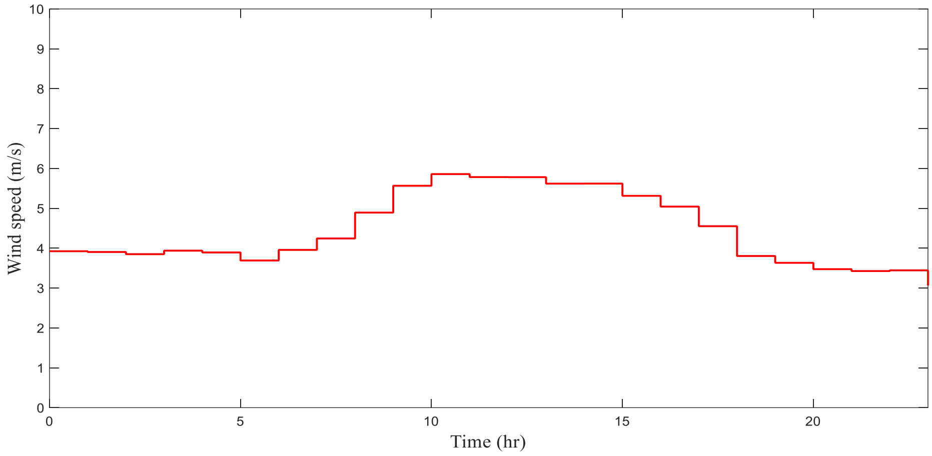

Figure 3: The average wind speed over the year

III. Analysis of objective function

The increase in power produced by a wind turbine is correlated with a decrease in the likelihood that energy will be lost during generation (LEGP), as long as the wind cube's maximum speed does not exceed 80% of the turbine's cut-off speed. The two wind cube radiuses, the height of the wind turbine hub, and the roughness factor are the choice variables needed for the best sizing. The LEGP's mathematical formula is as follows:

$$LEGP=\frac{E_{g.rated} - E_{g.actual}}{E_{g.rated}} \quad (5)$$

where $E_{g.rated}$, is the energy produced at the wind turbine's rated power, "$E_{g.rated}$ Prior to applying a second objective function (the metre cubic function) to select the best solution that satisfies the minimum parameters, the suggested algorithm is applied to an independent run for the objective function. The minimum parameters show that the wind cube and wind turbine costs are at their lowest levels. The following describes the second objective function:

$$f_{obj2}=R_1\times R_1\times h_2 \quad (6)$$

IV. Harris Hawks Optimization

The HHO is a metaheuristic optimisation method that mimics the "surprise pounce" chase behaviour of Harris Hawks. Like other metaheuristic algorithms, the HHO technique contains stages for exploration and exploitation. HHO is a population-based, gradient-free technique to optimisation. Therefore, when properly formulated, it can be used to address any optimisation problem. The HHO algorithm has two exploration phases and four exploitative phases. Furthermore, the mathematical using a representation of this cooperative behaviour, a unique stochastic approach to resolving various optimisation problems is suggested. The planned HHO's exploring and exploitative phases, which are modelled after the prey exploration, surprise pounce, and varied attacking strategies used by Harris hawks. With the appropriate formulation, HHO can be utilised to solve any optimisation problem because it is a population-based, gradient-free optimisation method [20].

V. Analysis of Results

The results of the suggested algorithm's analysis for the wind turbine described in Table 1 are shown in this section. Table 2 explains the turbine's decision variable's upper and lower bounds. The radius of the rotor blades and the height of the turbine hub both influence the choice of boundaries for the turbine. The rotor blades' radius and the wind cube radius from the turbine side are not even close to being equal. In order to prevent the wind cube from touching the ground, the wind cube radius from the airside is more than the rotor blade radius and smaller than the hub height with a set distance for the turbine.

Table 1: Types of wind turbines

Type	Rated power	Rotor radius	Cut-in speed	Cut-off speed	Rated speed
90 kW	90000	9.5	3.3	28	16.8

Table 2: Boundary limits for the decision variable

Type	Lower	Upper
	90 kW	90 kW
R1	8	9.5
R2	4	4.75
h2	20	30
α	0.14	0.25

Wind Turbine of 90 kW

The suggested HHO algorithm is used to process data for the wind turbine based on Section 2 and Tables 1 and 2. Results of the suggested HHO algorithm for a 90-kW wind turbine based on minimising the chance of a generated energy loss are shown in Table 3. The second objective function, which meets the minimal metre cubic function, is used to determine the best solution for these outcomes.

Table 3: likelihood loss of generated energy equal to 0.014717919765105 is achieved in all runs. Run 20's outcome is the best possible one since it meets the minimal objective function of minimising the metre cubic function. Figure 4 displays the power demand output from a wind turbine at the same height as the wind turbine hub without a wind cube at the best solution. For run 20 of the suggested HHO algorithm, the variation of wind speed applied for the wind turbine with and without wind cube is applied in figure5. Figure 6 displays the power demand output from the wind turbine with wind cube at the best solution.

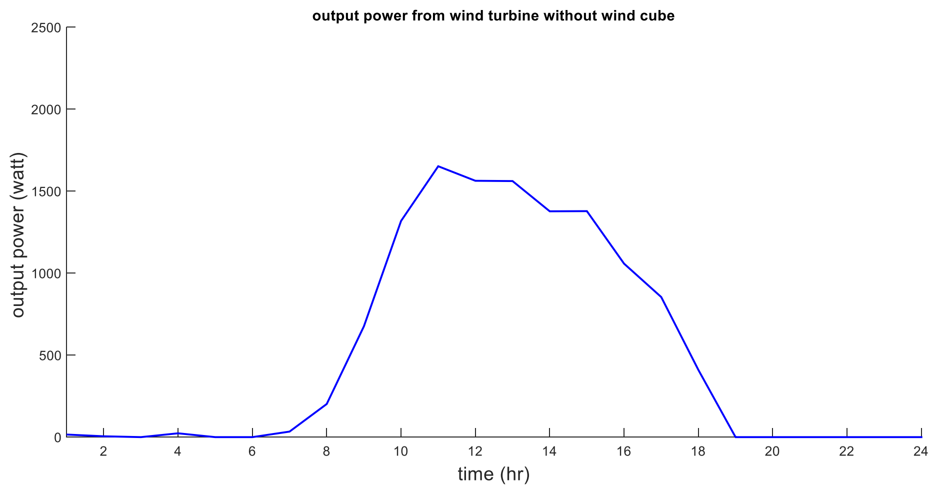

Figure 4: 90-kW wind turbine generated power without a wind cube.

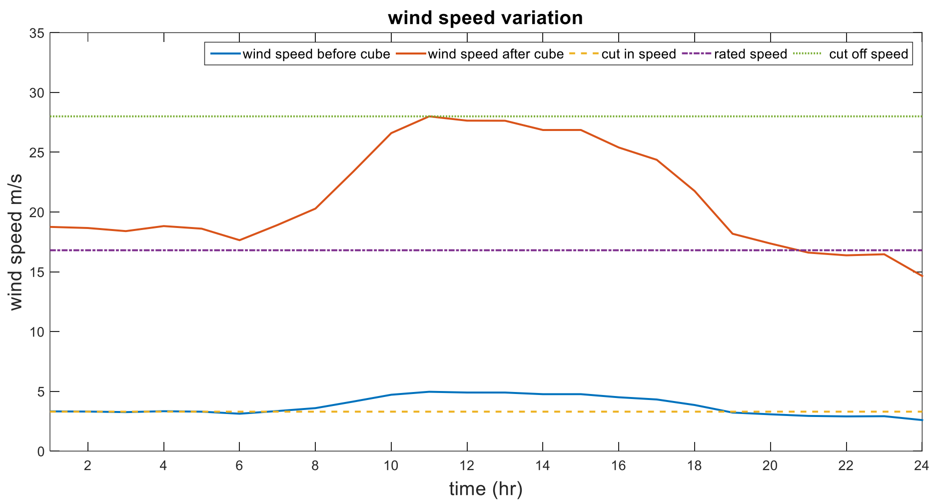

Figure 5: variation of wind speed with and without wind cube.

Table 3: Results of the estimated parameters for 90 kW from a HHO algorithm.

Run	R1	R2	H	A	fobj2
1	9.387073557	4.002449096	26.30514809	0.241944066	988.3181913
2	9.452410525	4.062347635	27.60880557	0.234173716	1060.149905
3	9.342774263	4.004251153	27.23439177	0.238349077	1018.860782
4	9.5	4.108080892	30	0.25	1170.803054
5	9.25609819	4.004339101	29.91621855	0.246540792	1108.831355
6	9.494822669	4.105616595	29.96098926	0.249521443	1167.942325
7	9.118350686	4.012129008	27.64529688	0.146035291	1011.375521
8	9.264315353	4.049662931	28.59307619	0.182377555	1072.736574
9	9.5	4	20	0.193770868	760
10	9.487288634	4.108663803	21.62082092	0.140730471	842.7813161
11	9.422718508	4.05386476	23.51981037	0.176904546	898.4197479
12	9.471289901	4.158231972	29.917704	0.18135199	1178.273484
13	9.385548898	4.005617743	23.37201976	0.198269423	878.6692411
14	9.155016156	4.045645133	28.7811602	0.140464971	1065.995073
15	9.273115804	4.020185902	23.03412992	0.150242475	858.7042884
16	9.15352645	4.019564521	28.33722977	0.161070864	1042.617083
17	9.497153274	4.105558398	26.68596955	0.199407545	1040.515771
18	9.406461551	4.067514492	29.98740026	0.249894981	1147.345483
19	9.15975028	4	27.0830133	0.168011911	992.2945546
20	9.347576249	4.006050242	25.77157103	0.216664703	965.0644147

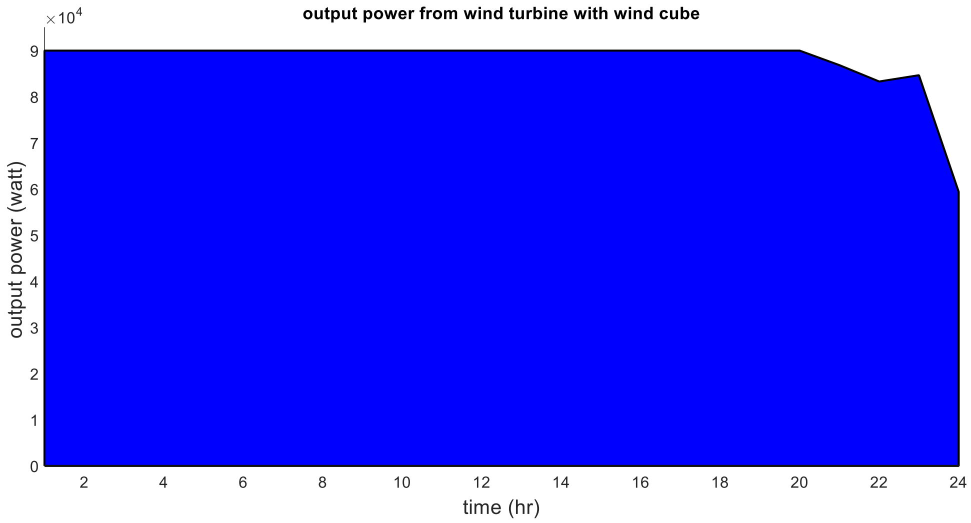

Figure 6: 90-kW wind turbine power output using wind cube.

IV. Conclusion

It is crucial work to increase the amount of energy the wind turbine generates. Using a successful optimization method, wind cubes increase the output of wind turbines. The inner radius of the wind cube, the height of the wind turbine hub, and the outer radius of the wind cube are all estimated using an HHO. In order to make these variables more affordable, the extraction of these parameters depends on reducing the decision variable and minimising the likelihood of a loss of generated energy. For the site, there is a tolerance of a 20% air speed increase over the speed mentioned in this study. The power production of wind turbines with and without the optimised wind cube was compared. This comparison shows that the energy produced from a 90-kW wind turbine with wind cube is 68 times that produced without the cube.

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