Optimized manufacturing of the small dual wind turbine used to generate electricity in central Iraq areas

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Abstract. Start your Due to the importance of generating electricity from wind turbines, single rotor wind turbine and dual rotor wind turbine. There was a need to design and manufacture the turbine system operating in both types mentioned above and have advantages to increase the generation of electric power. The aim of this work was to generate electrical power at a wind speed of up to 1 m/s and more to achieve this wind speed and direction of the wind were adopted from tables of the Zerbatiya Station of the Wasit Governorate (Geographically located in central Iraq). The simulation was used to generate rotational speed for front and rear blades from 1 m/sec to 13 m/sec. A new idea was used to induce the dual small wind turbine to generate electrical power at low speed (1 m/sec). In this case, there is latent energy in the surrounding wind turbine, but it is not that helps to rotate the wind turbine. To apply this idea the starter motor is used. Passive magnetic bearing supports have been used to reduce friction of the rotors this will reduce losing of wind energy. Brakes are the mechanical devices which aimed to slow or shut down the machine. They are also designed to prevent moving after stopping. Finally, the Genetic Algorithm (GA) was used within the program for the purpose of obtaining the best amount of power generated. All the above were for the purpose of determining the best position for blades at different speeds to generate electricity by using Permanent Magnetic Synchronous Generator (400W). Results of this paper: (a)- The starter motor proved good performance when using it. (b)- Using passive magnetic bearing proved effect on increase the power generation. (c)- Mechanical brakes work to stop the system within a period of time and not immediately as this will negatively affect the performance of the system.

Keywords: Dual wind turbine, passive magnetic bearing, the starter motor, passive magnetic bearing, mechanical brakes.

1. Introduction

The single-rotor wind turbines (SRWT) suffer high aerodynamic loss deficiency in the blade root region (approximately bottom 25%). This particular region of the blade is primarily designed for maintaining the structural integrity of the blade. It causes high aerodynamic losses and thus reduces
the overall efficiency of a turbine, [1]. A modern design of dual rotor wind turbines (DRWT) is suggested to mitigate the losses by introducing another rotor. The (DRWT) design is able to harness more wind energy by minimizing root loss in the vicinity of the roots of the main rotor blades for the same airflow, it also causes much larger dynamic wind load operating on the dual rotor wind turbine model, and higher velocity errors following the (DRWT) model, compared to the (SRWT) case, [2, 3]. Wind turbines have to be able to stop in case of failure of critical components or if wind speed goes over a critical limit. If the wind turbine does not brake, the rotation of the wind turbine may lead to loss in the whole structure, [4, 5]. Studied an experimental to investigated the aeromechanics and the properties of double rotor wind turbines (DRWTs) in either co-rotating or counter-rotating configuration, which compared with conventional single-rotor wind turbine (SRWT) model illustrating basic physics to optimize the wind turbine design in order to increase energy productivity and best durability [6]. Showed that the strongest correlation was between power and speed of the air stream. While incidence angles of the two rotors also affected the turbine’s power, no such effect was observed for changes in the distance between the rotors. Field tests confirmed the findings and observations made in the wind tunnel [7]; they found that the stiffness is improved by stacking the magnet in the special combination of different radial cum axial direction of magnetization. The best configuration based on this analysis is fabricated and tested in the vertical axis wind turbine [8]. Showed the efficiency of the wind turbines or the energy output can be increased by reducing the cut-in-speed and/or the rated-speed by modifying and redesigning the blades. The problem is tackled by identifying the optimization parameters such as annual energy yield, power coefficient, energy cost, blade mass, and blade design constraints such as physical, geometric, and aerodynamic. The present paper provides an overview of the commonly used models, techniques, tools and experimental approaches applied to increase the efficiency of the wind turbines [9]. Designed dual wind small turbine with used a device to reverse the rotor rotation to study multiple cases to achieve the best results and performance of the separation mechanism [10]. This paper shows the manufactured small wind turbine at different cases, single rotor wind turbine and dual rotor wind turbine. The most important advantage of using a starter motor is to generate an internal torque for the system and this torque is concentrated in the middle of rotor wind turbine. Passive magnetic bearing used to reduce friction to take advantage of wind energy without loss. A mechanical brakes performance for the front and rear rotors was tested at different operating cases as well as at different speeds.

2. Analysis of power produced from dual wind turbine

According to Betz theory, the maximum wind power is nearly 16/27 of the obtainable energy in the wind while less wind axial speed by two-thirds through a singular rotor disc. Whatever, the process of wind turbines is transforming lower than 40% of wind energy to electrical energy. Thus, approximately 60% of probable wind energy evades without being used. In fact, the energy in the wake of one rotary wake is large. Some of this energy might be extracted by constituting the other rotor in the wake. Since rotation behind first rotor rotates in reverse direction to the rotating direction of rotor. The output power of the turbine rotor and the wind kinetic energy per unit time are given as follows, [11].

\[ P_T = T_m \cdot \omega \]  \hspace{1cm} (1)

\[ P_W = \frac{1}{2} \rho \cdot V_0^3 \cdot A \]  \hspace{1cm} (2)

This limit is known as the Betz limit. So, the maximum power which the turbine can produce is expressed as follows.
The rotor power coefficient $C_p$ is defined as the ratio between the output power of the rotor and the dynamic power of the air as shown below.

$$C_p = \frac{Actual\ Electrical\ Power\ Produced}{Wind\ Power\ into\ Turbine}$$

$$C_p = \frac{P_T}{P_w} = \frac{T_m \cdot \omega}{\left(\frac{1}{2}\right) \rho \cdot V_0^3 \cdot A}$$

The power coefficient is a nonlinear function of the tip speed-ratio $\lambda$, which depends on the rotation speed of the shaft and wind velocity, [12].

$$\lambda = \frac{V_{Tip}}{V_0} = \frac{R \cdot \omega}{V_0}$$

3. Experimental work

In this section, explained the practical aspect of manufacturing a wind power system in two cases, single and dual wind turbine blades, which include different secondary operations states. The experimental work can be divided into three main sections, namely the mechanical components section, the electrical components section and the last section is the control of the whole system and the extraction of all the values to be desired.

3.1. Mechanical Components

The mechanical components can be divided into three parts, the first part is front part to be placed in the direction of the expected wind, the second part is the rear part and third part is gearbox and three-phase permanent magnet synchronous generator, as shown in Figure 1. The front and rear parts is divided into, movable wing and non-movable wing. All specifications and dimensions of the components will be handled according to their location as follows.

![Figure 1: Simplified layout of the dual wind turbine](image-url)
3.1.1 The Front Part

(a)-Movable Wing

The movable wing is important because it includes a new idea to be accomplished in this work, it contains:

i- Set of blades (three blades) with each Model Number: NE-M3. The total diameter is about (165cm) that made from (PVC) and variable thickness as shown in Figure 2-a and hub that the blades carry be with that dimensions an internal diameter of (16 mm) as shown in Figure 2-b. Thickness of blade tip 3mm and other side 4mm, thickness in the chord 4mm and other side 8mm and final in the root of blade 14.5mm.

Figure 2: Wind turbine blades used in this work
(a)-Front View of Blades  (b)- The Hub of Blades

ii- The movable wing base that dimensions (32cm x 40cm x 0.4cm).

iii- Figure (3) explains all that will be mentioned in (iii) to (v). Two ball bearings, that internal diameter (25mm), model P205, W/ Grease Zerk. Pillow, with manufactured bases of aluminum with dimensions (128 x 40 x 29 mm).

iv- The shaft length 575 mm, consist of three parts with diameters (16mm, 25 mm and 28 mm), made of mild steel material.

v- The movable wing shall be fixed with the non-movable wing of the front and rear parts by the help of two joints, it characterized by high durability and high tolerance to lift the moving part with full flexibility.

Figure 3: Movable wing.
(1)-Blade, (2) - Hub of blade, (3)-Bush, (4)-Ball bearing internal diameter (25mm), (5)-Shaft, (6)-Wing base, (7)-Arm for lifting, (8)-Joint, (9)-Hollow shaft with slots, (10)-Cardan joint, (11)- Ball bearing internal diameter (20mm), (12)- Simulation Device.
(b)-Non Movable Wing

Non movable wing with dimensions 52cm x 40cm x 0.4cm, as shown in Figure (4), it contains the following components:

i- Two types of ball bearings that internal diameter (20mm). The first type of ball bearing will be supported the horizontal front and rear shafts and the second type of ball bearing for supported the shaft of gearbox.

ii- Shaft with length 410 mm and diameter 20 mm is made of low carbon steel.

3.1.2 The Rear Part

(a)- Movable Wing

Contains the following components:

i- A sets of blades a symmetric with the front part.

ii- Hub that the blades carry which Featured they can be tightened in two cases, which match the angles between the front and rear parts, as well as when the deviation between blades of the front and rear. All components of this part are similar to which was mentioned in the front part.

(b)- Non Movable Wing

The end of the shaft of the front set and the shaft of the rear set involves gear from type (helical) number of teeth (15) that inner diameter (16mm) as shown in Figure 3. Figure 4 shows that these two gears they give motion to horizontal gear number of teeth (33) that inner diameter (20mm) and material (low carbon steel) which is connected to a vertical shaft with total length 225mm this shaft contain variable diameters as follows from beginning to end of length (12mm, 13mm, 16mm, 20mm, 23.5mm, 24mm,12mm).

Figure 4: Nacelle of this work during manufacture.

The non-movable wing contains the following components:

i- Two ball bearing that internal diameter (20mm) with manufactured bases of aluminum with dimensions (128*40*29mm).

ii- The total splined shaft length 210 mm, consist four parts with diameters (16mm, 20 mm, 21mm and 16 mm), made of low carbon steel material,

iii- Gear that connected shaft for the rear part with the center gear of the system number of teeth (15), material (Steel) and the inner diameter (16mm).
3.1.3 The Mechanical Brake

System of the brake is type Antilock Brake System (ABS) as shown in Figure 5, is installed in the front part used in this work consisting of a mechanical part and the other electric part (motor), components of the mechanical part are:

a- Rotary disk manufacture from stain steel with thickness 2mm, inner diameter 20mm and outer diameter 160mm.

b- Caliper assembly and brake pads: The disc caliper is further classified as floating and fixed caliper. This types of brake use only a single piston to squeeze the brake pad against the rotary disk.

c- Beam and hollow rod No. (1) using for supported wire with caliper assembly and brake pads and beam and hollow rod No. (2) using for supported another component.

d- Motor and Limit switch will discuss it later.

e- Two steel wire with diameter 0.4 cm used to pull the arm for move the piston of brake.

Operating principles of the brake as following:

i- By feeding the computer with the information of the amount of wind speed specified previously installed in the program when the arrival of this speed will work brake system and when the speed of arrival without it will stop brake work and the rotor wind turbine works well.

ii- To force brake performance by using a steel wire, a limit switch is used to reach close. The limit switch is at the bottom and vice versa.

Figure 5: Components of the mechanical brake.

3.2 Electrical Components

There is a state of compatibility between the work of the electrical components in the operation of all the mechanical parts of the dual wind turbine system in this work, details will be mentioned as follows:

3.2.1 Starter Motor Used in Dual Wind Turbine for Internal Rotation

Current wind turbines have a high inertia so that they must be provided by a starter motor in order to get them running in low winds (wind speed is about \( V_{\text{min}}=1 \text{m/sec} \)). The principle of the starter motor is the rotation of dual wind turbine by turning the ignition switch, the starter motor is energized throughout the magnetizing solenoid, causing a rod to be pushed out. The gear meets the flywheel and the starter turns. This increases the speed of the turbine. Starter Motor type New Starter 10455513 as shown in Figure 6 (a,b,c) and specifications are reported in the Table 1, [13].

Figure 6: Starter motor with their support.

(a)- Complete Structure of The Starter Motor, (b)- Starter Motor Without Coil and Solenoid (c)- Interlock The Starter Motor With Small Flywheel
Table 1 Specifications of the starter motor,[13].

| Specifications      | Value |
|---------------------|-------|
| Direct Drive        | Teeth | 10T  |
|                     | Voltage | 12V  |
|                     | Rotation | CCW  |
| Delco No.           |       | 10455513 |
| Bosch               |       | SK504X  |
| Brand               |       | TURQ5  |
| Item Weight         |       | 4.5 kg |
| Manufacturer Part Number |   | 6744  |
| No. of teeth        |       | 10    |

3.2.2 Passive Magnetic Bearing

The passive magnetic bearing was used in dual wind turbine in this work as the number one in each rotor instead of ball bearing to know the performance of the system would improve and thus the efficiency of electric generation would be more, type of magnetic bearing from Neodymium Magnets (These Neodymium Iron Boron magnets are also known as "Rare Earth" or NdFeB magnets), as shown in Figure 7. Magnetic bearings are manufactured of a typical passive magnetic bearing as following descriptions in Table 2. [14]:

Table 2 Data of the passive magnetic bearing, [14].

| Descriptions | Value |
|--------------|-------|
| Outer Diameter | 5.08 cm |
| Inner Diameter | 2.54 cm |
| Thick Ring | 2.54 cm |
| Material | Nickel (Ni) Plated (silver-like finish) |
| Grade | N88 - Extremem powerful magnetic material |
| Pull Force is approximately | 24.35 N against a 2.54 cm steel plate |

These rings are axially magnetized, so the strong North/South poles are on the flat sides. That makes them easier to stack into a cylinder than to connect side by side.

Figure 7 Two passive magnetic bearing with their support.

3.2.3 The Electrical Motor for The Mechanical Brake

An electric motor type ZGB37R is used for the purpose to complete the work of the mechanical brakes for two rotors of dual wind turbines used in this work, as shown in Figure 8 and specifications are reported in the Table 3.

Table 3 Specifications of the motor ZGB37R.

| Specifications      | Value |
|---------------------|-------|
| Motor diameter | 32.8 mm |
| Gear box diameter | 54.8 mm |
| Total height | 53.5 mm (without bearing) |
| Output shaft length | 6 mm (flat position is 5.25 mm) |
| Output shaft | 21.5 mm (measured from the panel) |
| Weight | 159 g |
| Voltage | 12 V |
| Speed | 6.5 rpm (motor speed 3000 rpm) |
| Current | 0.07 A |
| Voltage | 24 V |
| Speed | 13 RPM (motor speed 6100 rpm) |
| Current | 0.03 A |
| Reduction ratio | approximately 1:400 |
| Torque | 15 N.m |

Figure 8 The used motor for the mechanical brake.
Figure 9 shows the manufactured system, with the parts mentioned above with the base.

![Image of mechanical parts installation](image)

Figure 9 The installation of mechanical parts.

4. Results and discussion

4.1 Production of Wind Speed by Simulation Motor

The operation of the manufactured system in all studied cases was done by simulations by using the stepper motor mentioned in chapter four. Stepper motor rotates the front rotor and so the whole system will rotate in a manner similar to that happens in the presence of natural wind. The main goal of the system as mentioned previously is to take advantage of wind energy when the wind speed between (1-2 m/sec) and more. In order to ensure normal operation of the simulation, the speed of the motor was changed to suit the wind speed (1-13 m/sec) as shown in Table 4.

| No. | Rotational Speed of Motor (r.p.m) | Wind Speed |
|-----|----------------------------------|------------|
|     |                                  | m/sec      | km/hr      |
| 1   | 11                               | 0.950      | 3.421      |
| 2   | 13                               | 1.123      | 4.043      |
| 3   | 16                               | 1.382      | 4.976      |
| 4   | 18                               | 1.555      | 5.598      |
| 5   | 20                               | 1.727      | 6.220      |
| 6   | 23                               | 1.987      | 7.153      |
| 7   | 25                               | 2.159      | 7.775      |
| 8   | 27                               | 2.332      | 8.397      |
| 9   | 29                               | 2.505      | 9.019      |
| 10  | 32                               | 2.764      | 9.952      |
| 11  | 34                               | 2.937      | 10.574     |
| 12  | 36                               | 3.110      | 11.196     |
| 13  | 39                               | 3.369      | 12.129     |
| 14  | 41                               | 3.542      | 12.751     |
| 15  | 48                               | 4.146      | 14.928     |
| 16  | 52                               | 4.492      | 16.172     |
| 17  | 59                               | 5.097      | 18.350     |
| 18  | 71                               | 6.133      | 22.082     |
| 19  | 82                               | 7.084      | 25.503     |
| 20  | 93                               | 8.034      | 28.924     |
| 21  | 105                              | 9.071      | 32.656     |
| 22  | 116                              | 10.021     | 36.078     |
| 23  | 128                              | 11.058     | 39.810     |
| 24  | 139                              | 12.008     | 43.231     |
| 25  | 151                              | 13.045     | 46.963     |
4.2 Produce the power of the wind by theoretically analysis

The efficiency of the wind turbine is determined by the amount of energy obtained from the wind, which in turn depends mainly on several parameters: (i) Wind speed (ii) radius of wind turbine (iii) Other less important parameters. It was found the amount of energy obtained from the manufactured system by focusing on the wind speed ($V_0$) between (1-13m/sec) and the air density is (1.25kg/m$^3$). Note that the radius of the turbine is (0.825m) and from the application of Equations (2) and (3), find that the amount of the wind power generated is shown in Table 5.

| Wind Speed ($V_0$) (m/sec) | Rotated in The Same Direction | Wind Power (Watt) into Turbine ($P_W$) Front Rotor By Eq.( 2) | Wind Power (Watt) into Turbine ($P_W$) Front Rotor By Eq.( 3) |
|---------------------------|-------------------------------|-------------------------------------------------|-------------------------------------------------|
| 1                         | 1.335                         | 0.788                                           |                                                 |
| 2                         | 10.680                        | 6.301                                           |                                                 |
| 3                         | 36.045                        | 21.266                                          |                                                 |
| 4                         | 85.440                        | 50.409                                          |                                                 |
| 5                         | 166.875                       | 98.456                                          |                                                 |
| 6                         | 288.360                       | 170.132                                         |                                                 |
| 7                         | 588.735                       | 347.350                                         |                                                 |
| 8                         | 603.520                       | 356.076                                         |                                                 |
| 9                         | 973.215                       | 574.196                                         |                                                 |
| 10                        | 1335.000                      | 787.650                                         |                                                 |
| 11                        | 1776.885                      | 1048.362                                        |                                                 |
| 12                        | 2306.880                      | 1361.059                                        |                                                 |
| 13                        | 2932.995                      | 1730.467                                        |                                                 |

4.3 Single Wind Turbine

When construct a wind turbine system, it should be placed in the direction of the expected wind and this is known from the meteorological department. Table 6 shows in detail the operation of the single-rotation wind turbine when the speed (simulation speed) ranges from less than 1m/sec to more than 13m/sec. Since the stepper motor which is used for simulation operate in the mode of pulses, this means that when the measured speed is 11rpm, the system will give the actual number of readings for the voltages and current as well as the generated electrical energy. A software program was developed to read the genetic algorithm to obtain the best actual generation values. The genetic algorithm was programmed by (visual studio 2015).

To illustrate the importance of the change in the values of the generated power in Table 6 includes the actual values and the Genetic Algorithm (GA) for the voltages, the currents and powers. Figure 10, which includes three curves, the maximum values and minimum values generated during the operation of the system, found that the generated power when calculating by the Genetic Algorithm (GA) values is limited between these values.
Figure 10: Electric power generated at different wind speeds

Table 6: All results from operation single wind turbine with non tilt angle.

| Rotational Speed of Front Rotor | Wind Speed (m/sec) | Votages (Volt) | Current (A) | Power (W) | Votages (Volt) | Current (A) | Power (W) |
|---------------------------------|-------------------|----------------|-------------|-----------|----------------|-------------|-----------|
|                                 | 11                | 0.950          | 12.41       | 0.224     | 2.784          | 12.51       | 0.222     | 2.778     |
|                                 | 11                | 0.950          | 12.25       | 0.215     | 2.634          | 12.36       | 0.273     | 3.380     |
|                                 | 13                | 1.123          | 12.41       | 0.276     | 3.428          | 12.25       | 0.333     | 4.081     |
|                                 | 16                | 1.382          | 12.25       | 0.446     | 4.248          | 12.20       | 0.345     | 4.106     |
|                                 | 18                | 1.555          | 12.2         | 0.355     | 4.339          | 12.20       | 0.345     | 4.106     |
|                                 | 20                | 1.727          | 11.9         | 0.332     | 3.960          | 12.20       | 0.403     | 4.925     |
|                                 | 23                | 1.987          | 12.15        | 0.488     | 5.938          | 12.15       | 0.4545    | 5.522     |
|                                 | 25                | 2.159          | 12.2         | 0.510     | 6.222          | 12.10       | 0.499     | 6.042     |
|                                 | 27                | 2.332          | 12.2         | 0.568     | 6.929          | 12.20       | 0.583     | 7.113     |
|                                 | 29                | 2.505          | 12.3         | 0.597     | 7.173          | 12.20       | 0.583     | 7.713     |
|                                 | 32                | 2.764          | 12.2         | 0.660     | 8.296          | 12.15       | 0.666     | 8.096     |
|                                 | 34                | 2.937          | 12.1         | 0.599     | 7.256          | 12.15       | 0.693     | 8.482     |
|                                 | 36                | 3.110          | 12.36        | 0.719     | 8.888          | 12.15       | 0.719     | 8.737     |
|                                 | 39                | 3.369          | 12.2         | 0.803     | 9.807          | 12.15       | 0.795     | 9.666     |
|                                 | 41                | 3.542          | 12.3         | 0.801     | 9.859          | 12.15       | 0.810     | 9.844     |
4.4 Dual Wind Turbine

(i) The Rotation of The Front and Rear Rotors in The Same Direction

Table 7 show all the results obtained from the operation of the system when they rotate in one direction. Found the best value of the power generated at the rotation speed is about 151 rpm and these all values extracted are from the genetic algorithm.

Table 7: Results from The Dual Wind Turbine Rotation in The Same Direction.

| Simulation | Genetic Algorithm (GA) |
|------------|------------------------|
| Rotational Speed of Front Rotor (r.p.m) | Wind Speed (m/sec) | Voltages (Volt) | Current (A) | Power (W) |
| 11 | 0.950 | 12.25 | 0.236 | 2.892 |
| 13 | 1.123 | 12.2 | 0.265 | 3.235 |
| 16 | 1.382 | 12.25 | 0.316 | 3.873 |
| 18 | 1.555 | 12.41 | 0.355 | 4.414 |
| 20 | 1.727 | 12.25 | 0.395 | 4.841 |
| 23 | 1.987 | 12.36 | 0.454 | 5.618 |
| 25 | 2.159 | 12.25 | 0.494 | 6.052 |
| 27 | 2.332 | 12.25 | 0.533 | 6.536 |
| 29 | 2.505 | 12.20 | 0.573 | 6.991 |
(ii) The reverse rotation direction of the front and rear rotors

Table 8 shows the power generated by the system if the rotation of the front rotor reverses the rotation of the rear rotor. The following is found from the operation of the system in this case:

A - The work of the system is more stable, especially when the motor simulation used in this work is rotating at high speed when the position of the front blades match the position of the rear blades. But when the opposite position (non match) will generate mechanical vibration in the system and this is not desirable.

B - The results listed in the following table taken in the case of mismatching in the position of the front and rear blades as well as their reverse rotation. It was found that the generated power is lower than the previous case due to the resistance of the rear blades rotation.

C. In all previous cases, the rotation of the gearbox rotor is only in one direction for the purpose of increasing the torque.

Figure 11 shows a comparison between the results obtained from the two cases according to the direction of rotation and the positions of the front and rear blades. It was found that one-way rotation is better for generating power.

Table 8 Power From Dual Wind Turbine in Reverse Rotation Case.

| Simulation | Rotational Speed of Front Rotor (r.p.m) | Wind Speed (m/sec) | Voltages (Volt) | Current (A) | Power (W) |
|------------|----------------------------------------|--------------------|----------------|-------------|-----------|
| Genetic Algorithm (GA) | Wind Speed (m/sec) | Voltages (Volt) | Current (A) | Power (W) |
| 11 | 0.950 | 12.2 | 0.215 | 2.623 |
| 13 | 1.123 | 12.25 | 0.265 | 3.248 |
| 16 | 1.382 | 12.41 | 0.319 | 3.966 |
| 18 | 1.555 | 12.25 | 0.351 | 4.310 |
| 20 | 1.727 | 12.36 | 0.386 | 4.780 |
| 23 | 1.987 | 12.36 | 0.449 | 5.557 |
| 25 | 2.159 | 12.25 | 0.494 | 6.052 |
| 27 | 2.332 | 12.30 | 0.527 | 6.492 |
|   |   |   |   |   |
|---|---|---|---|---|
| 29 | 2.505 | 12.25 | 0.573 | 7.020 |
| 32 | 2.764 | 12.25 | 0.632 | 7.746 |
| 34 | 2.937 | 12.20 | 0.679 | 8.285 |
| 36 | 3.110 | 12.30 | 0.703 | 8.656 |
| 39 | 3.369 | 12.20 | 0.770 | 9.402 |
| 41 | 3.542 | 12.25 | 0.827 | 10.139 |
| 48 | 4.146 | 12.36 | 0.877 | 10.842 |
| 52 | 4.492 | 12.15 | 1.016 | 12.351 |
| 59 | 5.097 | 12.36 | 1.065 | 13.171 |
| 71 | 6.133 | 12.20 | 1.403 | 17.118 |
| 82 | 7.084 | 12.20 | 1.620 | 19.770 |
| 93 | 8.034 | 12.41 | 1.561 | 19.374 |
| 105 | 9.071 | 12.25 | 1.874 | 22.959 |
| 116 | 10.021 | 12.15 | 2.292 | 27.853 |
| 128 | 11.058 | 12.30 | 3.264 | 40.147 |
| 139 | 12.008 | 12.66 | 4.991 | 63.196 |
| 151 | 13.045 | 13.01 | 6.257 | 81.404 |

Figure 11: Power from dual wind turbine in different rotation directions.

4.5 The advantages of using starter motor

The most important advantage of using a starter motor is to generate an internal torque for the system and this torque is concentrated in the middle of dual rotor wind turbine. The following results were obtained: When the dual rotor wind turbine is stopped, starter motor is operated for 3 seconds and the front and rear blades will rotate at a speed of more than 25rpm. This corresponds to the previous Tables to a wind speed of 2m/sec. It was found that the best cases of starter motor work, which give the desired goal, are in the following two cases:

i- single rotor wind turbine
ii- dual rotor wind turbine, When the front and rear blades rotate in one direction and these blades are in matched position.
4.6 The effect of magnetic bearing

The reasons for the use of this type of bearing, which are alternative to ball bearing, are that they have low friction and do not need lubrication this was previously mentioned. In this work, only two passive magnetic bearings were used, as follows:

i- They were placed on the front movable wing. When testing the single wind turbine it was found that the power generated was more than the power generated when ball bearings is used as shown in Figure 12, because the friction in movable wing is low, as shown in Figure 13.

![Figure 12: Comparing between operating ball bearings and PM bearings.](image1)

![Figure 13: Passive magnetic bearings](image2)

5. Conclusions

From the results of this work the following conclusions can be obtained:

1- It was found that the operation of the system in the case of single rotor wind turbine will generate a little power at speed 1m/sec, but will multiply this power at speed 2m/sec. The value of GA is considered the best value, the best power value obtained at 151rpm is 81.821W.

2- Dual wind turbine operates in two cases: The best results of DWT rotation in one direction done with in position of the blades identical and inverse rotation when the blades position is not identical.

3- The starter motor proved good performance with external source of wind for the system.

4- Using one passive magnetic bearing in each side had a minimum effect on the power generation.

5- Mechanical brakes work to stop the system within a period of time and not immediately as this will negatively affect the performance of the system.

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