DESIGN AND IMPLEMENTATION OF THE 10 KW WIND CUBE

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ABSTRACT

The main objective of this paper is to present a design and implementation for a modern device that can generate electric power using wind energy, the wind cube. The wind cube sits on any where, the rooftop of residential and commercial buildings. By this way, the wind cube becomes suitable for urban areas and those areas in which traditional large wind turbines were not practical. The function of wind cube is to amplify the wind; actually, it nearly doubles the ambient wind speed by using wind tunnel effect. Doubling the wind speed with this tunnel effect actually increases electric energy generation by a factor approximately eight. The wind cube can operate at ambient wind speeds of as low as four meters per second. The wind cube is equipped with a 10 kW induction generator and all other electrical equipments required for conditioning the overall output power. The wind cube is used as off-grid power source; which is suitable for isolated places. It has a cheap cost of about US$ 35,000, which represents about 40% less of similar production. The design and implementation results will be investigated, demonstrated and discussed through the work of this paper.

INTRODUCTION

Wind is a free, clean, and inexhaustible energy source. It has served mankind well for many centuries by propelling ships and driving wind turbines to grind grain and pump water. People began to realize that the world's oil supplies would not last forever and that remaining supplies should be conserved for the petrochemical industry. Wind power and other forms of solar power are being strongly encouraged. Wind power may become a major source energy in spite of slightly higher costs than coal or nuclear power because of the basically non-economic or political problems of coal and nuclear power. This is not to say that wind power will always be more expensive than coal or nuclear power, because considerable progress is being made in making wind power less expensive. But even without a clear cost advantage, wind power may become truly important in the world energy picture [1].

For local use, wind power in Egypt is planned to take a good position in the electrical source Egyptian plan. This paper is to present a design and implementation for a modern device that can generate electric power 10 KW using wind energy, the wind cube. The wind cube sits on the rooftop of residential and commercial buildings [2].

Figure(1): A photo captured for the new device.

A photo of the designed system is captured as shown in Figure (1). This system consists mainly of the induction generator operating in the self-excited mode (SEIG), the exciting capacitor and the load as shown in Figure (2). By looking to the differences between the wind cube design as a new device based on its design beside the power it can give, and the regular design for wind application (windmill), it can be realized that, While the rest of the windmill generates energy through the use of free-stream wind, the Wind Cube captures and amplifies the wind, which produces more kilowatt-hours (kWh).The Wind Cube relies on its "wind tunnel" effect known in physics as the Bernoulli Principle as shown in Figure (4). As wind encounters the Wind Cube venture, it becomes concentrated creating high velocity and in turn, more power. By amplifying the natural wind speed, the Wind Cube is able to produce more power from smaller dimensions. Proportionally, the Wind Cube has the smallest dimensions with the largest amount of power output. Because of these attributes, the Wind Cube is uniquely designed to produce energy in urban, populated areas with space constraints [2].

This application may take a wide use for its advantages, which can be mentioned in the following :

1- The suitability for isolated places, which are away from the grid and face many problems in development due to absence of electricity.

2- The price of this modern device is available for many people, whose needs do not exceed ten kW.

3- The simplicity of installation compared to the regular wind mils, which are hard in installation.

4- The ease in maintenance due to the small height, which gives the opportunity of the short time maintenance.

5- The suitability for the low wind speed places, due to the design of the devise, which use the tunnel effect that maximise the speed, so it can operate at low speed that may be 2m/sec and can reach the rated output power at 7 m/sec.

6- The device can track the wind direction by using automatic motoring system.

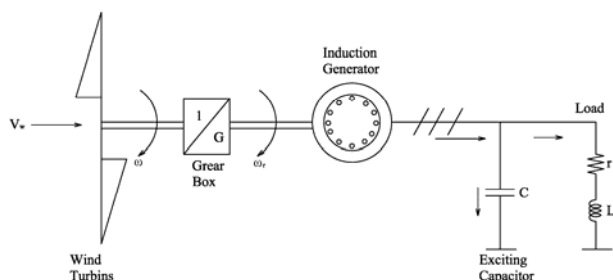7- The device is friendly with the environment with no pollution, no gases emissions and no waste disposal.

Figure (2): Wind energy conversion system

DESIGN OF 10 KW WIND CUBE

For the following section, the mechanical and electrical design for the cube will be presented.

A -Mechanical design

The dimensions of the wind cube are shown in Figure (3). The airfoil of the blade is S809 [3],[4] .The number of blades are five.
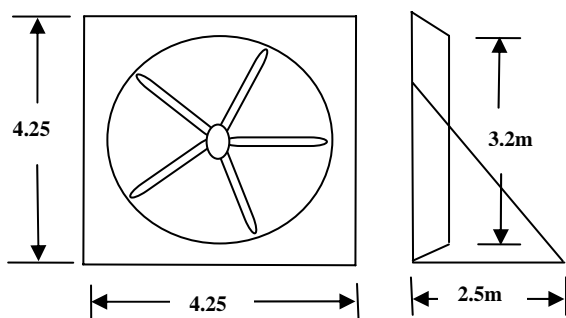

Figure (3): The dimensions of the wind cube

The kinetic energy stored in a flow per unit volume is $E_k = 1/2 \ \rho V^2$, where ρ is the density of the fluid. For a stream flowing through a transversal area "A" the flow rate is "AV" . Therefore, the power in the wind passing through an area "A" with speed V is $P = 1/2 \ \rho A V^3$. The energy available in the wind is obtained by integrating the power during a time interval" Tp", typically one year:

Average energy $=1/2 \ \rho A \int Tp \ V^3 dt$.

According to figure (4) it's clear that, the design of wind cube increases the velocity from V1 (the venture inlet wind speed) to V_2 (the venture outlet wind speed) by a factor greater than unity. For the above equations it is important to substitute V by V_2.
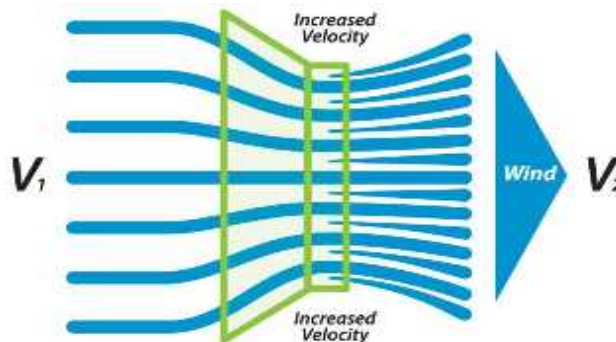

Figure (4): Wind tunnel effect which verify Bernoulli Effect [2]

The relation between the venture inlet wind speed and the venture outlet wind speed is mathematically obtained by comparing the inlet area and the outlet area as mentioned before. By applying Bernoulli's principals, it supposes to have double wind speed at the venture outlet side, but actually it was measured by using wind speed meter and its range was from 1.65 to 1.85. The venture outlet speed is now considered as the blades input wind speed.

B - Electrical design

The electrical design based on using self-excited induction generator with capacitor bank estimated by applying an analytical technique to calculate the minimum capacitance required to be connected to create enough excitation for induction generator [5].

This value of the capacitance is based on the values of the induction generator parameters (R_1 stator resistance , R_2 rotor equivalent resistance , X_1 stator inductance , X_2 rotor equivalent inductance , and X_m the magnetization inductance), all the parameters are measured in the laboratory by applying the open-circuit test (no-load test) and the short-circuit test (blocked rotor test) [6].

For simplicity the second order equation is used to calculate the capacitance.

$X_c = F^2 (X_1 + X_m)$

$F = \nu/2 \ (\ 1 \pm \ \sqrt{1 - (\nu_c/\nu)} \ )$

$\nu_c = (2/X_m) \ \sqrt{R_1 R_2}$

where ν_c is the cut- off speed. (The minimum speed that the generator can deliver power).

F is the per –unit frequency based on the cut- off speed.

ν is the per -unit rotor speed at which the generator can run.

It is obvious that the induction generator is generally simpler, cheaper, more reliable, and perhaps more efficient than either the AC generator or the DC generator. The induction generator and the permenant magnet (PM) generator are similar in construction, except for the rotor, so complexity, reliability, and efficiency should be quite similar for these two types of machines. The induction generator is likely to be cheaper than the PM generator by perhaps a factor of two, however, induction motors are used very widely, and it may be expected that many will be used as induction generators because of such factors as good availability, reliability, and reasonable cost. An induction machine can be made to operate as an isolated AC generator by supplying the necessary exciting or magnetizing current from capacitors connected across the terminals of the machine.

Figure (5) shows a typical circuit for a three-phase squirrel-cage induction machine
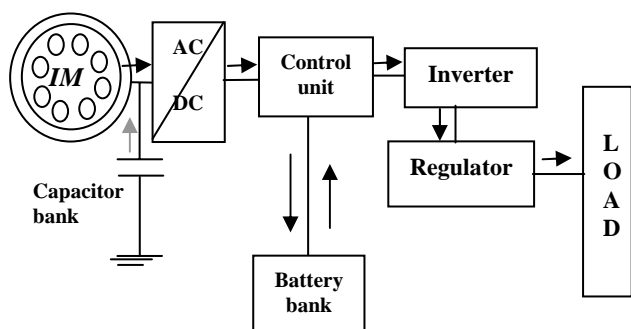

Figure:(5) schematic diagram of electric system of the modern device

As shown in Figure (5), the block diagram of electric system of the modern device can be described in the following table [7]:

Induction Machine	10KW,230-485V,400 r.p.m.
Capacitor Bank	20 KVAR ,400V,50Hz
AC/DC converter	230-460V
Voltage Regulation	230V±1% (Phase-Neutral), 485V±1% (Phase-Phase)
Frequency Regulation	50Hz ± 0.05%
Battery Charger	2.6A±2A to 15A±2A
Battery Bank	360V (30 battery)
DC/AC Inverter	3 Phase 400V O/ P
Output Waveform	Pure Sine Wave
Power Factor	0.8
Peak Efficiency	>92%

The system can be described as follows:
The Capacitor bank feed the induction machine by the required reactive power to give it the excitation needed to generate power. The AC generator output is converted to DC by the AC/DC converter to overcome the voltage and frequency fluctuation due to the change of the wind speed. This DC output is converted back to AC form by DC/AC

inverter and regulated by voltage and frequency regulator to obtain the normal output voltage and frequency that are suitable to the load. This case happens when the wind speed is in the range of working speed that ranged from (3m/sec – 13m/sec). Besides the normal feeding of the load, at this working wind speed, the battery bank is also charged. This operating case is automatically controlled and operated by the control unit, which divides the AC/DC converter output between the load and the battery bank.

In case of wind speed that is below the working speed, the control unit gives the order to the battery bank to backup the load, until the energy stored in the battery bank is consumed or the wind speed comes back to the working speed.

Now, it is important to talk about the capacitor bank. The capacitors are shown in a delta connection for economic reasons. That is, capacitors built for continuous duty, called motor-run capacitors, are most readily available in 370 and 460V ratings. Most induction motors in sizes up to 100 kW or more are built with 208, 230, or 460V ratings, so the available capacitors can readily handle the line-to-line voltages. If the capacitors were reconnected into a wye connection, the voltage across each capacitor is reduced to $1/\sqrt{3}$ of the delta-connected value, and the reactive power supplied by each capacitor is then one-third of the reactive power per capacitor obtained from the delta connection. Three times as much capacitance is required in the wye connection, which increases the system cost unnecessarily [8].

DISSECTION OF THE IMPLEMENTATION RESULTS

The paper presents the implementation details of the modern device, Wind Cube. This modern device has a new technique that is different from the regular design of the wind turbine. This design helps to operate at low wind speed which can be suitable for the places that have wind speeds less than that normal speed required to drive the wind turbine. It was important to record all parameters of this modern device and make the analysis to explain the effect of this new device.
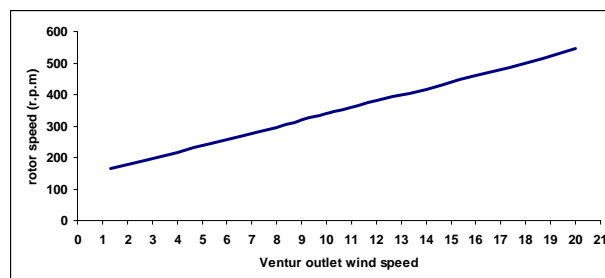

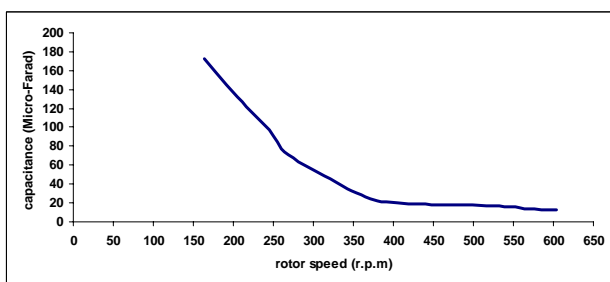Figure (6): The relation between the venture outlet wind speed (m/sec) and the rotor speed (r.p.m).

Figure (7): The relation between the required Capacitance (Micro Farad) and the rotor speed.
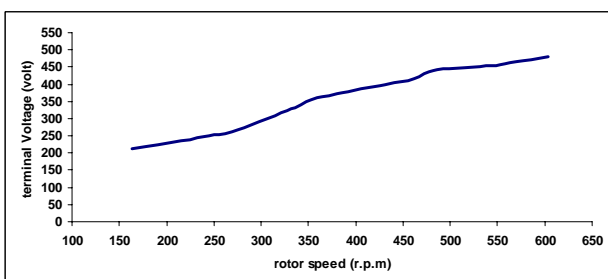

Figure (8): The relation between the generator terminals voltage and the rotor speed.
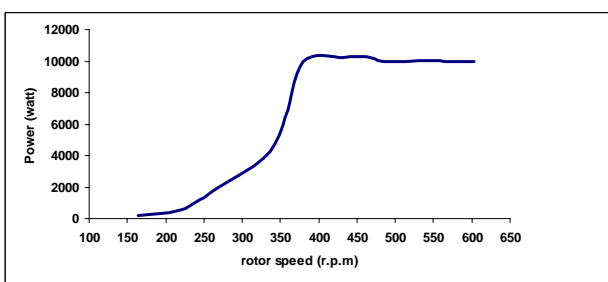

Figure (9): The relation between the generator power (watt) and the rotor speed (r.p.m).
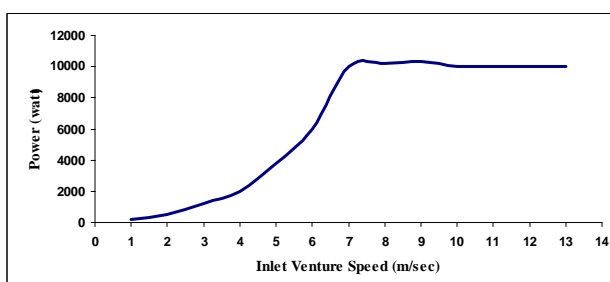

Figure (10): The relation between the output power (watt) and the venture's inlet wind speed (m/sec)

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The relation between the venture outlet wind speed and the angular speed is shown in figure (7). It is clear that this relation is nearly linear. The angular velocity is ranged from (167 - 603) r.p.m when the venture outlet wind speed is ranged from (1.65 – 23.66) m / sec. At this rang of rotor speed the capacitance must be nearly (12 – 180) μF as shown in figure (7) which represents the relation between the required Capacitance and the rotor

speed. In this case, the output voltage is approximately (235 – 485) volt, as demonstrated by the relation between the generator terminals voltage and the rotor speed that recorded in figure (8). So that, the corresponding output power is around 10 kW. These values are traced in figure (9). Finally, it can be verified that the desired output power can be obtained when the venture's inlet wind speed is ranged 7 m/sec and above this speed. The characteristic of output power against the venture's inlet wind speed is shown in figure (10)

CONCLUSION

The modern device (Wind Cube) is a unique wind turbine designed to captures and amplifies the wind that produces more kilowatt-hours (kWh). As wind encounters the Wind Cube venture, it becomes concentrated, creating increased velocity and in turn, more power. This modern device (Wind Cube) was built to overcome the problems of low wind speed and can capture wind energy at wind speeds as low as 2 m\sec. The complete electrical and mechanical design and implementation of the 10 kW wind cube are presented through this paper. It is clear that the Wind Cube has the smallest dimensions with the largest amount of power output.

Future work
The future work will be to study how to control the wind cube tracker to track the wind and position the Cube in the direction of the high wind speed to have the maximum power from the wind in order to increase the Wind Cube efficiency.

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