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Development of a Solar Powered Standing Dc Fan Using Three Phase

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ABSTRACT: *A solar powered standing dc fan is a small, portable type of fan that is used in various rooms of home or office. It is more convenient compared to other types, like kitchen exhaust, window, and pedestal fans because of its portability. It serves a number of functions for home owners and office workers such as conservation of energy, removal of heat and unwanted fumes from indoor areas, cooling a room and generation of Mechanical noise that helps to distract a person's attention from undesirable background noise so one could focus on his task. The idea of a solar fan has been proven to be very good especially for a country like Nigeria that enjoys an average of 8 hours of sunlight daily. In this research a 3-blade standing fan of 30 watts capacity capable of providing 6 hours of continuous operation was powered with just 1 photo-voltaic (PV) module of 80 watts power rating. Also a minimum of 85% efficiency was achieved and the fan runs at a low torque of 0.95 Nm. The fan blade rotates at a tip speed of 500 rpm and rotates on a 100 mm diameter shaft. In order to maintain constant operation during the night and when the sun is not at its peak, a 75Ah, 12V battery has been considered suitable for the power storage assessor.*
Keywords: *solar energy, photovoltaic cells, efficiency, blade, sunlight, solar panel.*

I. INTRODUCTION

Solar energy currently represents the most abundant inexhaustible, non-polluting and free energy resource that could be used economically to supply man's increasing energy demand (Nasir, 2004). Over the years, there has been a great insight into the renewable energy. As a result there have been great strides trying out many electrical gadgets and equipment as to how they could be powered with renewable energy sources like the solar energy.

The share of renewable energy in electricity generation is around 19% with 16% global electricity coming from hydroelectricity and 3% from new renewable (Renewable energy policy network for the 21st century, 2011). One of the most exciting developments in the renewable energy sector in recent years has been the decline in the cost of photovoltaic (PV) cells. PV module prices at the start of 2012 were nearly 50% down on a year earlier and some 76% below their level in the summer of 2008, when the Spanish PV boom was at its peak (UNEP, 2012).

As availability of fossil fuel is diminishing due to over-dependence, it becomes imperative to employ other energy sources, notwithstanding its effects on ozone layer depletion; it is convincing that solar energy can contribute significantly to addressing the current challenges in energy and climate change. There is a notable growing need for countries to reduce their emission and achieve greater energy independence while facing increasing volatility in fossil fuel prices, significant increase in energy demand and CO_2 emissions in emerging countries and decreased nuclear generation in the energy mix of developed and developing countries. Many though all day-to-day useful gadgets such as fans, water dispensers, among others should function on the solar energy. Actually, solar DC powered fan is more convenient compared to other types, like kitchen exhaust, window, and pedestal fans because of its portability.

There are two primary types of fans, namely; centrifugal and axial (U.S Department of Energy Efficiency and Renewable Energy, 2003). The standing fan under consideration is an axial type meant to be powered with a DC source from a solar panel with a 12V battery backup. A typical fan system consists of a fan, an electric motor, a drive system, duct or piping and flow control devices (Department of Energy Efficiency and Renewable Energy, 2003). Fan design is a compromise between the various fan parameters that affect fan efficiency. The capacity is directly proportional to the fan speed; the pressure (static, total, or velocity) is proportional to the square of the fan speed and the power required is proportional to the cube of the fan speed (BASF, 2006). The aim of this work therefore is to design an energy efficient 30 watts single user solar standing fan that will run for maximum of eight (8) hours, improve on the performance of previous ones with that which can be sustained by the available technology in Nigeria and also meet up ASHRAE recommended thermal comfort range of 50 – 100cfm for fans. This aim is achieved by creating design ideas on the product (solar fan) through product design specification that could enhance better lifestyles and comfort of the user, designing a solar fan that meets safety requirements of the user in his environments; and modeling the design. Hence, the design of this machine was carried out at Mechanical Engineering Department of Kaduna Polytechnic, and should be able to deliver 85% efficiency and rotate at a tip speed of 500rpm. This machine has not been designed to run for a whole day (24 hours) but rather between 6-8 peaks working hours in the home or office.

II. AIM AND OBJECTIVES OF THE RESEARCH

The aim of this research work is to develop a solar powered standing D.C. fan that can be used for both urban and rural areas.

Also this research therefore is aimed at achieving the following objectives:

i. To minimize the problems encountered due to the lack of adequate power supply.
ii. To fully utilize our abundant energy source, that is sunlight.
iii. To perform several functions for home owners and office workers.
iv. To determine the efficiency of the design using mathematical model.
v. To reduce the over reliance on alternating current.
vi. To simulate the behavior of solar powered standing D.C. fan design.

III. MATERIALS AND METHODS

The major components of the Solar Powered Standing Fan consists of the following: solar panel, blade case, electric motor, fan blade, control unit, connecting wire, fan base and battery as shown in Figure 2.0. All drawings in figure 1.0, 2.0 and 3.0 were achieved through Autodesk Computer Aided Design (AutoCAD) software because it is fast and more efficient to change and adjust any part of the drawing.

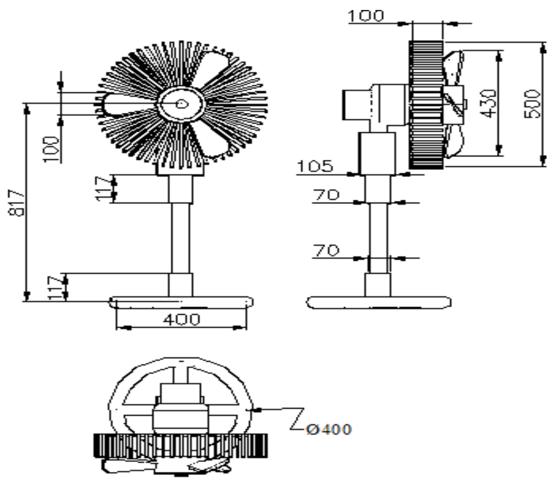

Figure 1.0: First angle orthographic projection of the Solar Fan

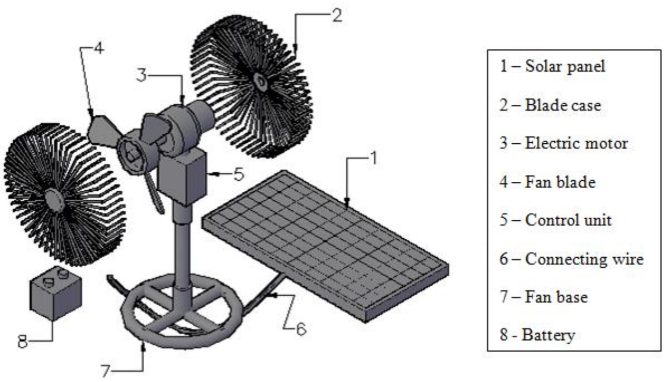

Figure 2.0: 3D exploded view of solar powered DC fan

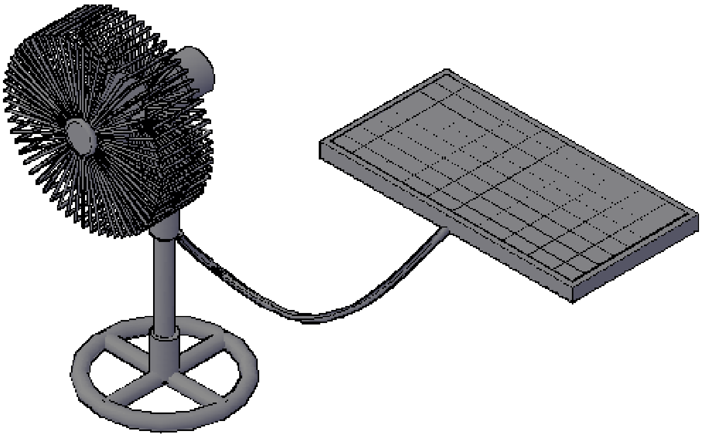

Figure 3.0: Assembled drawing

IV. DESIGN ANALYSIS

The design of this solar powered standing fan consists of the following major components; the blades, shaft, electric motor, PV Panel and battery.

4.1 Design of the Blade

The blade geometry

Taking a tip diameter dt = 305mm = 12in

Depending on the operation range of the static pressure, medium to high, the hub diameter can vary from 30% to 80% of the blade outside diameter taking r = 0.3, the ratio of hub radius to tip radius is given as;

$r = \frac{r_H}{r_t}$ …………… (1) (Basf, 2006)

r_t, tip diameter = $\frac{d}{2}$ = 6in

The tip radius $r_H = r \times r_t = 0.3 \times 6 = 1.8$in

And hub diameter d = 92mm = 3.62in

The number of blades is given by

$N_b = \frac{6r}{1-r}$ …………………(2) (Basf, 2006)

Using r = 0.3 given $n_b \cong 3$

The pitch radius and chord length determines flow rate per revolution from an aerodynamic standpoint, the chord length should increase from hub to tip from a structural stand point, and the reverse is preferred. As a compromise, however, it is suggested to use an almost constant chord over the entire blade length (Basf, 2006).

The pitch radius x_p which is the space between blades (pitch), at any radius $x_p = \frac{2\pi R}{n_b}$ …………………(3) (Sharma and Aggarwal, 2006)

The chord length x_c and the pitch length are related by the ratio called the 'solidity of the blade'.

$= \frac{x_c}{x_p}$ ………………… (4)

Using a chord length to pitch length ratio $\frac{x_c}{x_p}$ of 1:3 (Basf corporation, 2003)

At the tip with tip radius R = 6in

$x_p = \frac{2\pi \times 6}{3} = 12.57$in

The chord length of blade $x_c = \frac{x_p}{3} = \frac{12.57}{3} = 4.19$in = 106.43mm

At the mid-point with mid radius R = 1.8in

$x_p = \frac{2\pi \times 3.9}{3} = 8.17$in

The chord length of blade $x_c = \frac{x_p}{3} = \frac{8.17}{3} = 2.72$in = 69.09mm

At the hub with hub radius R = 1.8in

$x_p = \frac{2\pi \times 1.8}{3} = 3.77$in

The chord length of blade $x_c = \frac{x_p}{3} = \frac{3.77}{3}$ = 1.26in = 32mm

The chord and pitch lengths are used in constructing the blade geometry.

4.2 Design of Shaft Driving the Blade

Volume of propeller = 3 (volume of blade) + (volume of hub) … … (5)
(Shigley and Mischke, 2003)

Volume of propeller = (3 x 6470. 109 x 4) + ($\frac{\pi(75^2 - 31.44^2)}{4}$x 4)

= 92207.39mm^3

Therefore weight of propeller W = pvg

Using Nylon 6/6 GF30 a plastic material with 30% fiberglass reinforcement with a density of 1350.77kg/m^3

Using,W =pvg…………………(6)   (khurmi and Gupta, 2006)

= 1350.77 x 92207.39 x 10^{-9} x 9.81 = 1.22N

Maximum bending moment

M = 1.22 x 0.1 = 0.122Nm

For completely reversed fluctuating loading and using DE- Goodman criterion with a factor of safety n of 4 and G10180, and low carbon steel with medium manganese content. It has good hardening properties fair Machine ability. It is readily available and suitable for shafting with cold drawn condition it has ultimate tensile strength of s = 44IMPa

Ma – M = 0.122Nm, Ta – T = 0.95Nm,

Ma = Ta = 0………………… (7) (Budynas, 2006)

For end mill key seat,

$K_f = k_{ts} = 2.2: k_{ts} = k_f = 3.0$

Cold draw and machined surface

Finish, a = 4.51,b = - 0.265,

S_{ut}= 441Mpa

$S_g = 0.5S_{ut}$ and $k_a = as_{ut}b$

Assumed $K_b = 0.9$, $K_c = K_d = K_g = 1$, And

$Ps_g = K_a K_b K_c K_d K_g K_f S_g$

$Ps_g = (4.51 \times 441^{-0.265}) \times 0.9 \times 2.2 \times 0.5 \times 441 = 392.17MPa$

The expression for determine suitable diameter of the shaft

$$d = \frac{16 \times 4}{\pi}\left[\frac{1}{P_{s_g}}\left[4(k_t \times M)^2\right]^{1/2} + \frac{1}{S_{ut}}\left[3(k_f \times T)^2\right]^{1/2}\right]^{1/3}$$

$$= \left[\frac{16 \times 4}{\pi}\left\{\frac{1}{392.17 \times 10^6}\left[4(2.2 \times 0.122)^2\right]^{1/2} + \frac{1}{441 \times 10^6}\left(3(3 \times 0.95)^2\right)^{1/2}\right\}\right]^{1/3}$$

$$d = \left[\frac{16 \times 4}{\pi}\left\{\frac{0.54}{392.17 \times 10^6} + \frac{4.94}{441 \times 106}\right\}\right]1/3$$

d = 6.35 x 10^{-3} m ≈ 6.35mm

Therefore a shaft diameter of 10mm is chosen as the nearest standard.

4.3 Effective Fan Power

The ASHRAE recommended a thermal comfort range of 50-100mcfm for fan.

Therefore designing for air volume flow rate of 100cfm – 0.04719

Blast area Ao = 0.79   …………………(8) (khurmi and Gupta, 2005)

But

V=Qo/ Ao = 100/0.79 = 126.58ft/min

(Base cooperation,2003)

Volume rate = 1 X S$\frac{\pi}{12}$

$S = \frac{12 \times 126.58}{1 \times \pi} = 483rpm \approx 500rpm$

This gives an angular speed of w = 26.17rad/s

The dynamic pressure is given as

$$P_V = \left(\frac{V}{4005}\right)^2 = \left(\frac{126.58}{4005}\right)^2 = 9.99 \times 10^{-4} \text{ inch wg}$$

But state pressure

P = 450 Pa = 1.807in. wgat STP
Effective power out of fan
450 x 0.04719 = 21W
Fan state efficiency $\int_{FS} = = \frac{Nair}{Neh}$ ……………..(9) (Kreider and Kreith, 1981)
Using an efficiency of $\int_{FS} = 85\% = 0.85$
Therefore the driving shaft power $P = \frac{21}{0.8} = 25W$
$$T = \frac{P}{w} = \frac{25}{26.2}$$
T = 0.95Nm

4.4 Design of the Solar Power
The 30W DC fan is expected to run for 8 hours per day. Therefore, daily energy consumption is calculated. Thus;
Daily energy consumption = power x time
= 30W x 8hrs = 240Wh
Pv Module Sizing
Pv Module Array = $\frac{\text{Total daily energy consumption}}{\text{Daily peak run hours x Pv correction factor}}$
Pv Module Array = $\frac{240Wh}{\left(\frac{3hr}{module}\right) x\ 0.65} = 92.308w/m0dule$
Total Wattage of the Pv Module = 92.308W
Different sizes of modules in the market include 60W, 80W, 90W, 100W e.t.c these modules are sold per watt, putting into consideration the daily solar insulation on the collector surface and various latitudes in Nigeria has estimated by (Ezeilo, 1998). Therefore, an 80 Pv module is suggested to power the standing fan.
The number of Pv module = $\frac{92.308W}{\frac{80W}{module}} = 1.2 \quad \cong 1\ Pv\ module$

4.5 Battery Sizing
Battery is suggested as backup;
i. To store energy during the day
ii. To compensate for days of lesser peak sun hours
iii. If the fan is going to be used at night, there is no sun to power the fan at night, hence the need for battery input parameters.

The battery system voltage is 12V, this is because the voltage of the table fan is also 12V, this will also enable reduction of quantity and cost of components and installation.
Maximum depth of discharge (D_0D) = 50%
Number of storage days (no sun allowance) = 3
The battery capacity = $\frac{\text{total energy}}{\text{system wattage}} = \frac{240Wh}{12V} = 20Ah$
There is now a need to compensate for when the solar radiations would be less than designed i.e. considering 3 days of storage (to compensate for no sun situation) and the battery is to be discharged by at most 50%.
The battery capacity that will meet this condition $= \frac{20Ah\ x\ 3}{0.5} = 120Ah$
Different sizes of deep cycle batteries available in the market include 65Ah, 75Ah, 100Ah, 110Ah, 120Ah, 150Ah, 200Ah e.t.c. therefore, the 12V, 120Ah battery will meet this need.

Table 1.0: Performance Evaluation for three blade fan

Fan Type	6V, 3 blade	7V, 3 blade	8V, 3 blade	9V, 3 blade	10V, 3 blade	12V, 3 blade
Average Velocity (m/s)	0.19	0.22	0.32	0.32	0.61	0.56
Maximum Velocity (m/s)	0.90	0.84	1.37	1.14	1.81	1.69
Total Q(CFM)	852	1221	1476	1820	3925	3600
Total Q(l/s)	402	576	697	859	1853	1699
Total Watts	1.62	1.69	4.09	4.11	12.9	14.6
RPM	75	66	102	83	138	117

Table 2, shows the performance of the three-blade fan connected to the 30 watt panels. The panel was exposed to isolation at 5 p.m. and noon. The best fan performance was the 30 watt PV panel operating at noon, which provided 22.9 volts at 0.53 amps or 12.14 watts. Under this condition the fan ran at 135 RPM and provided a maximum velocity of 1.77 m/s directly below the hub. This configuration at 5 p.m. ran the fan at 123 RPM and provided a velocity of 1.4 m/s. The lowest fan performance was from the 30 watt PV panel running at 5 p.m., which provided 104 RPM and 1.3 m/s of maximum velocity.

Table 2: Test results on PV Powered Fan Performance

PV Watt	Time pm	Speed RPM	Power (Volts)	Current (Amps)	Energy (Watts)	Velocity (m/s)	RPM/Watt	m/s/Watt	Solar W/m^2
10	12	108	16.2	0.35	5.67	1.45	19.05	0.26	965
25	12	135	22.9	0.53	12.14	1.77	11.12	0.15	965
10	5	104	14.3	0.31	4.43	1.3	23.46	0.29	351
25	5	123	18.7	0.42	7.85	1.4	15.66	0.18	351

4.6 Evaluation of Fan Laws:

The fan laws represent how performance varies when one of the operating conditions is changed. The following laws apply when the same fan in the same circumstances is operated at a different power level by changing the voltage applied. Eqns. 1 and 2 were applied to the maximum and minimum RPM and velocity conditions. Applying Eqns. 1 and 2 to both RPM and velocity data yields comparable agreement.

Eqn. 1: $RPM_1/RPM_2 = Velocity_1/Velocity_2 = Q_1 / Q_2$

Eqn. 2: $Power_1/Power_2 = (Watt_1 \cdot h_2)/(Watt_2 \cdot h_1) = (RPM_1/RPM_2)^3 = (Velocity_1/Velocity_2)^3 = (Q_1/Q_2)^3$

Where:
RPM = fan revolutions per minute
Velocity = air velocity
Power = motor shaft power
Watt = Electrical power at motor terminals
h = motor efficiency as loaded
Q = volumetric air flow rate
Subscript 1 designates baseline conditions at 12 volts applied to the motor terminals.
Subscript 2 designates different conditions when 9 volts applied to the motor terminals.

Eqn. 1:138 RPM_{12v} / 66 RPM_{9v} = 2.09
1.81m/s_{12v} / .84 m/s_{9v} = 2.15
2.09/2.15 = 97%
Eqn. 2:
12.9W_{12v} / 1.69W_{9v} = 7.6
(138RPM_{12v}/66RPM_{9v}) 3 = 9.1
7.6/9.14 = 83%
12.9W_{12v} / 1.69W_{9v} = 7.6
(1.81 m/s_{12v}/0.84 m/s_{9v}) 3 = 10.2
7.6/10.2 = 75%

Eqn. 2 is applied to all tests shown in Table 1 and 2. Five additional "redundant" tests are not presented. A regression analysis was then conducted and presented in Table 3 and 4. The R-square values (.86 for Table 3 and .69 for Table 4) are comparable to the ratios in the examples above.

V. DISCUSSION

The fan laws would indicate that doubling the flow rate of a fan will increase the required shaft power by about eight times. For example, if flow was 100 CFM (472 l/s) at 10 watts shaft power, the power expected to reach 200 CFM (944 l/s) would be 3 x 10 = 30 watts. In the data from the above test reports, velocity at 9 volts is reduced to 46.4 percent of the velocity at 12 volts. 46.4 percent cubed is 10 percent, so by the fan laws, shaft power is expected drop to 10 percent. Shaft power was not measured but electrical power dropped to 13 percent. Electric power is not expected to drop quite as much as shaft power because motor efficiency is reduced at very low loads. The discrepancy here may be as a result of the accuracy associated with the 0.19 amp measurement at 9 volts.

VI. CONCLUSION

In this project, a table fan powered with a 30 watt PV module of solar panel was designed. The design was necessitated by the need to have a fan that could be powered with a renewable energy source. A 12V DC battery was included in the design as a source of power backup for use when there is no sunlight-in the night. In order to achieve a minimum consumption of power, the fan was made not to oscillate but rather was made such that it could be manually tilted up and down to change its orientation. The design is quite effective as it blows a large volume of air (100 cfm)at low speed (500rpm). As a result the design is expected to be relatively noiseless and energy efficient.

VII. APPLICATIONS

While fans have been used primarily in dwellings and schools to improve occupant comfort, these benefits may also apply in some warehouse applications. Standing dc fans connected directly to PV panels are ideal in dwellings where fans are needed during daytime hours. Fans benefits may include:

- Reduced need for air conditioning, resulting in reduced greenhouse gas emissions.
- Better ventilation and indoor air quality, due to increased mixing of outside air.
- Health benefits during hot weather and reduced presence of insects that transmit disease.
- Better air distribution and mixing of ducted HVAC systems.
- Space heating energy savings, due to reduced temperature stratification.

VIII. RECOMMENDATIONS

1. Demonstrate new applications discussed in this paper.
2. Evaluate higher efficiency DC fan motors and PV panels to optimize performance.
3. Assess cost effectiveness of optimum PV/motor packages in various applications.
4. Evaluate PV powered fan designs in various building applications.

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