VISVESVARAYA NATIONAL INSTITUTE OF TECHNOLOGY, NAGPUR

ELECTRICAL AND ELECTRONICS ENGINEERING

Project title

REPLACING ORDINARY CEILINGS FAN WITH BLDC MOTOR FAN

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1. ABSTRACT

A brushless DC MOTOR (BLDC MOTOR) is a synchronous electric motor which runs on the supply of direct current electricity. In these motors there is a linear relationship between current and torque and also in between voltage and rpm of the BLDC motor. This linear characteristic is the main reason for which BLDC motors give excellent results in the conventional ceiling fans. In this report we present the compatibility of BLDC motors for application of ceiling fans along with the comparative study of performances on various factors of BLDC motor driven fans and results have been compared. It is proved that efficiency of BLDC motor driven fans is comparatively higher compared to other fans.

2. INTRODUCTION

A significant amount of motor applications are found in the form of fan applications such as bathroom exhaust fans, kitchen hood exhaust fans, appliance cooling fans, dryer exhaust fans, desk fans, inline fans, axial fans, attic ventilator fans, roof ventilation fans, radon fans, etc. Typical ventilation fans range varies from 30W to 80W for residential applications. A ceiling fan is used to reduce the stratification of warm air in a room by forcing it down to affect both occupant's sensations and thermostat readings, thereby improving climate control efficiency. With windows open, fans circulate the fresh air so "canned" air doesn't even have to be used. Operating a ceiling fan requires electricity upto 100 watt and can save up to 40% off energy bill when used consistently. The performance of the fan can be improved by two main ways: 1) using an energy efficient motor, 2) using variable speed drives to control fan flow. In this report we have focused on using energy efficient motors to see if the investment is useful in the long run. Among the various types of motor used in the fan applications such as brushed DC motors, single-phase AC induction motors, shaded-pole induction motors, three-phase induction motors and many more, we have performed a comparative study of BLDC motor fan and Single phase Induction motor fan.The substitution of the AC motors with BLDC motors has advantages as higher efficiency, smaller volume, lower weight which are especially important in the variable speed applications. Moreover, the request for long life and no maintenance, leads us to use the BLDC motors instead of AC motors

3. MAJOR COMPONENTS OF A CEILING FAN

The five major components of a ceiling fan are as follows:

1. Fan Blades.
2. Capacitor.
3. Motor.
4. Flywheel.
5. Mounting Bracket.

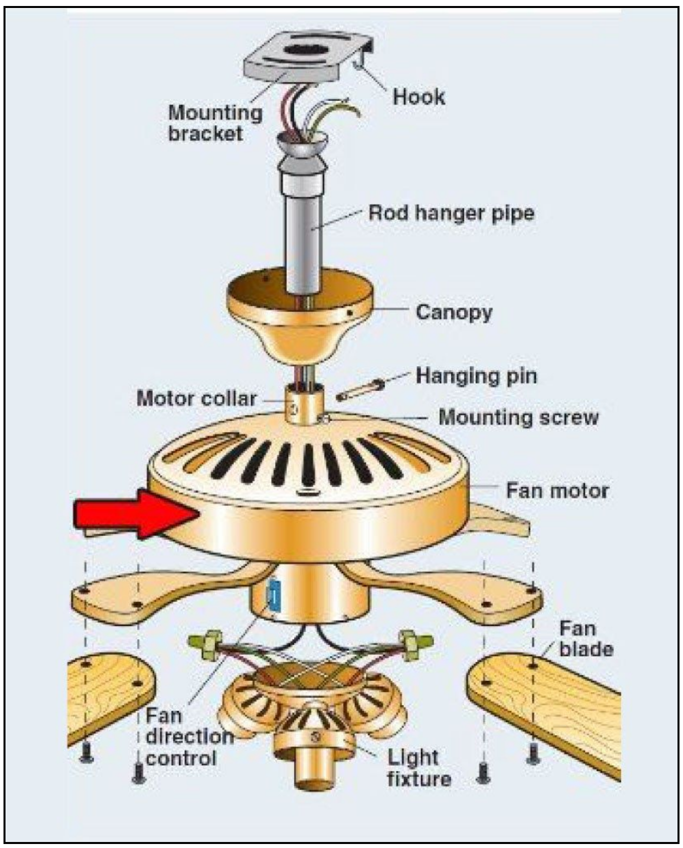


Fig.1 Components of a ceiling fan

3.1 Fan Blades:

Fan blades are the long wing-like structure integrated into the fan.The air circulation is a result of rotation of fan blades. Materials used for making fan blades include wood, MDF, plastic and metals.

3.2 Capacitor:

Capacitor maintains the speed of the ceiling fan and also its movement. There must be a revolving or rotating magnetic field to create a torque for rotating the rotor. Two or more phase lines are required to generate a revolving magnetic field. So in an induction motor, with the help of additional starting windings or auxiliary winding along with a capacitor, a two-phase supply is created from a single phase supply. If the capacitor is not in proper working condition your ceiling fan will surely not work properly.

3.3 Motor:

The electric motor is the soul of a ceiling fan.The motor is responsible for converting the electrical energy into mechanical energy which moves the fan for circulating the air. When the current reaches the coil of the motor a magnetic field is generated making the coil the apparatus moves in a clockwise direction. This movement of coils is then transferred into the fan blades resulting into conversion of electrical energy into mechanical energy.

3.4 Flywheel:

Flywheel is a plastic or rubber appendage that is attached to the motor body. It is the linkage between the fan blade irons or brackets and the motor. With the help of a lock screw, the inner ring of the flywheel is locked to the shaft, and the blade irons on the outer rings are secured using screws. Flywheels owing to the nature of the material they are built off are prone to wear and tear and also break downs. In case the fan breakdowns because of flywheel malfunction then the entire fan has to be disassembled in order to repair it.

3.5 Mounting bracket:

The ceiling fan is attached to the ceiling with the help of a hook which is attached to a mounting bracket. J hook also known as a claw hook is a device embedded into the mounting board. The ceiling fan is mounted on this hook. It is often fixed with a rubber grommet to reduce a fan’s operational vibration and helps in keeping the balance of the fan proper. The mounting brackets should properly be installed at the time of the ceiling fan installation because if the bracket is not installed properly there is always the danger of the fan to fall down.

4. FACTORS AFFECTING CEILING FAN AIRFLOW

The factors that work together to determine the airflow and efficiency of ceiling fan are as follows:

1. Blade pitch
2. Blade shape and size
3. RPM
4. Height from ceiling
5. Motor

4.1 Blade pitch:

The angle of the blades when they move through the air is referred to as blade pitch. Fan blades with a relatively flat pitch, around 10 to12 degrees, do not require a very large motor to reach a high speed. A steeper blade pitch, around14 to 15 degrees, requires a more powerful motor to achieve the same speed. Even at a high speed, the fan with the flatter pitch moves less air and may shake or make noise due to being overworked. On the other hand, the fan with the steeper blade pitch may get damage much faster if the motor isn't powerful enough to move larger amounts of air for longer periods of time.

The power of the motor and the pitch of the blades need to complement one another. If they work against each other, the fan will have to work much harder to move less air, resulting in less comfort and a motor that burns out faster.

4.2 Blade shape and size:

To maximize the ceiling fan airflow, the blades shouldn't be too long or too wide. lades that are too small and narrow can have a similar effect as the fan with larger and wider blades.

4.3 RPM:

The specific speed at which the blades spin is referred too as rpm. If the blades spin fast, more air is circulated given the blades have the right pitch.Ideally, to achieve the best airflow, fan with six different speed settings ranging from low to very high is preferred.

4.4 Height from the ceiling:

To achieve the best airflow, the height difference between the ceiling fan and the ground must be between 10 to 12 inches. If the ceiling is vaulted a longer downrod is added so the blades are about 8 to 9 feet from the floor.

4.5 Motor:

The motor is the most important factor that affects the service value and efficiency of a fan. Most powerful motors provide the best airflow, efficiency, comfort and durability.

5. TYPES OF MOTOR USED IN CEILING FANS

5.1 Single phase Induction Motor:

Ceiling fan application uses a single phase capacitive start capacitive run induction motor. Since, this motor is not self starting an external force is required to run it during starting and this property of the single induction motor is explained by the double field revolving theory. A capacitor which is used to overcome this drawback is connected across a part of the winding in the fan motor which creates a phase difference between the windings part connected with the capacitor and other part without the capacitor. This rotor rotates according to the direction of the resultant field which is resultant of these two fields. The capacitor is usually connected via a centrifugal switch to increase the efficiency of the fan. The single phase capacitive start capacitive run induction motor is developed for a low torque operation which depending upon the size of blade mostly ranges from 0.22 to 0.72 N-m. The induction motor of low cost and high value is mostly used with the fan blade sizes in the range of 800, 900 and 1200 mm. A 18 or 16 pole single phase induction motor is used in a ceiling fan giving a speed range between 50 rpm and 330 rpm.

5.2 BLDC Motor:

A BLDC motor is a permanent magnet synchronous motor in which armature currents are controlled by using position detectors and an inverter. The armature of the BLDC motor is in the stator and the magnets are on the rotor and its operating characteristics resemble those of a dc motor, therefore it is sometimes referred to as an inside-out dc motor. Instead of using a mechanical commutator as in the conventional dc motor, the BLDC motor employs electronic commutation making it a virtually maintenance-free motor,

There are two main types of bldc motors: a) Trapezoidal type b) Sinusoidal type. The trapezoidal motor has sinusoidal shaped back-emf induced in the stator windings and requires quasi-square currents for ripple-free torque operation. On the other hand, in a sinusoidal motor back-emf induced is sinusoidal in shape and its phases must be supplied with sinusoidal phase currents for ripple-free torque operation. The shape of the rotor magnets and the stator winding distribution helps to determine the shape of the back-emf . The sinusoidal motor has complex hardware as well as software. It needs a high resolution position sensor as for optimal operation the rotor position must be known at every instant. The trapezoidal motor is a more attractive alternative for most applications due to its simplicity, lower cost and higher efficiency.

Table 1: Comparison of few characteristics of Induction motor and BLDC motor.

Characteristics	**Induction motor**	**BLDC motor**
Losses	Higher than BLDC Motor	Lower because of elimination of pole winding and brushes.
Efficiency	Lower compared to BLDC motor because of higher losses.	Higher as losses are reduced by using permanent magnets to eliminate pole winding and inverter to eliminate brushes.
Thermal performance	Worse than that of the BLDC motor.	BLDC otor has best thermal performance as the thermal losses are in the stator winding and stator core which in most of the cases is on the outer part of the motor and the heat can easily go out.
Overload	Less overload due to weak thermal performance.	The ability for overload is high.
Dynamic respond	Slower	Low inertia because of absence of brushes and pole winding results in high dynamic speed.
Power to size ratio	Moderate since there are both stator and rotor windings.	Higher. Since there are only stator windings, the size is smaller than the induction motor for the same power.
Application	Noise and ripple of the torque limit the Applications of induction motor. This motor is used where it speed regulation is needed and the energy source is AC.	BLDC motors are used in many applications, for e.g. in electric and hybrid vehicles, aerospace, household appliances, industry, robotics, military, medicine, etc. In these applications weight and volume are important. BLDC motors are supplied with AC or DC voltage with appropriate circuits.

6. SINGLE PHASE INDUCTION MOTOR

6.1 Construction

The construction of a single phase induction motor consists of main two parts: Stationary stator and revolving rotor. The stator is separated from the rotor by a small air gap which has a range of 0.4 mm to 4 mm depending on the size of motor.

6.1.1 Stator

The single-phase motor stator has a laminated iron core with slots as shown in the following figure.

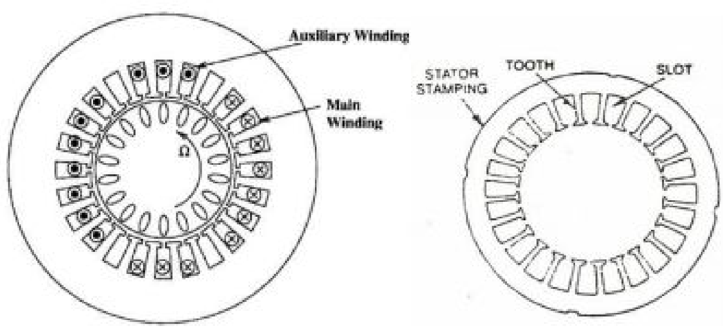


Fig.2 Single phase Induction motor stator.

There are two windings arranged vertically inside the slots of a stator:

1. Main (or running winding)
2. Auxiliary winding (or starting winding) as shown in the figure below.

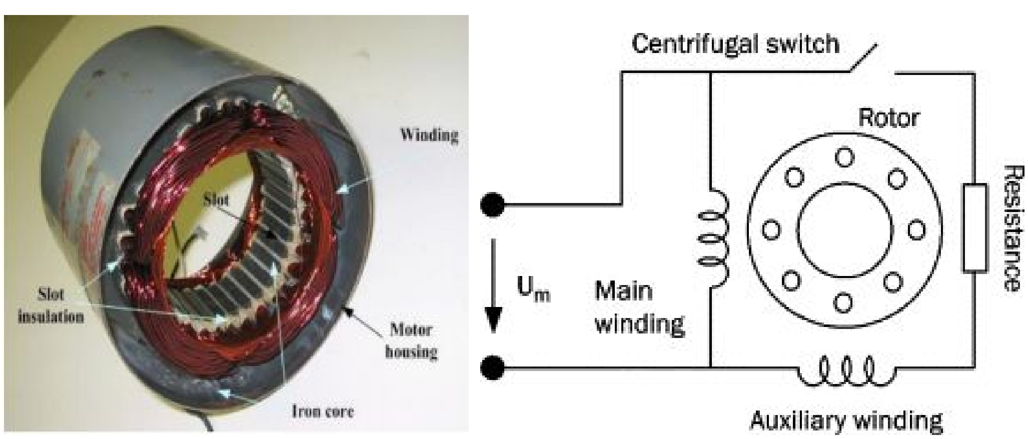


Fig.3 Auxillary winding.

6.1.2 Rotor

The rotor, mounted on a shaft, consists of a laminated cylindrical core with slots. Aluminum bars are moulded on the slots and short-circuited at both ends with a ring as shown in figure below. This type of rotor is called "Squirrel cage rotor ".

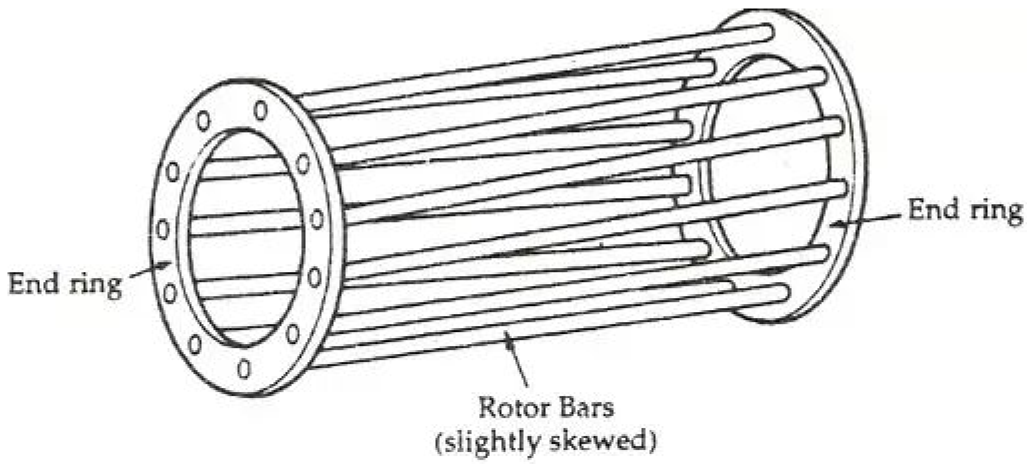


Fig.4 Squirrel cage rotor.

This forms a permanently short circuited winding which is strong. The entire construction (bars and end rings) resembles a squirrel cage, hence the name. The rotor is not connected electrically to the supply but current is induced in it by the transformer action from the stator. Most single phase induction motors use a squirrel cage rotor as it has a remarkably simple and robust construction enabling it to operate in the most adverse circumstances. However, it suffers from the disadvantage of a low starting torque. This is because the rotor bars are permanently short-circuited and it is not possible to add any external resistance to the rotor circuit to have a large starting torque. In this type of rotor, the conductor bars are skewed to reduce noise.

6.1.3 Centrifugal Switch

Many single-phase motors are not designed to operate continuously on both windings (main & auxiliary). At about 75 percent of the rated rotor speed, the centrifugal switch opens its contacts. It only takes a few moments for the motor to obtain this speed. An audible click can be heard when the centrifugal switch opens or closes. Once the start winding is disconnected from the circuit, the momentum of the rotor and the oscillating stator field will continue rotor rotation.

However, if the motor stops, the start winding is reconnected through the normally closed and spring-loaded centrifugal switch.

6.2 Starting of a Induction Motor

A single-phase induction motor is not self starting (as a 3-phase squirrel cage induction motor) and it requires some starting means. The single-phase stator winding produces a magnetic field that pulsates in strength in a sinusoidal manner. The field polarity reverses after each half cycle but the field does not rotate. Consequently, the alternating flux cannot produce rotation in a stationary squirrel-cage rotor. However, if the rotor of a single-phase motor is rotated in one direction by some mechanical means, it will continue to run in the direction of rotation. As a matter of fact, the rotor quickly accelerates until it reaches a speed slightly below the synchronous speed. Once the motor is running at this speed, it will continue to rotate even though single phase current is flowing through the stator winding. This method of starting is generally not convenient for large motors. Processes involved in the starting of a Single Phase Induction Motor:

A single-phase AC voltage supplies the main winding that produces a magnetic field change with respect to time around one access so that this field is called as pulsating. The currents generated due to this field in the rotor are in the right side which then reverse to the left side, making the total torque equal to zero, as shown in figure below.

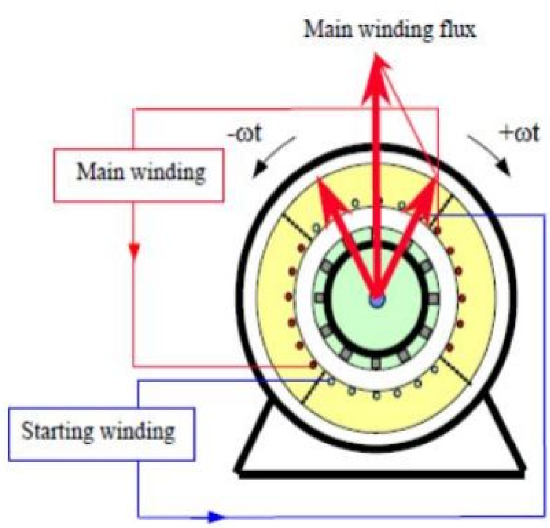


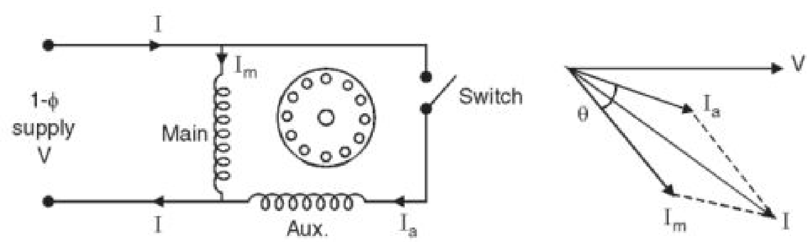
Fig. 5.

1. Mathematically, the pulsating field could be divided into two fields, which are rotating in opposite directions.
2. The pulsating field is divided into forward and reverse rotating fields. Under these conditions, with only the main field energized - the motor will not start.
3. To solve this problem, we put an auxiliary winding in the slots of the stator to shift the EMF.
4. The auxiliary winding and main winding are connected in parallel together and also with the supply.
5. The rotor then moves with a speed slightly lower than the synchronous speed after which the auxiliary winding is opened from connection.
6. However, if an external torque moves the motor in any direction, the motor will begin to rotate.

6.3 Types of Induction Motors

1. Split Phase Induction Motor:

In addition to the main winding (running winding), the stator of single phase induction motor carries another winding called auxiliary winding (starting winding). The two winding (main & auxiliary) are connected in parallel to a single phase source. A centrifugal switch is connected in series with auxiliary winding. The purpose of this switch is to disconnect the auxiliary winding from the main circuit when the motor attains a speed up to 75 to 80% of the synchronous speed. The auxiliary windings are displaced in space by 90 electric degrees as shown in the figure below.



Split phase induction motor

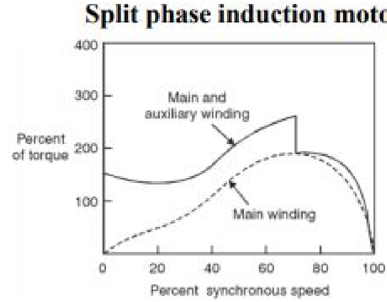
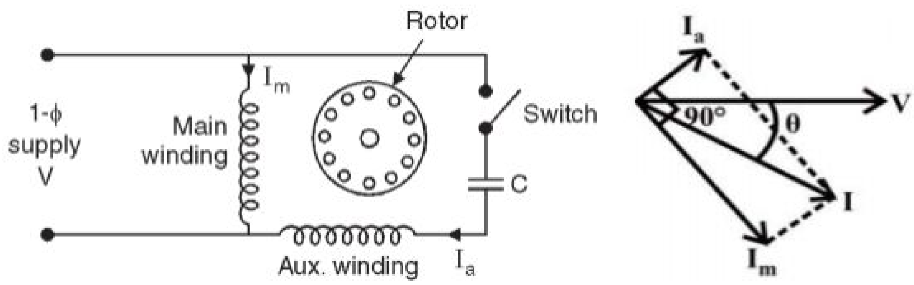


Fig.6. Torque speed characteristics of a Split phase Induction motor.

2. Capacitor Start Induction Motor:

The capacitor-start motor is identical to a split-phase motor except that a capacitor C (3-20 μF) is connected in series with the starting winding as shown in figure below. The auxiliary winding and the capacitor are disconnected at about 75% of the synchronous speed. Therefore, at the rated speed the capacitor start motor operates only on the main winding like a split-phase motor. A capacitor start motor is used when the starting torque requirements are 4 to 5 times the rated torque as shown in figure below.



Capacitor start motor

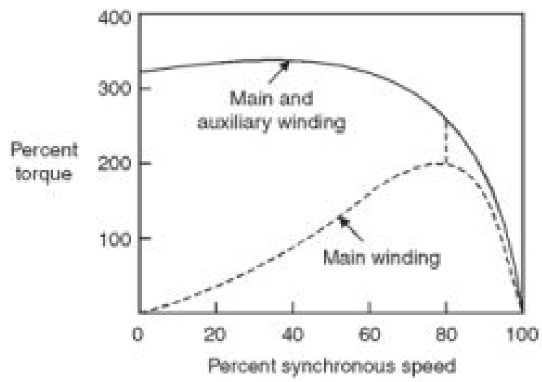
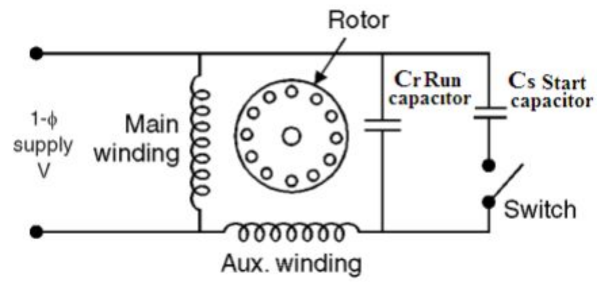


Fig.7. Torque speed characteristics of a Capacitor start Induction motor.

3. Capacitor Start Capacitor-Run Induction Motor:

This motor is identical to a capacitor-start motor except that starting winding is not opened after starting so that both the windings remain connected to the supply when running as well as at starting. Two capacitors C_r and C_s are used in the starting winding as shown in figure below. The smaller capacitor C_r required for optimum running conditions is permanently connected in series with the starting winding. - The much larger capacitor C_s is connected in parallel with C_r for optimum starting and remains in the circuit during starting. The starting capacitor C_s is disconnected when the motor approaches about 80% of synchronous speed. The motor then runs as a single-phase induction motor.



Capacitor-start capacitor-run motor

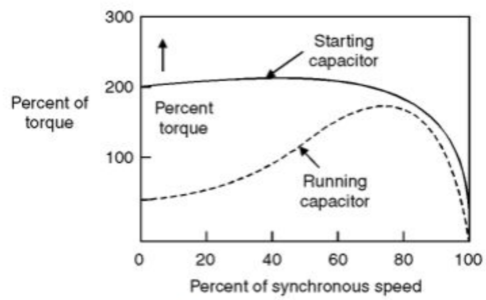
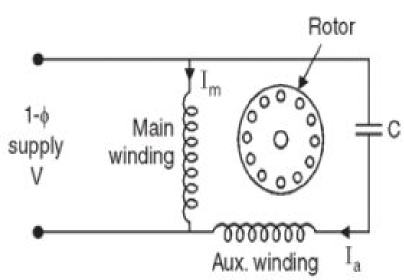


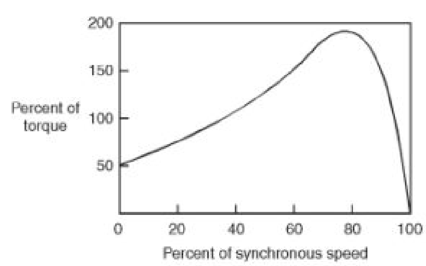
Fig.8. Torque speed characteristics of a capacitor start capacitor run Induction motor.

4. Permanent Split Capacitor Motor:

The schematic diagram of this type of motor is shown in figure below. This type of motor does not have a centrifugal switch, thus reducing maintenance problems. It is essentially the same as a two-value capacitor motor operating on the running connection and will have approximately the same torque characteristics. Since only the running capacitor (which is of relative low value) is connected in series with the auxiliary winding on starting, the starting torque is greatly reduced.



Permanent split capacitor motor



Torque-speed characteristic of a permanent split capacitor motor

Fig.6. Torque speed characteristics of a permanent split capacitor motor.

7. DESIGN OF SINGLE PHASE INDUCTION MOTOR FOR CEILING FANS

The design of this motor is such as to operate at a related frequency of 50Hz and a voltage of between 180-220 V to analyze the speed and efficiency. Now, to calculate the electrical parameters, we assume the following quantities:

7.1 Electrical Parameters

Table 2: Electrical parameters of Single phase induction motor ceiling fan.

Electrical Parameters	Specified Value
Input voltage range (V_{in})	180-220 V
Line frequency (f)	50 Hz
Output voltage (V_r)	220 ± 5% V
Output power (P_0)	50 Watts
Motor Current Density (J)	300 A/cm^2
Capacitor voltage (V_c)	440 V
Capacitor coefficient (K_c)	1.5
Efficiency goal ɳ(100)	85%
Magnetic material	Silicon
flux density (B_s)	1.95 T
Temperature rise goal (T_r)	50^{0}C
Power factor (cosΦ)	0.95

The electrical parameter design equations and calculations are done following the other as shown below,

$$\text{Stator voltage, } Vs = V_{in\,(min)} \cos\Phi = (180)(0.95) = 171.0 \text{ V}$$

Reflected resistance back to stator,

$$R_{o(R)} = \frac{\eta(V_s)}{P_O} = \frac{(171.0)(0.85)}{50}$$

$$= 2.89 \text{ ohms}$$

Required inductance and capacitance,

$$L = \frac{R_{0(R)}}{2\omega} = \frac{2.89}{2 \, x \, 377} = 0.00383 \approx 0.0038 \text{ Henry}$$

$$C = \frac{1}{3.3\omega R_{0(R)}} = \frac{1}{3.3 \, x \, 377(2.89)} = 0.000278 \text{ F}$$

The new capacitance value using the higher voltage,

$$C_\eta = \frac{C(V_s)}{V_c} = \frac{(0.000278)(171.0)}{(440)^2} = 2.455\mu F$$

The capacitor current,

$$I_c = K_c V_c \omega C = 1.5(440)(377)(2.455 \times 10^{-6}) = 0.61 \text{ Amps}$$

The Rotor Current,

$$I_r = \frac{P_O}{V_r} = \frac{50}{220} = 0.227 \text{ A}$$

The stator current related to the rotor due to capacitor winding,

$$I_s = \frac{I_r(V_r)}{\eta(V_s)}\left[1 + \sqrt{\frac{V_r}{V_c}}\right] = \frac{0.227(220)}{0.85(171.0)}\left[1 + \sqrt{\frac{171.0}{440}}\right] = 0.5577$$

The number of stator turns,

$$N_s = \frac{V_s(10^4)}{K_f B f A_c} = \frac{171.0(10^4)}{4.44 \times 1.95 \times 50 \times 18.8} = 210.11 \cong 210$$

The stator bare wire area,

$$A_{ws(B)} = \frac{I_s}{J} = \frac{(0.5577)}{(300)} = 0.00185925 \text{ cm}^2$$

7.2 Mechanical Parameters

Table 3: Mechanical parameters of Single phase induction motor ceiling fan.

Mechanical Parameters	Specified Value
Windows Utilization (K_u)	0.4
Core Number	EI - 175
Magnetic path length (MPL)	26.7 cm
Core weight (W_{tfe})	3.85 kilograms
Mean Length Turn (MLT)	35.6 cm
Iron Area (A_c)	18.8 cm^2
Window Area (W_a)	15.1 cm^2
Area product (A_p)	300 cm^4
Core geometry (K_g)	83.5 cm^2
Surface Area (A_t)	655 cm^2
Winding length (L_g) Lamination tongue (E)	0.276.cm 3.49 cm
No. of poles No. of stator slots / Magnet poles No. of laminations in stator Thickness of stator lamination No. of turns/ coil Overall diameter of motor Winding conductor diameter Outer diameter of the magnet Inner diameter of the magnet Thickness of the magnet (mm) Axial length of the magnet (mm) Outer diameter of the stator (mm) Axial length of the stator (mm) Length of air gap (mm) Thickness of the rotor back iron (mm) Axial length of the back iron (mm) Shaft diameter (mm) Weight of copper Weight of magnet	18 9 / 18 49 0.51 mm 450 140.9 mm 0.47/ 26 mm/ AWG 137.3 mm 121.76 mm 7.77 mm 34.5 mm 120.00 mm 25.00 mm 0.88 mm 1.80 mm 56.74 mm 17~18 mm 442.8 gm 392 gm

Weight of iron in stator laminations Weight of rotor back iron	997.30 gm 338.20 gm

The other mechanical parameters are calculated as follows:

The Area Product (A_p)

$$A_p = \frac{P_t(10^4)}{K_f K_u f B_s J} = \frac{(1544.77)(10^4)}{(4.44)(0.4)(50)(1.95)(300)} = 297.368$$

The window utilization (K_u)

$$K_u = \frac{N_s A_{ws(B)} + N_c A_{wc(B)} + N_r A_{wr(B)}}{W_a} = \frac{((210)(0.00930)) + ((330)(0.01013)) + ((270.17)(0.00387))}{(15.1)} = 0.419$$

8. BLDC MOTOR

BLDC motors can be configured in many different types but the three phase motor is the most common type due to its efficiency and low torque ripple. This type of motor also offers a good compromise between precise control and number of power electronic devices needed to control the stator currents.

8.1. Construction

The construction of this motor has many similarities of three phase induction motor as well as conventional DC motor. This motor has stator and rotor parts as like all other motors.

8.1.1 Stator

- Stator of a BLDC motor made up of stacked steel laminations to carry the windings. These windings are placed in slots which are axially cut along the inner periphery of the stator. These windings can be arranged in either star or delta. However, most BLDC motors have three phase star connected stator.
- Each winding is constructed with numerous interconnected coils, where one or more coils are placed in each slot. In order to form an even number of poles, each of these windings is distributed over the stator periphery.
- The stator must be chosen with the correct rating of the voltage depending on the power supply capability.

8.1.2 Rotor

- BLDC motor incorporates a permanent magnet in the rotor. The number of poles in the rotor can vary from 2 to 8 pole pairs with alternate south and north poles depending on the application requirement. In order to achieve maximum torque in the motor, the flux density of the material should be high. A proper magnetic material for the rotor is needed to produce required magnetic field density.
- Ferrite magnets are inexpensive, however they have a low flux density for a given volume. Rare earth alloy magnets are commonly used for new designs. Some of these alloys are Samarium Cobalt (SmCo), Neodymium (Nd), and Ferrite and Boron (NdFeB).

The rotor can be constructed with different core configurations such as the circular core with permanent magnet on the periphery, circular core with rectangular magnets, etc.

8.1.3. Hall Sensors

- Hall sensor provides the information to synchronize stator armature excitation with rotor position. Since the commutation of a BLDC motor is controlled electronically, the stator windings should be energized in sequence in order to rotate the motor. Before energizing a particular stator winding, acknowledgment of rotor position is necessary. So the Hall Effect sensor embedded in the stator senses the rotor position.
- Most BLDC motors incorporate three Hall sensors which are embedded into the stator. Each sensor generates Low and High signals whenever the rotor poles pass near to it. The exact commutation sequence to the stator winding can be determined based on the combination of these three sensor's responses.
- The BLDC motor has no mechanical part for switching electric currents in the stator windings, it is necessary to sense the positional relationship between the rotor and the stator in order to control electric currents applied to the stator windings.

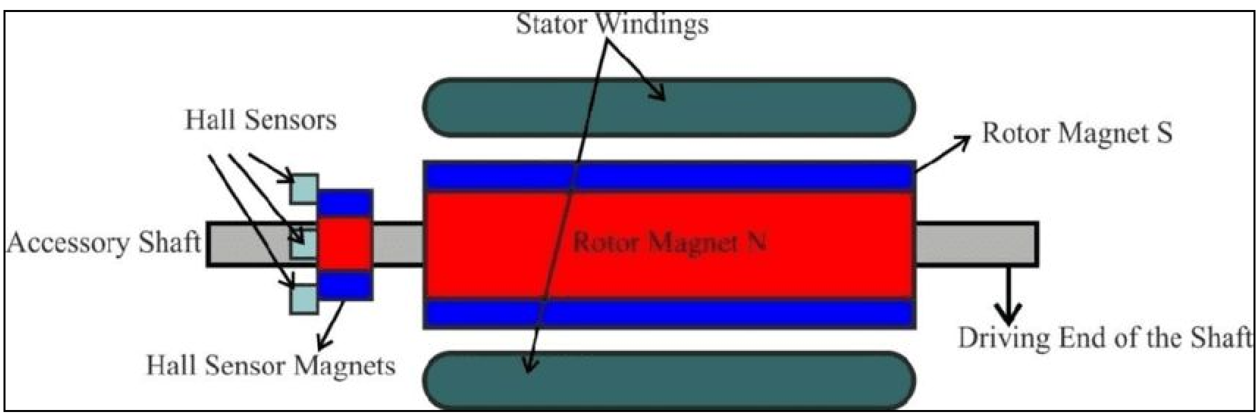


Fig. 9. BLDC motor transverse section.

8.2. Working

BLDC motor works on the principle similar to that of a conventional DC motor, i.e., the Lorentz force law which states that whenever a current carrying conductor is placed in a magnetic field it experiences a force. As a consequence of reaction force, the magnet will experience an equal and opposite force. In case of a BLDC motor, the current carrying conductor is stationary while the permanent magnet moves.When the stator coils are electrically switched by a supply source, it becomes electromagnet and starts producing the uniform field in the air gap. Though the source of supply is DC, switching makes to generate an AC voltage waveform with trapezoidal shape. Due to the force of interaction between electromagnet stator and permanent magnet rotor, the rotor continues to rotate.The three phase BLDC motor is operated in a two-phases-on fashion, i.e. the two phases that produce the highest torque are energized while the third phase remains off. The rotor position decides which two phases are energized. The signals from the position sensors produce a three digit number that changes every 60° as shown in figure 3 (H1, H2, H3). The figure also shows ideal current and back-emf waveforms.

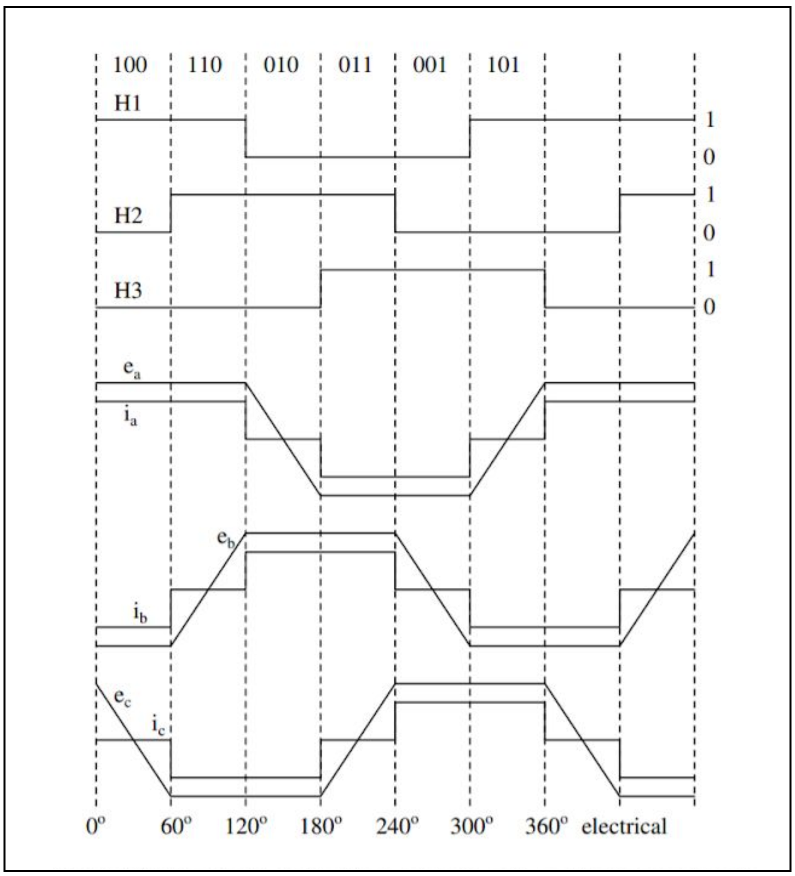


Fig. 10. Ideal back emf, phase current and position sensor signals

Fig.11. shows a cross section of a three-phase star-connected motor along with its phase energizing sequence. Each interval starts with the rotor and stator field lines 120° part and ends when they are 60° apart. Maximum torque is reached when the field lines are perpendicular. Current commutation is done by a six-step inverter as shown in a simplified form in figure 5. The

switches shown are bipolar junction transistor but MOSFET switches are more common. Table 4. shows the switching sequence, the current direction and the position sensor signals.

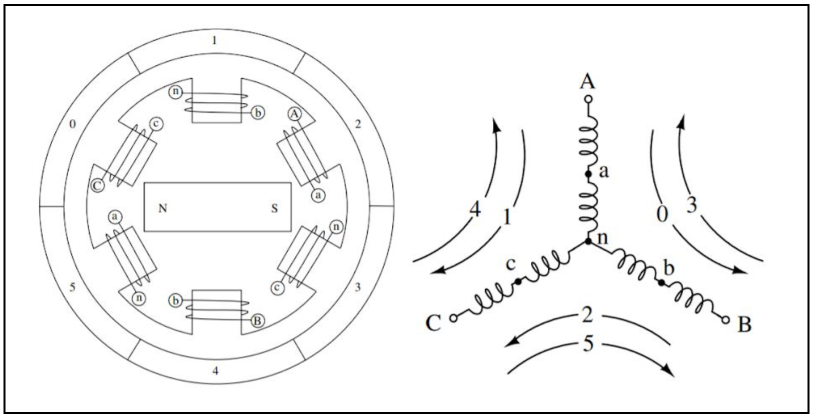


Fig.11. BLDC cross section and phase energizing sequence.

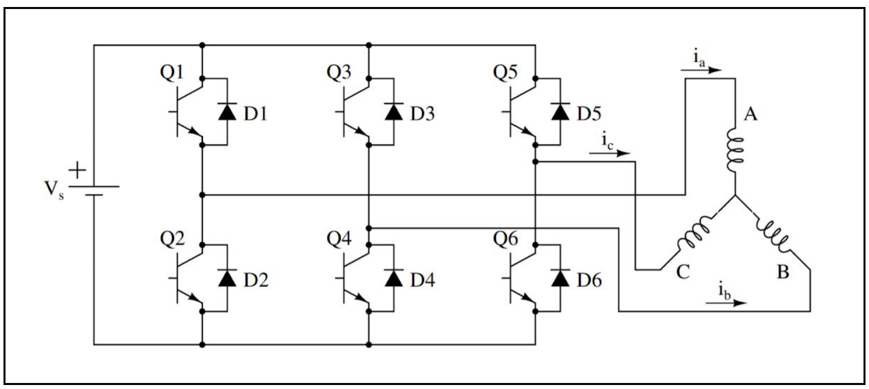


Fig.12. Simplified BLDC drive scheme.

Table 4: Switching sequence

Switching Interval	Seq. number	Pos. sensors			Switch closed		Phase current		
		H1	H2	H3			A	B	C
0°-60°	0	1	0	0	Q1	Q4	+	-	OFF
60°-120°	1	1	1	0	Q1	Q6	+	OFF	-
120°-180°	2	0	1	0	Q3	Q6	OFF	+	-
180°-240°	3	0	1	1	Q3	Q2	-	+	OFF
240°-300°	4	0	0	1	Q5	Q2	-	OFF	+
300°-360°	5	1	0	1	Q5	Q4	OFF	-	+

9. DESIGN OF BLDC MOTOR FOR CEILING FANS

The construction of modern brush less motors is very similar to the AC motor, which is also known as the permanent magnet synchronous motor. The stator windings are similar to those in a polyphase AC motor, and the rotor is composed of one or more permanent magnets. Brushless dc motors are different from ac synchronous motors in that the former incorporates some means to detect the rotor position (or magnetic poles) to produce signals to control the electronic switches. The most common position/pole sensor is the Hall element, but some motors use optical sensors.

9.1 Dimensions of BLDC motor

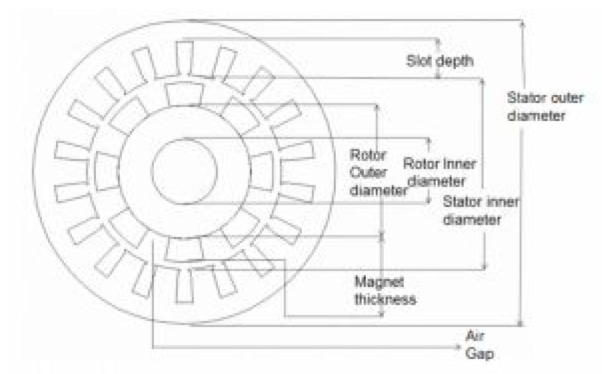


Fig.14. Dimensions of BLDC motor.

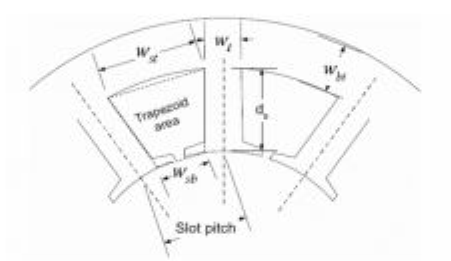


Fig.15. Stator slot dimensions of BLDC motor

9.2. Design Equations

9.2.1 Torque Expression of BLDC motor

Force on a current carrying conductor magnetic field is given by,

$$F = ILxB \qquad (1)$$

where, L is length of the conductor, B is magnetic flux density, and I is current through the conductor. The magnitude of the force is:

$$F = BIL\sin\boldsymbol{\theta} \qquad (2)$$

where **θ** is the angle between L and B.

The BLOC motor works on the same principle as a DC motor i.e. armature current and magnetic field are kept orthogonal to each other in space (**θ**=90). Thus the force on one conductor in the BLDC motor is given by,

$$F_c = B_g I_c L \qquad (3)$$

where, B_g - Air gap flux density in the middle (120°) of a pole in Wb/m^2

I_c - Current through a conductor in Amperes

Now, Torque on a conductor is given by,

$$T_c = B_g I_c L R_{si} \qquad (4)$$

where, R_{si} - Stator inner radius in mm

A tum consists of 2 conductors, one above north pole and other above south. Therefore torque on one turn is,

$$T_1 = 2B_g I_c L R_{s\,i} \qquad (5)$$

Torque on a coil with turns n_s is given by,

$$T_{coil} = 2B_g I_c L n_s R_{si} \qquad (6)$$

Each pole pair has to have all 3 phase coils. Therefore, the total number of coils per phase is equal to no. of pole pairs. A full pitch winding (SPP=I) is used to get a square mmf wave. Hence, Torque per phase is given by,

$$T_{phase} = 2pB_g I_c L n_s R_{si} \qquad (7)$$

The 3 phase inverter is operated in 120° conduction mode i.e. two phase carry current at any given time. Thus the total torque developed by the motor will be,

$$T = 2x2pB_g I_c L n_s R_{si} \qquad (8)$$

In this design, the coils of the same phase are connected in series. Also 120° conduction mode is used.

$$I_c = I_{phase} = I_s \quad (9)$$

$$T = 2PB_gI_cLn_sR_{si} \quad (10)$$

where $P = 2p$

9.2.2 Back EMF Expression of BLDC motor

In the same manner the back EMF can be calculated as torque expression of the motor,

EMF in one conductor: $E_c = B_gLv$ (11)

EMF in one conductor: $E_c = B_gLw_{sm}R_{si}$ (12)

EMF in one turn: $E_t = 2B_gLw_{sm}R_{si}$ (13)

EMF in one coil: $E_{coil} = 2B_gLn_sw_{sm}R_{si}$ (14)

EMF in one phase: $E_{phase} = PB_gLn_sw_{sm}R_{si}$ (15)

Back EMF of the motor: $E_b = 2PB_gLn_sw_{sm}R_{si}$ (16)

E_b is the back emf seen by the DC voltage source.

9.2.3 Stator Winding Design

The conductor wire gauge will be decided by the maximum current density.

$$A_c = \frac{I_c}{J} \qquad D_c = 2\sqrt{\frac{A_c}{\pi}} \quad (17)$$

Actually RMS value i.e. $I_c\sqrt{\frac{2}{3}}$ should have been used. However, I_c is taken leading to a conservative design. Now using standard wire gauge (SWG) table select a gauge with next higher diameter (D_c^*) than what has been obtained.

$$A_c^* = \frac{\pi}{4}(D_c^*)^2$$

$$A_{cu} = n_s \text{ x } A_{cu} = n_s \text{ x } A_c^* \quad (18)$$

A_{cu} is the area of copper in a slot. Next, the approximate overhang length is calculated. It is assumed that winding overhang is equal to coil pitch.

$$\tau_c = 2\pi(R_{si} + \frac{1}{2}d_s)\frac{1}{P}$$

$$l_t = 2L + 2\tau_c \quad \text{(19 and 20)}$$

9.2.4 Stator Slot Design

It is considered to have a uniform tooth and approximate the slot area as a trapezoid as shown in Fig 8.2. The slot area can be calculated as:

$$A_s = \frac{A_{cu}}{K_{fill}} \tag{21}$$

where, K_{fill} = slot fill factor

The slot fill factor takes care of insulation in the slot as well as all the approximations that are made while choosing the slot area as trapezoid. Using this area the various dimensions shown in Fig 8.1 and Fig 8.2 can be calculated as follows:

$$R_{ro} = R_{si} - g; N_s = P \times N_{ph} \tag{22}$$

$$\tau_s = \frac{2\pi R_{si}}{N_s}; \text{slot pitch} \tag{23}$$

where, R_{ro} = Rotor outer radius in mm

N_s = Number of slots

N_{Ph} = Number of phases

n_s = Total number of turns in a slot

$\boldsymbol{\tau}_s$ - Slot pitch

Tooth has to carry all the flux in the slot pitch,

$$\text{i.e. } \varnothing_{\tau s} = \varnothing_t \Rightarrow \tau_s L B_g = w_t L B_{max} \tag{24}$$

$$\therefore w_t = \frac{B_g}{B_{max}} \tau_s; w_{sb} = \tau_s - w_t \tag{25}$$

where, ϕ_{ts} = Flux in one slot pitch in Wb

ϕ_t = Flux in tooth in Wb

$w_{st/sb}$ = Bottom/top slot width in mm

B_{max} - Maximum flux density in Wb/m^2

w_t = Tooth width in mm

The area of the trapezoid is the slot area.

$$A_s = \tfrac{1}{2} (w_{st} + w_{sb}) \ x \ d_s \tag{26}$$

$$w_{st} = \frac{2\pi(R_{si} + d_s)}{N_s} - w_t \tag{27}$$

where, d_s = Slot depth in mm

Substitute w_{st} in A_s and solve the quadratic equation obtained to get "d_s "and "w_{st}".The maximum flux that the stator back iron has to carry is half the pole flux.

$$\frac{1}{2}\frac{2\pi R_{si}}{P}LB_g = w_{bi}LB_{max} \Rightarrow w_{bi} = \frac{B_g}{B_{max}}\frac{\pi R_{si}}{P} \tag{28}$$

where, w_{bi} = Back iron length in mm

In reality, pole flux density profile is trapezoidal in nature. Here it is assumed to be the same all along the pole pitch.

$$R_{so} = R_{si} + d_s + w_{bi} \tag{29}$$

This fixes all the dimensions of the machine. Now the weight of the motor is calculated. Rotor:

$$V_{rotor} = \pi R_{ro}^2 L \tag{30}$$

$$W_{rotor} = D_{steel} \text{ x } V_{rotor} \tag{31}$$

where, V_{stator} = Volume of stator in m^3

D_{steel} = Density of steel in Kg/m^3

This includes shaft and PM weight approximately.

Stator:

$$V_{stator} = \pi(R_{ro}^2 - R_{si}^2)L - N_s \text{ x } A_s L \tag{32}$$

$$W_{stator} = D_{steel} \text{ x } V_{stator} \tag{33}$$

Windings:

$$V_{cu} = N_{ph} p n_s l_t A_c \tag{34}$$

$$W_{cu} = D_{cu} \text{ x } V_{rotor} \tag{35}$$

where, l_t = - Length of a tum in m

A_c = Cross-sectional area of a conductor in mm

D_{cu} = Density of copper in Kg/m^3

V_{rotor} = Volume of rotor in m^3

Overall weight:

$$W_{motor} = W_{rotor} + W_{stator} + W_{cu} \tag{36}$$

This is an approximate value and weight of the frame is not considered.

9.2.5 Calculation of losses

Copper losses:

$$R_t = \rho_{cu} \frac{l_t}{A_c *}; R_{ph} = pn_s R_t \qquad (37)$$

As 2 phases carry current at any given time,

$$P_{loss\_cu} = 2I_s^2 R_{ph} \qquad (38)$$

Core loss: As compared to copper losses, core losses are very difficult to calculate as they consist of hysteresis and eddy current losses which vary nonlinearly with frequency and magnetic flux density. Fortunately manufacturers provide coreloss/kg data of the steel at various values of flux density and frequency which we can use to approximately calculate the core losses. Core losses occur only in stator.

$$P_{core\_loss} = \text{coreless/kg}(f_e \text{ x } B_{max}) \text{ x } W_{stator} \qquad (39)$$

9.3 Design of a 4 pole, 12 slot BLDC motor (typically used in fans)

9.3.1 Mathematical Model of BLDC motors

The instantaneous power produced by the BLDC motor is equal to the back electromotive force multiplied by phase current. This is the power that is transferred from stator to rotor. When the friction losses are extracted from the transmitted power, the net power from the motor shaft can be determined. Since the friction losses of the BLDC motor are very small, the power value can be written as in Equation 40.

$$P_e = i_a e_a + i_b e_b + i_c e_c \qquad (40)$$

where, $i_{a,b,c}$ = Currents of phases a, b, and c

$e_{a,b,c}$ = Induced back-electromotive force

Considering the 120º phase difference between the phases, the expression of the back electromotive force given in Equation 40 can be written as Equation 41.

$$
\begin{aligned}
e_a &= \omega\lambda(\theta) \\
e_b &= \omega\lambda\left(\theta - \frac{2\pi}{3}\right) \\
e_c &= \omega\lambda\left(\theta + \frac{2\pi}{3}\right)
\end{aligned}
\tag{41}
$$

The resulting back electromotive force is in the form of a trapezoidal wave, which varies depending on the position. The value of the back electromotive force depends on the number of turns, magnetic field strength, rotor speed, and position. The equivalent circuit of the 3-phase star-connected BLDC motor is given in the figure below.

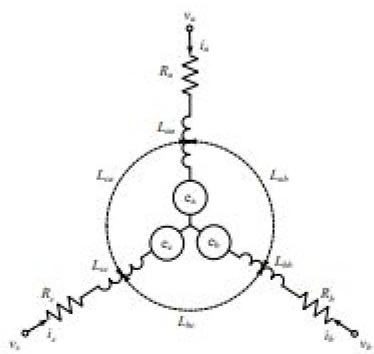


Fig.16. Equivalent circuit of the 3-phase star-connected BLDC motor

Voltage equation for the phase a is given in Equation 42 according to the equivalent circuit.

$$
v_a = i_a R_a + L_a \frac{d\,i_a(t)}{dt} + e_a \tag{42}
$$

The voltage equation for each phase of a BLDC motor is expressed as Equation 43.

$$
\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} R_a & 0 & 0 \\ 0 & R_b & 0 \\ 0 & 0 & R_c \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L_{aa} & L_{ab} & L_{ca} \\ L_{ab} & L_{bba} & L_{bc} \\ L_{ca} & L_{bc} & L_{cc} \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \tag{43}
$$

9.3.2 Design

Considering all the equations above, the design parameters for a 4 pole 12 slot motor are,

Table 5: Design parameters of a 4 pole, 12 slot BLDC motor fan.

Parameters	Dimension/Type
Stator Outer diameter (mm)	90
Stator Inner diameter (mm)	55
Stator Length (mm)	30
Stator Core Material	M270-35A
Rotor Outer diameter (mm)	54.2
Rotor Inner diameter (mm)	35
Rotor Length (mm)	30
Rotor Core Material	ST37
Magnet Type	N40UH
Magnet Thickness (mm)	3
Magnet Embrace	0.7
Slot clearance (mm)	2
Slot Width (mm)	13
Slot Area (mm^2)	106.53

Table 6: Performance values of a 4 pole, 12 slot BLDC motor fan.

Parameters	Value
Full load Output power (W)	100
Full load Efficiency (%)	85.16
Full load Rated torque (Nm)	0.312
No Load load Cogging torque (Nm)	0.204
No Load Stator teeth flux density (T)	1.79
No Load Rotor yoke flux density (T)	1.71

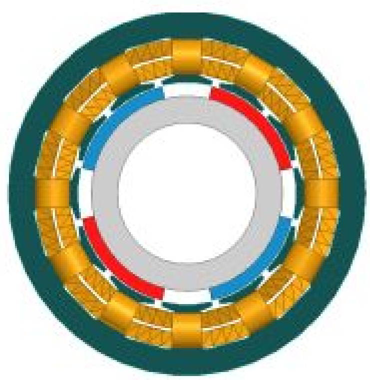


Fig.17. 4 pole, 12 slots BLDC motor.

10. COMPARATIVE PERFORMANCE ANALYSIS

The comparison analysis of recently used ceiling fan i.e. single phase induction motor ceiling fan and proposed BLDC ceiling fan is stated as below.

10.1 Power Consumption:

Table 7: Power Consumption of BLDC Motor and Ordinary ceiling fan

The speed of the Fan	BLDC Motor Fans	Ordinary Ceiling Fans
1	6 Watts	16 Watts
2	10 Watts	27 Watts
3	14 Watts	45 Watts
4	19 Watts	55 Watts
5	28 Watts	75 Watts

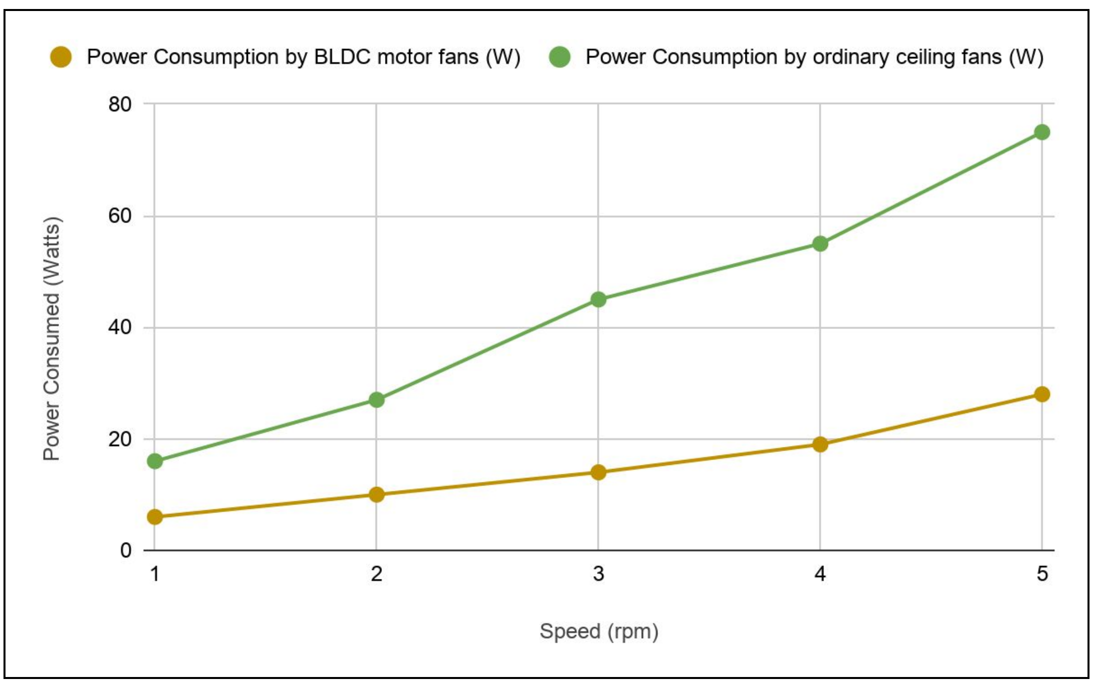


Fig. 18. Bldc motor vs Ordinary ceiling fan: Power Consumption Comparison

10.2 Torque-Speed Characteristics:

The Torque speed characteristic of a single capacitive start capacitive run induction motor is shown in Fig. 9 (a) and that of BLDC motor is shown in Fig. 9 (b) . The starting torque is nearly 300 to 400% of total torque in the induction motor while in BLDC motor it is nearly 60 to 70% of total torque. As a result of this, the starting current of an ordinary ceiling fan is nearly twice that of a BLDC ceiling fan.

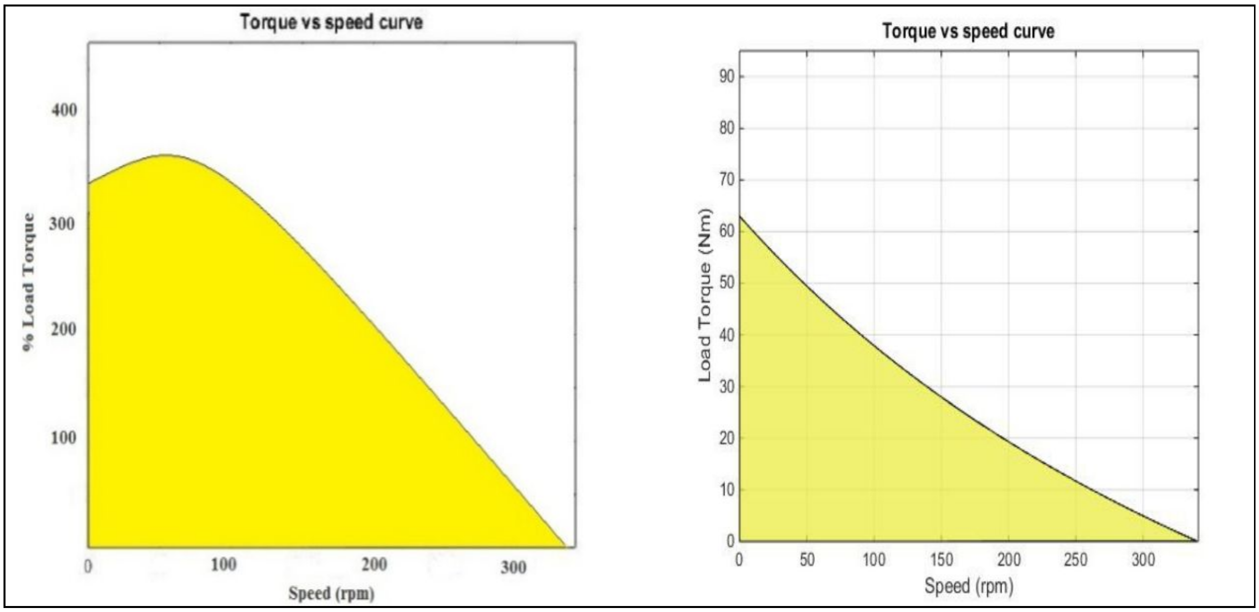


Fig. 19. Torque speed characteristics: a) Single phase induction motor b)BLDC motor

10.3 Energy efficiency:

According to IS standards the energy rating is calculated as the ratio of air flow in m3/min and the input power in watt of total energy rating. For a single phase induction motor 72 W ceiling fan of an air density of 270 m3/min, the energy star rating is calculated as 270/72 which is nearly 2 star rating. The BLDC motor with 24 W power input with the same air flow of 270 m3/min gives a 5 star rating. As a result, BLDC fan is more energy efficient.

10.4 Output Airflow:

The total amount of air flow or displacement is based on the blade size & rpm and does not change due to any other factor. The proposed solution is to keep the same air flow or displacement with less of energy usage along with improving the PF using the BLDC motor based ceiling fans.Typical BLDC motor based ceiling fan has much better efficiency and excellent constant rpm control as it operates out of fixed DC voltage

Table 8: Airflow of BLDC Motor and Ordinary ceiling fan

Speed(rpm)	BLDC motor fan (cfm)	Ordinary Ceiling fan (cfm)
140	467	434
210	267	234
270	200	167
310	134	109
360	100	34

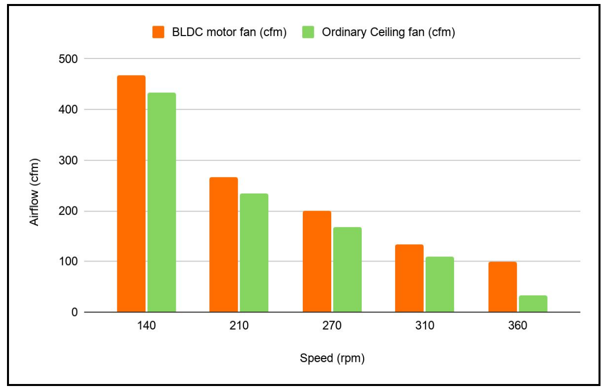


Fig. 20. Bldc motor vs Ordinary ceiling fan: Airflow Comparison

10.5 Service value/air flow efficiency:

Table 9: Airflow efficiency of BLDC Motor and Ordinary ceiling fan

Speed (rpm)	BLDCmotor fan	Ordinary Ceiling Fan
140	13.34	5.78
210	7.6	3.12
270	5.71	2.22
310	3.8	1.33
360	2.87	0.453

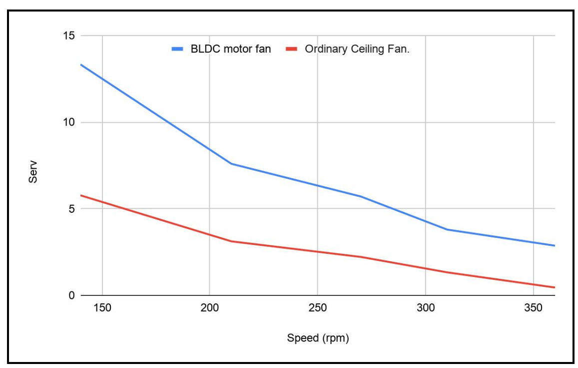


Fig. 21. Bldc motor vs Ordinary ceiling fan: Airflow efficiency comparison

Table 10: Comparison between BLDC Motor and Induction Motors

Features	BLDC Motors	Induction Motors
Speed/Torque Characteristics	Flat – Enables operation at all speeds with rated load	Nonlinear – Lower torque at lower speed
Output Power/ Frame Size	High – Since it has permanent magnets on the rotor, smaller size can be achieved for a given output power	Moderate – Since both stator and rotor have windings, the output power to size is lower than BLDC
Rotor Inertia	Low – Better dynamic characteristics	High – Poor dynamic characteristics
Starting Current	Rated – No special starter circuit required	Approximately up to seven times of rated – Starter circuit rating should be carefully selected
Control Requirements	A controller is always required to keep the motor running. The same controller can be used for variable speed control	No controller is required for fixed speed; a controller is required only if variable speed is desired
Slip	No slip is experienced between stator and rotor frequencies	The rotor runs at a lower frequency than stator

11. COST ANALYSIS

The typical induction-based fan consumes around 75 watts whereas a BLDC fan consumes about 30 watts. Unlike lights which are only used during nights, a fan is an appliance which runs most of the time if the ambient temperature is high with irregular airflow of cool air. So, assuming they run regularly for 15 hours every day for for an year, the calculation would be:

Table 11 : Ordinary ceiling fan vs BLDC motor fan: Yearly cost comparison

	Ordinary ceiling fan	**BLDC Fan**
Wattage	75 Watts	30 Watts
Hourly Electricity Consumption	0.075 units	0.030 units
Daily Electricity Consumption	1.125 units	0.45 units
Yearly Electricity Consumption	410.625 units	164.25 units
Yearly Costs (assuming Rs 6 per unit)	Rs. 2463.75	Rs 985.5

Typical price of electricity in India is assumed to be around 6 Rs per unit for residential users. Though the pricing per unit varies greatly between regions, power companies and whether the usage is commercial or residential. For metros, it is better to assume tariffs around 10 Rs per unit but for India as a whole 6 Rs is more practical.

With BLDC fans one can save approximately 1500 rupees per year. 1500 rupees is usually the price differential when buying a BLDC fan i.e BLDC fans starts with the pricing of around Rs 3,000 while ordinary fans are rough prices around Rs 1,500. So, in short, fans run for more than 15 hours daily and per unit electricity cost exceeds 6 Rs, one can expect to recover the complete cost of the fan in less than 2 years in the form of energy savings which BLDC fans give.

12. FAN DESIGN PARAMETERS FOR DIFFERENT ROOMS

Room 1:

Length of the room *(L)*: 12 ft = 3.6 m

Breadth of the room *(B)*: 11.5 ft = 3.35 m

Height of the room *(H)*: 10.4 ft = 3.2 m.

Height of work Plane *(W):* 2.788 ft = 0.85m

The recommended values for air changes per hour for bedroom as per NBC-5.2.2.1 & CPWD are between 2 to 4.

Assuming, air changes per hour = 3

Volume of the room = L*B*W = 12*11.5*10.4 = 1435.2 cubic ft.

Airflow (in cfm) = (Volume*Air changes per hour)/60= 71.76 cfm

As per NBC,

Height of fan blades above the floor = = (3H + W)/4

Minimum distance between fan blades and the ceiling = 0.3m

Therefore,

Area of the room = L*W = 12*11.5= 138 sq.ft.

Thus, recommended fan size = 1067mm (42")

Height of fan blades above the floor = (3*3.2 + 0.85)/4 = 2.615 m

Ceiling fan rod extend length for H (10.4ft) = 12"

Room 2:

Length of the room *(L)*: 21.3 ft = 6.5 m

Breadth of the room *(B)*: 18 ft = 5.5 m

Height of the room *(H)*: 13.1 ft = 4 m.

Height of work Plane *(W):* 2.788 ft = 0.85m

The recommended values for air changes per hour for room as per NBC-5.2.2.1 & CPWD are between 3 to 6.

Assuming, air changes per hour = 5

Volume of the room = L*B*W = 21.3*18*13.1 = 5022.54 cubic ft.

Airflow (in cfm) = (Volume*Air changes per hour)/60 = 418.545 cfm

Therefore,

Area of the room = L*W = 21.35*18= 384.3 sq.ft.

Thus, recommended,

2 fans of size = 1400 mm (55”)

Distance between two fans = 3 m

Height of fan blades above the floor = (3*4 + 0.85)/4 = 3.2105 m

Ceiling fan rod extend length for H (13.12 ft) = 36”

Table 12: Fan design Parameters for different rooms.

Parameter	Room 1	Room 2
Airflow (cfm)	71.76	418.545
No of fans	1	2
Distance between fans	-	3 m
Fan Size	42”	56”
Distance between fan blades and ceiling	0.3 m	0.3 m
Height of fan blades above the floor	2.615 m	3.2105
Ceiling fan rod extend length	12’	36”

13. USE OF SOLAR POWER

13.1 Total power per module

The 70W Ceiling fan is expected to run for 12 hours per day. Therefore, daily energy consumption is calculated.

Thus, Daily energy consumption = power x time = 70W x 12hrs = 840Wh

Photovoltaic Module Sizing

Pv Module Array = $\frac{Total\ Daily\ Energy\ Consumption}{Daily\ peak\ run\ hours\ x\ Pv\ correction\ factor}$

Assuming the Pv correction factor to be 0.65

Pv Module Array = $\frac{840\ Wh}{\frac{3\ hr}{module}\ x\ 0.65} =$ 323.078 watt/module

Total Wattage of the Pv Module = 323.078 W

13.2 No of Pv modules

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 India, we assume a 60 Pv module to power the standing fan.

The number of Pv module required are: $\frac{323.078\ W}{\frac{60\ W}{module}}$ = 5.364

It would require approximately 5 modules.

14. ADVANTAGES OF BLDC MOTOR FANS

Following are the few advantages of BLDC motor fans:

• ***High speed operation***

A BLDC motor can operate at speeds above 10,000 rpm under loaded and unloaded conditions.

• ***Responsiveness and quick acceleration***

Inner rotor BLDC motors have low rotor inertia, allowing them to accelerate, decelerate, and reverse direction quickly.

• ***High power density***

BLDC motors have the highest running torque per cubic inch of any DC motor.

• ***High reliability***

BLDC motors do not have brushes, meaning they are more reliable and have life expectancies of over 10,000 hours.

This results in fewer instances of replacement or repair and less overall down time for your project

15. DISADVANTAGES OF BLDC MOTOR FANS

- When a brushless DC motor is operated at low speed, slight vibrations occur during low-speed rotation. However, vibrations reduce at high speed.
- Due to the inherent natural vibration frequency of brushless DC motors, sometimes this natural frequency can match or can come closer to the vibration frequency of the body or plastic parts resulting in the occurrence of resonance phenomenon. However, this resonance can be minimized by adjustment, and it is common to observe resonance phenomenon in many brushless DC motor based devices.
- Brushed DC motors are easy to operate having simple wiring as the positive terminal is connected to positive and negative terminal is connected to negative wire and motor starts to rotate. However, in the case of brushless DC motor, wiring and operation of the motor are not that simple due to the involvement of electronic control and its link to all the electromagnets.

16. SCOPE FOR IMPROVEMENT IN THE DESIGN OF CEILING FANS

The improvements in the design of motors of ceiling fans has been discussed above. Improving fan blade design has been shown to have a significant influence on fan efficiency. Efficiency improvements have been achieved by multiple approaches. For example, these include incorporation of aerodynamic attachments for conventional blades (Volk 1990), a decrease in the angle of attack through the use of twisted, tapered (TT) blades (Bird 2004), and use of TT blades with an airfoil (Sonne and Parker 1998). We focus on the last of these options due to the wide use of this type of blade and the potentially large energy savings that are associated with this design. TT blades with an airfoil increase efficiency by reducing energy lost to turbulence and flow separation as discussed by Parker et al. (1999).

Optimal blade design requires a balance between multiple objectives including maximization of air speed, uniform air speed along the fan radius, and maximization of airflow coverage. A test of one such patented blade design indicates that the subject invention has an efficacy 86–111 % higher than that of a conventional flat blade, indicating remarkable potential for energy efficiency improvements from changes in fan blade design (Parker et al. 2000). These blades can also be used to reduce motor size and cost, and the resulting device will still outperform a conventional fan. Some efficient blade designs have been adapted for aesthetic purposes to appear like traditional blades from the bottom side while being aerodynamic on the top side, thus improving efficiency 10–26 % when compared to conventional designs (Parker and Hibbs 2010). The blade has been designed to meet a market preference by some consumers for energy-efficient fans with a traditional appearance.

16.2 Costs involved

The cost of manufacturing efficient ceiling fan blades in the USA is estimated to be about US$ 2.25, versus US$ 0.25 per conventional flat blade (Parker and Hibbs 2010; Parker et al. 2000). The incremental cost of manufacturing an efficient blade versus a conventional blade in India is about INR 60 for three blades, i.e., US$ 0.36 per blade. Although these appear to be significant cost increases for these components, they are not very large (~5 %) compared to the total retail price of a ceiling fan. An important point to mention in the case of efficiency improvement through blade design is that blade design and manufacturing are driven by aesthetic considerations rather than just efficiency. This is also reflected in divergent estimates of the costs of manufacturing depending on the design, material, manufacturing, and treatment/finishing processes. The significance of aesthetic considerations in blade manufacture implies that mandating more efficient blades through minimum energy performance standards (MEPS) is not likely to be a practical or desirable option. However, given that some fans may be designed to meet energy efficiency policy specifications by using more efficient blades, it is still useful to estimate the costs of efficiency improvement through more efficient blades, particularly for labeling and incentive programs.

17. CONCLUSION

From the various comparisons done between the single phase induction motor and BLDC motor fan , it is clear that energy conservation purpose the new proposed BLDC fan motor should be used for the ceiling fan application. BLDC motor gives better performance than the single phase induction motor even if the speed regulation is not smooth. The efficiency also increases by nearly 30% to 40%.

Saving electrical energy when driving the fan is ensured by replacing a single-phase induction motor with a BLDC motor. This replacement also brings advantages such as no noise, no maintenance, low volume and weight, etc. This is important especially in applications with variable speed drives because of fast dynamic response, less waiting time etc.

In the industrial and the residential sectors, the main use of energy is the conversion of electromechanical energy. This conversion is usually done with the help of electric motors. If it is used as an efficient form of the conversion of energy, then it reduces the cost of energy and the impact on the environment. The induction motor was for a long time a favorable solution compared to ceramic magnet motors which were not a cost effective solution to generate a strong magnetic field for energy conversion. But advancement in magnetic materials creates the conditions for designing a new, cost-effective motor such as BLDC motors. They have shown to offer a better performance and efficiency compared to single-phase induction motors.

18. REFERENCES

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