

Energy efficient Ceiling fans using BLDC motors- A practical implementation.

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Abstract— A brushless DC (BLDC) motor is a synchronous electric Motor powered by direct-current (DC) electricity and having an electronic commutation system, rather than a mechanical commutator and brushes. In BLDC motors, current to torque and voltage to rpm are linear relationships. This linearity provides an excellent opportunity to use the BLDC motor in the conventional ceiling fans. This paper presents practical implementation of such BLDC motor for ceiling fan application along with the actual power measurements in comparison with conventional ceiling fans. Complete electronics and the associated advantages and disadvantages of this BLDC ceiling fans are also presented.

Keywords— *Brushless DC Motor, Ceiling fans, energy conservation.*

1. Introduction

In the past decade, India has been recording a phenomenal GDP growth of more than 8% per annum and this growth is fueling the demand for energy requirements tremendously. Even though the energy demand is not linearly related to the GDP growth in India, it does have a bearing on the growth. The below graph indicates the typical demand of power in India and its expected demand by 2020 [1].

As the ways to generate energy is limited in India due to various factors such as the environment and availability of raw materials (fossil fuels etc), which lend to only conservation as the best option to curtail the energy needs as much as possible. In order to understand the various segments and their energy consumptions etc, we can look at the below graph and the accompanying table. It is clear that residential sector is the one where a maximum conservation is possible while the other sectors are so commercialized that it is not neither possible nor is there enough incentive to propose and sustain any major conservation of energy through other alternate energy efficient appliances in these sectors. So the focus in this paper has been on the residential sector and more specifically on the ceiling fans which sells more than 30 million units per year with an installed base of more than 250 million units in India.

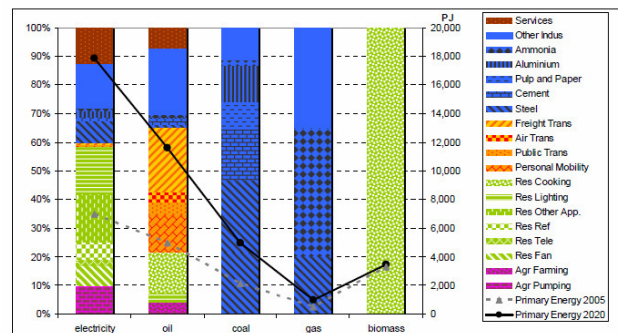


Fig 1. India Primary Energy Demand

From the above graph it is clear that the energy consumption by various segments are as in the table 1.

Table 1: Energy Consumption by various segments

Sl#	Segments	% of total
1	Heavy Industries	23
2	Transportaion	21
3	Agriculture	18
4	Residential	18

Further when the residential consumption was analyzed, it is found that the total consumption of power by Ceiling fans amounts to 6% which is more than that of the TV + Frigde combined.

This paper describes a method of using Brushless DC Motor to reduce the power consumption of the ceiling fans by more than 50% with out sacrificing on the performance or any other features.

2. Historical Background:

This section describes the basics of the various kinds of motors and their typical advantages and disadvantages along with the potential market opportunity for the proposed solution in the ceiling fan power consumption problem

DC Motors (brushed) are there in the market for commercial use from as early as 1886 and the concept of the BLDC motors

and its commercial use was from 1962, however, due to various limitations, one of them being mainly the electronics, BLDC motors were confined to few applications only.

Typically we see three kinds of motors in the market place. While there are various other specific types used in specialized applications, it is enough for the purpose here to consider these three and their applications and differences in general.

They are:

- **Direct current (DC) motor:** DC applied to both the stator and the rotor (via brushes and commutator), or else a permanent magnet stator.
- **Synchronous (or stepping) motor (AC):** AC in one, DC in the other (i.e., rotor or stator). If it has a permanent-magnet rotor, it is much like a BLDC motor.
- **Induction motor (AC):** AC in both stator and rotor (mentioned for completeness).

A BLDC motor has an external armature called the stator, and an internal armature (permanent magnet) called the rotor which is more like an AC motor (permanent magnet type). The main difference is the controller implementation and the way in which the AC (switched DC) is fed into them. The AC supplied is not a pure sinusoidal AC but controlled pulse width modulated waveform through an electronic control into two of the legs at a time with full positive and negative waveforms, leaving the third leg not driven at all times.

Typical BLDC motors are high rpm, low torque motors which are used in computer applications or DVD/CD drives. They are quiet and have long life with no serviceability related issues unlike the typical AC or DC motors along with the other advantage of high efficiency.

Typical conventional motors (brush DC motors) are limited by their efficiency and the susceptibility of the commutator assembly to mechanical wear and consequent need for servicing, at the cost of potentially less rugged and more complex and expensive control electronics.

BLDC motors offer several advantages over brushed DC motors, including higher efficiency and reliability, reduced noise, longer lifetime (no brush and commutator erosion), elimination of ionizing sparks from the commutator, more power, and overall reduction of electromagnetic interference (EMI). In general, BLDC motors are more efficient at converting electricity into mechanical power than brushed DC motors. This improvement is largely due to the absence of electrical and friction losses due to brushes.

A BLDC motor's main disadvantage is higher cost, which arises from two issues. First, BLDC motors require complex electronic speed controllers to run. Second, there are not too many practical uses which are using the BLDC motors in the commercial sector, that is the volume based cost reductions.

However, due to the advantages which are listed above, and with the smart low cost electronics, now a days there are various applications (electric vehicles, hybrid vehicles, PC cooling fans, exhaust fans, etc) where BLDC motors are being used commercially, and a new application which is being looked at for commercialization is the typical ceiling fan.

A typical BLDC fan motor is shown below:



Fig 2. Typical BLDC motor

3. Why BLDC for ceiling fan ?

Today the typical ceiling fan is based on AC motors which are power hungry. Along with this the typical AC motor based fans have the rpm control through the capacitor or resistor based regulators and is not efficient as there is loss in the regulator itself to some extent. In addition the RPM control is by controlling the voltage and the voltage fluctuations of the mains make it very challenging to have constant RPM based on the AC mains supply. Further, existing AC motor solution, results in power factor (PF) degradation with no improvement for PF and there are other ill effects like harmonics injection to the AC mains, etc.

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. The proposed BLDC motor and the

control electronics operates out of 24V DC through an SMPS having input AC which can vary from 90V to 270V. A comparison between BLDC and conventional ceiling fans is shown below (42" ceiling fan is considered).

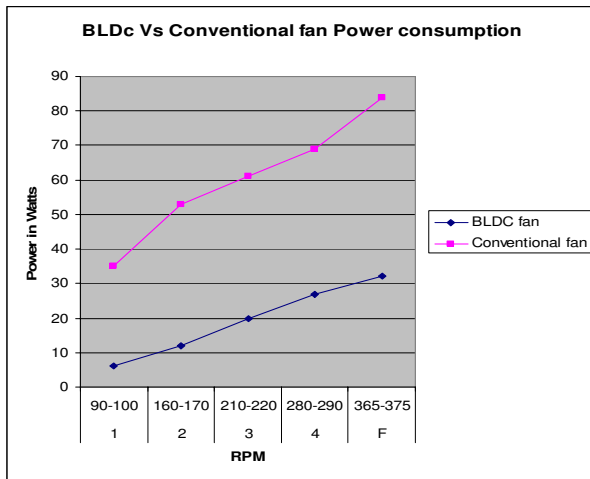


Fig 3. BLDC Vs Convention Ceiling fan (42") -Power consumption comparison.

The power consumption is less than half at full speed and is about 20% at low speed for the BLDC motor compared to the conventional motor based ceiling fan, as can be seen from the graph above. The Power Supply (PS) used is at 85% efficiency and the electronics consumes less than 0.5W. The power curves for the BLDC ceiling fan considers the total power consumed from the wall socket.

The mechanical energy required to rotate at full speed (typically 360rpm) for a 42" conventional ceiling fan is about 0.65Newton Meter. The equivalent electrical energy, as per the below equation, would be around 26Watts, considering about 95% efficiency for mechanical to electrical energy conversion. The total power consumption of 32 watts as seen in the above design seems to be with in the design boundaries for such a motor. Further what can be done to lower that power consumption is discussed in the improvements section of this paper.

$$\text{power (kW)} = \frac{\text{torque (N} \cdot \text{m)} \times 2\pi \times \text{rotational speed (rpm)}}{60000} \text{-----1}$$

4. Architecture discussions

BLDC motors come in single-phase, 2-phase and 3-phase configurations. Corresponding to its type, the stator has the same number of windings. Out of these, 3-phase motors are

the most popular and widely used. The focus here is on 3-phase motors.

In a BLDC motor the windings are on the stator and the rotor is a permanent magnet. To make the rotor turn, there must be a rotating electric field. Typically a three-phase BLDC motor has three stator phases that are excited two at a time to create a rotating electric field [2]. This method is fairly easy to implement, but to prevent the permanent magnet rotor from getting locked with the stator, the excitation on the stator must be sequenced in a specific manner while knowing the exact position of the rotor magnets. Position information can be obtained by either a shaft encoder or, more often, by Hall effect sensors that detect the rotor magnet position. For a typical three phase, sensor based BLDC motor there are six distinct regions or sectors in which two specific windings are excited at a time [3].

BLDC Motors use the DC voltage as input which is converted using the Pulse Width Modulation Techniques to control the excitation of the coils to generate the motion in prescribed fashion. We have proposed an electronic control for the PWM generation and the motion detection and control through the "hall effect" sensors which are embedded inside the BLDC Motor. There is also a way to use the "back emf" generated by the excitation on the "third leg" of the motor for calculating the relative position for the motion control [4]. This sensorless or back emf method, while it reduces the cost of the motor, has certain challenges and drawbacks and is not being considered here for the particular application.

Each commutation sequence has one of the windings energized to positive power (current enters into the winding), the second winding is negative (current exits the winding) and the third is in a non-energized condition. Torque is produced because of the interaction between the magnetic field generated by the stator coils and the permanent magnets. Ideally, the peak torque occurs when these two fields are at 90° to each other and falls off as the fields move together. In order to keep the motor running, the magnetic field produced by the windings should shift position, as the rotor moves to catch up with the stator field as shown in Fig 4 below.

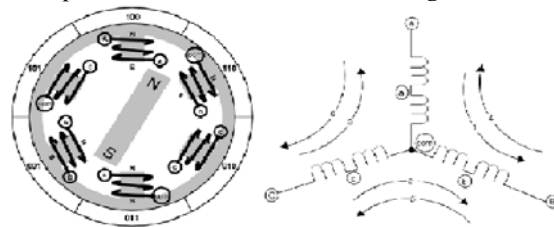
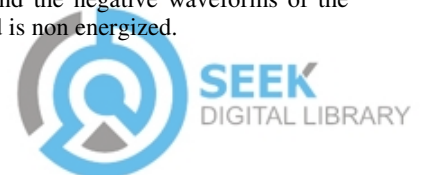


Fig 4. Electrical Diagram of a BLDC Motor.

The three legs of the electrical coils as indicated are excited through the PWM technique so at any point, two of them are applied with the positive and the negative waveforms of the PWM output while the third is non energized.



In essence we have two components required for the BLDC motor control: One is the PWM generation and control electronics for the BLDC motor and the other is the DC voltage generation based on the AC mains. Both of these are addressed here and details are provided. In the proposed BLDC motor based ceiling fan solution, the DC power is supplied through an SMPS which converts the AC mains supply to DC voltage (24V or 48V). The electronics of the BLDC Motor controller as such has the ability to either take the 24V DC from battery or from AC Mains and the SMPS design (AC DC converter module) allows varying AC voltage to be used as input while keeping the constant DC output, as desired. Speed control of the motor is achieved through the remote. Fig 4. below indicates the complete BLDC motor controller diagram.

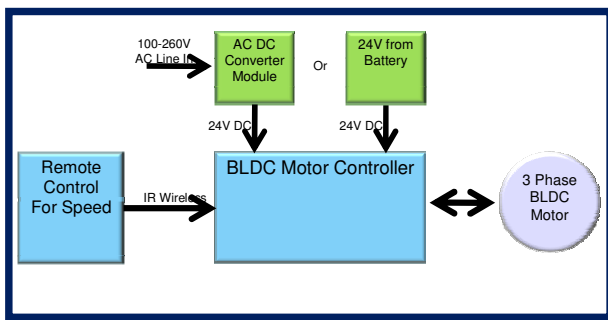


Fig 5. BLDC Motor controller – block diagram.

5. Solution overview.

Various building blocks and our solution approach and technology recommendations are discussed in this section. There are two main components of the BLDC motor control as implemented here and they are the SMPS power supply and the electronic controller card.

a. SMPS power supply

The following are the salient features of the Power supply specifications to which the solution has been delivered with the help of Power Integrators .

As can be seen, there is wide range of input voltage variations which the power supply can handle and the efficiency is at 85%. Typically input voltage variations of 150V AC to 265V AC are common, but in this design it has been guaranteed for 100V to 265V AC which makes it truly Universal in nature. Power factor improvement can be incorporated into such design so that the overall efficiency and the losses can be minimized, with the increased cost due to PF improvement components.

The input voltage requirements from 100 to 265V can be further reduced to 190 to 265V to reduce the cost along with some of the other safety features such as the Inrush current protection for high value, stall protection, etc., can be relaxed to decrease the overall cost of this solution.

Table 2. SMPS specifications

Sl#	Description	Min	Typical	Max	Units
1	Input voltage	100	230	265	Volts
2	Frequency	47	50/60	63	Hz
3	No load power			500	mW
4	Inrush Current			50	A
5	Output Voltage		24		Volts
6	Output ripple	200		200	mVolts
7	Output power			70	Watts
8	output current			9.5	A
9	Efficiency	75			%

Above specs were implemented as shown in the SMPS below (fig. 6). This power supply is based on the offline fly back converter using the TOP261EN (Power Integrators IC). The circuit is designed to operate from 100 VAC to 265 VAC input and provides one isolated output of 24V, 3A continuous and 9.5A peak as per the above requirements.



Fig 6. SMPS Power supply PCB

Input AC is rectified by a Full wave Bridge Rectifier through the TOP switch and the transformer along proper filtering circuit for both AC and EMI filtering. Thus generated 24V DC with further LC filtering for ripple reduction is being used for the electronics and motor control. The SMPS met all the required parameters as indicated in the table and Power Integrators solution using “top switch” did provide better than expected results [5]

b. Electronics Controller card:

Motor controller is based on Renesas 16 bit R8C25 microcontroller as shown in the below block diagram Fig 7. The electronics uses 5VDC derived from the SMPS output. ADC channels of the R8C25 are used for sensing the signals out of the Hall effect sensors from the BLDC Motor and the PWM generator drives the 2 stage MOSFET drives as shown in Fig 7.



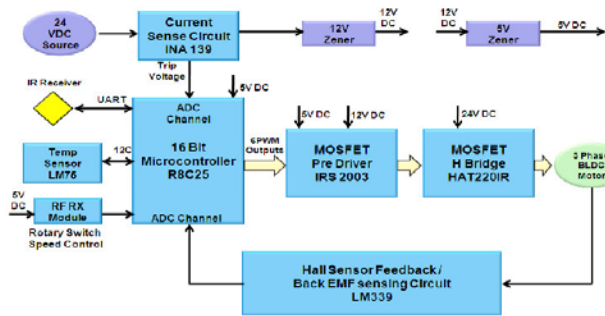


Fig 7. Block Diagram of controller card

Based on the hall effect sensor values, we will know the rotor position with respect to the magnetic poles. The MOSEFT bridge is switched based on that position information and this will start the rotation of the rotor and the switching operation so as to ensure the smooth rotation. Using the PWM technique, at zero crossing, a dead band is provided so as to avoid electrical short.

Firmware for the controller was developed using programming language C with the Renesas provided proprietary tools and the overall design was validated with that[6,7]. Following features were implemented in the firmware such as handling of the PWM generation and maintaining of the proper dead band, ensuring that with the proper hall effect sensors feedback, the current drive to the MOSFETs are maximized to generate highest torque for the given PWM cycle while controlling the motor speed through the PWM duty cycle. Further, the speed control is achieved through the IR or temperature control sensors along with providing the safety features such as the over current protection, short circuit protection, inrush current protection, etc.

Fig 8. BLDC controller PCBA



6. Future enhancements:

Following future enhancements can be envisaged based on either the cost reductions or the performance improvements

1. Decreasing the cost of the electronics by carefully reviewing some of the specifications such as the power supply input and output requirements.
2. Redesigning the BLDC motor construction so as to improve the overall torque generated by the motor through the number of poles and permanent magnet positioning, etc. Present motor is a 12 pole motor, by increasing to 18 poles the RPM and torque can be further improved, of course, the cost does increase.
3. Reduction in the air gap between the stator and the rotor: Present motor was done as the first proto type and it would require further few variations to achieve the most optimal design parameters to meet the power requirements.
4. Thickness of the copper coil used: This can be experimented to decrease the resistance and the losses, and to improve efficiency. This may result in small additions to the power consumption improvements.

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