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Study of Energy Efficient Five Phase BLDC Ceiling Fan

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***Abstract*— A ceiling fan is a must in any home. Single phase induction motors used in conventional ceiling fans use roughly 80 watts of power. This work aims to present a model of an energy-efficient ceiling fan that uses just 24 watts for the same output power, based on a five phase BLDC motor. The fundamentals of BLDC motors are covered in this paper, followed by an addition of five phase BLDC motors. Discussions have also been held over the actual laboratory results, fan specs, and electronic circuitry needed to create a trapezoidal waveform. Additionally, the study addresses the significance of energy-efficient household appliances in fostering a culture of conservation and energy efficiency for load side control.**

Keywords: (BLDC) motors, Driver circuit, MOSFET, ceiling fans, Efficiency

I.INTRODUCTION

The global energy crisis of the present has increased demand for energy-saving and energy-efficient practices at all scales. In addition to focusing on growing the generation as a whole, fundamental home electrical equipment need to incorporate energy-saving and energy-efficient features. The most common household appliance in warmer regions, such as Pakistan, India, Brazil, China, and the USA, is a ceiling fan, which creates a wind chill effect to give cold air. Single phase induction motors are used in conventional ceiling fans to generate the mechanical energy needed for rotational motion. A significant portion of the electricity used in homes is produced by ceiling fans that are powered by single phase induction motors. [1]-[5]
According to estimates, the electrical energy used by ceiling fans alone will rise to about 9% of the total electricity used in homes [2]. Multiphase permanent magnet Brushless Direct Current (BLDC) motors can be used to replace single phase induction motors, reducing this energy requirement by about 75%. With substantially less power, PM BLDC motors offer excellent torque that is equivalent to single phase induction motors.[2] Therefore, the integration of BLDC motors into ceiling fans will encourage a culture of energy efficiency on a home scale and have a measurable effect on the total amount of energy consumed in the home. In order to increase performance, the study presents a five-phase BLDC Energy Efficient Ceiling Fan as an alternative to the conventional single-phase induction motor and three-phase BLDC fans.[3]-[5]

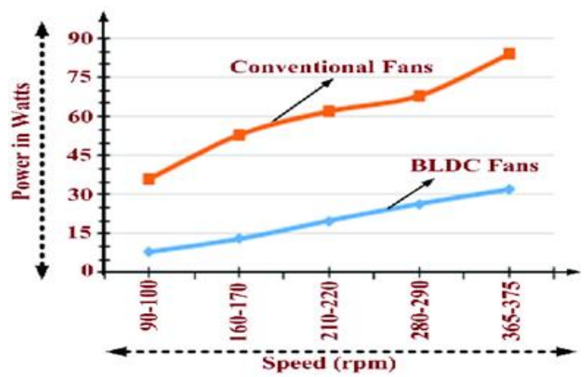

Figure. 1. Energy Consumption of BLDC

II.POWER CONSUMPTION

Single phase induction motors used by conventional fans need between 75 and 80 watts of power. Figure 1 compares the power consumption of ceiling fans with traditional and BLDC-based systems. Pakistan's domestic demand accounts for around 45.6% of the country's total energy production, and that percentage is expected to rise to 55% by 2020 [4]. As was previously mentioned, one of the main SEUs (Significant Energy Users) of household power use is ceiling fans, and it is anticipated that this usage would rise quickly due to rising temperatures and population density. Pakistan's energy problem is becoming worse, and according to recent research, 25% of electricity is lost because of inefficient equipment. [1]-[5]

- Low Power Consumption
- Noiseless Operation
- Energy Conservation
- Minimal Insulation Failures

III.INTRODUCTION OF BLDC

On the other hand, are synchoroidal DC motors in which the magnetic flareld is supplied by permanent magnets, which are made up of hard rare earth magnets. Permanent magnets attached to the stator supply the permanent magnetic flear.[2] This makes BLDC motors useful for applications where there is no need to control the speed by varying the flear excitation. The internal structure of a BLDC motor is shown in Figure 2.

PM BLDC motors exhibit characteristics similar to those of shunt motors, with the exception of speed torque characteristics, which are more linear and predictable.[3]

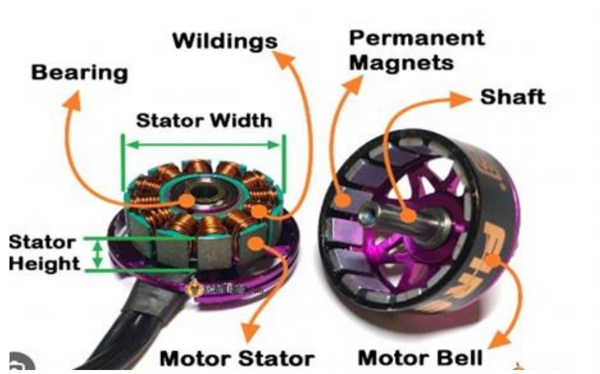

Fig. 2. BLDC Motor [5]

A. Working of PM BLDC Motors

BLDC motors operate on a same concept as conventional DC motors, which is the electromotive force impressing an electrified wire positioned inside a magnetic intensity. Fleming's Left Hand Rule may be used to compute the force's direction [6]. A torque is often produced by the force acting on the conductor of the armature windings, which results in a rotating force. From equation 1, one can get the force an acting on the electrified conductor.[2]-[3]

$$F = LIB \tag{1}$$

where B represents the intensity of magnetic field, I represents current produced in the conductor and L represents the lengthof the conductor. The generated torque can be calculated from equation 2

$$T = 2rBILN \tag{2}$$

where N denotes the number of winding turns, I denotes current in the conductor, B denotes magnetic field strength, L denotes conductor length, and T denotes produced torque. The distance between the rotating axis and the conductor is given by r in meters.

Moreover, BLDC motors are categorized as

- BLDC Out Runner Motors
- BLDC In Runner Motors

➢ BLDC Out Runner Motors*:* On the outside of the electromagnets of these BLDC motors are permanent magnets. These are in handy in situations requiring strong torque at low rpm. They also offer quiet operation.

➢ BLDC In Runner Motors*:* On the inside of the electromagnets are permanent magnets found in these BLDC motors. These operate noisily but are helpful in applications requiring low torque and high rpm.

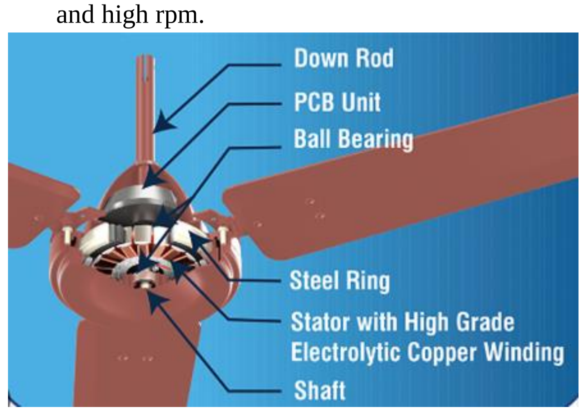

Figure 3. Phase BLD Prototype

IV.BLDC MOTORS DESIGN

BLDC motors generate rotational energy by using switches to electrically carry out a predefined commutation sequence in response to data on rotor position received from Hall Sensors. The rotor windings can be keyed up by a DC voltage that reverses polarity on the rotor coils in a predefined order to generate an AC voltage on the coils with a trapezoidal waveform because the rotor windings and permanent magnets on the stator provide uniform air gap flux concentration. [7]. Because of their high efficiency, low maintenance requirements, fast torque characteristic, wide speed range, low electrical noise, and extended lifespan, BLDC motors are a great option for drive mechanisms, control systems, speed-adjustable applications, and precision control. [8].

V. IMPLEMENTATION OF 5 PHASE BLDC

Single phase and three phase rotor windings formed the foundation for the majority of BLDC motors in the past. The usage of several motor rotor phases in accordance with application requirements has been made possible by the switch-based inverter fed motor drive mechanism. This technique has revolutionized BLDC technology by enabling the development of motors with high order ratings in terms of both design and power. The output torque of multiphase BLDC motors rises with the number of poles. [6]-[8]

The five phase BLDC motors utilized in Energy Efficient Fans function according to the same concept as BLDC motors. The motor is designed as an outrunner BLDC motor with permanent magnets on the external perimeter acting as the stator and armature windings on the interior periphery acting as the rotor in order to provide high torque for ceiling fans. A five-phase BLDC motor with 12 poles and 15 winding slots is designed to run at 500 rpm while preserving a 72-degree voltage differential between phases. The BLDC motor's inside view is displayed in Fig. 3. Rotor windings are divided into 5 sets representing 5 phases namely A B C D and E rendering each phase three set of

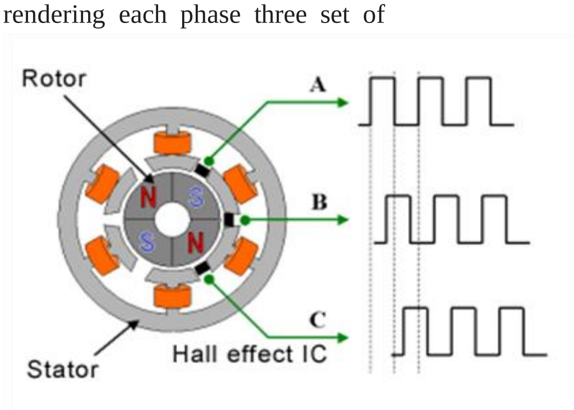

Fig. 4. Star Connected Windings

rotor coils and connected in series with each other. To boost the motor's speed, the wiring plan is designed with star connections. Fig. 4 depicts the wiring configuration for a five phase BLDC prototype motor. A sophisticated inverter control technique with a 10-step commutation cycle and a switching frequency of 50 Hz is needed for the entire switching process. The rotor's present position is detected by hall sensors installed on the rotor windings, which provides feedback to the BLDC driver circuit for precise commutation sequence switching. The motor is powered by an input voltage of 220V AC, and the rotor windings get 12V via the mosfet circuits. [7]-[8]

FAN SPECIFICATIONS

The specifications of the 5-phase BLDC motor include the following characterstics:

- *Power 25 W*
- *Speed 500 rpm*
- *Torque 0.754 Nm*
- *Number Poles 12*
- *Number of Slots 15*
- *Winding- Star*

PHASE BLDC FAN WORKING

Various strategies have been used to regulate and supply power to BLDC motors, contingent on their intended use. More intricate applications lead to more intricate designs and electrical circuitry. The ROM or EEPROM memory store for the commutation sequence is the foundation of the technology used to produce the BLDC Fan. In order to achieve the appropriate commutation sequence in line with the data received, ROM or EEPROM memory is powered by Hall sensor signals, which are discussed in the subsequent section. The gate signals are then sent to the mosfet driver circuit. To achieve a trapezoidal waveform, the circuit makes use of operational amplifiers, clock generators, and monostable

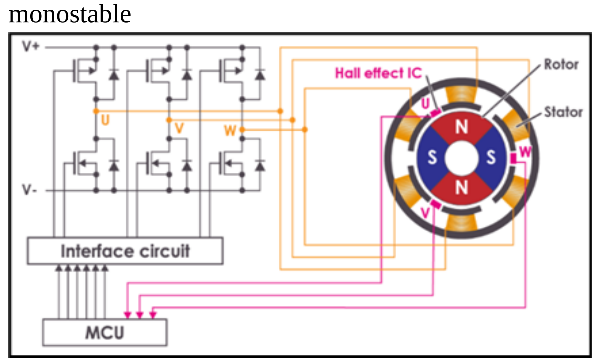

Figure 5. Control circuit of BLDC

Fig. 5 displays the block diagram illustrating the fundamental operation of the BLDC fan.Three-phase BLDC motors provide output energy after six pulses of electrical rotation, whereas five-phase BLDC motors generate output energy at a rate of ten pulses of electrical rotation. For a three phase BLDC motor to provide the same amount of energy as a five phase BLDC motor, greater pulse sizes are needed [10]. Higher power levels can be achieved by dividing the required power over numerous phases in multiphase BLDC motors, such as five phase BLDC motors. The multiphase system's restricted range power electrical gadgets and switches can also function thanks to this power splitting across many phases. By reducing the amplitude and increasing the frequency of the torque pulse rate, BLDC motors enhance the output torque while decreasing the per-phase rotor current without hurdles. [3]-[8]

VI.HALL SENSORS IN BLDC MOTORS

Electronic commutation is used by BLDC motors to finish their revolution cycle. The rotor position must be known in order for the BLDC driver to calculate the precise time and location for correct switching. This information serves as an indication, allowing the driver to deliver current to the rotor windings at the appropriate time. Hall sensors are a type of gadget that provides precise information on the position of the rotor [11]. In essence, Hall Sensors are magnetic switches that are driven by the rotor windings' magnetic field. The Hall Sensor amplification circuit is depicted in Fig. 6. These devices are essentially monolithic integrated circuits that, when the magnetic field impressed at the Hall sensor beyond the magnetic operating point threshold (BOP), output a low signal. [4]-[5]

Hall Sensors are mounted at an angle of 72 degree to pro- vide the status of each phase winding. Moreover amplification circuit is also required to obtain desired level signal from Hall sensors for proper sensing. The positioning of Hall Sensor on BLDC prototype is shown in Fig 7.

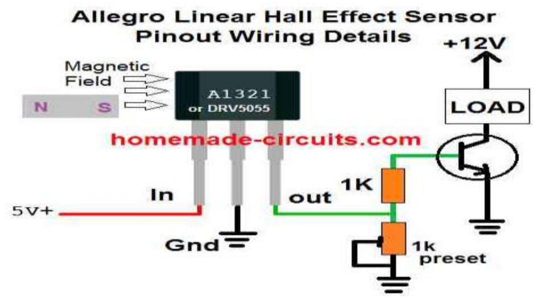

Fig. 6. Hall Sensor Amplification Circuit

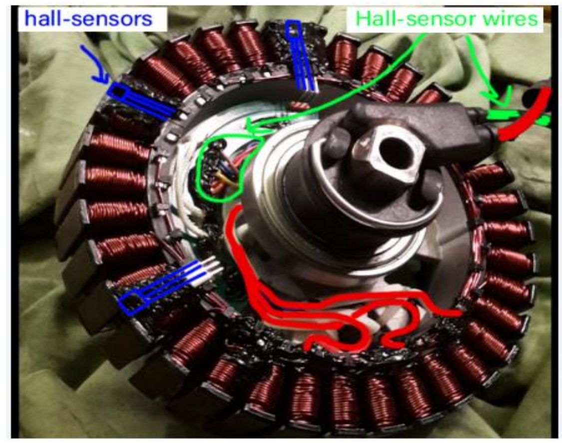

Fig. 7. Hall Sensor PCB on BLDC

VII. BLDC MOTOR DRIVER

By turning transistors on and off in response to feedback on rotor position received from Hall Sensors, the BLDC Mosfet Driver circuit carries out the predefined commutation sequence. Push-pull mosfets running at 12V make up BLDC Mosfet drivers. A totem pole-shaped combination of n and p channel mosfets makes up a mosfet driver. To accomplish switching, pulse width modulation (PWM), and speed control, the circuit additionally incorporates snubber circuits, monostable multivibrators, logic gates, and operational amplifiers. The 12V output of the BLDC driver impressed on the rotor windings is shown in Fig. 8. To achieve all necessary levels of excitation, high, low, and pulse width modulation (PWM) impulses at various configurations must be applied to the mosfet gates. Fig. 9 depicts the whole mosfet driver circuit with all necessary parts.[6]-[9]

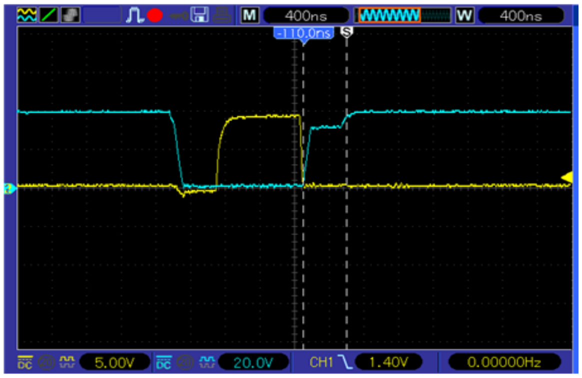

Fig. 8. MOSFET Driver Output

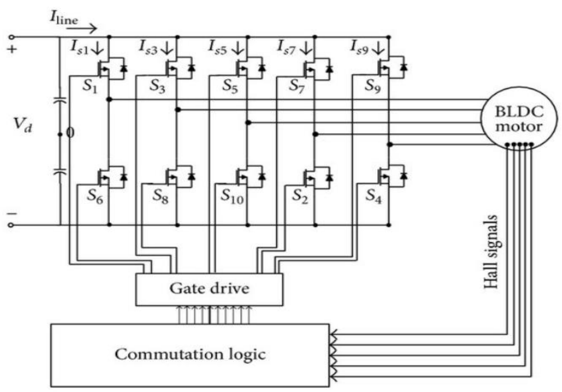

Fig. 9. BLDC Motor control

VIII.POWER SAVE IN 5 PHASE BLDC FAN

Conventional ceiling fans are highly inefficient in terms of energy losses since their rpm is controlled by either capacitors, regulators based on resistors, or by regulating the voltage from the main supply, which is itself fluctuating and not constant. Because of their higher power factor, BLDC motors cause comparatively less energy waste when used in fans. The BLDC allows for constant RPM control, which greatly increases their efficiency [12]. When running under loaded conditions, a BLDC motor may achieve high torque ratings and exceed 500 rpm in speed. Because BLDC motors have a low rotor moment of inertia, they can accelerate and decelerate quickly.[9]-[10]

IX.CONLUSSION

BLDC motors have an efficiency rating of up to 90%, making them extremely efficient motors. These motors are primarily employed in the automotive and aviation industries and have great torque and speed characteristics. The use of these highly efficient motors in household appliances for energy conservation and efficiency is now feasible thanks to the development of multiple feed inverters. These devices find wide use as an alternative to traditional single-phase induction motors. Since five phase BLDC is a commodity that every home owns, the inclusion of this technology in ceiling fans represents a significant advancement in home energy savings.

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Kumar has published three papers, including two in IEEE International Conferences, and is continuing his research in the core of BLDC technology.