

Design and Testing of Brushless DC Motors in Fan

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Brushless DC (BLDC) motors have harvested significant attention in various industrial, commercial, and consumer applications owing to their high efficiency, low maintenance, and robust performance characteristics. This paper presents design and testing of an efficient BLDC motor in accordance with IEC 61000-4-11 standard. The detailed analysis of the circuit and PCB design of an efficient BLDC motor is presented. The various kind of test like input characteristics test, Safety test, EMI/EMC test and reliability test are performed to check performance of BLDC fan motor PCB. The designed BLDC fan motor shows excellent performance, with power consumption rising from 3.13 W to 32.49 W and the power factor improving from 0.52 to 0.99 as speed increases. The significant THD reduction from 58.51% to 3.87% highlights superior power quality. These results affirm the motor's suitability for various real-world applications

Keywords: BLDC; IEC61000-4-11; Total Harmonic Distortion; EMI/EMC test; Safety test

1 Introduction

Brushless DC (BLDC) motors have emerged as a popular choice in various applications due to their efficiency, reliability, and versatility. BLDC motors consist of a permanent magnet rotor and a stator with windings. The commutation process, which determines the direction of current flow in the stator windings, is achieved through electronic control based on the rotor position feedback. BLDC motors find widespread use in various industries, including automotive, aerospace, robotics, HVAC (Heating, Ventilation, and Air Conditioning), industrial automation, and consumer electronics. The paper¹ explores key challenges and future research directions in the field of BLDC motors. The review paper² surveys recent developments in sensor less control techniques for BLDC motors, which eliminate the need for position sensors, reducing system complexity and cost. Challenges such as motion planning, trajectory tracking, and integration with sensory systems are discussed in³. BLDC fans offer several advantages over conventional AC fans. As discussed in⁴ BLDC fans exhibit higher energy efficiency, reduced noise levels, and longer lifespan due to the absence of brushes and commutators. Automotive cooling systems benefit from BLDC fan technology, as evidenced by research⁵, which emphasizes the superior thermal management capabilities and reduced power consumption of BLDC fans in electric vehicles. Despite their advantages,

BLDC fan systems face certain limitations and challenges. Cost remains a significant barrier to widespread adoption⁶. Additionally, the need for sophisticated electronic components pose challenges for design and integration⁷. Recent research has focused on advancing BLDC fan technology to address existing challenges and expand its application areas⁸. The novel control strategies for optimizing BLDC fan performance and efficiency has been explored in⁹. This paper presents the design and testing of a BLDC motor. The functionality of its BLDC motor PCB design circuits is verified in accordance with the IEC 61000-4-11 standard. The findings contribute valuable insights into the reliability and efficiency of BLDC motor designs, offering a foundation for future advancements in motor technology.

2 Working Principle of BLDC motor

In order to make the operation more reliable, more efficient, and less noisy, the recent trends have been used to use brushless DC motors. They are also lighter compared to brush motors with the same power output. The brushes in conventional DC motor wear out over time and may cause sparking. Thus, the brushed DC motor should not be used for operation that demands long life and reliability. The rotor of a brushless DC motor is a permanent magnet. The stator has a coil arrangement as shown in Fig. 1. By applying DC power to the coil, the coil energizes and becomes an electromagnet. The operation of a BLDC motor is based on the simple force interaction

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between the permanent magnet and the electromagnet. In this condition, when the coil is energized, the opposite poles on the rotor and stator are attracted to each other. The stator of a BLDC motor consists of windings energized with alternating currents, creating a rotating magnetic field. Sensors detect the rotor's position, enabling precise control of the commutation sequence. This sensor feedback allows for efficient torque generation and smooth operation across a wide range of speeds. In BLDC motor, electronic controller is used for this purpose. A sensor determines the position of the rotor and based on this information, the controller decides which coil to energize. Most often a Hall Effect sensor is used for this purpose.

2.1 BLDC Vs Normal FAN

The transition from old incandescent bulbs to LED bulbs and from traditional fans to BLDC fans has brought significant energy efficiency improvements. LED bulbs are approximately 80% more efficient than incandescent bulbs, while BLDC fans can be up to 50% more power efficient than traditional fans. Additionally, when paired with inverters, BLDC fans can run almost twice as long as regular fans on the same battery backup, making them more practical during power outages or in areas with unreliable electricity supply. These advancements contribute to energy conservation and cost savings for households. BLDC motor fans offer greater control flexibility, allowing for precise speed regulation and integration with smart control systems for automated operation. While BLDC motor fans may have a higher initial cost compared to traditional fans, the long-term energy savings and reduced maintenance costs often outweigh the initial investment. A comparison is summarised in Table 1.

3 BLDC fan block diagram

The block diagram presented in Fig. 2 outlines the architecture of a Brushless DC (BLDC) ceiling fan system. It details the power conversion and control circuitry required to operate the BLDC fan motor. The key components describing the working of a BLDC motor fan system are:

3.1 AC Input and Power Conversion

The system accepts an alternating current (AC) input ranging from 90V to 300V. The AC input is fed into a Switch Mode Power Supply (SMPS), BP3609, which converts the AC input to direct current (DC) output. The BP3609 adopts a built-in quick start up function which can realize quick start.

3.2 Voltage Regulation and Control

The BP2525X is an ultra-low standby power non-isolated buck converter for constant output voltage application. The device is suitable for 85Vac~265Vac universal input non-isolated auxiliary power supply. It integrates a high voltage power MOSFET. With the proprietary output voltage and current control technique, it can get excellent CV regulation. BP32MC057EM6S8, is 32-bit microcontroller targeting motor control applications. The microcontroller is responsible for



Fig 1 — BLDC fan motor

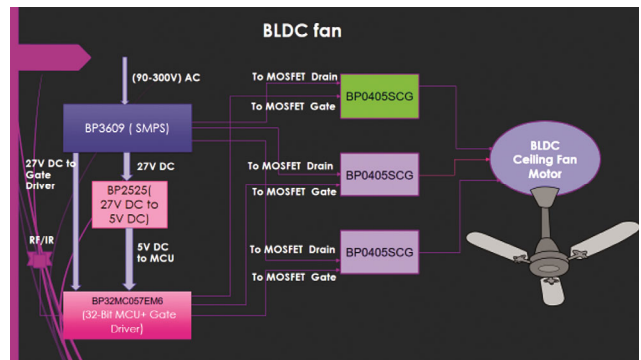


Fig 2 — BLDC fan Block diagram

Table 1 — BLDC/Normal Fan

	BLDC Fan	Normal Fan
Power	28W	75 W
Weight	3.8 kg	4 kg
Control	BLDC fan can be controlled with the help of remote provided the feature of Sleep and Time	Fan controlled with the help of regulator
Cost	Rs 3000	Rs 1500
Electricity consumption	12 hrs/28 W	12 hrs/75 W
1 year bill @Rs 7/unit	Rs 1442	Rs 2300
1 year bill @Rs 7/unit	Rs 11,500	Rs 41292

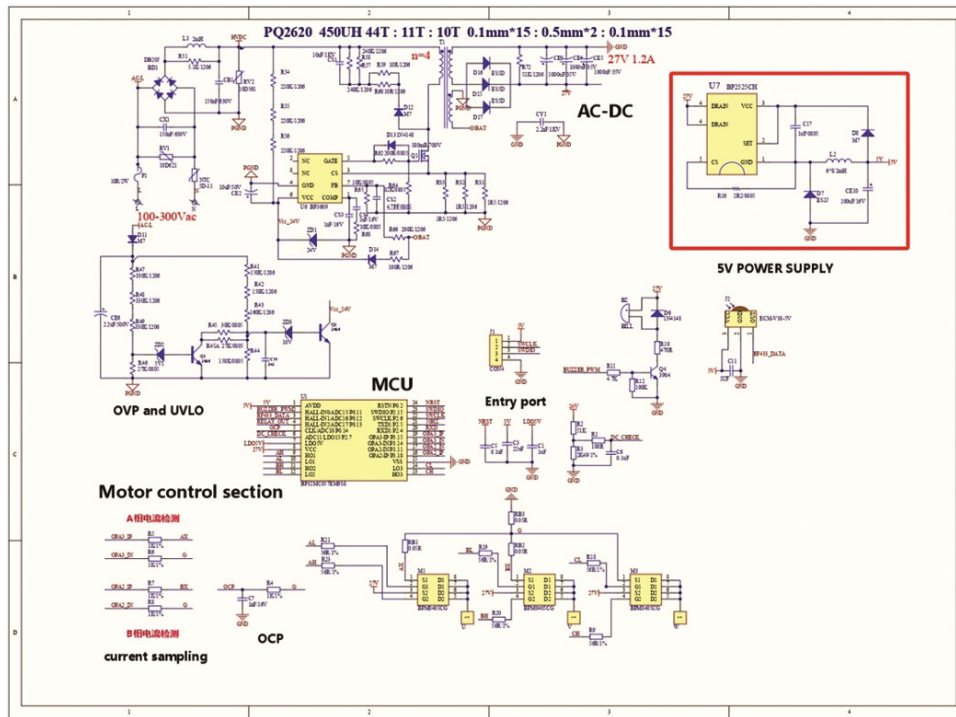


Fig 3 — Circuit Diagram Description

controlling the overall operation of the BLDC motor by generating appropriate control signals.

Gate Drivers

The diagram shows three MOSFET gate drivers, each connected to the microcontroller. These drivers are labeled BP0405SCG and are essential for switching the MOSFETs, which in turn control the current flow to the BLDC motor windings.

4 Circuit diagram Description

The schematic shown in Fig. 3 for the BLDC ceiling fan demonstrates a comprehensive and robust design for controlling a Brushless DC motor in a ceiling fan application. The diagram is divided into several key sections

4.1 Power Supply Section

AC-DC Conversion

The circuit converts AC mains voltage (100-300V AC) to a regulated 27V DC supply. Key components include a bridge rectifier (BD1), filter capacitors (CE2, CE3), and a BP3609 controller for power management.

Over Voltage Protection (OVP) and Under Voltage Lockout (UVLO)

This section ensures that the circuit operates within safe voltage limits using Zener diodes (ZD2, ZD3), resistors, and transistors.

5V Power Supply

The 27V is further stepped down to 5V using a BP2525CH DC-DC converter (U7), which powers the microcontroller and other low-voltage component

4.2 Microcontroller Unit Section

BP32MC057EM6S: This microcontroller (U1) handles the overall control and processing tasks. It interfaces with various sensors and output drivers. The microcontroller allows precise control of the BLDC motor through PWM signals, driving MOSFETs in a half-bridge configuration.

4.3 Motor Control Section

BLDC Motor Drive: The motor is driven by three half-bridge circuits, each controlled by MOSFETs (M1, M2, M3). The MOSFETs are driven by PWM signals from the microcontroller

Current Sensing: Each phase of the motor has current sensing resistors (RB1, RB2, RB3) and operational amplifiers (OPA2, OPA3) to measure the motor current, providing feedback to the microcontroller for precise control. Current sensing ensures that motor operation remains within safe limits, protecting both the motor and the control electronics.

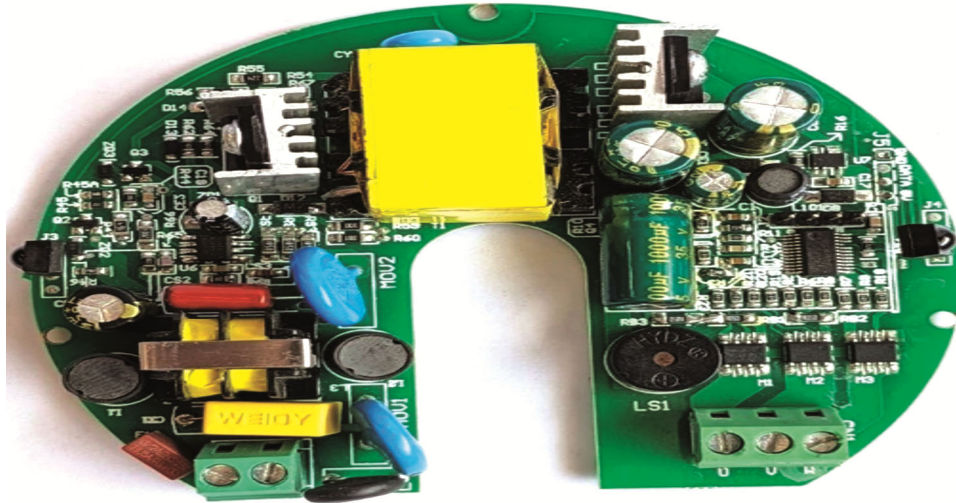


Fig. 4 — BLDC fan motor PCB

Hall Effect Sensors: The rotor position is detected by Hall sensors interfaced with the microcontroller, which is essential for commutation control.

4.4 Peripheral Interface Section

RF Module: An RF433 MHz module interfaces with the microcontroller for wireless control.

Relay Output: A relay driver is controlled by the MCU to switch external devices.

Buzzer: The circuit includes a buzzer (BZ) driven by a transistor (Q4) and controlled by the MCU's PWM signal for audio alerts.

4.5 Protection and Filtering

Current Limiting and Filtering: The power lines include several filtering capacitors (C1, C5, C11) and resistors to ensure smooth power delivery and reduce noise.

Thermal Protection: A thermistor (NTC) provides over-temperature protection by limiting inrush current.

4.6 PCB Layout

The printed circuit board (PCB) designed for a Brushless DC (BLDC) ceiling fan control system is shown in Fig. 4. The circular PCB layout is optimized to fit within the fan's housing, likely around the motor shaft. A large yellow transformer at the center is used for stepping down and isolating the AC voltage. Additionally, there are smaller inductors and transformers likely for further voltage regulation and filtering. This PCB is compact control system for a BLDC ceiling fan, integrating power conversion, motor control, and thermal management in a circular

layout to fit seamlessly into the fan's structure. Heat sinks are attached to the MOSFETs to dissipate heat generated during operation, ensuring the components remain within safe operating temperatures. The design ensures efficient operation and precise control of the BLDC motor, contributing to the fan's overall performance and energy efficiency.

5 Results

Testing of BLDC motor is done in accordance with the referred standard IEC61000-4-11¹² in which the device under test (DUT) should be tolerant to voltage dip variation of 0–80% of normal input supply voltage. The various kind of test like input characteristics test, Safety test, EMI/EMC test and reliability test are performed as mentioned in Table 2 to check performance of BLDC fan motor .

5.1 Input characteristics Test

The PCB is tested for variation in voltage (140-260 V) and frequency (47-53 Hz) and found to be working properly in all condition as summarised in Table 3. In Table 4, PCB is tested for standby power consumption and it is found to be <3W .This circuit incorporates a low-voltage and high-voltage tripping mechanism to protect the appliances from any damage as shown in Table 5.

5.2 Safety Test

Testing the dielectric strength, insulation strength, and leakage current of a PCB is crucial for ensuring its safety and reliability. The designed PCB passes the dielectric strength test discussed in Table 6, and hence can be considered safe for use within the specified

Table 2 — Performance check test

Test Name	Test Description	Test result
Input characteristics	Input Voltage and Frequency Range	PASS
	Stand-By Power Consumption	
	Input UVP & OVP	
	Wrong Connection Test	
Safety test	Dielectric Strength	PASS
	Insulation Strength	
	Leakage Current	
EMI/EMC	Surge Test	PASS
	EFT Test	
	ESD Test	
	DIPTest	
Reliability test	Input Harmonic Current	PASS
	Repeated I On/Off Test	
	Low Voltage Run Test	
	High Voltage Run Test	

Table 3 — Input Voltage and Frequency Range

V _{in} (Vac)	Input frequency (Hz)	P _{in} (W)	PF	I _{in} (A)	Power supply	Voltage (5 V)	Remote control	Working state	Conclusion
140	47	30.8	0.99	0.22	OK	4.92	OK	OK	PASS
140	53	30.6	0.99	0.22	OK	4.92	OK	OK	PASS
230	47	30.8	0.99	0.13	OK	4.92	OK	OK	PASS
		31.6	0.99	0.14	OK	4.93	OK	OK	PASS
230	53	32.2	0.98	0.12	OK	4.93	OK	OK	PASS
		32.8	0.98	0.12	OK	4.93	OK	OK	PASS

Table 4 — Standby Power Consumption

Sl.NO	V _{in}	Ambient Temp	Input current (I)	Input power (P _{in})	Power Factor	Specification requirements	Conclusion
1	140 Vac	27°C	11.6 mA	0.59 W	0.36	<3 W	Pass
2	160 Vac	27°C	10.9 mA	0.61 W	0.35	<3 W	Pass
3	180 Vac	27°C	10.4 mA	0.66 W	0.35	<3 W	Pass
4	200 Vac	27°C	10.9 mA	0.73 W	0.33	<3 W	Pass
5	220 Vac	27°C	11.2 mA	0.76 W	0.3	<3W	Pass
6	240 Vac	27°C	12.1 mA	0.88 W	0.3	<3 W	Pass
7	260 Vac	27°C	12.8 mA	0.95 W	0.27	<3W	Pass

operating conditions. For this test, a high voltage which is significantly higher than the normal operating voltage is applied. The PCB is able to withstand the voltage without breakdown. The purpose of the Insulation Strength Test discussed in Table 7 is to verify that the insulation between conductive parts of the PCB is sufficient to prevent leakage current and ensure safe operation. The Leakage Current Test aims to verify that the PCB has adequate insulation between conductive parts to prevent excessive current flow and ensure safe operation. The measured leakage current is less than

or equal to the specified maximum allowable value, the PCB passes the leakage current test demonstrated in Table 8.

5.3 EMI/EMC Test

The Electromagnetic Interference (EMI) and Electromagnetic Compatibility (EMC) test is a critical evaluation to ensure that a Printed Circuit Board (PCB) meets electromagnetic compatibility requirements. This test verifies that the PCB does not emit excessive electromagnetic radiation and is not susceptible to external electromagnetic interference.

Table 5 — Over voltage and under Voltage protection Test

Ambient Temp	Load	PCA status	OVP and UVP voltage	Conclusion	
28°C	Fan on Turbo Speed (Max)	Input Over voltage Protection	Cut off	290 Vac	PASS
28°C	Fan on Turbo Speed (Max)		Cut In	280 Vac	
28°C	Fan on Turbo Speed (Max)	Input Under voltage Protection	Cut off	84 Vac	PASS

Table 6 — Dielectric Strength

Test Setting	Test time	Measured Data	Status	Requirement	Reference standard	Conclusion
1500 Vac/ 50 Hz	60 s	0.079 mA	OK	Leakage current < 10 mA	IEC 60243-1	Pass

Table 7 — Insulation Strength

Test Setting	Test time	Measured Data	Status	Requirement	Reference standard	Conclusion
500 V _{dc}	60 s	>4 GΩ	OK	Insulation strength >5 MΩ	IEC 60243-1	Pass

Table 8 — Leakage Current Test

Test Setting	Test time	Measured Data	Status	Requirement	Reference standard	Conclusion
230 V/50 Hz	10 s	0.079 mA	OK	Leakage current <3.5 mA	IEC 60243-1	Pass

The Surge Test is performed to ensure the robustness and reliability of a Printed Circuit Board (PCB) against transient overvoltage events. This test simulates sudden increases in voltage, such as lightning strikes or power surges, to verify the PCB's ability to withstand such events without damage. Table 9 verifies that PCB passes the Surge Test as it remains operational and undamaged after the surge event. Further, the Electrical Fast Transient (EFT) test shown in Table 10 is performed to ensure PCB can withstand voltage fluctuations without malfunction and damage. The PCB passes the EFT Test as it remains functional after EFT disturbance. The Electrostatic Discharge (ESD) test is a critical evaluation to ensure the robustness and reliability of a Printed Circuit Board (PCB) against electrostatic discharge events. The ESD Test shown in Table 11 ensures that the PCB can withstand electrostatic discharge events, maintaining reliable operation and minimizing the risk of malfunction or damage under real-world operating conditions. The designed BLDC motor PCB shown in Fig. 4 is subjected to voltage dips of 0%, 40%, 70% and 80% for various time durations generated from programmable AC source,

at 28 °C temperature and 60% relative humidity. Table 12 summarizes the respective performance status of the PCB under test. The Input Harmonic Test shown in Table 13 is conducted to evaluate the harmonic content of the input current drawn by the PCB. The PCB passes the Input Harmonic Test as the harmonic content of the input current is within the specified limits, when connected to an AC power supply, minimizing interference with other electronic devices and ensuring compliance with regulatory standards.

5.4 Reliability Test

The reliability test results are summarised in Table 14. In this test BLDC motor fan PCB is tested at voltage 230VAC at full load for cycles of 59 seconds ON and 1 second OFF, repeated 3600 times. It assesses the device's endurance and performance under continuous operation, ensuring it meets reliability standards for sustained use. The Low Voltage Run Test is conducted to evaluate the performance and functionality of a Printed Circuit Board (PCB) when operated under low voltage conditions. This test results shown in Table 15

Table 9 — Surge Test

Ambient Temp		30°C	Humidity		60% RH	Reference standard:IEC 61000-4-5	
Input: 230 Vac/ 50 Hz		Test instrument: Prima Combined Disturbance Simulator				Test Result: Pass	
Surge	Polar	Phase angle	Surge voltage	Test times	State	Conclusion	
L-N	-	0	±2kV,±3kV,±4kV	5	Normal Working	PASS	
		90	±2kV,±3kV,±4kV	5	Normal Working	PASS	
		180	±2kV,±3kV,±4kV	5	Normal Working	PASS	
		270	±2kV,±3kV,±4kV	5	Normal Working	PASS	
	+	0	±2kV,±3kV,±4kV	5	Normal Working	PASS	
		90	±2kV,±3kV,±4kV	5	Normal Working	PASS	
		180	±2kV,±3kV,±4kV	5	Normal Working	PASS	
		270	±2kV,±3kV,±4kV	5	Normal Working	PASS	

Table 10 — EFT Test

Ambient Temp		30°C	Humidity		60 %	Reference standard:IEC 61000-4-4	
Input: 230 Vac/ 50 Hz		Test instrument :Prima Combined Disturbance Simulator				Test Result: Pass	
EFT	PeakVoltage	Frequency	Duration	State	Conclusion	Remarks	
L+N	±2kV, ±3kV, ±4kV	5 kHz	15 ms	On State-Normal Working	PASS	Normal Performance within limits	
	±2kV, ±3kV, ±4KV	100 kHz	0.75 ms	On State-Normal Working	PASS		
L+N	±2kV, ±3kV, ±4kV	5 kHz	15 ms	Standby	PASS		
	±2kV, ±3kV, ±4kV	100 kHz	0.75 ms	Standby	PASS		

Table 11 — ESD Test

Ambient Temp		28°C	Humidity		%	Reference standard :IEC 61000-4-2	
Input:230 V/50 Hz		Test instrument: Prima Combined Disturbance Simulator				Test Result :Pass	
Sr. No	Parameters	Nominal Value/ Requirement	Observation	Result			
1	ESD Test: (IEC61000-4-2) Type of Contact & Air Discharge Test Voltage (Air Discharge:8 kV Test Voltage (Contact Discharge): 6 kV No of Discharge:10 PCB card along with load under normal operating condition	After the test the PCB shall continue to operate as intended without any malfunctioning & degradation in performance	After the test PCB was working without any malfunctioning & degradation in performance	Normal Performance within limits.			

ensures that the PCB operates correctly and reliably within the specified low voltage range. The High Voltage Run Test results summarised in Table 16 ensures that the PCB operates correctly and reliably within the specified high voltage range, ensuring its functionality and performance under high voltage conditions. The various test results providing crucial

insights into the device's power consumption, power factor, RPM (revolutions per minute), and Total Harmonic Distortion (THD) are summarised in Table 17. The wattage increases with speed, the fan consumes 32.49W at turbo setting delivering high performance with high energy efficiency. The power factor (PF) improves significantly as the speed

Table 12 — DIP Test

Ambient Temp	28°C		Humidity	60% RH			Reference standard : IEC 61000-4-11	
Input: 230 Vac/ 50 Hz	Output : Fan on Max speed						Test Result: Pass	
Test Instrument: CHROMA Programmable AC Source (Model 6560)	Continuous test time:5 minutes per Condition							
Test Class	10 ms (0.5 T)	20 ms (1 T)	50 ms (2.5 T)	500 ms (25 T)	1 s (50T)	5 s (250 T)	Remarks	Conclusion
0% UT	OK	OK	OK	OK	OK	OK	Fan works without any failure after regaining the normal working voltage range	PASS
40% UT	OK	OK	OK	OK	OK	OK		PASS
70% UT	OK	OK	OK	OK	OK	OK		PASS
80% UT	OK	OK	OK	OK	OK	OK		PASS

Table 13 — Input Harmonic Test

Vin	Input freq.(Hz)	P _{in} (W)	PF	In (A)	Harmonic current THD (%)	LOAD	Conclusion
180 V	50	32	0.99	0.17	3.89	Fan on Turbo speed	Pass
230 V	50	31.5	0.99	0.14	4.24		Pass
250 V	50	31.3	0.98	0.12	4.57		Pass
280 V	50	31.9	0.98	0.11	6.0		Pass
Ambient temperature: 28°C				Relative Humidity: 60% RH			

Table 14 — Reliability Test

Test Specs.	230 V _{AC} , full load, 59sec.ON and 1sec.OFF for 3600 times.						
Start time 10:00AM	Readings Taken at Different Timing					Specification requirement	Conclusion
End time 7:00PM	10:00AM	12:00AM	3:00PM	5:00PM	7:00PM		
Parameters	Voltages should be (230±5) V						
Input Voltage (AC)	231.6 V	231.9 V	231.4 V	231.6 V	231.5 V		Pass
Transmitter	OK	OK	OK	OK	OK	Transmitters should work properly.	Pass
FanMotor	OK	OK	OK	OK	OK	Fan Motor shouldn't jerk and runs at set speed.	Pass
+5 V _{dc}	4.92 V	4.93 V	4.92 V	4.92 V	4.93 V	Voltages should be (5±0.1) V	Pass

increases, starting from 0.52 at the lowest speed and reaching 0.99 at the Turbo setting. Lower THD values at higher speeds reflect improved power quality and reduced harmonic distortion, contributing to the longevity and reliability of the motor and associated electronics. Table 18 summarises performance comparison data of BLDC motors against brushed DC and AC motor. These parameters are essential for evaluating the efficiency, stability, and overall performance of the equipment, helping engineers

assess its compliance with standards and optimization potential for real-world applications.

6 Future Work

Future research in BLDC motor technology presents several promising directions. Integration with Internet of Things (IoT) systems could enable remote monitoring, automated control, and predictive maintenance, optimizing motor performance across various applications. Advanced cooling techniques,

Table 15 — Low Voltage run Test

Test Specs	(150V±5) V for 4 hrs., Fan at Turbo speed								Specification requirements	Conclusion
Starting time 10.00	Reading are Taken at different timings									
Parameters	10.00	10.30	11.00	11.30	12.00	12.30	13.00	13.30		
Input Voltage	150 V	150 V	150 V	150 V	150 V	150 V	150 V	150 V	Voltage should be (140±5) V	Pass
Transmitter	OK	OK	OK	OK	OK	OK	OK	OK	Transmitter should work Properly.	Pass
FanMotor	OK	OK	OK	OK	OK	OK	OK	OK	Fan motor shouldn't jerk and runs at set Speed.	Pass
+5 V _{dc}	4.92	4.93	4.92	4.93	4.93	4.93	4.92	4.93	Voltage should be (5±0.1) V	Pass

Table 16 — High Voltage Run Test

Test Specs	(280V±5) V for 4hrs. Fan at Turbo speed								Specification requirements	Conclusion
Starting time 14.00	Reading are Taken at different timings									
Parameters	14.00	14.30	15.00	15.30	16.00	16.30	17.00	17.30		
Input Voltage	280 V	280 V	280 V	280 V	280 V	280 V	280 V	280 V	Voltage should be (280±5) V	Pass
Transmitter	OK	OK	OK	OK	OK	OK	OK	OK	Transmitter should work properly.	Pass
FanMotor	OK	OK	OK	OK	OK	OK	OK	OK	Fan motor shouldn't jerk and runs at sets	Pass
+5V _{dc}	4.93	4.92	4.92	4.92	4.93	4.93	4.93	4.92	Voltage should be (5±0.1) V	Pass

Table 17 — BLDC Ceiling Fan test results

Voltage	Speed	RPM	Power (W)	Power factor PF	THD (%)
230 V _{ac}	1	119-120	3.13	0.52	58.51
	2	157-160	5.08	0.71	39.84
	3	198-200	8.04	0.89	24.10
	4	229-230	11.39	0.94	14.23
	5	268-270	17.98	0.97	6.80
	6	308-310	26.71	0.98	5.08
	7(Turbo)	329-330	32.49	0.99	3.87

Table 18 — Performance comparison data of BLDC motors against brushed DC and AC motor

Motor Type	Efficiency (%)	Power Factor	Speed Control	Maintenance	Applications
BLDC Motor	85-95%	High (0.9+)	Excellent	Low (no brushes)	High efficiency fans, EVs
Brushed DC Motor	75-85%	Moderate	Good	High (brush wear)	Low-cost applications
AC Motor	75-90%	Moderate	Moderate	Low	Industrial machinery

such as liquid cooling and improved heat dissipation materials, would enhance the motor's efficiency and durability, particularly in high-power settings. Further advancements in sensorless control could improve accuracy and reliability in high-speed, high-torque applications, reducing system complexity and cost. Incorporating energy harvesting technologies would enable BLDC motors to recover energy during braking or idle periods, further improving overall efficiency. Additionally, research into novel magnetic materials and optimized rotor and stator designs could significantly reduce power losses, increasing motor efficiency under varying load conditions. These

advancements would position BLDC motors as more efficient, cost-effective, and adaptable solutions in a wide range of industries.

6 Conclusion

In this paper, the designing as well as testing of a BLDC motor is demonstrated. Functional verification of the BLDC motor PCB of designed circuit is conducted in accordance with IEC 61000-4-11 standard. The designed BLDC fan motor exhibits excellent performance characteristics across different speed settings, with a high-power factor and low THD at higher speeds. These results demonstrate the motor's potential for real-world

applications, combining efficiency, reliability, and superior power quality. The fan motor adheres to the IEC 61000-4-11 standard, ensuring its suitability for various industrial, commercial, and consumer applications. While they may entail a higher initial cost, the long-term benefits in terms of energy savings and reliability make them a compelling choice for various applications. The future of BLDC motor technology in fan systems is poised for significant growth and innovation. Emerging trends such as the integration of BLDC motors with smart control systems, IoT connectivity, and energy harvesting technologies present opportunities for enhancing performance.

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