ACTION RESEARCH PROJECT (ARP) REPORT

on

Pre-standardization report of Brushless DC (BLDC) Motor

Submitted By:

Ms Neha Agarwal

Scientist 'C'

Electrotechnical Department (ETD)

POLICY, RESEARCH AND TRAINING DEPARTMENT

Our Ref: PRTD/R/5:2/AR-0052 12 Jun 2020

Subject: Action Research Project Proposal.

Ms Neha Agarwal, Sc B, ETD may please refer to her Action Research Project Proposal for ' Pre-standardization report of Brushless DC (BLDC) motor '.

She is informed that her proposal has been approved in-principle by the Assessment Committee. A Unique Project Number 'AR/0052' has been assigned to her above said project, which is required to be quoted in all future correspondences in this regard.

The officer is advised to undertake the Action Research accordingly and submit the report in the prescribed proforma.

(Renu Gupta)
Sc F & H(PRTD)

Copy to **Head ETD** - to kindly ensure that administrative & financial provisions contained in the approved guidelines on Action Research PRTD/AR/G:01/Apr 2020, as uploaded on BIS intranet on 29 Apr 2020, are complied with.

भारतीय मानक ब्यूरो
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Doc. No. : PRTD/AR/PF:04	Issue No. : 1	Issue Date 05-05-2021	DECLARATION OF ORIGINAL WORK

DECLARATION OF ORIGINAL WORK

I, Neha Agarwal, Scientist 'C' , Employee No- 067580 hereby declare that the Action Research Project titled 'Pre-standardization report of Brushless DC (BLDC) Motor' is the original research work done by me. I have not copied from any other Action Research Project or any other work of similar nature and topic done by any person/institution/body either published or yet to be published. Data and information from other sources, used if any, have been with prior permission, wherever required and is duly acknowledged appropriately in the project report submitted by me.

This declaration is made on the 5th of May 2021

Neha Agarwal 5/05/2021

Sign. of Officer with Date

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BACKGROUND

Brushless DC Motors or BLDC Motors have become a significant contributor of the modern drive technology. BLDC motors offer high efficiency and controllability and have a long operating life. They are widely used in devices that run continuously e.g. washing machines, air conditioners, and other consumer electronics; and more recently, they are appearing in fans, where their high efficiency has contributed to a significant reduction in power consumption. In future, BLDC motors may also be replacing simple brushed dc motors in several applications.

A Brushless DC Motor is similar to a Brushed DC Motor but as the name suggests, a BLDC doesn't use brushes for commutation but rather they are electronically commutated. It has a rotor with permanent magnets and a stator with windings. Since there are no brushes in a BLDC Motor, the commutation is controlled electronically. A Position Sensor, which is usually a Hall Sensor (that works on the principle of Hall Effect) is generally used to detect the position of the rotor and transform it into an electrical signal.

Brushless motors have come to dominate many applications, namely hard drives, CD/DVD players, pumps, fans, robotic vacuum cleaners, coffee machines, mixers, hairdryers, bread cutters and spindle drives in adjustable or variable speed applications.

However, no Indian/international standard exist to check the quality and performance parameters of BLDC motors.

This pre-standardization report may be utilised to set the basic minimum quality and performance parameters including efficiency in Indian standard on BLDC motors.

INTRODUCTION

Electric motor is the electro-mechanical machine, which converts the electrical energy into mechanical energy. In other words, the devices, which produce rotational force is known as the motor. The working principle of the electric motor mainly depends on the interaction of magnetic and electric field. The electric motor is mainly classified into two types- AC motor and the DC motor. The AC motor takes alternating current as an input, whereas the DC motor takes direct current.

Brushless DC Motors or BLDC Motors have become a significant contributor of the modern drive technology. China is the largest consumption region of Brushless DC Motors, with a consumption market share nearly 31% in 2017.
Europe is the second largest consumption region of Brushless DC Motors, with consumption market share over 20% in 2017. Asia Pacific (APAC) region seems to have good growth potential in the coming years. This growth can be attributed to the increasing demand in China, Japan and India. The worldwide market for Brushless DC Motor is expected to grow at a CAGR of roughly 6.8% over the next five years, will reach 27.2 billion US$ in 2027, from 17.3 billion US$ in 2020, according to a new GIR (Global Info Research) study. In future, BLDC motors may also be replacing simple brushed dc motors in several applications.

BLDC motors offer high efficiency and controllability and have a long operating life. They are widely used in devices that run continuously e.g. washing machines, air conditioners, and other consumer electronics; and more recently, they are appearing in fans, where their high efficiency has contributed to a significant reduction in power consumption. Brushless motors have come to dominate many applications, namely hard drives, CD/DVD players, pumps, fans, robotic vacuum cleaners, coffee machines, mixers, hairdryers, bread cutters and spindle drives in adjustable or variable speed applications.

As no National/International standards or specification/reports exist to test the quality and performance parameters of BLDC motors, hence this pre standardization report will be utilized to draft Indian Standard on BLDC motors. The Indian Standard will ensure the quality production of BLDC motors and therefore the ensuring enhanced performance of the appliances using BLDC motors. A highly efficient BLDC motor may substantially reduce the energy consumption of appliances and thereby improving the overall efficiency of appliance.

OBJECTIVE

This project is envisaged to study the Brushless DC motor for standardization. As stated earlier also, these motors are more efficient at converting electricity into mechanical power than brushed motors. In addition to high efficiency, they offers high reliability, high quality and precise speed control. Nowadays BLDC motors are being used in various household applications like air-conditioner, ceiling fans, washing machines, mixers etc. No Indian/international standards or specification/reports exist to test the quality and efficiency of BLDC motors.

In view of this, following objectives were identified for this action research project:

1) Studying all possible use cases of BLDC motors in various applications in following aspects:
   a) Preferred rating for each use case
   b) Possibilities of variety reduction
   c) Various specification available in market
   d) Various performance parameters of BLDC motors
   e) efficiency of BLDC motors in different applications
   f) Comparison with AC motors as per IS 996
2) studying different technologies available for position and speed control of BLDC motor
3) determine the tests applicable on BLDC motors
4) exploring the possibility of standardization of sensor less controlled BLDC motors

The methodology followed for fulfilling the objectives are as follows:

1) Literature Survey

2) Consultation with BLDC motor manufactures to collect various data through online meetings

LITERATURE SURVEY

1. Brushless DC Motor Market Size, Share & Trends Analysis

(https://www.grandviewresearch.com/industry-analysis/brushless-dc-motors-market)

Market analysis report as published by 'Grand view research' states the historical data (2016-2019) for BLDC motors market Size, share & trends analysis by power output (Above 75 kW, 0-750 Watts), end-use (motor vehicles, industrial machinery), region, and segment forecasts, 2021 – 2028.

As per the report BLDC motor market size was valued at USD 17.1 billion in 2020 and is expected to grow at a compound annual growth rate (CAGR) of 5.7% from 2021 to 2028. These motors offer optimum efficiency and reliability at the same time, which proves to be economical in the majority of applications, such as window lifters, air conditioners, and sun-roof actuators. In terms of application, the motor vehicle segment dominated the market with a share of 27.6% in 2020. It is also anticipated to emerge as the fastest-growing segment at a CAGR of over 6% from 2021 to 2028.

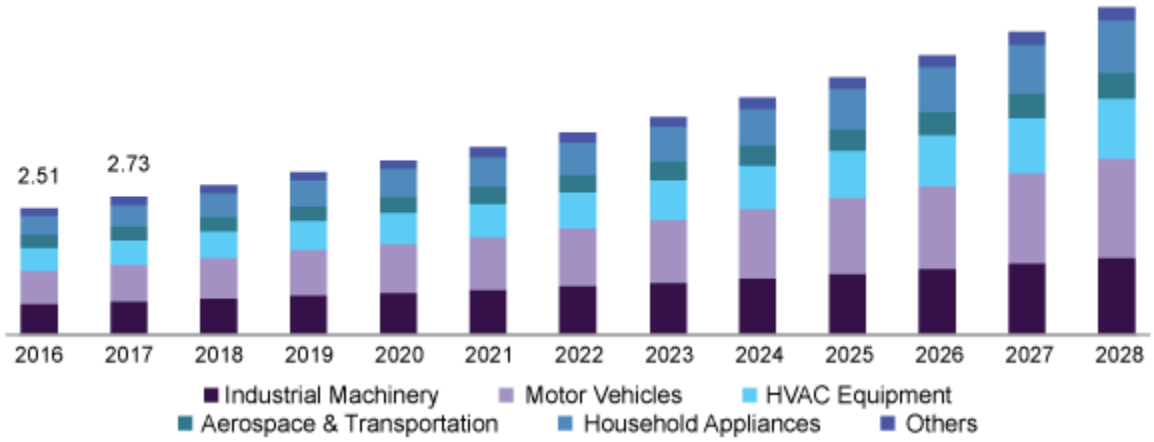


Fig 1: BLDC motor market size, by end use, 2016-2018

In terms of power output, the 0-750 watts segment dominated the market with a share of 47.6% in 2020 with wide usage of these products in numerous applications, such as fans, pumps, compressors, machine tools, domestic appliances, electric cars, HVAC applications, power tools, and automated robots.

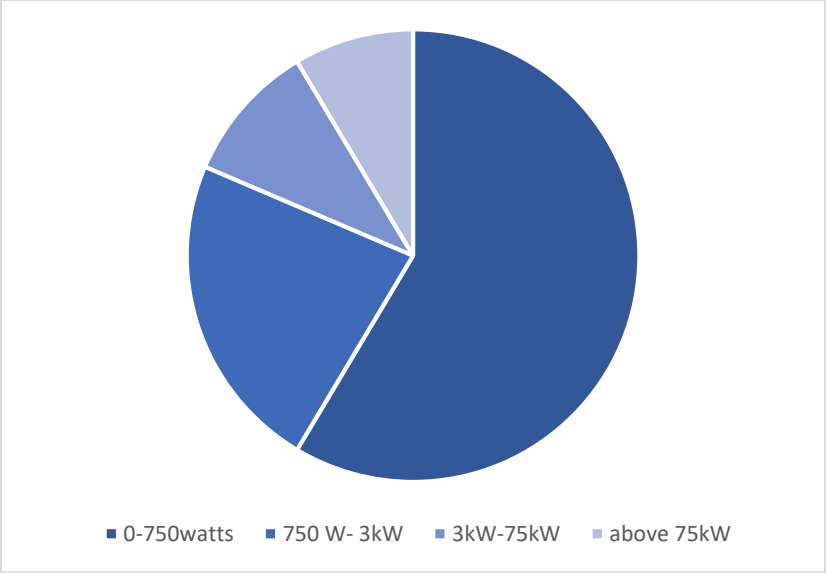


Fig: 2 Global BLDC market share, by power output, 2020

The above 75kW segment is expected to witness substantial growth from 2021 to 2028. This is owing to advantages, such as better performance, in terms of efficiency and reliability over the traditional DC motors with the same power output rating. These BLDC motors are used for a variety of industrial applications, such as milling, drilling, and grinding, deployed in industrial machinery, such as the CNC machines.

2. Introduction to various motor types

IRJPEE-Assessment of BLDC Motor for EV Application Considering Vehicle Design Strategy by Chethan S1 and Abhijith Singh S

Electric motor is the electro-mechanical machine, which converts the electrical energy into mechanical energy. In other words, the devices, which produce rotational force is known as the motor. The working principle of the electric motor mainly depends on the interaction of magnetic and electric field. The electric motor is mainly classified into two types- AC motor and the DC motor. The AC motor takes alternating current as an input, whereas the DC motor takes direct current.

AC Motor

The AC motor converts the alternating current into mechanical power. The main two types are induction motor, synchronous motor.

- **Induction Motor**

The machine, which never runs at synchronous speed, is called the induction or asynchronous motor. This motor uses electromagnetic induction phenomenon for transforming the electric power into mechanical power. According to the construction of rotor, there are two types of an induction motor. Namely squirrel cage induction motor and phase wound induction motor.

- **Synchronous Motor**

The motor, which runs at synchronous speed is known as the synchronous motor. The synchronous speed is the constant speed at which motor generates the electromotive force.

DC Motors

A machine that converts the DC electrical power into mechanical power is known as DC motor. Its work depends on the basic principle that when a current carrying conductor is placed in a magnetic field, then a force exerted on it, and torque develops. DC motors are mainly classified into two types in the way of rotor is powered. They are Brushed DC motors and Brushless DC motors.

Permanent Magnet Synchronous Motor (PMSM)

PMSM motors have some resemblance to BLDC motors, but are made to run by sinusoidal signals by which lower torque ripple is achieved. Due to their permanent magnet rotor, they also have higher torque with smaller frame size and no rotor current, all of which are advantages over AC Induction Motors (ACIMs).

Comparison- Brushless DC Motor vs. Brushed Motor vs. AC Motor

Table 1

Feature	Brushless DC Motor	Brushed DC Motor	AC motor as per IS 996
Commutation	Electronic commutation based on Hall position sensors	Brushed commutation	Induction
Maintenance	Low or no maintenance	Periodic maintenance	Low maintenance
Life	Longer	Shorter	Longer
Speed/Torque	Moderately Flat	Flat	Non-linear
Efficiency	High	Moderate	Moderate
Speed Range	Higher- no mechanical limitation	Lower- mechanical limitation	Low
Electric Noise Generation	Low	High	Low
System Cost	High- because of external controller	Low	Low

3. What is BLDC Motor

AN885 Brushless DC (BLDC) Motor Fundamentals by Padmaraja Yedamale

A Brushless DC Motor is similar to a Brushed DC Motor but as the name suggests, a BLDC doesn't use brushes for commutation but rather they are electronically commutated. It has a rotor with permanent magnets and a stator with windings. Since there are no brushes in a BLDC Motor, the commutation is controlled electronically. A Position Sensor, which is usually a Hall Sensor (that works on

the principle of Hall Effect) is generally used to detect the position of the rotor and transform it into an electrical signal.

Construction

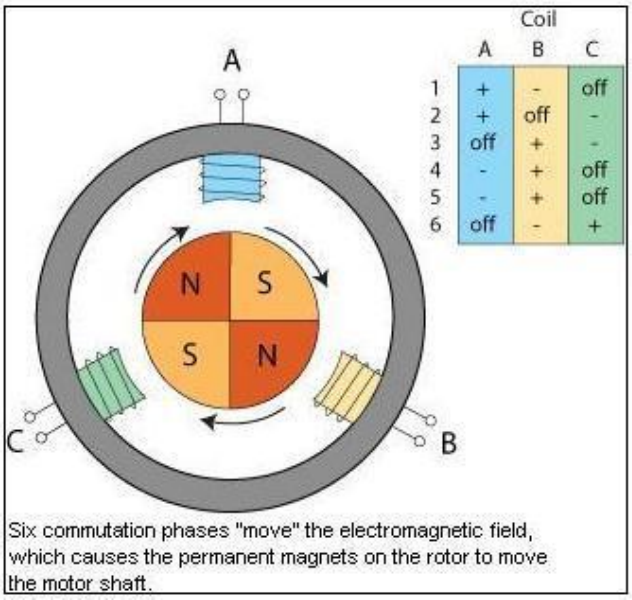
BLDC motors have many similarities to AC induction motors and brushed DC motors in terms of construction and working principles respectively. BLDC motors come in single-phase, 2-phase and 3-phase configurations. Corresponding to its type, the stator has the same number of windings. Out of these, 3-phase motors are the most popular and widely used. Just like any other electric motor, a BLDC motor also consists of two main parts a stator and a rotor.

- Stator

Similar to an Induction AC motor, the BLDC motor stator is made out of laminated steel stacked up to carry the windings. The stator windings can be seen on the outside ring of figure 1.1. Windings in a stator can be arranged in two patterns; i.e. a star pattern (Y) or delta pattern (Δ). The major difference between the two patterns is that the Y pattern gives high torque at low RPM and the Δ pattern gives low torque at low RPM. There are two types of stator windings variants: trapezoidal and sinusoidal motors. Back EMF and phase current has trapezoidal and sinusoidal variations in the respective types of motor

- Rotor

The rotor part of the BLDC Motor is made up of permanent magnets. This is represented by the north and south poles in figure 3. Based on the application, the number of poles can vary between two and eight with North (N) and South (S) poles placed alternately. Increasing the number of poles does give better torque but at the cost of reducing the maximum possible speed. Another rotor parameter that impacts the maximum torque is the material used for the construction of permanent magnet; the higher the flux density of the material, the higher the torque.



Structure of BLDC motor

Fig: 3

- **Position Sensors**

Since there are no brushes in a BLDC Motor, the commutation is controlled electronically. In order to rotate the motor, the windings of the stator must be energized in a sequence and the position of the rotor (i.e. the North and South poles of the rotor) must be known to precisely energize a particular set of stator windings.

A Position Sensor, which is usually a Hall Sensor (that works on the principle of Hall Effect) is generally used to detect the position of the rotor and transform it into an electrical signal. Most BLDC Motors use three Hall Sensors that are embedded into the stator to sense the rotor's position.

The output of the Hall Sensor will be either HIGH or LOW depending on whether the North or South pole of the rotor passes near it. By combining the results from the three sensors, the exact sequence of energizing can be determined.

Principle Operation of Brushless DC (BLDC) Motor

The principles for the working of BLDC motors are the same as for a brushed DC motor, i.e., the internal shaft position feedback. In the case of a brushed DC motor,

feedback is implemented using a mechanical commutator and brushes while in brushless motors, this is performed by sensors.

As per Lorentz force law, 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 the 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.

With the switching of windings as High and Low signals, corresponding winding energized as North and South poles. The permanent magnet rotor with North and South poles align with stator poles causing motor to rotate.

Motor produces torque because of the development of attraction forces (when North-South or South-North alignment) and repulsion forces (when North-North or South-South alignment). By this way motor moves in a clockwise direction.

As mentioned above also, Hall sensors give shaft position feedback to the electronic controller unit. Based on this signal from sensor, the controller decides particular coils to energize. Hall-effect sensors generate Low and High level signals whenever rotor poles pass near to it. These signals determine the position of the shaft.

3. Position and Speed Control of BLDC Motors

ICCSP-Motor Control Design for Position Measurement and Speed Control Rajesh Kannan Megalingam, Shree Rajesh Raagul Vadivel, Bhanu Teja Pula, Sarveswara Reddy Sathi, and Uppala Sai Chaitanya Gupta

*ISSN 1424-8220 Position and Speed Control of Brushless DC Motors Using Sensorless Techniques and Application Trends by José Carlos Gamazo-Real *, Ernesto Vázquez-Sánchez and Jaime Gómez-Gil*

IJERT BLDC Motors – A Survey of Topologies, Control & Applications by Dr. B. Mahesh Kumar and Mr. R. Babu Ashok

IRJET Speed Control of Brushless DC Motor Using Different Intelligence Schemes by Rubi batham, Rameshwar singh

IJERT Position and Speed Control of Brushless DC Motors using Sensorless Techniques: A Review by Ms. Poonam M. Yadav, Prof. Mr. Gadgune S. Y.

The control of BLDC motors can be done in sensor or sensorless mode, but to reduce overall cost of actuating devices, sensorless control techniques are normally used. The advantage of sensorless BLDC motor control is that the sensing part can be omitted, and thus overall costs can be considerably reduced. The disadvantages of sensorless control are higher requirements for control algorithms and more complicated electronics.

Conventional Control Method Using Sensors

some of the most frequently used devices in position and speed applications are Hall-effect sensors, variable reluctance sensors and accelerometers. Controller needs some means of determining the rotor's orientation/position (relative to the stator coils), such as Hall-effect sensors, which are mounted in or near the machine's air gap to detect the magnetic field of the passing rotor magnets.

The process of switching the current to flow through only two phases for every 60 electrical degree rotation of the rotor is called electronic commutation. The motor is supplied from a three-phase inverter, and the switching actions can be simply triggered by the use of signals from position sensors that are mounted at appropriate points around the stator. These Hall switches deliver digital pulses that can be decoded into the desired three-phase switching sequence.

In summary, permanent magnet motor drives require a rotor position sensor to properly perform phase commutation, but there are several drawbacks when such types of position sensors are used. The main drawbacks are the increased cost and size of the motor, and a special arrangement needs to be made for mounting the sensors. Further, Hall sensors are temperature sensitive and hence the operation of the motor is limited, which could reduce the system reliability because of the extra components and wiring.

Sensorless Control

Position sensors can be completely eliminated, thus reducing further cost and size of motor assembly, in those applications in which only variable speed control (*i.e.*, no positioning) is required and system dynamics is not particularly demanding. control methods, such as back-EMF and current sensing provide enough information to estimate with sufficient precision the rotor position and, therefore, to operate the motor with synchronous phase currents. Conventional and recent advancement of back-EMF sensing methods for the PM BLDC motors and generators are split in two categories: direct and indirect back-EMF detection.

4. Typical Applications of BLDC motors

EES-Review Paper- A review on recent applications of brushless DC electric machines and their potential in energy saving by Mehdi Shirania, Abbass Aghajania, Saeed Shabania, Jalil Jamalib

This review paper illustrates several examples of recent applications of brushless DC machines in the oil & gas, transportation, home appliance, HVAC and refrigeration, marine propulsion and energy production areas and the potential of energy saving for these applications.

Many functions basically done by brushed DC motors can be fulfilled by brushless motors but control complexity and cost restricts brushless motors from completely replacing brushed motors.

We can categorize the applications of BLDC motor into three major types on the basis of connected load:

- Constant load
- Varying loads
- Positioning applications

Applications With Constant Loads

These are the types of applications where a variable speed is more important than keeping the accuracy of the speed at a set speed. In addition, the acceleration and deceleration rates are not dynamically changing. In these types of applications, the load is directly coupled to the motor shaft. For example, fans, pumps and blowers come under these types of applications. These applications demand low-cost controllers, mostly operating in open-loop.

Applications With Varying Loads

These are the types of applications where the load on the motor varies over a speed range. These applications may demand a high-speed control accuracy and good dynamic responses. In home appliances, washers, dryers and compressors are good examples. In automotive, fuel pump control, electronic steering control, engine control and electric vehicle control are good examples of these. In aerospace, there are a number of applications, like centrifuges, pumps, robotic arm controls, gyroscope controls and so on.

Positioning Applications

Most of the industrial and automation types of application come under this category. In these applications, the dynamic response of speed and torque are important. Also, these applications may have frequent reversal of rotation direction. Computer Numeric Controlled (CNC) machines are a good example of this. Process controls, machinery controls and conveyer controls have plenty of applications in this category

In summary, major applications catered by BLDC motors can be listed as:

a) Hermetic Compressors for Refrigerators and Air-conditioners
b) Heating Ventilation and Air conditioning Air Moving applications (e.g. Fan Motors for Aircon Indoor and Outdoor Applications)
c) Household ceiling and exhaust fans
d) Hub motors for electric 2 wheelers and electric bikes
e) Elevator door opening motors
f) Health Care and surgical application Motors
g) Vacuum cleaners
h) Washing machine motors
i) Mixer grinders

DATA COLLECTED FROM BLDC MANUFACTURERS

Through meetings and consultation with various relevant stakeholders, real time data was collected regarding efficiency with different applications, various performance parameters and tests applicable, BLDC motors specification available in market.

Efficiency of BLDC motor with different applications:

Table 2

Sl No.	Application	Output	Efficiency %	Remarks
1.	Hermetic Compressor motor for Refrigerators	35-120W	81-90	Estimated
2.	Hermetic Compressor for Aircon	400-1000W	88-92	Estimated
3.	Split Aircon Indoor Unit Fan Motors	30W	70	Estimated
4.	Split Aircon Outdoor Unit Fan Motors	60W	70	Estimated
5.	Frost Free Refrigerator Freezer Fan Motor	1.5-2W	60	Estimated
6.	Household ceiling	20-25W	65-70	Estimated
7.	Condenser cooling Motors in Chest Freezers	10-30W	65-70	Estimated
8.	Aircooler Motors	75W	70-80	Estimated
9.	Vacuum Cleaners	350W	75-80	Estimated

10.	Washing Machine Motors Top Load	120W	75	Estimated
11.	Washing Machine Front load	200-400W	75-80	Estimated
12.	Mixer Grinders	500W	70	Estimated
13.	exhaust fans	20W-180W		Estimated

Various Specification Available in Market

Table 3

Rated Power/W	1200W	1500W	1800W	2200W
Rated Voltage	48/60/72 V DC	48/60/72 V DC	60/72 V DC	60/72 V DC
Unload current/A	<6.0/5.4/4.5 A	<6.0/5.4/4.5 A	<6.0/5.5A	<6.5/6.0 A
No load speed/rpm	3500	4100	4500	4800
Rated torque/N.m	4.0	5.2	6.0	7.2
Rated speed/rpm	2850	3000	3200	3550
Rated current/A	<32.0/25.0/21.0	<39.0/31.5/26.0	<37.5/31.5	<46.0/38.0
Efficiency	>82%	>82%	>83%	>84%

Various Performance Parameters of BLDC Motors

a) Maximum torque delivery capacity
b) Torque Density (Torque delivery per unit motor volume)
c) Peak current drawn by the motor with the risk of demagnetization of permanent magnets.
d) Torque Constant (torque delivered per unit current drawn)
e) Back EMF constant (Voltage produced per 1000 rotor revolutions)
f) Efficiency of the motor

Various Tests Applicable on BLDC Motor

a) Voltage/current
b) Input/output power
c) Efficiency at rated and fractional loads
d) Power factor
e) Back EMF Measurement
f) Speed Torque characteristics
g) Temperature rise test
h) Demagnetization of test
i) Noise
j) Vibration
k) Harmonic measurement
l) Environment Condition tests
m) Phase sequence determination
n) Hall sensor error positioning; accuracy

SUMMARY

In conclusion, BLDC motors have advantages over brushed DC motors and induction motors. They have better speed versus torque characteristics, high dynamic response, high efficiency, long operating life, noiseless operation, higher speed ranges, rugged construction and so on. Also, torque delivered to the motor size is higher, making it useful in applications where space and weight are critical factors. With these advantages, BLDC motors find wide spread applications in automotive, appliance, aerospace, consumer, medical, instrumentation and automation industries. The Indian standard will ensure the quality production of BLDC motors and therefore the ensuring enhanced performance of the appliances using BLDC motors. A highly efficient BLDC motor may substantially reduce the energy consumption of appliances and thereby improving the overall efficiency of appliance.

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