Brushless DC electric motor

Brushless DC motors (**BLDC motors**, **BL motors**) also known as **electronically commutated motors** (ECMs, EC motors) are synchronous motors which are powered by a DC electric source via an integrated inverter, which produces an AC electric signal to drive the motor; additional sensors and electronics control the inverter output.

The motor part of a brushless DC motor is often permanent magnet synchronous motor, but can also be a switched reluctance motor, or induction motor.

BLDC motors may be described as stepper motors, however, the term *stepper motor* tends to be used for motors that are designed specifically to be operated in a mode where they are frequently stopped with the rotor in a defined angular position; this page describes more general BLDC motor principles, though there is overlap.

Two key performance parameters of brushless DC motors are the Motor constants Kv and Km.

Motor from a 3.5" floppy disk drive. The coils are copper wire coated with green film insulation. The rotor (upper right) has been removed and turned upside-down. The grey ring just inside its cup is a permanent magnet.

Brushless versus brushed motor

Brushed DC motors have been in commercial use since 1886.[1][2] BLDC motors, however, have only been commercially possible since 1962.[3][4]

BLDC motors develop maximum torque when stationary and have linearly decreasing torque with increasing speed.[5] Limitations of brushed DC motors overcome by BLDC motors include lower efficiency and 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.

A typical BLDC motor has permanent magnets which rotate and a fixed armature, eliminating the problems of connecting current to the moving armature. An electronic controller replaces the brush/commutator assembly of the brushed DC motor, which continually switches the phase to the windings to keep the motor turning. The controller performs similar timed power distribution by using a solid-state circuit rather than the brush/commutator system.

BLDC motors offer several advantages over brushed DC motors, including more torque per weight, more torque per watt (increased efficiency), increased reliability, reduced noise, longer lifetime (no brush and commutator erosion), elimination of ionizing sparks from the commutator, and overall reduction of electromagnetic interference (EMI). With no windings on the rotor, they are not subjected to centrifugal forces, and because the windings are supported by the housing, they can be cooled by conduction, requiring no airflow inside the motor for cooling. This in turn means that the motor's internals can be entirely enclosed and protected from dirt or other foreign matter.

BLDC motor commutation can be implemented in firmware or VHDL. This provides several capabilities not available with brushed DC motors including speed limiting, "micro stepped" operation for slow and/or fine motion control and a holding torque when stationary.

The maximum power that can be applied to a BLDC motor is limited almost exclusively by heat, which can weaken the magnets, or damage insulation. A BLDC motor's main disadvantage is higher cost, which arises from two issues. First, BLDC motors require complex electronic speed controllers (ESCs) to run. Brushed DC motors can be regulated by a comparatively simple controller, such as a rheostat (variable resistor). However, this reduces efficiency because power is wasted in the rheostat. Second, some practical uses have not been well developed in the commercial sector. For example, in the radio control (RC) hobby arena, brushless motors are often hand-wound while brushed motors are usually machine-wound. (Nevertheless, see *Applications*, below.)

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. The enhanced efficiency is greatest in the no-load and low-load region of the motor's performance curve.[citation needed] Under high mechanical loads, BLDC motors and high-quality brushed motors are comparable in efficiency. [citation needed]

Environments and requirements in which manufacturers use brushless-type DC motors include maintenance-free operation, high speeds, and operation where sparking is hazardous (i.e. explosive environments), or could affect electronically sensitive equipment.

Controller implementations

Because the controller must direct the rotor rotation, the controller requires some means of determining the rotor's orientation/position (relative to the stator coils.) Some designs use Hall effect sensors or a rotary encoder to directly measure the rotor's position. Others measure the back EMF in the undriven coils to infer the rotor position, eliminating the need for separate Hall effect sensors, and therefore are often called *sensorless* controllers.

A typical controller contains 3 bi-directional outputs (i.e. frequency controlled three phase output), which are controlled by a logic circuit. Simple controllers employ comparators to determine when the output phase should be advanced, while more advanced controllers employ a microcontroller to manage acceleration, control speed and fine-tune efficiency.

Controllers that sense rotor position based on back-EMF have extra challenges in initiating motion because no back-EMF is produced when the rotor is stationary. This is usually accomplished by beginning rotation from an arbitrary phase, and then skipping to the correct phase if it is found to be wrong. This can cause the motor to run briefly backwards, adding even more complexity to the startup sequence. Other sensorless controllers are capable of measuring winding saturation caused by the position of the magnets to infer the rotor position.

Variations in construction

BLDC motors can be constructed in several different physical configurations: In the 'conventional' (also known as *inrunner*) configuration, the permanent magnets are part of the rotor. Three stator windings surround the rotor. In the *outrunner* (or external-rotor) configuration, the radial-relationship between the coils and magnets is reversed; the stator coils form the center (core) of the motor, while the permanent magnets spin within an overhanging rotor which surrounds the core. The flat or axial flux type, used where there are space or shape limitations, uses stator and rotor plates, mounted face to face. Outrunners typically have more poles, set up in triplets to maintain the
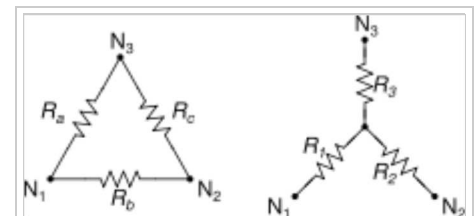
Schematic for delta and wye winding styles. (This image does not illustrate the motor's inductive and generator-like properties)

three groups of windings, and have a higher torque at low RPMs. In all BLDC motors, the coils are stationary.

There are two common electrical winding configurations; the delta configuration connects three windings to each other (series circuits) in a triangle-like circuit, and power is applied at each of the connections. The wye (*Y*-shaped) configuration, sometimes called a star winding, connects all of the windings to a central point (parallel circuits) and power is applied to the remaining end of each winding.

A motor with windings in delta configuration gives low torque at low speed, but can give higher top speed. Wye configuration gives high torque at low speed, but not as high top speed.[6]

Although efficiency is greatly affected by the motor's construction, the wye winding is normally more efficient. In delta-connected windings, half voltage is applied across the windings adjacent to the undriven lead (compared to the winding directly between the driven leads), increasing resistive losses. In addition, windings can allow high-frequency parasitic electrical currents to circulate entirely within the motor. A wye-connected winding does not contain a closed loop in which parasitic currents can flow, preventing such losses.

From a controller standpoint, the two styles of windings are treated exactly the same, although some less expensive controllers are designed to read voltage from the common center of the wye winding.

Motor control power supplies

Typical BLDC motors are permanent magnet synchronous AC motors, combined with sensor electronics (detecting rotor position) and a AC signal generator (Inverter) driven by a DC supply. Typical BLDC inverters use a switched power supply pulse width modulation to generate an AC drive signal. Various terms are used to refer to the inverters/electronic control systems, including "Vector Drives", and "VVVF drives" (variable voltage variable frequency).

Applications

BLDC motors fulfill many functions originally performed by brushed DC motors, but cost and control complexity prevents BLDC motors from replacing brushed motors completely in the lowest-cost areas. Nevertheless, BLDC motors have come to dominate many applications, particularly devices such as computer hard drives and CD/DVD players. Small cooling fans in electronic equipment are powered exclusively by BLDC motors. They can be found in cordless power tools where the increased efficiency of the motor leads to longer periods of use before the battery needs to be charged. Low speed, low power BLDC motors are used in direct-drive turntables for gramophone records.

The four poles on the stator of a two-phase BLDC motor. This is part of a computer cooling fan; the rotor has been removed.

Transport

High power BLDC motors are found in electric vehicles and hybrid vehicles. These motors are essentially AC synchronous motors with permanent magnet rotors.

The Segway Scooter and Vectrix Maxi-Scooter use BLDC technology.

A number of electric bicycles use BLDC motors that are sometimes built into the wheel hub itself, with the stator fixed solidly to the axle and the magnets attached to and rotating with the wheel.[7]

Heating and ventilation

There is a trend in the HVAC and refrigeration industries to use BLDC motors instead of various types of AC motors. The most significant reason to switch to a BLDC motor is the dramatic reduction in power required to operate them versus a typical AC motor.[8] While shaded-pole and permanent split capacitor motors once dominated as the fan motor of choice, many fans are now run using a BLDC motor. Some fans use BLDC motors also in order to increase overall system efficiency.[9]

In addition to the BLDC motor's higher efficiency, certain HVAC systems (especially those featuring variable-speed and/or load modulation) use BLDC motors because the built-in microprocessor allows for programmability, better control over airflow, and serial communication.

Industrial Engineering

The application of brushless DC (BLDC) motors within industrial engineering primarily focuses on manufacturing engineering or industrial automation design. In manufacturing, BLDC motors are primarily used for motion control, positioning or actuation systems.

BLDC motors are ideally suited for manufacturing applications because of their high power density, good speed-torque characteristics, high efficiency and wide speed ranges and low maintenance.

Motion control systems

BLDC motors are commonly used as pump, fan and spindle drives in adjustable or variable speed applications. They can develop high torque with good speed response. In addition, they can be easily automated for remote control. Due to their construction, they have good thermal characteristics and high energy efficiency.[10] To obtain a variable speed response, BLDC motors operate in an electromechanical system that includes an electronic motor controller and a rotor position feedback sensor.[11]

Positioning and actuation systems

BLDC motors are used in industrial positioning and actuation applications.[12] For assembly robots,[13] brushless stepper or servo motors are used to position a part for assembly or a tool for a manufacturing process, such as welding or painting. BLDC motors can also be used to drive linear actuators.[14]

Model engineering

BLDC motors are a popular motor choice for model aircraft including helicopters. Their favorable power-to-weight ratios and large range of available sizes, from under 5 gram to large motors rated at thousands of watts, have revolutionized the market for electric-powered model flight, displacing virtually all brushed electric motors. They have also encouraged a growth of simple, lightweight electric model aircraft, rather than the previous internal combustion engines powering larger and heavier models. The large power-to-weight ratio of modern batteries and

brushless motors allows models to ascend vertically, rather than climb gradually. The low noise and lack of mess compared to small glow fuel internal combustion engines that are used is another reason for their popularity.

Legal restrictions for the use of combustion engine driven model aircraft in some countries have also supported the shift to high-power electric systems.

A microprocessor-controlled BLDC motor powering a micro remote-controlled airplane. This external rotor motor weighs 5 grams, consumes approximately 11 watts and produces thrust of more than twice the weight of the plane.

Their popularity has also risen in the radio controlled car, buggy, and truck scene; brushless motors have been legal in North American RC car racing in accordance to ROAR since 2006.