Design Considerations when Implementing Motor Control Technology

Benefits and design challenges of implementing stepper, BLDC, and Brushed motor control technologies in the 5 W – 100 W power range as well as how to transition from brushed to brushless technology.
Electric Motor Type Classification

**Electric Motors**

- **AC Motor**
  - Asynchronous
    - Polyphase
      - Squirrel cage
      - Wound Rotor
        - Squirrel cage
    - Single Phase
      - Permanent Split Cap
      - Split Phase
      - Cap Start
      - Shaded Pole
      - Variable reluctance

- **DC Motor**
  - Synchronous
    - Stepper
    - BLDC
    - Brush DC
    - Reluctance
      - Sine Wave
      - Variable Reluctance
      - Commutator
      - Homopolar
      - SYNC Reluctance
      - PM
      - Wound Field
      - PM
      - Switched Reluctance
      - Shunt
      - Compound
      - Series

Public Information
## Motor Comparison

### Stepper Motor

#### Key Features:
- **Reliability:** OK
- **Power Density:** Bad
- **Efficiency:** Ghastly
- **Precision:** Very Good
- **Cost Motor:** Low
- **Cost Electronics:** OK

### DC Motor

#### Key Features:
- **Reliability:** Low
- **Power Density:** Good
- **Efficiency:** OK
- **Precision:** OK
- **Cost Motor:** Cheap
- **Cost Electronics:** Cheap

### BLDC Motor

#### Key Features:
- **Reliability:** Excellent
- **Power Density:** Excellent
- **Efficiency:** Good
- **Precision:** Depends
- **Cost Motor:** High
- **Cost Electronics:** High

### Table Comparison:

<table>
<thead>
<tr>
<th></th>
<th>Stepper Motors</th>
<th>Brush DC Motors</th>
<th>BLDC Motors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reliability</strong></td>
<td>OK</td>
<td>Low</td>
<td>Excellent</td>
</tr>
<tr>
<td><strong>Power Density</strong></td>
<td>Bad</td>
<td>Good</td>
<td>Excellent</td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td>Ghastly</td>
<td>OK</td>
<td>Good</td>
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<td><strong>Precision</strong></td>
<td>Very Good</td>
<td>OK</td>
<td>Depends</td>
</tr>
<tr>
<td><strong>Cost Motor</strong></td>
<td>Low</td>
<td>Cheap</td>
<td>High</td>
</tr>
<tr>
<td><strong>Cost Electronics</strong></td>
<td>OK</td>
<td>Cheap</td>
<td>High</td>
</tr>
</tbody>
</table>
MOTORS in a nutshell...

- Almost 99% guarantee it was a Motor Failure due to Control issues

1. All of the Controls are driven by Motor or Inductive Actuator of sorts
2. Steering
3. Braking
4. Accelerator
5. Shifting
Motor Types

- Universal Motor
- Permanent Magnet Brush DC Motor
- Switched Reluctance Motor
- Stepper Motor
- Brushless DC with Commutated Control
- AC Induction Motor with Scalar/Slip Control
- AC Induction Motor with Field Oriented Control
- Permanent Magnet Synchronous Motor with Field Oriented Control
Motor Markets & Applications

Home
- Refrigerator Compressors
- Washers/Dryers
- Exercise Equipment
- Small Appliances / Hand tools
- Computers / Office Equipment

HVAC
- Air Conditioning Compressors
- Pumps / Fans / Blowers
- Building Automation / Regenerative Systems

Industrial
- Conveyor Systems
- Industrial Drives
- Industrial Servo/ CNC / Robotic Assembly / Pick and Place

Transportation
- Automotive Body
- Electric Power Steering
- Automotive PowerTrain
- Hybrid-Electric Vehicles
- Personal Transport

Medical
- Medical Pumps
- CPAP
- Medical Scanners
PMDC-to-BLDC Pros

• **No Mechanical Brushes** - Lower Maintenance, Lower Radiated EMI, Higher Reliability, Improved Compatibility with Bi-Directional Applications

• **Torque Ripple** - BLDC offers more control over torque ripple via which algorithms are implemented.

• **Acoustic Noise** - BLDC has the ability to rotate in a virtual silence, depending on the motor-winding pattern, sensing, and modulation scheme.

• **Speed Control** - PMDC motor speed control (assuming no encoder) is typically done by measuring the BEMF of the motor winding. To significantly improve the accuracy of the estimated speed, IR (current-resistance) compensation is implemented to make up for errors due to winding losses. The total accuracy of the speed control in this case is functional, but poor. BLDC motors with Hall sensors can very accurately use this information to know precise speed. BLDC motors without Hall sensors can accurately measure speed based on the feedback signals (current or voltage) used by their sensorless algorithms.

• **Position Control** - Without an encoder, PMDC controls have no way to understand the position of the shaft w.r.t. the rotor nor w.r.t. any application reference. BLDC motors with Hall sensor can use the Halls for additional position control purposes. BLDC motors without Hall sensors can sometimes use current or voltage feedback signals to accurately provide position information, depending on the algorithm implemented.
PMDC-to-BLDC Pros (Part 2)

- **Torque Control** - BLDC and PMDC have very similar speed-torque curve shapes and similar torque-producing capabilities. As current increases, BLDC has the advantage of improved lifetime. Torque is proportional to current.

- **Speed Range** - BLDC can operate at very high speeds without sacrificing reliability. Although there are some high-speed PMDC motors, they are usually implemented due to decreased cost; and not because they are more reliable. To operate BLDC at high commutation rates requires some faster processing and careful algorithm selection.

- **Because PMDC motors have fixed commutator ring transitions**, their magnetics and commutation cannot be optimized for various applications. BLDC motors are often dynamically tuned in the electronic control to operate at higher efficiencies, and to use the motor materials more effectively thereby reducing motor material cost. Today, there are very few applications where PMDC motors are the better choice over BLDC.

- **Environmental Compatibility** - PMDC motors are considered unacceptable and dangerous for applications where open sparks (from the brushes) can cause explosion or contamination issues. BLDC motors have no electrical sparking or similar molecular breakdown of materials while rotating. BLDC motors can even be designed to operate submersed in liquid
PMDC-to-BLDC Cons

• **BLDC and its cousins (PMSM, BLAC, PMAC) all require electronic controls to successfully rotate the motor** - Technically, PMDC motors can spin simply by being connected to a DC power source with zero control electronics. For PMDC motors to spin as a predictable speed or torque, electronics are required.

• **Uni-directional PMDC** applications are often implemented in their power bridge with a single low-side transistor. Uni-directional BLDC controls always require 6 transistors. Be aware that the increase in BLDC control cost is often completely offset by the improved system cost of the motor and other materials. i.e. heat sink.

• **Bi-directional PMDC applications** are often implemented in their power bridge with 4 transistors (H-Bridge). Bi-directional BLDC controls still require the same 6 transistors. Be aware that the increase in BLDC control cost is often completely offset by the improved system cost of the motor and other materials. i.e. heat sink.
BLDC Motor Drive Generic Block Diagram

(a) H-bridge

(b) Three-phase bridge

<table>
<thead>
<tr>
<th></th>
<th>PMDC:</th>
<th>3-phase:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quiet:</td>
<td>Moderate</td>
<td>Excellent</td>
</tr>
<tr>
<td>Efficiency:</td>
<td>Good</td>
<td>Excellent</td>
</tr>
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</table>
## Motor Type Comparison

<table>
<thead>
<tr>
<th>Feature</th>
<th>BLDC Motor:</th>
<th>Brushed Motor:</th>
<th>BLDC Advantages:</th>
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</thead>
<tbody>
<tr>
<td>Commutation</td>
<td>Electronic commutation based on rotor position information</td>
<td>Mechanical Brushes and commutator</td>
<td>Transistors replace mechanical brushes</td>
</tr>
<tr>
<td>Efficiency</td>
<td>High</td>
<td>Moderate</td>
<td>Transistors based drives operate very efficiently</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Little/none</td>
<td>Periodic</td>
<td>No brushes/commutator maintenance</td>
</tr>
<tr>
<td>Thermal Performance</td>
<td>Better</td>
<td>Poor</td>
<td>Only the armature windings generate heat, which is the stator and is connected to the outside case of the BLDC. The case dissipates heat better than the rotor located inside of the brushed DC motor.</td>
</tr>
<tr>
<td>Power Density: Output Power / Frame Size (Ratio)</td>
<td>High</td>
<td>Moderate/Low</td>
<td>Modern permanent magnet and no rotor losses.</td>
</tr>
<tr>
<td>Speed /Torque Characteristics</td>
<td>Flat</td>
<td>Flat</td>
<td>No brush friction to reduce useful torque.</td>
</tr>
<tr>
<td>Dynamic Response</td>
<td>Fast</td>
<td>Slow</td>
<td>Lower rotor inertia because of permanent magnets.</td>
</tr>
<tr>
<td>Speed Range</td>
<td>High</td>
<td>Low</td>
<td>No mechanical limitation imposed by brushes or commutator.</td>
</tr>
<tr>
<td>Electric Noise</td>
<td>Low</td>
<td>High</td>
<td>No arcs from brushes to generate noise, causing EMI issues.</td>
</tr>
<tr>
<td>Lifetime</td>
<td>Long</td>
<td>Moderate</td>
<td>No brushes and commutator</td>
</tr>
</tbody>
</table>
BLDC Three-phase Commutation Sequence w/ Hall Effect

Hall (a, b, c) Input decoded to a lookup table for FET Control and Commutation Sequencing (Trapezoid) every 60° electrical, 30° mechanical rotation.

Hall Sensor: 120° Phase Shift
Trapezoidal vs. Sinusoidal Commutation

Trapezoidal references a lookup table for each Hall Sensor Change (rotor angle), or every 60° (electrical cycle).

Sinusoidal generates (algorithm) a continuous, higher resolution, series of steps.

**Sinusoidal:**

1. **Finer (smoother) resolution commutation**
   - a) improves torque ripple.
   - b) reduces acoustic noise

2. More complicated control.

U is High Side, X is Low Side for U Stator Winding
V is High Side, Y is Low Side for V Stator Winding
W is High Side, Z is Low Side for W Stator Winding
Industrial Motor – ON offers a Complete BOM Coverage

- High efficiency FS4 650V & UFS 1200 IGBTs
- High precision Current Sense Amps
- Gel-filled & Transfer Molded Modules

2014
- FS3 IGBT
- IPM
- LV/MV FET
- LDO
- Op-Amp
- Rectifier
- Small Signal

2016
- UFS 1200V IGBT
- Vincotech PIM Packages
- High Perf. Analog
- GaN
- HV Gate Driver

2017
- FS4 650V IGBT
- IFX PIM Packages
- SuperFET up to 800V
- Opto-Coupler
- Opto Gate Driver (4A)
- SiC

Performance LDOs
- High efficiency SuperFET III 650V FETS
- Smart Opto-coupler / Gate Drivers
- EMI Filter
- Input Bridge Rectification
- Power Factor Correction
- Isolated Gate Driver
- Regulator
- No Solution
- MCU
- Inverter
- Motor
- Aux Power Supply
- Current Sense
3-Phase Motor Drive

Processor

- PWM
- Isense

Dual MOSFET Gate Driver NCP81080
- Isense

NCS210R
- 1mΩ

Control

Hall a

Hall b

Hall c

LS

HS

3 Phase BLDC Motor

Hall b

Hall a

Hall c

U

V

W
Motors – Controllers and Drivers
What Motor to use?
# MOTOR Technical Specifications (Boilerplate)

## Specifications for Motor Controller/Driver

<table>
<thead>
<tr>
<th>Customer Name/Region</th>
<th>General Application</th>
<th>Motor Type-BLDC/Brushed/Stepper/AC</th>
<th>COMMENTS</th>
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</thead>
<tbody>
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### Definitions

<table>
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<tr>
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<th>Tech-Specs</th>
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<tbody>
<tr>
<td>1 Rated Capacity</td>
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<tr>
<td>2 Input Voltage</td>
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<tr>
<td>3 Rated Current (MIN/MAX)</td>
<td>A</td>
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</tr>
<tr>
<td>4 Starting Current</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>5 Overcurrent Limit</td>
<td>A</td>
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<tr>
<td>6 Speed Range</td>
<td>RPM</td>
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<tr>
<td>7 MAX Speed @ MAX Voltage</td>
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<tr>
<td>8 Rated Torque</td>
<td>Kt</td>
<td></td>
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<tr>
<td>9 Rated Voltage</td>
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<tr>
<td>10 Overvoltage Limit</td>
<td>V</td>
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<td>11 Motor Feedback</td>
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<td>12 Commutation</td>
<td>Trajectory Shape</td>
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<td>13 Mode of Operation</td>
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<tr>
<td>14 Features</td>
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<tr>
<td>15 Input Signal</td>
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<td>16 Display Functions</td>
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<td>17 Operating Temp/Humidity</td>
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<tr>
<td>18 Vibration Levels</td>
<td>Hz - AdB/Octave Level</td>
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<td>19 Airborne noise</td>
<td>dbA</td>
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<td>20 Approx Size</td>
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<td>21 Cooling for Driver/Inverter</td>
<td>Air/Water/Forced</td>
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<td>22 Miscell</td>
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<tr>
<td>23 Motor Poles</td>
<td>Number</td>
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<tr>
<td>24 Load Information</td>
<td>Gearhead/Linear/Rotational</td>
<td></td>
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<tr>
<td>25 Operating Frequency of Driver/Inv</td>
<td>Hz</td>
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</tr>
</tbody>
</table>

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Public Information
MOTOR SIZING DESIGN CONSIDERATIONS

Certain design parameters should be considered while selecting a motor. Depending on the application, different combinations of parameters will determine which motor(s) are suitable. Below is a checklist of parameters to consider while selecting a motor. Not all parameters will be constraints but particular care should be given to identifying constraints and conveniences.

✓ **Power Source**
  - AC (120V, 220V...), - DC (batteries, etc)

✓ **Torque Requirements (Power)**
  - Constant Torque (Torque depends on RPM’s. Many manufacturers list motors by power (hp) rather than torque for a given RPM)
  - Variable Torque
  - Stall torque characteristics

✓ **RPM Requirements**
  - Built in gear reduction (AC or DC gear motors)
  - External gear reduction (Will a gear reduction be incorporated after the motor output in the design or will the motor need to supply a certain RPM)

✓ **Controls**
  *How will the motor be controlled? To what extent will control be an issue? This really needs to be addressed before a motor is selected.*

✓ **Positioning during Rotation**
  - Precision
  - Braking
  - Reversibility (rotation in both directions?)

✓ **Operating Environment**
  - Temperature
  - Chemical

✓ **Physical size / Mounting position**
  - length
  - diameter
Helpful Generalizations

✓ If speed control is needed remember DC are much easier. (AC motors require frequency control instead of voltage control.)

✓ Is it single phase or 3 phase? You really don't have a choice...ask the customer which is appropriate.

✓ DC induction motors will stall at higher RPM's where industrial will maintain torque through until stall torque is reached (think of a cordless drill.) Look at the manufacturer’s torque curves.

✓ Careful with gear motors... is the torque given by the manufacturer the actual output torque after gear reductions?

✓ If precision stopping control is needed consider which is more appropriate:
  - Stepper Motors
  - Servo Motors

* Servo motors actually have to sense position of the motor and control accordingly. Stepper motors may be open loop because they move to specified angles (i.e. in 3 degree increments) but there is no way to sense if it actually stopped at the desired position. Overloading a stepper motor may cause it to not arrive at the desired position and there would be no way to sense that.
Description of Brush DC Motors:
In order for any DC motor to operate, the current to the motor coils must be continually switched relative to the field magnets. In a brush type unit, this is accomplished with carbon brushes contacting a slotted commutator cylinder which has each motor coil connected to a corresponding bar of the commutator. The switching continues as the motor rotates. With this arrangement, there are physical limitations to speed and life because of brush wear. Speed depends on amount of voltage applied.

Typical Use of Brush DC Motors:
• Variable speed applications (like all DC motors)
• Applications with simple controls

Advantage Over Brushless DC Motors:
• Cheaper (generally)
• Stand alone: requires no sensing (driver)
• Requires no controller
• Speed control is easier (via changing voltage only)
Brushless DC Motor

Description and Comparison to Brush Motors:
The main difference between Brushless and Brush concepts is the means of commutating the motor coils. In a BLDC motor, the position of the rotor is sensed and continually fed back to the commutation electronics to provide for appropriate switching.

Advantages of Brushless DC Motors:
Since there are no carbon brushes to wear out, a BLDC motor can provide significantly greater life being now only limited by bearing wear. BLDC motors also offer additional advantages as by-products of the inherent construction:

1. Higher efficiencies
2. High torque to inertia ratios
3. Greater speed capabilities
4. Lower audible noise
5. Better thermal efficiencies
6. Lower EMI characteristics

As compared to Brush DC Motors

In a BLDC system, the coil windings are typically stationary, while the field magnets are part of the inner rotating member. This allows the heat generated in the windings to be transferred directly to the motor housing and any adjacent heat sinks, thus providing cooler operation. The temperature rise per watt (TPR) is typically less than a brush type motor of comparable size. Since the field magnets are on the inner rotor, the inertia is less than brush type motors, thus providing faster acceleration rates for the BLDC unit. Brushless DC motors can operate in a wide variety of environmental conditions while still providing the linear speed torque characteristics found in brush motors.

Public Information
AC Motors

General AC Motor Description:
An AC motor has two basic electrical parts: a "stator" and a "rotor" as shown in Figure 6. The stator is in the stationary electrical component. It consists of a group of individual electro-magnets arranged in such a way that they form a hollow cylinder, with one pole of each magnet facing toward the center of the group. The rotor also consists of a group of electro-magnets arranged around a cylinder, with the poles facing toward the stator poles. We progressively change the polarity of the stator poles in such a way that their combined magnetic field rotates, then the rotor will follow and rotate with the magnetic field of the stator.

Single Phase AC
Single phase AC motors utilize single phase AC electricity.

Uses:
Residential or areas where only single phase wiring is available. Good performance up to 1.0 hp; can use 110V up to nearly 5 hp. Also, some are available for 220V single phase.

Three Phase AC
Three phase AC motors utilize three phase AC electricity (that must be wired in the outlet)

Uses:
Industrial or areas with appropriate wiring.

Advantages:
• Uses 1/3 the amount of current (increased efficiency)
• More easily reversed
• Huge power capabilities
Universal Motors

✓ General Description:

Universal or series motors are those having brushes, a wound rotor, and a wound stator. They are compatible with both AC and DC power. They are also distinguished by their noisiness. These motors produce so much noise because the brushes rub on the slotted armature.

✓ Uses:

Manufacturers use universal motors because they are smaller and much lighter than induction motors. An example of this type is that found in a portable drill or a Dremel tool.

Basically the DC motor characteristics that can be run on AC.

✓ Comparison to Induction Motors:

A 3/4 Hp induction motor...runs at 1075 - 3450 RPM, is about 6" long x 6" diameter and weighs about 19 pounds. If we compare this with a universal motor with 3/4 horsepower output, we see a speed increase of about 15,000 RPM, a size reduction to about 6" long x 3" diameter (1/4 of the volume) and a weight reduction of greater than 85%.

✓ Advantage

The weight difference is huge: Universal motors are much lighter than induction motors

Torque goes clear down to stall torque (DC motors will stall at a high RPM)

Lower cost

Variable speeds

✓ Disadvantage:

Non reversible (one direction)

Noisy
Linear Motors

Linear Motor Technology
The same electromagnetic force that produces torque in a rotary motor also produces direct force in a linear motor. For example, a permanent magnet DC linear motor is similar to a permanent magnet DC rotary motor and an AC induction linear motor is similar to a squirrel cage induction motor.

Take a rotary motor, split it radially along its axis of rotation and flatten it out. The result is a flat linear motor that produces direct linear force instead of torque. Linear motors utilize the same controls as rotary motors. And similar to a rotary motor with rotary encoders, linear motor positioning is provided by a linear encoder. A variation of the linear motor is the tubular linear motor. This design rolls up the motor about an axis parallel to its length. This results in a “non-commutated” motor.

Features of Linear Motors
• High accelerations – up to 10 g’s [98 m/s]
• Small, compact – fits into smaller spaces
• No backlash from gears or slippage from belts – provides smooth operation
• Reliability – non-contact operation reduces component wear and reduces maintenance
• Linear motor output is measured in Lbs. [N] of force or thrust.
• Linear motors provide force to 2000 Lbs. [8900N], and speeds to 200 in/sec [5 m/s] depending upon encoder resolution.
• Higher speeds are possible with special controls
• Unlimited strokes from 0.01 in [0.000254m]
• Submicron positioning when coupled with an appropriate feedback element and bearing system.
• Designs are available with either a moving coil or moving magnets.

Uses for Linear Motors:
• Linear applications (lower precision)
Stepper Motors

**HOW STEPPER MOTORS WORK**

Stepper motors behave differently than standard DC motors. First of all, they cannot run freely by themselves. Stepper motors do as their name suggests – they "step" a little bit at a time.

Steppers don’t simply respond to a clock signal, they have several windings which need to be energized in the correct sequence before the motor’s shaft will rotate. Reversing the order of the sequence will cause the motor to rotate the other way.

If the control signals are not sent in the correct order, the motor will not turn properly. It may simply buzz and not move, or it may actually turn, but in a rough or jerky manner. A circuit which is responsible for converting step and direction signals into winding energization patterns is called a *translator*. Most stepper motor control systems include a *driver* in addition to the translator, to handle the current drawn by the motor’s windings.

**Use of Stepper Motors:**

applications where the motor may be starting and stopping, while the force acting against the motor remains present

**Features of Stepper Motors:**

• They produce the highest torque at low speeds
• Holding torque (not present in DC motors)

**Comparison to Servo Motors:**

Servos usually implement a small DC motor, a feedback mechanism (usually a potentiometer with attached to the shaft by gearing or other means), and a control circuit which compares the position of the motor with the desired position, and moves the motor accordingly. This can get fairly complex and expensive compared to other DC motors. Stepper motors need no position feedback.
In a simple, single-coil brush DC motor, a split ring fixed to the rotor and in contact with brushes acts as a sliding switch to reverse the polarity of the current in the winding. The process is called commutation.

Examples of brush DC motors of various types and frame sizes. The largest motor shown here has a diameter of three inches.
In a BLDC motor, the magnets (blue and green) are on the rotor and the windings (copper) are on the stator. This improves heat transfer, thereby enabling higher performance than brush motors of equivalent size. The motor shown in this diagram uses Hall-effect sensors to determine rotor position.

In a three-phase BLDC motor, the stator has three separate coils that are displaced from one another by 120 electrical degrees.
Driving Motors (BLDC) Made Simple

**System MCU (optional)**

**Controller/Pre-driver**

**Gate Driver**

**Command Center**

“Motor Controller”

Pre-driver converts MCU commands into motor drive waveforms (commutation)

Most intelligent part of motor drive system

“Gate Driver”

is *Optional*, depending on Power Switches Gate Drive capability

“Power Stage”

Most important part of the Motor Drive System.

Usually consists of *IGBT’s* or *MOSFET’s*, depending on power level
Power Switches for Motor Drive Apps are MOSFET and IGBT

What's best for your application?

The two main choices for power-switching elements for motor drives are the & ON Semi has very wide MOSFET and IGBT Portfolio

Challenge – Is to create and select best suited Power Devices and Feedback for a given Motor Driver application

To keep in mind -

• IGBTs and HV MOSFETs are similar in many ways but differ from a performance and application perspective
• A one size fits all approach does not work
• The best device is the one that best meets the application needs in terms of size, efficiency and Amps/$ capability..!
### MOSFETs – Any Size, Any Package

<table>
<thead>
<tr>
<th>$2B$</th>
<th>TO-3P</th>
<th>TO-247</th>
<th>TO-220</th>
<th>D2PAK</th>
<th>DPAK</th>
<th>SO-8</th>
<th>TO-LL</th>
<th>8x8</th>
<th>SO8 DFN</th>
<th>SO8 LFPAK</th>
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<td>150V</td>
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<td>250V</td>
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<tr>
<td>$1B$ TAM</td>
<td>600V</td>
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<td>900V</td>
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<td>1.5kV</td>
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<td>1.7kV</td>
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Public Information
IGBTs – Now a Premier IGBT Supplier

<table>
<thead>
<tr>
<th>Voltage (V)</th>
<th>TO-3P</th>
<th>TO-247</th>
<th>TO-247 4L</th>
<th>TO-220</th>
<th>TO-220 FullPak</th>
<th>D2PAK</th>
<th>DPAK</th>
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<tbody>
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<td>600V</td>
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<td>ON</td>
<td>ON</td>
<td>ON</td>
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<tr>
<td>650V</td>
<td>ON</td>
<td>ON</td>
<td>ON</td>
<td>ON</td>
<td></td>
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</tr>
<tr>
<td>1200V</td>
<td>ON</td>
<td>ON</td>
<td>ON</td>
<td>ON</td>
<td>Fairchild FullPak</td>
<td>ON</td>
<td></td>
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<td>1350V</td>
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<td>ON</td>
<td>ON</td>
<td>ON</td>
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<td>1500V</td>
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<td>1600V</td>
<td>ON</td>
<td>ON</td>
<td>ON</td>
<td>ON</td>
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<td></td>
</tr>
</tbody>
</table>

**650V**
- 650V FS4 exceeding IFX H5 Performance

**1200V**
- 1200V UFS exceeding IFX H3 Performance

Public Information
ON Semi MOSFETS – 20 V – 1500 V in Application with Optimized Process

- Low Voltage Family optimized for $Q_{gd} \times R_{ds(on)}$  
- Separate family optimized for pure $R_{ds(on)}$ performance  
- 600 V – 700 V Super Junction MOSFET for Motor Driver + SMPS

ON Semi IGBTs – 300 V – 1500 V Discrete Devices

- Class-leading turn-off loss  
- High-speed, short-circuit rated, and low  
- $V_{ce(on)}$ optimized using thin wafers  
- Multiple package options and bare die option available
Discrete and Integrated Power Products

Broad Line of Packages and Devices

Current ratings from 0.8A to 30A rms
Voltage ratings from 600V to 1500V
Junction temperature to 175 °C

WBG – SiC, Fast Recovery & GaN

SiC Schottky barrier diodes for very high switching speeds
3A to 30A, 600V – 1200 V GaN parts available
SBD optimized for high switching speeds
BLDC H-Bridge Gate Driver Portfolio

VM (V):

- 600V
- 180V
- 24V

Gate (Source/Sink) Drive (A):

- 250mA
- 1A
- 2A
- 3A
- 4A

VM (max):

- 600V
- 180V
- 24V

* FAN7388/ * FAN73894
50ns (250mA) / 30ns (500mA)

* FAN7384
50ns (350mA) / 30ns (500mA)

* FAN7888
50ns (250mA) / 30ns (650mA)

* NCP81080
19ns (500mA) / 17ns (800mA)

* FAN3268
12ns (1.6A) / 9ns (2.4A)

* FAN73933
40ns (2.5A) / 20ns (2.5A)

* FAN7390
25ns (4.5A) / 20ns (4.5A)

* NCP81075
8ns (4A) / 7ns (4A)

* FAN73933
40ns (2.5A) / 20ns (2.5A)

* FAN3268
12ns (1.6A) / 9ns (2.4A)

* FAN7390
25ns (4.5A) / 20ns (4.5A)

* NCP81075
8ns (4A) / 7ns (4A)
When to Use Summary: **Conditions Based**

**IGBT Preferred..!**
- ✓ Low Switching Frequency (<20kHz)
- ✓ High Power levels (above say 3 kW)
- ✓ High \( \frac{dv}{dt} \) needed to be handled by the diode
- ✓ Med full load Efficiency is needed

**MOSFET Preferred..!**
- ✓ High Switching Frequency (>50kHz)
- ✓ Lower Power levels (below 3 kW)
- ✓ High \( \frac{dv}{dt} \) needed to be handled by the diode
- ✓ High full load Efficiency is needed
When to Use Summary: **Applications Based**

**IGBT Preferred..!**
- ✓ Motor Drives (>250W)
- ✓ UPS and Welding H Bridge inverters
- ✓ High power PFCs for Motors (>3kW)
- ✓ High Power Solar/Wind Generators/Inverters (>5kW)

**MOSFET Preferred..!**
- ✓ Motor Drives (<250W)
- ✓ Universal input AC-DC Flyback SMPS for Motors Drives and forward converter power supplies
- ✓ Low to Mid power Motor PFCs (75W to 3 kW)
- ✓ Solar/Wind Generators Micro inverters
## The Motor PFC Stage: IGBT or SJ-MOSFET

### Application Conditions

<table>
<thead>
<tr>
<th>Application Conditions</th>
<th>Device Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical Power Range is 1 kW to 4 kW</td>
<td>High average currents, large die/package devices</td>
</tr>
<tr>
<td>Typical Switching Frequency: 25 kHz to 150 kHz</td>
<td>At lower levels IGBTs, at higher levels MOSFETs preferred</td>
</tr>
<tr>
<td>Typically Devices are Hard switched</td>
<td>Fast switching capabilities essential</td>
</tr>
<tr>
<td>Typically lower inductor current ripple</td>
<td>Less stressful for the device</td>
</tr>
</tbody>
</table>

### CCM (Continuous Conduction Mode) Topologies

- Relatively smaller die/package devices could be considered
- Typical Switching Frequency range is wide (50 kHz to 300 kHz)
- Typically Devices are Soft switched at turn on and hard switched turn off
- Typically higher inductor current ripple M

### CRM (Critical Conduction Mode) Topologies

- Low Rdson is as important as gate charge
- More stressful for the device

---

*Some Key Application Conditions and Device Requirements*
### The Motor Driver Stage: IGBT or FET

#### Some Key Application Conditions and Device Requirements

<table>
<thead>
<tr>
<th>Power Level</th>
<th>75 W to 200W</th>
<th>500 W to 5 kW</th>
<th>200 W to 500 W</th>
<th>Few kHz to say 25 kHz</th>
<th>Above say 25 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fast Body Diode FET preferred</td>
<td>IGBT is preferred</td>
<td>Could be either, based on cost, target efficiency, etc.</td>
<td>IGBT is generally preferred</td>
<td>Also depends on power level, but a Fast body diode FET may be preferred</td>
</tr>
</tbody>
</table>
## The Inverter Stage: IGBT or FET

### Some Key Application Conditions and Device Requirements

<table>
<thead>
<tr>
<th>Application Conditions/Requirements</th>
<th>IGBT (with FRD) or HV FET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diode Recovery Loss Important</td>
<td>IGBT (with fast recovery diode co-packaged) preferred</td>
</tr>
<tr>
<td>High Light load efficiency requirement</td>
<td>Fast Body Diode FET preferred</td>
</tr>
<tr>
<td>Lowest device cost</td>
<td>IGBT (with FRD) typically preferred</td>
</tr>
</tbody>
</table>
Gate Drive Requirements and Considerations

**Total Gate Charge (Qg)**
Generally higher for HV MOSFETs (larger die compared to IGBT, for same current rating)

**Turn on gate resistors**
Generally higher values used for IGBT (lower input capacitance compared to HV MOSFETs)

**Gate Drive Voltage**
Higher (15 V) preferred for IGBT, 10 V is ok for HV MOSFETs

**Negative Gate Drive Voltage**
Generally not needed for HV MOSFETs, sometimes used for older process IGBTs
## 3-PH BLDC Gate Driver/FET Guidance, 1st Order Approximation

### 1st Order Approximation Considerations:
1. 85°C Max Ambient Temp.
2. Matching Gate Drive Strength to FET Input Capacitance.
3. FET Power Dissipation = 50°C below max operating die temp
4. FET Voltage = 2-3x Motor Voltage.

<table>
<thead>
<tr>
<th>Motor HP</th>
<th>Power:</th>
<th>DC Rail (VM):</th>
<th>Gate Driver:</th>
<th>N-Channel Family:</th>
<th>N-FET Examples:</th>
<th>RdsonMax @ VGS =10V</th>
<th>N-FET Package:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/8</td>
<td>93W</td>
<td>12V</td>
<td>FAN7888 (1x)</td>
<td>Trench 6</td>
<td>NTTFS5C466NL (40V)</td>
<td>7.3mΩ</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>NCP81080 (3x)</td>
<td></td>
<td>NTTFS5C673NL (60V)</td>
<td>9.3mΩ</td>
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<tr>
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<td></td>
<td></td>
<td>MV7</td>
<td>6.5mΩ</td>
<td>3.3 x 3.3mm</td>
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<tr>
<td>1/4</td>
<td>186W</td>
<td>12V</td>
<td>FAN73933 (3x)</td>
<td>Trench 6</td>
<td>NTTFS5C573NL (60V)</td>
<td>6.5mΩ</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>MV7</td>
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<tr>
<td>1/2</td>
<td>372W</td>
<td>24V</td>
<td>FAN73933 (3x)</td>
<td>Trench 6</td>
<td>NTMFS5C646NL (60V)</td>
<td>4.7mΩ</td>
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<td></td>
<td>Trench 8</td>
<td>NTMFS6H824N (80V)</td>
<td>4.5mΩ</td>
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<tr>
<td>3/4</td>
<td>559W</td>
<td>24V</td>
<td>FAN73933 (3x)</td>
<td>Trench 6</td>
<td>NTMFS5C628NL (60V)</td>
<td>2.4mΩ</td>
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<td>Trench 8</td>
<td>NTMFS6H801N (80V)</td>
<td>2.8mΩ</td>
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<td>1</td>
<td>745W</td>
<td>24V</td>
<td>NCP81075 (3x)</td>
<td>Trench 6</td>
<td>NTMFS5C604NL (60V)</td>
<td>1.2mΩ</td>
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<td>NCP7390 (3x)</td>
<td>Trench 6</td>
<td>NTMFS6H800N (80V)</td>
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<td>931W</td>
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<td>Trench 8</td>
<td>NTMFS5C604NL (60V)</td>
<td>1.2mΩ</td>
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<tr>
<td>1 1/2</td>
<td>1,117W</td>
<td>24V</td>
<td>NCP81075 (3x)</td>
<td>Trench 6</td>
<td>NCP81075 (3x)</td>
<td>1.35mΩ</td>
<td>8x8mm Dual Cool w/ Heat Sink</td>
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<td>FDMT80080DC (80V)</td>
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Public Information
Choosing Between *Brush* and *Brushless* DC Motors

**Brush DC Motor Trade-Offs**

**BRUSH DC MOTOR PROS**

1. Simple
2. Rugged
3. Low Cost
4. Do not require complex/expensive Control for Commutation
5. Can work directly from DC Supply via Resistor or Potentiometer to control speed
6. Can have simple control added to create Servo Based Motor for greater accuracy at reduced cost
7. Great Motor for Moderate to Low Speed Applications

**BRUSH MOTOR CONS**

1. Due to Mechanical Commutator – Weight and size of Motor is increased
2. Presence of Brushes for commutation will generate Arcing, greatly increasing EMI/EMC and not being able to work in environment where flammable substance present
3. Increased Friction from Brushes present problems at Start up for Low-Torque/High Precision applications
4. Contact and Friction will increase Brush wear, require maintained/replacement over time, increasing cost of ownership
5. Speed of Brush DC can only be controlled down to 15%
6. With Brush Replacement may require Commutator to be resurfaced
7. Life time of Brush DC motor is around 4000 hours MAX, very low
Choosing Between Brush and Brushless DC Motors

**BLDC Motor Trade-Offs**

**BLDC MOTOR PROS**
1. Greater Torque Density than Brush
2. Can Operate at much higher Speeds than Brush
3. Speed/Torque curve is much flatter than that of Brush
4. Speed Control is easier and can control speed within 5%
5. Paired with Good Controller speed can be controlled down to 1%
6. Removing Brushes decreases Friction and increase Efficiency as well as reducing EMI/EMC due to removing Arcing of brushes.
7. Removing brushes increases Motor Service life to up to 20,000 hours
8. Smaller Motor for higher Torque than same size Brush DC Motor

**BLDC MOTOR CONS**
1. BLDC Motors more complex that Brush with more windings therefore more expensive
2. BLDC needs some type of Commutation Controller in order to Operate
3. Need for Controller also has need to Power and Cables between Motor and Driver, adding cost and decreasing MTBF with more points of failure
4. If Commutation Controls are integrated into Motor then heat/vibration can facilitate failures as well, decreasing MTBF
5. With onboard electronics, usually Hall-Effect sensors, BLDC Motors need extra care when used in Industrial environment
6. BLDC Motor Cost is higher that of Brush but the price point is getting close with advance for Technology
The Choice is clear (Well..., not really...), it lies in our APPS

The bottom lines for making a choice between components of any type are the type of application and the cost cutoff for the end product.

For instance, a toy robot targeting the six- to eight-year-old market may require four to nine motors.

They can all be brush or brushless dc components or a mixture of both.

If this robot only performs basic movements or is part of an introductory kit, there’s no need to go with long-life BLDCs that cost more than brushed counterparts. The toy or kit will probably end up in the recycling bin well before the brush motors have burned out.

Typical brushed dc motor applications include motorized toys, appliances, and computer peripherals. Auto makers enlist them for power windows, seats, and other in-cabin designs because of their low cost and simple design.

BLDC motors are more versatile, mainly because of their savvy in the speed and torque departments. They also come in compact packages, making them viable for a variety of compact designs. Typical apps include computer hard drives, mechanical-based media players, electronic-component cooling fans, cordless power tools, HVAC and refrigeration, industrial and manufacturing systems, and direct-drive turntables.
Thank you very much for your attention!

Questions & Answers?