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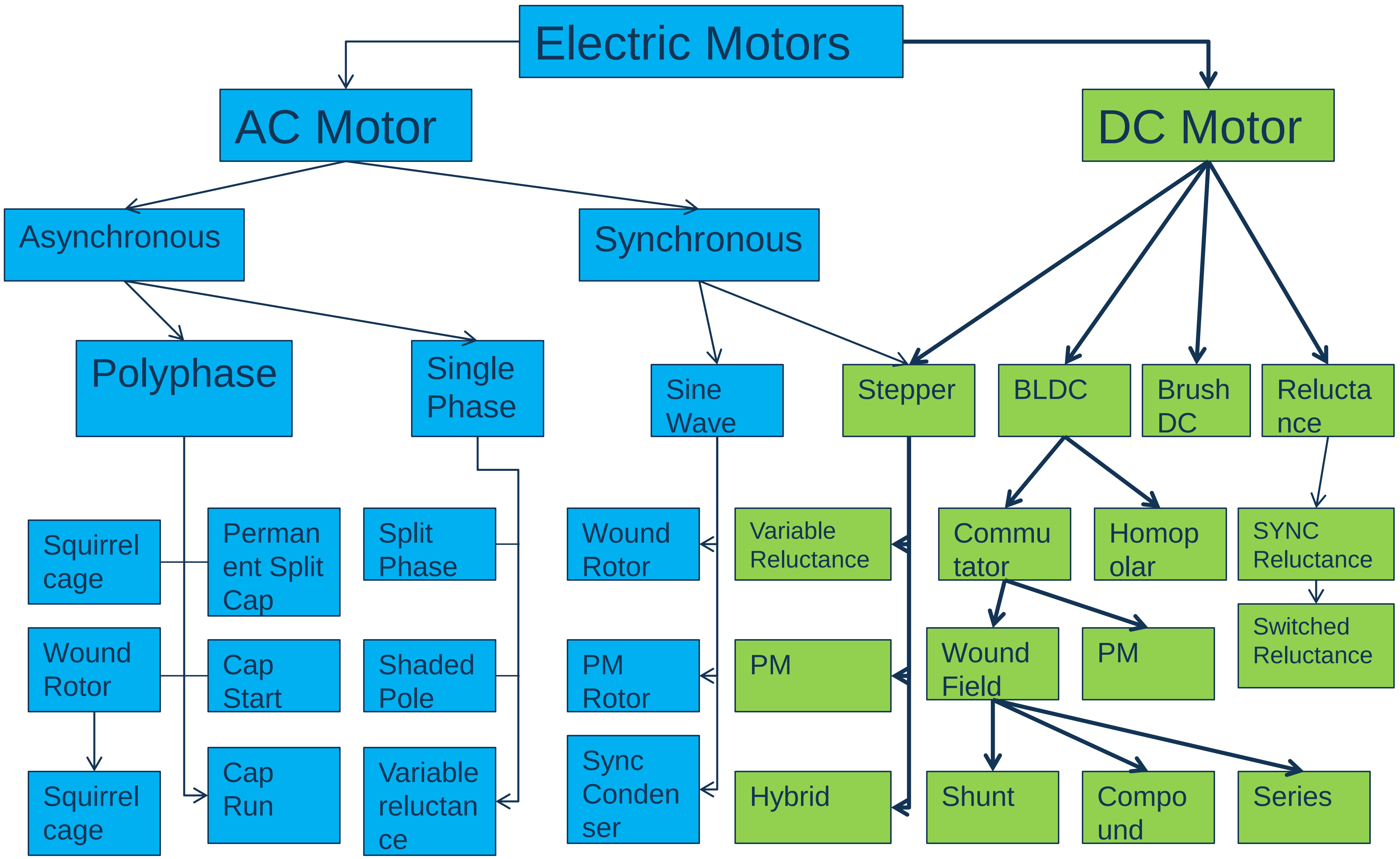
Design Considerations when Implementing Motor Control Technology

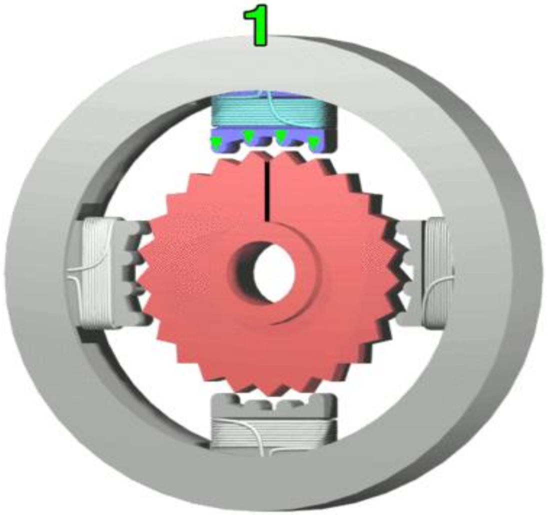
Benefits and design challenges of implementing stepper, BLDC, and Brushed motor control technologies in the 5 W – 100 W power range as well as how to transition from brushed to brushless technology

Electric Motor Type Classification

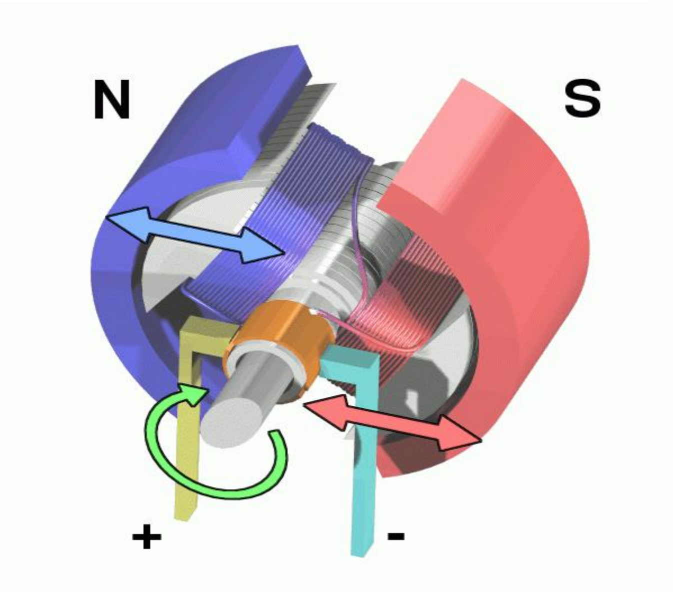


Motor Comparison

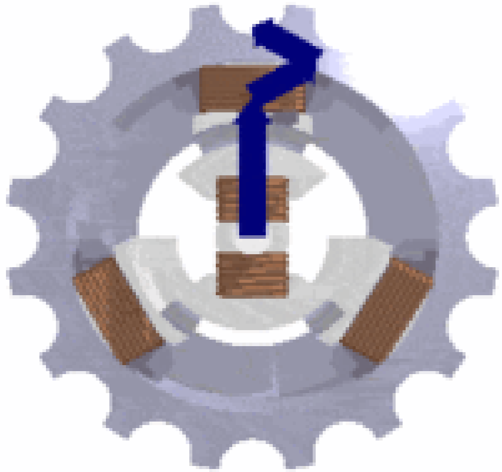
Stepper Motor



DC Motor



EC Motor



	Stepper Motors	Brush DC Motors	BLDC Motors
Reliability	OK	Low	Excellent
Power Density	Bad	Good	Excellent
Efficiency	Ghastly	OK	Good
Precision	Very Good	OK	Depends
Cost Motor	Low	Cheap	High
Cost Electronics	OK	Cheap	High

Power Solutions Group

Power Solutions Group

Denotes Power Products

Protection & Signal Division

- ESD Protection
- LED Protection
- Small Signal Devices
- eFuse
- Smart Passive Sensors

Integrated Circuit Division

- Linear Regulators
- Op-Amps
- Standard Logic
- Analog Switches
- Opto
- EEPROM

High Power Division

- Intelligent Power Module
- HV Rectifiers
- IGBTs
- PIMs
- Gate Drivers

Power MOSFET Division

- LV, MV, HV MOSFETs
- Automotive MOSFETs
- Automotive Power Modules
- Wide Bandgap

MOTORS in a nutshell…

❖ ***<u>Almost 99% guarantee it was a Motor Failure due to Control issues</u>***

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

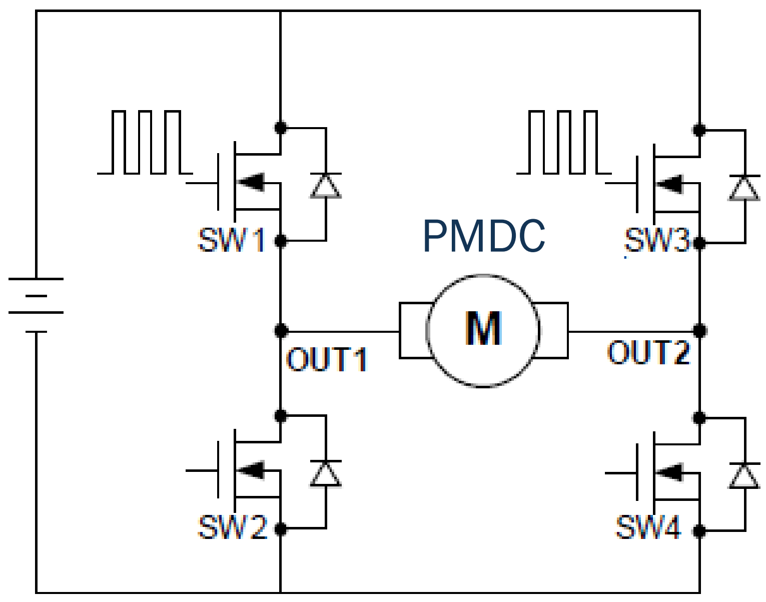
PMDC-to-BLDC Cons

- **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.

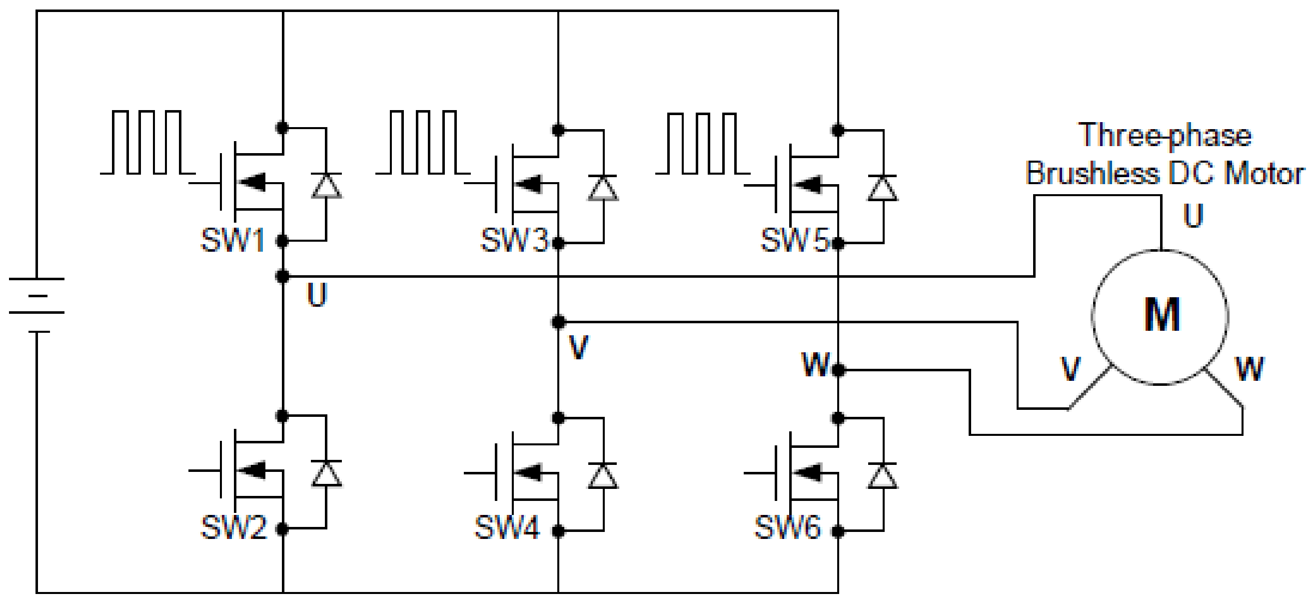
- **Uni-directional PMDC** applications are often implemented in their power bridge with a single low-side transistor. Uni-directional BLDC controls always require *6 transistors*. Be aware that the increase in BLDC control cost is often completely offset by the improved system cost of the motor and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



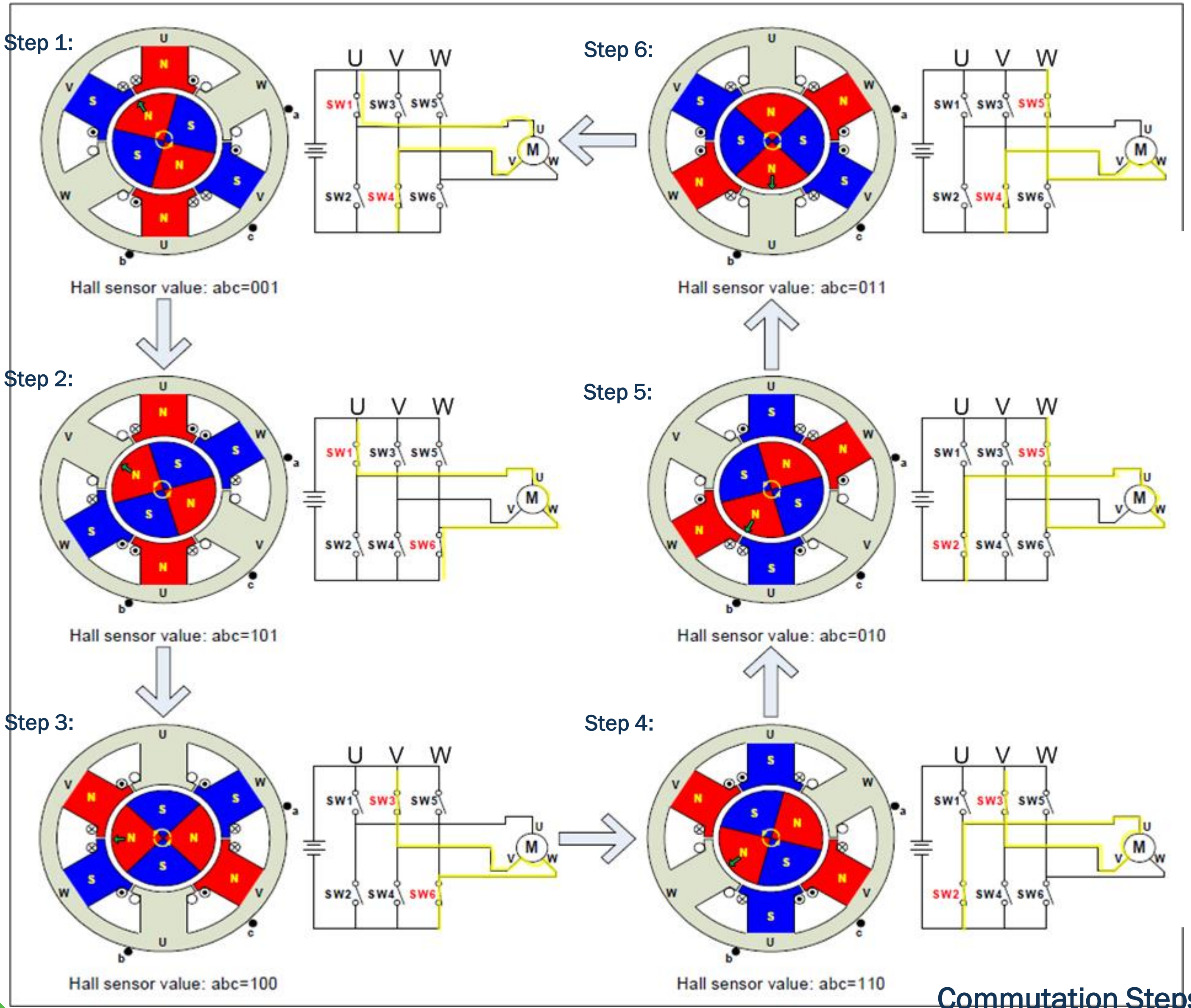
(b) Three-phase bridge

	PMDC:	3-phase:
Quiet:	Moderate	Excellent
Efficiency:	Good	Excellent

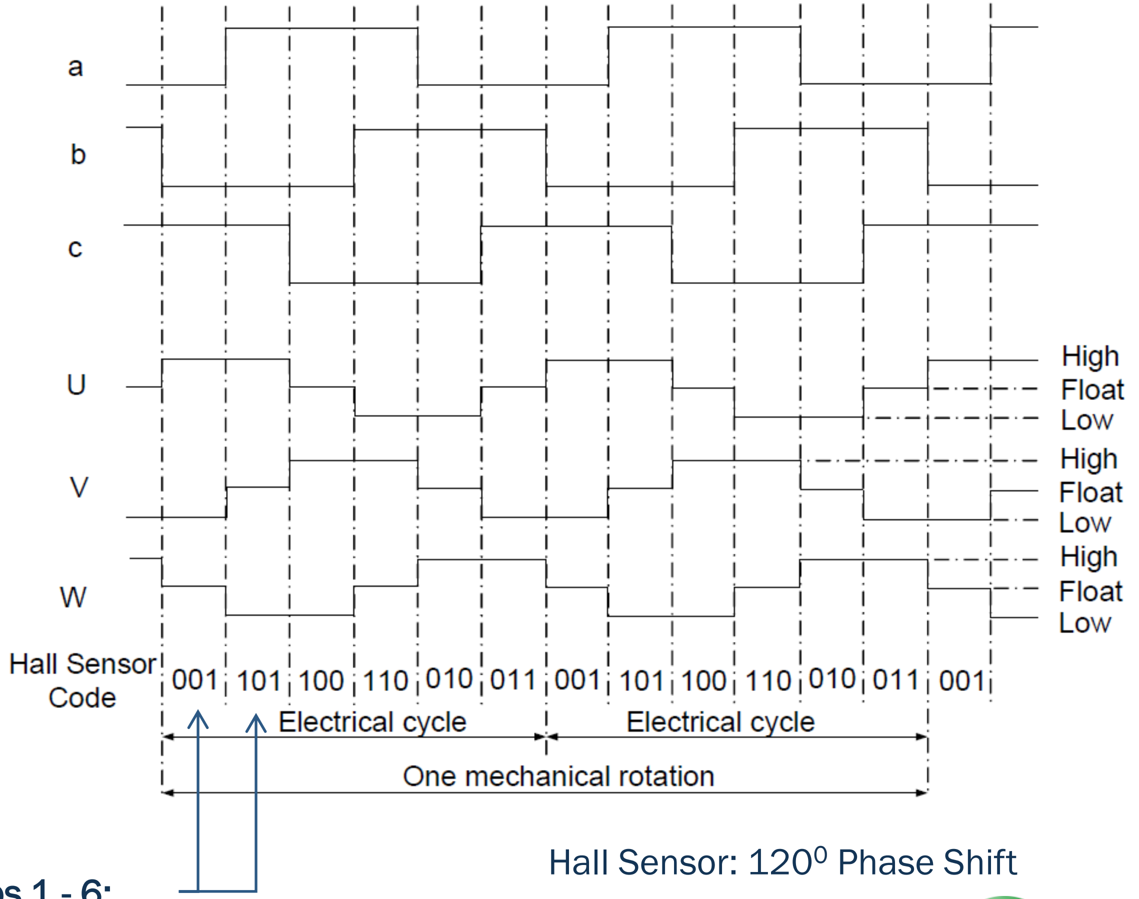
Motor Type Comparison

Feature:	BLDC Motor:	Brushed Motor:	BLDC Advantages:
Commutation	Electronic commutation based on rotor position information	Mechanical Brushes and commutator	Transistors replace mechanical brushes
Efficiency	High	Moderate	Transistors based drives operate very efficintly
Maintenance	Little/none	Periodic	No brushes/commutator maintenance
Thermal Performance	Better	Poor	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.
Power Density: Output Power / Frame Size (Ratio)	High	Moderate/Low	Modern permanent magnet and no rotor losses.
Speed /Torque Characteristics	Flat	Flat	No brush friction to reduce useful torque.
Dynamic Response	Fast	Slow	Lower rotor inertia because of permanent magnets.
Speed Range	High	Low	No mechanical limitation imposed by brushes or commutator.
Electric Noise	Low	High	No arcs from brushes to generate noise, causing EMI issues.
Lifetime	Long	Moderate	No brushes and commutator

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 60^0 electrical, 30^0 mechanical rotation.



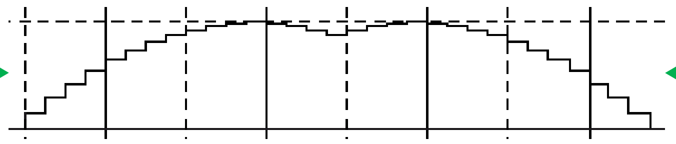
Commutation Steps 1 - 6:

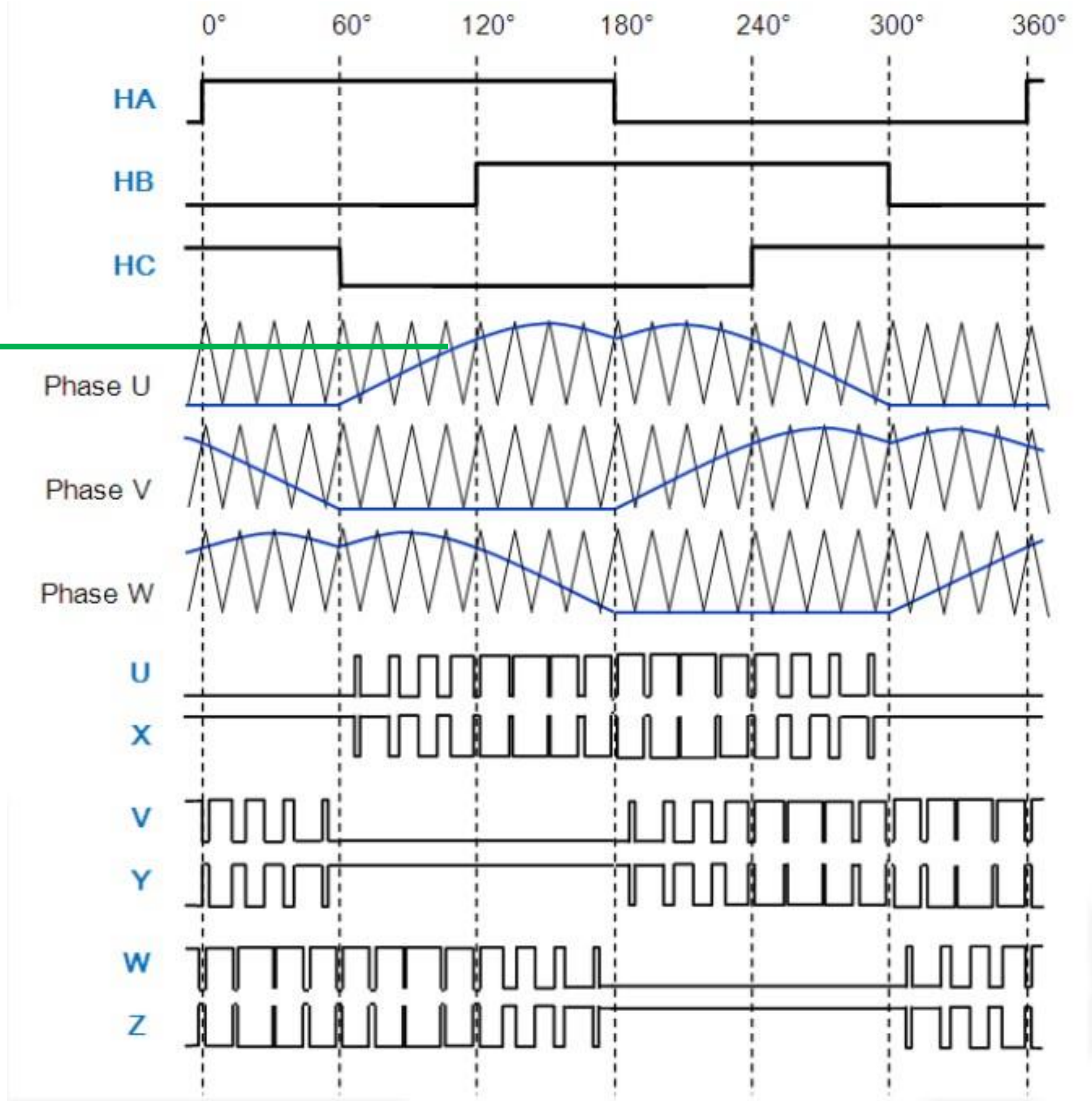
Hall Sensor: 120^0 Phase Shift

Trapezoidal vs. Sinusoidal Commutation

Trapezoidal references a lookup table for each Hall Sensor Change (rotor angle), or every 60^0 (electrical cycle).

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



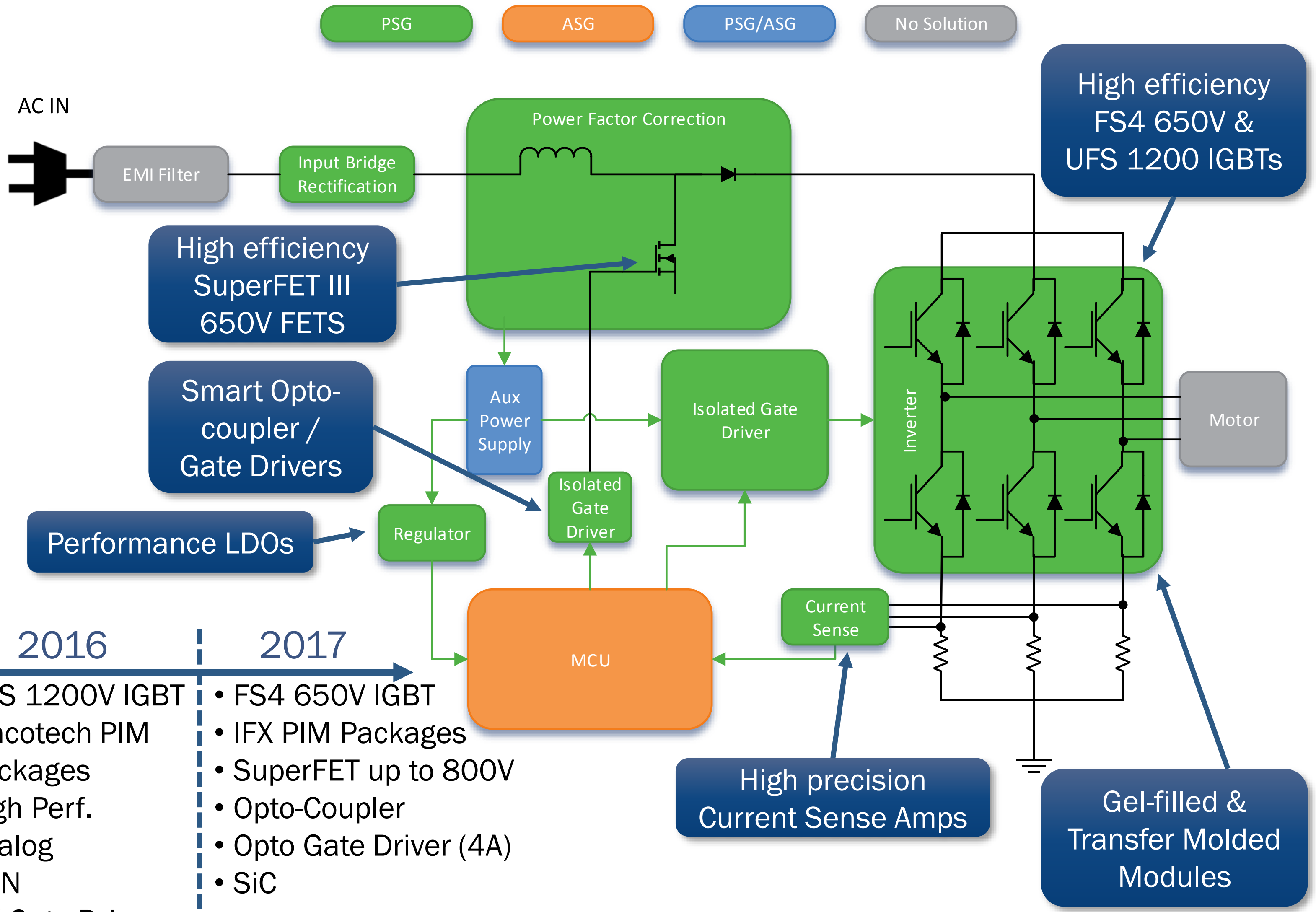


Sinusoidal:

1) Finer (smoother) resolution commutation
    a) improves torque ripple.
    b) reduces acoustic noise
2) More complicated control.

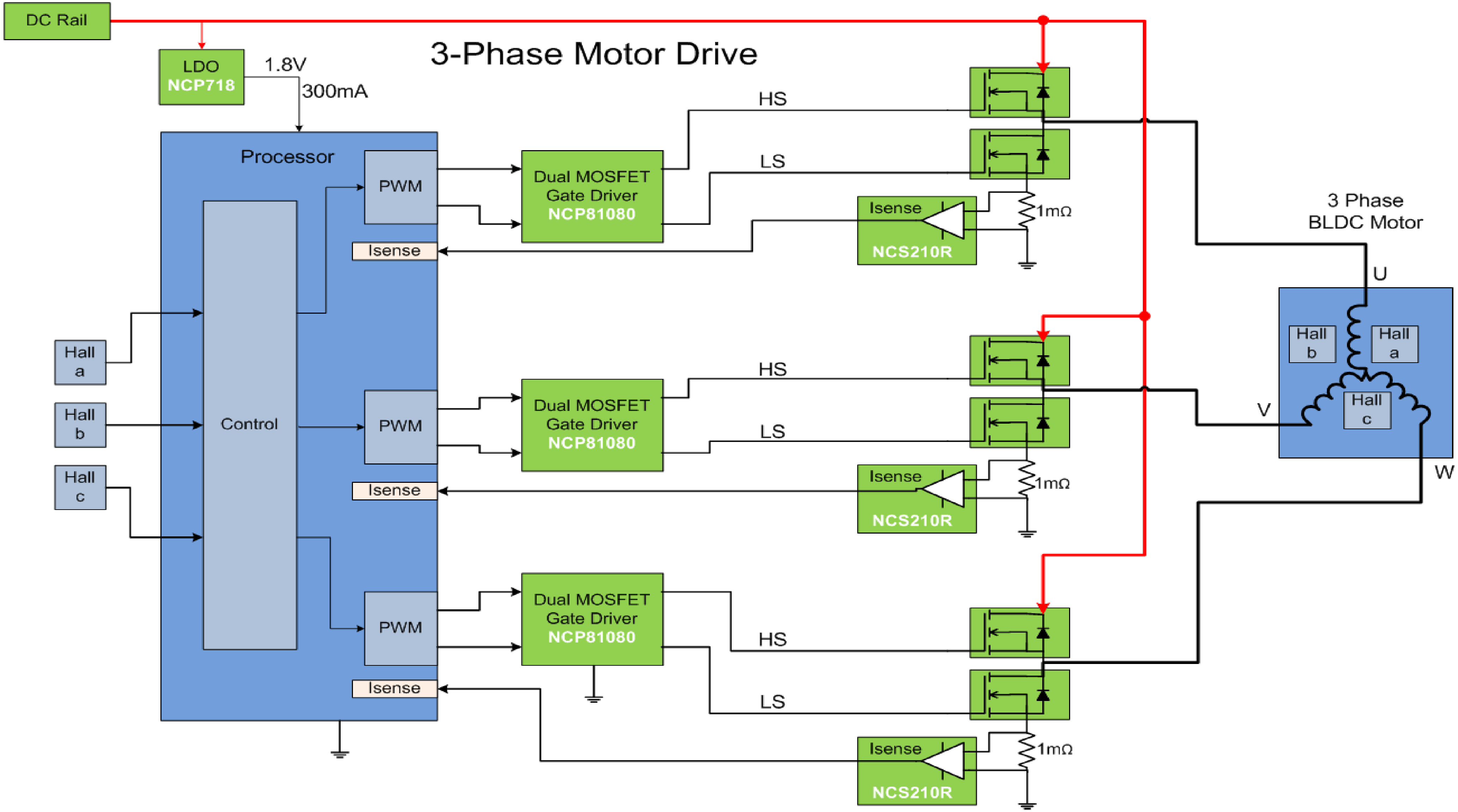
U is High Side, X is Low Side for U Stator Winding
V is High Side, Y is Low Side for V Stator Winding
W is High Side, Z is Low Side for W Stator Winding

Industrial Motor – ON offers a Complete BOM Coverage



2014	2016	2017
• FS3 IGBT • IPM • LV/MV FET • LDO • Op-Amp • Rectifier • Small Signal	• UFS 1200V IGBT • Vincotech PIM Packages • High Perf. Analog • GaN • HV Gate Driver	• FS4 650V IGBT • IFX PIM Packages • SuperFET up to 800V • Opto-Coupler • Opto Gate Driver (4A) • SiC

3-Phase


3-Phase Motor Drive
DC Rail
LDO
NCP718
1.8V
300mA
Processor
Control
PWM
Isense
PWM
Isense
PWM
Isense
Hall a
Hall b
Hall c
Dual MOSFET Gate Driver NCP81080
Dual MOSFET Gate Driver NCP81080
Dual MOSFET Gate Driver NCP81080
HS
LS
HS
LS
HS
LS
Isense
NCS210R
Isense
NCS210R
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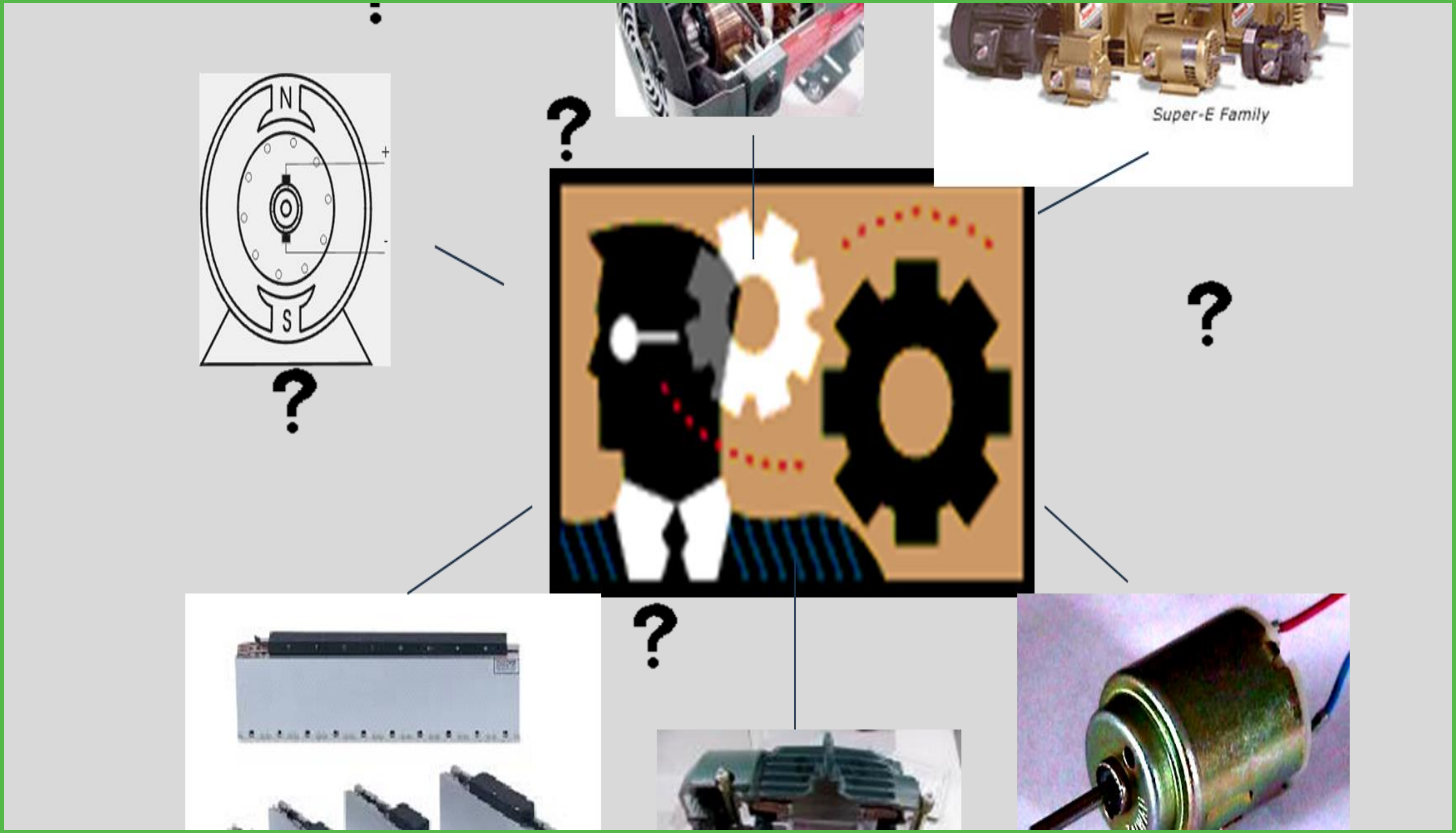
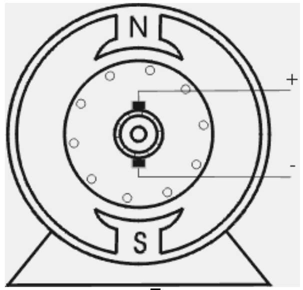
NCS210R
1mΩ
1mΩ
1mΩ
3 Phase BLDC Motor
U
V
W
Hall b
Hall a
Hall c

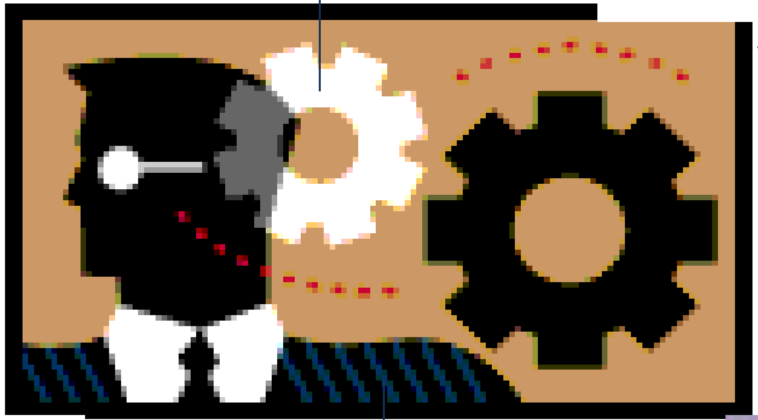


Motors – Controllers and Drivers

MOTOR SIZING DESIGN CONSIDERATIONS

What Motor to use?





MOTOR Technical Specifications (Boilerplate)

Specifications for Motor Controller/Driver				
	Customer Name/Region	General Applcaition intel	Motor Type-BLDC/Brushed/Stepper/AC	COMMENTS
	Definitions	Specifications	units	Tech-Specs
1	*Rated Capacity*		*W*	
2	*Input Votlage*		*V*	
3	*Rated Current (MIN/MAX)*		*A*	
4	*Starting Current*		*A*	
5	*Overcurrent Limt*		*A*	
6	*Speed Range*		*RPM*	
7	*MAX Speed @ MAX Voltage*		*Wnl*	
8	*Rated Torque*		*Kt*	
9	*Rated Voltage*		*Kv*	
10	*Overvotlage Limit*		*V*	
11	*Motor Feedback*			
12	*Commutation*		*Trajectory Shape*	
13	*Mode of Operation*			
14	*Fatures*			
15	*Input Signal*			
16	*Display Functions*			
17	*Operating Temp/Humidity*		*Deg C/%*	
18	*Vibration Levels*		*Hz - AdB/Octave Level*	
19	*Airborne noise*		*dbA*	
20	*Approx Size*		*HxWxD*	
21	*Cooling for Driver/Inverter*		*Air/Water/Forced*	
22	*Miscll*			
23	*Motor Poles*		*Number*	
24	*Load infomration*		*Gearhead/Linear/Rotational*	
25	*Operating Frequency of Driver/Inv*		*Hz*	

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.*

Brush DC Motor

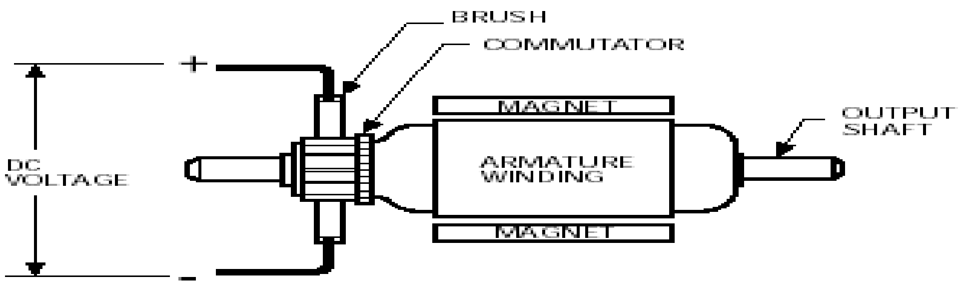


Figure 1

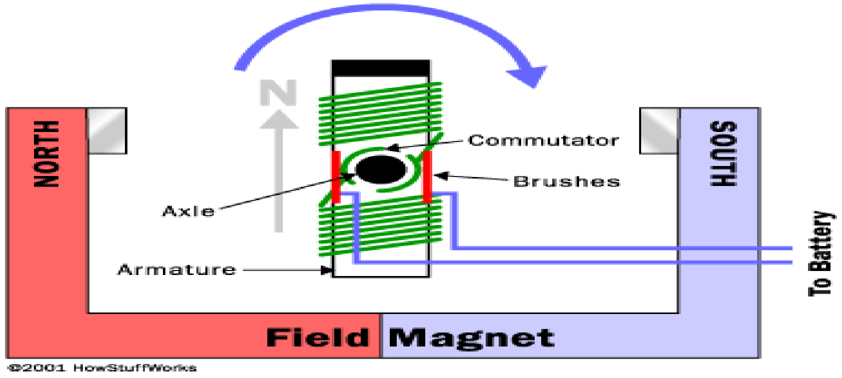


Figure 2

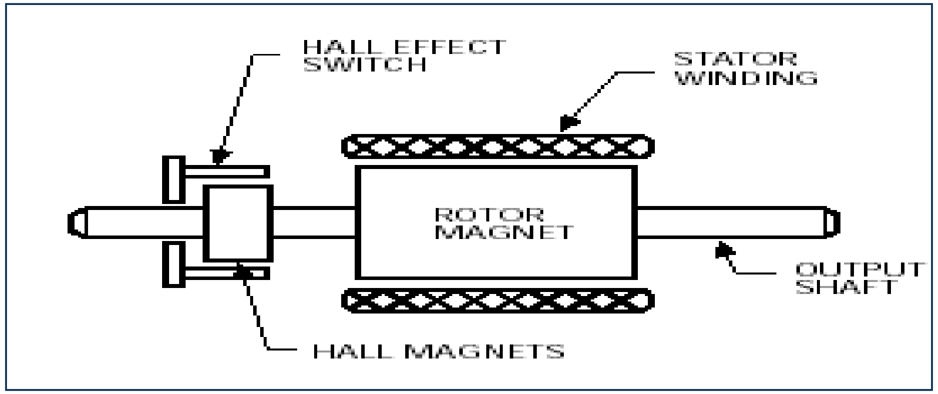
Description of Brush DC Motors:
In order for any DC motor to operate, the current to the motor coils must be continually switched relative to the field magnets. In a brush type unit, this is accomplished with carbon brushes contacting a slotted commutator cylinder which has each motor coil connected 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.

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

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

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.



Notes on Brushless DC Motors:
- Require some sort of driver (sensing)
- Some sort of controls are needed

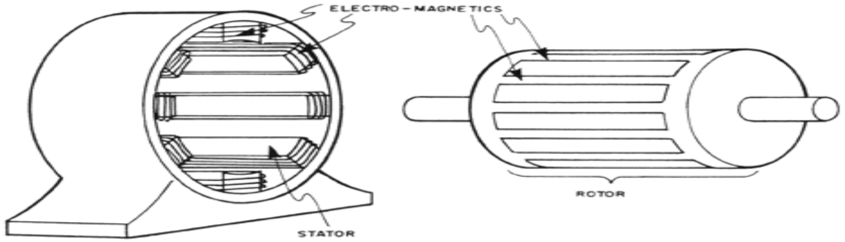
Advantages of Brushless DC Motors:
Since there are no carbon brushes to wear out, a BLDC motor can provide significantly greater life being now only limited by bearing wear. BLDC motors also offer additional advantages as by-products of the inherent construction:

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.

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

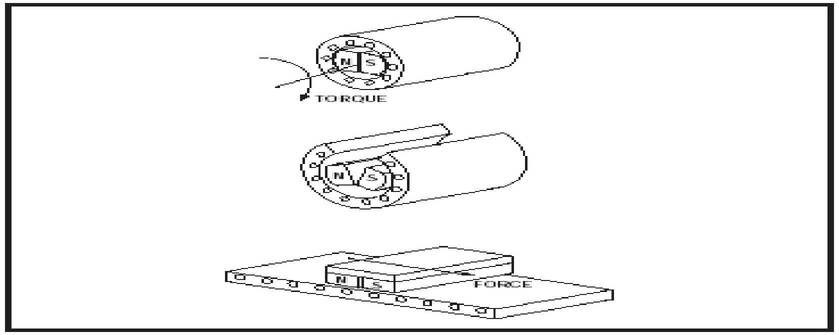
  Variable speeds

- ✓ **Disadvantage:**

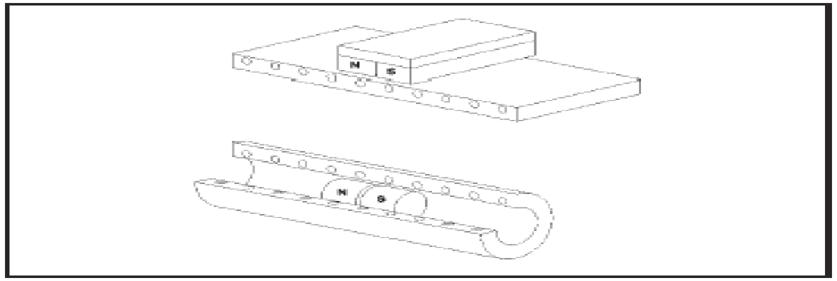
  Non reversible (one direction)

  Noisy

Linear Motors



Imaginary process of unrolling a rotary motor.



Tubular non-commutated DC Linear Motor.

Uses for Linear Motors:

- Linear applications (lower precision)

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.

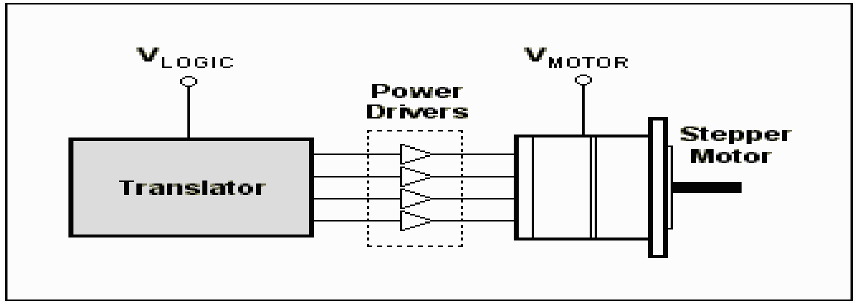
- Designs are available with either a moving coil or moving magnets.

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.



A typical translator / driver connection

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.

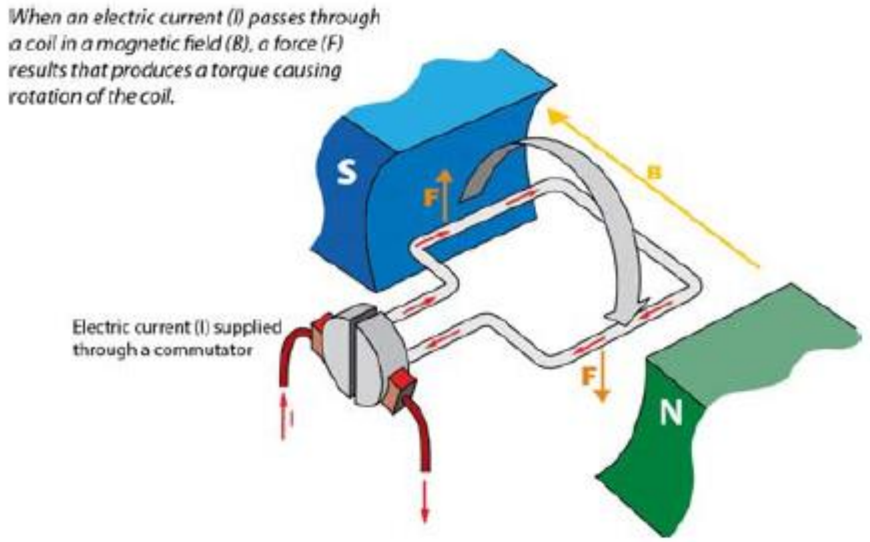
Use of Stepper Motors:
applications where the motor may be starting and stopping, while the force acting against the motor remains present

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

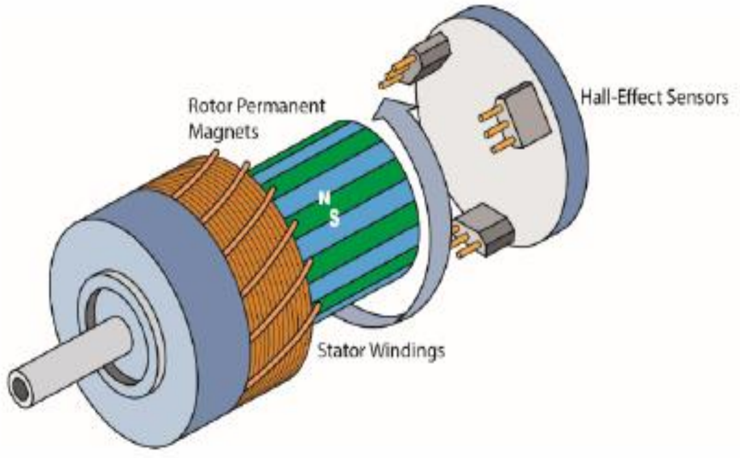
Brush DC Motor Construction



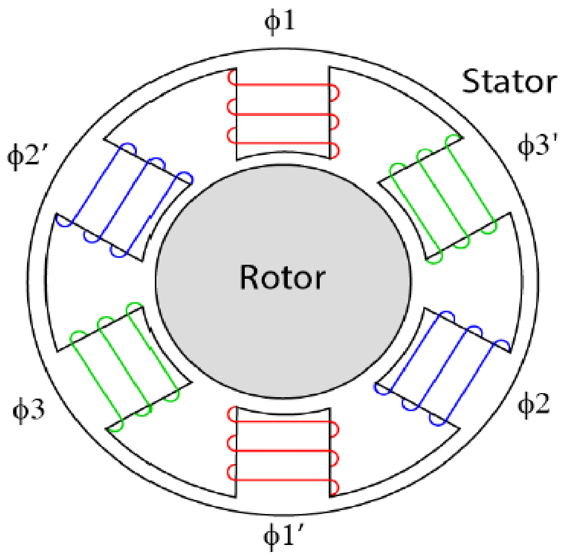
In a simple, single-coil brush DC motor, a split ring fixed to the rotor and in contact with brushes acts as a sliding switch to reverse the polarity of the current in the winding. The process is called commutation

Examples of brush DC motors of various types and frame sizes. The largest motor shown here has a diameter of three inches.

Brushless DC (BLDC) Motor Construction

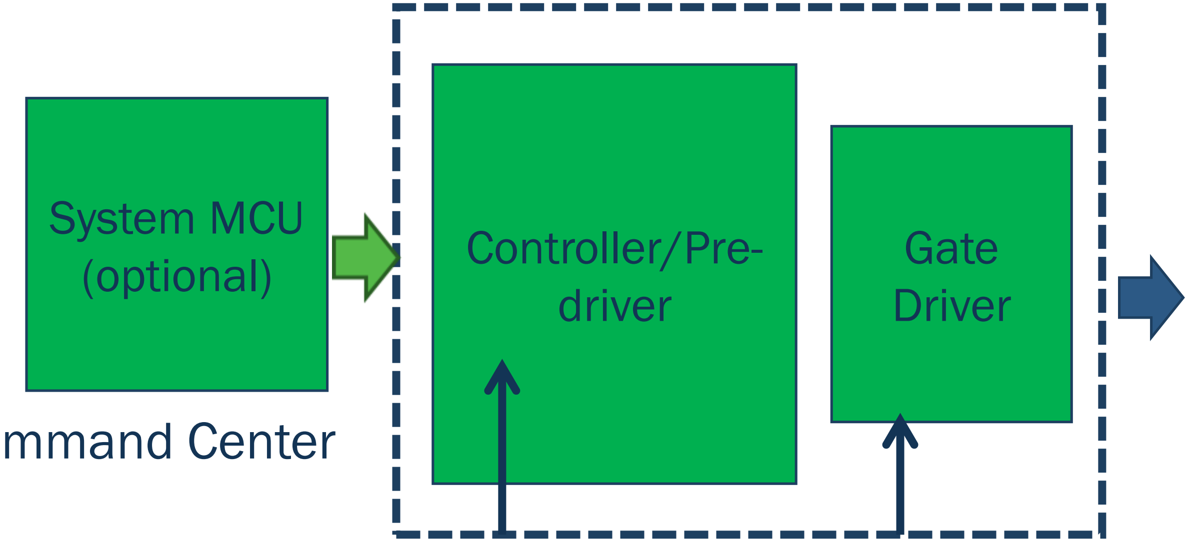


In a BLDC motor, the magnets (blue and green) are on the rotor and the windings (copper) are on the stator. This improves heat transfer, thereby enabling higher performance than brush motors of equivalent size. The motor shown in this diagram uses Hall-effect sensors to determine rotor position



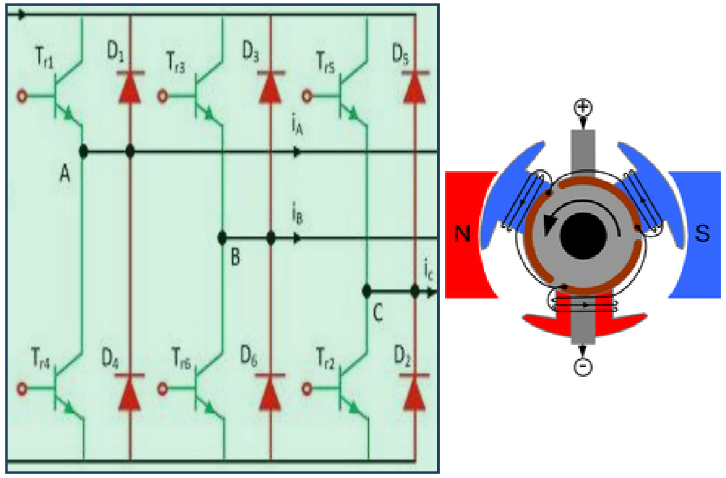
In a three-phase BLDC motor, the stator has three separate coils that are displaced from one another by 120 electrical degrees

Driving Motors (BLDC) Made Simple



Command Center

Power to motor



"<u>Motor Controller</u>"

Pre-driver converts MCU commands into motor drive waveforms (commutation)
Most intelligent part of motor drive system

<u>"Gate Driver</u>"

is ***<u>Optional</u>****,*
depending on Power Switches Gate Drive capability

"<u>Power Stage</u>"

Most important part of the Motor Drive System.
Usually consists of ***<u>IGBT's</u>*** *or* ***<u>MOSFET's</u>****, 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..!

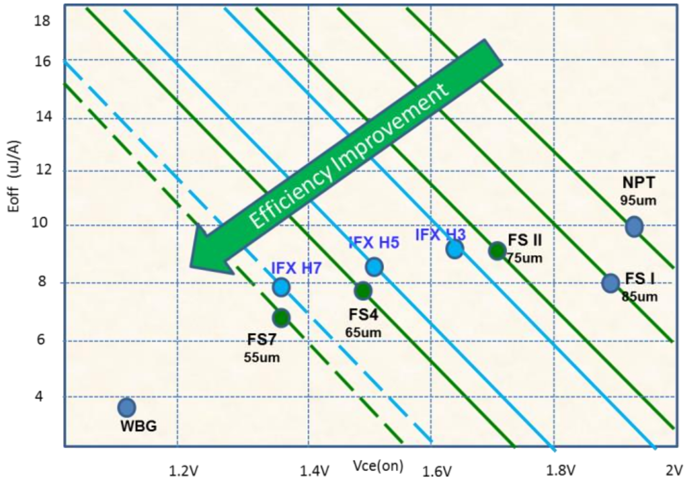
MOSFETs – Any Size, Any Package

		TO-3P	TO-247	TO-220	D2PAK	DPAK	SO-8	TO-LL	8x8	SO8 DFN	SO8 LFPAK
$2B	25V				NXP	ON, FAIRCHILD	Infineon			ON, Infineon, FAIRCHILD	NXP
	30V		Infineon	NXP, FAIRCHILD	ON, NXP, FAIRCHILD	ON, NXP, FAIRCHILD	ON, NXP, FAIRCHILD	Infineon		ON, Infineon, FAIRCHILD	NXP
$2B TAM	40V		Infineon	ON, NXP, FAIRCHILD	ON, NXP, FAIRCHILD	ON, NXP, FAIRCHILD	ON, Infineon, FAIRCHILD	FAIRCHILD		ON, Infineon, FAIRCHILD	NXP
	60V		Infineon	ON, NXP, FAIRCHILD	ON, NXP, FAIRCHILD	ON, NXP, FAIRCHILD	ON, Infineon, FAIRCHILD	Infineon, FAIRCHILD		ON, Infineon, FAIRCHILD	NXP
	80V			NXP, FAIRCHILD	NXP, FAIRCHILD	NXP, FAIRCHILD	Infineon, FAIRCHILD	Infineon, FAIRCHILD		Infineon, FAIRCHILD	NXP
	100V		Infineon, FAIRCHILD	ON, NXP, FAIRCHILD	ON, NXP, FAIRCHILD	ON, NXP, FAIRCHILD	ON, NXP, FAIRCHILD	Infineon, FAIRCHILD		ON, Infineon, FAIRCHILD	NXP
	150V	FAIRCHILD	Infineon, FAIRCHILD	NXP, FAIRCHILD	NXP, FAIRCHILD	NXP, FAIRCHILD	NXP, FAIRCHILD	Infineon, FAIRCHILD		Infineon, FAIRCHILD	NXP
	250V		Infineon	Infineon, FAIRCHILD	Infineon, FAIRCHILD	Infineon, FAIRCHILD	FAIRCHILD	Infineon		Infineon, FAIRCHILD	
$1B TAM	600V		Infineon, FAIRCHILD	Infineon, FAIRCHILD	Infineon, FAIRCHILD	Infineon, FAIRCHILD			Infineon, FAIRCHILD	Infineon	
	800V		Infineon, FAIRCHILD	Infineon, FAIRCHILD	Infineon, FAIRCHILD	Infineon, FAIRCHILD					
	900V	FAIRCHILD	Infineon	Infineon, FAIRCHILD	Infineon	Infineon, FAIRCHILD					
	1.5kV	ON		ON	ON						
	1.7 kV	ON									

IGBTs – Now a Premier IGBT Supplier

	TO-3P	TO-247	TO-247 4L	TO-220	TO-220 FullPak	D2PAK	DPAK
600V	ON FAIRCHILD	ON FAIRCHILD		ON FAIRCHILD	ON FAIRCHILD	FAIRCHILD	ON FAIRCHILD
650V	FAIRCHILD	ON FAIRCHILD	ON FAIRCHILD	Infineon	FAIRCHILD	Infineon	
1200V	FAIRCHILD	ON FAIRCHILD	ON FAIRCHILD	Infineon	Infineon	FAIRCHILD	FAIRCHILD
1350V	FAIRCHILD	ON FAIRCHILD					
1500V	FAIRCHILD	FAIRCHILD					
1600V		Infineon					

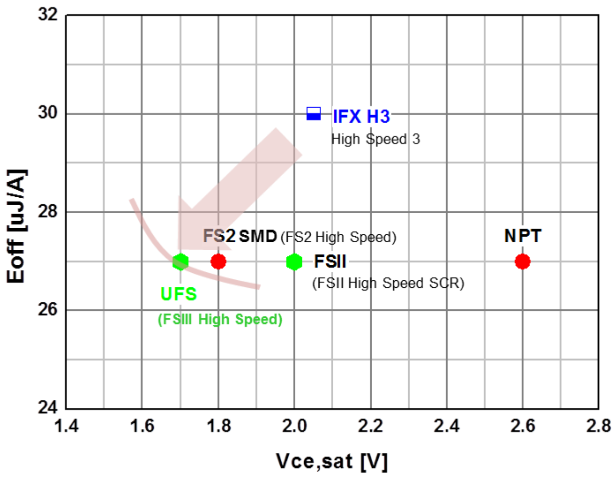
650V



650V FS4 exceeding IFX H5 Performance

1200V UFS exceeding IFX H3 Performance

1200V



Discrete and Integrated Power Products

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

- Low Voltage Family optimized for Qgd x Rds(on)
- Separate family optimized for pure Rds(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
- Vce(on) optimized using thin wafers
- Multiple package options and bare die option available

Discrete and Integrated Power Products

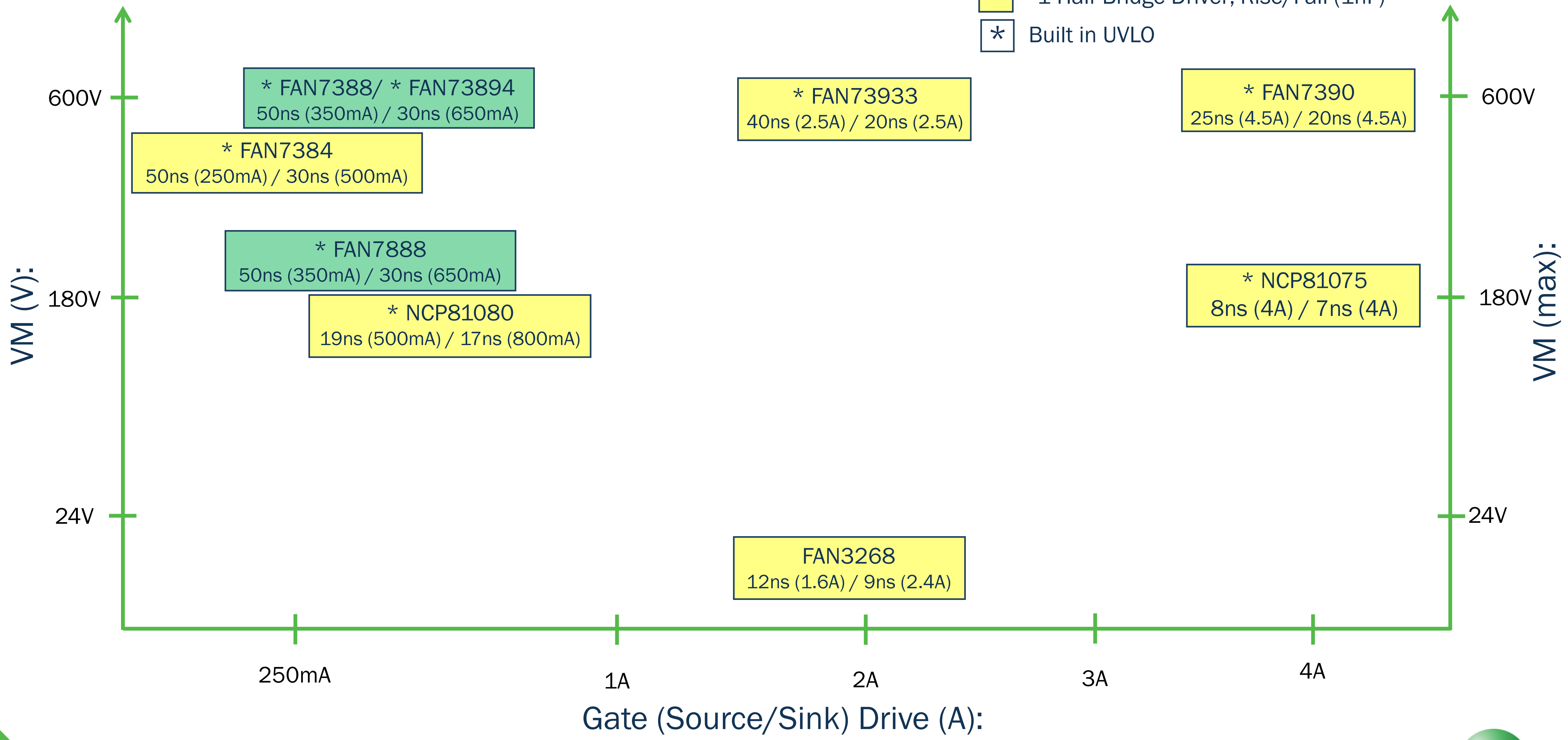
Broad Line of Packages and Devices

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



When to Use Summary: *Conditions Based*

IGBT Preferred..!

- ✓ Low Switching Frequency (<20kHz)
- ✓ High Power levels (above say 3 kW)
- ✓ High 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 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

Some Key Application Conditions and Device Requirements

CCM (Continuos Conduction Mode) Topologies

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

CRM (Critical Conduction Mode) Topologies

Application Conditions	Device Requirements
Typical Power Range is 100 W to 1 kW	Relatively smaller die/package devices could be considered
Typical Switching Frequency range is wide (50 kHz to 300 kHz)	Almost always MOSFETs are used
Typically Devices are Soft switched at turn on and hard switched turn off	Low Rdson is as important as gate charge
Typically higher inductor current ripple M	More stressful for the device

The Motor Driver Stage: IGBT or FET

Some Key Application Conditions and Device Requirements

Application Conditions/Requerments		IGBT (with FRD) or HV FET
Power Level	75 W to 200W	Fast Body Diode FET preferred
	500 W to 5 kW	IGBT is preferred
	200 W to 500 W	Could be either, based on cost, target efficiency, etc.
PWM Frequency	Few kHz to say 25 kHz	IGBT is generally preferred
	Above say 25 kHz	Also depends on power level, but a Fast body diode FET may be preferred

The Inverter Stage: IGBT or FET

Some Key Application Conditions and Device Requirements

Application Conditions/Requirements	IGBT (with FRD) or HV FET
Diode Recovery Loss Important	IGBT (with fast recovery diode co-packaged) preferred
High Light load efficiency requirement	Fast Body Diode FET preferred
Lowest device cost	IGBT (with FRD) typically preferred

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

<table>
<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>
<tr><td>1/8</td><td>93W</td><td>12V</td><td rowspan="3">FAN7888 (1x)
NCP81080 (3x)</td><td rowspan="2">Trench 6</td><td>NTTFS5C466NL (40V)</td><td>7.3mΩ</td><td rowspan="5">3.3 x 3.3mm</td></tr>
<tr><td rowspan="2">1/4</td><td rowspan="2">186W</td><td rowspan="12">24V</td><td>NTTFS5C673NL (60V)</td><td>9.3mΩ</td></tr>
<tr><td>MV7</td><td>FDMC86340ET80 (80V)</td><td>6.5mΩ</td></tr>
<tr><td rowspan="2">1/2</td><td rowspan="2">372W</td><td rowspan="4">FAN73933 (3x)</td><td>Trench 6</td><td>NTTFS5C573NL (60V)</td><td rowspan="2">6.5mΩ</td></tr>
<tr><td>MV7</td><td>FDMC86340ET80 (80V)</td></tr>
<tr><td rowspan="2">3/4</td><td rowspan="2">559W</td><td>Trench 6</td><td>NTMFS5C646NL (60V)</td><td>4.7mΩ</td><td rowspan="7">5 x 6mm</td></tr>
<tr><td>Trench 8</td><td>NTMFS6H824N (80V)</td><td>4.5mΩ</td></tr>
<tr><td rowspan="2">1</td><td rowspan="2">745W</td><td rowspan="6">NCP81075 (3x)
FAN7390 (3x)</td><td>Trench 6</td><td>NTMFS5C628NL (60V)</td><td>2.4mΩ</td></tr>
<tr><td>Trench 8</td><td>NTMFS6H801N (80V)</td><td>2.8mΩ</td></tr>
<tr><td rowspan="2">1 1/4</td><td rowspan="2">931W</td><td>Trench 6</td><td>NTMFS5C604NL (60V)</td><td>1.2mΩ</td></tr>
<tr><td>Trench 8</td><td>NTMFS6H800N (80V)</td><td>1.9mΩ</td></tr>
<tr><td rowspan="2">1 1/2</td><td rowspan="2">1,117W</td><td>Trench 6</td><td>NTMFS5C604NL (60V)</td><td>1.2mΩ</td></tr>
<tr><td>MV7</td><td>FDMT80080DC (80V)</td><td>1.35mΩ</td><td>8x8mm Dual Cool w/ Heat Sink</td></tr>
</table>

1st Order Approximation Considerations:

1. 85⁰C Max Ambient Temp.
2. Matching Gate Drive Strength to FET Input Capacitance.
3. FET Power Dissipation = 50⁰C below max operating die temp
4. FET Voltage = 2-3x Motor Voltage.

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. Pared 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?