Field Oriented Control (FOC) Made Easy for Brushless DC (BLDC) Motors Using TI Smart Gate Drivers

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TEXAS INSTRUMENTS

Introduction

Brushless DC (BLDC) motors continue to grow in popularity due to their high efficiency, high operating speed, high flux density per unit volume, compact size, low maintenance requirements and low electro-magnetic interference (EMI) problems. For these reasons, the BLDC motors are replacing the brushed DC (BDC) motors in a variety of applications such as appliances, electric vehicles, medical applications, heating ventilation and air conditioning (HVAC), motion control and robotics, etc. The BLDC motor is a three-phase synchronous motor with stator composed of three-phase windings (concentrated windings for trapezoidal-BLDC motor and sinusoidally distributed windings for sine-BLDC motor) and a rotor having permanent magnets (or vice versa in exterior rotor PM motors). BLDC motors do not have mechanical brushes and commutator assembly. Therefore, issues associated with BDC motors, such as wear and tear of the brushes, sparking concerns, and EMI problems, are eliminated. This motor is also referred to as an electronically commutated motor, because an electronic commutation based on the rotor position is used rather than a mechanical commutation. The rotor position of the BLDC motor is generally sensed using the Hall-effect position sensors.

There have been numerous control algorithms developed for controlling BLDC motors. The algorithms are typically classified based on the type of BLDC motor (trapezoidal or sinusoidal), position sensor requirements (sensored or sensorless) and speed and torque (current) control requirements. With the increased capacity of today's micro-controllers, industry is expanding boundaries on the implementation of high-end control algorithms such as field oriented control (FOC). FOC implementation allows the BLDC motor to run more efficiently (high power factor and better light load efficiency), more smoothly (lower torque ripples) with quick dynamic response (better dynamic performance to load and speed changes). FOC control makes the stator and rotor magnetic field orthogonal to each other to achieve the maximum electromagnetic torque. It uses a decoupled control of flux and torque due to which it can also allow motor to run above the nominal speed using field weakening technique.

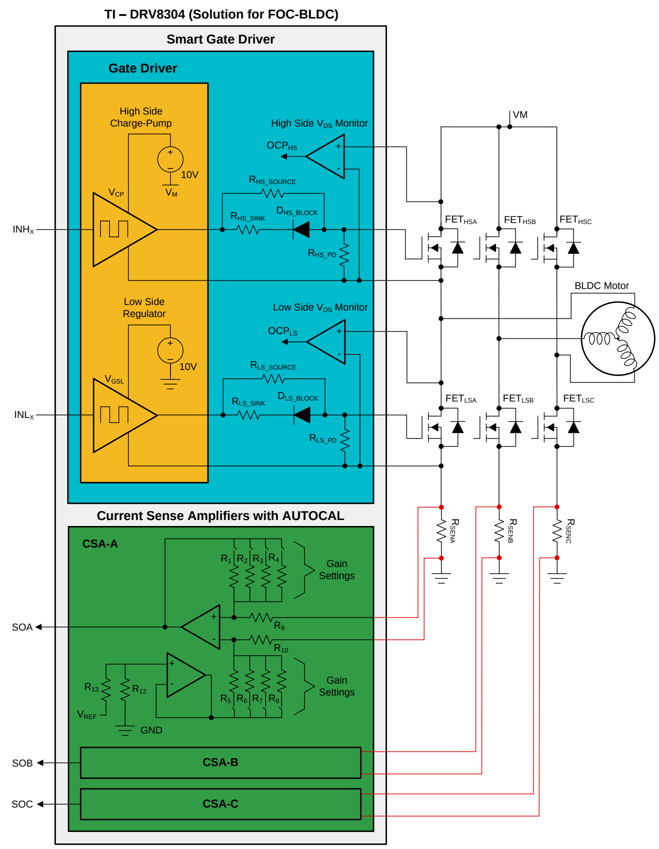

Figure 1. TI Smart Gate Driver for FOC Implementation

The 3-phase BLDC motor needs a 3-phase voltage source inverter (VSI) to feed AC current to motor. The switches of this VSI are generally field effect transistors (FETs) for low voltage applications (or Insulated Gate Bipolar Transistors - IGBTs for high power applications), which are driven by the gate driver. Most gate drivers available today require external gate components (resistors and Zener diodes) for operation and protection. However, TI's Smart Gate Drive (SGD) technology eliminates external gate components as shown in Figure 1. With its adjustable gate drive currents (gate slew-rate control), the SGD architecture provides flexibility in reducing electromagnetic interference (EMI). The SGD architecture optimizes the dead time for a better efficiency while fully protecting the FET's to avoid any shoot-through conditions. A strong-pulldown current is also added for prevention of any spurious dv/dt gate turnon.

The DRV8304 device is a three-phase gate driver based on the TI's Smart Gate Drive (SGD) architecture. The operating maximum voltage of 38-V of this device is fully optimized for the 12-V and 24-V BLDC motor FOC application. DRV8304 support external N-channel high-side and low-side power MOSFETs and can drive up to 150- mA source, 300-mA sink peak currents with a 15-mA average output current. DRV8304 is a highly integrated device which includes gate driver supplies (high side charge-pump and low side linear regulator), three current sense amplifiers (CSA) and a 3.3-V, 30-mA regulator which can be used for powering up the external controller.

The integrated current-sense amplifiers (CSA) in DRV8304 are used for sensing three phase currents of BLDC motors for optimum FOC and current-control system implementation. An adjustable gain settings of 5, 10, 20 and 40 V/V provides a flexibility to user for choosing the optimum sense resistor suiting the end-application. The CSA can also be configured to sense the unidirectional current which can be used in implementing the current limit control for trapezoidal BLDC motor. The CSA in DRV8304 includes an AUTOCAL feature which automatically calibrates the CSA offset error at power-up for accurate current sensing.

Various PWM modes are available in DRV8304 which make it an easy-to-interface driver. User has the flexibility to choose 6x or 3x mode for the FOC (or sinusoidal current control), 1x mode for trapezoidal current control with on-chip block-commutation feature and independent mode for driving the solenoids relays. A high level of protection feature-set makes this device invulnerable in any operating scenarios. These features include power-supply undervoltage lockout (UVLO), charge-pump undervoltage lockout (CPUV), VDS overcurrent monitoring (OCP), gate-driver short-circuit detection (GDF), and overtempertaure shutdown (OTSD) and fault events are indicated by the nFAULT pin. A summary set of features which makes DRV8304 an ideal for BLDC motor FOC application is as follows.

- Optimized driver absolute maximum voltage (40-V) for 12-V and 24-V BLDC motors
- Triple CSA for three phase BLDC motor current sensing with 4 settings of gain selection
- AUTOCAL feature for reduced CSA input offset error which provides better motor rotation jitter performance
- High operating switching frequency for achieving better noise performance
- Adjustable slew rates for optimized EMI performance
- Very low dead time for higher switching efficiency
- Very low propagation delay for better pulse-control accuracy and better dynamic response
- Highly integrated driver and small package size for reduced board area
- Advance on-chip protection features and diagnostics

Alternate Device Recommendation

Depending on the necessary system requirement, there are additional devices available that may provide the required performance and functionality. For applications requiring detailed diagnostics and limp-home mode support, DRV8305 is recommended. DRV832x is preferred in the applications requiring a higher operating voltage such as 36-V battery operation.

Table 1. Alternative Device Recommendations

Device	Optimized Parameters	Performance Trade-Off
DRV8305	45-V Abs-max Voltage Limp-Home Mode 1-A / 1.25-A (Source / Sink) Gate Drive	Higher CSA Input Offset No AUTOCAL feature
DRV832x	65-V Abs-max Voltage 1-A / 2-A (Source / Sink) Gate Drive Integrated Buck Option	Higher CSA Input Offset
DRV835x	100-V Abs-max Voltage 1-A / 2-A (Source / Sink) Gate Drive Integrated Buck Option	Higher CSA Input Offset

Table 2. Adjacent Tech Notes

SBOA174	Current Sensing in an H-Bridge
SBOA161	Low-Drift, Low-Side Current Measurements for Three-Phase Systems
SBOA171	Bi-Directional, Low-Side Phase Current Sensing with Integrated Over-Current Detection
SBOA160	Low-Drift, Precision, In-Line Motor Current Measurements With Enhanced PWM Rejection