Application Note

Relating Payload to Brushless DC Motor Driver Specifications

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ABSTRACT

The growth of factory automation and robotics has revolutionized modern manufacturing process by increasing speed, precision and volume of consumer goods production. The once labor-intensive tasks are now being automated resulting in more efficient manufacturing techniques. Advanced motor modules are the driving forces being used to drive these robots, delivering high degree of accuracy and power to move loads and perform tasks as needed. Brushless DC (BLDC) motors with quiet operation, high speed and high torque density are the preferred choice for these applications.

TI's Brushless DC portfolio offers a wide variety of motor drivers that can be used to drive the BLDC motors for robotics and factory automation systems. This application note includes how to correlate motor power to current and how to determine if the motor driver is capable of driving the MOSFETs needed to deliver the motor power. The application note also covers how TI's smart-gate drive technology offers extensive control in adjusting your switching speeds allowing the motor drivers to drive a larger variety of MOSFETs.

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Trademarks

1 Introduction

When designing the motor driver system, the key consideration is to account for the power needed to move the payload within the mechanical constraints of the end application. The torque needed to drive the payload directly corresponds to the power requirement for the motor. The motor selected needs to be rated for the bus voltage of the system and be able to deliver the current required from the application.

2 System Power Requirements

Most emerging robotics applications run on a 48V rail and with power requirements varying from few 10s of watts in small robots to 10s of kilowatts in cobots used to lift large payloads.

The load being moved can range from a few kilograms to a few hundreds of kilograms and the designer can translate this value to the power needed from the bus supply through the MOSFETs.

The formula shown in Equation 1, states how power is directly proportional to voltage and current.

$$P = V \times I \tag{1}$$

The motor voltage is the rated voltage of the motor and can be determined by the system's bus voltage supply. The motor current can be determined by the load that is being driven by the motor. The designer need to verify that the motor is able to handle the current required by the application.

A common concern when selecting a motor driver for high power application is whether or not the gate driver is able to drive the MOSFETs chosen for the application. The following sections can explain how BLDC motor driver designs work and cover two example MOSFETs for different power ranges that can be driven by TI's BLDC gate drivers.

3 Motor Current and MOSFET Selection

3.1 How Does a BLDC Motor Driver System Work?

Brushless DC motors use electrical commutation to drive a three-phase motor. Modulated PWM signals are applied as input to the motor driver to control the torque and speed of the motor. A BLDC gate driver is used to control 3 sets of half bridges. The input commands from the controller get scaled through the driver's power stage to generate gate driving voltage of the MOSFET. The commutation algorithm is used to supply power to the motor in the manner required by the application. The magnetic field on the stator coils, from the applied voltage, interacting with the magnetic field of the rotor, is used to spin the motor.

In a 3-phase BLDC motor driver system, Figure 3-1, the current is supplied from the battery to the motor using 6 N-type MOSFETs arranged in 3 pairs of H-Bridges.

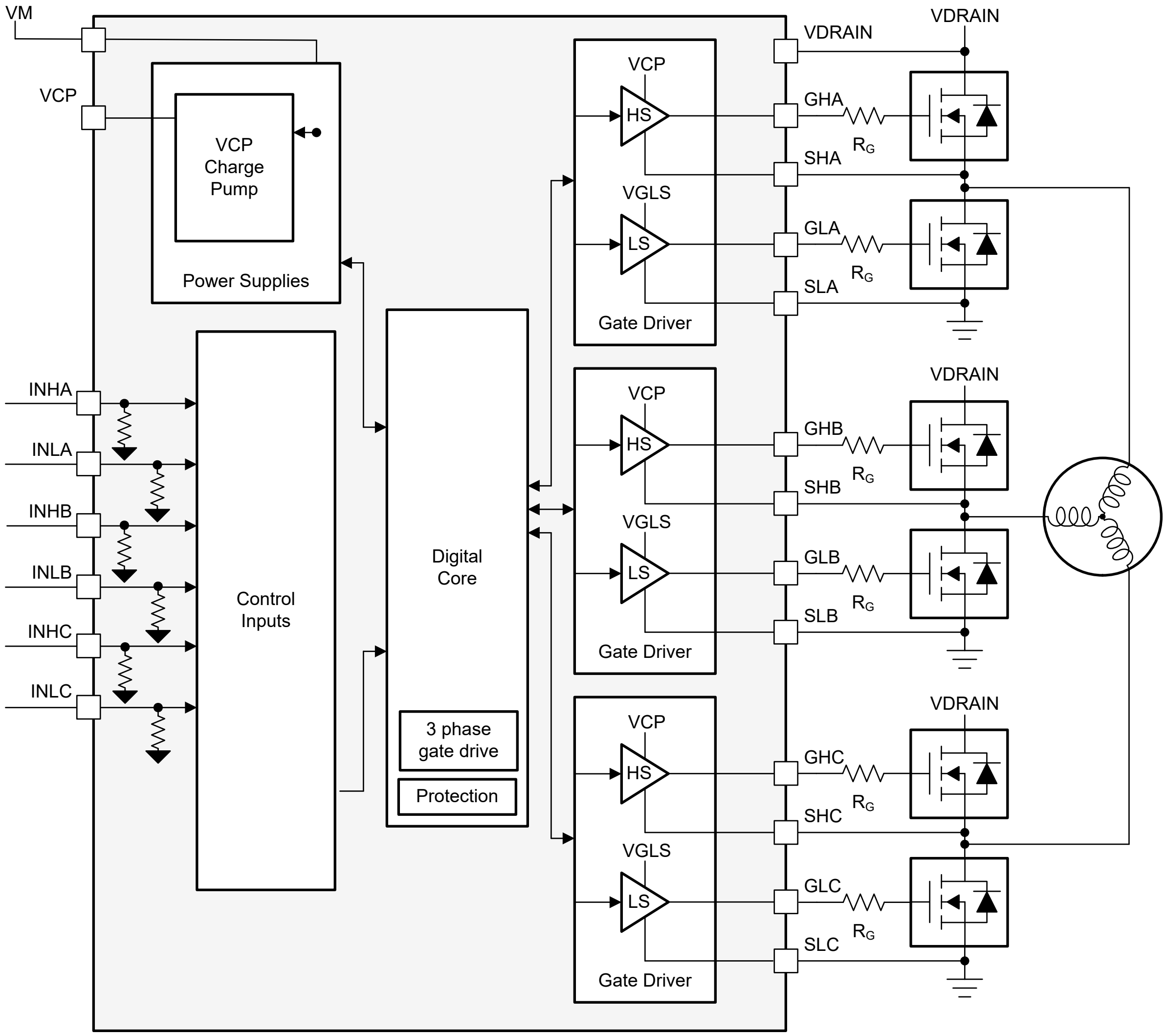

Figure 3-1. Three-Phase BDLC Motor Driver

3.2 Motor Current and Q_G Value Relation

The current that can be delivered by the MOSFETs to the motor depends on the drain current (I_D) rating of the MOSFET.

To turn on the N-type MOSFET one needs to apply a differential voltage across the gate and source of the FET to enhance the channel thereby creating a path for the current to flow from drain to the source. Figure 3-2 shows the schematic for an N-type MOSFET.

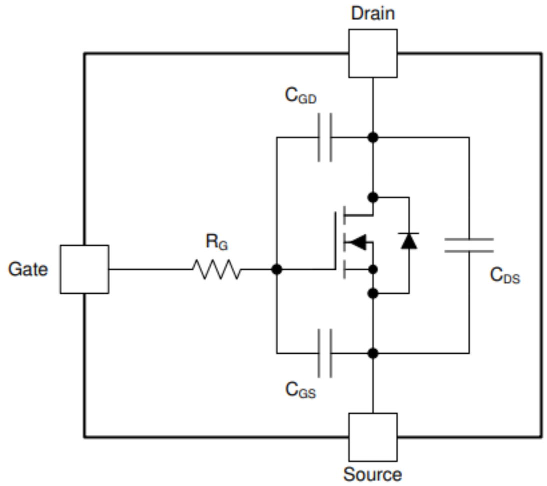

Figure 3-2. MOSFET Circuit Model

To create this channel, the MOSFET's gate charge capacitance (C_g) needs to be charged up. Generally, the larger the current rating of the MOSFET, the larger the gate charge needed to turn on the MOSFET.

3.3 Role of a Motor Driver

The motor driver provides the gate current needed to charge the gate capacitance. By adjusting the current, the user is able to vary the time taken to charge the gate. Equation 2 shows the relation of current, charge and time.

$$I = \Delta Q / \Delta t \quad (2)$$

3.4 Can my MOSFET be Driven or Commutated?

To determine if the MOSFET chosen to drive a load can be driven by the motor driver, the designer needs to consider the average gate current that the gate driver is able to supply. This is the average current that can be consumed while switching the MOSEFT and is dependent on how often you switch per cycle and how many MOSFETs get switched.

Factors to consider:

1. Number of MOSFETs being switched (based on commutation Trapezoidal vs FOC)
2. PWM Switching Frequency
3. Gate Charge, Q_g, of the MOSFET

$$I_{AVG} = \#\ of\ MOSFETs\ Switching \times PWM\ Frequency \times Q_G \quad (3)$$

3.4.1 Example 1 – Medium Power (4.8kW – 48V × 100A)

Note

The following MOSFET specifications are based on common designs that are available for the chosen motor current.

Assumption:

MOSFET A:

- VDS – 80V
- I_D – 150A
- Q_G – 130nC
- Q_{GD} – 30nC
- F_{PWM} = 20kHz

Number of switching FETs = 6

Calculation:

I_{AVG} = 6 × 20kHz × 130nC = 15.6mA

3.4.2 Example 2 – High Power (19.2kW – 48V × 400A)

Note

The following MOSFET specifications are based on common designs that are available for the chosen motor current.

Assumption:

MOSFET B:

- VDS – 80V
- I_D – 500A
- Q_G – 180nC
- Q_{GD} – 40nC
- F_{PWM} = 20kHz

Number of switching FETs = 6

Calculation:

I_{AVG} = 6 × 20kHz × 180nC = 21.6mA

4 Motor Driver Specifications to Consider

The following are two examples of 100V rated gate drivers from TI's BLDC portfolio that are designed to drive 48V motor systems.

4.1 DRV8353 - Internally Generated Gate Drive Supply

DRV8353 uses a charge-pump architecture to generate the high side drive voltage and a linear regulator to generate the low side gate drive voltage.

Using the larger power Example 2, the average gate current of 21.6mA is needed from the gate driver. More specifically 10.8mA from high side supply and 10.8mA from low side supply.

The data sheet states that at 15V VM, the driver can output up to 25mA from VCP (high side supply) and 25mA from VGLS (low side supply). Therefore, the driver is more than capable of driving loads at such high power.

4.2 DRV8161/DRV8162 – Externally Generated Gate Drive Supply

DRV816x family of devices use a bootstrap topology with externally supplied gate drive voltage using the GVDD pin. With an externally supplied voltage to charge the bootstraps and supply the low side VGS voltage, the average gate current can be drawn from this external supply. As long as the external supply is properly designed to supply the needed current to recharge the bootstraps and supply the low side gate charge for the chosen MOSFETs, then the driver can be used to drive said MOSFET. In the case of Example 2, the external supply needs to be designed to support an average gate current of 21.6mA.

5 Advantages of TI's BLDC Drivers With Smart Gate Drive

A key consideration when driving a MOSFET is determining how fast the gates can be charged as it determines the MOSFET's slew time. The charge needed by the MOSFET to connect the drain voltage to the source, and the rate at which the driver is configured to deliver that charge, determines the VDS (Voltage Drain to Source) slew rate. The VDS slew happens during the Q_{GD} portion of the MOSFET gate charge. Figure 5-1 shows the different charging regions of the MOSFET. By increasing the gate current, the MOSFET is able to turn on and off faster, decreasing the switching losses of the MOSFET.

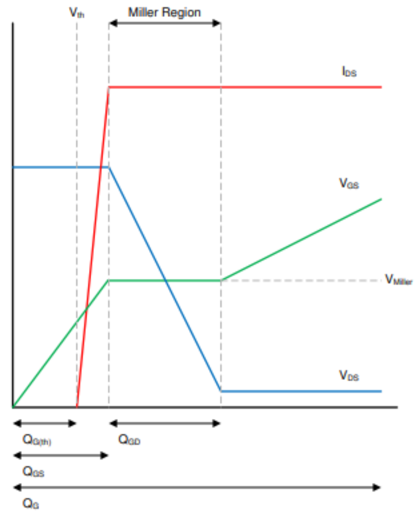

Figure 5-1. MOSFET Turn-on Response

TI's Smart Gate Drive (SGD) technology allows the user to select the peak gate drive current needed to turn-on/turn-off the MOSFET. For more information on SGD please check out Understanding Smart Gate Drive application note.

Most of TI's BLDC drivers offer a peak source/sink gate current of 1A/2A respectively. The SGD offers numerous levels of adjustment to the gate current allowing the driver to adjust the VDS slew rate and allow the driver to work with various sized MOSFETs.

Equation 4 shows how to calculate peak gate current needed for desired slew times.

$$T_{turn-on/turn-off} = \frac{MOSFET \;\; Q_{GD}}{I_{source/sink}} \tag{4}$$

Table 5-1 calculates the peak gate current needed to achieve desired slew rates for the MOSFETs described in earlier examples. Using SGD, the user is able to choose a current level closest to the desired slew rate.

Table 5-1. Gate Current and Slew time calculation

Example MOSFET	Gate-Drain Charge	Turn On Time	Turn Off Time	Source Current	Sink Current
MOSFET A	QGD (nC)	Turn on (ns)	Turn off (ns)	Isource (mA)	Isink (mA)
	30	100	50	300.0	600.0
		200	100	150.0	300.0
		300	150	100.0	200.0
		400	200	75.0	150.0
MOSFET B	QGD (nC)	Turn on (ns)	Turn off (ns)	Isource (mA)	Isink (mA)
	40	100	50	400.0	800.0
		200	100	200.0	400.0
		300	150	133.3	266.7
		400	200	100.0	200.0

Note

Generally, the turn off time is selected to be faster than the turn on time.

6 Maximum Source and Sink Current and Q_{GD}

For increasing switching efficiency in robotic applications, the rise time up to 48V can be as little as 100ns. Using the 1A peak source setting, the peak Q_{GD} MOSFET that can be switched is calculated as shown below:

$$100ns = Q_{GDmax}/1A \quad (5)$$

$$Q_{GDmax} = 100nC \quad (6)$$

In earlier Example 2 with 19.2kW application, a MOSFET with 40nC QGD was sufficient. Therefore, the driver can be used to scale for higher power applications if needed.

Note

In reality, achieving extremely fast slew rates can result in switch node ringing issues or other power stage related transient issues, so trade-offs needs to be considered for each specific system.

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7 Older Designs

Earlier motor drive systems used simple 3-phase gate drivers or half bridges to drive the MOSFETs. Some of these devices had 3-4A peak gate drive current and needed to be scaled down using series gate resistors to limit the gate current. The resistance was used to tune the VDS slew rate. With earlier calculations on rise or fall times and gate current, there is evidence that 1/2A peak current is more than sufficient for many robotics and factory automation systems.

With TI's Smart Gate drive technology, the series gate resistor might not be needed resulting in lower build cost and board space savings.

8 Summary

The rise of factory automation and humanoid robotics has increased the efficiency and volume of production and assembly of various components. These advancements have been centered around BLDC motors delivering the precise control with high power output needed in these applications. The power needed in these systems directly relate to the current needed to be delivered by the power stage of the motor driver. The heavier the payload to be lifted the greater the motor current needed to deliver the torque from the motor. The gate driver is utilized to adjust the gate current needed to charge the gate of the MOSFET based on the VDS slew time required for the given application.

TI's Smart gate drivers are able to deliver up to 1/2A peak source/sink current, along with several smaller gate current options. Thus, enabling fine tune control of slew rates needed to drive high power systems seen in factory robots. By offering various gate current levels, the gate drivers are suited to drive various sized MOSFETs depending on the application, while potentially eliminating the need for series gate resistors seen in non-Smart Gate Drivers.

9 References

- Texas Instruments, *DRV816x 100V Half-Bridge Smart Gate Driver with Integrated Protection and Current Sense Amplifier*, data sheet.
- Texas Instruments, *DRV835x 100-V Three-Phase Smart Gate Driver*, data sheet.
- Texas Instruments, *Understanding Smart Gate Drive*, application note.
- Texas Instruments, *48V, 3.5kW Small Form-Factor Three-Phase Inverter Reference Design for Integrated Motor Drives*, design guide.
- Texas Instruments, *Three-Phase vs Three-Single Half-Bridge Gate Drivers*, application note.

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