Brushless DC Motors--Part II: Control Principles

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Read part 1 of this series on construction and operating principles here.

Having understood the construction and basic operating principle of BLDC motor in the first part of this article, it becomes important to understand the motor control options available for the reliable operation and protection of motors. Based on the functions served, motor control can be classified into following categories:

- Speed control
- Torque control
- Motor protection

Implementation of these control functions requires monitoring of one or more motor parameters and then taking corresponding action to achieve the required functionality. Before getting into the details of these control function implementations, it is important to understand the implementation of logic and hardware required to build up the rotation of the motor or to establish commutation.

Commutation implementation

As discussed in the previous part of this article, based on the position of the motor (identified using feedback sensors), two of the three electrical windings are energized at a time. To be able to energize the windings, external circuitry is required to be able to meet the current requirements of the motor. A typical control circuit with a 3-phase winding connection is shown in Figure 1. V1, V3, V5 and V2, V4, V6 make a 3-phase voltage source inverter connected across the power supply. V1 and V4 form one bridge. V1 is high side, which is connected to the high voltage DC source while V4 is low side, which is connected to ground.

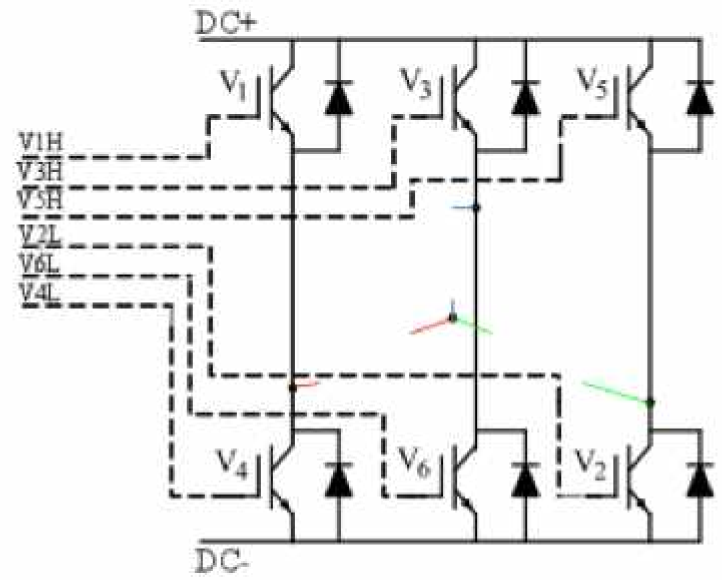

Figure 1: Control circuit for 3 phase BLDC windings

By adjusting the high-side and low side of the power device (via signals V1H, V3H, V5H and V2L, V4L, v6L), the current flow through the stator winding can be controlled. For example, if current has to flow in to the RED winding and flow out from the BLUE winding, turning on V1 and V6 while keeping the other signals will cause the current to flow in the required direction, as shown in Figure 2 (A). Next, by switching ON V5 and V6 and turning all other signals OFF, the current can be switched to flow in from the GREEN winding and out from the BLUE winding, shown in Figure 2 (B).

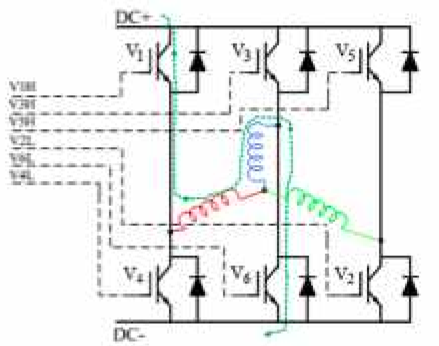

Figure 2 (A) – V1 and V6 ON; remaining all OFF

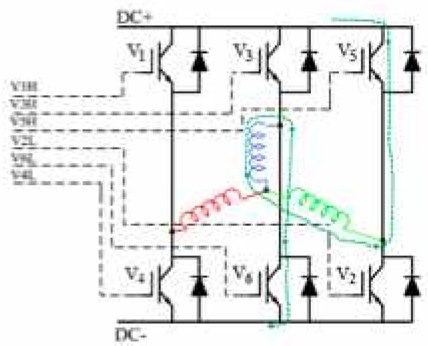

Figure 2 (B) – V5 and V6 ON; remaining all OFF

Following the same procedure, the 6-step driving sequence for a BLDC motor can be generated. Table 1 provides the switching sequence for power circuitry based on a Hall sensor output.

Table 1: Switching sequence

Hall C	Hall B	Hall A	Green	Red	Blue	Sector No.	MOSFET - ON
0	0	1	DC+	NC	DC-	0	V5, V6
0	1	1	DC+	DC-	NC	1	V4, V5
0	1	0	NC	DC-	DC+	2	V3, V4
1	1	0	DC-	NC	DC+	3	V2, V3
1	0	0	DC-	DC+	NC	4	V1, V2
1	0	1	NC	DC+	DC-	5	V1, V6

To build up the rotation, the motor should be periodically switched from one phase to another as shown below.

$$\rightarrow 0 \rightarrow 1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 5 \rightarrow$$

However, if the rotation has to be reversed, then the sequence needs to be reversed as well. Figure 3 shows the excitation waveform, including phase current, phase voltage, Hall sensor, and sector value. The top half of the figure shows the 3-phase winding excitation current and voltage in which black lines are phase current, while green, red, and blue lines are the phase voltage. As the phase current is trapezoidal, we call 6-step BLDC control trapezoidal control.

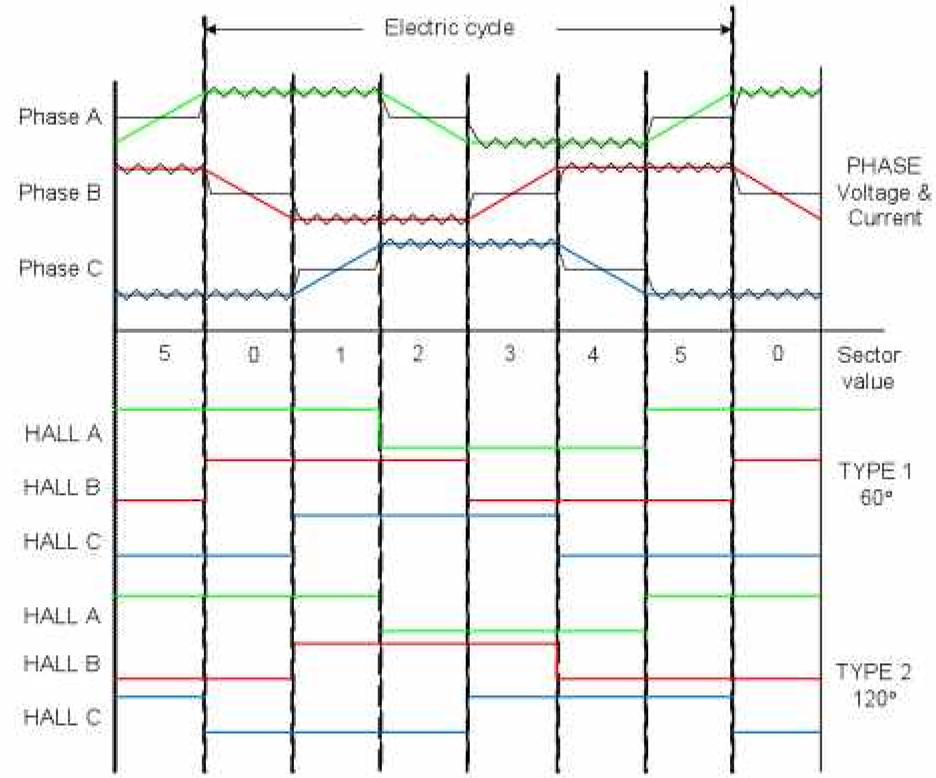

Figure 3 – Voltage and current through the windings

The Hall sensor and the excitation have a fixed relationship. Typically, there are two types of Hall sensors. For the first type, for each HALL phase, their waveforms have a 60-degree time-lapse. For the second type, the waveform time-lapse is 120 degrees.

With a basic understanding of commutation, let us now switch to the implementation of control functions, which are critical for any motor design.

Speed control

Following the commutation sequence in a given order helps in ensuring the proper rotation of the motor. Motor speed, then, depends upon the amplitude of the applied voltage. The amplitude of the applied signal is adjusted by using pulse width modulation (PWM). Figure 4 shows the switching signals for various power devices.

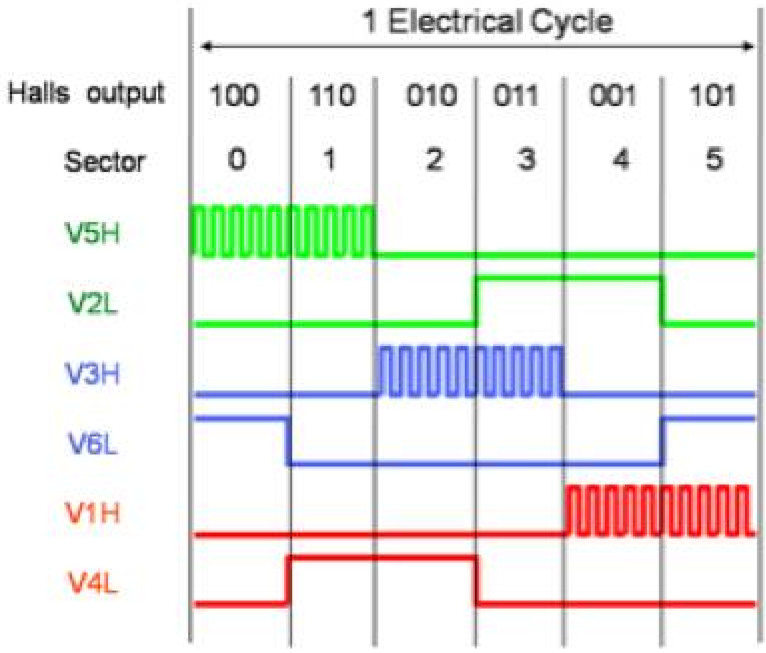

Figure 4: Switching signals of Power devices

It can be noted from the above diagram that the higher side transistors are driven using PWM. By controlling the duty cycle of the PWM signal, the amplitude of the applied voltage can be controlled, which in turn will control the speed of the motor. To be able to achieve the required speed smoothly, the PI control loop is implemented as shown in Figure 5.

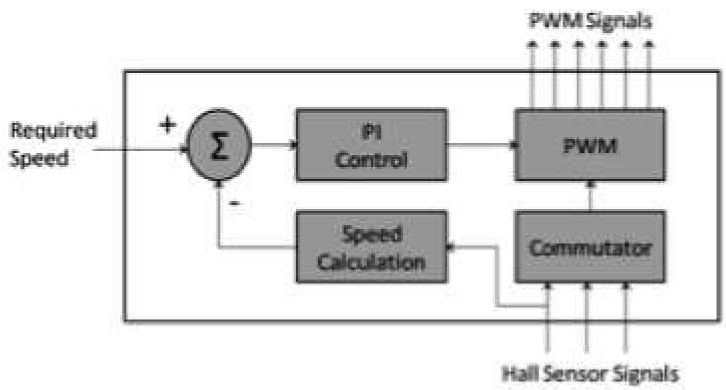

Figure 5: Speed control loop

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The difference between the required speed and the actual speed is input into the PI controller, which then modulates the duty cycle of the PWM based on the error signal obtained by the difference between the actual speed and required speed.

Torque control

Torque control is important in various applications where at a given point of time, the motor needs to provide a specific torque regardless of the change in load and speed at which the motor is running. Torque can be controlled by adjusting the magnetic flux, however flux calculations require complex logic. However, magnetic flux is dependent upon the current flowing through the windings. Thus, by controlling current, torque of a motor can be controlled.

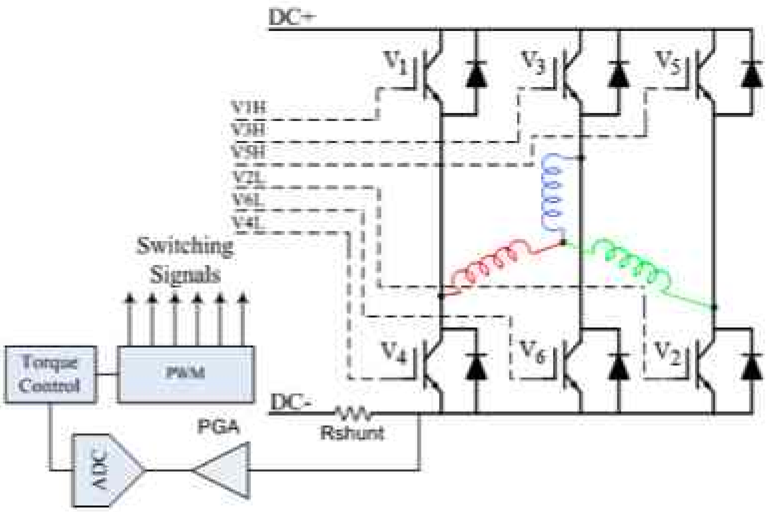

Figure 6: Torque control

Figure 6 shows the torque control implementation logic. By maintaining the current flowing through the windings, torque can be controlled. A PI loop similar to that used to control speed can be implemented to smooth the torque response curve with changes in load.

Motor Protection

In a motor control design, it is important to have protection logic to ensure safe operation of the system. For example, when the motor get stuck, the current through the windings can build up to a very high level, which can burn the power devices driving the motor.

Peak current This is the maximum instantaneous current allowed to flow through the windings for safe operation. This condition occurs in case of a short circuit. Hardware protection is applied to kill the PWM output whenever the current crosses the peak current limit.

Maximum Working Current This is the maximum output current when the motor stalls or is overloaded. This current can be controlled by application firmware. Implementation for this logic is similar to torque control.

Under Voltage – When the system is running on batteries, it becomes important to cut off the supply if the battery voltage drops below a particular limit. Since voltage drop is a slow process, it can be controlled via firmware.

Hall Sensor Failure – In sensor-based BLDC motors, rotation of the motor is based solely on the feedback obtained from the Hall sensors. Thus, in case of failure of the Hall sensors, the commutation sequence will break, which may cause the BLDC motor to become stuck and the current to rise above a particular limit. Hall sensor failure can be detected in firmware by checking whether the hall sensor signal changes its logic level or not. If it gets stuck to a particular level, then it can be detected as a failure and the motor drive can be disconnected, letting it run on inertia or be stopped by applying the brake. The action to be taken depends on the requirements of the design.

There are controllers available in the market which can do BLDC motor control. With the advent of System-On-Chip (SOCs) controllers, the complete control logic for implementing BLDC motor control can be implemented within a single device. This not only helps in reducing the cost but such integration provides flexibility to enable designers to manage control of the system according to application-specific requirements.

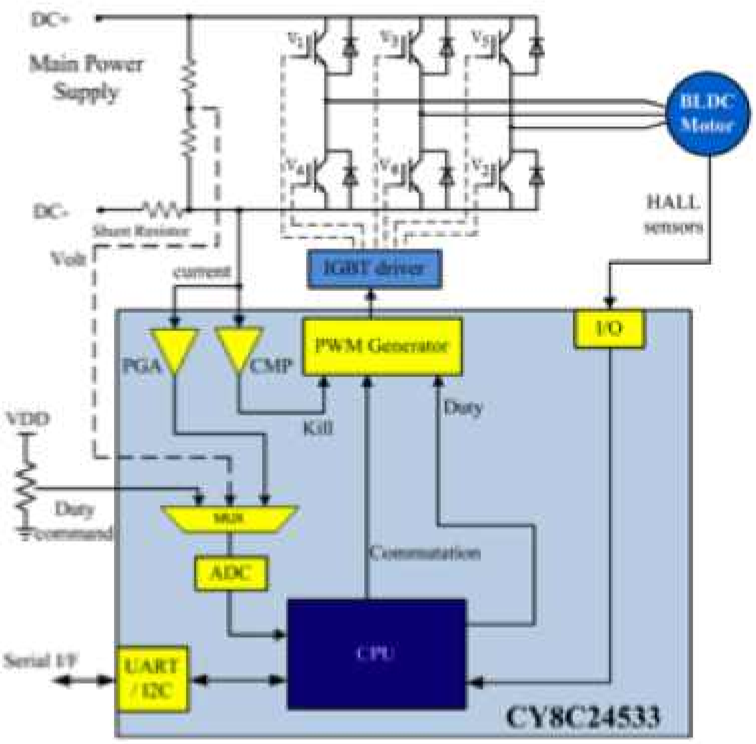

Figure 7: Implementation of BLDC motor control system using PSoC

Figure 7 shows the design of a motor control system using Cypress's flagship controller Programmable System on Chip (PSoC) – CY8C24533. In this design, which uses a Hall sensor input the commutation sequence is controlled by generating PWM signals. This device has a built-in ADC, amplifier (PGA), and comparator (CMP), which are used to measure voltage and current for the implementation of speed and torque control. The PI control loop is implemented in firmware to execute on the CPU. For over current protection, the comparator (CMP) is used to kill the PWM output in case of over current. CMP blocks available inside the device provide an internal programmable threshold voltage for use in accommodating for motors across a wide range of currents. This device also provides access to communication blocks which can be used to implement communication protocols like UART, SPI, and I2C to transmit debug / control data to the host controller.

This article provides the basic implementation of BLDC motor control system for speed and torque control. It also discusses the importance of protection logic and how to implement the same in a given system.

About the Author

Pushek Madaan *is currently working with Cypress Semiconductor India Pvt. Ltd. as a Senior Application Engineer. His interests lie in designing Embedded system applications in C and assembly languages, working with analog and digital circuits, developing GUIs in C# and, above all, enjoying adventure sports. Pushek can be reached at pmad@cypress.com.*