



Trapezoidal Control of BLDC Motors

Trapezoidal Control of BLDC Motors

Trapezoidal control, also called six-step or 120° block commutation, is one of the simplest brushless DC (BLDC) motor control methods available. The basic concept of trapezoidal control is to apply square-wave currents to the motor phases that align with the BLDC motor's trapezoidal back-EMF profile for optimum torque generation. The six-step name comes from the fact that the inverter MOSFETs assume only six on/off state combinations, resulting in six possible stator field orientations within the rotor magnetic field's plane of rotation. The six possible inverter states must follow a specific sequence depending on the desired rotation direction of the motor so that the stator and rotor field orientations arrangement produces maximal torque. Rotor position feedback, generally achieved with hall sensors mounted on the motor (sensored) or by sensing the back-EMF of the motor phases while rotating (sensorless), determines proper commutation timing.

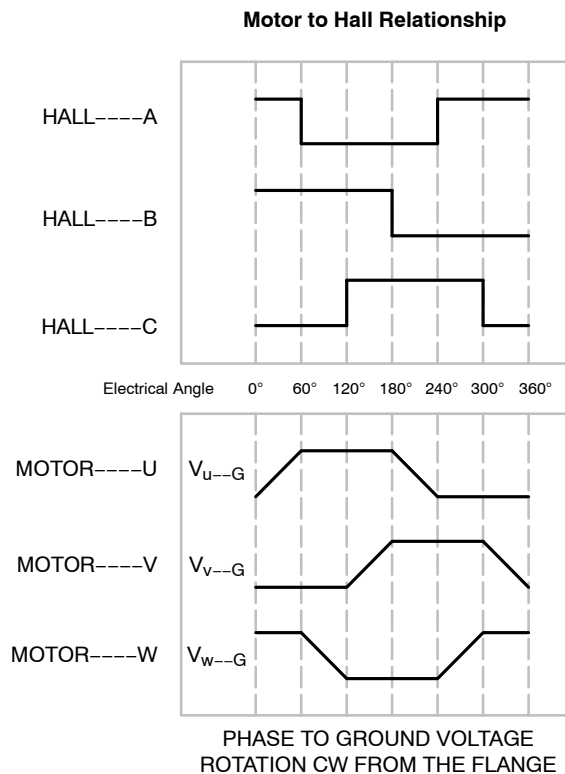


Figure 1. Hall Sensor Commutation Timing Diagram

Sensored trapezoidal control does not require any voltage or current feedback signals for operation. Instead, it uses position feedback from Hall sensors to determine the correct sequence for energizing the phases of the motor. Hall sensors are mounted on the motor and sense rotor position through the Hall Effect caused by the rotor permanent magnet's rotating

magnetic field. Sensored trapezoidal control is generally easier to implement and allows for proper commutation even at startup because the rotor position information is present even at zero speed. A typical Hall sensor–phase voltage commutation timing diagram is shown in Figure 1.

Sensorless trapezoidal control uses the back–EMF generated by the motor’s rotation to determine the correct motor commutation sequence. For trapezoidal control, only two motor phases are energized at a time. Because no current flows in the non–energized phase, the back–EMF of that phase can be directly sensed during that time. For BLDC motors, the back–EMF profile is trapezoidal; during the non–energized time frame, the phase back–EMF is either linearly increasing or decreasing. Most back–EMF position feedback techniques for trapezoidal control rely on a technique involving back–EMF zero–crossing detection (ZCD). The back–EMF is monitored to determine the moment when it crosses a reference point – either the neutral motor voltage or half the DC bus voltage. One major drawback of sensorless control is that because back–EMF magnitude is proportional to rotational speed, the motor must rotate at a minimum speed to have a high enough back–EMF magnitude to sense the rotor position properly. Thus, some startup mechanism is required to “kickstart” the motor until it achieves sufficient rotational speed.

While sensored trapezoidal control is easier to implement, it requires increased cost due to the hall sensors installed in the motor. It also requires more wiring from the motor, which may not be possible in some environments. Sensorless control is more complex, must be tuned for specific loads or operating conditions, and may have difficulty starting up under heavy loads. However, sensorless control is well suited for applications where the load profile is well known and/or increases with speed, such as a fan.

Figures 2 and 3 below illustrate examples of sensored and sensorless trapezoidal motor control systems.

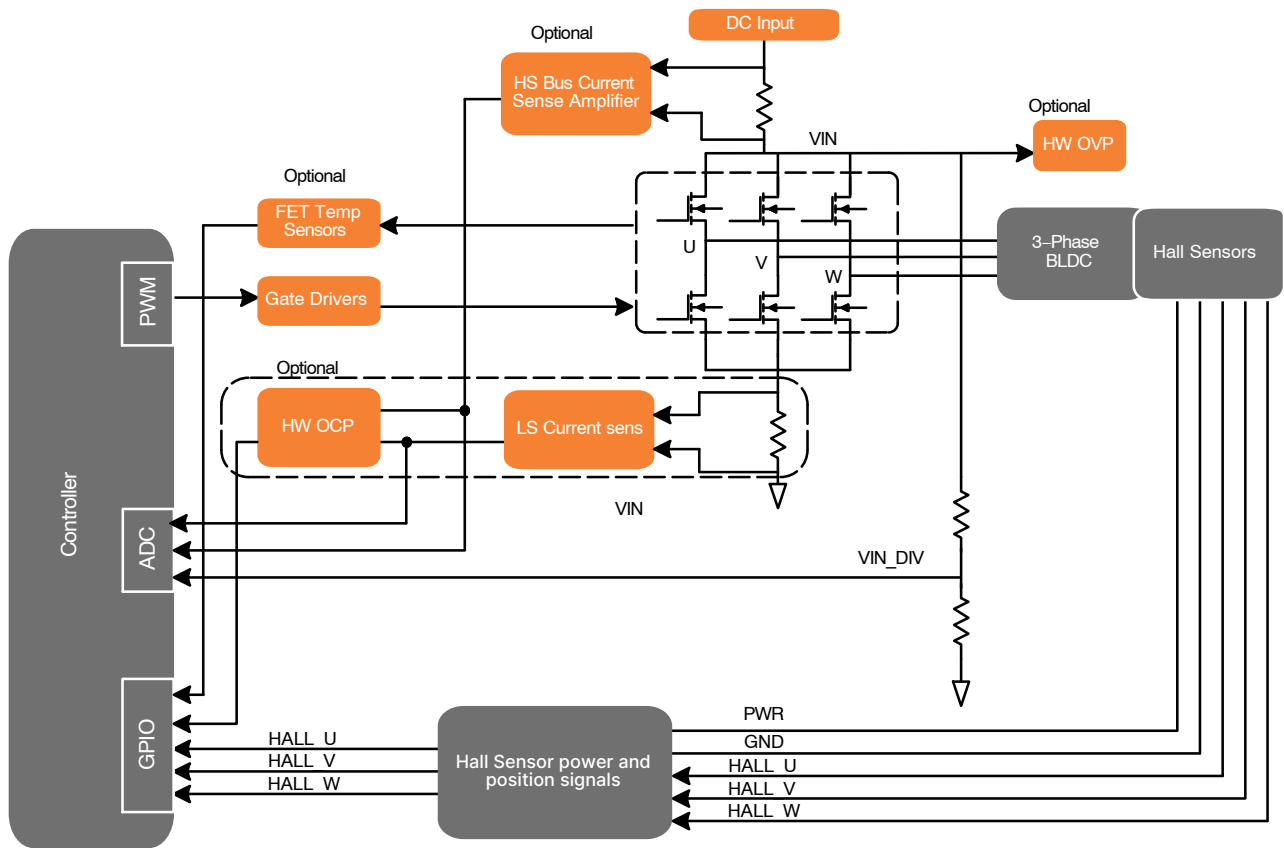


Figure 2. Sensored Trapezoidal Motor Control System Block Diagram

Figure 2 shows the required signals for sensored trapezoidal control. Hall sensors must be powered externally and are generally open–drain outputs, though they can be push–pull. When placing Hall sensors at 60° or 120° intervals on the motor, determining the correct commutation sequence requires decoding the Hall signal sequences differently. Always refer to the motor manufacturers’ Hall sensor commutation timing diagrams to determine the correct Hall sensor–phase commutation sequence. If no timing diagram is available, the correct commutation sequence can be determined empirically. Hall sensor signals can also be noisy and may benefit from hardware or software filtering.

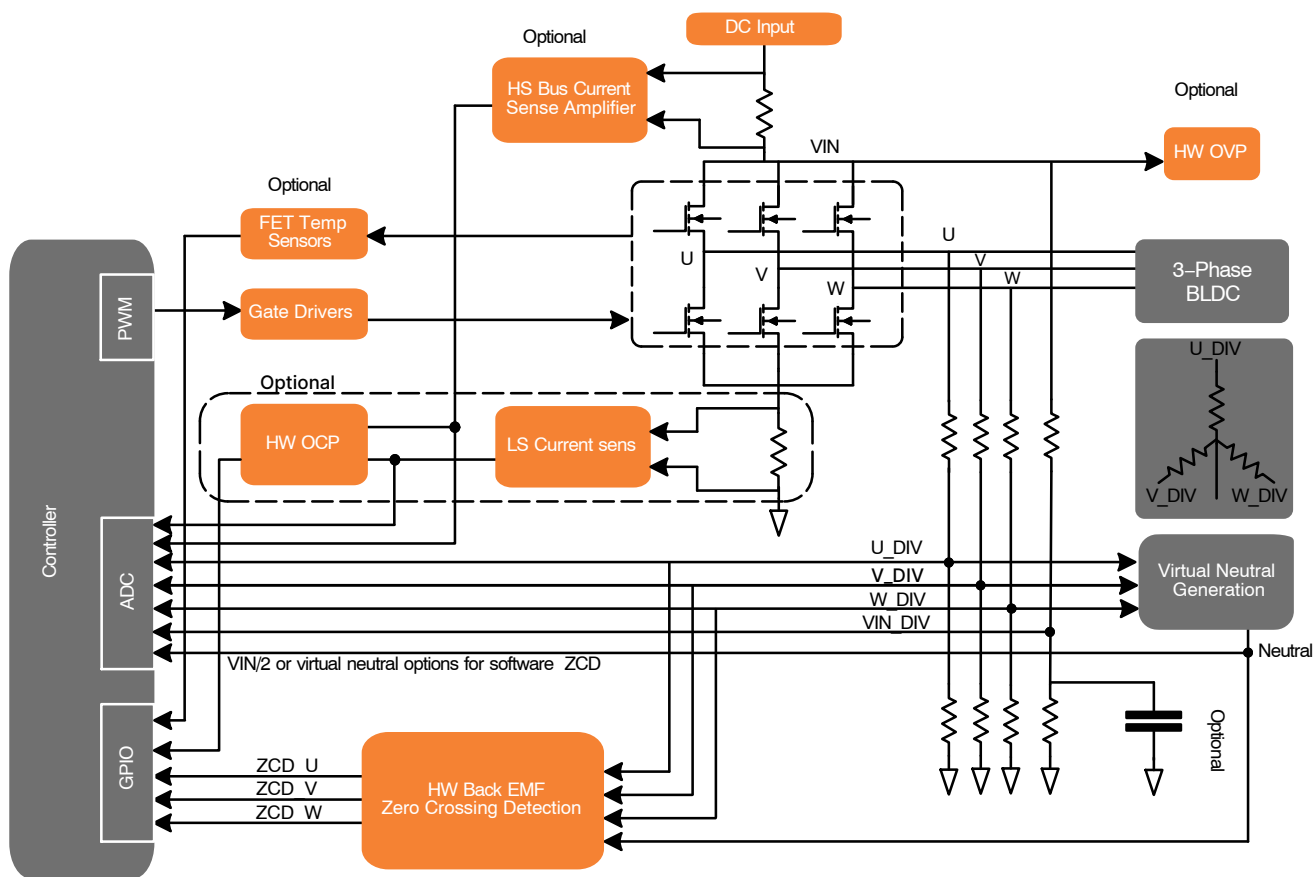


Figure 3. Sensorless Trapezoidal Motor Control System Block Diagram

Figure 3 shows the signals required for sensorless trapezoidal control. Back-EMF ZCD can be performed either in firmware or hardware. For software ZCD, back-EMF detection requires an ADC with a minimum of four inputs (3x phase voltage, $V_{IN}/2$, or neutral reference), with all voltages divided to adjust to the controller ADC's full-scale range. Hardware ZCD implements comparators to compare the phase voltages to the reference points and provide the zero-crossing signals directly to the controller via GPIO pins. If using hardware ZCD, the recommendation is to filter the divided phase voltages (filter out PWM switching) and implement comparator hysteresis to prevent glitches in the ZCD signals due to non-ideal and noisy back-EMF signals. Note, however, that this may limit the maximum rotational speed available due to the delay caused by filtering. Digital filtering can also be implemented in software ZCD – advantageous because motor speed can adjust filtering, e.g., heavy filtering at lower speeds and reduced filtering at higher speeds. While using a comparison to half the DC bus voltage is possible, a comparison to the motor neutral (virtual or actual) is preferred as it is more tolerant to phase imbalance. If the motor neutral is not accessible from the motor, a simple Wye-connected resistor network connected to the motor phases can recreate virtual neutral.

Additional Design Considerations

Over-Current Protection (OCP)

OCP can be achieved in hardware, software, or both. Typically, hardware-based OCP will provide faster response, but software-based OCP has more flexibility. Another limitation of software-based OCP is that the full-scale current measurement range of the ADC limits the maximum trigger point. A combined hardware/software implementation may implement a latching OCP to mitigate catastrophic hard faults quickly and use software-based OCP for dynamic events such as cycle-by-cycle phase current limiting.

Over-Voltage Protection (OVP)

In specific applications, such as where regenerative braking may cause excessively high voltages on the DC bus, it may be necessary to implement HW OVP via diode-clamping or crowbar circuit. Software-based OVP can also be implemented by monitoring the DC bus and protecting the motor from potentially damaging voltages above the rated voltage of the motor by disabling the inverter output.

Over-Temperature Protection (OTP)

Monitoring the inverter MOSFET and board temperatures is generally a good idea for all control methods, especially when the system is subjected to varying ambient temperatures or in the event of cooling system failure. For example, PWM duty cycle limits can be dynamically reduced as temperature increases, and thermal monitoring can also help determine component degradation over time.

MOSFET Selection

Selecting the best MOSFET or switch is critical for any motor control system and should be specifically tailored to system requirements. The output inverter stage influences the system's overall efficiency, and an incorrect MOSFET selection could result in significant performance degradation and even catastrophic system failure. It is beyond the scope of this material to discuss all specific factors related to proper switch selection. However, onsemi offers a wide variety of [highly efficient MOSFETs](#) and transistors designed for motor control applications for different voltage ranges.

Trapezoidal control combined with essential protection and design techniques can be one of the most efficient methods of driving an electric motor for power tools and robotics by improving the control and accuracy of the motors.

onsemi, **Onsemi**, and other names, marks, and brands are registered and/or common law trademarks of Semiconductor Components Industries, LLC dba "**onsemi**" or its affiliates and/or subsidiaries in the United States and/or other countries. **onsemi** owns the rights to a number of patents, trademarks, copyrights, trade secrets, and other intellectual property. A listing of **onsemi**'s product/patent coverage may be accessed at www.onsemi.com/site/pdf/Patent-Marking.pdf. **onsemi** reserves the right to make changes at any time to any products or information herein, without notice. The information herein is provided "as-is" and **onsemi** makes no warranty, representation or guarantee regarding the accuracy of the information, product features, availability, functionality, or suitability of its products for any particular purpose, nor does **onsemi** assume any liability arising out of the application or use of any product or circuit, and specifically disclaims any and all liability, including without limitation special, consequential or incidental damages. Buyer is responsible for its products and applications using **onsemi** products, including compliance with all laws, regulations and safety requirements or standards, regardless of any support or applications information provided by **onsemi**. "Typical" parameters which may be provided in **onsemi** data sheets and/or specifications can and do vary in different applications and actual performance may vary over time. All operating parameters, including "Typicals" must be validated for each customer application by customer's technical experts. **onsemi** does not convey any license under any of its intellectual property rights nor the rights of others. **onsemi** products are not designed, intended, or authorized for use as a critical component in life support systems or any FDA Class 3 medical devices or medical devices with a same or similar classification in a foreign jurisdiction or any devices intended for implantation in the human body. Should Buyer purchase or use **onsemi** products for any such unintended or unauthorized application, Buyer shall indemnify and hold **onsemi** and its officers, employees, subsidiaries, affiliates, and distributors harmless against all claims, costs, damages, and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if such claim alleges that **onsemi** was negligent regarding the design or manufacture of the part. **onsemi** is an Equal Opportunity/Affirmative Action Employer. This literature is subject to all applicable copyright laws and is not for resale in any manner.

PUBLICATION ORDERING INFORMATION

LITERATURE FULFILLMENT:

Email Requests to: orderlit@onsemi.com

onsemi Website: www.onsemi.com

TECHNICAL SUPPORT

North American Technical Support:

Voice Mail: 1 800-282-9855 Toll Free USA/Canada

Phone: 011 421 33 790 2910

Europe, Middle East and Africa Technical Support:

Phone: 00421 33 790 2910

For additional information, please contact your local Sales Representative

