EECS 3216

Project Proposal: BLDC Motor Driver

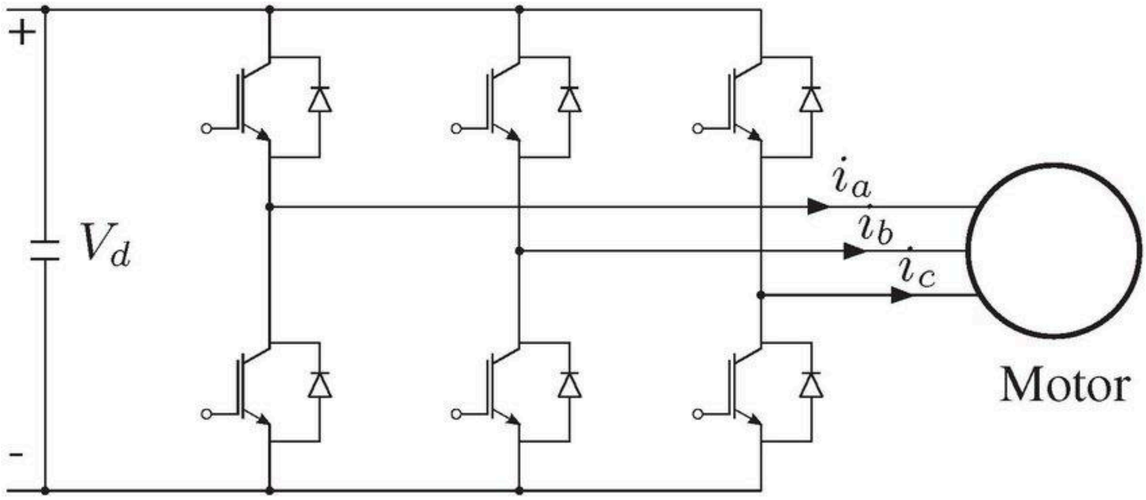
Feb 24 - March 1

Abstract

Our project is about a driver for a three-phase BLDC motor. We will implement SVPWM (space vector PWM) in order to control the three phases of the motor. We will also implement an inverter with discrete components (capacitors, transistors, fly back diodes, etc) in order to demonstrate the driver working, using an RC low pass filter and oscilloscope probes.

Circuit Topology

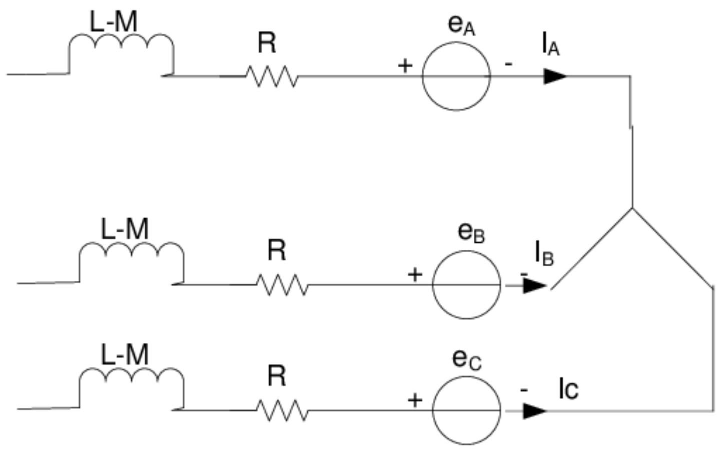
The following is the topology we will implement. We'll be using MOSFETs to be able to control the fast switching efficiently. The diodes across the transistors are for flyback protection in order to protect the transistors from the back EMF emitted by the motor. The control of the transistor states will be done by the SVPWM.sv module.



(*Fig. 2. Three Phase Inverter Topology*, n.d.)

Analysis

Assuming proper implementation of the SVPWM module (and balanced loads $i_a + i_b + i_c = 0$), we can model the above driver as the following circuit.



(*Figure 2.2. Circuit Diagram Stator Winding BLDC Motor Circuit Equations...*, n.d.)

From this we can get the equations (*Torque and Speed Controlling of a PMSM/BLDC Using Simulink and SOLO Blockset*, 2022).

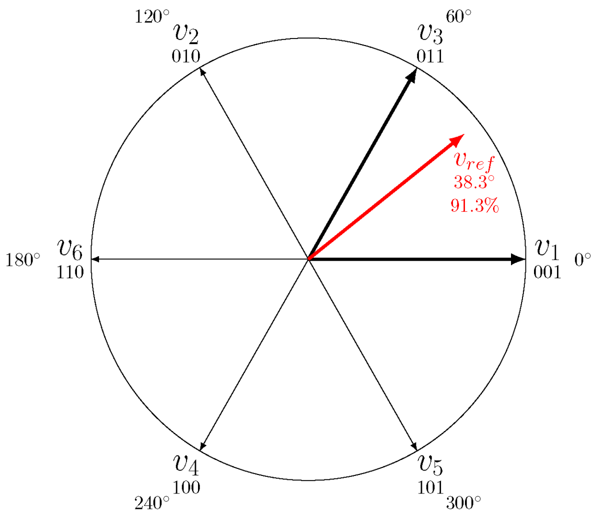
$$\frac{d}{dt}\begin{bmatrix} i_a \\ i_b \\ i_c \\ \omega \end{bmatrix} = \begin{bmatrix} -R/L & 0 & 0 & -k_e\psi_a/L \\ 0 & -R/L & 0 & -k_e\psi_b/L \\ 0 & 0 & -R/L & -k_e\psi_c/L \\ k_e\psi_a/J & k_e\psi_b/J & k_e\psi_b/J & -B/J \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \\ \omega \end{bmatrix} + \begin{bmatrix} V_a/L \\ V_b/L \\ V_c/L \\ 0 \end{bmatrix}$$

(Lee et al., 2023)

Where $\varepsilon_k = k_e\psi_k \cdot \omega$ is the back emf of the motor, R is the winding resistance, L is the winding inductance, J is the moment of inertia of the motor, B is the coefficient of rotational friction and $\frac{\varepsilon_a i_a + \varepsilon_b i_b + \varepsilon_c i_c}{w} = k_e(\psi_a i_a + \psi_b i_b + \psi_c i_c) = T_e$ is the electrical torque. It can be further shown $T_e = \frac{3}{2}k_t \cdot Icos(\phi)$ where I is the magnitude of the current phases, k_t the torque constant and ϕ the angle between the voltage and current phasors are. At equilibrium, we get that $\omega = \frac{T_e}{B} = \frac{3k_t}{2B} \cdot Icos(\phi)$ which is the control that we aim to achieve.

Software Implementation

In order to maximize the power transmitted to the motor through the inverter, we will implement Space Vector Pulse Width Modulation instead of SPWM (Sinusoidal Pulse Width Modulation). The SVPWM module will be implemented in system verilog to be used with the De10-lite board.



(*Space Vector PWM Intro*, 2017)

In SVPWM, we are able to control the states of the transistors in an inverter in order to generate three-phase AC sine waves to drive a BLDC motor. The inner components of the motor (winding resistance and inductance) act as a low pass filter, smoothing the jumps of the raw PWM signal.

Concept

In order to control the inverter states there are 8 possible "vector" states. I assume the convention that the output vector is a 3-bit number, and each bit represents if a given top transistor in each leg is conducting. In order to not short the power supply, if a top transistor on leg A is on, the bottom transistor must be off. The possible vector states are as follows.

Vector	V_{AB}	V_{BC}	V_{CA}
V0 = 000	0	0	0
V1 = 100	+V	0	-V
V2 = 110	0	+V	-V
V3 = 010	-V	+V	0
V4 = 011	-V	0	+V
V5 = 001	0	-V	+V
V6 = 101	+V	-V	0
V7 = 111	0	0	0

("Space Vector Modulation," 2024)

Notice that the vectors do not follow a normal counting order; this is in order to minimize the switching losses in the inverter. If on some vector transition we flip two or more bits of the output, there are going to be greater switching losses; for this reason, there are two zero voltage vectors, V0 and V7.

Each sector of the trapezoid has a specific vector transition sequence to represent an output voltage within that sector and minimize switching losses (as mentioned in the previous paragraph). Follow the vector sequence for each sector.

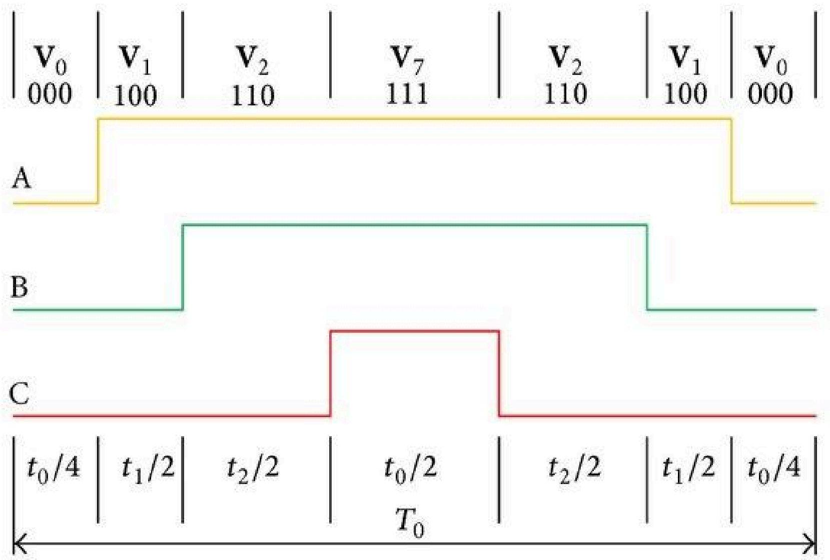
Sector	Vector Sequence
S1	V0 - V1 - V2 - V7 - V2 - V1 - V0
S2	V0 - V3 - V2 - V7 - V2 - V3 - V0
S3	V0 - V3 - V4 - V7 - V4 - V3 - V0
S4	V0 - V5 - V4 - V7 - V4 - V5 - V0
S5	V0 - V5 - V6 - V7 - V6 - V5 - V0
S6	V0 - V1 - V6 - V7 - V6 - V1 - V0

Analysis

In order to actually dynamically generate a sinusoidal wave, we need to control the period allocated to each vector. These can be calculated with the following equations. (*Space Vector PWM Techniques*, n.d.).

1. $T_1 = \frac{T_s}{\sqrt{3}} sin(\theta - \pi/3)$
2. $T_2 = \frac{T_s}{\sqrt{3}} sin(\theta)$
3. $T_0 = T_s - (T_1 + T_2)$

Where T_s is the switching period (dependent on frequency, number of samples etc) T_1, T_2 are the periods of the first and second active vectors respectively and T_0 is the period of the zero vectors (V0 and V7). Below is an image of the allocated periods for each vector in sector 1.



(*Switching Sequence of Traditional SVPWM.*, n.d.)

Zero Mark Deliverables

Certain deliverables we'd like to add to the project include being able to demonstrate the driver working with a real BLDC motor. If we are able to find an affordable motor it would be very interesting to test our project in it.

Another zero-mark deliverable would be to implement control systems into the driver. Maybe a simple PID control, or even FOC (Field Oriented Control).

References

Fig. 2. Three phase inverter topology. (n.d.). ResearchGate. Retrieved February 27, 2025, from https://www.researchgate.net/figure/Three-phase-inverter-topology_fig1_317297464

Figure 2.2. Circuit diagram stator winding BLDC motor circuit equations... (n.d.). ResearchGate. Retrieved February 28, 2025, from https://www.researchgate.net/figure/Circuit-diagram-stator-winding-BLDC-motor-circuit-equations-can-be-described-by-the_fig2_355046440

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