Three-Phase Variable Frequency Motor Controller & Inverter Implemented using Space Vector Pulse Width Modulation on a Field Programmable Gate Array

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Introduction

In this project, Space Vector Pulse Width Modulation is implemented through an FPGA based design process for powering a Formula SAE Electric Racecar. Formula SAE is an intercollegiate design competition where students design and build small-scale open-wheel open-cockpit racecars. Due to the lack of specialized motor controllers available in the market, the decision was made to create a custom Three-Phase variable frequency motor controller.

Description

Space Vector Pulse Width Modulation (SVPWM) is a switching algorithm used to generate a digital approximation of a three-phase AC power signal. SVPWM offers many advantages over other inverter and motor controller alternatives. The SVPWM switching algorithm is highly efficient and generally offers less harmonic distortion.

SVPWM uses a rotating reference vector to mathematically replicate each phase with the use of a square wave. Four steps are completed to properly implement the correct SVPWM switching algorithm.

Step 1) Calculation Va, Vb, and Vc (The voltage values of each phase).

$$V_a = V_{dc} sin(\omega t)$$
$$V_b = V_{dc} sin(\omega t + \frac{2\pi}{3})$$
$$V_c = V_{dc} sin(\omega t + \frac{4\pi}{3})$$

Step 2) Calculation of V_{alpha}, V_{beta}, and V_{ref} vectors.

$$V_\beta = \frac{\sqrt{3}}{3} V_b - \frac{\sqrt{3}}{3} V_c$$
$$V_\alpha = \frac{2}{3} V_a - \frac{1}{3} V_b - \frac{1}{3} V_c$$
$$V_{reff} = \sqrt{V_\alpha^2 + V_\beta^2}$$

Table 1 Value for placement position in each sector

Sector	Angle
1	0-59
2	60-119
3	120-179
4	180-239
5	240-299
6	300-359

Step 4) Calculation of T_a, T_b and T_0.

$$T_0 = \frac{1}{f_z}$$

$$T_1 = \frac{\sqrt{3}T_0V_{reff}}{V_{dc}} * \sin\left(\frac{n\pi}{3} - (\omega t)\right)$$

$$T_2 = \frac{\sqrt{3}T_0V_{reff}}{V_{dc}} * \sin\left((\omega t) - \frac{(n-1)\pi}{3}\right)$$

around two lookup tables that are used to initiate an Inverse Clarke pproximate two different sine waves. V_{Alpha} and V_{Beta}. The Inverse Clarke Transform runs these vectors through a module that enables one of six equations based on the current sector the vectors are found in. After the equation is applied, the resulting values are fed to a state machine constructed as a Pattern Generator.

The Pattern Generator is responsible not only for generating the third phase from the inverse Clark Transform values, but, as its name suggests, the Pattern Generator is the primary component in generating the Space Vector Pulse Width Modulation output signal. The Pattern Generator is a six state state-machine that outputs a pulse width modulation signal biased off the values provided by the Inverse Clark Transform.

The six PWM signals from the pattern generator I filtered through a final state machine before output to six IGBTs. This final state machine generates dead time in between the PWM transitions. This dead time compensates for the slew rate of the IGBT's without this generated dead time the IGBT's would momentarily short to ground when the PWM transitions from high to low. The basic IGBT inverter circuit can be seen in the figure below.

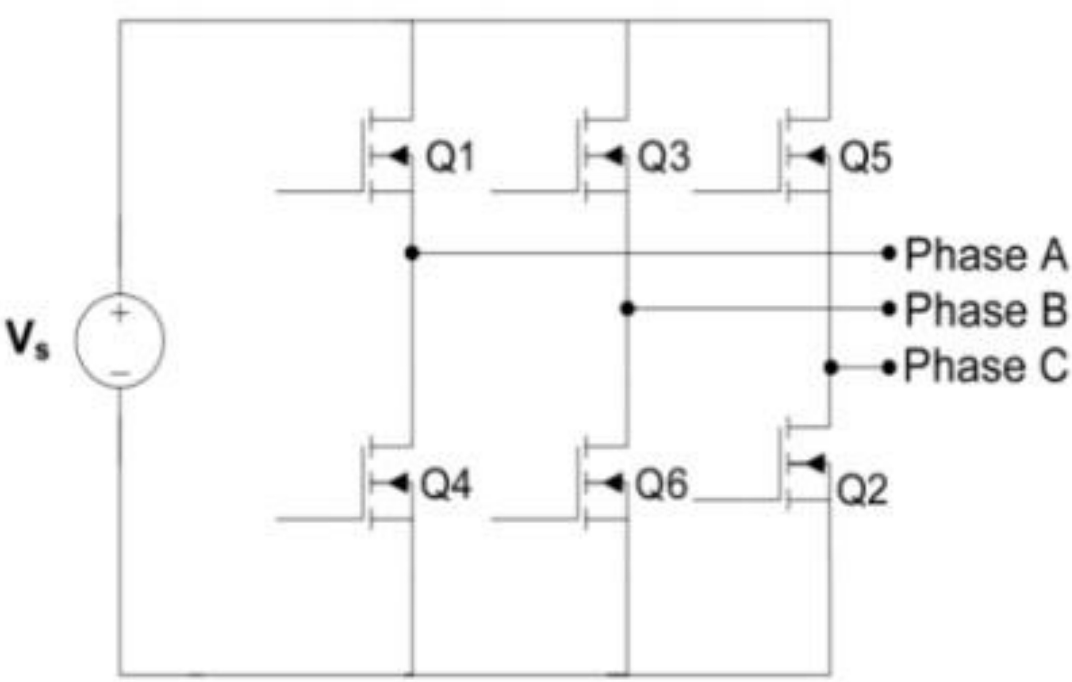

Figure 1: basic IGBT inverter circuit

Future plan

Our final goal is an operational digital variable frequency drive motor controller and inverter controlled by a SVPWM IP core. The IP core will be simulated in a Verilog test bench for all possible inputs. In addition to simulation testing, the IP core will be run through at least 100 hours of automated testing using a small 12V three phase motor. After the simulation and low voltage testing is completed the IP core will be declared safe for high voltage (300V) testing. After an additional 24 hours of automated testing at 300V the SVPWM motor controller will be declared safe for implementation on the formula SAE car.