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Field-Oriented Control - Permanent Magnet Synchronous Machines

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Hi, I'm Jonathan Dodge with Qorvo. This video provides a quick overview of field oriented control for permanent magnet synchronous machines. Let's begin.

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First, a quick story. A long time ago, I took two induction machine control classes as part of my master's degree curriculum, and I managed to pass the classes and I even received A grades. But it was not until I started working at Qorvo that I really began to understand field oriented control. It has been super helpful for me to work here, among other experts at Motor Control.

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And with that, let's talk about what we will cover in this video. First, a quick overview of three phase permanent magnet synchronous machines of so-called permanent magnet synchronous motors. And then we'll peek at Qorvo motor controller and driver architecture. We'll focus on field oriented control topics. And then we'll finish up with road field oriented control solutions and support.

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When using a control motor controller and driver, a motor drive system reduces to four building blocks. First, a variety of power source options. Second, the motor controller and driver with built in power management gate drivers. ARM cortex microcontroller configurable analog front end and communications. Third, a three phase inverter. And finally the motor, which in this video is a permanent magnet synchronous machine.

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The inverter is the ubiquitous two level voltage source inverter. At any given time, one switches on in each inverter leg except during switching. When there is a short dead time with both switches off, the switches are usually MOSFETs and the inverter allows current to freewheel during dead time through the MOSFET. Body diode voltage is applied to the motor terminals by six switch states and motor current free wheels through the inverter, and two redundant zero voltage states.

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A switch map is a convenient way to visualize switch states and corresponding motor voltages. The n or p notation corresponds to the bottom or top switch driven on, respectively. Here we have a couple images of disassembled permanent magnet synchronous machines. The one on the left shows the magnets on the rotor and windings on stator poles. Magnet shape and winding scheme produce nearly sinusoidal back emf as the rotor spins.

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Windings are usually white connected, so they have a common center node. The right side image shows an exterior rotor with magnets. The stator and windings are not shown. Field oriented control requires current feedback. Ideally, at least two phase currents are sampled. Often, all

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three are sampled to mitigate noise by checking whether there's some equal zero, and you can force them to equal zero.

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There's noise precision differential programable gain amplifiers. Condition current sent signals, which are typically the voltage drop across current sensor resistors. Single ended programable gain amplifiers facilitate sensing DC link voltage, temperature and other parameters. Overcurrent protection. Comparators with digital to analog converters provide fast acting and more filtered overcurrent protection. The extremely fast analog to digital conversion and hardware multiply and divide in each PAC5500

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MCD minimum delay induced errors in field oriented calculations. If position sensing is needed, such as in high precision positioning, the Qep module decodes quadrature encoder signals. The pulse width modulation generator is the premium and dead time block. It includes safety logic from overcurrent, comparators, and other sources. The Integrated Power Manager delivers power to the high side and low side gate drivers, and all internal circuitry.

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Torque causes the rotor to spin. As permanent magnet flux is pulled toward rotating electromagnetic state of flux. Field oriented control regulates stator flux locations and intensities and thus controls torque. In the cartoon cutaway drawing on the right. The x's indicate stator current going away, while a dot indicates current coming towards you. Each magnetic axis has a corresponding winding.

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With the DC link as the energy source. The inverter alternately applies line to line voltages to the motor. Remember that flux is volts seconds, so in the end the inverter creates rotating stator flux. The outputs of field oriented control are three voltage references that are inputs to the wind generator. The generator gate drivers and inverter approximate the reference voltages at the motor by averaging time spent at nearby vectors.

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There are many methods. There are books and countless papers written on this subject. All methods are independent of field oriented control. Space vector, which has many types, fully utilizes the DC link voltage by varying the potential of the motor winding common connection point with respect to the DC link. Now it's time for a little math. The Clark transformation, also called alpha beta transformation, results in a two axis stationary reference frame.

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This is possible because we force phase voltages and hence currents to be balanced, meaning they sum to zero. The Clark transformation is actually a 3 to 3 axis transformation, but gamma axis values are always zero in a balanced three phase system, so we ignore the gamma axis. Alpha beta parameters are needed in field oriented control, as we will soon see.

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The park transformation, also called DQ transformation, results in a two axis rotating reference frame. The same simplification from balanced three phase operation applies here. So we ignore the zero axis. It is always zero because there is no direct current in the motor. The park transformation includes sine and cosine functions that require the rotor flux angle. This allows alignment of the d axis with the rotor flux, as indicated by the magnet in the image.

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Motor torque is proportional to current along the q axis, and because a permanent magnet synchronous machine is synchronous, dx axis current is zero for maximum torque per motor. Current control variables are direct currents and so are easy to process with proportional integral controllers. We already looked at what is inside a core of a motor controller and driver. Now let's look at the computations which are highlighted in the green rectangle.

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The synchronized current measurements go through the Clark transformation, resulting in alpha beta currents. The motor position module uses these along with feedforward signals V, alpha and beta to calculate rotor flux angle and angular velocity. Motor position library functions available from Qorvo handle both position feedback and sensor loss control. Various methods can be used to estimate rotor position, which is theta, and speed which is omega.

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Shown here are two observers and an angle demodulator motor parameters, namely stator winding, resistance and inductance are required. Knowing the rotor flux angle, the park transformation yields ID and IQ in a rotating reference frame. These become VD and VQ after filtering and proportional integral controllers. An inverse park transformation yields the alpha and beta, which after inverse Clarke transformation, become the three phase reference voltages needed by the generator.

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All these computations are processed extremely fast in the PAC5500, with a 150MHz ARM cortex CPU and single cycle multiply and divide and floating point unit. The oscilloscope waveforms here show an example of a well tuned IQ proportional integral controller. The waveforms on the top and one that needs tuning on the bottom. The bottom image shows IQ reference drifting after a step change in torque, along with speed reference and estimated speed.

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You can see the parameters are wandering around the top image shows normal response to the torque change to make tuning easy. Kerviel auto-tuning functions can identify motor parameters and automatically calculate proportional integral controller gains. In summary, field oriented control maximizes motor performance and efficiency, time sensitive measurements and math intensive calculations are readily implemented in Qorvo PAC5500 series motor controller and drivers.

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High integration consolidates functions which saves space by eliminating many components from the circuit board. And perhaps most importantly, it greatly reduces design risk. For example, integrated power management includes feedback compensation. This eliminates the need to tune a DC to DC converter to supply power to the controller and to the gate drivers. Finally, pre certified firmware is available to perform the intricate field oriented control calculations for you.

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on Qorvo.com. You will find everything you need to design a motor control system including data sheets, user guides, firmware libraries, evaluation kits, and application support. And with that, I would like to thank you for watching.

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