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MultiMotor Series

Application Note

Vector Control of a 3-Phase AC Induction Motor Using the ZNEO Z16FMC MCU

AN037803-0117

Abstract

This application note discusses the Field Oriented Control (FOC) of 3-phase AC induction motors. Field Oriented Control is also referred to as Space Vector Control. Vector control provides efficient and accurate control of the motor's speed and torque, for example, in a DC motor, where the motor's field flux and armature MMF are always orthogonal to each other, independent of the speed. Additionally, RAM and ROM memory is continuously checked for Class B requirements.

3-phase AC-induction motors are mechanically simple, rugged, highly reliable, lower in cost per horsepower than DC motors, and capable of more torque and efficiency than single-phase AC motors. Depending on the size, these motors are more efficient than permanent synchronous motors. A 3-phase AC induction motor can be controlled by varying its inputs according to a mathematical model of the rotor flux field in a complex vector space. Vector Control has been the domain of Digital Signal Processors (DSPs) and a few 32-bit and 16-bit microcontrollers. Cost pressures and increased consumer expectations have driven design engineers to seek basic hardware solutions that extract maximum performance from motors used in consumer goods. This application note demonstrates the use of Zilog's Z16FMC ZNEO! 16-bit microcontroller to implement Vector Control of an AC induction motor.

The Z16FMC Series of Flash MCUs used in this application are based on Zilog's advanced 16-bit ZNEO CPU core and are optimized for motor control applications.

Note: The source code file associated with this application note, AN0378-SC01, was tested with version 5.0.1 of ZDSII for ZNEO MCUs. Subsequent releases of ZDSII may require you to modify the code supplied with this application.

Discussion

The currents flowing through each of the three motor windings can be summed up to form a current vector *Is,* which can be transformed into an orthogonal two-current stationary frame. The orthogonal components are referred to as *d* for the flux direct component and *q* for the torque producing quadrature current. The physical relationship between flux and torque currents is utilized in electro-magnetic machines, such as an electro motor, to convert electrical energy into kinetic energy. However, there are situations in which this orthogonal relationship between the *d*-*q* vectors becomes distorted and mechanisms have to be applied to compensate for the non-orthogonal effects. High speeds can disturb this orthogonal relationship in a motor, partially due to the effects of the increased BEMF. In this situation, the *q*-component may be lagging and optimal efficiency is no longer achieved. Vector control aims to compensate for this effect. Additionally, it allows for a near-instantaneous control of the torque.

Zilog's Z16FMC Series Flash MCUs are based on Zilog's advanced Z16FMC 16-bit ZNEO CPU core and are optimized for such motor control applications. These MCUs support the control of single and multiphase variable speed motors. Target applications include consumer appliances, HVAC, factory automation, refrigeration, and automotive applications. To rotate a 3-phase motor, three AC voltage signals must be supplied and phase shifted 120 degrees from each other. To do so, the Z16FMC Series Flash MCUs feature a flexible PWM module with three complementary pairs, or six independent PWM outputs, supporting dead-band operation and fault protection trip inputs. These features provide multiphase control capability for various motor types and ensure safe operation of the motor by providing immediate shutdown of the PWM pins during a fault condition. The duty cycle of each microcontroller PWM output is varied to control the period and amplitude of the generated AC signal, which in turn determines the speed and torque of the motor.

An AC induction motor consists of a stator, which is the stationary frame with a rotating component and the rotor, which is mounted on a shaft and ball bearings. In a 3-phase AC induction motor, the stator is laced with three sets of inductor windings energized by three AC voltage inputs that are phase-offset 120 degrees from each other, producing a rotating field of magnetic flux inside the stator. The rotor flux field is controlled to be orthogonal to the stator flux field to obtain optimal torque production when the stator current is ninety degrees with respect to the rotor flux field. The interaction of both fields is such that the stator field exerts a magnetic force on the rotor flux field, resulting in torque on the output shaft, which is highest when the rotor and stator fields are 90 degrees to each other. This electro-magnetic interaction is governed mathematically by Equation 1:

Equation 1:

$$\overline{T} = \overline{Bs} \times \overline{Br}$$

The expression in the above equation states that the resulting torque vector from the cross product of the rotor flux vector *Bs* and stator flux vector *Br* is greatest when they are at a 90 degree angle to each other, as shown in Figure 1.

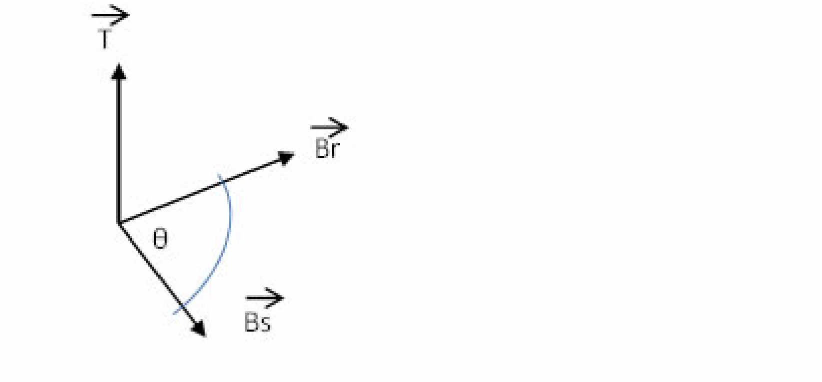


Figure 1. Torque Resulting from Interaction of Stator and Rotor Flux Fields

It is necessary to align the rotor and stator fields at 90 degrees to each other to achieve efficient torque control. In this 90 degree alignment, the torque is the highest and the current is the lowest.

To operate an ACIM motor with Field Oriented Control, the following steps are involved:

1. The AC from mains is rectified.
2. The resulting DC power is applied to the logic and power circuit.
3. The Z16FMC microcontroller generates the motor control signals to the inverter bridge.
4. This inverter bridge converts the control signals back to three 120 degree phase shifted AC signals.

These processes are illustrated in Figure 2. The inverter bridge consists of six IXYS MOSFETs capable of handling 64 A (continuous) at 55 V.

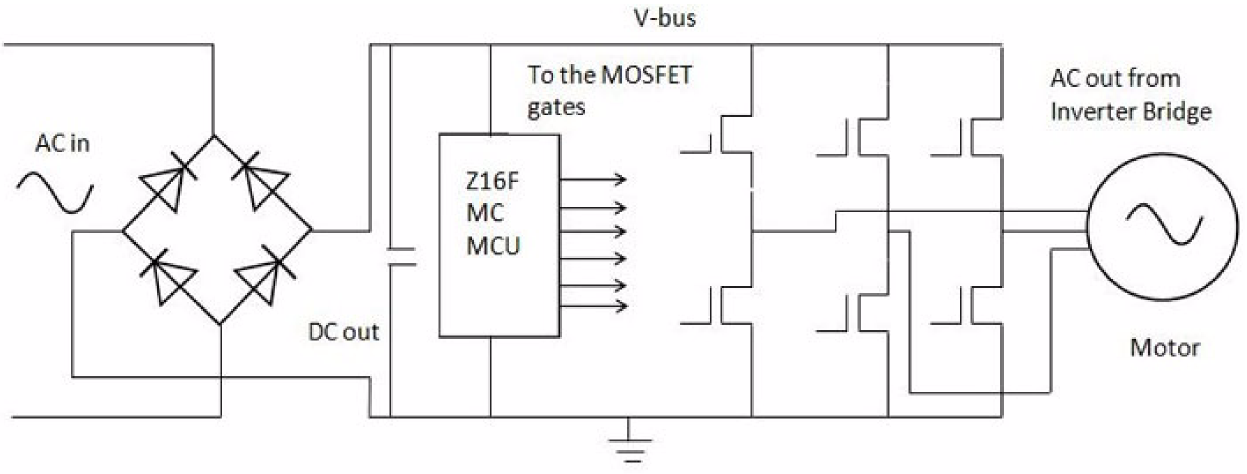


Figure 2. AC to DC to AC Conversion Scheme

Field Oriented Control Theory of Operation

To achieve the orthogonal relationship between stator and rotor fields, the slip frequency (see the Slip Frequency section on page 13) and reading and controlling the stator currents is a fundamental part of Field Orientation Control. This application note discusses Field Oriented Control using a single current shunt FOC method with implementation of the forward and reverse Clarke and Park transforms.

Field oriented control consists of space vector control and space vector modulation. The space vector control term refers to the independent control of the flux and torque currents, i.e., the *d*-*q* components and the necessary ninety degree alignment between the rotor flux and the stator flux. The space vector modulation term refers to the sinusoidal pulse width modulation pattern to rotate the reference vector *Is* within the hexagon with a magnitude and angle adjustment based on the field oriented control corrections, as shown in Figure 3.

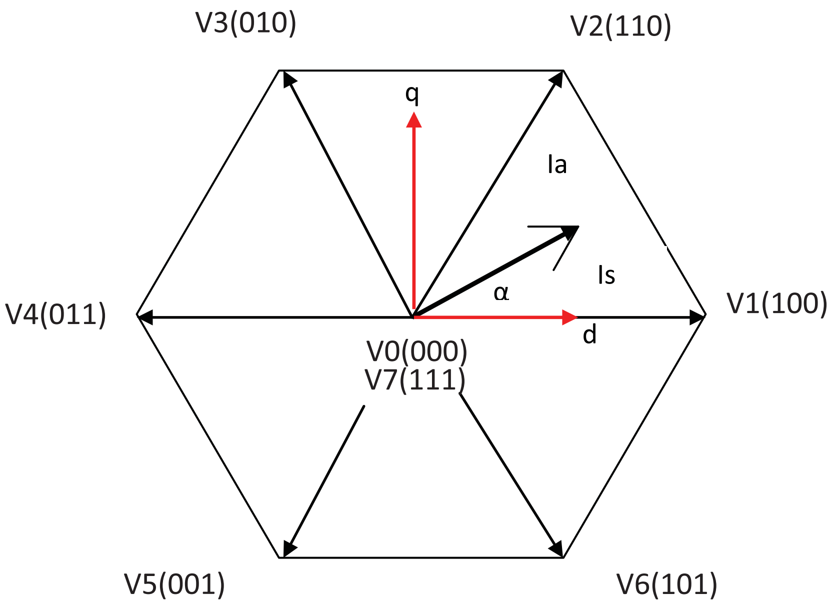


Figure 3. Hexagon with Rotating Reference Vector Is

Generally, all field oriented control algorithms are contained within the PWM service interrupt routine, referred to as inner loop in this application note. These algorithms consist of:

- Phase current measurements
- Clarke transform (3-2 axis transformation)
- Flux estimator (flux speed integrator to estimate rotor angle)
- Park transform
- PI current controllers

- Inverse Park transformation
- Inverse Clarke transformation
- Applying resulting PWM signals to the inverter bridge

The block diagram in Figure 4 illustrates this process.

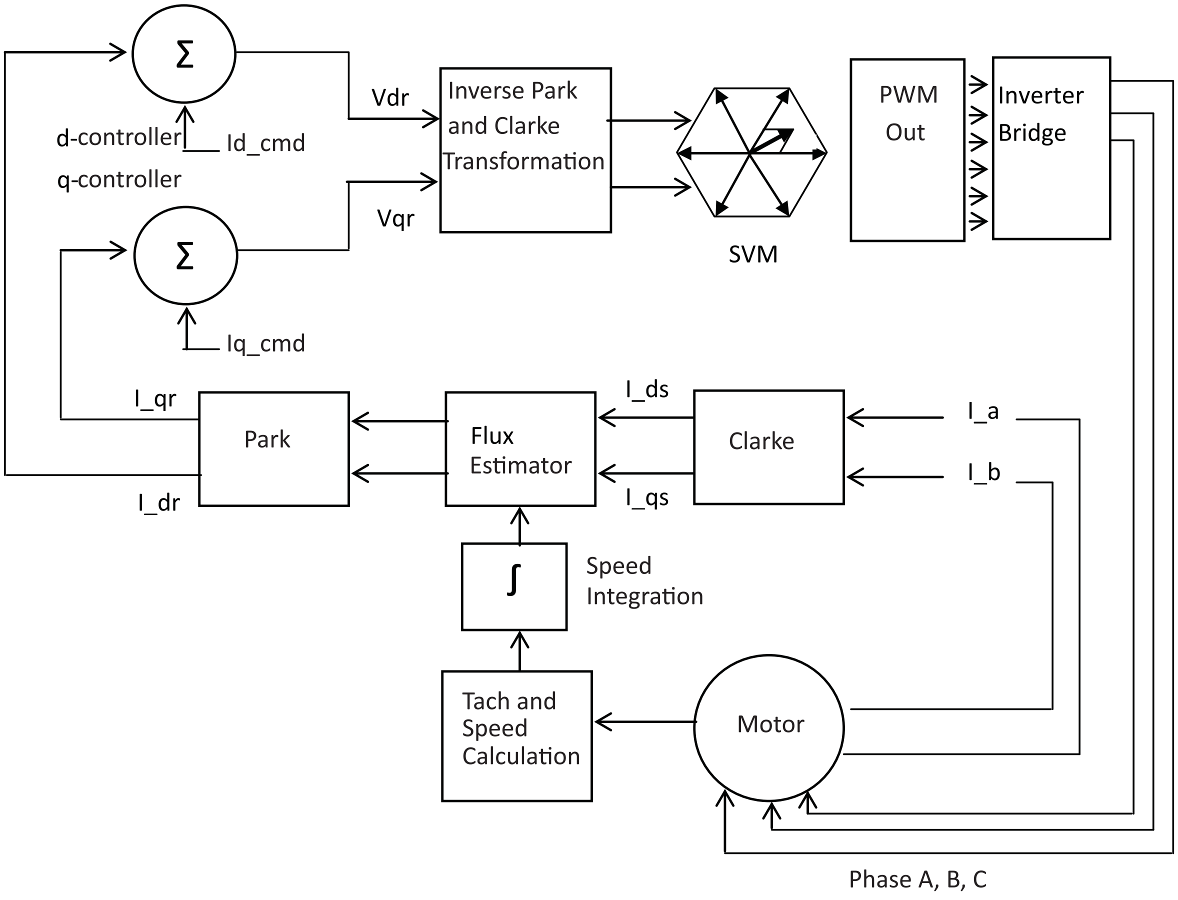


Figure 4. Vector Control Flowchart

Phase Current Reconstruction

Phase current reconstruction is based on the two current samples previously obtained plus the PWM space vector state. The state value is updated within the space vector modulation block to reflect the stator flux vector angle arrived at in that pass. Phase voltage polarities according to the sector state are shown in Figure 5. The state determines how each current sample is interpreted. In Table 1, the variables *I_a*, *I_b*, and *I_c*, represent the current variables for phases A, B, and C and their polarity according to the vector state 0-5 shown in Figure 5.

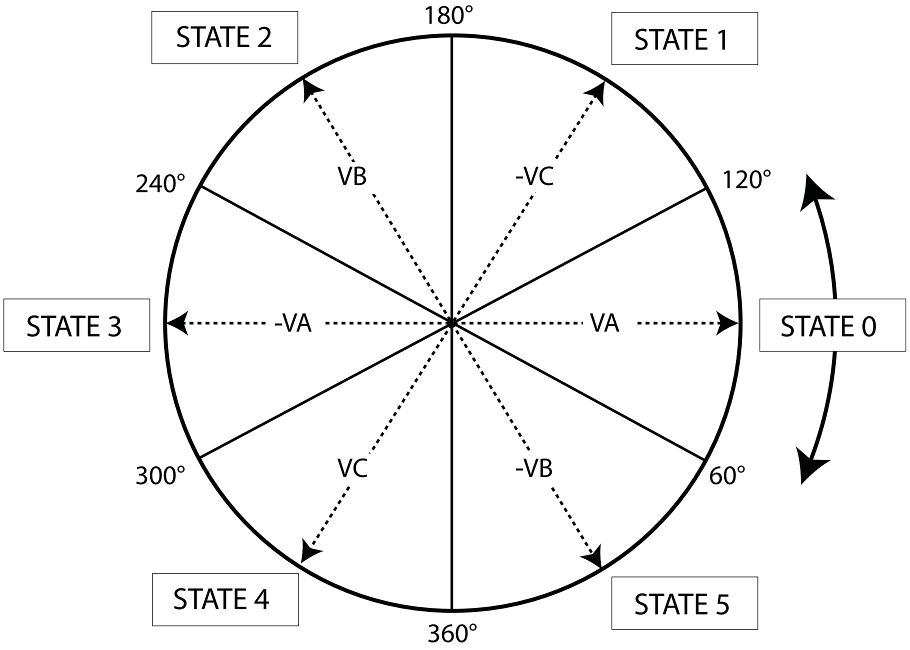


Figure 5. Phase Voltage Polarity Versus Space Vector PWM States

Table 1. Current Sample Interpretation by the PWM State

PWM State	First Current Sample	Second Current Sample
0	– I_c	– I_b
1	I_b	I_a
2	– I_a	– I_c
3	I_c	I_b
4	– I_b	– I_a
5	I_a	I_c
6	Not used	
7	Not used	

Using Kirchhoff's current law and assuming no zero sequence currents (zero sequence currents are only possible in an imbalanced delta wound motor, not in a Wye winding), the sum of the three phase currents equals zero. The third current can be derived from the other two samples using the following equation:

Equation 2:

$$I_a + I_b + I_c = 0$$

With the PWMs in edge alignment, the two currents are obtained from energized phase A and from energized Phase B, as shown in Figure 6.

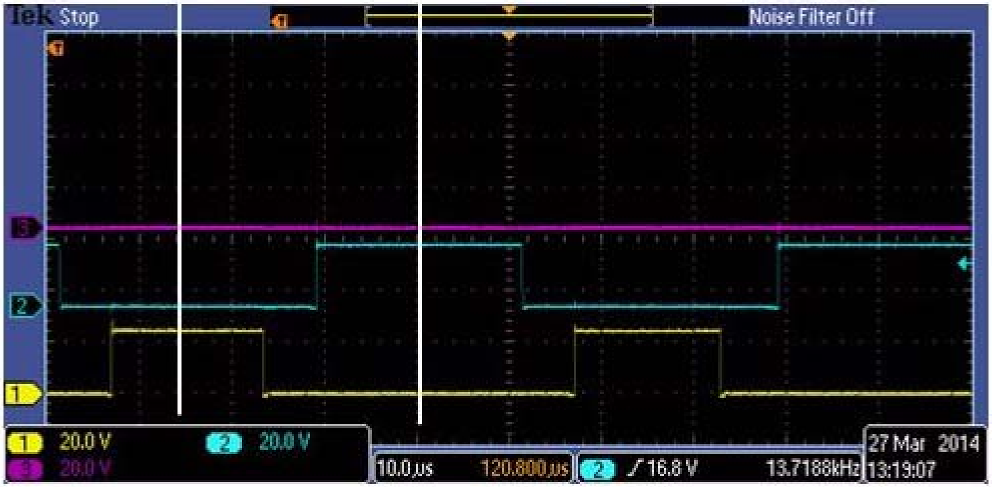


Figure 6. Taking the First and Second Current Sample when Phase A and Phase B are Energized

Clarke Transformation

As previously discussed, the vector addition of three stator phase currents form a reference current *Is*. This reference vector is governed by Equation 3.

Equation 3:

$$\overline{\mathbf{Is}} = \overline{Ia}(t) \times e^{j\theta} + \overline{Ib}(t) \times e^{j\left(\theta - \frac{2\pi}{3}\right)} + \overline{Ic}(t) \times e^{j\left(\theta + \frac{2\pi}{3}\right)}$$

This *Is* current vector consisting of three currents can be simplified by using the Clarke transform, as shown in Equation 4, to produce a 3-axis to 2-axis (direct and quadrature) stationary reference frame. The *d-q* currents are the flux- and torque-producing currents, which are orthogonal to each other and are controlled independently.

Equation 4:

$$\mathbf{Ids} = \mathrm{Ia} - \frac{1}{2} \times (\mathrm{Ib} + \mathrm{Ic})$$

$$\mathbf{Iqs} = \frac{\sqrt{3}}{2} \times (\mathrm{Ib} - \mathrm{Ic})$$

Rotor Flux Estimator and Sine Wave Table Lookup

For Field Oriented Control, it is crucial to obtain the rotor flux speed and its angular position correctly. To do so, the rotor's angular period times are provided by a tachometer and are captured with the Z16FM's Timer0 peripheral to calculate the speed of the rotor flux (frequency), as shown in Equation 5. The rotor flux frequency is then integrated to provide the phase-angle information of the rotor flux as follows:

RotorAngle.word + = Slip + Rotorfreq

The frequency and speed equations are shown in Equations 5 and 6.

Equation 5:

$$\mathrm{Freq} = \frac{1}{\mathrm{period}}$$

$$\mathrm{Speed} = 120 \times \frac{\mathrm{Freq}}{\mathrm{p}}$$

In the above equations, *Freq* refers to the applied frequency and *p* is the number of pole pairs.

The number of pole pairs determines the mechanical revolutions, which is a multiple of the electrical revolution of the rotor. The information of the rotor angle variable is then used to determine the sine and cosine values for the vector rotation in the forward Park transform. The sine and cosine values are provided in a look-up table containing 256 values for a 90 degree sine wave. Therefore, the entire wave is generated with a 1024-bit resolution:

$$\frac{360 \text{ degrees}}{1024} = 0.351 \text{ degrees/step}$$

Park Transformation

The angular information from the flux estimator and the outputs of the Clarke transform become the inputs to the Park transformation to rotate the stationary 2-current *d-q* reference frame to the rotating reference frame of the rotor flux. This is implemented using Equation 6 and illustrated in Figure 7.

Equation 6:

$$I\_dr = I\_ds \times \cos(\theta) + I\_qs \times \sin(\theta)$$

$$I\_qr = -I\_ds \times \sin(\theta) + I\_qs \times \cos(\theta)$$

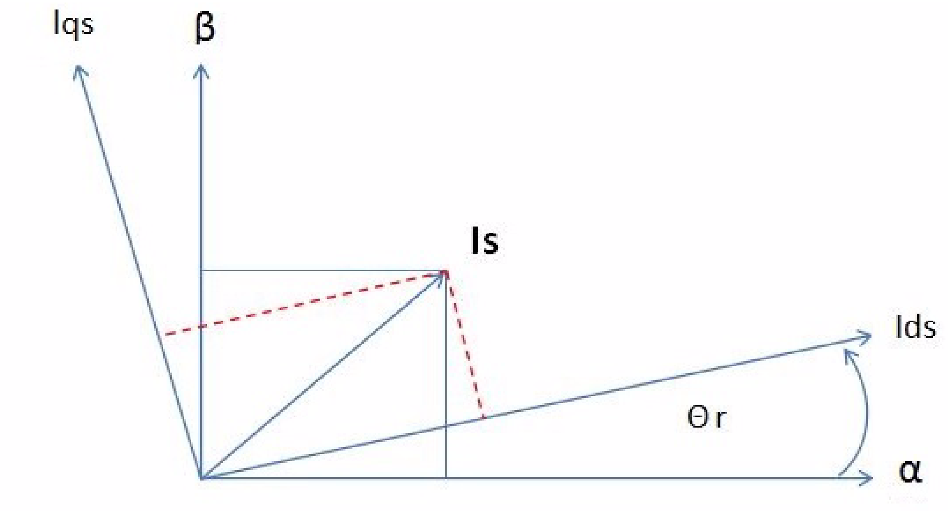


Figure 7. Forward Vector Rotation

In Figure 7, the subscripts *r* and *s* denote the rotor and stator respectively and α is the phase A reference axis to which the rotor angle (θ) is referenced. As seen from the stator, controlling the *d-q* currents is difficult as they change in AC-like patterns (sinusoidal). However, by projecting the orthogonal two current vector stationary reference frame onto the rotational vector reference frame with the Park transform, the *d* and *q* currents are more easily controlled as they rotate with the rotor coordinates and therefore act more like DC values, just like in a DC motor.

PI Regulators

A potentiometer and ADC conversion is used to obtain the demand magnetizing flux *Id_cmd* and the torque command *Iq_cmd* together with the *I_dr* and *I_qr* outputs of the Park transform to be input to the flux and torque current regulators. The purpose of the PI current controllers is to separately control the *d* and *q* components in magnitude according to the demanded flux and torque. Only the *d-q* magnitudes are controlled because the 90 degree relationship was already established in the Park transform and should not be further altered.

After the currents are adjusted to the demanded values, the PI controller outputs the control values *Vdr* and *Vqr*. Note that the PI controller outputs are now in terms of voltage instead of current.

Inverse Park Transform (Vector Rotation)

The Inverse Park Transform rotates the two phase voltages *V_dr* and *V_qr*, referred to as the rotating reference frame of the rotor flux, back to the stationary reference frame of the stator. The inverse Park transform equation is shown in Equation 7 and Figure 8.

Equation 7:

$$V\_ds = V\_dr \times \cos(\theta) - V\_qr \times \sin(\theta)$$
$$V\_qs = V\_dr \times \sin(\theta) + V\_qr \times \cos(\theta)$$

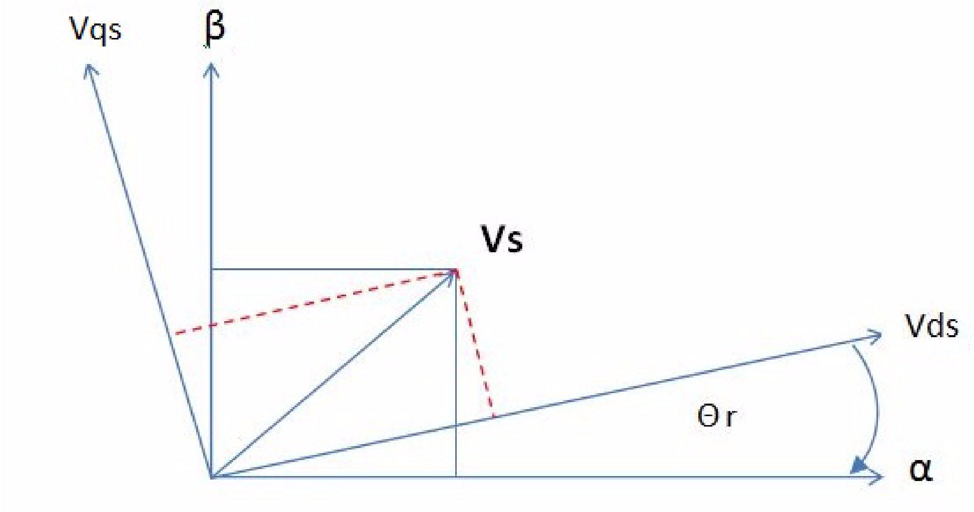


Figure 8. Backward Rotation to the ABC Reference Frame of the Stator Windings

Inverse Clarke Transform

The inverse Clarke Transform converts the two phase voltages of the rotated DQ reference frame back to the ABC reference frame of the stator windings. The inverse Clarke Transform equation is shown in Equation 8 and Figure 9.

Equation 8:

$$V\_a = V\_ds$$

$$V\_b = \left(-\frac{1}{2}\right) \times V\_ds + \frac{2}{\sqrt{3}} \times V\_qs$$

$$V\_c = \left(-\frac{1}{2}\right) \times V\_ds - \frac{2}{\sqrt{3}} \times V\_qs$$

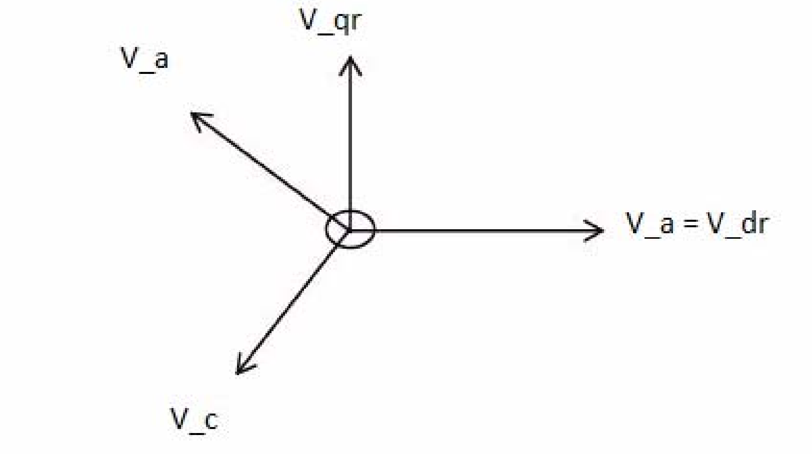


Figure 9. Two to Three Phase Conversion (Inverse Clarke)

Space Vector Modulation Block

Space vector modulation starts with the six states that represent the six voltage vectors VA, VB, VC and –VA, –VB, –VC. Table 2 shows the PWM duty cycle calculations used in each state. States 6 and 7 represent the unmodulated phase (Off or On).

Table 2. PWM Duty Cycle Calculations by State

PWM State	Phase A	Phase B	Phase C
0	0	– Vb + Va	PWMmax – (–Vc + Va)
1	Va + (–Vc)	PWMmax – (Vb + (–Vc))	0
2	PWMmax – (–Va + Vb)	0	–Vc + Vb
3	0	Vb + (– Va)	PWMmax – (Vc + (–Va))
4	– Va + Vc	PWMmax – (–Vb + Vc)	0
5	PWMmax – (Va + (–Vb))	0	Vc + (–Vb)
6	PWM/2	PWM/2	PWM/2
7	PWM/2	PWM/2	PWM/2

Test for End of PWM Period

At the end of the PWM interrupt routine, the IRQ0 register is checked for a pending PWM interrupt and clears this interrupt so that there is time for the duration of a PWM period to do anything else in the outer loop. In addition, at the end of this inner main loop (PWM interrupt), a counter is used to delay the code to be executed in the outer loop processing in main. The code in the inner-loop is executed in 51 uS and does not vector into the inner loop for another 72 uS. This process is shown in Figures 10 and 11.

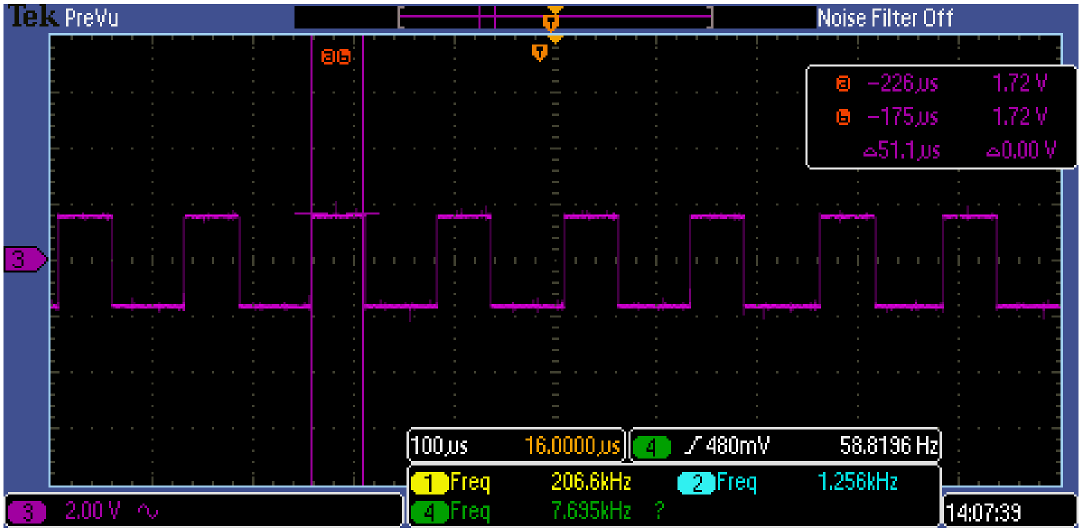


Figure 10. End of PWM Period Test

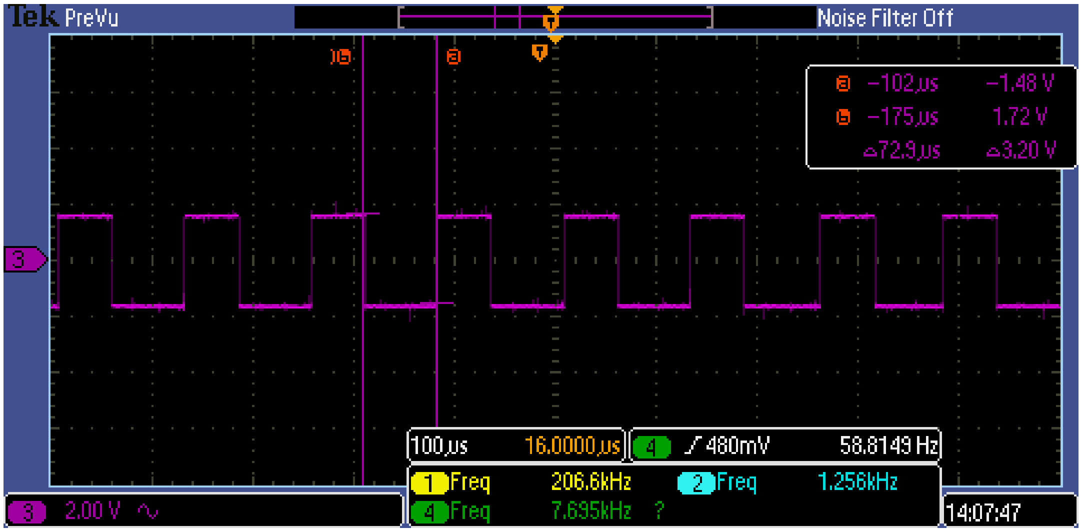


Figure 11. Outer Loop Processing

In Figure 10, the time between the cursors is 51 uS, which is the time taken to execute all code in the inner loop (PWM interrupt). In Figure 11, the time between the falling and rising edge is the time to do anything else, which is about 72 uS.

Bus Ripple Compensation

This routine tracks changes in the bus voltage and looks up a pre-calculated ripple compensation factor which is inversely proportional to the ADC sample of the bus voltage. The PWM duty cycle is scaled by this factor to compensate for variations in the DC bus voltage, (for example, dead-band distortion) so that a smaller factor value corresponds to a reduced PWM duty cycle, which clamps the output waveform to a nominal voltage.

Slip Frequency

Slip frequency is an intrinsic part of AC induction motor control. In an AC induction motor, the stator flux field is rotating at synchronous speed according to the sinusoidal frequencies of the currents that produce this stator flux field. The resulting induced flux field in the rotor interacts with the stator flux field and causes a torque to rotate the motor at the synchronous speed minus a frequency that is referred to as slip frequency. In simple terms, the rotor frequency is always less than the stator field frequency. This is essential because only an alternating current field can induce a voltage in the rotor. If the rotor frequency and stator frequency were the same, then, from the view of either stator or rotor, there is no alternating field and hence no voltage is induced to cause a torque from the interacting rotor and stator force field. To properly align the stator flux with the rotor flux for correct vector control, the slip frequency must be calculated as shown in Equation 9.

Equation 9:

$$f_s = \frac{1}{2\pi Tr} \times \frac{Iq}{Id} \text{ where Tr is } \frac{Lr}{Rr}$$

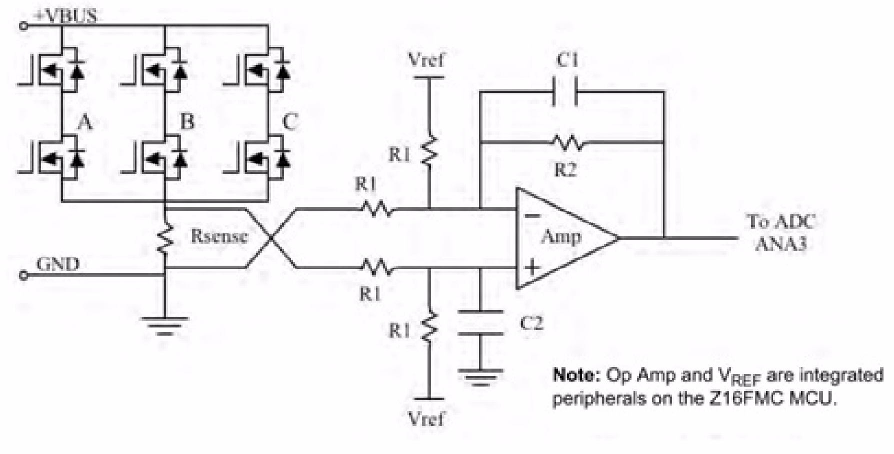
In the above equation, *Lr* is the rotor winding inductance and *Rr* is the rotor winding resistance. *Tr* is the rotor time constant and *Iq* and *Id* are the magnetizing and torque-producing *d*-*q* components.

The slip frequency is calculated in the `main.c` function of the program and the resulting slip value is added to the rotor frequency using:

RotorAngle.word + = Slip + Rotorfreq

Z16FMC MCU Phase Current Reading

Figure 12 illustrates the current reading implementation using the Z16FMC's operational amplifier circuit built into the microcontroller.



Note: Op Amp and V_{REF} are integrated peripherals on the Z16FMC MCU.

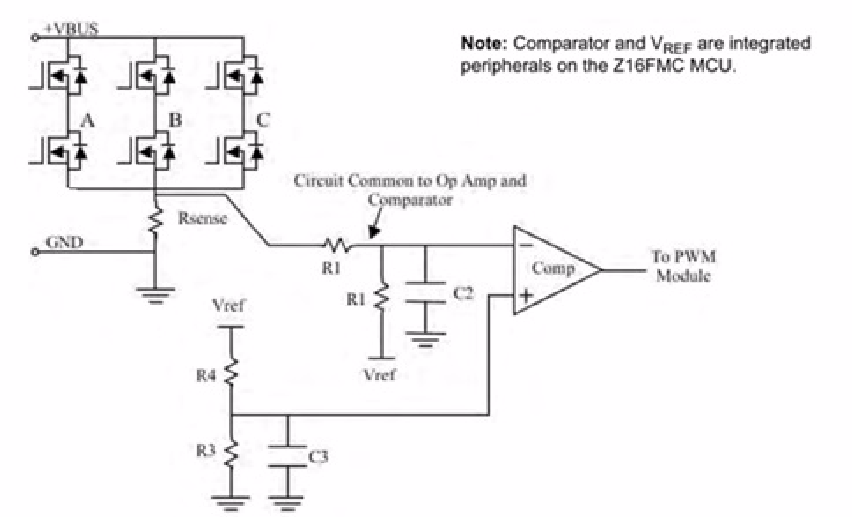
Figure 12. Current Sense Operational Amplifier

For current sensing using a single current sense resistor, the operational amplifier is used to offset the ground referenced current sense signal to 1 V (half of the 2 V reference); the voltage gain increases by a factor of 5. For a sense resistor value of 20 mΩ and a current of ± 4 A gained by a 5, a 1 V signal can swing ± 0.4 V.

At zero current across the current sense resistor, the output of the amplifier is 1 V, which centers around the 2 V reference voltage for the ADC module. A current normalization is then performed to generate the offset to be subtracted from the actual current readings. This offset should be at Vref/2, or ADC range / 2 and convert the unsigned quantities of the currents to signed quantities.

For example, if the obtained ADC current reading has a value of 90, the obtained current value is 90 – 127 = – 37. If the reading is 220, the obtained current value is 220 – 127 = 93.

Figure 13 shows the overcurrent protection circuit switch with the Z16FMC internal comparator.



Note: Comparator and V_{REF} are integrated peripherals on the Z16FMC MCU.

Figure 13. Overcurrent Sense Circuit

In Figure 13, R3 and R4 set the overcurrent trip threshold. Because it is a DC value, a bypass capacitor (C3) of 0.1 µF is used. For R4 = 10, R3 is selected as:

Equation 10:

$$R3 = R4 \times \frac{(V_{REF} + I\_max \times Rsense)}{(V_{REF} - I\_max \times Rsense)} = 10\ k\Omega \times \frac{(2V + 10A \times 0.10\Omega)}{(2V - 10A \times 0.10\Omega)} = 12.2\ k\Omega \approx 12.4\ k\Omega$$

As shown in Figure 13, when an overcurrent event occurs, the output of the comparator provides the shutdown signal for the PWM module to disable the motor operation in near real time.

Flux Weakening

If the macro in the `main.h` header file is enabled, the motor can be speed-controlled with flux weakening. The flux weakening equation is shown in Equation 11.

Equation 11:

$$E = Vbemf = Blv,\ \text{and}\ v = \frac{E}{Bl}$$

The above equation indicates that the motor speed is inversely proportional to the magnetic flux density. Therefore, the weaker the magnetic flux field, the higher the steady state speed.

The demand currents to form vector *Is* are calculated as shown in Equation 12.

Equation 12:

$$Is = \sqrt{(Id)^2 + (Iq)^2}$$

In this equation, the *Id* term for the magnetizing flux is used for flux weakening and the *Iq* term is the quadrature current command. In the software program, flux weakening is implemented by obtaining the flux speed, scaling the value down, and fetching a magnetizing value from the `Flux_magnet` Look-up Table (LUT), which is then squared and used for *Id_cmd*. Flux weakening takes effect at speeds greater than 2900 RPM by applying lower flux values for *Id_cmd*.

The *Iq* command is not utilized to obtain square root values from a LUT; it is derived from the speed PI controller output. Future versions of this program will utilize the *Iq* square root term for regenerative breaking implementation.

Subfunctions

Subfunctions are subroutines that are not required to be updated every time the PWM ISR executes. Using signed integer variables throughout, the program becomes relatively short and readable with the code processed in reasonably short times.

These subroutines include:

- UART_CheckInput
- UART_control
- Class B routine
- Flux weakening calculation
- Slip frequency calculation
- Speed ramp
- Speed PI loop
- AD_conversion
- Get_speed
- Direction_update
- LED_blink

These subroutines are executed every time the `pwm_step` variable in the PWM interrupt is greater than 30. All subroutines need to be executed within 50 µs before the next PWM interrupt takes priority again.

Parameter Tuning

To operate different AC induction motors, certain parameters in the `main.h` header file of the project may require to be tuned. These parameters are:

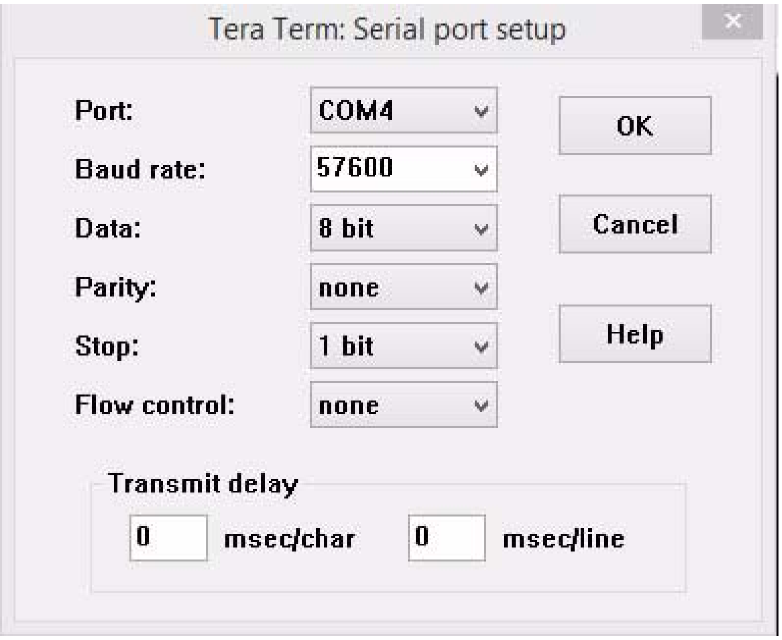
- #define KSPEED (used to determine the speed of the motor (frequency)
- #define ID_CMD (magnetizing flux command)
- #define ROTOR_TIMECONST (rotor time constant, which may be different for other than the one used in this application note)
- #define KP (proportional coefficient for the PI loops)
- #define KI (integral coefficient for the PI loops)
- #define INTEGRAL_LIMIT (Integral limit for the PI loops)
- Slip frequency calculation (based on equation provided in Slip Frequency on page 13)

UART Terminal

The AC induction motor can be operated under UART control. The main parameters to control are:

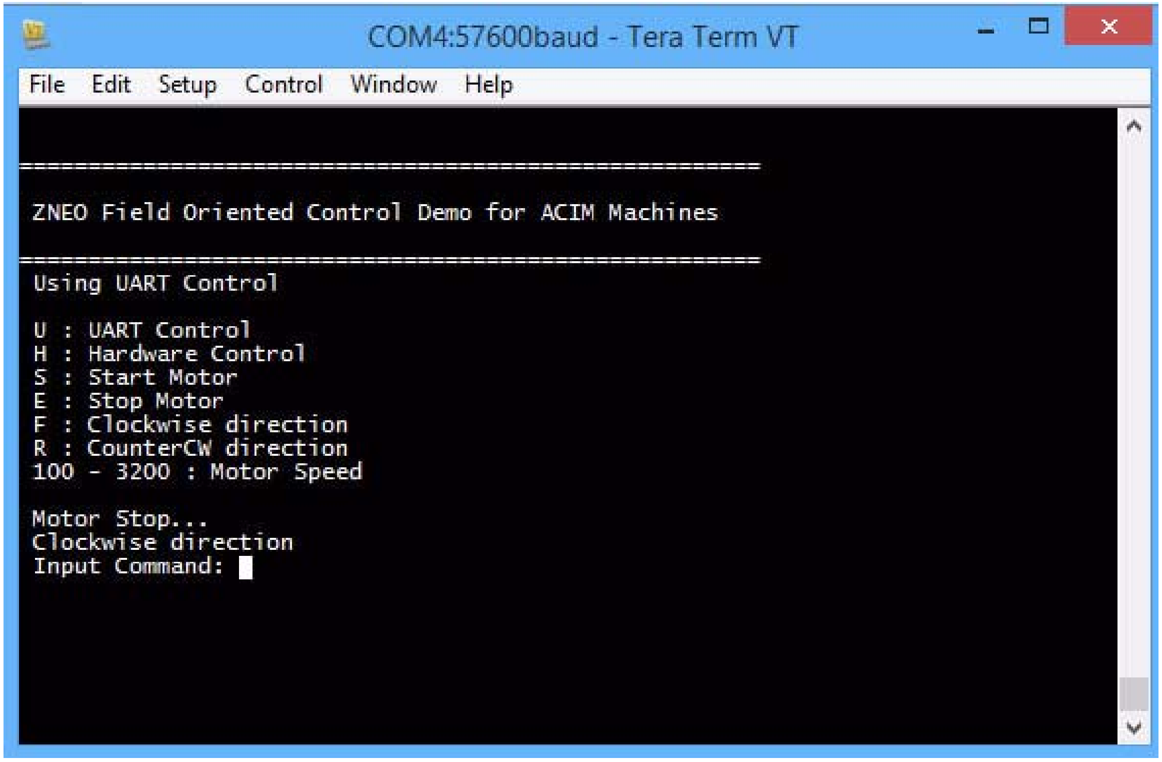
- Speed (enter any speed between 100–3200)
- Spin direction (motor will only change spin direction upon coming to a full stop)
- Start (green LED on)
- Stop (red LED blinks after motor comes to a full stop)
- UART control (yellow LED on)
- Hardware control (yellow LED off)

To use UART serial communication, ensure that the macro `#define UART` in the `main.h` header file is uncommented. The serial port settings for this setup are shown in Figure 14, and the control parameters of the motor are shown in Figure 15.



Port: COM4
Baud rate: 57600
Data: 8 bit
Parity: none
Stop: 1 bit
Flow control: none
Transmit delay
0 msec/char
0 msec/line

Figure 14. Serial Port Setup for UART Communication



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 ZNEO Field Oriented Control Demo for ACIM Machines

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 Using UART Control

 U : UART Control
 H : Hardware Control
 S : Start Motor
 E : Stop Motor
 F : Clockwise direction
 R : CounterCW direction
 100 - 3200 : Motor Speed

 Motor Stop...
 Clockwise direction
 Input Command:
```

Figure 15. Display Showing the Control Parameters of the Motor

When the motor is stopped, the red LED is lit. When the motor is started, the green LED is lit. The yellow LED is lit under UART control.

Equipment Used

The following equipment was used for the setup:

- Tektronix DPO 2014B Digital Phosphor Oscilloscope.
- Zilog MultiMotor Development Kit Main Board (99C1358-001G)
- Zilog Z16FMC MCU module (99C1357-001G)
- BK Precision 1667 power supply
- Opto-isolated USB Smart Cable (99C0968-001G)
- Opto-isolated UART to USB adapter (99C1359-001G)
- BOSCH AC Induction motor 250V/2A
- Tektronix A622 AC/DC current probe

Hardware Setup

Figure 16 shows the ACIM, the opto-isolated USB SmartCable and Zilog's MultiMotor Development Kit.

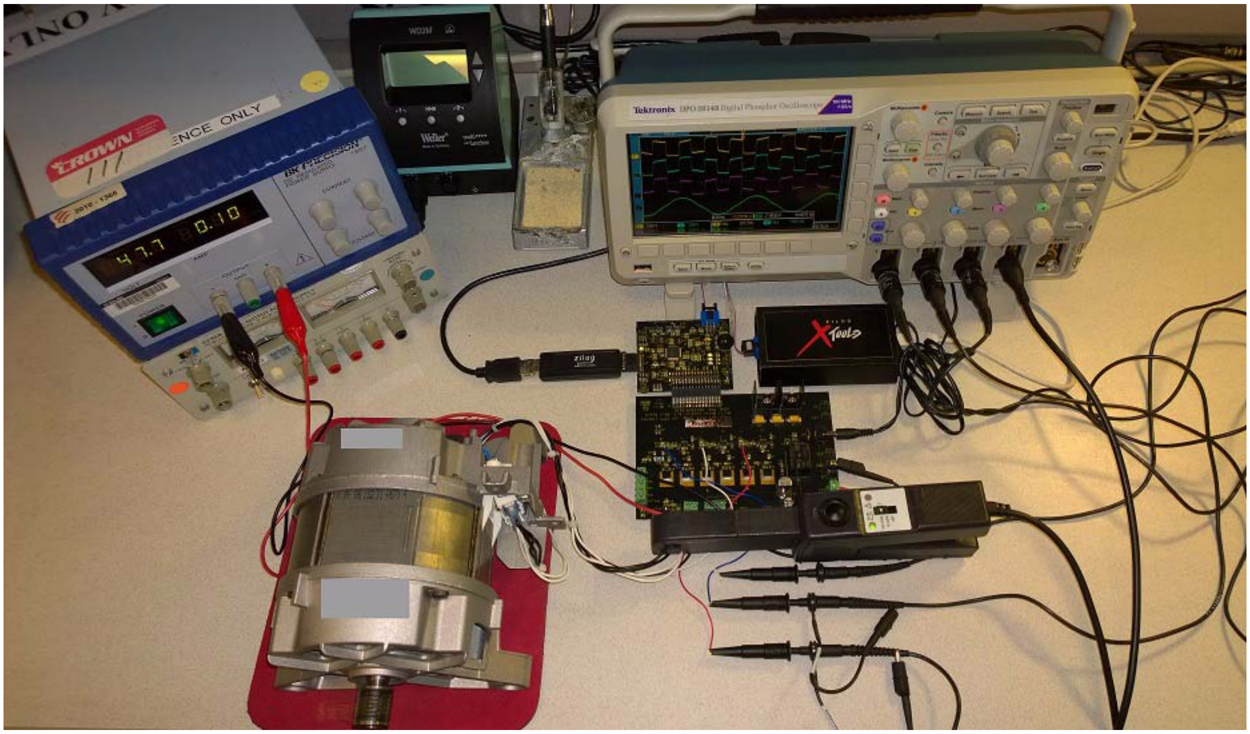

Figure 16. The MultiMotor Development Kit

Test Results

The MultiMotor Development Kit was designed with the intent to demonstrate multiple driving schemes for BLDC motors with a 24V operating voltage. For testing this ACIM machine, a 48V power supply was connected to J7 in addition to the 24V, 1.25A power supply included in this development kit. Therefore, the AC induction motor tested with the MultiMotor development kit, a BOSCH 2A/250V motor, was not operated at the maximum power rating. However, schematics for a high power hardware design are available on the Zilog website.

Using the test setup shown in Figure 16, three oscilloscope probes were connected to the BEMF voltage dividers of Phase A, Phase B, and Phase C of the MultiMotor Series Development Board to show the three phase voltages. A current probe was connected to one of the phases to show the current wave form. The speed control potentiometer was set to the middle of the entire range to start at full speed. The potentiometer was then adjusted to any position between the lowest speed (all the way down from the middle position) and up to full speed again (middle position).The following criteria were observed during motor operation with no load:

- PI loop action (minimum of over or undershoot and time to ramp to full speed)
- PI loop stability (waveforms and power supply currents should show no fluctuations)
- Closed loop performance (must maintain speed when applying more or less voltage to the motor, i.e., constant power)
- Current consumption during ramp up (avoiding excessive currents)
- Shape of phase voltage and currents (currents in all three phases must be approximately sinusoidal)

The waveforms, shown in Figure 17, indicate phase voltages in yellow, blue, and purple, and a current signal in green

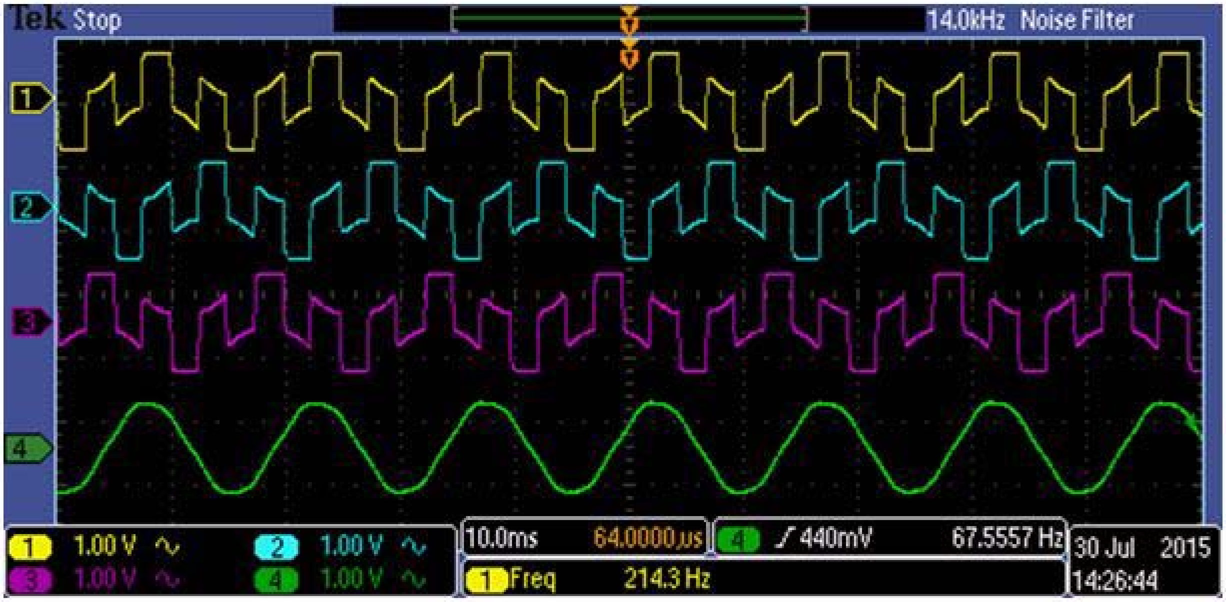

Figure 17. Single Shunt Displaying Three Phase Voltages and One Current Signal

Summary

This application note discusses the implementation of a Field Oriented Control scheme for AC induction motors with flux weakening and slip calculation, using one current sense resistor for cost-sensitive applications.

The older generations of AC induction motors were supplied directly from the AC mains, which limited the flexibility to control the motor, especially with no control over the rotor’s and stator’s flux position necessary for vector control. With the introduction of microcontrollers, these limitations have been eliminated. In today’s microcontroller applications, the AC mains is rectified and converted to logic DC levels to operate the MCU at the required voltage level. The other DC voltage levels are applied to the inverter bridge consisting of six IXYS MOSFETS and the high and low side drivers for those MOSFETS, as shown in Figure 2. This inverter bridge receives the sinusoidal changing PWM outputs of the MCU to convert the DC signals back to AC signals and apply these to the AC induction motor windings.

With this intermediate step of converting from AC to DC and back to AC, and using Zilog's Z16FMC MCU, a high degree of controllability of an AC induction motor is achieved.

Field Oriented Control discussed in this application note consists of:

- Stator current reading *I_a* and *I_b*
- Clarke transformation from 3-current to a 2-current axis static reference frame
- Rotor flux phase angle update
- Park transformation (forward vector rotation)
- *d-q* current controller PI loops
- Inverse Park transformation (reverse vector rotation)
- Inverse Clarke transformation (2 phase-voltages DQ-reference frame to ABC reference frame of the stator windings)
- SVPWM block (Space Vector PWM)

The control of an AC induction machine consists of two parts, Field Oriented Control to align the rotor flux and stator flux at an angle of 90 degrees to each other, and the Space Vector Modulation scheme to apply control voltages to the three phases of the motor to achieve this alignment under torque control.

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- Field Oriented Control Using Polar Coordinates for AC Induction Motors (AN0374)

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