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Digital Control of Acim Using dsPIC

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ABSTRACT: The AC Induction Motor (ACIM) is the workhorse of industrial and domestic applications, due to its simple construction and durability. The control of ACIM can be accomplished by simple open loop control technique using conventional Volt-Hertz method. But, when dynamic responses are required, it is essential to use a closed loop control technique to reduce high current transients.

The aim of this paper is to design a closed loop control of ACIM using SVPWM technique. This Vector control technique controls the ACIM by field weakening method and is superior to the Conventional Volt-Hertz method. This is implemented by using dsPIC for controlling the drive, as it provides higher efficiency and lower operating costs, (i.e.,) it reduces the cost of drive components.

I.INTROUCTION

The AC induction motor (ACIM) is the workhorse of industrial and residential motor applications due to its simple construction and durability. These motors have no brushes to wear out or magnets to add to the cost. The rotor assembly is a simple steel cage. ACIM's are designed to operate at a constant input voltage and frequency, but you can effectively control an ACIM in an open loop variable speed application if the frequency of the motor input voltage is varied. If the motor is not mechanically overloaded, the motor will operate at a speed that is roughly proportional to the input frequency. As you decrease the frequency of the drive voltage, you also need to decrease the amplitude by a proportional amount. Otherwise, the motor will consume excessive current at low input frequencies. This control method is called Volts-Hertz control. In practice, a custom Volts-Hertz profile is developed that ensures the motor operates correctly at any speed setting. This profile can take the form of a look-up table or can be calculated during run time. Often, a slope variable is used in the application that defines a linear relationship between drive frequency and voltage at any operating point. The Volts-Hertz control method can be used in conjunction with speed and current sensors to operate the motor in a closed-loop fashion. The Volts-Hertz method works very well for slowly changing loads such as fans or pumps. But, it is less effective when fast dynamic response is required. In particular, high current transients can occur during rapid speed or torque changes. The high currents are a result of the high slip factor that occurs during the change. Fast dynamic response can be realized without these high currents if both the torque and flux of the motor are controlled in a closed loop manner. This is accomplished using Vector Control techniques. Vector control is also commonly referred to as Field Oriented Control (FOC).

The benefits of vector control can be directly realized as lower energy consumption. This provides higher efficiency; lower operating costs and reduces the cost of drive components. Vector Control Traditional control methods, such as the Volts-Hertz control method described above, control the frequency and amplitude of the motor drive voltage. In contrast, vector control methods control the frequency, amplitude and phase of the motor drive voltage. The key to vector control is to generate a 3-phase voltage as a phasor to control the 3-phase stator current as a phasor that controls the rotor flux vector and finally the rotor current phasor. Ultimately, the components of the rotor current need to be controlled. The rotor current cannot be measured because the rotor is a steel cage and there are no direct electrical connections. Since the rotor currents cannot be measured directly, the application program calculates these parameters indirectly using parameters that can be directly measured.

The technique described in this application note is called indirect vector control because there is no direct access to the rotor currents. Indirect vector control of the rotor currents is accomplished using the following data:
• Instantaneous stator phase currents, i_a, i_b and i_c
• Rotor mechanical velocity
• Rotor electrical time constant

The motor must be equipped with sensors to monitor the 3-phase stator currents and a rotor velocity feedback device.

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Vol. 2, Issue 2, February 2013

II. A MATTER OF PERSPECTIVE

The key to understanding how vector control works is to form a mental picture of the coordinate reference transformation process. If you picture how an AC motor works, you might imagine the operation from the perspective of the stator. From this perspective, a sinusoidal input current is applied to the stator. This time variant signal causes a rotating magnetic flux to be generated. The speed of the rotor is going to be a function of the rotating flux vector. From a stationary perspective, the stator currents and the rotating flux vector look like AC quantities. Now, instead of the previous perspective, imagine that you could climb inside the motor. Once you are inside the motor, picture yourself running alongside the spinning rotor at the same speed as the rotating flux vector that is generated by the stator currents. Looking at the motor from this perspective during steady state conditions, the stator currents look like constant values, and the rotating flux vector is stationary! Ultimately, you want to control the stator currents to get the desired rotor currents (which cannot be measured directly).With the coordinate transformation, the stator currents can be controlled like DC values using standard control loops.

III. VECTOR CONTROL SUMMARY

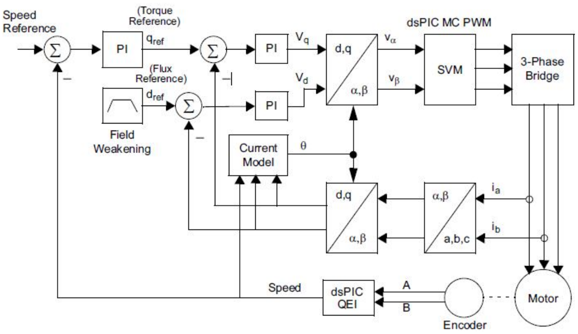

Fig. 1 Vector Control Block Diagram

To summarize the steps required for indirect vector control:
1. The 3-phase stator currents are measured. This measurement provides ia, ib and ic. The rotor velocity is also measured.
2. The 3-phase currents are converted to a 2-axis system. This conversion provides the variables iα and iβ from the measured ia, ib and ic values. iα and iβ are time varying quadrature current values as viewed from the perspective of the stator.
3. The 2-axis coordinate system is rotated to align with the rotor flux using transformation angle information calculated at the last iteration of the control loop. This conversion provides the Id and Iq variables from iα and iβ. Id and Iq are the quadrature currents transformed to the rotating coordinate system. For steady state conditions, Id and Iq will be constant.
4. Error signals are formed using Id, Iq and reference values for each. The Id reference controls
rotor magnetizing flux. The Iq reference controls the torque output of the motor. The error signals are input to PI controllers. The output of the controllers provide Vd and Vq, which is a voltage vector that will be sent to the motor.
5. A new coordinate transformation angle is calculated. The motor speed, rotor electrical time constant, Id and Iq are the inputs to this calculation. The new angle tells the algorithm where to place the next voltage vector to produce an amount of slip for the present operating conditions.

6. The Vd and Vq output values from the PI controllers are rotated back to the stationary reference frame using the new angle. This calculation provides quadrature voltage values vα and vβ.7. The vα and vβ values are transformed back to 3-phase values va, vb and vc. The 3-phase voltage values are used to calculate new PWM duty cycle values that generate the desired voltage vector. The entire process of transforming, PI iteration, transforming back and generating PWM is illustrated in Figure 1.

Coordinate Transforms

Through a series of coordinate transforms the time invariant values of torque and flux can be indirectly determined and controlled with classic PI control loops. The process starts out by measuring the three phase motor currents. In practice you can take advantage of the constraint that in a three-phase system the instantaneous sum of the

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Vol. 2, Issue 2, February 2013

three current values will be zero. Thus by measuring only two of the three currents you can know the third. The cost of the hardware is reduced because only two current sensors are required.

IV. CLARK TRANSFORM

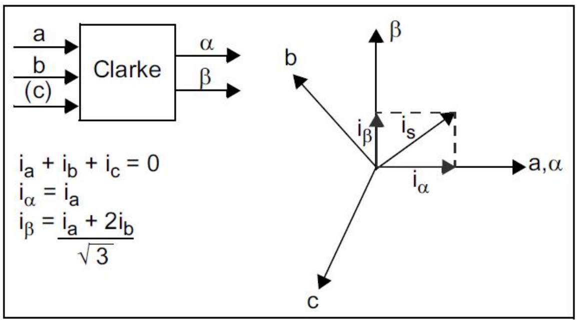

Fig.2 Clark Transform

The first transform is to move from a 3-axis, 2-dimensional coordinate system referenced to the stator of the motor to a 2-axis system also referenced to the stator. The process is called the Clarke Transform, as illustrated in Figure 2.

V. PARK TRANSFORM

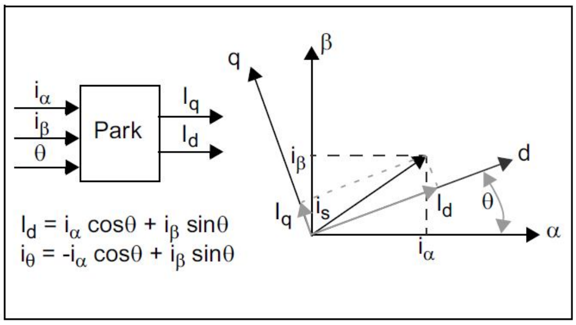

Fig. 3 Park Transform

At this point you have the stator current Phasor represented on a 2-axis orthogonal system with the axis called α-β. The next step is to transform into another 2-axis system that is rotating with the rotor flux. This transformation uses the Park Transform, as illustrated in Figure 3. This 2-axis rotating coordinate system is called the d-q axis. From this perspective the components of the current Phasor in the d-q coordinate system are time invariant. Under steady state conditions they are DC values. The stator current component along the d axis is proportional to the flux, and the component along the q axis is proportional to the rotor torque. Now that you have these components represented as DC values you can control them independently with classic PI control loops.

VI. INVERSE PARK

After the PI iteration you have two voltage component vectors in the rotating d-q axis. You will need to go through complementary inverse transforms to get back to the 3-phase motor voltage. First you transform from the 2-axis rotating d-q frame to the 2-axis stationary frame α-β. This transformation uses the Inverse Park Transform, as illustrated in Figure 4.

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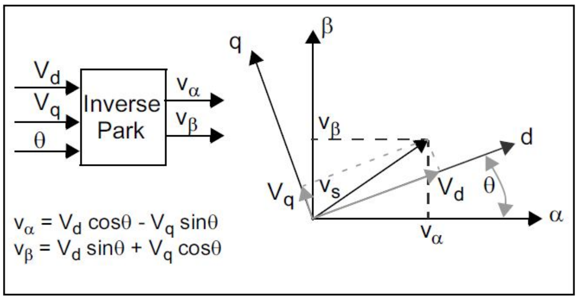

Fig. 4 Inverse Park Transform

VII. INVERSE CLARKE

The next step is to transform from the stationary 2-axis α-β frame to the stationary 3-axis, 3-phase reference frame of the stator. Mathematically, this transformation is accomplished with the Inverse Clark Transform, as illustrated in Figure 5.

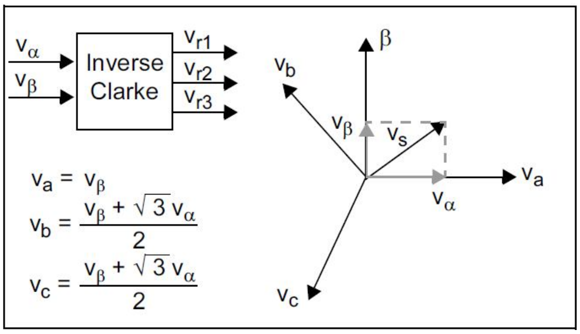

Fig.5 Inverse Clarke

Flux Estimator

In an asynchronous squirrel cage induction motor the mechanical speed of the rotor is slightly less than the rotating flux field. The difference in angular speed is called slip and is represented as a fraction of the rotating flux speed. For example if the rotor speed and the flux speed are the same the slip is 0 and if the rotor speed is 0 the slip is 1.You probably have noticed that the Park and Inverse Transforms require an input angle θ. The variable θ represents the angular position of the rotor flux vector. The correct angular position of the rotor flux vector must be estimated based on known values and motor parameters. This estimation uses a motor equivalent circuit model. The slip required to operate the motor is accounted for in the flux estimator equations and is included in the calculated angle. The flux estimator calculates a new flux position based on stator currents, the rotor velocity and the rotor electrical time constant. This implementation of the flux estimation is based on the motor current model and in particular these three equations:

$$I_{mr} = I_{mr} + \frac{T}{T_r}(I_d - I_{mr})$$

Equation 1: Magnetizing Current

$$f_s = (P_{pr} \cdot n) + \left(\frac{1}{T_r \omega_b} \cdot \frac{I_q}{I_{mr}}\right)$$

Equation 2: Flux Speed

$$\theta = \theta + \omega_b \cdot f_s \cdot T$$

Equation 3: Flux Angle

where:

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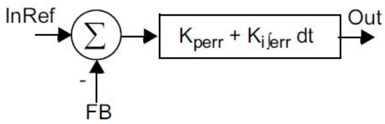
Imr = magnetizing current (as calculated from measured values)
fs = flux speed (as calculated from measured values)
T = sample (loop) time (parameter in program)
n = rotor speed (measured with the shaft encoder)
Tr = Lr/Rr = Rotor time constant (must be obtained from the motor manufacturer)
θ = rotor flux position (output variable from this module)
ωb = electrical nominal flux speed (from motor name plate)
Ppr = number of pole pairs (from motor name plate)

During steady state conditions, the Id current component is responsible for generating the rotor flux. For transient changes, there is a low-pass filtered relationship between the measured Id current component and the rotor flux. The magnetizing current, Imr, is the component of Id that is responsible for producing the rotor flux. Under steady-state conditions, Id is equal to Imr. Equation 1 relates Id and Imr. This equation is dependent upon accurate knowledge of the rotor electrical time constant. Essentially, Equation 1 corrects the flux producing component of Id during transient changes. The computed Imr value is then used to compute the slip frequency, as shown in Equation 2. The slip frequency is a function of the rotor electrical time constant, Iq, Imr and the current rotor velocity. Equation 3 is the final equation of the flux estimator. It calculates the new flux angle based on the slip frequency calculated in Equation 2 and the previously calculated flux angle. If the slip frequency and stator currents have been related by Equation 1 and Equation 2, then motor flux and torque have been specified. Furthermore, these two equations ensure that the stator currents are properly oriented to the rotor flux. If proper orientation of the stator currents and rotor flux is maintained, then flux and torque can be controlled independently. The Id current component controls rotor flux and the Iq current component controls motor torque. This is the key principle of indirect vector control.

PI Control




```
Err = InRef - FB;
U = Sum + Kp*Err;
If (U > Outmax);
        Out = Outmax;
else if (U < Outmin)
        Out = Outmin;
else
        Out = U;
Excess = U - Out;
Sum = Sum + (Ki*Err)-(Kc*Excess);
```

Fig. 6 PI Control

Three PI loops are used to control three interactive variables independently. The rotor speed, rotor flux and rotor torque are each controlled by a separate PI module. The implementation is conventional and includes a term (Kc*Excess) to limit integral windup, as illustrated in Figure 6.

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Space Vector Modulation

The final step in the vector control process is to generate pulse-width-modulation signals for the 3-phase motor voltage signals. By using Space Vector Modulation (SVM) techniques the process of generating the pulse width for each of the 3 phases reduces to a few simple equations. In this implementation the Inverse Clarke Transform has been folded into the SVM routine, which further simplifies the calculations. Each of the three inverter outputs can be in one of two states. The inverter output can be either connected to the + bus rail or the – bus rail, which allows for 23=8 possible states that the output can be in (see Table 1). The two states where all three outputs are connected to either the + bus or the – bus are considered null states because there is no line-to-line voltage across any of the phases. These are plotted at the origin of the SVM Star. The remaining six states are represented as vectors with 60 degree rotation between each state, as shown in Figure 7.

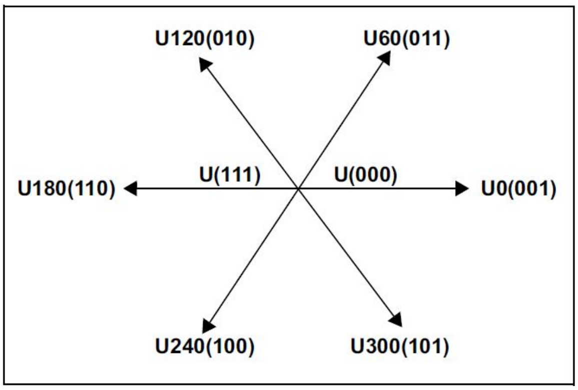

Fig. 7 Space Vector Modulation

The process of Space Vector Modulation allows the representation of any resultant vector by the sum of the components of the two adjacent vectors. In Figure 8, UOUT is the desired resultant. It lies in the sector between U60 and U0. If during a given PWM period T U0 is output for T1/T and U60 is output for T2/T, the average for the period will be UOUT.

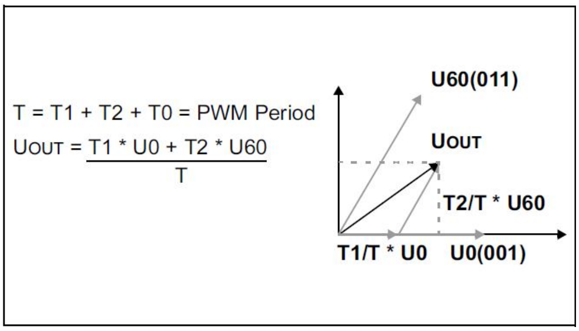

Fig. 8 Average Space Vector Modulation

The values for T1 and T2 can be extracted with no extra calculations by using a modified Inverse Clark transformation. By reversing vα and vβ, a reference axis is generated that is shifted by 30 degrees from the SVM star. As a result, for each of the six segments one axis is exactly opposite that segment and the other two axis symmetrically bound the segment. The values of the vector components along those two bounding axis are equal to T1 and T2. See the CalcRef.s and SVGen.s files in “Appendix B. Source Code” for details of the calculations.You can see from Figure 9 that for the PWM period T, the vector T1 is output for T1/T and the vector T2 is output for T2/T. During the remaining time the null vectors are output. The dsPIC® device is configured for center aligned PWM, which forces symmetry about the center of the period. This configuration produces two pulses line-to-line during each period. The effective switching frequency is doubled, reducing the ripple current while not increasing the switching losses in the power devices.

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Table 1: Space Vector Modulation Inverter States

C	B	A	V_{ab}	V_{bc}	V_{ca}	V_{ds}	V_{qs}	Vector
0	0	0	0	0	0	0	0	U(000)
0	0	1	VDC	0	-VDC	2/3VDC	0	U_0
0	1	1	0	VDC	-VDC	VDC/3	VDC/3	U_{60}
0	1	0	-VDC	VDC	0	-VDC/3	VDC/3	U_{120}
1	1	0	-VDC	0	VDC	-2VDC/3	0	U_{180}
1	0	0	0	-VDC	VDC	-VDC/3	- VDC/3	U_{240}
1	0	1	VDC	-VDC	0	VDC/3	- VDC/3	U_{300}
1	1	1	0	0	0	0	0	U(111)

VIII. CONCLUSION

From above, it is clear that Control of ACIM through dsPIC serves good and is much efficient and economically for both industrial and domestic applications.

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