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Technological Horizons

DSP Motor Control In Domestic Appliance Applications

DSP-based motor control systems offer the control bandwidth required to make possible the development of advanced motor drive systems for domestic appliance applications.

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Electric motors are the major components in electric appliances such as refrigerators, washing machines. The energy consumed by the electric motor is a very significant portion of the total energy consumed by the machine. Controlling the speed of the appliance motor can both directly and indirectly reduce the total energy consumption of the appliance. In many major appliances advanced three phase variable speed drive systems provide the performance improvements needed to meet new energy consumption targets. DSP based motor control systems offer the control bandwidth required to make possible the development of advanced motor drive systems for domestic appliance applications.

DSP Motor Control In Domestic Refrigeration Applications

System Requirements: Energy efficient compressors require the motor speed to be controlled in the range from 1200 rpm to 4000 rpm. In fractional horsepower applications, the motor of choice with the highest efficiency is an electronically controlled three phase permanent magnet motor.

Motor Control Strategy: In order to run the permanent magnet motor efficiently, it is important to synchronize the frequency of the applied voltage to the position of the permanent magnet rotor. A very effective control scheme is to run the motor in a six-step commutation mode with only two windings active at any one time. In this case, the back emf on the unconnected winding is a direct indication of the rotor position. The rotor position is estimated by matching a set of back emf waveform samples to the correct segment of the stored waveform profile. This technique averages the data from a large number of samples giving a high degree of noise immunity. The control system, outlined below, has an inner position control loop which adjusts the angles of the applied stator field to keep the rotor in synchronization.

Integrator input tracks the motor velocity when the rotor position error is forced to zero. The outer velocity loop adjusts the applied stator voltage magnitude to maintain the required velocity. The controller is capable of accelerating the compressor to its target speed within a few seconds and can regulate speed to within 1 percent of its target.

Motor Control Hardware: The essential hardware in a variable speed AC drive system consists of an input rectifier, a three-phase power inverter and the motor control circuits. The motor control processor calculates the required motor winding voltage magnitude and frequency to operate the motor at the desired speed. A pulse width modulation circuit controls the on and off duty cycle of the power inverter switches to vary the magnitude of the motor voltages.

An analog to digital converter allows the processor to sample motor feedback signals such as inverter bus voltage and current. In this sensorless control application, the motor winding back emf signals are sampled in order to calculate to drive the motor at its most efficient point of operation. The voltage signal conditioning consists of resistive attenuators and passive filters. A precision amplifier is used to capture the motor winding current by sensing the DC bus current. The controller uses this information to limit the motor starting current and to shut down the compressor in overload conditions.

The DSP based motor IC is the heart of the system. On power up, the program performs initialization and diagnostic functions before starting the motor. The motor is started in open loop until the back emf reaches a minimum level, before switching to running mode. Then, every PWM cycle, the DSP uses the A/D converter to sample the motor back emf, the motor current and the bus voltage. The internal multiplexer selects the appropriate back emf signals to be converted. The control law calculates a new rotor position estimate and calculates the PWM duty cycle required applying the required voltage to the motor. At particular values of estimated rotor position angle, the algorithm selects a new set of active motor windings by writing to the PWM segment selection register. The DSP algorithm also performs diagnostic functions, monitoring dc bus voltage, the motor current and speed. In the case of overload conditions, the drive will be shut down and attempt to restart after a short time delay.

DSP Motor Control In Washing Machine Applications

System Requirements: The drum in the horizontal axis washing machine is driven at speeds between 35 rpm and 1200 rpm. The motor, however, must run at speeds in the range of 500 rpm to 15,000 rpm. Three phase AC induction motors provide advantages over universal motors through the elimination of brushes and a wider speed range.

To properly control a three-phase AC induction motor over a wide speed range both motor current and motor speed information is required. The speed ripple

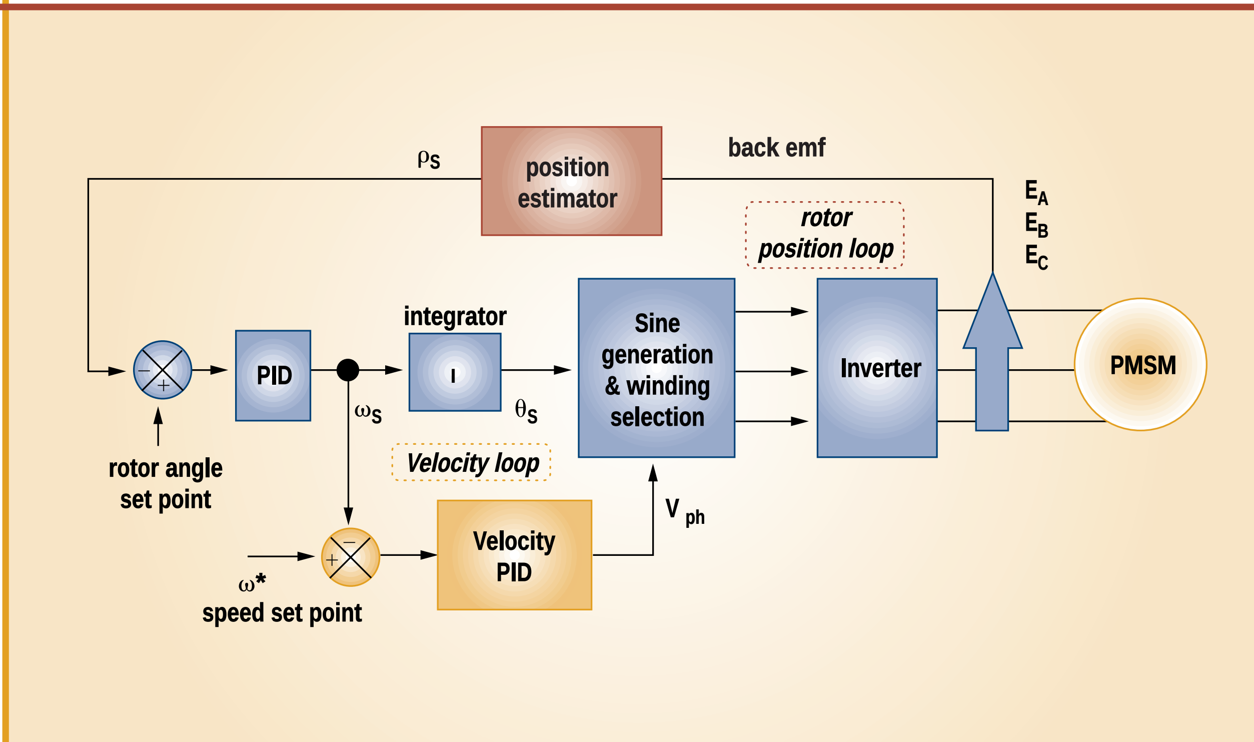

Figure 1. Sensorless Control System

and load torque of the washing machine motor also provides valuable information about the washing load. The washing drive described here is for a 500W AC induction motor with a speed range from 500 to 15,000 rpm.

AC Induction Motor Control Strategy: The control of an AC induction motor (ACIM) is potentially much simpler than that required for a permanent magnet ac motor. The ACIM can be driven in open loop by a three-phase inverter giving adequate speed control performance for many simple pump and fan applications. However, when a wide speed range and high dynamic performance is required, then a field oriented control scheme is necessary. In this case the flux and torque currents are independently controlled to give a performance similar to that obtainable from a permanent magnet synchronous motor. In the low speed range of operation, the flux is kept constant and torque is directly proportional to the torque current. In the high-speed range, when the motor voltages are limited by the DC bus voltage, the flux is reduced to allow operation at higher speeds

A direct stator field oriented control algorithm is described in Figure 3. The key motor variables are the flux and torque producing components of the motor currents. The choice of reference frame is the key element that distinguishes the various vector control approaches from one another.

In this scheme, a reference frame synchronized to the rotating stator flux is selected because of the availability stator current and DC bus voltage information. A number of other field oriented schemes require position information, or stator flux measurements and are not suitable for this application where controlled operation close to zero speed is not required. The Park and Clark reference frame transformation functions calculate the effect of the stator currents and voltages in a reference frame synchronized to the rotating stator field. This transforms the stator winding currents into two quasi DC currents representing the torque producing (Iqs) and flux producing (Ids) components of the stator current.

The stator flux angle is an essential input for the reference frame transformations. The stator flux is calculated in the fixed reference frame by integrating the stator winding voltages. In this system, the stator voltage demands to the inverter are known, so the applied stator voltages can be calculated from the voltage demands and the DC bus voltage measurement. The flux estimation block uses stator current to compensate for the winding resistance drop. The outputs of this block are the stator flux magnitude and the stator flux angle.

There are four control loops closed in this application. There are two inner current loops which calculate the direct and quadrature stator voltages required to force the desired torque and flux currents. The Park and Clark functions transform these voltages to three AC stator voltage demands in the fixed reference frame. The outer loops are the speed and flux control loops. The flux demand is set to rated flux for below

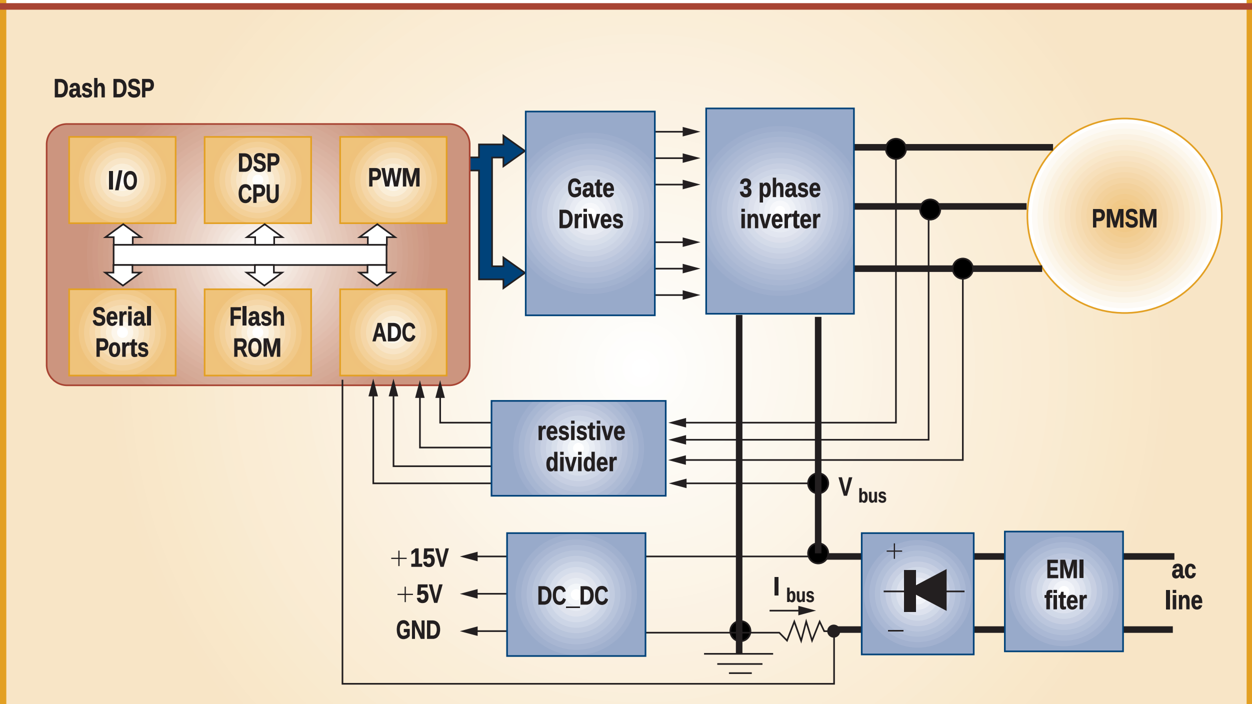

Figure 2. PMSM Control Drive

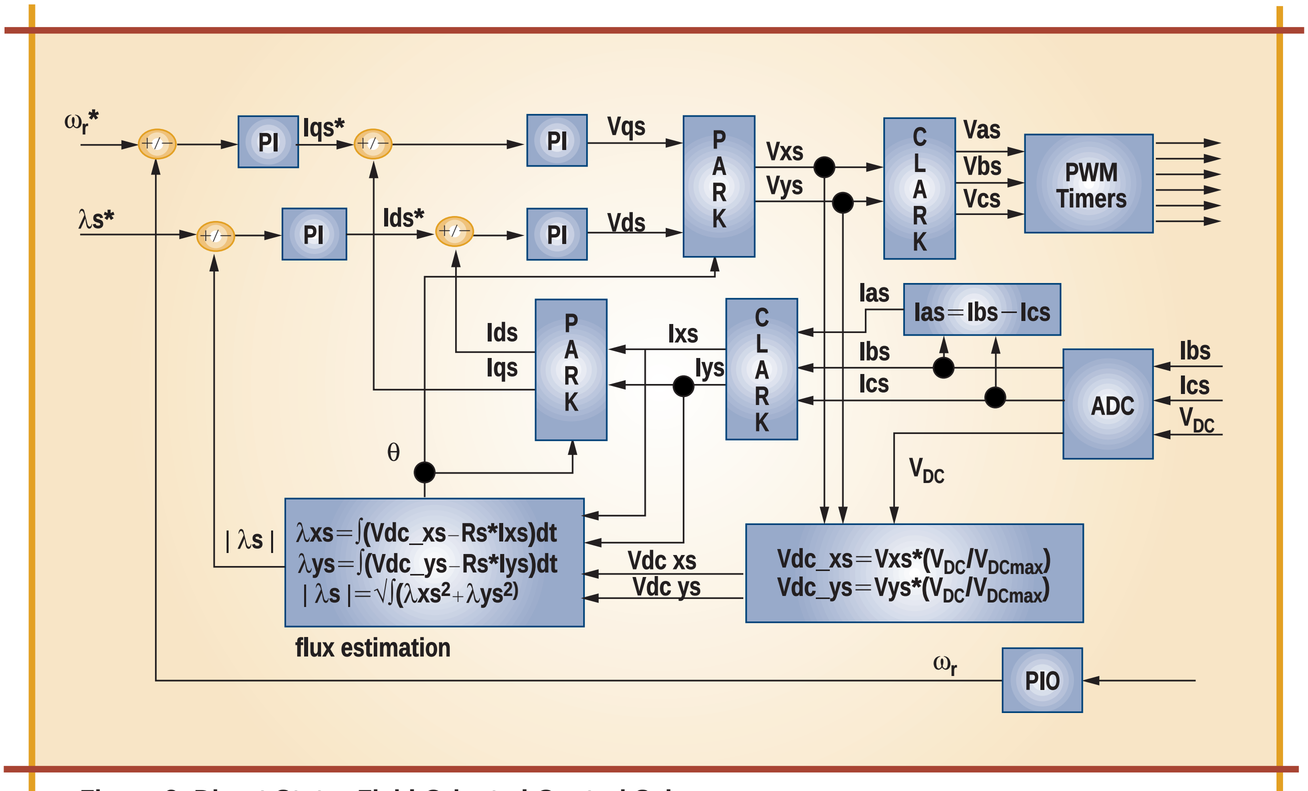

Figure 3. Direct Stator Field Oriented Control Scheme

base speed operation and is reduced inversely with speed for above base speed operation in the 'field weakening mode'. Finally, the torque loop is the same as in any classical motion control system.

AC Induction Motor Control Hardware The DSP based AC induction motor system has similar hardware to the permanent magnet drive described previously. In this case, the motor is rated at over 500 W and so IGBTs are the power devices most suited. The feedback signals include the motor currents, the bus voltage and a pulse train from a digital tachometer. The motor winding currents are derived from sensing resistors in the power inverter circuit.

AC Induction Motor Control Software: One challenge in the development of the control software was to run four simultaneous control loops where the variables have a very wide dynamic range. A solution, which very much improved performance, was to use floating point variables for all the PI control loops. This extended the processing time somewhat but was not found to be a significant burden when using a 25 MIPS DSP core. The processor can easily handle the multiple interrupt sources from the A/D converter, the digital I/O block, the communications ports and the timer. A number of useful device features of the device such as the auto-buffered serial port and the single context switch made the task possible without significant overhead in pushing or popping a stack. Finally, the code development was somewhat simplified by the availability of motor control library functions in the internal DSP ROM.

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