Control of three-phase PM motors in home appliances

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The iMOTION motor control platform helps to increase the power efficiency of sensorless motors in home appliances.

■ Until recently, AC induction motors have been the preferred motor choice in most appliance applications. This is mainly due to the fact that they can run directly from the AC supply without the need for additional control electronics or position feedback sensors. The traditional appliance controller in a refrigerator, for example, is a simple circuit, which cycles the compressor on and off to maintain the temperature within the target range. When the system starts operation, the compressor runs continuously. Once the temperature reaches the target range it runs at a low duty cycle. Refrigeration systems take a number of minutes to reach their most efficient operating point after starting, while the pressure builds up in the system. When the system operates with a low on/off duty cycle, the compressor runs for a large fraction of time away from its most efficient operating point. Varying the compressor speed to match the cooling load reduces energy consumption by as much as 40% because the refrigeration system operates at a much higher duty cycle.

Further appliance efficiency improvements are made possible by employing three-phase PM motors and controlling these motors to deliver variable speed operation. Such motors typically have efficiencies as high as 90% - compared to a typical single-phase induction motor efficiency of 70% - and allow for simplified speed and torque control. At the same time, greater efficiency may allow deployment of a smaller motor, thereby reducing per-unit costs as well as easing mechanical design. And, naturally, the key to getting the most from these motors lies in the methods chosen to drive them.

To accurately and effectively drive a variable speed motor in an application such as a refrigerator or a washing machine, it is important to be able to obtain information on rotor position. The most obvious way to do this is through the use of additional sensing components. However, the impact that this has on both reliability and cost actually makes the approach impractical. As a result, designers are looking to sensorless techniques. Fortunately, advances in motor control technology are now enabling high efficiency in three-phase PM AC drives without the need for position sensors. An example of such a system is illustrated in figure 1. The three-phase power inverter on the right hand side of the diagram controls the flow of current from the DC source to the PM motor windings, while the space-vector PWM unit calculates the timing signals for the power transistors, which then provide the three-phase sinusoidal voltages to the motor.

The interface between the low voltage control signals and the power switches connected to the high voltage DC bus is a HVIC (high-voltage gate-drive IC). These ICs offer a more robust and elegant alternative to discrete gate drive circuits or conventional opto-coupled, or pulse transformer-based approaches. The latest HVIC technologies make use of advanced mixed-signal semiconductor processes to combine low-voltage input capabilities with high-voltage drive outputs and a large number of on-board functions. International Rectifier's latest HVICs for motion control applications, for example, which have voltage ratings from 200V to 1200V and are compatible with logic inputs down to 3.3V, incorporate features such as undervoltage lockout protection, shutdown inputs, cross conduction prevention logic and fixed or programmable dead times.

As figure 1 shows, the key element of the control circuit is that required to implement a field-oriented control (FOC) algorithm. This algorithm, which is commonly used in industrial drive systems, calculates the motor voltages and currents necessary to deliver the desired speed and torque, with the highest motor efficiency. FOC uses vector transformations to resolve the AC motor-winding currents into two quasi-DC current components driving motor flux and torque. The transformations include a vector rotation (e-j) as a function of the rotor flux angle to derive a current component aligned with the rotor flux (ID) and a quadrature component that generates motor torque (IQ). The

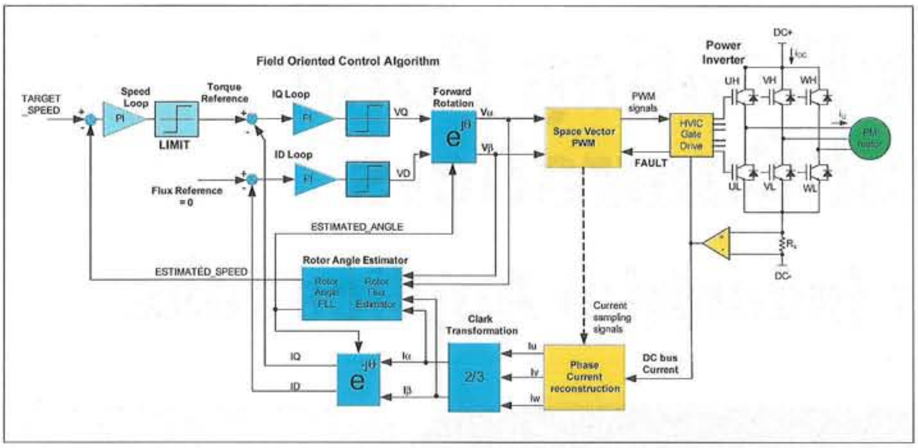

Figure 1. Sensorless field-oriented control of a PM AC motor

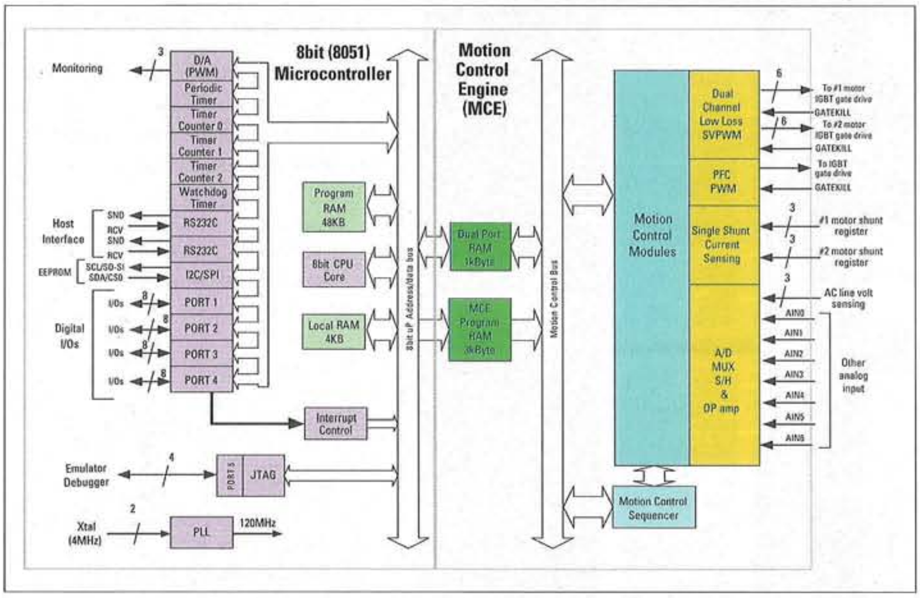

Figure 2. MCE and co-integrated 8051 microcontroller, with A/D also on-chip

current feedback control loops calculate two quasi DC voltage components, VD and VQ, necessary to maintain the target torque and flux. A second vector rotation calculates the AC voltage references for the pulse-width modulator. The advantage of the FOC algorithm is that the motor torque is a linear function of the IQ reference, which results in a simple, linear velocity-control law. In the case of the PM motor, the controller maximises the motion-system efficiency by maintaining the flux current component (ID) at zero. A key advantage of employing this algorithm is that the controller is able to calculate rotor position by measuring the current in the inverter DC link used to drive the motor currents using just one DC link shunt. Using the circuit the rotor angle estimator supports sensorless rotor position feedback by using the motor winding circuit equations below. The three-phase to two-phase transformation simplifies the calculation and yields two terms that are sine and cosine functions of the rotor-flux angle. The integration of these equations yields sine and cosine functions of the motor currents and voltages. An inverse-tangent calculation could determine the rotor angle, but a phase-locked loop based on the error function below is a more robust approach and delivers a filtered velocity measurement as a byproduct.

The controller reconstructs the motor phase currents by synchronising the current sampling from the DC link shunt resistor and timing the power inverter switching. As mentioned, a significant advantage of the described approach is that motor feedback signals derive from a single DC shunt resistor thus avoiding position sensors or isolating current sensors. The result is cost-effective control of PM AC motors in home appliances with greatly improved efficiency and performance.

While implementing the types of scheme described provide a reliable, accurate and elegant approach to motor control, they have typically presented a major challenge for design engineers – especially in terms of creating the software coding. It is for this reason that International Rectifier developed the concept of its iMOTION platform, which encompasses integrated motor control systems for a variety of application areas, including home appliances.

At the heart of the iMOTION platform concept are dedicated motion control ICs. These ICs contain, in a single chip, two computation engines, as shown in figure 2. The first is the motion control engine (MCE), which incorporates all the coding required for sensorless control of PM motors, and the second is an 8-bit high-speed microcontroller. The MCE contains a collection of hardware-implemented control elements which the designer configures as appropriate to create the application-specific motion control algorithm. Configuration is via a simple-to-use graphic compiler. Key components of the FOC algorithm are provided within the MCE as complete, pre-defined control blocks. The IC also incorporates an ADC and associated algorithm to fully support single shunt current reconstruction.

With the MCE handling the motion control, the 8051 microcontroller is free to run the appliance application software including sequencing, user interface, host communication and upper layer control tasks. The MCE and the 8051 MCU have shared access to dual-port RAM, allowing set points such as target speed to be shared and adjusted under application control. ■