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Smart Pumping: Motion-Control Advancements Aid Intelligent-Pumping Applications

Sinusoidal current control ensures quiet operation

The latest motion-control semiconductor technologies help designers rapidly implement intelligent-pump controls.

By Aengus Murray, International Rectifier

Variable-speed intelligent pumps are rapidly gaining favour in applications as diverse as chemical processing and building services. The growing demand for these pumps is largely due to efficiency improvements over conventional fixed-speed 'on/off' designs. Companies find that using intelligent pumps to improve efficiency helps them comply with environmental legislation and also leads to operating-cost reductions.

Traditional fixed-speed pumps always work at full capacity. Variable-speed systems match pump speed to demand. The pump-drive circuitry need only supply the power necessary to satisfy the system's instantaneous demands. Designers can choose smaller, lighter, less expensive pumps while customers benefit from the fact that a pump that operates most often at a fraction of its full capacity is inherently more reliable.

Water and wastewater management and building automation are typical target applications for intelligent pumps. They are sensitive to operating costs and are commonly subject to Governmental control. Building regulations and other legislation designed to address environmental concerns, such as the UK Government's Code for Sustainable Homes are influential in these applications.

Intelligent pumps can contribute most in systems with widely fluctuating fluid demand or narrow-ranging pressure requirements over a wide range of flow rates. An example is the system supplying chilled water in an office building's heating and cooling system. Estimates suggest that a variable-speed pump can reduce energy consumption in such systems by 30 to 70% (ARC Advisory Group Intelligent Pump Market Analysis).

In these applications, however, energy efficiency and cost of ownership tell only a part of the story. Just as important is the need to keep acoustic noise as low as possible. Moreover, such applications often require fast response times and high control accuracy to accommodate the full range of flow requirements and to quickly match supply with demand. All of this increases the complexity of controlling the PMSMs (permanent-magnet synchronous motors) at the heart of intelligent-pumping designs.

A PMSM controller must sense or calculate both the rotor angle and speed. The traditional method of detecting these parameters uses external components such as Hall-effect sensors. Such sensors require additional circuitry, however, adding to the system cost. Sensor-based designs are also less reliable than sensorless alternatives — a fact that is exacerbated by the environment in which the motors operate. Consequently, more designers are looking towards sensorless PMSM-control schemes for intelligent-pumping deployments.

Sensorless control

Historically, however, designing a sensorless PMSM controller has been a challenge for pump-system OEMs. The most straightforward method measures the motor-winding currents and derives estimates of the rotor's position and speed. Direct measurements of motor-phase currents are expensive to

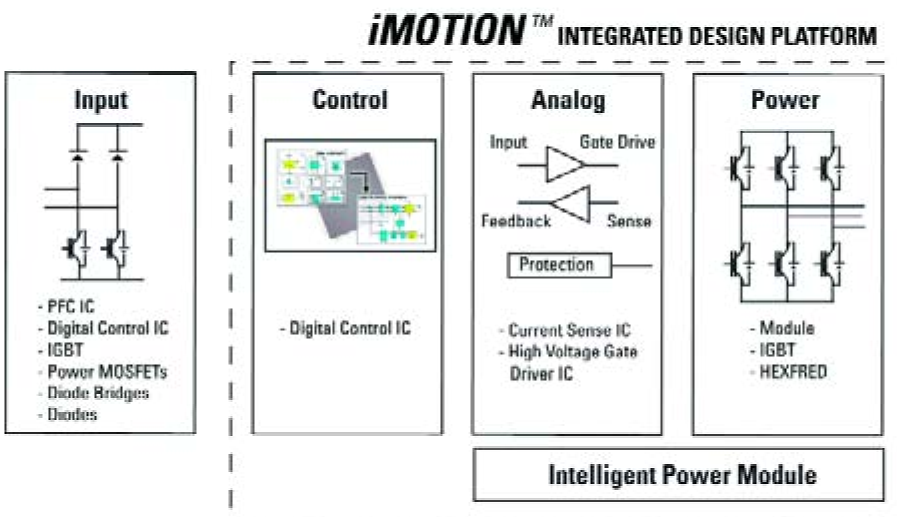

Figure 1: International Rectifier's iMOTION platform includes a digital motor controller, a current sensor, and a three-phase power stage.

implement and, in general aren't economic for many commercial intelligent-pump applications. Cost-effective sensorless designs make position and speed calculations based on an indirect current measurement. The controller computes the motor-winding currents from this indirect measurement and derives the rotor speed and torque from the winding-current calculations.

Though practical in terms of implementation, sensorless pump controllers until recently have required the design team to combine pumping-systems knowledge, control algorithms expertise, and advanced programming abilities. The latter are often unavailable in house. Even when the requisite system-development skill set exists in-house, writing and testing the complex code can increase design risk, cost, and cycle time.

The need to quickly and cost-effectively build control systems for PMSMs has created a demand for dedicated ICs that can implement sensorless control. Semiconductor manufacturers such as International Rectifier have developed motor-control platforms comprising building blocks that OEM designers can quickly bring together to create a finished variable-speed, sensorless drive design.

International Rectifier's iMOTION™ platform, for example, is based on digital motor controllers running PMSM-control algorithms, current sensing ICs, and power modules (Figure 1). Platforms such as these accelerate the design process, cut component count, reduce risk, and lower project costs.

Dedicated intelligent pump platform

International Rectifier's latest iMOTION development is a platform that delivers quieter operation and higher efficiency to PMSM-based intelligent-pumping applications with power requirements up to 300 W. Combining IR's mixed-signal motion-control IC with an intelligent power module (IPM) such as the IRAMS06UP60B, engineers can now rapidly develop a sensorless PMSM-control system for smart pumps. This system achieves higher performance and reliability than alternative discrete. Sinusoidal current control ensures quiet operation while delivering the efficiency benefits of a PWM-based design. Additionally, the control IC also enables smooth pump start-up.

The IRMCF371 combines IR's proprietary MCE (Motion-Control Engine) with all of the control and analogue interface functions necessary for accurate, sensorless, sinusoidal control of PMSMs using DC link-current measurements (Figure 2). These include a differential amplifier, dual sample-and-hold circuits, and a 12-bit ADC. Predefined hardware blocks implement key sensorless-control-algorithm components such as an angle estimator. The controller IC also features an integrated 60-MIPS, 8-bit, 8051 microcontroller, which operates independently from the MCE to execute application-layer functions.

The IRAMS06UP60B is a compact, intelligent, motor-driver power module in an isolated package. The module includes short-circuit-rated IGBTs, the measurement shunt, over-temperature and over-current protection, under-voltage lockout. Integrated bootstrap diodes for the high-side driver and single-supply operation simplify the pump-control circuitry.

Pump motor control operation

The control IC's ADC samples the low-voltage signal across the power module's DC-link shunt. The MCE's algorithm reconstructs the motor-winding currents from the samples. During two inverter-switching states the current flowing in the DC bus matches the current in a motor winding. The controller measures two of the three motor-phase currents by sampling twice within each PWM cycle. The three phase currents sum to zero so the algorithm calculates the third current from the two measurements. A Clarke transform converts the three-phase current data into an equivalent two-phase dataset. A rotor-angle estimator uses the two-phase current data and voltage values from a forward vector-rotation block to calculate the rotor angle and speed.

An FOC (field-oriented control) algorithm transforms the AC motor winding currents into two DC components representing torque (IQ) and flux (ID). This transform simplifies the controller design because the current-loop tuning becomes independent of the motor speed. The outer speed loop calculates the torque-reference command for the IQ loop based on the speed error. There is a RAMP function at the speed loop's input, which limits acceleration to specified limits, and a LIMIT function on the output to limit the motor current. An additional control function introduces phase advance to maximise the torque output when driving an IPM (interior permanent-magnet) motor.

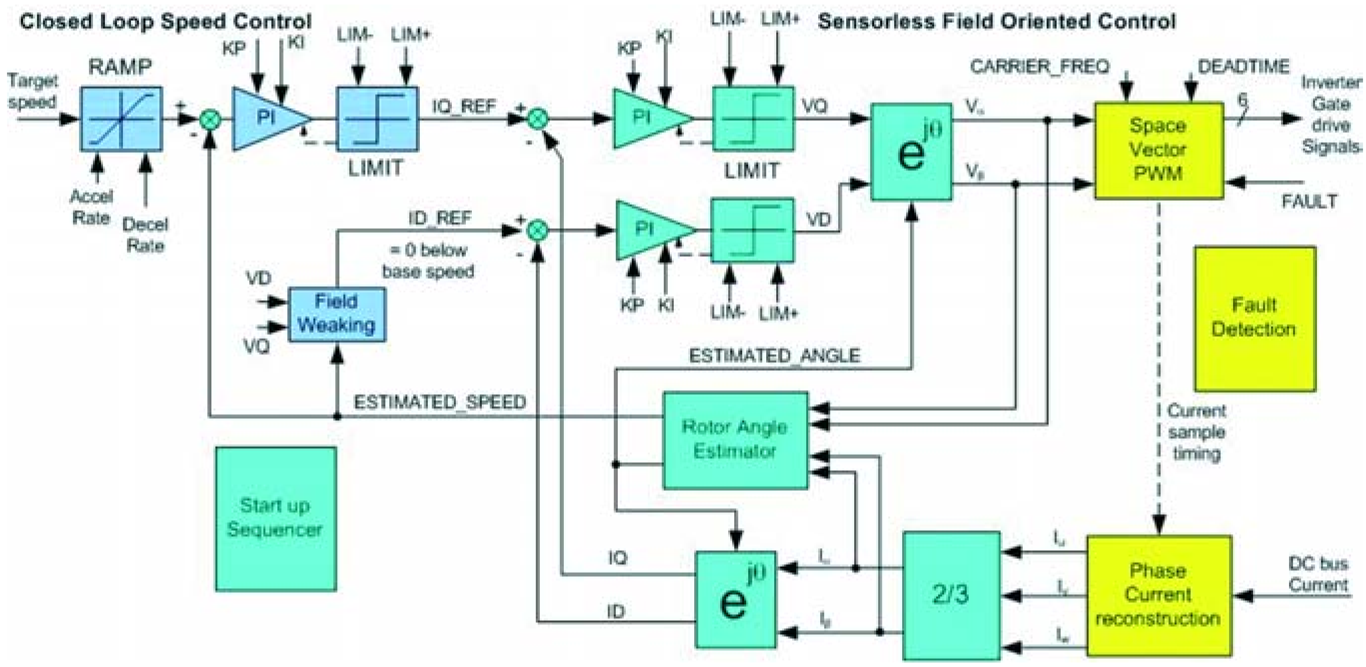

Figure 2: The IRMCF371 implements an FOC (field-oriented control) algorithm for intelligent pump control.

Motion control programming
A graphical-compiler tool integrated into the MATLAB/Simulink™ development environment facilitates programming the MCE. The graphical programming method reduces design errors and promotes quick design cycles. The developer selects functions from the available MCE-control elements including proportional plus integral, vector rotator, angle estimator, multiply/divide, low-loss low-EMI space vector PWM, and single-shunt IFB. The developer then uses the compiler to link the functions together (Figure 3).

The 8051 8-bit microcontroller executes sequencing, user interface, host communication, and upper-layer-control tasks. The microcontroller includes a JTAG port for emulation and debugging. The configurable nature of the MCE also makes the iMotion platform highly flexible for implementing various control strategies or product variations on a hardware set.

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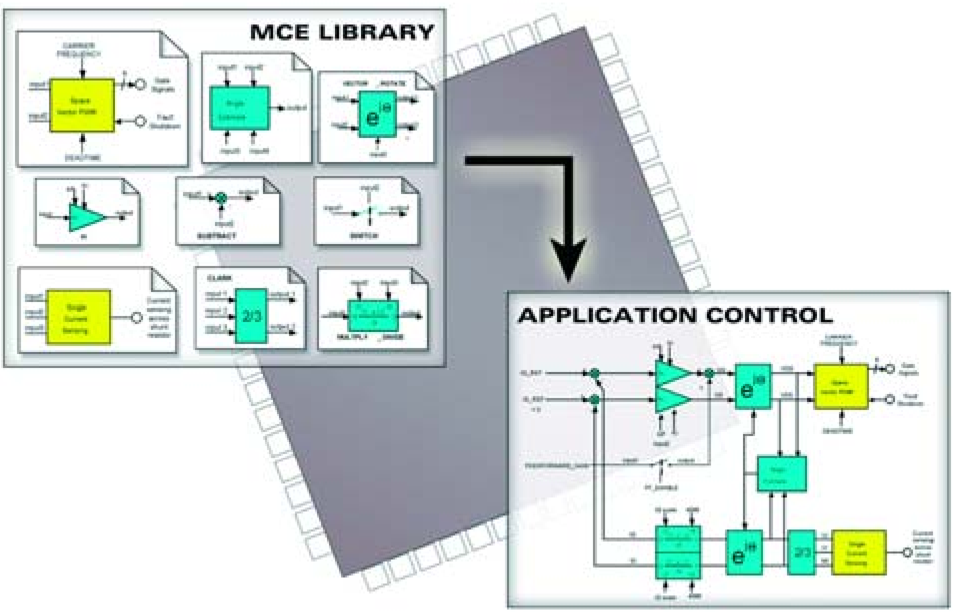

Figure 3: The iMOTION graphical programming environment promotes quick, error-free design cycles.