Drivers of change

Embedded DSP-based motor control

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When people step onto an escalator, they don't expect it to slow down under the extra load: Rather, the power output should rise to maintain a constant speed. In industrial applications; belts, shafts and pumps are similarly expected to maintain preset speeds or torque values, regardless of changing conditions. Such requirements are not fulfilled through inherent properties of the motors, but through the use of motor control systems (drives).

An important criterion for such a control system is its responsiveness. How long does it take to respond to and compensate for a parameter change? Progress in microprocessor technology is not only permitting faster data throughput in such systems, but is also allowing increasingly sophisticated mathematical functions to be implemented. ABB's Direct Torque Control (DTC) relies on powerful digital signal processors (DSP) that deliver a very fast response time and an accurate and responsive control system.

Direct Torque Control (DTC) is a control method that gives electronic variable speed motor controllers (AC drives) an excellent torque response time 1. For AC induction machines, it delivers levels of performance and responsiveness reaching the machine's theoretical limits in terms of torque and speed control.

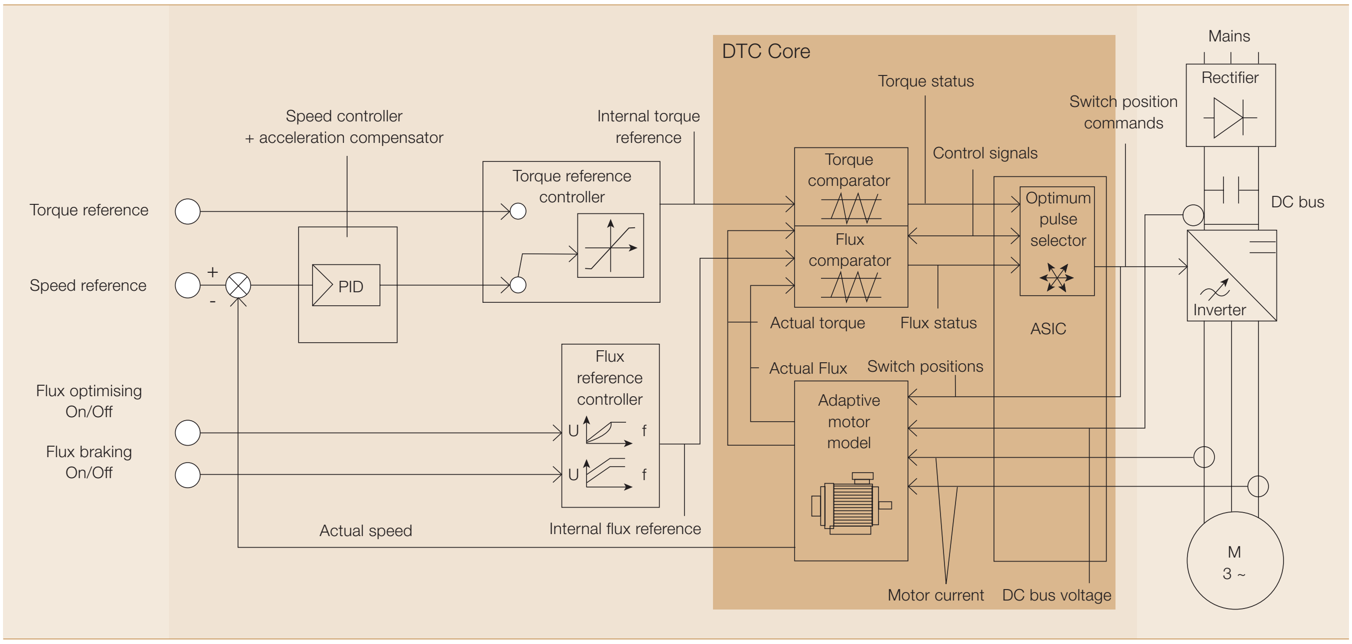
DTC uses a control algorithm that is implemented on a microcontroller embedded in the drive. The technology was first used commercially by ABB in 1995, and rapidly became the preferred control scheme for AC drives, especially for demanding or critical applications, where the quality of the control system could not be compromised. To understand the interplay of control theory and progress in embedded control, the history of DTC should be considered.

The emergence of a new technology

The main function of a variable speed drive (VSD) is to control the flow of energy from the mains to a process via the shaft of a motor. Two physical quantities describe the state of the shaft: torque and speed. Controlling the flow of energy depends on controlling these quantities.

In practice, either of these can be controlled and the implementation is referred to as "torque control" or "speed control". When a VSD operates in torque control mode, the load deter-

Block diagram of DTC



An Ideaplast plant in Italy with a single-line extruder (detail of the extruder's head and winding film rolls)

Reliable conveyor operation is essential in bakery automation (Fazer Bakery, Finland)

A pressure-boosting station (Pietersaari Finland). The drives are equipped with DTC and intelligent pump control (IPC)

mines the speed. Likewise, when operated in speed control mode, the load determines the torque. In either case, there is a relationship between the torque, the actual current and the actual flux in the machine. The idea of DTC is that motor flux and torque are used as primary control variables. This is contrary to the way in which traditional AC drives control input frequency and voltage, but is similar in principle to what is done with a DC drive.

Also, with traditional PWM (pulse width modulation) and flux vector drives, the voltage applied to the motor requires a modulator stage. This stage adds to the signal processing time and therefore limits the responsiveness of the control system, and hence the torque and speed response time.

The fact that DTC does not require a modulator is one of the reasons why this control method offers such fast response times – ten times faster than can be achieved through conventional flux vector control. Moreover, DTC achieves this fast field-oriented control without the need for speed feedback: It uses advanced motor theory to calculate the motor torque and stator flux.

The reaction time of DTC is so fast that it opens new possibilities for variable speed control. For example, a DTC drive is ideal for protecting the mechanics from overload and load shocks.

DSP enables breakthrough

Although the advantage of DTC was understood in theory, it could not be implemented until progress in embedded control made it possible to execute the primary control cycles at a sufficiently high frequency. Conventional microprocessors, as used in personal computers, do not achieve a sufficiently high data throughput. It was the introduction of digital signal processors (DSPs) that made the implementation of DTC possible. DSPs were first developed for the telecommunications industry, but have now found widespread use in drive control. A modern DTC drive calculates the actual torque on the motor shaft at least 40,000 times per second (every 25 µs). This provides an extremely fast reaction to load changes on the motor shaft, as well as to changes in the speed or torque reference made by the user.

Today's drives are smaller, faster, more efficient, more reliable, and easier to use than the previous generation – all thanks to progress in embedded control.

The reaction time of DTC is so fast that it opens new possibilities for variable speed control. For example, a DTC drive is ideal for protecting the mechanics from overload and load shocks. Also, fast torque control means that sophisticated algorithms can be readily implemented for the damping of mechanical vibrations in applications where mechanical resonances are inherently present. Similarly, a DTC drive can rapidly detect a loss of load torque caused by a mechanical failure – for example a broken conveyor belt – and act to prevent further damage. Because of its fast time response, there are many other examples of DTC being integrated into protective functions for both machine and motor.

Whereas simpler control methods – such as sensorless vector control – are typically used in low-power drives for less demanding applications, DTC is preferred in the more demanding applications that require a very fast torque response time for optimum performance. Because high power drives are significant investments, DTC is also used in all such drives from ABB, regardless of the application.

Spreading to other applications

With the advent of DTC there is little to improve in the control method of variable speed drives: It is no longer the frequency converter that limits the performance of a variable speed drive, but the motor itself. Research has now shifted towards the application of DTC in other settings. Some exciting new developments of embedded drive control have been opened.

One of these is the application of DTC to permanent magnet motors. Although the principal of permanent magnet motors has been known for some time, their commercial breakthrough had to wait until magnetic materials were sufficiently developed.

NdFeB (neodymium iron boron) magnets have been available since 1987, but there have been several further improvements in the material composition before the mechanical and magnetic properties of these magnets allowed them to be used in the production of motors. Since then, production techniques have steadily improved – today powerful permanent magnet motors are commercially viable.

The result is a line current that is practically sinusoidal and free of disturbances.

The permanent magnet motor is a synchronous motor – operating on somewhat different principles than an asynchronous motor. ABB has created a modified version of DTC specifically for permanent magnet motors. This combination of DTC and permanent magnet motors (PM-DTC) offers several benefits. Although compatible with traditional drives, the motors come in standard IEC frames and mechanical dimensions, the PM-DTC combination offers more accurate control, without the need for encoders, and high torque at low speeds. As a result it has been possible to displace gearboxes from paper machines. PM-DTC drives can lead to substantial cost savings. Compared with traditional solutions these drives use fewer components (no gears, no couplings, no encoders), require less engineering, save space, reduce maintenance costs, have a lower noise levels, higher availability and higher energy efficiency. Many of these benefits can be traced back to the development of DTC and advancements in embedded control. Although paper machines where among the first applications in which PM-DTC technology was applied, other applications can be found in ship propulsion and wind turbines.

Motor control

Control systems come in two basic varieties. Closed-loop control systems have encoders in the motor to report its status. This is used as feedback information for the control algorithm. Open loop systems are simpler because these encoders are omitted – but at the price of a lower control accuracy. Can the accuracy of a closed-loop be achieved without encoders? ABB's DTC does exactly this – it uses mathematical functions to predict the motor status. The accuracy and repeatability delivered is comparable to closed-loop systems, but with the added bonus of a higher responsiveness (up to ten times as fast).

Another new application of DTC is on the front-end of the drive. With modifications, ABB has applied DTC to the supply unit that is connected to the mains and provides the inverter unit with power. With the help of DTC it has been possible to create a drive that produces only very low harmonic distortion.

Traditional drives are supplied with mains power rectified through a passive diode bridge. The problem with this method is that the diode bridge distorts the voltage in the mains. This voltage distortion can affect other equipment connected to the same grid. A very effective way to mitigate this is to use a drive with a so-called "active front-end" that uses DTC for its control. The DTC supply unit controls the line current and removes low harmonic distortions. High harmonic distortions are removed using a small filter. The result is a line current that is practically sinusoidal and free of disturbances.

Modern offices are full of sensitive equipment that requires harmonics in the network be kept as low as possible. Low harmonic drives with DTC are ideal for this type of environment.

Traditional solutions are based on increasing the number of pulses in the supply unit, 12-pulse or 24-pulse inverters, and the use of a bulky phase-shift transformer. The active front-end with DTC does not need such a transformer and the whole package is considerably smaller. These examples illustrate an important trend: Progress in electronics has led to increased embedded processing power and memory in the drive. This in turn has led to the successful implementation of a superior control method: DTC. The advantages of DTC have themselves led to new applications and new functionality. Today's drives are smaller, faster, more efficient, more reliable, and easier to use than the previous generation – all thanks to progress in embedded control.

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