ACS 600 – a growing family of DTC based products

Since being introduced to the market in 1995 the ACS 600 AC drive, which is based on Direct Torque Control (DTC), has had its power range extended to 2.2 – 3,000 kVA for supply voltages of up to 690 V. The original model has also provided the basis for further versions of the product family, such as the ACS 600 Pump & Fan Drive, ACS 600 CraneDrive and ACS 600 Motion Control unit, with dedicated designs for specific market segments. The latest member of the family, the ACS 600 MultiDrive, is designed for system applications in the metallurgical and pulp and paper industries, etc.

The ACS 600 is the first AC drive to be based on Direct Torque Control [1–4]. DTC makes use of an optimized AC drive control principle in which inverter switching directly controls the motor variables of flux and torque. It has key advantages over DC drives, pulse width modulated frequency control and flux/vector control, with which it competes in a wide range of industrial applications 1:

- The good torque control performance of the *DC drive* 1a is based on separate control of the field current (flux) and armature current (torque). Accurate speed control is ensured by tachometer feedback. The DC drive is simple and reliable, but DC motors have more parts than AC motors which are subject to mechanical wear.
- The first AC drives 1b were *pulse amplitude and pulse width modulated (PWM) scalar controlled inverters*. In the case of PWM, the controlling variables are frequency and voltage, both of which have to be passed through a modulator on their way to the motor. The motor current is determined by the load applied to the motor shaft. Both the torque and speed are controlled by varying the frequency and voltage.
- *Vector or flux vector control* of AC drives 1c was introduced in the early 1980s. Torque control in this case requires feedback of the speed, which can be either measured or estimated. A speed or torque reference is converted into voltage and frequency references, which are fed to the inverter control unit and compared with the measured signals. The inverter control takes place via a modulator, and relatively good static speed accuracy is achieved.
- Although the principle of *Direct Torque Control* 1d, 2 was developed in the 1980s, it was not until the 1990s that the first practical applications appeared. DTC requires no modulator. Very good torque and speed control is achieved with DTC, which has a shorter dynamic response time than, eg, PWM control, as no time is lost due to modulation 3.

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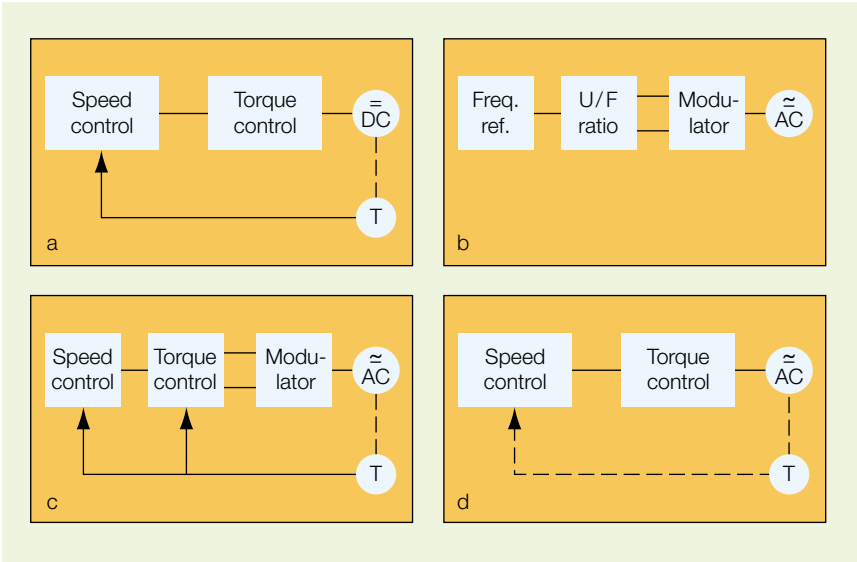
Operating principle of DTC

2 shows the operating principle of Direct Torque Control, in which an adaptive motor model plays an important role. The model receives, as inputs, the measured motor current and voltage values, producing from them exact actual values of both the torque and flux every 25 ms. Motor torque and flux comparators compare the actual values with the reference values produced by the torque and flux reference controllers. The optimum pulse selector determines the ideal inverter switch positions on the basis of the outputs from the two-level controllers. These inverter switch positions act on the motor voltage and current, which in turn influence the motor torque and flux, thereby closing the control loop.

ACS 600 – a product range with common roots

The different products in the ACS 600 family (*Table 1*) 4 are designed to meet the requirements of different industrial and commercial applications. Whereas the standard version was geared to the requirements of most open-loop control applications, the *Pump & Fan Drive* version has been optimized for flow control



Different methods of variable-speed control **1**

a *DC drive*
b *AC drive with, eg, PWM control*
c *AC drive with vector or flux vector control*
d *AC drive with Direct Torque Control*

applications with variable or quadratic torque characteristics. Due to its compact size, it is a very competitive option for applications in pumping stations and HVAC installations.

The *Motion Control* version utilizes the excellent Direct Torque Control performance, with added enhancement in the form of encoder feedback from the motor shaft. In addition, this version features built-in intelligent, time-optimal positioning algorithms.

Motion Control offers servo-drive performance for more demanding applications. The *CraneDrive* version has been equipped with dedicated software developed by ABB. ACS 600 *MultiDrive* uses a common DC bus supply and is designed mainly for larger systems in the metallurgical and pulp and paper industries, etc.

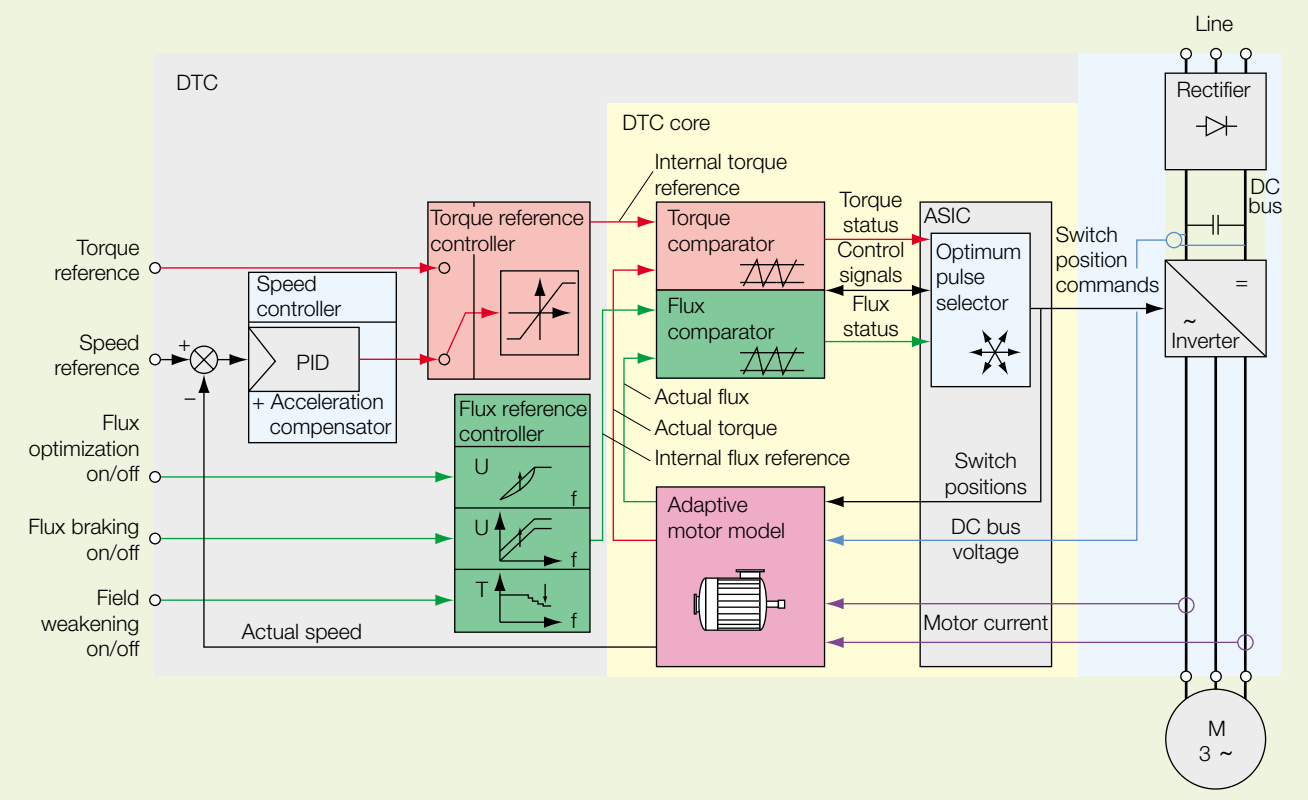
All of these ACS 600 products are based on a common DTC platform and incorporate common hardware and software solutions.

A standard product for a wide range of applications

Since ACS 600 was first launched it has been used successfully for a multitude of applications. Optimized drive solutions based on ABB state-of-the-art technology have been provided for customers in a wide variety of industries. In the following, examples are given of applications for which it has been possible to replace

Table 1:
ACS 600 family members, although designed for different applications with different features, include many common hardware and software solutions.

ACS 600 products	Standard	Pump & Fan	Motion Control	CraneDrive	MultiDrive
Applications	Universal	Flow control	Positioning	Hoist/travel	Multimotor
Main features	Demanding open-loop applications	Optimized for variable torque Compact size	Accurate closed-loop control	Dedicated crane software	Integrated process control
Maintenance Commissioning Man-machine interface Configuration Communication Technology Power electronics			Drives Support Drives Window Control panel + Drives Link Drives Size + Drives Builder With all main fieldbuses Direct Torque Control (DTC) IGBT power plates		

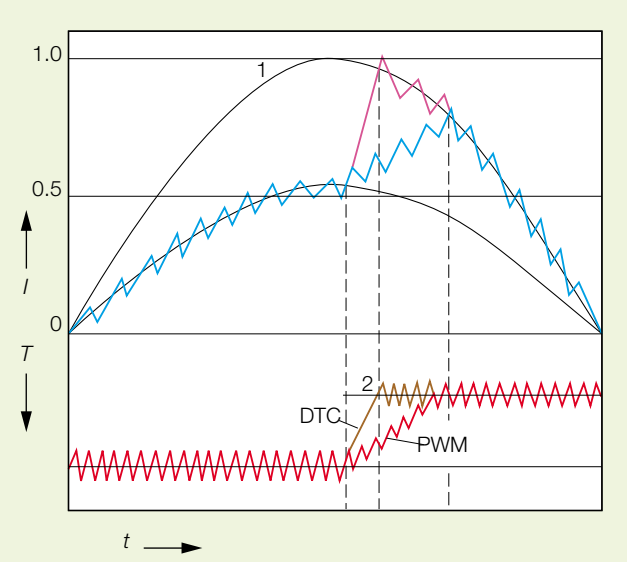


Operating principle of Direct Torque Control (DTC) **2**

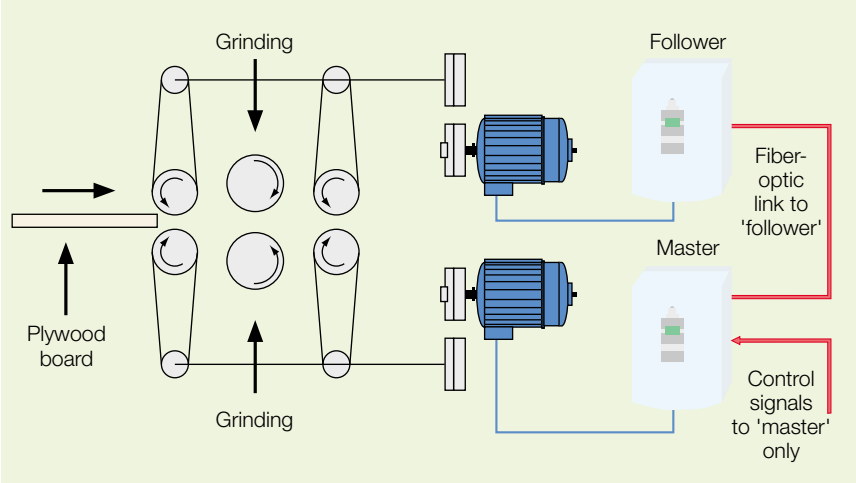
Direct Torque Control (DTC) has a shorter dynamic response time than pulse-width modulated (PWM) control as no time is lost on modulation. **3**

1 *New current level*
2 *New torque level*

I *Current*
T *Torque*
t *Time*



ACS 600 family of drives; wall-mounted units are shown in foreground, a drive module on the left, and a free-standing drive on the right. **4**



Example of master/follower solution with ACS 600 used in a plywood grinding application 5

DC drives with open-loop ACS 600 drives.

Master/follower operation in plywood grinding

A sawmill operator in eastern Finland wanted to increase the productivity of its mill by replacing the DC drives in the plywood grinding part of the plant, which had become a bottleneck, with AC drives. This was because the DC drives required regular maintenance, forcing the mill to routinely close down. The use of AC drives would effectively eliminate this problem 5.

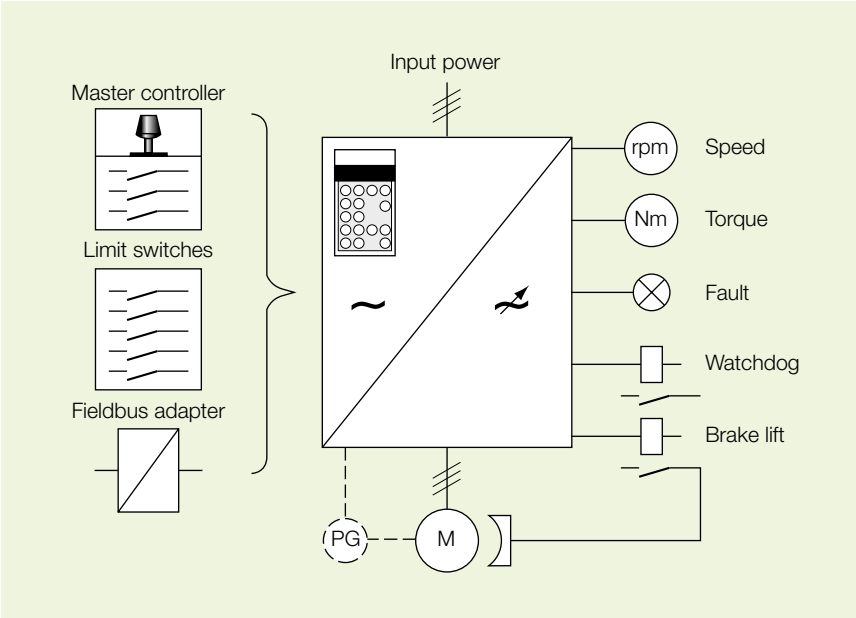
The installed ACS 600 equipment made it possible to utilize open-loop AC drives in the feeder rows of the grinding machine. The benefits of ACS 600 which come to the fore in this application are the improved motor control performance, application control, and data transfer between the drives.

In such applications, DTC allows accurate torque control for AC drives down to low speeds without the need for expensive, vulnerable pulse encoders for measuring the motor shaft speed and position.

The operation of the two drives is synchronized by the master/follower application macro in ACS 600. This comprises the operating logic with which the master drive transmits the control word and references to the followers every 12 ms. By means of the follower parameter settings it is possible to determine whether the follower is using the speed or torque reference from the master, or a combination of these. In the latter case, the follower is in torque control mode and a so-called window function is used which makes sure that the follower speed will not become too high when one plywood board has been ground and the next one is not yet ready for grinding.

ACS 600 has some clear benefits for the customer, including high reliability, improved end-product quality and the elimination of spurious trips or similar interruptions. The absence of shaft feedback devices in this application further translates into minimal maintenance.

Standard interfaces with ACS 600 CraneDrive 6



Safer and faster crane operation

To meet the special needs of crane builders and users worldwide, ABB in Sweden and Finland jointly developed and introduced ACS 600 CraneDrive (ACC 600).

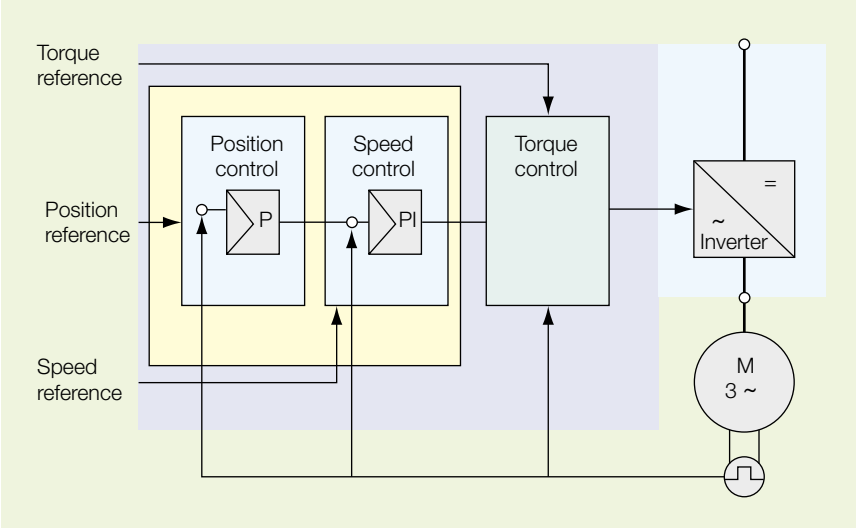
ACS 600 CraneDrive optimizes performance and safety while meeting the specific needs of a wide range of cranes. This dedicated crane drive provides precise speed and torque control under even the most difficult and demanding conditions, for hoist as well

as travel motions. The integration of DTC in ACS 600 ensures full speed control down to zero at full torque and allows better performance than with earlier drives.

ACS 600 CraneDrive is supplied as a standard, cost-effective and ready-to-use package incorporating all the necessary control and safety functions. No additional hardware is necessary. The programming and fault diagnostic tools are the same as those used with other ACS 600 products **6**.

The standard functionality includes control interfaces for most crane controls, reference and logic handling, speed and torque control, torque memory, power optimization for maximum hoist speed relative to the load, limit switch supervision, a master follower function, mechanical brake control, torque proving, torque monitoring and fault handling.

To date some 1,000 ACS 600 CraneDrive units have been delivered, principally for different types of container crane in sea ports, and for EOT cranes steel mills, paper mills and power plants. Revamps of older cranes is also a growing market.



ACS 600 Motion Control **7**

Motion Control for accurate positioning and synchronizing

Aimed at the OEM and system integrator market, ACS 600 Motion Control is a high-performance, closed-loop AC drive offering precision positioning and synchronization operating modes in addition to the accurate torque and speed control modes that are the hallmark of DTC technology **7**. When it is installed, servo-drive performance can be approached with standard AC induction motors.

The integrated positioning software eliminates the need for external motion control systems, thus reducing the costs associated with solutions employing traditional closed-loop AC drives. The software moves the ACS 600 into applications which previously used servo-drive technology.

Implementation is easy, as the software functions only have to be parameterized; no programming is required.

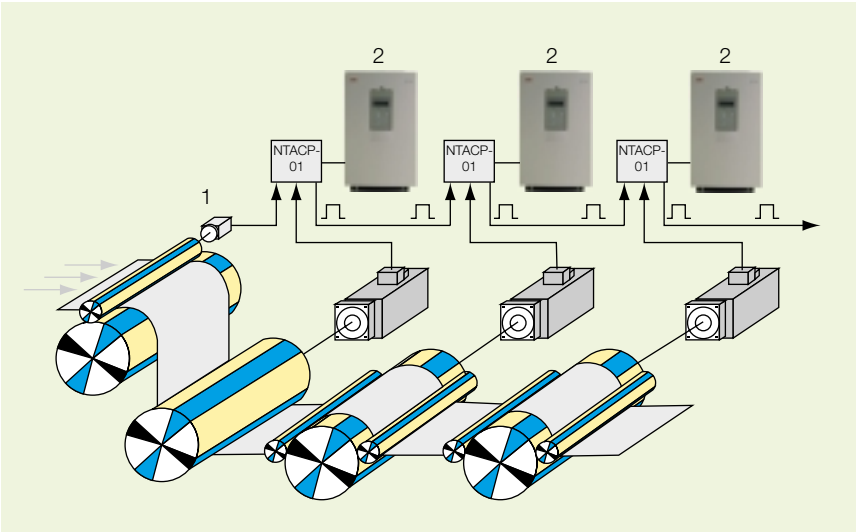
The drive covers the range from 2.2 kW to 315 kW for voltages from 380–500 V, and is targeted especially at machine builders. It is available as wall-mounted modules up to 90 kW, as modules for integration in cubicles from 55 kW to 250 kW, or as complete cubicles from 55 kW to 315 kW.

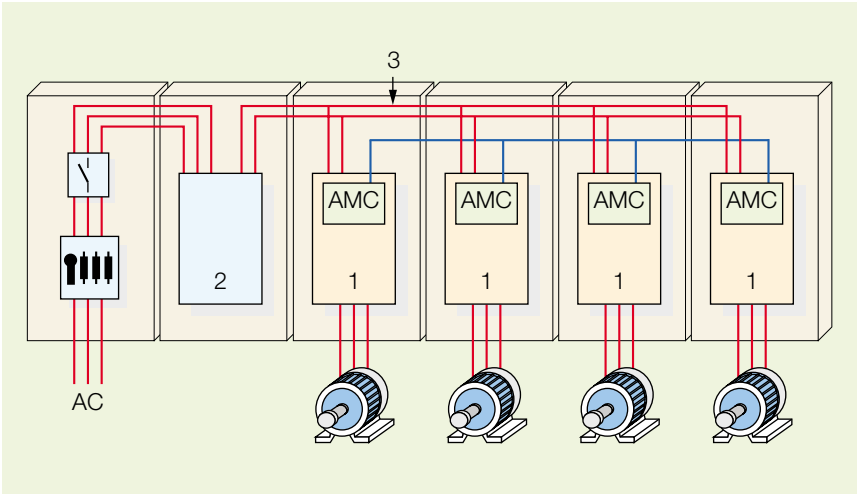
Positioning

In the positioning mode, the ACS 600 Motion Control unit has a fixed target.

Synchronizing application with ACS 600 Motion Control in the plastics industry **8**

1 Master encoder *2 ACS 600 Motion Control*





MultiDrive has a common rectifier supplying power to several inverters. 9

1 *Inverter*
2 *Diode or thyristor supply unit*
3 *Common DC bus*

The target position is entered in a 'look up' table by means of parameters. This table can store up to 32 user-defined positions. Each of the 32 data sets also describes the motion associated with any given position, such as velocity, acceleration rate, deceleration rate, and mode of operation.

A software pointer locates the next selected position in the 'look up' table, which is easily addressed by means of machine pushbuttons, switches or a PLC.

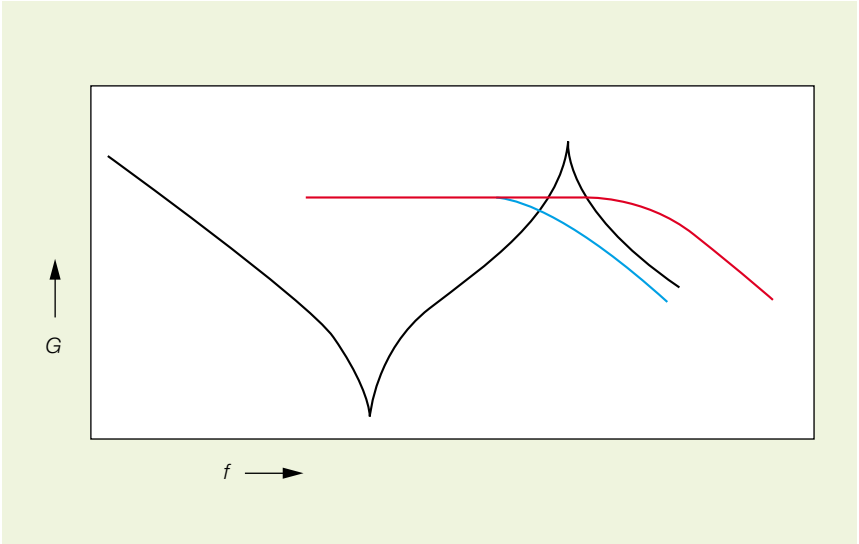
When the command to start is given, the drive moves from a predefined start position to the target position with the help of a 'motion profile' generated by the position interpolator. The position data can be given in either mm, inches, degrees, revolutions or pulses.

The positioning mode is used for single or multiple linear axes and is ideal for a wide range of applications, including conveyor lines, rotary tables, stacking machines, package handling and hoists.

Direct Torque Control also dampens torsional oscillations caused by resonant frequencies more effectively and faster than flux vector control. 10

Black *Mechanical system in which resonance occurs*
Blue *Flux vector control*
Red *Direct Torque Control*

f *Frequency*
G *Gain*



Synchronization

In the synchronizing mode, ACS 600 Motion Control follows a moving target which is generated by a master encoder mounted on either the machine or another motor.

This mode is intended for applications in which the shaft angle between two or more axes of motion need to be controlled. The motor shaft may be connected to the load by a gearbox or other mechanical system with a gear ratio. Integrated electronic gear functions allow the control of correct load shaft angles.

Applications include web handling (eg, for delicate materials), shaftless coordination of multiple motors 8 (eg, for lift tables, textile machines).

MultiDrive for small and large systems

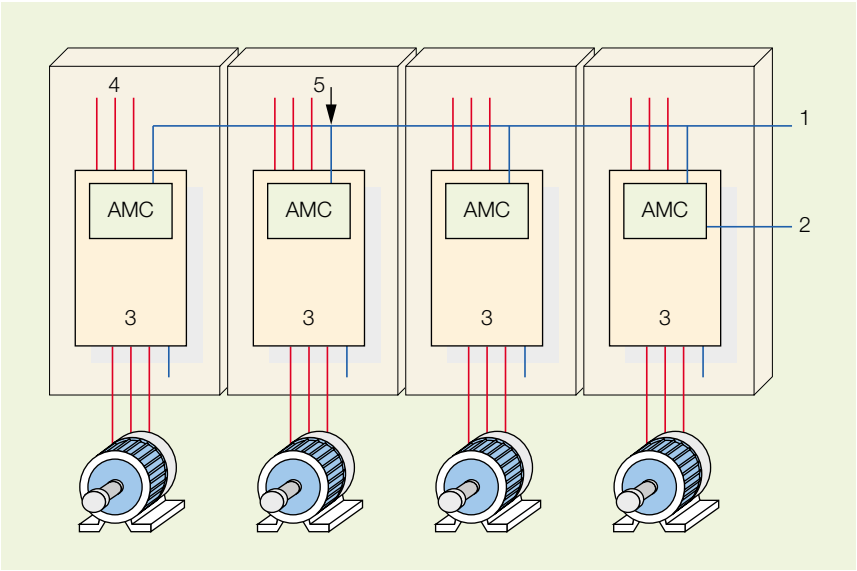
MultiDrive is especially well suited for systems in which several motors are run together, eg line drives 9 in the metal, paper, plastics and textile industries. Such applications require high speed accuracy during acceleration, deceleration and load impact, as even small errors can cause damage to the material.

In a frequency converter, the incoming AC power is rectified into DC and then converted into AC by an inverter that allows adjustment of the frequency and amplitude of the motor voltage. MultiDrive has a common rectifier for the supply of power to several inverters. The rectifier supplies DC power to the inverters via a DC busbar that runs through the inverter lineup. Benefits of the MultiDrive system include:

- Single power cable or bus from the supply transformer
- Fewer components, only one main switch and rectifier
- Direct motor-to-motor braking via the DC bus
- Common braking resources for resistor or regenerative braking

Special benefits of DTC in Multidrive applications are:

- Fast torque control, for fast speed control. The speed follows the reference accurately even during acceleration and load impact.
- Improved damping of mechanical oscillation 10.
- Power loss ride-through. After short power breaks, the control function detects the rotation of the motor shaft and running can continue.
- Robust control with minimum risk of overcurrent tripping.



Inverter controllers have application software capacity. The software can be fixed or freely programmable. The inverters are connected together and to a possible overriding system by the system bus, which can be an ABB proprietory bus (usually AF 100) or a generic bus. 11

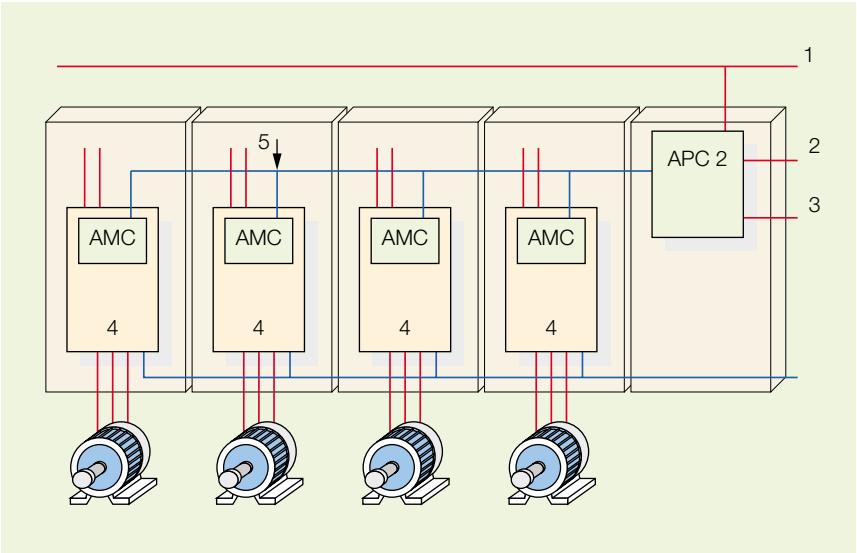
1 *System bus (AF100 link)*
2 *Data from local I/Os*
3 *Inverter*
4 *Power inputs*
5 *Control inputs*

AMC *Motor control card*

APC 2 is a commonly used application controller. It can coordinate 8 or even 12 inverters. For larger systems, several APCs are linked together by AF 100 or a generic data bus. 12

1 *System bus (AF100 link)*
2 *Data from remote I/Os and panels*
3 *Data from local I/Os*
4 *Inverter*
5 *Control inputs*

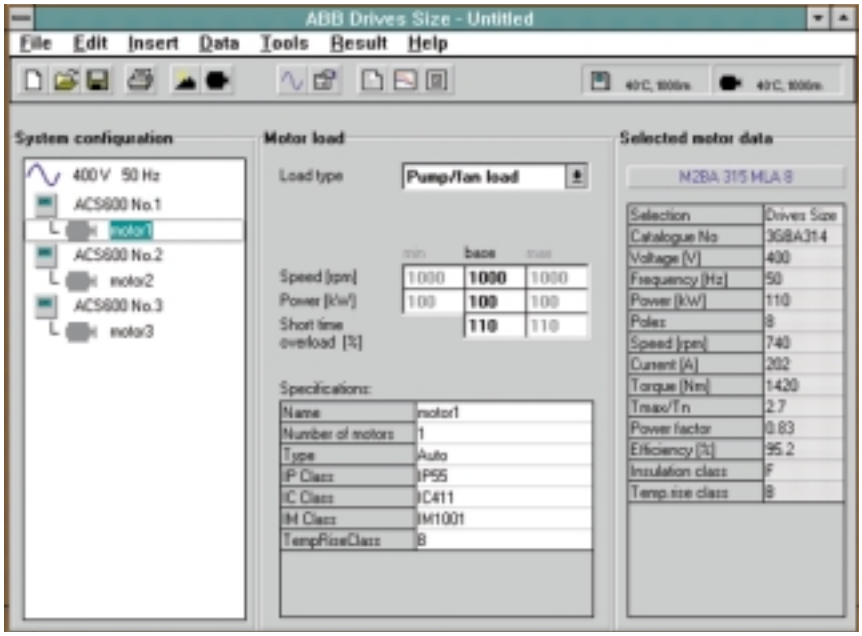
AMC *Motor control card*
APC2 *Application controller*



Flexible configuration and system architectures

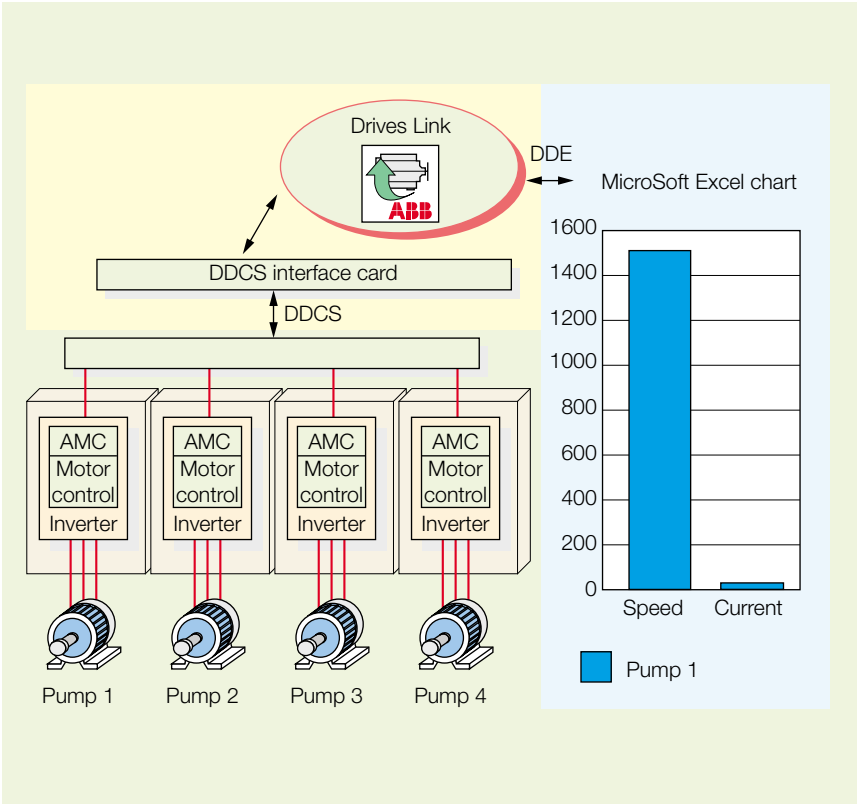
The coordination of drive systems and the man-machine interfacing differs from application to application and even from product to product. ACS 600 inverters allow dedicated application programs. Standard software is also available for crane and winder applications, etc. If required, new programs can easily be created using the graphic PC-based programming tool FCB. This tool is widely used in ABB automation products.

ACS 600 inverters can be connected to most common databuses, both pro-



Interface of the ABB Drives Size dimensioning tool, used to optimize supply bridges, inverters and motors in terms of their power, speed and duty cycles 13

Increasingly, the overriding system is a PC. A fiber-optic link protects the PC from voltages and electromagnetic interference. The Distributed Drive Control System (DDCS) acts as application interface. 14



prietary and generic, allowing links to a wide variety of PLCs and process controllers 11, 12.

Software tools

Recent years have seen the engineering, commissioning and maintenance costs increase as a percentage of the total costs. Software tools are available today with which these costs can be minimized.

Also available are expert tools that can be programmed to perform special functions with high resolution and accuracy.

Drive tools for configuration and maintenance

ABB has developed a comprehensive range of dedicated software tools which support the life cycle of AC drives. Five software products make up the Drive Tools suite, which covers dimensioning and engineering through to commissioning and maintenance support for ABB Drives products.

Drives Size is ABB's advanced internal dimensioning tool for improving the response time to customers' questions 13. It suggests the best supply unit, inverter and motor combination, based on the input data, and shows the result in numerical or graphic form. It provides optimized dimensioning for:

- ABB standard and customer-specified motors
- ACS 600 StandAlone and MultiDrive

Drives Size also calculates the harmonics in the supply network which are caused by the drives, based on the network input information.

Drives Builder is a configuration tool designed to produce bills of material, actual cabinet dimensions and electrical single-line diagrams. To this end, the dimensioning results from Drives Size is imported directly into the Drives Builder. Customer documentation is automati-

cally generated by the tool, allowing the customer to immediately check the details of the proposal and make any corrections that are needed.

Drives Window is a dedicated AC drive commissioning and maintenance tool with versatile features for parameter setting and for monitoring and controlling drives. It can be run on a laptop or desktop PC connected to a drive via an optical fiber link and PCMCIA card or ISA card. Future developments will include a MODBUS serial link (RS 485).

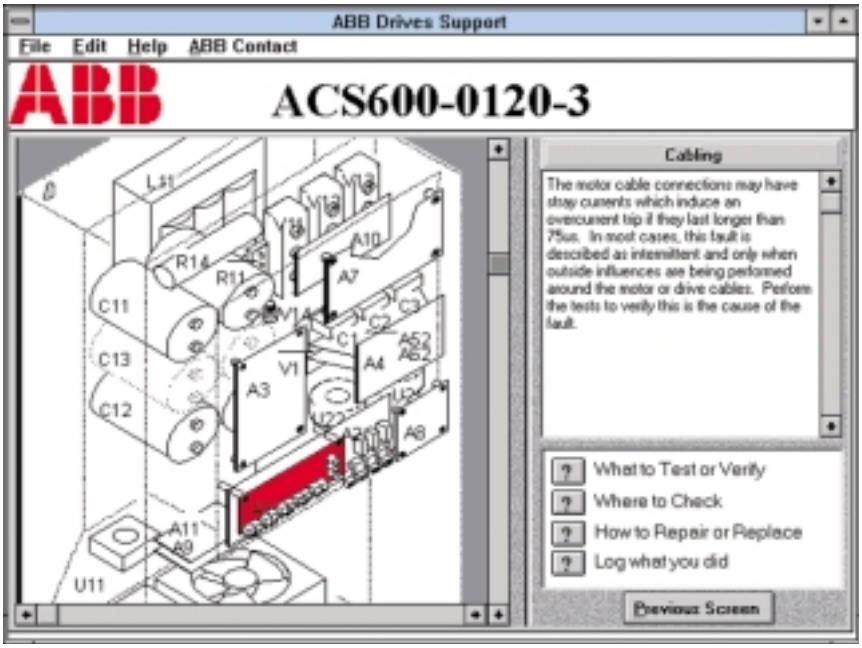
Drives Link is a software package allowing Dynamic Data Exchange (DDE) communication between Windows applications and drives 14. It is an ideal tool for linking drives to integrated PC monitoring systems, such as Intouch, Genesis, and Fix. Basic functions include operational commands, reading and writing parameters, etc. The communication link to drives is the same as for Drives Window.

Drives Support is the customer's tool for servicing, maintenance and advanced trouble-shooting for ACS 600 drives. Drives Support is fully configurable for ABB drive products/projects, and provides:

- Testing and verification of possible causes of faults
- Viewing of the location of faulty components
- Step-by-step replacement procedures
- Recording maintenance activities

During the design phase, displays automatically show components which could be faulty. The user can edit the instructions, for example indicating where a replacement can be found and what tools are required 15.

Drives Support works on-line together with Drives Window.



Drives Support offers automatic displays of components which are likely to be faulty. The customer can edit the instructions, eg to indicate where replacements can be found and what tools are required. 15

Outlook

Since being launched in 1995, more than 40,000 units of the ACS 600 family have been delivered to industry. ACS 600 is part of the platform upon which ABB has based its new, leading-edge technology for integrating drive systems and industrial process control, thereby offering new approaches to improving plant efficiency and cutting costs [5].

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