New Life for Conventional DC Drives Using Power Electronic Solutions

Technical Report

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REPORT SUMMARY

This report addresses the problem of improving DC drive performance with power electronic solutions.

Background

DC drives have been used in process industries since electricity was first adopted by industry. As technology advanced, simple resistor control evolved into more complicated mercury arc rectifiers that used magnetic regulators, and control became faster and more energy efficient. The advent of silicon-controlled rectifiers in the 1960s gave the DC drive outstanding control, which enabled very fast process control. DC drives were used in every industry that required speed control in the manufacturing process. There developed a large base of users who, quite correctly, relied entirely on this technology. In the 1970s, AC drives continued to be developed, but they made very few inroads into the process industry where the rugged performance of the DC drive dominated. The simple control and excellent torque capability of the DC drive was achieved with analogue control. Only after digital control and new switching devices such as the IGBT arrived in the late 1980s was the AC drive able to displace the DC drive on new applications. The first paper mill using vector control started in 1986, and by 1988 all major systems companies had switched development efforts into keeping up with fast-paced AC drive development.

Users of DC drives remain loyal to the product and faithfully upgrade old analogue regulators with digital control systems. DC motor drives are simple to understand and provide very reliable operation in very rigorous conditions. These drives will be in operation for a long time even though new and better products are currently available and continue to be developed.

Objectives

To improve DC drive performance under AC line transient conditions, to enhance product quality, and to avoid the cost of downtime and equipment repairs.

Approach

The project team surveyed DC drive manufacturers. Performance characteristics of “early” DC drives are well known and understood, and the survey was to determine if new drives would perform differently. While AC drives have now incorporated some of the features that make DC motors and drives so appropriate in process industries, improved DC drives would still be appropriate in many applications.

Results

A survey of DC drive manufacturers revealed that significant new product development is underway. However, the DC drive’s ability to ride through an AC line transient is not an aspect of development being undertaken by manufacturers since users of DC drives are not seeking this

feature. Work that is being undertaken by DC drive manufacturers will indirectly improve ride through performance by removing “misbehaviors” that are currently encountered in the field.

DC drives will continue to play an important part in the industrial drive business. Product currently under development will bring an improved range of functions to the drives. This will reduce startup time and enable faster maintenance and more predictable performance under line transient conditions. Drives will be able to stop and restart without component failure. In the future, semiconductor devices that have already been tested on matrix convertors will inevitably find application in DC drives. Since these devices are not reliant on AC supply waveform to be turned off, more robust performance can be expected in the future. Changes in semiconductor power devices will be mirrored by improvements in digital regulators. Digital signal processors (DSP) will provide entirely new and improved personalities for DC drives. In the long run, there may be little difference between AC and DC drives except for motor and field control. A simple software change will convert the advanced matrix convertor from AC to DC.

EPRI Perspective
Planned enhancements by DC drive manufacturers will bring an improved range of features to DC drives. These features will enable users to operate processes more efficiently and at lower cost. This will have a positive impact on process industries as a whole and will increase electrical power use. Advances are possible using new semiconductors that are available but, as yet, not used in DC drives. Voltage notching characteristics of the DC drive, together with their vulnerability to under voltage conditions, will be eliminated. These future advances will be very positive for electric utilities.

Keywords
DC drive
Improved performance
Voltage notching
Matrix convertors
Regeneration

ABSTRACT

DC drives currently continue to be very popular in process industries. The users have learned how to accommodate the product characteristics. Manufacturers are developing product with enhanced capability. These new products will be of great benefit in the field enabling faster start up and reduced down time. Ride through will not be tackled in the current development cycle.

Newly available power semiconductors will bring improvements to the control of DC motors. The Matrix convertor currently under trial with AC motors is also applicable to DC motors. This development will find its way into all aspects of motor control. Electronic control will continue to advance.

Many of the application issues currently associated with DC drives will disappear as new technology is introduced. The sensitivity to voltage unbalance, sags and even momentary interruptions will be eliminated. Regeneration faults that result in short circuits will be avoided. The iniquitous voltage notch, so long a trademark of the DC drive, will soon be a thing of the past.

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OVERVIEW OF CURRENT DC DRIVE PRODUCT PERFORMANCE

DC drives have been used in process industries since the use of electricity was first adopted by industry. As technology advanced, simple resistor control evolved into more complicated mercury arc rectifiers that employed magnetic regulators, and control became faster and more energy efficient. The advent of the Silicon Controlled Rectifier in the 1960s gave the DC drive outstanding control, which enabled very fast process control to be achieved. DC drives were used in every industry that required speed control in the manufacturing process. There developed a large base of users who, quite correctly, relied entirely on this technology. In the 1970s AC drives continued to be developed but they made very few inroads into the process industry where the rugged performance of the DC drive dominated. The simple control and excellent torque capability of the DC drive was achieved with analogue control. Only after digital control and new switching devices such as the IGBT arrived in the late 1980s was the AC drive able to displace the DC drive on new applications. The first paper mill using vector control started up in 1986 and by 1988 all major systems' companies had switched development effort into keeping up with the fast paced AC drive development

Users of DC drives remain loyal to the product, and faithfully upgrade old analogue regulators with digital control systems. The DC motor drives are simple to understand and provide very reliable operation in very rigorous conditions. These drives will be in operation for a long time in the future even though new and better products are currently available and continue to be further developed

Digital regulators were first used in the mid 1980s on very sophisticated system drives. The cost of the new regulator was high and this limited the market penetration. However, it was clear that as the benefits of digital control became field proven, digital control would be more widely used. In the early, so named, "digital" regulators, only the slower outer control loops were converted to digital. The inner, and much faster, current control remained an analogue function. Current DC drives are fully "digital." This provides fast and accurate control for both the main armature loop and the motor field control. Digital control brought with it the following advantages:

- Circuit parameter drift was eliminated.
- Start up time was reduced because precise setup was achieved through self-tuning.
- Maintenance and fault finding time was reduced.
- Internal performance records allowed the replay of events.

Clearly these new features rejuvenated the DC drive. The new digital regulators initially were blended onto equipments designed for analogue regulator controlled drives. The original SCR power convertor bridge was reutilized easily under digital control.

Despite the vastly increased numbers of control and maintenance features derived from the digital regulator the fundamental, yet unwelcome and unfavorable issues remain in the product even to this day. These are as follows:

- The SCR convertor introduces voltage notching on the supply voltage. The notching is a basic and undesirable feature of SCR control. A transient short circuit is applied between phases as the current in one SCR is transferred sequentially to the next device.
- Conventionally AC voltage from the utility is connected directly to the motor armature. There is no energy storage, except in the leakage inductance in the circuit. Here the aim of the circuit designer is to minimize inductance in order to achieve fast response and low transient voltage. The DC drive convertor selects the portion of the AC waveform to be applied to the armature in order to control speed and torque.
- AC voltage helps the transfer or commutation of current in the normal forward transfer of energy, referred to as the " motoring mode of operation". Should the AC voltage reduce, the transient performance of the system reduces. Sudden return to nominal voltage will cause a current transient that may cause the drive to trip. These events are well accounted for in the conventional regulator and do not cause operational problems.
- Under regenerative conditions, during fast reduction in speed or during direction reversal, the SCR needs the AC supply waveform to be present in order to force the current to transfer to the next device. Should the AC supply waveform not be present, at a level substantially greater than the armature voltage, a short circuit will be produced within the drive. Impedances within the drive are low and so the only suitable protection is the operation of a fast fuse.
- Voltage unbalance causes significant current unbalance because the drive uses one phase reference or firing angle for all three phases.
- Motor field loss detection is required to be very fast. Loss of the motor field could cause the motor speed to run away. This fact has led to many spurious field loss trips.
- Motor ventilation failure detection has customarily been an instantaneous trip. This has made the DC drive very sensitive to voltage sag conditions.

It can be seen that there are two categories of problems exhibited by the conventional phase controlled DC drive; those that can be handled relatively easily in the detection and control circuits and those that cannot be economically overcome with the traditional SCR controller.

Those that are relatively easy to handle are those related to the field loss and motor ventilation failure. The issues relating to the instantaneous use of the AC line waveform for motoring and regeneration are more difficult to deal with and are fundamental to this form of control. Energy storage devices classically hold their energy at fixed DC levels. Connecting such storage devices to the DC armature is a very difficult and expensive task.

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REVIEW OF DEVELOPMENTS CURRENTLY ENVISIONED

Contact was established with fifteen out of some thirty DC drives' manufacturers in order to review current product offerings and future development plans. The most striking aspect of the manufacturers' response was the lack of interest in ride through performance. The current activity centers on producing better digital regulators and increasing the range of control features.

The first area of development was in the self-tuning capability of the drive armature regulator. Each DC motor has a particular set of armature characteristics that needs to be accommodated by the drive. Set up, in order to test the motor in the field required specialist labor and materials. This used valuable resources and delayed the start up process. The digital regulator is now capable of inserting a trial current transient and, on the basis of the resulting characteristic waveform, it tunes the main armature loop stabilization parameters.

The next area of development reported was the control of the field regulator. Owing to safety issues relating to field control, the larger manufacturers are preparing additional control features. Field regulators will become self-tuning and the performance of those regulators will be closely monitored by the supervisory control within the drive.

Some new products for the US are being developed in the UK and Italy. There is a strong global demand for improved DC drives. However, the number of companies offering these products is on the decline. Several smaller companies that in the past served both AC and DC markets have decided to specialize in AC drives only.

A number of companies are reporting their improvements in auxiliary circuits used to protect the DC drives. Control relays, main DC armature contactors and specialist surge arrestors were mentioned as areas of development. Control relays are being selected for longer drop out times. Typically, low voltage DC has been used beneficially in the coil circuit. AC contactors are displacing DC loop contactors because, historically, DC loop contactors been expensive and difficult to obtain. This change is being promoted in Europe and provides a technically sound arrangement at much reduced cost.

New methods of dealing with a supply transient are being developed. The new digital regulators that are now available enable safe levels of under-voltage and recovery time to be programmed into the drive.

Wherever power ride-through is an important issue, the power circuit of the DC drive can be chosen as an H bridge. This format of convertor is commonly used in servo drives. These convertors have very high response rates. However, this configuration is uneconomic at ratings above 50Kw. The H bridge system is very convenient for the addition of ride-through. But, like all diode bridge fed equipments, there is no convenient method of returning power to the AC supply.

The classical DC drive application for industrial motor drives rated between 1and 1000kW requires efficient and cost effective regeneration which is available inherently in the traditional SCR based DC drive at minimal extra cost.

The manufacturers reported that the use of oversized AC line reactors were very effective in avoiding faults on elevator drives.

Respondents reported that recovery from a line transient could range from the restarting of a spinning motor through to an automatic restart after two seconds.

It was very clear that the main emphasis in the development programs was the conversion to full digital control. The driving force behind development is reduction of start up and trouble shooting time. These improvements will reduce labor costs. The basic cost of the DC convertor system is being reduced by the use of AC rather than DC armature loop protection.

3
REVIEW OF DEVELOPMENTS IN CONVERTOR TOPOLOGY

The SCR or Thyristor convertor topology is the configuration of choice for DC motors. This topology has been well chosen to provide single and three phase operation for DC motors up to several thousand horsepower. It is well proven over more than thirty years of field applications. SCRs have proven to be very robust and easy to protect. Reversing DC drives contain just 12 SCRs to accomplish a fully regenerative duty. This configuration is called the anti-parallel convertor because two SCRs are clamped under a pair of heat sinks arranged to conduct in opposite directions.

AC drive technology is being driven in the direction of the Matrix convertor. At the recent European Power Electronics Conference [1] there were a number of papers devoted to the practical application of this concept. The principle behind this convertor is the direct conversion from fixed frequency AC to variable frequency, variable voltage AC without going through a fixed DC link. The topology has been delayed because suitable semiconductor switches were not available for the task. Now, at last, the Insulated Gate Bipolar Transistor (IGBT) has been manufactured without an anti-parallel diode. This gives the device reverse blocking performance similar to the SCR. The new IGBT also has the capability to operate at very high frequency and it can be switched on and off quickly with low losses. The SCR is not a gate turn-off device. Once turned on it has to stay on until the voltage is removed or reversed. Gate turn-off devices or Gate Turn-off Thyristors (GTOs) were found to be impractical and not cost effective when compared with the IGBT.

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FUTURE TRENDS

The DC drive may well become a special form of the Matrix convertor. The new reverse blocking IGBT devices will enable AC voltage to be turned directly into DC. The polarity could be made positive or negative under the control of a very fast regulator. The elegance of the new Matrix convertor is that the AC waveform is not needed to provide turn-off conditions. Motor conditions will also be improved. In SCR applications the motor is subjected to six discreet humps of voltage per cycle of line frequency. Under the proposed Matrix convertor, the voltage supplied to the motor will be a series of high frequency blocks of DC. This will make the future convertor very robust and able to accommodate AC line transients.

These changes in power convertor topology will be mirrored by improvements in digital regulators. Digital Signal Processors will be widely used and provide entirely new and improved personalities for the DC drive. In the long run there may be little difference between AC and DC drives except for the motor and field control. A simple software change will adapt the advanced Matrix convertor from AC to DC mode of operation.

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1. Proceedings of the 9th European Conference on Power Electronics and Applications. Held August 27 to 29th 2001 Gratz Austria.

Target:
Process Industries

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