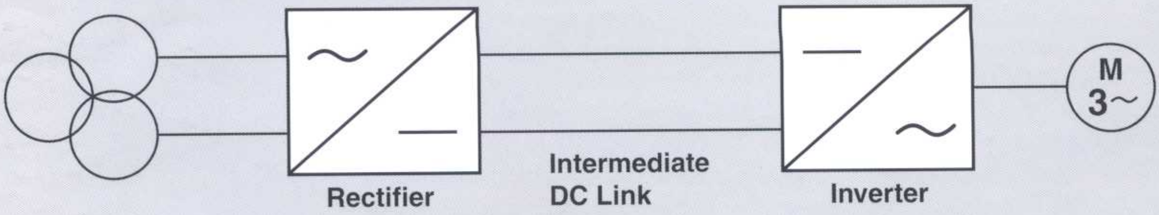
A Guide to Standard Medium Voltage Variable Speed Drives

Part 1:

Questions & answers and medium-voltage variable speed drive selection



ABB

A guide to medium-voltage standard AC drives

Who should read this guide

This Technical Guide is available in six parts from the ABB address given on the back cover.

It is aimed at the key decision makers engaged in the specification, selection, purchasing, installation and/or commissioning of medium-voltage AC variable speed drives, as a standard solution.

It is therefore aimed at electrical, mechanical and plant engineers as well as managers, consultants and technicians.

There is a new thinking within industry. Standard, 'off-the-shelf' medium-voltage AC drives can often be a more cost effective solution than traditional 'engineered' drive systems, which are tailor made and consequently more costly.

This Technical Guide series, therefore, aims to give a basic understanding of the technologies and practices presently available to those considering purchasing 'standard' medium-voltage AC drives.

However, in a Technical Guide of this nature it is not possible to give an in-depth analysis of all aspects of selecting, purchasing, installing and commissioning medium-voltage AC drives. The reader is advised to consult ABB for more detailed information.

Contents

Questions and answers

Q

What is a medium-voltage AC drive?

A

In its simplest form, a medium-voltage AC drive consists of a frequency converter, which is used to vary the speed of the most commonly used industrial motor, the squirrel cage induction motor. *(For a more detailed explanation of how a variable speed drive works see Part 2).*

Medium-voltage AC drives are available in a variety of arrangements, depending on whether the motor to be controlled is asynchronous or synchronous (see Part 2). For example, asynchronous motors are typically controlled by Voltage Source Inverters (VSI) or Current Source Inverters (CSI). Synchronous motors are typically controlled by Load Commutated Inverters (LCI) or Cycloconverters.

The drives are normally in the power range 315 to 5,000kW (400 - 6,000kVA) in voltages 2.3, 3.3, 4.16 and 6 to 6.9kV.

Q

Where would I use a medium-voltage AC drive?

A

A medium-voltage AC drive would be used to vary the speed of a medium-voltage AC motor. The key industry sectors that would use medium-voltage AC drives are shown in Table 1.

EQUIPMENT	INDUSTRY SECTOR	APPLICATION
Pumps Fans Compressors Blowers Extruders Conveyors Crushers & mills Rolling mills Mixers Propulsion Test beds Synchronous condensors Gas Turbine starts Propulsion Conveyors Hoists Winders	Petrochemicals	downhole pumps, pipeline pumps, gas compressors, water injection pumps
	Mining	slurry pumps, water pumps, conveyors, crushers and mills
	Water/ Waste	all pump applications, sewage and fresh water
	Pulp & Paper	fans and pumps, grinders, chippers, yankee blowers, winders
	Cement	kiln and baghouse fans, cooler exhaust, forced draft and induced draft fans, kiln drives, crushers and mills
	Chemicals	pumps, compressors, extruders
	Power Generation	forced draft and induced draft fans, boiler feed pumps, recirculating pumps
	Metals	descaling pumps, cooling pumps and fans, coilers, rolling mills
	Marine	propulsion, thrusters, off-load pumps

Table 1: Key industry sectors for medium-voltage AC drives

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What is meant by an 'ENGINEERED' medium-voltage AC drive?

A

Until now, most AC drives available in the medium-voltage range have been 'engineered' drives. This means the customer details precisely the specification of the drive, which is then put out to tender.

The successful bidder then engineers a drive as a one-off tailored solution.

Engineered drives offered by manufacturers are mainly for critical system applications such as rolling mills, where attention needs to be given to non-typical load cycles which can not usually be handled by a standard product.

Engineered drives often require specific solutions to overcome problems associated with harmonics, torque pulsations, EMC, voltage reflections and motor loadability, whereas standard drives often have built-in solutions to these technical challenges.

What is meant by a STANDARD medium-voltage AC drive?

In contrast to an 'engineered' drive, a 'standard' drive has been designed to accommodate the most common system specifications with minimal engineering. A standard drive, therefore, meets the need of at least 85% of all applications which tend to be fans, pumps, compressors and conveyors for example.

A standard drive is a core product from a manufacturer with many engineered solutions actually built into the product. Some of these solutions appear as application macros.

The manufacturer's local engineering division can then make minimal modifications to this 'standard' solution to suit the customer's requirements. This can bring significant benefits to end-users such as shorter delivery times. Because the drive is pre-engineered, the initial purchase cost can be lower as any engineering investment is spread over a larger customer base. Reliability is also improved as the unit is not a one-off customized design but has been proven in numerous applications.

Although this is referred to as a 'standard' solution, reputable manufacturers will provide significant design and application support, should it be required.

When would a STANDARD medium-voltage AC drive be preferable?

As 85% of applications are for standard pumps, fans, compressors and conveyors which do not need too much tailored engineering knowledge, the standard drive solution becomes a viable proposition.

The standard solution is also suitable for most retrofit applications. There is an enormous retrofit market, as less than 3% of the world's industrial medium-voltage motors are fitted with drives. Because standard AC drives tend to be quick to install and commission, as well as compact in design, they can be a useful solution to existing plants which can not afford to be off-line for any length of time. A standard drive should be suitable for any standard motor in both NEMA or European standards.

Moreover, a standard drive should be retrofit ready and offer seamless connectivity to existing PLCs and distributed control systems.

Q **What are the disadvantages of STANDARD drives?**

A There are no disadvantages to using a standard medium-voltage AC drive in simple applications, such as those described on page 2. However, once the application moves into critical areas, such as rolling mills, then an engineered solution may be required.

Q **When would an ENGINEERED medium-voltage AC drive be preferable?**

A An engineered drive should still be used whenever an application requires a very demanding customized load cycle or if the environmental operating conditions dictate.

Q **What are the disadvantages of ENGINEERED drives?**

A The biggest disadvantage of engineered drives has to be the higher cost as a result of the longer engineering hours. Also designing, building, installing and commissioning an engineered drive demands a lot of time. Very often, the same engineer who designed the drive needs to be on site at start up.

Q **How easy is it to select and purchase a STANDARD medium-voltage AC drive?**

A A standard medium-voltage AC drive is an easy catalog selection. The manufacturer provides the core data such as kW, the rpm range and the control options available.

With the arrival of advanced software tools, selection is becoming even easier. Most reputable drives manufacturers offer a range of sizing and dimensioning software which provides rapid and accurate data via a simple telephone call. Some manufacturers make this software available for direct use by customers.

Q

What are the main reasons for wanting to use a medium-voltage AC drive?

A

Medium-voltage AC drives enable industrial manufacturers and public utilities to improve production, boost power efficiencies and reduce overall energy costs.

But medium-voltage AC drives have not been widely accepted in recent years. Some potential users see medium-voltage AC drives as an expensive and unreliable solution and may even revert to low voltage AC drives.

However, today's technology and experience has resulted in medium-voltage AC drives which at certain powers and applications are more cost effective than low-voltage drives.

For example, with low-voltage drives, the current drawn is higher for a given motor power than for medium-voltage and therefore if the cable length between a motor and inverter is long, using a medium-voltage AC drive can prove to be less expensive than a low-voltage AC drive.

This is because, with lower current, a cable's cross sectional area will be smaller and subsequently the cost of the cable will be lower.

Another benefit is that the current rating of other electrical equipment used in the network, such as circuit breakers, will be reduced.

As power levels increase into the MW range, medium-voltage drives become the preferred solution.

Table 2: There is an increasing demand world-wide for AC drives. There are many reasons but top of the list include the following:

FEATURE	BENEFIT	REFERENCE
High overall efficiency	• To save energy	see Part 2 & 6 of Technical Guide
Precise speed and torque control. New control platforms	• To better control processes and better protect motor and load	see Part 2 of Technical Guide
Wide speed control range	• To avoid mechanical equipment such as gears, valves and dampers • This minimizes maintenance	see Part 5 of Technical Guide
Soft starting	• Reduced impact on electrical network and therefore no penalties from supply authority • Reduced stress on motor, coupling and load	see Part 5 & 6 of Technical Guide
Speed reversal Regenerative braking	• Saves energy • Avoids mechanical equipment	see Part 6 of Technical Guide

Q What are the main benefits that medium-voltage AC drives bring?

A The key features and benefits are shown in Table 3, on page 7.

FEATURE	BENEFIT
Soft starting	• Reduced impact on electrical network means no penalties from utility • Reduced stress on motor, coupling and load, giving extended lifetime • Unlimited number of starts per hour
Precise speed and torque control	• Better product quality • Reduced cost of quality • Better protection of motor (e.g. stall protection) and load • Consistent product quality despite input power variations and sudden load changes
Lower electrical currents for a given power compared with low-voltage drives	• Reduced cable cross sectional area and reduced current rating of other electrical equipment, e.g. circuit breakers.
Wide speed control range	• Improved efficiency compared to traditional flow control methods, e.g. damper control • Lower maintenance
High reliability and availability	• Reduced downtime • Improved process availability
Low audible noise	• Improved working environment for operators
Capability for speed reversal/ regenerative braking	• Constant torque during braking, therefore better product quality • Rapid braking • Higher efficiency
Flux optimization *(Motor flux automatically adapted to load)*	• Improved motor efficiency • Reduced motor noise
Power loss ride through	• Reduced number of drive trips • Better process availability
Automatic start *(drive can catch a spinning load)*	• Reducing waiting time • Reduced downtime
Wide power range	• Medium-voltage drives offer a common power platform for many applications beyond the scope of low-voltage drives
Energy saving	• Medium-voltage drives can be retrofitted to standard induction motors, to provide substantial energy savings

Q

How reliable are medium-voltage AC drives today?

A

Decision-makers need a truly safe choice when selecting their medium-voltage AC drive. The drives are usually installed right in the cash stream of the plant - if the drive stops, it is an immediate and expensive problem.

In the past, the biggest drawback for major industries in using medium-voltage AC drives has been concern about reliability. But recently, reliability has vastly improved.

There is now more accumulated experience and previous concerns have been resolved. Also, some manufacturers are utilizing their knowledge, experience and technology which they have gained with low-voltage drives - which have been sold in high volumes and therefore heavily field tested - and applying this to medium-voltage AC drives.

Knowledge of application engineering has improved vastly. As a result of this experience, technical problems are better understood leading to cost effective solutions.

Q

What power semiconductors are used in today's medium-voltage AC drives?

A

There are basically three types of power semiconductor used today: IGBTs, GTOs and IGCTs.

Until now the power switches for medium-voltage AC drives have been either GTOs or IGBTs. For medium-voltage applications such devices have led to compromizes in design that increase the cost and complexity of power control systems.

IGBT (Insulated Gate Bipolar Transistor) - both low-voltage and high-voltage IGBTs have been used in medium-voltage drives. IGBTs are fast switching but losses are high at medium-voltage levels. Also, complicated series connection of multiple IGBTs is required. This increases the parts count, while decreasing reliability, forcing the drives to become larger and more expensive.

High voltage IGBTs have fewer series connected devices, relative to low voltage IGBTs but losses are higher than lower voltage IGBTs.

GTO (Gate Turn-Off thyristor) - is reliable and losses at medium-voltages are tolerable. The problem is that non-homogenous switching requires huge additional circuitry for turn off, resulting in increased parts count, lower reliability and larger and more expensive drives.

IGCT (Integrated Gate Commutated Thyristor) - is fast switching and has inherently low losses. The component features a transparent anode on the silicon wafer level and a low inductance gate driver circuit. Both of these mean the device can be switched fast and without a snubber, which would otherwise be needed to keep the voltage rate of change within set limits. The power switching device and gate driver are in one compact unit, which lowers cost. When used with Voltage Source Inverter topology (VSI) (see Part 2), the drive is intrinsically less complex, more efficient and reliable.

Q

Which technology should I choose?

A

While the choice is yours, it is worth considering that IGCT technology generally requires a maximum one-third the number of power semiconductors in the inverter of a medium-voltage drive which utilises high-voltage IGBTs.

This means IGCT-based medium-voltage drives are, on average, three times more reliable than high-voltage IGBT-based drives. Furthermore, lower losses mean less cooling equipment and higher inherent reliability.

Compared to high-voltage and low-voltage IGBT solutions, the IGCT has a low parts count. A medium-voltage drive utilizing IGCTs typically has one-fifth the number of power semiconductor components of a medium-voltage drive which uses low-voltage IGBTs.

Q

What are the advantages of a low parts count?

A

Low parts count brings much improved reliability along with a smaller inverter and a smaller footprint. Fewer parts also brings a reduction in complexity which ensures maximum installation flexibility and offers particular advantages for retrofits.

Q

What should users consider when purchasing a medium-voltage AC drive?

A

There are many factors worth considering, but the following is a useful guide to observe:

Commercial	Performance
• Reliability	• Electrical impact
• Cost	• Torque pulsations
• Efficiency	• Speed control
• Layout	• Voltage fluctuations
• Technology	• Ride through
• Commissioning/ Maintenance	• Noise
• Performance	

For more explanation on each of the above, turn to page 11.

Purchasing decisions

What to look for when purchasing medium-voltage AC drives

There are many considerations that need to be taken before purchasing medium-voltage AC drives. Other than technical issues, which will be described in Part 6, prospective purchasers and users of such drives would be advised to consider the following:

Reliability

Q

What is reliability?

A

Medium-voltage AC drives are often used in applications where high reliability and availability are paramount, such as feedwater pumps, draft fans in power stations and process compressors in the chemical and petrochemical industry.

The calculations, which can be carried out on problems of reliability, are based on statistics obtained from long-term testing of components and from service experiences.

In order to use the results of long-term testing, appropriate mathematical models must be used. For the main circuit components which are found in a medium-voltage AC drive - such as power semiconductors, capacitors, resistors and their associated failure mechanisms - the exponential distribution is appropriate.

Q

How is reliability measured?

A

The reliability of a component or a system can be defined by the simple equation:

$$R = e^{-\lambda t}$$

where

t = the time that any unit operates failure free

λ = failure rate of a component or system

for example, the probability that the unit is still operational after one year is:

$$R = e^{\frac{-8760hr}{MTBF}}$$

where

t = 8760 hours

R = reliability

MTBF = Mean Time Between Failure

Furthermore, the availability of a component or system can be calculated according to the following equation:

$$A = \frac{MTBF}{MTBF + MTTR}$$

where

MTTR = Mean Time To Repair

A = availability

High reliability is the best way to achieve high availability. Availability is influenced by failure rate and the ability to repair.

Q

What is the reliability of today's medium-voltage AC drives?

A

A high calculated MTBF value is naturally a figure of merit for a piece of equipment and knowing the failure rate of different components is important to the designer.

However, care must be taken when comparing MTBF values from different manufacturers as the way the calculations have been carried out may differ considerably. Therefore, making meaningful direct comparisons between various manufacturers is not always straight forward.

Notwithstanding this, if the basis of the calculation is understood, it can be useful to compare values for MTBF.

Improvements in design and serviceability mean that users of medium-voltage AC drives should be expecting availabilities in the order of 99.9%.

Q

How is reliability achieved with today's modern technology?

A

Advanced power semiconductors have significantly reduced the parts count of inverters.

IGCT technology, for example, (see Part 3) requires a maximum of one-third the number of parts of high voltage IGBT technology. IGCT-based medium-voltage drives are more reliable than medium-voltage drives based on IGBT technology. Furthermore, lower losses mean less cooling equipment and higher inherent reliability.

Lower parts count brings a reduction in complexity and a smaller medium-voltage AC drive. This, in turn, ensures maximum installation flexibility and offers particular advantages for retrofits.

Electronic speed control can bring less maintenance since drives often replace a mechanical transmission system.

The mechanical stresses on the machines, bearings and shafts are lower, which prolongs the service life of the equipment. A reduction in the bearing speed dramatically increases the bearing lifetime.

Because of the low starting current, the thermal stress on the machine itself and the electrical stress on the power supply are substantially reduced. All these factors contribute to high reliability and very low downtime of the machinery.

Summary Pad -
RELIABILITY - what to look out for

- A high calculated MTBF value is a figure of merit for equipment.
- Knowing the failure rate of different components is important to the designer.
- Take care when comparing MTBF values from different manufacturers.
- High reliability is the best way to achieve high availability.
- Availability is influenced by failure rate and the ability to repair.
- Users of medium-voltage AC drives should expect availability of 99.9%.

Cost

Q **What cost issues arise with medium-voltage AC drives?**

A The industrial market is changing. New projects are now demanding a quick payback as developers demand a more rapid return on their investments. As a result, the purchase of every component is highly cost driven. Typically, if you meet the performance specification at the lowest cost you get the order.

Downtime in critical industries like petrochemical, water, pulp and paper, metals, power generation and mining seriously impacts on customer profitability with thousands of dollars lost even for short process interruptions.

Today's medium-voltage AC drives need to take these commercial constraints into consideration and as such drives are being introduced which waste no space by having fewer parts but while still using proven technology.

Q **How important is the initial purchase cost of a medium-voltage AC drive?**

A Initial purchase price will always be an important consideration. But it is not the only consideration. You need to look at other aspects such as running cost and service, each of which adds to the lifecycle costs.

Q **What is meant by lifecycle costs?**

A There is a change in purchasing attitudes throughout industry. Initial capital expenditure is not the only driver. Industry is becoming more aware of the need to consider lifecycle costs - that is the cost of running a drive from cradle to grave, often referred to as the **total cost of ownership**.

Cost issues to be considered include:

- floor space
- installation and commissioning
- training
- energy consumption
- reliability
- maintenance
- spare parts
- after-sales support
- disposal

Q

When will the initial purchase price be recovered?

A

Medium-voltage AC drives based on current technologies are energy efficient and allow very attractive pay back times. Payback times of 12-18 months are typical, for applications where energy saving alone is considered. When the drive is used to improve product quality or reduce re-work, the payback times can be even shorter, depending on cost of energy, application and duty cycle.

As standard drives are pre-engineered, the initial purchase cost can be lower as any engineering investment is spread over a larger customer base.

Summary Pad - COSTS - what to look out for

- Initial purchase price is not the only consideration.
- Consider running costs and service, each of which adds to the lifecycle costs.
- Take into account transformer losses into the room and the subsequent need for air conditioning; cost of floor space; cost of support and service; energy consumption; training, disposal and reliability.
- Payback times of 12-18 months are typical, depending on cost of energy, application and duty cycle.

Efficiency

Q **How efficient are today's medium-voltage AC drives?**

A Users should strive for efficiency levels for medium-voltage AC drives of about 97%, including the transformer, power factor correction equipment and harmonic filters (if used).

Care should be taken to consider the total drive system efficiency, not just the efficiency of the converter. A drive system, therefore, comprises transformer, power factor correction equipment and harmonic filters (if used), converter, output filter (if used) and motor.

Q **What energy savings can be achieved?**

A The energy savings alone in a drive rated at even less than 1MW may be so large that the drive will pay for itself in a few months. For example, take a 746kW fan at a speed of 870rpm and following a given duty cycle. Then comparing a medium-voltage AC drive with a fluid coupling during one year's operation reveals that the energy consumed by the fluid coupling is about 800,000kWh more than that consumed by the AC drive.

Dividing the actual energy consumed by the amount of hours in a year gives average losses for the fluid coupling drive of 121kW compared to 25kW for the AC drive. Thus, the fluid coupling drive's average losses are nearly 100kW larger than those of the medium-voltage AC drive.

Q **What other efficiency related issues are provided by medium-voltage AC drives?**

A Electronic speed control offers much more than just energy savings. Less maintenance is one benefit, since electronic speed control often replaces a mechanical transmission system.

Summary Pad -
EFFICIENCY - what to look out for

- Efficiency levels of 97% can be achieved with medium-voltage AC drives, including the input isolation transformer.
- Always consider the total drive system efficiency, not just the efficiency of the converter.
- The energy savings in a medium-voltage AC drive may be so large that the drive will pay for itself in a few months.

Layout

One often-overlooked factor is the amount of space that a medium-voltage AC drive will occupy.

In some industries such as petrochemicals, available floor space is limited and the cost per square foot can be very high.

This means that medium-voltage AC drives which have large footprints will occupy expensive real estate.

Some of today's medium-voltage AC drives have small footprints. Small footprints are usually achieved through a compact design and also a flexible input transformer configuration. This configuration enables the transformer to be placed outside the electrical room.

This brings an additional benefit - the losses from the transformer are not going into the electrical room so there is no need to remove this heat through air conditioning.

Summary Pad -
LAYOUT - what to look out for

- Medium-voltage AC drives which have large footprints occupy expensive floor space.
- Some of today's medium-voltage AC drives have small footprints.
- Small footprints are usually achieved through a compact design and a flexible input transformer configuration.
- This configuration enables the transformer to be placed outside the electrical room.

Technology

The technology platforms for all variable speed drives are constantly changing. Refer to Part 2 (Motor Control Platforms) and Part 3 (Power Semiconductor Technology) of this series for some of the latest ideas.

Commissioning / Maintenance

Commissioning

Once the medium-voltage AC drive has been successfully installed and before start up, it needs to be checked out. A rapid, yet thorough and efficient commissioning routine needs to be adopted so as to minimize start-up delays and subsequent costs.

This is particularly important for retrofits where there may be a tight timeframe to commission the drive during a planned maintenance shutdown.

Commissioning is normally undertaken by the manufacturer's service engineer who will follow a detailed checklist and will:

- Perform a visual inspection of the installation
- Check that the insulation levels are correct
- Energize the drive and check the power supplies and phase sequence
- Check the interface with the external control system

The drive is then connected to the AC motor and energized. Some standard medium-voltage AC drives feature a motor identification run which simplifies the start-up procedure by determining all key motor parameters once the nameplate data has been entered.

The drive and control system are used to adjust the motor's speed from minimum to maximum and is usually performed with the motor disconnected from the load. With some drives it is not necessary to disconnect the motor from the load.

Once all checks have been carried out, the motor is connected to the load and the drive is ready for start-up.

Together with on-board application macros and auto-tuning facilities, the motor identification run contributes to faster start-up which minimizes commissioning time and saves costs.

Determining energy savings

Energy savings can be verified and compared to the calculated savings prior to start-up of the drive by following this procedure:

- Operate the motor at constant speed on its normal load-duty cycle for a fixed period of time, based on the process load cycle
- If possible, control the motor by its normal constant speed control method
- Measure the energy consumed using this method
- Then operate the motor on speed control using the same load-duty cycle for an identical time period
- Measure the energy consumed
- The difference between the energy used at constant speed and variable speed is the energy savings

Maintenance

The very concept of a standard medium-voltage AC drive implies minimal maintenance.

As described throughout this guide, and subsequent parts of the Technical Guide, the technologies of DTC and IGCT power semiconductors combine to provide a low component count which increases reliability and extends Mean Time Between Failures and improves availability.

Summary Pad - COMMISSIONING/MAINTENANCE - what to look out for

- A rapid and efficient commissioning routine needs to be adopted to minimize start-up delays and costs.
- Perform a visual inspection of the installation.
- Check the insulation levels are correct.
- Energize the drive and check the power supplies and phase sequence.
- Check the interface with the external control system.
- Some standard medium-voltage AC drives have a motor identification run which determines motor parameters once the nameplate data is entered.

Performance

Q

What are the key performance criteria of medium-voltage AC drives?

A

Substantially improved process control is a significant additional benefit obtained by using variable speed drives.

A control system offers comprehensive, accurate control of speed and torque. Whenever co-ordination is important, the control system regulates the process and ensures that the relative speeds of motors will always be optimized.

There are several main performance related factors:

Harmonics

Users should be sure they comply with the limits or regulations which are imposed by local electricity authorities or utilities such as IEEE519 in the USA or G5/3 for the UK. Reputable drive suppliers will be able to advise on precisely where their products stand in relation to these authorities requirements.

Some suppliers have also developed harmonic analysis tools which enable rapid and efficient harmonic calculations to be undertaken.

Torque Pulsations

Some medium-voltage AC drives produce problematic torque pulsations and the negative effects of these need to be avoided otherwise they can damage the weakest link in the chain such as the gearbox or even the load.

For drives which do produce unacceptable torque pulsations, suppliers should advise on problematic torque pulsations and a decision should be made as to whether a full torsional vibration analysis is needed. Reputable drives suppliers should be able to provide this service.

Motor Control

Innovative motor control platforms like Direct Torque Control (see Part 2), provide outstanding speed and torque control performance. A properly controlled motor contributes to a well controlled process which means better and consistent product quality.

Voltage Fluctuations

Wherever there is a weak network or unreliable power supply then voltage fluctuations pose a potential problem for medium-voltage motors. A motor running on such a network needs to be able to **ride through** these transient voltage dips. Medium-voltage AC drives should be able to handle normal fluctuations without tripping.

Medium-voltage motors are also limited to the number of starts they can undergo per hour without damage occurring from temperature rise. Frequent trips can mean long process downtime for motors which are connected direct-on-line. However, variable speed drives overcome any problems by providing a soft start. Thus, unlimited number of starts can be achieved with no inrush currents.

Ride through

See above.

Noise

Compared to conventional frequency drives with modulators, new motor control technologies like Direct Torque Control, do not use fixed carrier frequencies and also incorporate techniques like flux optimization - both of which provide a low motor noise.

Furthermore, the use of components such as low noise fans help alleviate unnecessarily high sound levels.

NOTES

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