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Adding Reliability and Availability to Your Manufacturing Process

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While there may be hundreds or even thousands of motors in a large industrial plant, medium-voltage motors are the workhorses that do most of the heavy lifting. As such, their importance cannot be overstated. If a low-voltage motor fails, the usual effect on overall plant production will be minimal — but that's not the case with medium-voltage motor failures.

Reliability and availability of medium-voltage equipment is critical in virtually all applications; any failure will generally disable a relatively large portion of the plant. Further, because medium voltage drives and their associated equipment are relatively expensive, it is nearly impossible to provide redundancy or stock spares — making reliability even more important.

Medium voltage variable frequency drives (VFDs) are applied to relatively large motors that range in size from 200 to 100,000 Hp. Such medium-voltage motors typically operate between 10 and 15,000 rpm at voltages between 2.3 kV and 13.8 kV.

Many medium-voltage motors can consume over $1,000,000 per year of electrical energy. Therefore, the application of an energy-saving medium voltage VFD should be considered for every medium-voltage motor in the plant. The energy (and perhaps process) savings associated with using a medium voltage VFD will usually justify its installation.

Some installations can pay for themselves in as little as 18 months due to energy savings, although a two- to three-year payback period is typical. But it only takes one failure that trips the VFD offline to quickly erase those savings, making reliability — and more importantly, availability — a key concern.

Siemens SINAMICS PERFECT HARMONY GH180 air-cooled variable frequency drive and Siemens AboveNEMA motor

Leading Medium Voltage VFD Applications in Major Vertical Industries	
Building automation	Cooling tower pumps, cooling tower fans, chiller fans, chilled water pumps, refrigeration compressors
Chemical and petrochemical	Utility pumps, process pumps, fans, blowers, air compressors, process compressors, coolers, cooling tower pumps, cooling tower fans
Food and beverage	Utility pumps, fans, blowers
Mining	Conveyors, ball mills, grinders, crushers, mobile equipment (haul trucks, draglines, shovels)
Oil and gas	Utility pumps, process pumps, fans, process compressors, air compressors
Power	Induced draft fans, forced draft fans, cooling tower pumps, cooling tower fans, atomization air compressors
Water / wastewater	Process pumps, fans, blowers, air compressors

Table 1

For decades, medium voltage VFDs have been used in industrial and other facilities for applications where it is necessary or desirable to closely control motor speed. Most industries are aware of medium voltage VFDs and how to use them in traditional applications. But more and more users are finding new applications that improve product quality, increase productivity and reduce maintenance. Table 1 lists the vertical industries where medium voltage VFDs are commonly applied, along with their specific applications.

Medium voltage VFDs have advantages over the simple medium-voltage starters sometimes used to soft-start motors. In some applications that use a starter, the motor can stall if the transient voltage drop, caused by starting the motor excessively, limits the amount of motor torque available to rotate the load.

Medium voltage VFDs don't have this limitation because full motor torque is always available. Not only does the inherently softer VFD start reduce stress on the motor, but it also produces a smaller transient voltage drop that tends to have a lesser effect on other electrical loads in the plant. This attribute can make a medium voltage VFD easier to apply in the overall plant power system — even though it may be more difficult to specify and install, compared to a medium-voltage starter.

Medium voltage VFDs are complex devices, and if not designed carefully, they can exhibit lower reliability than medium-voltage starters. In addition to selecting high-reliability medium voltage VFDs, facilities can further improve reliability by installing redundant process equipment and / or motors to ensure continued operation in the event of a failure.

Although this approach is sometimes used, it's often not possible or viable. For example, installing a second medium-voltage motor on a mining conveyor belt is often not physically possible. In a water treatment plant, installing a spare pump with a 5,000 kW motor would be expensive. In these and other instances, a better approach is to select a medium voltage VFD with very high reliability and availability.

Purchasers and users are generally aware of how important reliability is for their plant's medium voltage VFDs. However, many are unfamiliar with the significant and unique patented innovations incorporated into Siemens SINAMICS PERFECT HARMONY drives to improve reliability — and even allow the VFD to continue operating in the unlikely event that one or more of its power modules fail.

Note that the failure of only one power cell would overwhelm and trip a conventional drive not equipped with the appropriate redundancy option. Such features provide significant differences between the reliability of SINAMICS Perfect Harmony drives and the reliability of seemingly similar products offered by competitors.

The remainder of this paper will examine the technical features unique to SINAMICS Perfect Harmony drives. It will show how each feature contributes to increased reliability and availability, and will mention other important advantages of those features. For reference, these features are listed in table 2.

Siemens SINAMICS Perfect Harmony Drive Features That Increase Reliability
Use of low-voltage IGBTs
21 output levels versus 4–7 for competitors
Advanced Cell Bypass
Fewer components in drive system
Process-Tolerant Protection Strategy (ProToPS™)
Greater operating experience

Table 2

Use of low-voltage IGBTs

A medium voltage VFD provides power to the motor from its output power circuits. The power semiconductors used in these circuits are typically high-voltage IGBTs that are customized to the rated motor voltage and current. Motor voltages are typically between 2.3 and 13.8 kV, while full load currents can be over 1,000 A.

These state-of-the-art IGBT semiconductors are expensive and designed to operate on full motor voltage — and in many cases, these semiconductors are only manufactured by a single company. This could pose operational problems if parts are needed quickly during an unscheduled plant outage, a semiconductor plant outage or a VFD failure.

A better approach is to use multiple power modules in series that operate with low-voltage IGBTs. The SINAMICS Perfect Harmony drives use low-voltage power cells (rated for 750 V) that have been built in high volume for many years. These power modules are less expensive, less prone to failure and more reliable. This topology allows the use of more mature components that can be designed more conservatively, providing a greater immunity to failure and exhibiting faster switching times.

Thermal design is a critical aspect of power electronics design. The use of multiple power modules enables the drive to distribute the generation of heat, which makes semiconductor heat dissipation more manageable.
Faster semiconductor switching times allow more efficient medium voltage VFD operation and further reduce heat dissipation requirements, compared to conventional full-voltage semiconductors.

Increasing VFD efficiency, reducing heat generation and distributing heat dissipation requirements contribute to increased semiconductor life and improved medium voltage VFD reliability. In addition, motor stress is reduced due to the smaller voltage step size and the ability to manipulate switching frequencies, two concepts discussed in detail below.

More output levels versus competitors

Across-the-line starters power the motor with a near-perfect sinusoidal line-frequency voltage waveform containing few frequency harmonics. Conventional medium voltage VFDs with one pair of medium-voltage IGBTs per motor phase power motors with a square-shaped sine-wave with three, four and sometimes five output voltage levels (figure 1).

This square-shaped waveform contains significant amounts of higher-frequency harmonics. Some of the energy associated with these harmonics will be absorbed by the motor and dissipated as heat. This added heat can potentially increase the operating temperature of the motor and reduce motor life; it's also wasteful in terms of energy usage.

Utilizing multiple power output modules in series, SINAMICS Perfect Harmony drives can generate up to 21 power output voltage levels. This enables the drives to better emulate a sinusoidal waveform, thereby reducing the harmonic content of the voltage waveform to the motor (figure 2). This reduces the amount of harmonic energy that the motor absorbs as heat, which potentially reduces the operating temperature of the motor, prolongs motor life and increases energy efficiency.

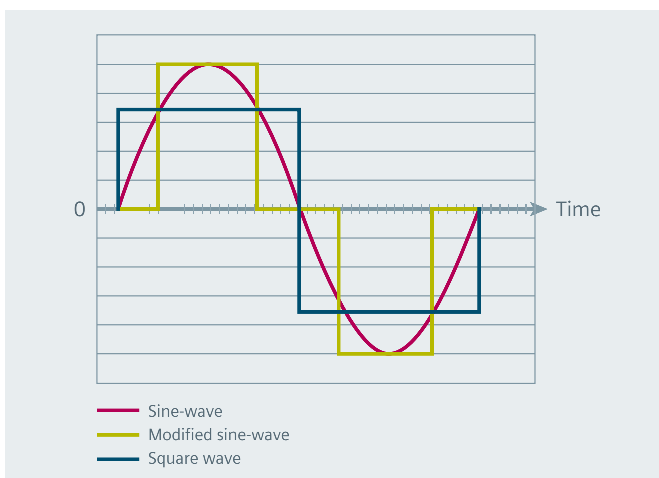

Figure 1: Two- and three-level output waveforms

The voltage within a motor fed by a sinusoidal waveform is generally limited to the line voltage. However, transient voltages encountered during motor operation with a VFD can be significantly higher than line voltage, due to the voltage gradient (dv/dt) resulting from the VFD step waveform. The ability to generate up to 21 power output voltages allows the output voltage to be manipulated in smaller steps, which better approximates a sinusoidal waveform. This reduces the generation of high voltages that can damage the motor insulation, thereby increasing motor life.

VFDs with fewer than five output levels generally require a filter to remove harmonics. Operating a motor using smaller voltage steps that better approximate a sinusoidal waveform reduces the amount of harmonic energy that needs to be dissipated as heat. This improves efficiency and often eliminates the need for a filter. Project cost-benefit analysis calculations often do not take these losses into account — but they should, if they intend to calculate the true cost.

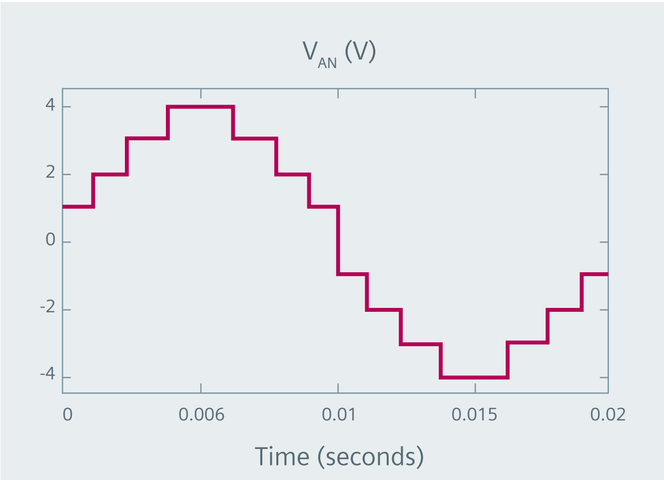

Figure 2: Two- and three-level output waveforms

Advanced Cell Bypass

Series connection of the individual power modules is a characteristic inherent to the use of many low-voltage modules rather than a few high-voltage modules. This characteristic enables the implementation of another important feature that increases reliability: the ability to continue to operate the medium-voltage motor if one or more power modules fail. Each power module has an independent bypass control that ensures automatic bypass of the failed module in less than 500 milliseconds.

In the event of power module loss, SINAMICS Perfect Harmony VFDs employ a neutral shift algorithm to keep the motor voltages balanced, thus eliminating potentially harmful neutral currents. And should the process require additional availability, redundant cells can be added to extend the motor voltage or increase the redundancy to N+2 and N+3 as required. This is another advantage of the multi-cell topology, as it offers a further layer of protection against operational disturbances.

For example, if one of five power modules fails on one phase, 80 percent of the maximum voltage would be made available on the other two phases. This might not pose a problem for a motor that always runs below 80 percent of speed and / or uses less than 80 percent of full load motor power. But the medium voltage VFD can be designed with an extra (sixth) power module per phase so that one failure would still allow full voltage to be applied to the motor after the failed and intentionally selected power modules are bypassed.

Stated more explicitly, medium voltage VFD systems can be designed so the motor will continue to operate even if a power module fails. In addition, prudent design can allow the VFD system to continue operating at full capacity until it can be shut down for power module replacement.

Fewer components in drive system

All conventional medium voltage VFD systems contain a rectifier, a direct current link element (capacitors or inductors) and an output inverter that work together to generate the voltage and current necessary to power the motor. In addition to these three basic components, equipment is sometimes required to meet facility power requirements on the line side of the drive (e.g., capacitors that improve power factor). Harmonic filters and motor filters are used to reduce the harmonic effects of VFD operation on the incoming power and motor waveforms respectively. Overall VFD operation is controlled by the VFD electronics.

SINAMICS Perfect Harmony VFD systems contain an isolation transformer and power modules, each of which contains its own low-voltage rectifier diodes and IGBTs. The isolation transformer is specially designed and wound to provide an individual secondary for each power module. The power modules are connected in series and selectively fire to generate the necessary motor voltage (figure 3).

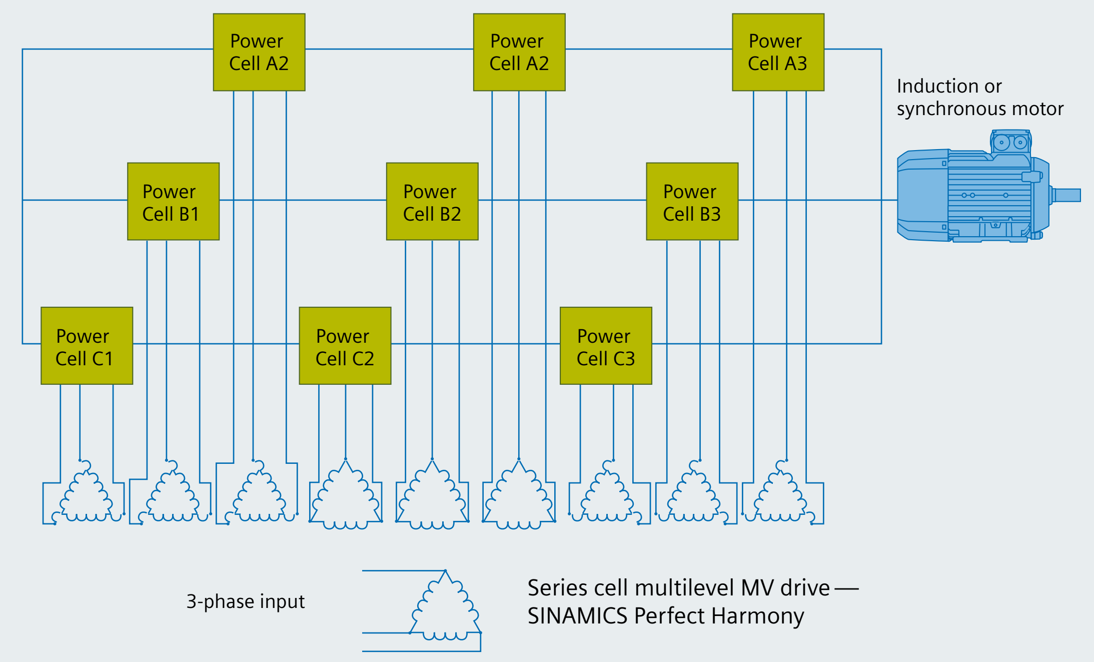

Figure 3: SINAMICS Perfect Harmony Topology

Nonlinearities associated with the power modules do not spread notably to the isolation transformer primary nor to the motor, making power factor correction, harmonic filtering and motor filtering unnecessary. The VFD electronics control overall VFD operation and the firing of each power module.

Eliminating the power factor capacitors, harmonic filter and motor filter tends to increase the reliability and efficiency of medium voltage VFDs. Similarly, conservative design in conjunction with reducing power module voltage requirements for individual components tends to increase medium voltage VFD reliability and efficiency.

In addition to improving reliability, eliminating components removes the need for their installation, physical housing space and ongoing maintenance.

Overall system efficiency is a critical component in cost of ownership. It is important to understand that payback calculations should include the installation and operation of all components that comprise a workable drive system, including filters, capacitors and the like — not just the converter section efficiency.

Process-Tolerant Protection Strategy (ProToPS™)

Process-Tolerant Protection Strategy (ProToPS™), an optional feature for SINAMICS Perfect Harmony drives, provides hierarchical warnings that improve reliability by alerting the operator of potential problems while the medium voltage VFD is still operating. These alarms allow the operator time to evaluate potential problems and respond to avoid a system trip. This tends to increase the reliability of the medium voltage VFD system by limiting the number of trips and confining subsequent process interruptions to extreme situations.

Greater operating experience

A number of electric heater manufacturers attempted to design small low voltage VFDs and gave up after discovering that nonresistive motor loads were much more complex than resistance heaters. Similarly, a number of low voltage VFD manufacturers attempted to offer higher and higher horsepower VFDs, only to discover that there were considerable technical hurdles to overcome. As a result, there are currently only a handful of manufacturers that offer medium voltage VFD systems.

Siemens has been at the forefront of technical innovations in higher horsepower and low voltage VFDs, medium voltage VFDs, and medium voltage VFDs with low-voltage power cells in series. Siemens has manufactured these types of VFDs for almost 50 years. Since 1968, Siemens has designed, manufactured and commissioned almost every type of medium voltage VFD topology, including the SINAMICS Perfect Harmony, first produced in 1994.

Further, operating experience is paramount to improving the reliability of medium voltage VFDs with low-voltage power cells in series. Only a handful of manufacturers have nearly this much operating experience with large low voltage VFDs and medium voltage VFDs. This operating experience has been critical in improving the reliability of medium voltage SINAMICS Perfect Harmony VFD systems.

Conclusion

Reliable medium voltage VFD systems are critical to the operation and economic viability of many industrial facilities and industrial processes. The initial design of medium voltage SINAMICS Perfect Harmony VFD systems considered many aspects of reliability, including best topology, elimination of components, production of more sinusoidal waveforms, use of low-voltage IGBTs, advanced cell bypassing, Process-Tolerant Protection Strategy (ProToPS™), final component selection and, most importantly, feedback from users.

Over time, additional reliability has been integrated into the medium voltage Siemens SINAMICS Perfect Harmony VFD systems from actual VFD systems based on over 50 years of operating experience and an install base of over 10,000 VFDs. No other company can match the operating experience of Siemens, nor the reliability of its systems.

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