Medium voltage drives in the sugar industry

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Abstract

This paper first outlines the benefits of medium voltage variable frequency drives compared to classical drivers or control methods (i.e. steam/gas turbines, hydraulic coupling and Direct-On-Line operation with, for example, valve/damper control). The paper then focuses on typical variable frequency drive applications in the sugar industry and also describes two real cases, namely an ABB drive system used in a soft-starter application at Al Khaleej Sugar Refinery, Dubai, UAE and the replacement of inefficient steam turbines for cane mill drives at Compania Azucarera Hondurena S.A, Honduras, Central America (which produced significant returns of additional 1 million U$/year). Next, the main selection criteria for a medium voltage drive system are described.

Transmisores de voltaje mediano en la industria azucarera

En este trabajo se esbozan inicialmente los beneficios de los transmisores de frecuencia variable y voltaje medio cuando se comparan con los transmisores clásicos o métodos de control (por ejemplo turbinas de vapor / gas, acoplador hidráulico y operación En Línea Directa con, por ejemplo un control de válvula y amortiguador). A continuación se analizan las aplicaciones típicas de los transmisores de frecuencia variable en la industria azucarera y describen dos casos reales, el sistema de transmisor ABB utilizado en dispositivos de arranque suave en Al Khaleej Sugar Refinery, Dubai, UAE y el reemplazo de las ineficientes turbinas de vapor para los transmisores de un ingenio azucarero en la Compañía Azucarera Hondureña S.A, Honduras, América Central (que produjo ganancias adicionales significativas de hasta 1 millón de dólares por año). Para concluir, se describen los principales criterios de selección para un sistema de transmisión de voltaje medio.

Mittelspannungsantriebe in der Zuckerindustrie

Das vorliegende Paper umreißt zunächst die Vorteile von Mittelspannungsantrieben mit veränderlicher Frequenz im Vergleich zu klassischen Antrieben oder Regelmethoden (ob Dampf-/Gasturbinen, hydraulische Regeleinrichtungen oder direkter Betrieb am Netz, z.B. mit Ventil-/Dämpfersteuerung). Dann verlegt das Paper seinen Fokus auf typische Anwendungen von Antrieben mit veränderlicher Frequenz in der Zuckerindustrie und beschreibt zwei reale Fälle, und zwar ein ABB Antriebssystem, das in der Softstarter-Anwendung in der Zuckerraffinerie Al Khaleej in Dubai (Vereinigte Arabische Emirate) verwendet wird, und die Ersetzung ineffizienter Dampfturbinen für Zuckerrohr-Mahlantriebe bei Compania Azucarera Hondurena S.A, Honduras, Zentralamerika, (durch die signifikante Gewinne von zusätzlichen 1 Mio. US$/Jahr erreicht werden konnten). Anschließend werden dann die Hauptauswahlkriterien für ein Mittelspannungsantriebssystem beschrieben.

Introduction

What is a Variable Frequency Drive?

A variable frequency drive (VFD) is basically an electrical circuit, which is connected between a supplying network and a motor. Unlike a Direct-On-Line (DOL) operated motor, the speed of which is fixed to the frequency of the supplying AC network, the main purpose of a variable frequency drive is to provide the motor with an AC supply voltage (or AC current) of variable frequency, enabling a variable motor speed and torque. In general, a state-of-the-art variable frequency drive consists of a rectifier section, a DC-link section and an inverter section. The rectifier section rectifies the supplying AC network voltage of fixed frequency (usually 50 or 60Hz) into a DC voltage (or DC current), which then, in the inverter section of the variable frequency drive, will be transformed into an AC voltage (or AC current) of variable amplitude and frequency.

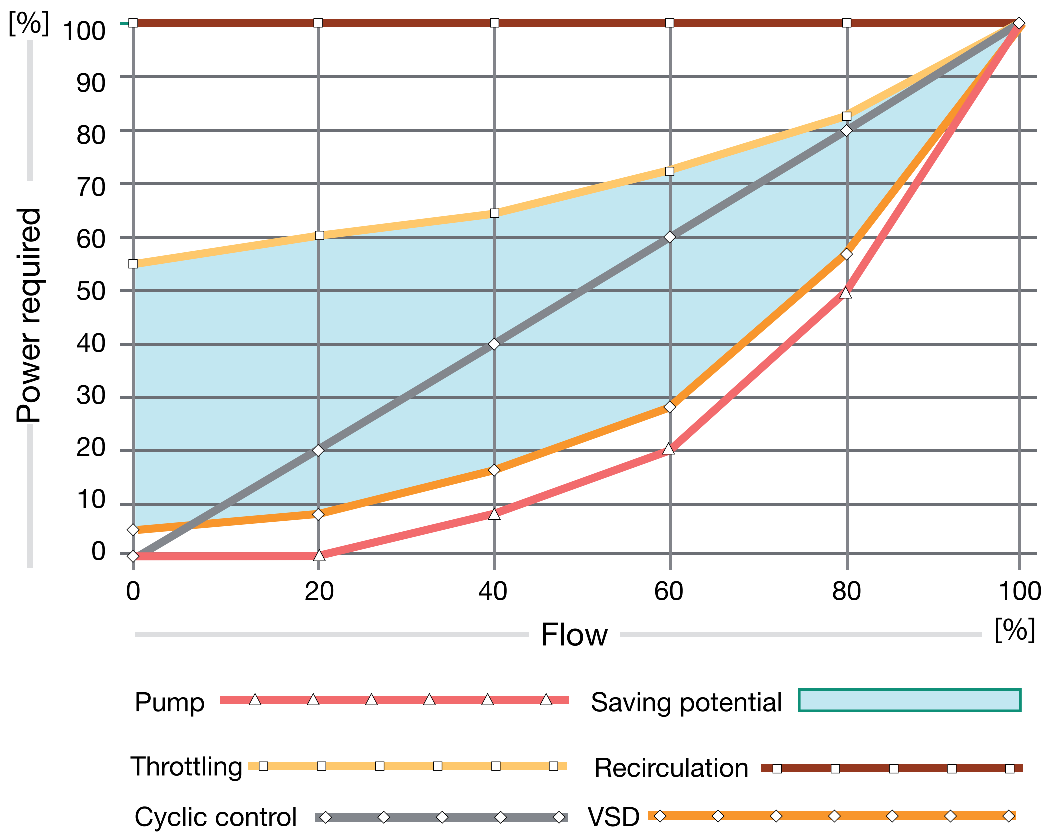
Low voltage versus medium voltage drives

When talking about VFDs, one has to distinguish between Low Voltage (LV) variable frequency drives (up to 690V motor voltage) and Medium Voltage (MV) variable frequency drives (above 1kV motor voltage). This paper focuses on medium voltage-variable frequency drives although a lot of the statements made can also be applied for low voltage variable frequency drives.

Short history of medium voltage-variable frequency drives

Medium voltage-variable frequency drives were introduced into the market in the late 60's. The benefits of medium voltage-variable frequency drives in those days were basically the same as today (e.g. energy savings, improved process control, less maintenance…). However these benefits were, to some extent, compensated by drawbacks such as power factor issues, harmonic distortion, torque pulsations and, maybe worst of all, reliability problems. These problems

Figure 1. Comparison of different pump control methods in regard to their efficiency



have now been basically eliminated allowing the advantages of a medium voltage variable frequency drive system to clearly dominate. This opened the doors for medium voltage-variable frequency drives in many industries such as oil and gas (see [1]), petrochemical, power, water and waste water, metals, minerals and mining, marine, to name just a few, mainly for the controlled and economical transport of liquids, gas and solids.

Medium voltage-variable frequency drives in the sugar industry

In the sugar industry, a lot of applications are suited for operation with variable frequency drives instead of the conventional driving methods (e.g. gas or steam turbines, damper/throttle-, vane-, On/Off- or pitch control). Besides a short description of the benefits of a medium voltage variable frequency drive system, this paper will give an overview of the processes where medium voltage-variable frequency drives result in significant advantages for the customer. Furthermore, it will give some basic guidelines for the selection of such a medium voltage variable frequency drive system.

Benefits of medium voltage variable frequency drive systems

Energy savings

Variable frequency drives offer a wide range of benefits such as improving the quality of a product by having a better control of the process and, due to an optimal pressure or flow control, substantial energy savings.

Where are these energy savings coming from? As an example, we assume a Direct-On-Line, also called fixed speed motor, driving a pump. An electrical motor, which is directly connected to the power grid, will operate at a fixed speed, which is defined by the network frequency and the motor pole number. Therefore, the connected load machine is always rotating at the same speed.

The process requirements however may change, depending on various factors such as change in production quantity or quality, change of the media or deviations from the nominal power grid parameters (change in frequency), varying temperatures or simply new requirements such as production increase. These changes in process requirements also require control actions in the driving system.

The only possible control methods for fixed speed solutions are throttling, bypass control, On/Off control or the upgrade with a variable frequency drive solution.

The least efficient control method is the bypass control followed by the On/Off control. With bypass control, the superfluous flow is redirected back to the pump via the bypass valve. With On/Off control, the system is switched on and off depending on the actual flow or level requirement. This control method is often used in applications where a certain fluid level or capacity is controlled. The control method usually used for fixed speed operation is throttling where opening or closing a valve controls the flow. Depending on the valve position the motor has to work against the valve. This results in a waste of energy and higher maintenance cost. The use of a variable frequency drive is the optimal, most energy-efficient control method,

Figure 2. VFD line-up of the ACS 1000 air-cooled version

which ensures that only the energy, which is required by the driven mechanical load, will be consumed. The variable frequency drive system losses are comparably low.

For a summary of the different control methods in regard to their efficiency, see figure 1.

Minimized maintenance

By replacing mechanical components such as valves, dampers and gas/steam turbines with electrical equipment, i.e. a medium voltage variable frequency drive system, the maintenance efforts will be minimized.

A reliable and well-designed drive system will, with a minimum of maintenance, not require any major component replacements within the first 10+ years.

Improved process control performance

Compared to mechanical solutions such as damper/throttle-, vane-, On/Off- or pitch control, medium voltage-variable frequency drives provide a much smoother and more accurate way of controlling a process.

Extended lifetime of motor and mechanical equipment

Due to the soft-start capabilities and the smooth, in a wide range adjustable speed and torque control capabilities of a medium voltage variable frequency drive system, the lifetime of the motor and the driven mechanical equipment will be extended. For example, due to the reduced pressure at partial load, the lifetime of pipes and other components is increased. By applying a variable frequency drive system, vibrations can be reduced which increases the lifetime of the equipment.

Elimination of motor inrush currents

With a medium voltage variable frequency drive system, the high inrush currents during start-up, which typically can exceed 5-7 times of the nominal motor current, will be eliminated. Especially in applications with high inertias (e.g. fans), high inrush currents may result in a considerable over-design of the motor due to the extended acceleration times at high inrush currents, which increases the price of the motor. With a medium voltage variable frequency drive system, the start-up is extremely soft, and the currents on both the line supply side and the motor side will not exceed their nominal values during start-up. It should be stressed at this point that a start-up with a so-called soft-starter would not result in the same low motor current values as in a start-up with a variable frequency drive system. Although significantly reduced compared to direct-on-line starting, the inrush currents still considerably exceed the nominal motor current values when soft-starters are applied.

Elimination of voltage sags during motor startup

The start-up of a motor connected Direct-On-Line typically comes with high inrush currents as pointed out in the previous paragraph. These currents are mainly of an inductive nature and therefore will cause a remarkable voltage sag at the Point of Common Coupling where the motor is connected and also at upstream and downstream Points of Common Coupling. As a result, many other electrical loads connected to one of these Points of Common Coupling can be severely disturbed and therefore malfunction. Opposed to that, during the start-up of a motor which is controlled via a medium voltage variable frequency drive system, none or only negligible voltage drops will occur and no other electrical equipment in the plant will be negatively affected.

Improved immunity against supply disturbances

Typically, disturbances in the supplying network such as

- transient spikes
- unbalance
- voltage dips lasting over a few cycles
- frequency deviations
- or, most severe, interrupts

will have an impact on the performance of a direct-on-line -operated motor. Especially voltage dips above a certain magnitude (typically >10%) will instantly result in a reduced output power or a complete loss of the driven process. With a medium voltage variable frequency drive system, "ride through" capabilities will ensure that the process will not at all or to a reduced amount be affected by supply disturbances of the kind mentioned above.

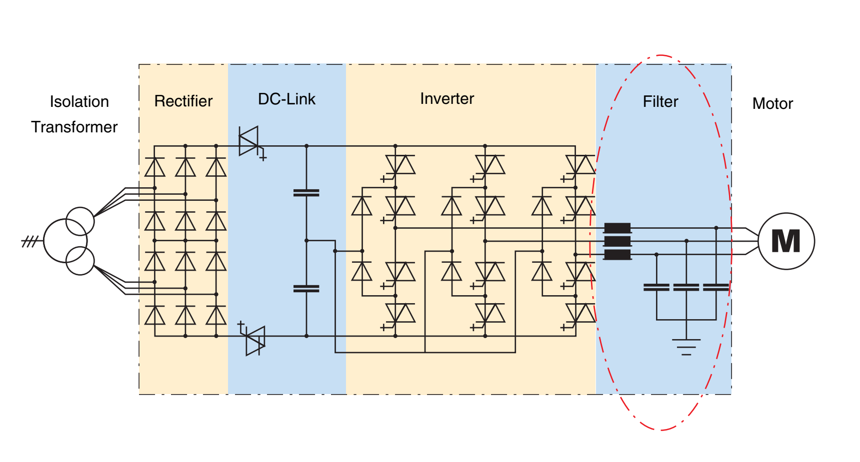
Medium voltage variable frequency drive applications in the sugar industry

Pump applications

The sugar industry in particular uses pumps for transferring liquor with, (a) controlled flow rate, (b) controlled pressure, (c) controlled level in the vessel. Besides the transfer of liquor, pumps are also used in power generation to feed water to the boiler.

Using variable frequency drives for such applications contributes to very high energy saving potential, making it the most economical and efficient method available as of today.

Figure 3. Topology of ABB's ACS 1000 medium-voltage variable frequency drive



air. In order for this to be achieved with better performance and remarkable energy savings, variable frequency drives are used for the control of boiler Induced Draft (ID) and Forced Draft (FD) fans.

Centrifuge applications

Variable frequency drives can also be applied in centrifuge applications - being the heart of sugar refining - for the batch centrifugal speed control. In this application the use of variable frequency drives with common DC bus is also the most reliable and efficient control method, contributing to minimum electrical equipment installations, lowest energy consumption and almost negligible impact on the power grid.

Conveyor applications

Variable frequency drives can be used to control the speed and torque of belt conveyors, resulting in easy management and very precise control.

ID and FD fan applications

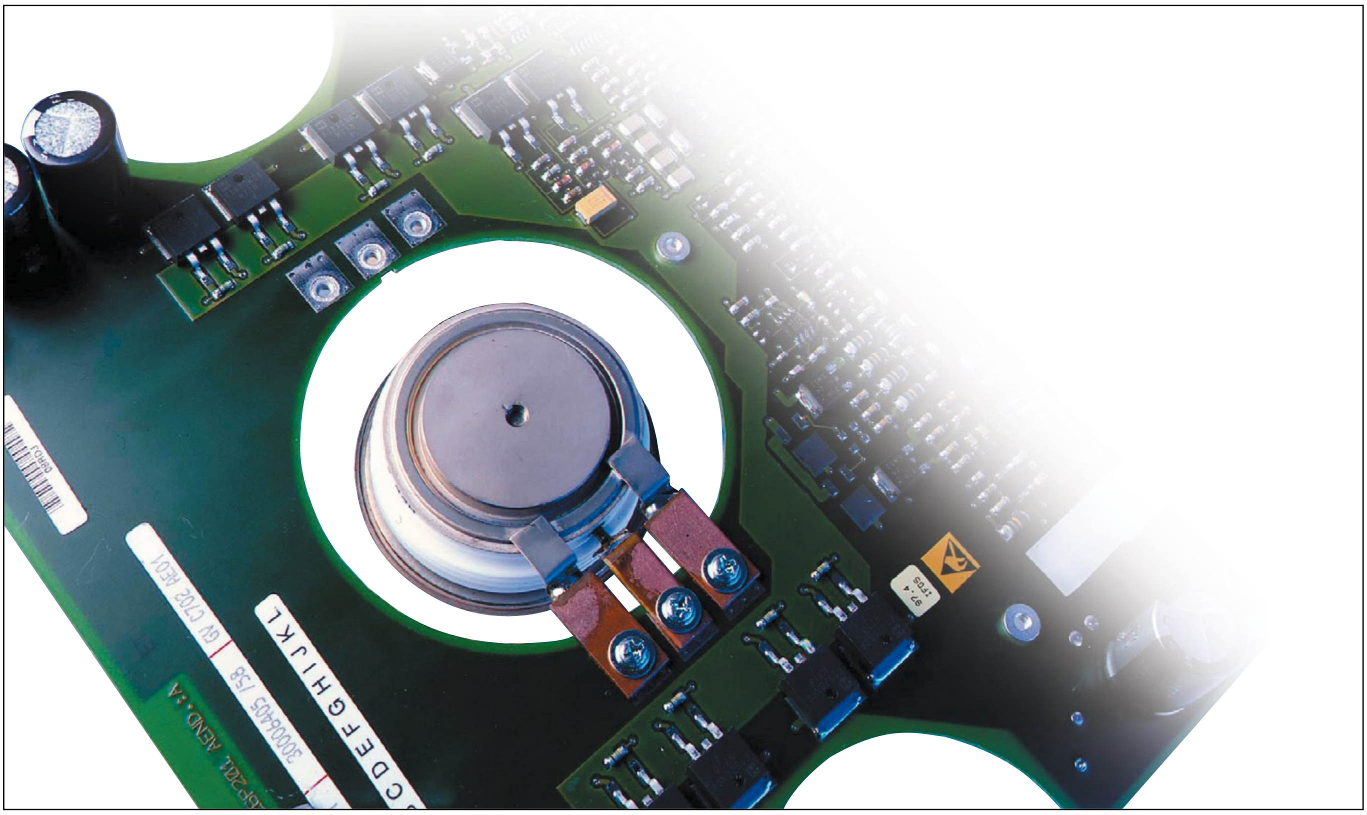
Sugar plants use boilers to generate high-pressure steam for electrical power generation and low-pressure steam for heat exchangers. Since the steam consumption varies depending on the demand, the boiler has to accommodate this variation by controlling the fuel and

Projects for medium voltage variable frequency drive applications in the sugar industry

Project 1: Soft-start of mechanical vapor compressors with medium voltage-variable frequency drives

Al Khaleej Sugar in Dubai, UAE has been using variable frequency drives for all previously mentioned applications for the past ten years. The installation of Mechanical Vapor Compressors (MVR) to reuse waste vapor is the latest ongoing innovative project at Al Khaleej Sugar. Two air-cooled ACS 1000 medium voltage-variable frequency drives (figure 2) from ABB are used as a soft-starting

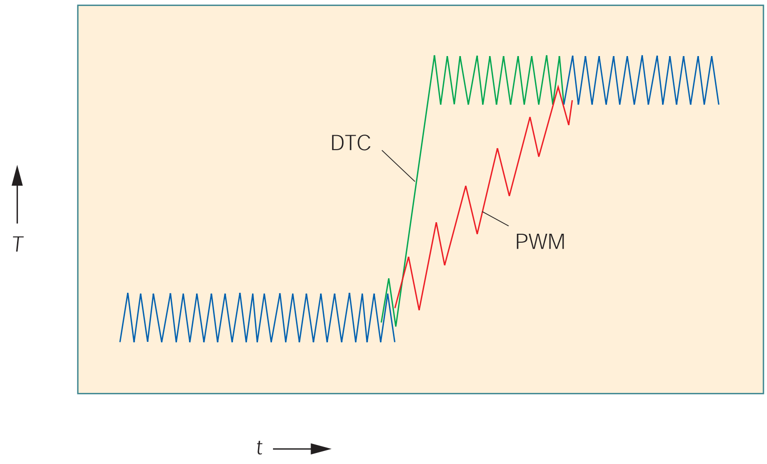
Figure 4. IGCT module with integrated reverse conducting diode and Gate Unit for ACS 1000



device for four 4000kW motors and associated compressors with very high inertia, without any impact to the power supply grid, such as inrush current, voltage dips etc. In this specific application, the starting sequence can be sub-divided into three phases. In the first phase, a selected motor is smoothly accelerated with the variable frequency drive from standstill up to nominal speed. This is followed by the second phase, in which the motors are synchronized with the supply network. Once the synchronization is completed, the motors will then, in the third phase, be smoothly transferred to the grid. Due to the fact that the start-up and transfer is performed at low compressor load, the medium voltage-variable frequency drives can also be designed for a lower power rating.

At present, only a few benefits of a medium voltage variable frequency drive system are utilized in this application. However, in case the mechanical vapor compressor application proves to be a successful innovation, it is planned to upgrade the installation with medium voltage-variable frequency drives that are rated for the full motor power in order to fully control the process with medium voltage-variable frequency drives. The additional benefits of such a system, in particular energy savings, can then be fully exploited. For further information about the mechanical vapor compressor project at Al Khaleej Sugar, see [6].

Figure 5. Torque step-response of DTC compared to conventional PWM control scheme



Project 2: Cane mills

Compania Azucarera Hondurena S.A., founded in 1938, is one of the largest sugar companies in Honduras, Central America. Their Santa Matilde plant has a capacity of 10200 tons/day (of cane) operating 155 days per year. They expect to increase their capacity to 12000 tons of cane per day. In order to generate electric energy the plant produces steam by combustion of bagasse, which is the principal waste product from sugar production. Part of the steam is used to run steam turbines, which in turn drive cane-crushing mills. The rest of the steam is used to generate electricity for use by the factory. Under normal operating conditions, there is sufficient steam to drive the cane mill turbines and to generate electricity for the plant. The cost of electricity in Honduras is relatively high because it is mainly produced by fuel oil. Thus the opportunity to optimize the energy use in the plant to be able to deliver more energy to the grid becomes very attractive.

Therefore, at their Santa Matilde plant, Compania Azucarera Hondurena S.A. replaced five steam turbines, which were driving the cane mill, with ACS 1000 variable speed drives and induction motors. By controlling the cane mill with these drives and electrical motors instead of steam turbines, the steam can now be used exclusively to generate electricity, which will feed the whole plant and can even be sold to the grid.

Now, what does this mean in real numbers? In the case of this particular plant, five 750kW steam turbines are needed to drive the cane mills, resulting in 3750kW total power.

Considering the steam requirement of 35 pounds/kW in these small turbines, about 131,000 pounds of vapor were required to drive the complete cane mill. On the other hand, turbines with high-pressure boilers to drive electrical generators only need 12.7 pound/kW. This means there is a potential of up to 22.3 pounds/kW that can be used to generate electricity instead of being wasted in inefficient turbines driving the cane mills.

Using all of the steam for electric energy generation gives some 10,300kW generating capacity which is used to feed the electrical drives. Furthermore, excess energy of about 6550kW can be sold to the grid. This brings about 1 million US$/year additional revenue to the Compania Azucarera Hondurena S.A. resulting in a payback time for the medium voltage drive investment of about 1 year!

Besides the remarkable improvement of overall energy efficiency of the plant, there are other clear benefits.

The speed of the mill can be accurately controlled depending on the amount of cane coming into the machine. This is a great advantage compared to the use of the steam turbines.

Another advantage is that the electrical drives can estimate the shaft torque and protect the mill against overload. In this case the mill can be driven in reverse to get the excess material out of the machine and resume normal operation with minimum production loss.

Further, the ACS 1000 medium voltage drives require only a fraction of maintenance compared to maintenance-intensive steam turbines. This results in a higher up time and lower maintenance costs. Furthermore, after a shutdown, the cane mill driven by ACS 1000 medium voltage drives returns to operating conditions much faster than the steam turbine driven cane mill. Finally, due to ABB's ACS 1000 control method DTC (Direct Torque Control), the noise level is considerably reduced for both the variable frequency drive and the motors and is almost negligible compared to that of steam turbines.

Selection criteria for a medium voltage variable frequency drive system

A medium voltage variable frequency drive system as discussed in this paper basically consists of an incoming disconnector (fused contactor, main circuit breaker), an isolation transformer with surge protection, the converter (medium voltage-variable frequency drive) and its control, medium voltage cables and a medium voltage motor (induction or synchronous).

Figure 6. ABB's ACS 1000i VFD with integrated switchgear, protection and 24-pulse VFD isolation transformer

This paper focuses mainly on the drive rather than the complementing system components (breakers, transformer and motor), since the variable frequency drive is the most complex and probably the least familiar component for most readers.

Reliability

Reliability is probably the most important demand on a medium voltage-variable frequency drive.

One crucial key to achieve maximum reliability is to design the converter with a minimum of passive and active components (figure 3).

Active components in this context are semiconductor switches (e.g. thyristors, GTOs (Gate Turn Off Thyristor), IGCTs (Integrated Gate Commutated Thyristor, figure 4), IGBTs (Insulated Gate Bipolar Transistor). Designs with a high parts count, especially active components, cannot, by their physical nature, guarantee the best reliability numbers and should therefore be avoided.

Further, it is recommended that the protection concept is fuseless. Fuses are unreliable and subject to aging. According to [2], more than 7% of all medium voltage variable frequency drives failures are due to blown fuses.

Besides a low parts count, it is also recommended to have reasonable safety margins in the design of all components, which will result in a longer lifetime and consequently in higher reliability.

Efficiency

As shown in the previous chapter, one of the main benefits of a medium voltage variable frequency drive system is energy savings achieved by running the driven process at its optimum operation point.

In order not to sacrifice this benefit, the medium voltage variable frequency drives itself should also be as efficient as possible. Efficiency numbers of 98.0% or higher are desirable at the nominal operation point. It should be stressed at this point that even small differences of a few points, can result in remarkable annual energy costs of several thousand US$.

Line friendliness

The number of power electronic circuits connected to the grid is steadily increasing. Each medium voltage variable frequency drives is such a circuit. Due to their non-linear nature, these circuits have the inherent attribute of generating harmonics, which have to be limited in order not to cause undesired interactions with other electrical and electronic loads connected to the same bus.

For that purpose, there are standards recommending strict harmonic limits. Examples of these standards are IEEE 519-1992, IEC 61000-2-4 or G5/4 [3]-[5]. In many cases, a 12-pulse input diode rectifier design will fulfill the above-mentioned harmonic standards. In some cases, where the network is weak, an 18-or 24-pulse configuration may be required. This has to be evaluated on a case-by-case basis.

Motor friendliness

Motor friendliness is another demand on a medium voltage-variable frequency drive. This basically means that the driven motor can be a standard direct-on-line motor, with no special insulation or de-rating needed. This requirement is especially crucial in the case of retrofit applications where an existing (fixed speed) standard motor is upgraded with a medium voltage-variable frequency drive.

Ideally, the variable frequency drive output voltage should therefore be as close to sinusoidal as possible. In particular, the variable frequency drive output voltages at the motor terminals should not exceed the peak-value of the nominal motor voltages and the max. dv/dt should be limited to values of about 500V/us. Further, the current harmonics, being a result of the non-ideal sinusoidal variable frequency drive output voltage, should not exceed 5%.

The common mode voltages should be fairly low, or even better, nonexistent in order to utilize a standard motor design.

Control performance

Another selection criterion for a medium voltage variable frequency drive is its control performance, i.e. its capabilities to accurately control speed and torque and to respond to transient events like load changes in a fast and stable manner (figure 5).

Even if high dynamic control performance, i.e. torque response times in the range of 5ms, may not always be required from a process point of view, it is crucial in case of line supply disturbances in order to minimize the impact of such a disturbance on the motor side and the load.

The more dynamic a motor control scheme is, the faster it can counteract to these line supply disturbances and the less the impact will be for the mechanical driven load.

Further, encoderless motor control schemes are recommended, since encoders are unreliable and may have undesired impacts on the speed control performance.

Low maintenance

Low maintenance of a medium voltage variable frequency drive is crucial in order to obtain high availability and to keep the life-cycle costs down.

Therefore an ideal medium voltage variable frequency drive is not only reliable but also consists of components which have a long lifetime and do not require regular time-and cost-intensive maintenance. Critical components, which should be carefully selected during a drive design phase, are cooling fans or pumps, cooling system materials (e.g. stainless steel) and DC-link capacitors, which ideally should not be of the electrolytic type (lifetime only about 5 years). Electrolytic capacitors on Printed Circuit Boards (PCB) should be of extended lifetime type and not be operated above 75% of their maximum temperature.

Flexibility

In order to save building costs and costs for indoor HVAC installations, it is a wise idea that the variable frequency drive and the supplying transformer can be located separately and are not necessarily integrated in the same cubicle.

This provides the flexibility to choose between a dry-type or oil-immersed transformer located either indoors or outdoors.

In many applications, the actual building size can be smaller (and therefore cheaper) if the transformer is located outdoors. Furthermore, the transformer losses do not have to be handled by an additional HVAC system, which saves extra costs.

Solutions where the drive's supply transformer can be eliminated or replaced by line inductors will certainly result in a smaller footprint, less weight and overall cost savings, but it has to be kept in mind that the driven motor will have to be of a special design in order to cope with common mode voltages. In addition common mode components will be injected into the line supply system and no galvanic isolation between breaker, isolator switch, surge protection, 24-pulse transformer and the the feeding supply system and the medium voltage variable frequency drive will exist.

Should the preference be to have the isolation transformer in the line-up of the drive, a repackaged air-cooled ACS 1000, namely the ACS 1000i, is a suitable alternative (figure 6). This newest member in ABB's MV-VFD portfolio is a highly compact drive with incoming breaker, isolator switch, surge protection, 24-pulse transformer and the VFD integrated in one cubicle.

Conclusions

The multiple benefits of a medium voltage variable frequency drive system were introduced in this paper. It was shown that, in the sugar industry as well as in many other industries, various applications can benefit from the application of a medium voltage variable frequency drive system. This was highlighted by two examples: a) the most innovative mechanical vapor compressor application at Al Khaleej Sugar, where ABB's ACS 1000 drive family is applied as a soft-starting device b) the replacement of inefficient steam turbines for a cane mill application at Compania Azucarera Hondurena S.A. Following this, basic selection criteria for a medium voltage variable frequency drive were given.

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