Medium Voltage Drives in the Sugar Industry

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Abstract

This paper first outlines the benefits of Medium Voltage Variable Frequency Drives (MV-VFD) 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 a MV-VFD 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.
Next, the main selection criteria for a MV-VFD system are described and finally a state-of-the-art example of such a product complying with the above-described selection criteria will be presented.

I. Introduction

A. What is a Variable Frequency Drive?

A 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 VFD 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 VFD 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 VFD, will be transformed into an AC voltage (or AC current) of variable amplitude and frequency, see also Fig.1.

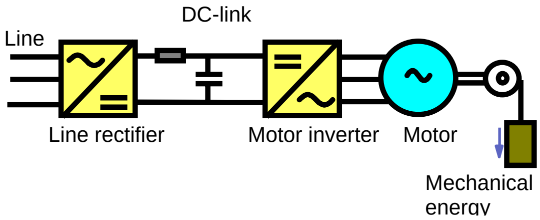


Fig. 1: Basic components of a VFD

B. Low voltage versus medium voltage drives

When talking about Variable Frequency Drives (VFDs), one has to distinguish between Low Voltage (LV) VFDs (up to 690V motor voltage) and Medium Voltage (MV) VFDs (above 1kV motor voltage). Typically the economically reasonable power range for LV-VFDs is about 0...1000Hp, whereas MV-VFDs start to become economical from about 500 Hp up to more than 100 000 Hp.
This paper is focusing on MV-VFDs although a lot of the statements made can also be applied for LV-VFDs.

C. Short history of MV-VFDs

MV-VFDs were introduced into the market in the late 60's. The benefits of MV-VFDs 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 have now been basically eliminated allowing the advantages of a MV-VFD system to clearly dominate.
This opened the doors for MV-VFDs in many industries such as oil & gas (see [1]), petrochemical, power, water & waste water, metals, minerals & mining, marine, to name just a few, mainly for the controlled and economical transport of liquids, gas and solids.

D. MV-VFDs in the sugar industry

In the sugar industry, a lot of applications are suited for operation with a MV-VFD 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 MV-VFD system, this paper is also dedicated to giving an overview of the processes where MV-VFDs will result in remarkable advantages for the customer. Furthermore it will give some basic guidelines for the selection of such a MV-VFD system.

II. Benefits of MV-VFD systems

A. Energy savings

VFDs 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 (DOL), 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 VFD solution, see Fig. 2

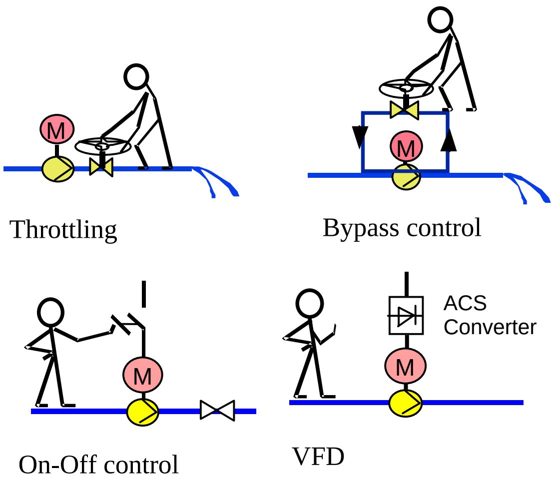


Fig. 2: Examples of fluid control

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 VFD is the optimal, most energy-efficient control method, which ensures that only the energy, which is required by the driven mechanical load, will be consumed. The VFD system losses are comparably low.
For a summary of the different control methods in regard to their efficiency, see also Fig. 3.

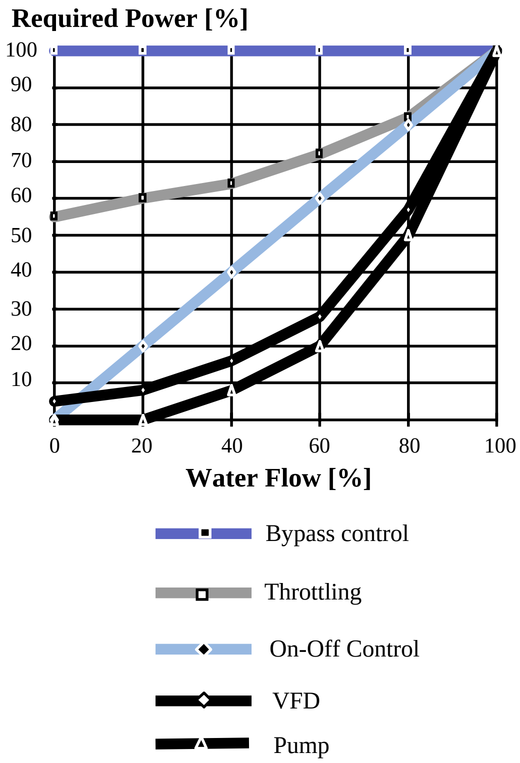


Fig. 3: Comparison of different pump control methods in regard to their efficiency

In order to calculate potential energy savings in a convenient way, ABB has developed two easy-to-use programs, named PumpSave and FanSave. These tools calculate, based on some basic inputs, the estimated energy savings and payback times for a specific pump and fan application. The programs are based on Microsoft Excel® and are available free of charge from ABB MV drives.
Calculations typically result in payback times for a VFD investment between 1.5 to 4 years, mainly depending on the load cycle and the energy costs.
Fig. 4 shows the input data mask of the PumpSave tool.

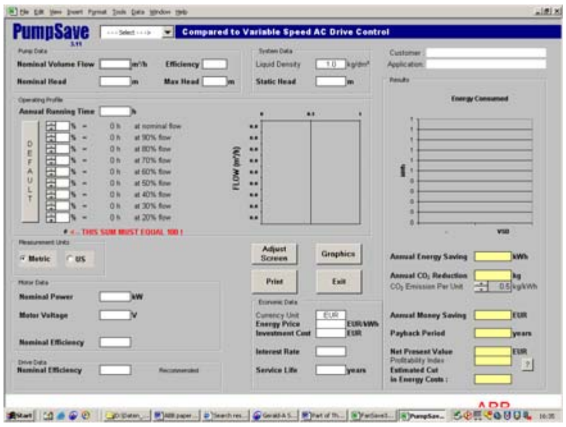


Fig. 4: Input data mask of ABB's PumpSave Tool

B. Minimized maintenance

By replacing mechanical components such as valves, dampers and gas/steam turbines with electrical equipment, i.e. a MV-VFD system, the maintenance efforts will be minimized.

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

The only components requiring a yearly check are, for example, back-up batteries, deionizer vessels (in water-cooled VFDs) or air filters (in air-cooled VFDs). Although it is recommended to have a regular maintenance schedule, many of these checks can be done while the drive system is in operation, which will avoid a process shutdown.

C. Improved process control performance

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

With a MV-VFD system, speed and torque can be adjusted and maintained with accuracies of 0.1% and better.

As a result, depending on the application, the process is controlled in a more efficient way and the process output is of better quality.

Other benefits include a lower system noise level and the integrated motor protection equipment, which is part of the VFD scope of supply. At DOL operation the motor protection equipment has to be supplied separately.

D. 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 MV-VFD 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 VFD system, vibrations can be reduced which increases the lifetime of the equipment.

E. Elimination of motor inrush currents

With a MV-VFD 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 MV-VFD 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 VFD system. Although significantly reduced compared to DOL starting, the inrush currents still remarkably exceed the nominal motor current values when soft-starters are applied.

F. Elimination of voltage sags during motor start-up

The start-up of a motor connected Direct-On-Line (DOL) 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 (PCC) where the motor is connected and also at upstream and downstream PCCs. As a result, many other electrical loads connected to one of these PCCs can be severely disturbed and therefore malfunction.

Opposed to that, during the start-up of a motor which is controlled via a MV-VFD system, none or only negligible voltage drops will occur and no other electrical equipment in the plant will be negatively affected.

G. 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 DOL-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 MV-VFD 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.

This is achieved with a DC link, which, as a part of the VFD system, decouples the motor side from the feeding supply side, as well as sophisticated motor control schemes.

Also a short circuit in a DOL-operated motor will have a remarkable negative impact on the supplying network. With a VFD between the network and the motor, these short circuits are handled by the VFD system in a very fast manner and will have a minimum impact on the supply system.

III. MV-VFD applications in the sugar industry

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

B. Conveyor applications

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

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

D. Centrifuge applications

VFDs 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 VFDs 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.

IV. Projects for MV-VFD applications in the sugar industry

A. Project 1: Soft-start of mechanical vapor compressors with MV-VFDs

Al Khaleej Sugar in Dubai, UAE has been using VFDs 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 MV-VFDs from ABB are used as a soft-starting 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. For more information on ABB's ACS 1000 VFD family, the reader is referred to chapter VI of this paper.

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 MV-VFD 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 bumplessly transferred to the grid.

Due to the fact that the start-up and transfer is performed at low compressor load, the MV-VFDs can also be designed for a lower power rating.

The basic one-line diagram in Fig. 5 illustrates the equipment line-up.

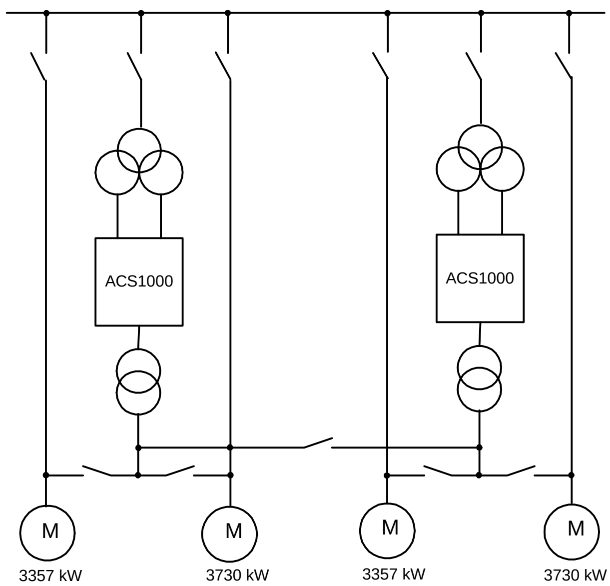


Fig. 5: Basic one-line diagram of the electrical equipment at Al Khaleej Sugar for soft start of mechanical vapor compressors

At present, only a few benefits of a MV-VFD 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 MV-VFDs that are rated for the full motor power in order to fully control the process with MV-VFDs. 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, the reader is referred to Fig. 15 and Fig. 16 in the appendix and to [6].

B. 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. In 2006 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 USD/year additional revenue to the Compania Azucarera Hondurena S.A. resulting in a payback time for the MV 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 VFD and the motors and is almost negligible compared to that of steam turbines.

V. Selection criteria for a MV-VFD system

A MV-VFD 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 (MV-VFD) and its control, MV cables and a MV motor (induction or synchronous). Fig. 6 illustrates a MV-VFD system.

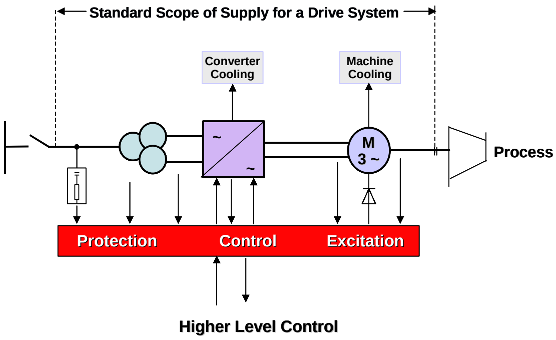


Fig. 6: Typical components of a MV-VFD system

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

A. *Reliability*

Reliability is probably the most important demand on a MV-VFD.
One crucial key to achieve maximum reliability is to design the converter with a minimum of passive and active components.
Active components in this context are semiconductor switches (e.g. thyristors, GTOs, IGCTs, IGBTs). 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 MV-VFD 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.

B. *Efficiency*

As shown in the previous chapter, one of the main benefits of a MV-VFD system is energy savings achieved by running the driven process at its optimum operation point.
In order not to sacrifice this benefit, the MV-VFD 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 USD.

C. *Line friendliness*

The number of power electronic circuits connected to the grid is steadily increasing. Each MV-VFD 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.
It is, however, questionable to extensively exceed the harmonic standards by means of overly complex transformer configurations and a high parts count, since this contradicts the reliability requirement.
In the context of line friendliness, common mode components (i.e. harmonic orders being an odd multiple of three: 3, 9, 15…) should also be considered. Having an isolation transformer between the MV-VFD and the supplying network can mitigate these common mode components. In case of a transformer-less MV-VFD system solution, these common mode voltages will be injected into the supplying network.

D. Motor friendliness

Motor friendliness is another demand on a MV-VFD. This basically means that the driven motor can be a standard DOL (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 MV-VFD.
Ideally, the VFD output voltage should therefore be as close to sinusoidal as possible. In particular, the VFD 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 VFD 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.

E. Control performance

Another selection criterion for a MV-VFD 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. Speed and torque accuracy should be in the range of 0.1%. The required dynamic performance in case of load steps varies with the load. While fan, pumps and compressors require less demanding torque step response times >10ms, applications such as rolling mills may require step response times <5 ms.
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.

F. Low maintenance

Low maintenance of a MV-VFD is crucial in order to obtain high availability and to keep the life-cycle costs down.
Therefore an ideal MV-VFD 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 in a MV-VFD 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.

G. Flexibility

In order to save building costs and costs for indoor HVAC installations, it is a wise idea that the MV-VFD 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 MV-VFD 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 the feeding supply system and the MV-VFD will exist.

VI. Example of a state-of-the-art MV-VFD

This chapter describes ABB’s ACS 1000 MV-VFD as an example of a state-of-the-art MV-VFD system, which complies with the basic selection criteria outlined in the previous chapter.

A. *General ACS 1000 information*

The ACS 1000, launched in 1998, is available for the motor voltages 2.3kV, 3.3kV and 4kV in a power range between 300kW up to 5000kW.
Up to about 1800kW output power, the ACS 1000 product is available with air-cooling, between 1800kW and 5000kW with water-cooling.
For photos of the ACS 1000 line-up and the topology, see Fig. 7 –8.
For further publications on the ACS 1000 VFD, the reader is referred to [7] – [9].

Fig. 7: VFD line-up of the ACS 1000 air-cooled version

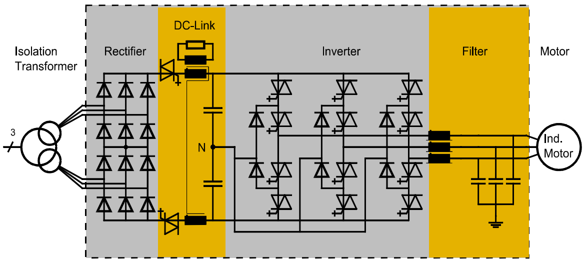


Fig. 8: Topology of ABB's ACS 1000 MV-VFD

B. *IGCT technology*

The chosen semiconductor technology has a major influence on the fulfillment of the previously described MV-VFD selection criteria. The ACS 1000 VFD is based on the IGCT (Integrated Gate Commutated Thyristor) technology, which combines the benefits of the Gate Turn Off Thyristor (GTO) (reliability & robustness, high current density, low on-state losses) and the Insulated Gate Bipolar Transistor (IGBT) (low switching losses, fast switching, snubberless), but eliminates their individual drawbacks.
The IGCT is the semiconductor of choice for all MV high power applications and is superior to other semiconductor switches (e.g. IGBT, IEGT, GTO) in regard to reliability, robustness, current density and overall losses (see Fig. 9).

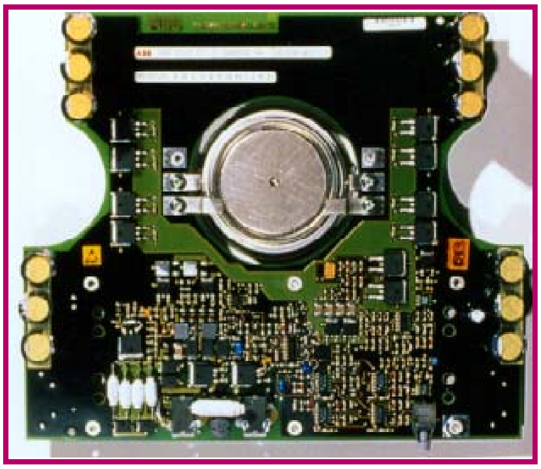


Fig. 9: IGCT module with integrated reverse conducting diode and Gate Unit for ACS 1000

C. *Reliability*

The IGCT technology enables a compact inverter design that is based on the lowest possible parts count with no series or parallel connection of semiconductor switches.
The inverter unit of the ACS 1000 VFD is a 3-level Voltage Source Inverter (VSI) with just 12 IGCTs with integrated reverse conducting diodes plus some 6 Neutral Point Clamped (NPC) diodes.
The DC link consists of a minimum number of self-healing, high power, film type MV capacitors, which do not need any maintenance.
The standard rectifier, which rectifies the incoming supply voltages from AC to DC, is a simple 12-pulse diode bridge with high power MV diodes, resulting in the minimum parts count of not more than 12 diodes.
Further, the protection concept is not based on fuses but on 2 additional IGCTs, the so-called protection IGCTs, which are located between the 12-pulse diode rectifier and the DC-link capacitors, see Fig. 8.
The protection IGCTs are not only much more reliable than fuses, they are also about 100 times faster (about 25μs) and do not have to be replaced after the rare event of a failure.
Moreover, the ACS 1000 components are designed with safety margins, which results in an overall Mean Time Between Failure (MTBF) number of 51000 hours or 5.8 years.
Finally, the design of the ACS 1000 VFD is very service friendly. In case of a failure, it can be repaired in a minimum time (e.g. exchange of a diode or IGCT takes only 15–30 min.), which shows its impact in a high availability number of 99.93%.

D. *Efficiency*

Due to the minimum number of semiconductor components and the very efficient IGCT technology, the efficiency of the ACS 1000 VFD is excellent. This is based on the fact that IGCTs show the overall lowest losses compared to other semiconductor switches like GTOs or IGBTs. Even if the output sine filter contributes with some points to the loss balance, the overall

ACS 1000 VFD efficiency (incl. aux. losses) at the nominal operation point is typically around 98.5%.

E. Line friendliness

The standard 12-pulse diode rectifier bridge fulfills the strict harmonic standards for most applications. To quantify this statement, see Fig. 10, which shows the network voltage and currents generated by an ACS 1000 12-pulse diode bridge and benchmarked against IEEE519 for a typical industrial network. It can be clearly seen that the IEEE519 standard is not only fulfilled but even exceeded. In cases where the network is very weak, a 24-pulse option is available.
Also the supply side power factor is only varying slightly over the whole load range and is typically better than 0.95.

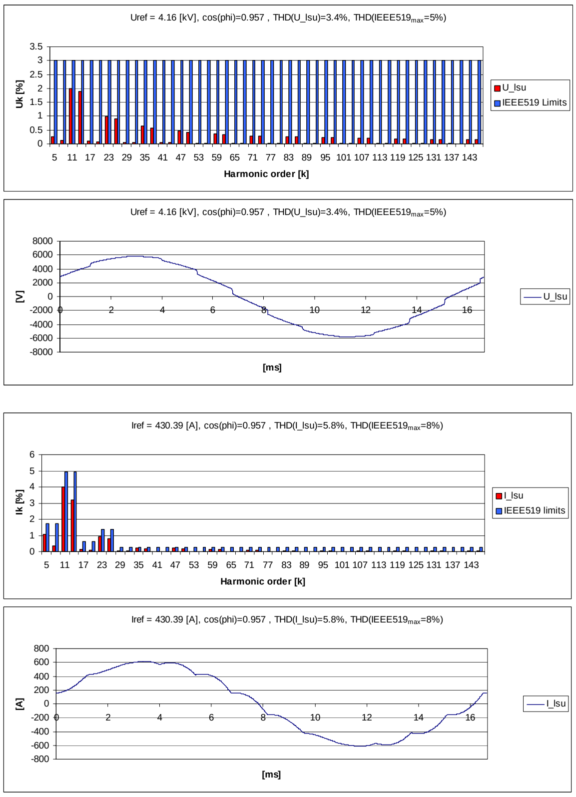


Fig. 10: Harmonic spectrum benchmarked against IEEE519 limits and line diagram of the voltage and current generated by an ACS 1000 VFD with 12-pulse diode rectifier input, I_{sc}/I_L=25, I_{SC}=network short circuit current, I_L=nominal ACS 1000 drive current

F. Motor friendliness

The ACS 1000 VFD features almost pure sinusoidal output voltages and currents and is therefore perfectly suited to drive standard motors with no special insulation or de-rating requirements. Even very old motors can be retrofitted with the ACS 1000. For output voltage and current waveforms, please refer to Fig.11.
In addition, the unpopular common mode voltages are eliminated at the motor terminals, since they are exclusively captured inside the ACS 1000 VFD.
These ideal output voltages are achieved with the integrated sine filter, see Fig. 12. Further, since the sine-filter star-point is grounded, it is guaranteed that the driven motors are not opposed to common mode voltages. Another remarkable benefit is an almost unlimited cable length between the VFD output and the motor (no voltage reflections at the end of the cable).

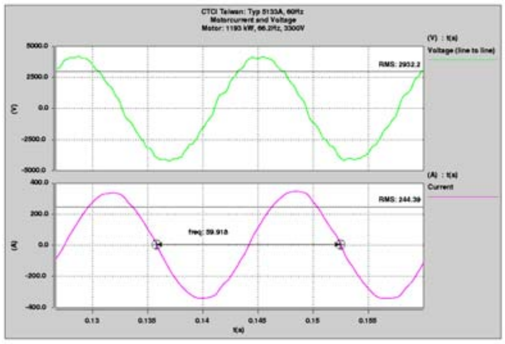


Fig. 11: Filtered line-line ACS 1000 output voltage (upper trace) and corresponding motor currents (lower trace)

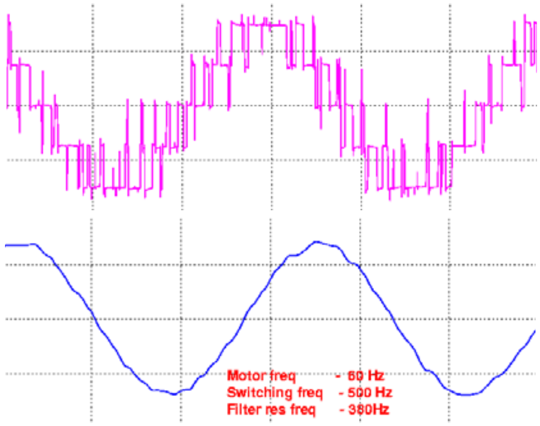
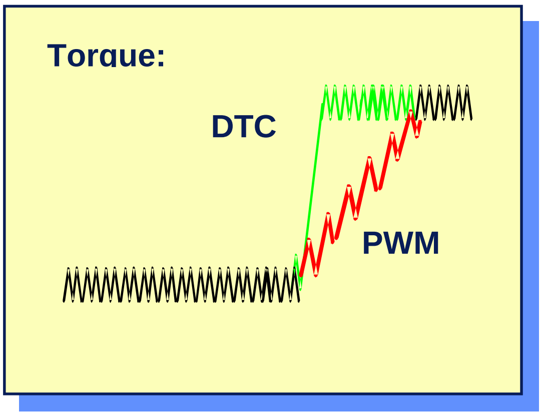


Fig. 12 Unfiltered (upper trace) and filtered (lower trace) line-line ACS 1000 output voltage

G. Control performance

The control method of choice in ABB's ACS 1000 product is the so-called Direct Torque Control (DTC). This, ABB-patented, control scheme is undeniably the most dynamic and efficient control scheme existing on the drives market today.
With DTC, both the torque and the flux of the motor are kept within a given hysteresis band, which is checked every 25µs. Switching of the semiconductors does not occur according to a fixed determined pulse pattern, but only if one of the two controlled quantities touch the hysteresis band limits. In this case however, the switching will be immediate.
This algorithm ensures an unmatched static (speed accuracy $< 0.1\%$) and dynamic control with no overshoot during transient torque steps and step response times as low as 1-2ms (see Fig. 13). Additionally, the switching frequency, and with that the switching losses, will be kept at a minimum.
Another positive side effect is a very low motor noise. This is due to the fact that the harmonic spectrum of

the motor voltages is distributed over the whole frequency range with low amplitudes rather than having



distinctive harmonic orders with high amplitudes.

Fig. 13: Torque step-response of DTC compared to conventional PWM control scheme

H. Low maintenance

The required maintenance is more or less limited to exchanging (intervals depending on the ambient conditions) a few items such as the air filter in the case of an air-cooled drive (once a year) or the deionizer vessel in the case of a water-cooled version (every second year) or the back-up battery (every second year).
In addition to the basic maintenance, ABB offers maintenance contracts, which include additional checks (not replacements!), which, in the course of time, will result in higher reliability and availability at a minimum cost.

I. Flexibility

The ACS 1000 product provides the flexibility to have the VFD isolation transformer located indoors in the line-up of the drive or outdoors, separated from the drive. Either a dry-type or an oil-immersed transformer can be chosen.
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 very interesting alternative (Fig. 14). It is a highly compact drive (L x D x H = 3.3m x 1.1m x 2.7m) with incoming breaker, isolator switch, surge protection, 24-pulse transformer and the VFD integrated in one cubicle (= 3 cables in, 3 cables out).

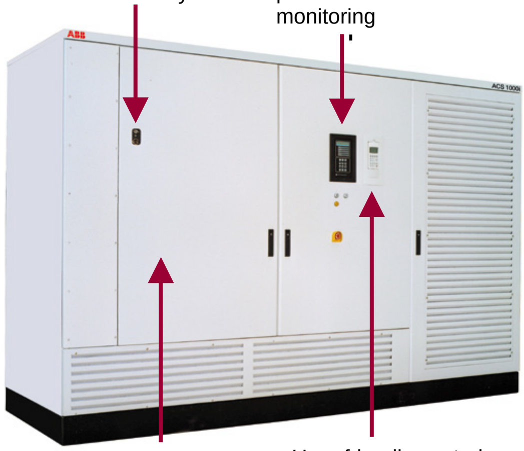


Fig. 14: ABB's ACS 1000i VFD with integrated switchgear, protection and 24-pulse VFD isolation transformer

VII. Conclusions

The multiple benefits of a MV-VFD 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 MV-VFD 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 MV-VFD were given and finally, ABB's ACS 1000 drive family, as an example of a state-of-the-art MV-VFD, was presented.

VIII. *References*

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IX. Biography

Gerald Scheuer received his Masters degree in Electrical Engineering from the Technical University in Karlsruhe, Germany and his Ph.D. in Power Electronics from the Swiss Federal Institute of Technology in Zurich, Switzerland. He joined ABB MV Drives in Switzerland in Feb.1998 where he held positions in development and systems engineering, followed by an assignment in September 2001 as senior application engineer with ABB Medium Voltage Drives in the USA. Since November 2004 he is back with ABB MV Drives in Switzerland and is presently Head of Product Management.

Thomas Schmager started his career with ABB MV Drives in 1991 as an electrical engineer in LCI converter engineering. In 1995 he accepted a position as project manager and in 1999 he became sales manager for the Middle East countries. Since 2003 he is leading a MV drives sales group, having worldwide responsibility for Water & Power and Other Applications.

L.C. Krishnan graduated as B.E [Honours] Electrical Engineer in 1972, from the University of Madras, India.
From 1972 – 1978 he worked as an Electrical Engineer in a Cane Sugar factory in India.
In 1979 he joined the Steel Authority of India as a Divisional Engineer with responsibility for the first S.S Rolling Mill Project in India.
He then joined Kenana Sugar Co, Sudan, working as Chief Electrical & Instrument Engineer, from Oct 1979 to Sept, 2002.
Since Nov 2002, he has held the position of an Engineering Manager with Al Khaleej Sugar, Dubai, which is playing a major role in the process of Sugar Refining, with advanced technology and continuous improvement programs for challenging performance. Under the leadership of Mr.Jamal Al Ghurair – as Chairman.

X. Appendix

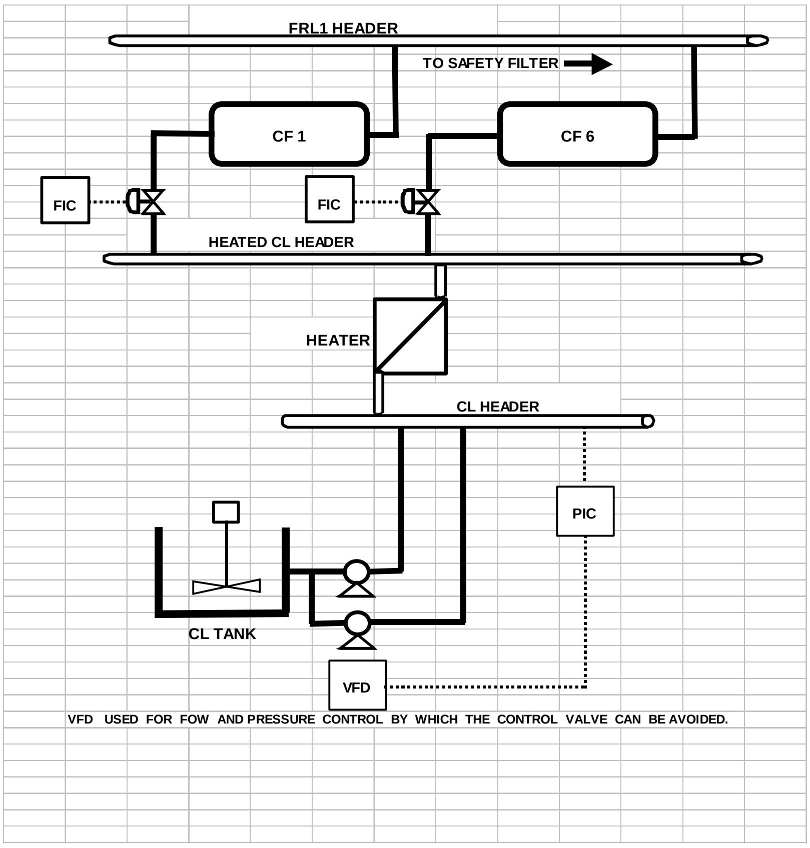

Fig. 15: Schematic of the Mechanical Vapor Compressor arrangement

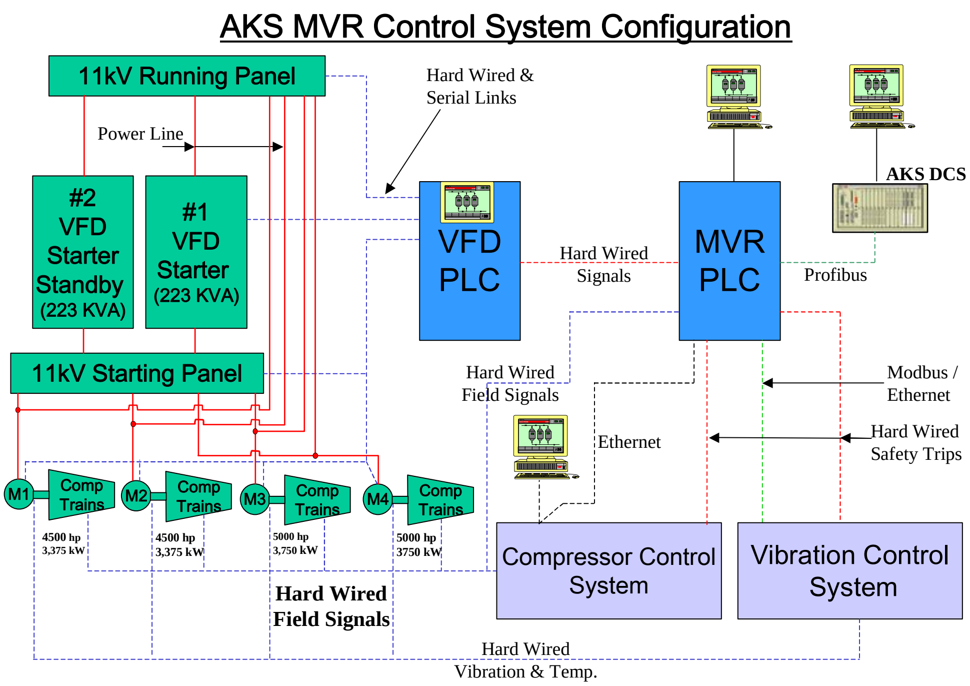

Fig. 16: Control system configuration for the Mechanical Vapor Compressors with VFD as soft-starting device