Detroit Contracting, Inc.

Variable Frequency Drive

Answers for Industry

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GENERAL DESCRIPTION

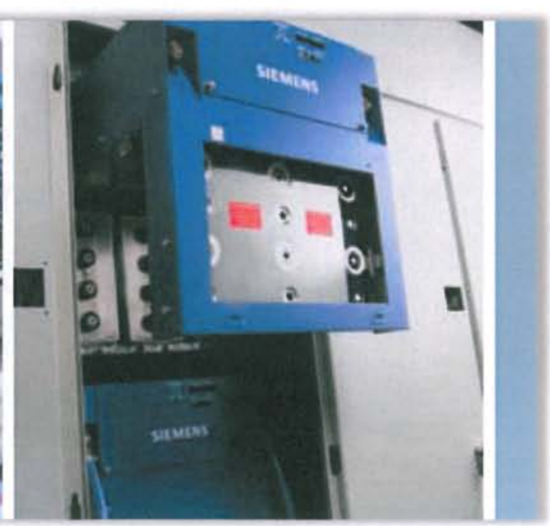
50% of the total electrical energy generated in the United States is used my rotating equipment. 65% of this total is consumed by centrifugal or flow related applications such as fans, blowers, compressors, and pumps .With using Variable Speed Drive technology the advantage gained in both productivity improvements and reduced energy consumption has been widely documented in the past few years. For example, by lowering fan or pump speed by 15% to 20%, shaft power can be reduced by as much as 30%. The main reason variable speed drives are used is to reduce energy costs and prolong the life of equipment by adjusting motor speed to meet load requirements. It's a series of a voltage cells are linked together to build and scaled precisely for a very wide range of voltage and output power- Low, Medium, High voltage power output of the drive system. Furthermore, the integral transformer with phase-shifted secondaries provides 18-pulse or better input harmonic cancellation with a power factor above 0.95 under any operation conditions. This eliminate the need to input harmonic filters or power factor compensation, while completely avoiding any common-mode voltages from being imposed on motor.

Figure 1 Medium-Voltage Converter

The quality of the output voltage is so close to perfect sine-wave shape that motors of literally any type- old or new, low–speed or high-speed – can be operated without any additional stress. Issues related to dV/dt, overheating and increased torsion vibrations are a thing of the past.
Also it can be described as:

1. *The AC Drive shall convert the input AC mains power to an adjustable frequency and voltage.*
2. *The input power section shall utilize a full wave bridge design. The rectifiers shall convert AC line Power of fixed voltage and frequency to fixed DC voltage.*
3. *The output power section shall change fixed DC voltage to adjustable frequency AC voltage.*
4. *The adjustable frequency NEMA (Type 1, 12, or 3R) drive package shall consist of a circuit Breaker disconnect, an optional 2- or 3-contactor bypass, 120 V control transformer, and control Circuit terminal board for digital and analog field wiring.*

The Hand-Off-Auto switch, Speed Potentiometer and Adjustable Frequency Controller-Off-Bypass Switch shall be mounted and wired to the drive door or located on the drive keypad.
The entire drive package, including the bypass starter circuit, shall be UL 508C listed and coordinated with NEMA ICS 7.1. A UL 508A panel builders label does not meet this specification.



WHAT IS THE VARIABLE FREQUENCY DRIVE

A variable frequency drive is an electronic controller that adjusts the speed of an electric motor by regulating the power being delivered. Variable-frequency drives provide continuous control, matching motor speed to the specific demands of the work being performed. Variable-frequency drives are an excellent choice for adjustable-speed drive users because they allow operators to fine-tune processes while reducing costs for energy and equipment maintenance. It is used to control the speed of a 3-phase motor all the way from stopped to full speed, and anywhere in between. They are used to control pumps, fans, conveyor belt drives, valves.

VFDs are usually installed to allow for better process control. The use of VFD is unfortunately not so straight forward. There are numerous technical aspects to take into account when designing a VFD controlled pumping system. The synchronous speed of an induction motor is primarily a function of the number of poles and the frequency:

$$n = 120 * \frac{frequency}{\#\, of\, poles}\ [rpm]$$

A slip between actual and synchronous speed is generated by the applied load torque. This slip is usually small, typically 1-3% of synchronous speed. A way to achieve a variable speed motor is to vary the frequency. Such a device is called a frequency converter. Frequency converters, also called variable speed drives, are usually installed to allow for a better process control and to save energy. The usage of variable frequency drive (VFD) control in pump applications is becoming increasingly common.

The cost of a VFD has decreased over the years while the performance has improved. A modern VFD is a compact, well-developed unit which is relatively easy to install.

Unlike an old VFD, the modern version does not require as much power margin (de-rating) and so does not affect the induction motor to the same extent; this is due to the fact that VFD switching frequency is higher today. The high switching frequency however, induces transients which can lead to other problems such as nuisance tripping of control equipment. This effect can be minimized by using shielded cables and appropriate filters. Despite the non-ideal VFD problems with clogging of the pump and sedimentation in pipe systems (due to low velocities) are more likely to occur when the speed of the pump is reduced.

Pumping with variable frequency drives can be separated into two cases.

1. *A variable continuous flow is required by the process. The normal way to control the flow is by throttling. The use of VFD control will, in all cases, lead to an energy reduction.*
2. *VFD vs. on/off regulation. Variable speed drive is used to reduce losses whilst pumping. The effect of a VFD depends upon the system. Systems with a high percentage of friction losses relative to the static head are suitable for VFD operation. More pure lift systems, on the other hand, are not generally suitable for variable operation. The frequency normally decreases when the speed is reduced and there is a risk that the pump will operate outside allowed operational range. A thorough system analysis has to be performed in order to determine if variable speed control can be economically beneficial. Waste-water pumping is a typical application where VFD and on/off control have to be compared.*

VFD BASIC PRINCIPLE

Single-speed drives start motors abruptly, subjecting the motor to high torque and current surges up to 10 times the full-load current. Variable frequency drives offer a soft start, gradually ramping up a Motor to operating speed. The variable frequency lessens mechanical and electrical stress on the motors and can reduce maintenance and repair costs and extend the motor life. Variable frequency drives also allows more control of processes such as water distribution, aeration and chemical feed. Wastewater treatment plants can consistently maintain desired dissolved oxygen concentrations by using automated controls to link dissolved oxygen sensors to variable

Frequency drives on the aeration blowers. Energy savings from variable-frequency drives can be significant. For example with centrifugal pumps even a small reduction in motor speed can reduce a pump's energy use by as much as 50%. For a 25 horse power motor running 23 hours per day (2 hours at 100% speed; 8 hours at 75%: 8 hours at 67%; and 5 hours at 50%) a variable frequency drives can reduce energy use by 45%. Because benefits vary depending on system variables it's important to calculate benefits for each application before specifying a variable Frequency drive. We have been discussing the cost saving variable frequency drive but we have not spoken about the cost of a variable frequency drive. Installed drives can range from about $3000 for a 5 horsepower motor to almost $45,000 for a custom-engineered 300 horsepower motor, and more for larger version. Installation can take from 10 to 70 labor-hours, depending on the system and the complexity of the system. However, payback for a variable frequency drive can range from just a few months to less than three years for a 25-250 horsepower models. Remember also they can drive more than one motor, so some costs can be consolidated. Savings from reduced maintenance and longer equipment life can significantly contribute to a rapid payback and long term saving. Many utilities offer financial incentives that can help reduce the installation cost of variable frequency drive.

A thorough understanding on how to match the variable frequency drive to the driven load is the key to a successful application. When applied properly, it is the most effective motor controller in the industry today. Variable frequency drives are affordable and reliable, and having flexibility of control, plus offering significant electrical savings through reducing electric bills.

Variable Frequency Drives are used in a wide variety of applications for various reasons. They are the most effective energy savers in pump and fan application. In most facilities, centrifugal pumps and fans run at one speed. An automatic value or some mechanical means varies fluid flow rates. With a variable frequency drive you can change motor speeds electronically. By being able to adjust a pump or fan speed to get the desired rate you can significant reduces energy cost.

Variable frequency drive has been successfully applied to large boiler feed water pumps in power plants, hot water circulation pumps in commercial buildings and for waste water treatment plants. Variable Frequency Drives provide soft-start capabilities, which decrease electrical stresses and line voltage sags associated with full voltage motor start-ups, especially when driving high-inertia loads. Variable-frequency drives are reliable, easy to operate, increase the degree of flow control, and reduce pump noise. But despite the benefits, problems are common and we should be aware of them.. Variable frequency drives can produce harmonic distortion, which adversely affecting power quality and other electrical machinery. Manufacturers have developed many solutions to correct this problem. By installing isolation transformer with a variable frequency drive can reduce distortion to an inconsequential level.

Applying a variable frequency drive to a specific application you need a clear understanding of the basic theory and should gain a working knowledge of the variable frequency drive. Our article on AC Variable Frequency Drive can give you this information and also discuss loads types, sizing and specifications.

THEORY

In theory the basic idea is simple; the process of transforming the line frequency to a variable frequency is basically made in two steps.

1. *Rectify the sine voltage to a DC-voltage.*
2. *Artificially recreate an AC-voltage with desired frequency. This is done by chopping the DC-voltage into small pulses approximating an ideal sine wave.*

A VFD consists basically of three blocks: the rectifier, the DC-link and the inverter.

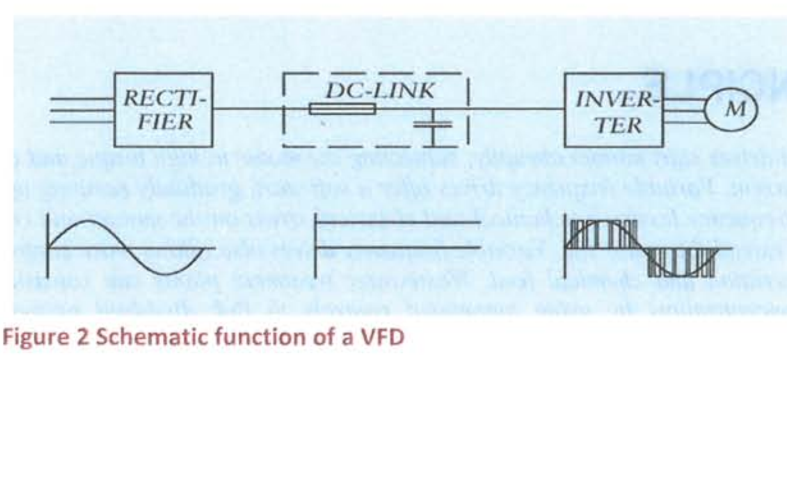


Figure 2 Schematic function of a VFD

There are three different types of VFDs:
- *VSI - Voltage Source Inverter, e.g. PWM.*
- *CSI - Current Source Inverter.*
- *Flux vector control.*

The CSI has a rough and simple design and is considered to be very reliable, but the output signal means a lot of noise. Furthermore the CSI induces high-voltage transients in the motor. The flux vector control is a more sophisticated type of VFD which is used in applications where the speed should be controlled very precisely, e.g. paper mills. This type is expensive and pump applications cannot take advantage of its benefits.

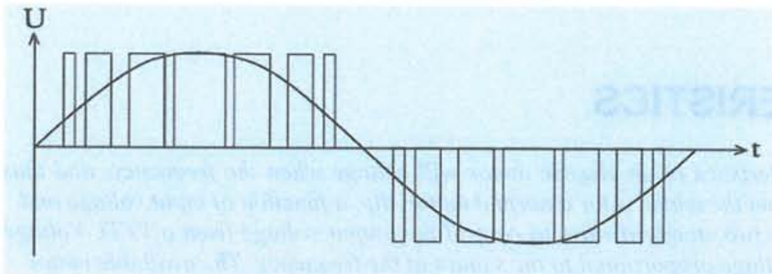


Figure 3 Schematic signal from a PWM-type VFD

The PWM-type VFD normally uses a constant voltage which is pulsed with integrated bi-polar power transistors (IGBT). The sine wave is generated by varying the width of the pulses. The frequency Which the transistors are turned on and off by, is called switching frequency, The higher the switching frequency, the better the reproduction of the ideal sine wave. Electric motors consume about 63% of the electricity used in US manufacturing. They are the main force in most commercial buildings, industrial facilities, and appliances. In the United States reducing energy consumption has become a priority and businesses are seeking solutions to help them save energy. Some of these technologies to reducing consumption of energy is a Variable Frequency Drive which we have discuss on this site. Another method is the use of a Soft Starter. A soft start Drive starts the motor at a lower voltage, slowly ramping up to operation voltage.

Typical Applications

VFD is used in many sewer pumping applications, water treatments plants, water main control gate and butterfly valves, retrofit, power generation plants, oil and gas refineries, pulp/paper factories and anywhere a motor needs to be controlled to a precise speed other than the normal nameplate full speed, or where the speed needs to change to meet different operating conditions with the intention of saving energy. Not every pump or motor application will benefit from VFD control. The only way to determine if VFD is the correct choice is to do a thorough analysis. The system characteristics determine if VFD control is economically motivated or not.

MOTOR CHARACTERISTICS

The characteristics of an electric motor will change when the frequency, and thus the speed, is reduced. The output torque from the motor is for a normal motor slip, a function of input voltage and frequency. There are two standard ways to control the output voltage from a VFD. Voltage that is proportional to the frequency and voltage proportional to the square of the frequency. The available motor Torque remains constant when the frequency is reduced, if a VFD with an output voltage proportional to the frequency is used. Having voltage proportional to the square of the frequency implies that torque is proportional to the square of frequency A pump represents a cubical load, the load curve is shown in fig 4.

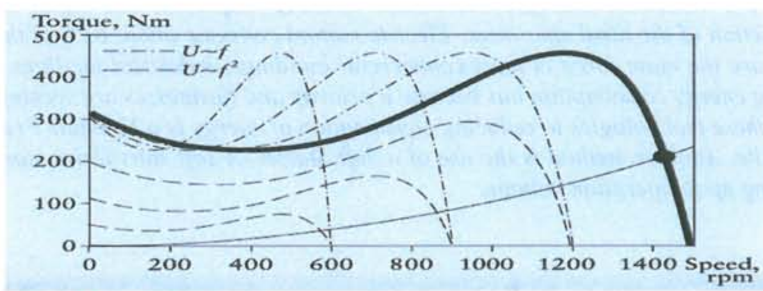


Figure 4 Motor Duty-Point Movements

The diagram shows how the duty point, the intersection between the motor torque curve and load curve, moves down on the right flank of the torque curve for U~f when the frequency is reduced. The duty point at nominal frequency is somewhere in the middle of the right-hand flank, whereas the duty point at 20 Hz is almost at the end. This means that the slip will change when the frequency is reduced. The efficiency of the motor is related to the slip, and the efficiency of the motor will drop even though the

Hydraulic (pump) efficiency remains constant. The motor efficiency curve will also change when the Frequency is reduced. It can be seen from fig 9 that the relative position of the duty point on the right flank is relatively constant when having the voltage proportional to the square of the frequency. I.e. the slip and hence the motor efficiency will not change so much. A voltage proportional to the square of the frequency is recommended for pump applications in order to maintain both motor efficiency and the correct magnetization level.

VFD INFLUENCE ON INDUCTION MOTORS

An induction motor feels most comfortable when it is supplied from a pure sine voltage source which mostly is the case with a strong commercial supply grid. In a perfect motor there are no harmonics *in the flux and the losses are kept low. When a motor is connected to a VFD it will be supplied with a non-sinusoidal voltage, this signal is more like a chopped square voltage. A square shaped signal contains all orders of harmonics. As these harmonics will induce additional heat losses that may require the induction motor to be de-rated, a margin between maximum output power and nominal-rated output power is required. The required power margin depends upon the application and the supplied equipment. When in doubt contact the local Flygt engineering office for details.*

The performance of the VFDs has improved over the years and is still improving, and the output signal is looking more and more like an ideal sine wave. This implies that a modern VFD with high switching frequency can run with a low or no power margin whatsoever, while an old one might need a margin of 15%. Unfortunately the extensive work needed to develop VFDs' ability to reduce losses in the motor and in the VFD, tends to emphasize other problem areas. VFDs with high switching frequency tend to be more aggressive on the stator insulation. A high switching frequency implies short rise time for the pulses which leads to steep voltage transients in the windings. These transients stress the insulation material. We recommend reinforced stator insulation for voltages 500 V and above. This problem can also be solved partially by adding an output filter to the VFD. See section "Noise suppression" for more details.

The Advantages Of Soft Starts

1. *Reduced wear on mechanical gears, chains and sprockets, and unexpected repair of broken belts and jammed gearboxes.*
2. *Lower inventory of spare mechanical parts and operating costs.*
3. *Increased production rates by reducing machine maintenance downtime.*
4. *Prolonged life of electrical switchgear with lower inrush currents.*
5. *Soft stops on pumping applications reduce piping system stresses and "hammer" effect.*
6. *Energy optimizing reduces motor energy losses when operating motor below maximum capacity.*

SIZING CRITERIA

The data needed to determine the correct size of a VFD are:

1. *Motor KVA rating.*
2. *Nominal voltage*
3. *Rated current*
4. *Ratio max. torque/nom. torque*

If the ratio between peak torque and nominal torque, Tp/Tn, is greater than 2.9 it might be necessary to choose a larger VFD. There are basically two reasons why a motor can have a ratio greater than 2.9:

1. *The motor has a high magnetization level*
2. *The motor has been de-rated.*

Cost Efficiency

A modern VFD is a compact, well-developed unit which is relatively easy to install. The cost of a VFD has decreased over the years while the performance has improved. The VFD can be a perfect harmony in Synch with your Business Goals

- *Lower operation coast*
- *Precise process control*
- *Increased production efficiency*

- *Exceptional reliability*
- *Intuitive*

VFD COOLING SYSTEM

There are four cooling systems available for a pump:

1. *Cooling by surrounding media, water/air.*
2. *Integrated cooling. Water is pumped through a cooling jacket with back vanes on the impeller. The water flows with rotation in the cooling jacket which surrounds the stator house, e.g. medium and large C pumps.*
3. *Axial-flow cooling. The motor is cooled by the pumped media, the water flows along the outside of the stator house, e.g.*
4. *External cooling.*

The integrated cooling system of larger pumps has many advantages. One restriction however is that the pump must not run at too low speeds unless it's working in clear water. The cooling is adequate, but sediment may accumulate and the risk of clogging in the cooling system is higher when the speed is reduced. When the pump is sped up again and retains nominal speed, the efficiency of the cooling system is lower and the motor can overheat. The critical minimum speed is different for different pumps, but a rule of thumb is that no adverse effects are likely to occur for speeds higher than 35 Hz for 2- and 4-pole machines, and 40 Hz for higher pole numbers. Another restriction is that the speed of the pump must not be too low when it's started for the first time after service –or a longer stop. This is due to the fact that all air in the cooling jacket has to be evacuated.

Axial-flow cooling efficiency decreases rapidly when the flow goes down. The cooling efficiency is not a function of speed, it's a function of flow and the flow is dependent upon the system characteristics. Axial-flow pumps are often installed in lift systems and are therefore not suitable for operation with variable speed drive. Pumps cooled with surrounding media and pumps with external cooling are generally not affected by VFD duty. The thermo-contacts should always be connected regardless of whether the pump is VFD-controlled or not.

CLOGGING

Waste-water pumping stations are in general designed for peak flows which occur approx. 5 % or less of the time. Pumps operated on VFDs run at reduced speed almost all the time. Lower flows result in lower velocities in the sump and a higher risk for sedimentation. Sizeable clusters of large particles may build up in the sump. Eventually they will break loose and may cause clogging in the impeller. The risk of logging is generally higher in dry installed pumps. Sedimentation may build up in the inlet pipe; large solid particles can easily get stuck in the 90° inlet bend leading into the pump.

When running at reduced speeds, the available energy for the impeller to keep itself from clogging decreases rapidly. Available energy in the impeller is proportional to the square of speed.
The available impeller energy will drop 75% when the speed is reduced from nominal speed to half speed (see equation). The distance from the leading edge of the impeller or propeller blades to the point where the flow becomes turbulent, will increase when the pump is running at reduced speed. This fact increases the risk of catching long fibrous materials on the leading edge. The pump is less effective in

$$T = \frac{I_p \bullet \omega_2}{2}$$

Where:

T= Energy
Ip = Polar moment
ω= speed [rad/s]

carrying away solids and clogging materials, when the velocity of the liquid is decreased. Long fibrous materials are more likely to catch on vanes when the velocity of the pumped media is low. The rapid acceleration at start-up of on/off controlled pumps, effectively removes initial clogging in the pump. There is also a natural back flush when the pump stops, which prevents clogging. VFD-controlled pumps are, as mentioned above, seldom running at full speed. They are often running continuously and cannot gain from the on/off controlled pumps' benefits. This can be handled by adding a cleaning sequence 1-2 times per hour, where the pumps start and stop at full speed a couple of times. It is important that the ramping time at start and stop is short. When running multiple pumps in continuous duty, it is possible that one particular pump handles the small flows and runs almost all the time with reduced speed. The risk for clogging and sedimentation is higher for this pump. This can be avoided by alternation of the pumps.

VIBRATIONS

Pumps running with variable frequency drives excite a broader range of frequencies. The probability of exciting one of the system's natural frequencies increases when running pumps with variable speed drives. This can lead to problems with vibrations and noise, especially in stations with dry installed pumps. If one of the system's natural frequencies is in the duty range of the VFD, this frequency can be blocked in the VFD control unit. Most modern VFDs have this blocking function. Some pump curves are dashed at low flows (close to shut-off head). Running the pumps in this area can cause vibration problems.

Get up
And
Running Fast

Factory System Test

You can be confident that the VFD will get your process up and running because we have the ability to test every product as a complete system at full load – prior to delivery. At our factory, we test every Transformer and power converter together to ensure performance meets precise specifications. In addition, factory testing allows accurate efficiency measurements.

Easy Setup and Control

- *Easy-to-use high-function keypad on the door*
- *Touch-screen interface on door also available*
- *Auto-tune feature shortens start-up and guarantees operational efficiency*
- *Drive tool runs on PCs that can interface through the RS 485 or Ethernet ports that are standard*
- *Other protocols supported:*

    - *Modbus Plus™*
    - *DeviceNet Profile 12™*
    - *ControlNet™*
    - *PROFIBUS DP™*

Other connectivity as required by the user options adds versatility to your VFD drive. It is available with forced-air cooling (left) or self-contained, closed-loop, water cooling (far left). Redundant pumps are Standard on water-cooled units. Redundant blowers are a standard option for air-cooled units. The multi-cell design allows quick rack in/ out of power cells, making maintenance of the supplying company simple. A hydraulic "cell lifter cart" is an option for larger cell designs.

Codes

1. *ANSI®/NFPA® 70 - National Electrical Code® (NEC®)*
2. *UL 508 - UL Standard for Industrial Control Equipment*
3. *UL 508C - UL Standard for Power Conversion Equipment*
4. *NEMA ICS 7.1*

Technical Aspects To be Consider

1. *Clogging: VFD-controlled pumps often run at reduced speeds, which mean that the energy available for the impeller to keep itself from clogging also is reduced. Therefore it is recommended to control the pumps in a way that long periods of running the pumps at low frequencies are avoided, especially in tough sewage applications.*
2. *Sedimentation in pipes: Avoid running at low frequencies that will result in velocities in the pipes lower than 0.7 meters per second to minimize the risk of having sedimentation*
3. *Nuisance tripping: The high-frequency emission from a VFD can interfere with sensor control systems and other equipment. The use of shielded cables and appropriate filters are therefore recommended.*
4. *NPSH/power limit problems: The VFD does not directly have an impact on the NPSH required of a pump. However, decreasing speed with a VFD will in many cases significantly change the duty point for the pump. The new duty point could be at a position on the pumps performance curve where the NPSH required is much higher than at the duty point at full speed.*

References And Recommended Manufacturers

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4. *SIEMENS AG Industry Sector* *{HYPERLINK "http://www.siemens.com/robicon-perfect-harmony"}*
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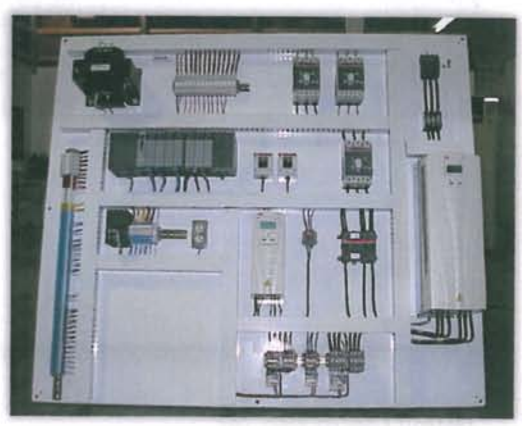

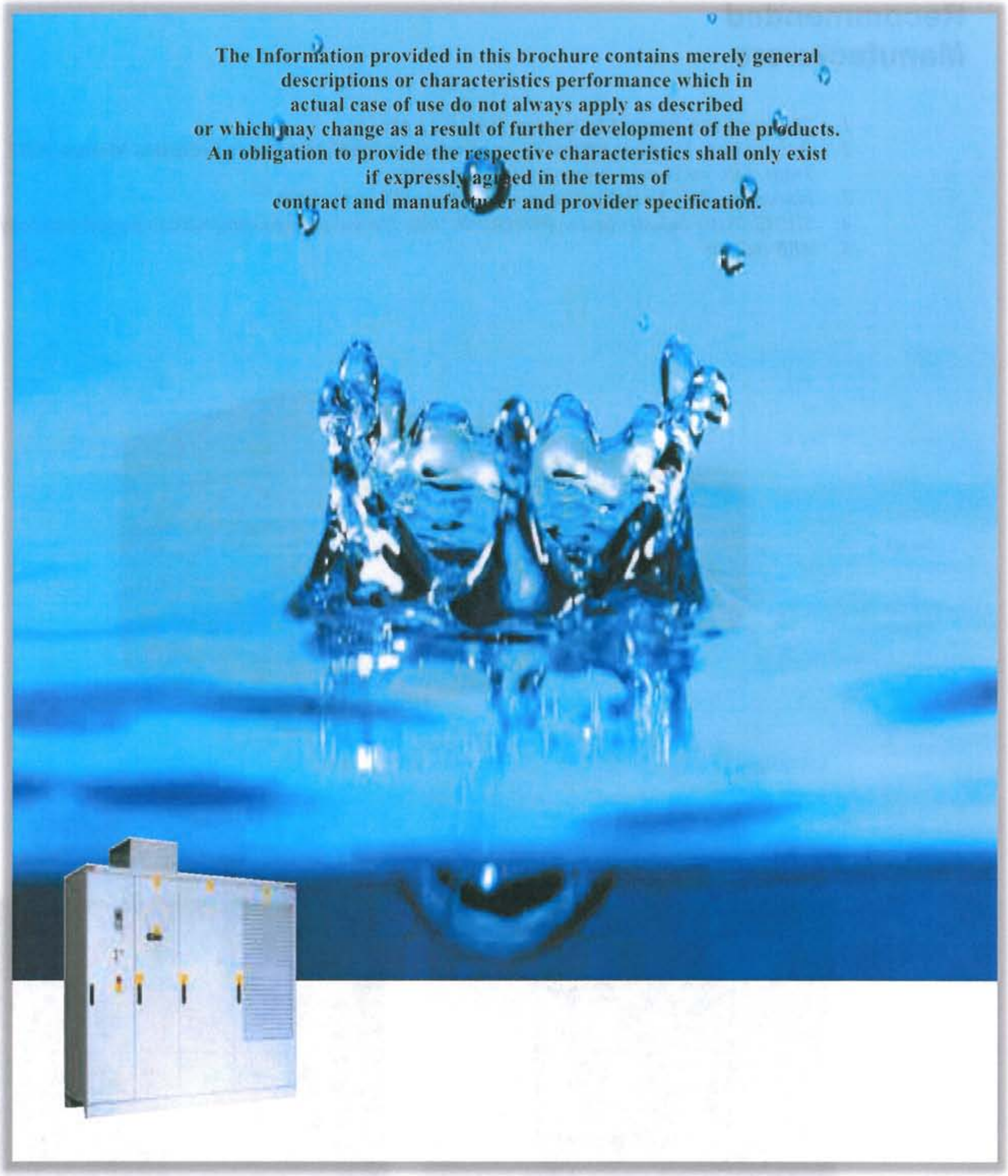

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