SAN ANTONIO
4729 Shavano Oak, San Antonio, TX 78249-4020
210/ 492-4200 800/ 229-8965 FAX 210/ 492-4280
http://www.vfd.com

Using Variable Frequency Drives on Pump Systems

Variable Frequency Drives (VFDs) on pumps offer many advantages over traditional methods when it comes to constant pressure control. They cost less than water towers, offer precise pressure control, reduce water leakage, increase pump life and save energy.

Traditionally, water towers or ground/ underground reservoirs equipped with pumps are used for water storage and maintaining pressure in the distribution systems. Mechanical devices such as control valves are used to regulate pressure. These methods have disadvantages when it comes to operation, flexibility and energy consumption. Water towers can be an expensive choice when it comes to maintenance and system upgrades. Selecting the wrong control valves can significantly reduce pump efficiencies and could lead to routine maintenance problems. With the proper design, VFD technology offers solutions to these problems.

A VFD is an electronic controller that adjusts the speed of an electric motor by modulating the power being delivered. VFD and pump combinations maintain a constant pressure in the system by taking 4-20 mA signal from a pressure transmitter and adjusting motor output according to the feedback requirements. VFDs overcome the disadvantages of traditional methods mentioned earlier and offer many benefits-increased pump life, precise pressure control, reduced water leakage, easy upgradability and energy savings.

Factors Influencing the Water Distribution System

- Pressure Fluctuations
  Maintaining sufficient pressure in the water distribution network is vital for a drinking water supply. Pressure in a water distribution system is affected by numerous factors-water consumption during the day and night, seasonal changes, age of the piping network and topography, to mention a few. A reliable pressure control system is vital for a distribution network.

- Water Leakage
  Water leakage (also called Non-Revenue Water [NRW]) from a distribution system makes a significant impact on the water management. Water leakage can account anywhere from 10% to over 50% of the total volume treated for supply. Excessive pressures and/or pressure fluctuations in the distribution system can be a major contributor. This is shown well Figure 2, which illustrates water leakage at a given pressure through 1 mm (0.04"), 2 mm (0.08"), 4 mm (0.16") and 6 mm (0.24") diameter holes. The plot suggests that reducing pressures whenever possible could lead to significant reduction in water leakage. Reducing pressure during non-peak hours or at night is a good example.

- Water hammer
  Another major factor of the distribution network is the waterhammer or transient internal pressure due to stoppage of flow caused by an abrupt closing of a valve or halting of a pump. This will have a significant impact on pumps, check valves and the piping network.

- Other Factors
  Consider the operation and maintenance costs, system upgrades, system closures and the water quality. The following paragraphs compare the traditional methods and how VFDs in combination with pumps help to optimize the distribution system.

Water Towers

- Beware of the Costs
  Water towers have been a good choice for many decades. They have proven very dependable during power outages and provide an abundant storage capacity. However, their disadvantages are equally well recognized during renovations and upgrades-the tower has to be taken off-line, massive supporting structure for accessibility of the exterior tank installed, OSHA requirements for interior cleaning complied with, to mention a few. Last but not least, the tower demolition charges can be significant.

- Pressure Control
  Changing pressure set points is a problem. Water towers provide a constant pressure in the distribution system determined by one factor: the height of the water column. The system requires 2.31 feet of the water column to generate one psi of pressure. Water towers give marginal flexibility in changing the system pressures for leakage control and/or for future needs. Typically, the water level variations (Dh) can only be a fraction of the static head (H).

  As an example, a 500,000 gallon capacity spheroid with dimensions of 55’6" diameter and a head range of 37’6" is selected for comparison. Using these dimensions, the required height of the tower to maintain a pressure of 90 psi at high water level (HWL) is approximately 208’ (90 x 2.31). Assuming Dh can be varied between a low water level (LWL) of 20’0" and 37’6" (HWL), the pressure reduction at LWL is calculated to be 7.6 psi (8%).

- Water Leakage-Difficult to Lower Pressures
  Reducing water leakage by lowering system pressures in water towers is difficult. The majority of towers are filled to the maximum capacity at night so that they can meet the water demand during the day. Because of this, the water leakage will be higher at night and tend to decrease during the day.

  An option is to install leak detection systems and implement leak prevention methods throughout the distribution network. This, however, leads to significant O&M costs.

- Cost Comparison with VFD
  According a recent survey, the cost comparisons between a water tower of 500,000 gallon capacity and the alternate option, a ground level storage tank and pumps equipped with VFDs of equivalent capacity are:

  Storage tanks with VFDs have installation costs 42% lower than water towers and a significant reduction in O&M costs-77% less than water towers. The cost savings over the life cycle of an average water tower (60 years) is 61%. The survey assumes that VFDs are replaced every ten years and the associated costs are accounted under O&M costs. The survey also includes the installation of a back-up generator for a VFD option during power failures

- Storage Tanks and Pump Systems
  Choosing pressure controlling devices can be tricky. As an alternative to water towers, underground or above ground storage tanks with pumps are used. While tanks give enough storage capacity, pumps provide pressure to the distribution network. The pressure in the system fluctuates constantly-it decreases as the water consumption increases and increases substantially during the night if proper pressure controlling methods are not used.

- Pressure Control
  In a conventional pumping system, one or more pumps are operated at all times based on a predetermined pressure value (Psetpoint) that is selected to meet the peak water demand. At other times, Psetpoint will lead to excess pressures in the distribution system as the water usage reduces overnight. An improvement to the conventional pumping system is sending the feedback signal from the pressure transmitter to the pumps. The pump(s) will be turned on and off by a programmable logic controller (PLC) according to the pressure variations. Although this is an improvement, there are some drawbacks with this arrangement. The frequent on of pumps will draw the current abruptly each time the pump(s) starts, subjecting the motor to high in-rush current six to ten times the full-load current. The frequent on-off operation will lead to waterhammer problems. This results in high energy costs and reduced equipment life. The following sections discuss VFD technology and the advantages of using it for constant pressure control in a distribution network.

  Application - Pressure Control
  VFDs are added to the pumps, forcing water into the distribution network. The pressure in the lines can be manually controlled by a potentiometer on the drives for applications with minimal pressure fluctuations. For a system with highly variable pressure fluctuations, VFDs are connected to the pressure transmitter to receive 4-20mA signal monitoring the pressure fluctuations. The internal controller (Proportional and Integral Control, PIC) of the VFD

monitors the pressure fluctuations and adjusts the motor output to maintain the pressure closer to the set point. As discharge pressure drops, the pump speed is increased to increase the pressure; conversely, when the pressure rises, the PI controller of the VFD decreases pump speed. When properly tuned, this type of control system has the ability to maintain the pressure within 1 psi. An improvement to the conventional pumping system is sending the feedback signal from the pressure transmitter to the pumps. The pump(s) will be turned on and off by a programmable logic controller (PLC) according to the pressure variations. Although this is an improvement, there are some drawbacks with this arrangement. The frequent on of pumps will draw the current abruptly each time the pump(s) starts, subjecting the motor to high in-rush current six to ten times the full-load current. The frequent on-off operation will lead to waterhammer problems. This results in high energy costs and reduced equipment life.

Other Benefits

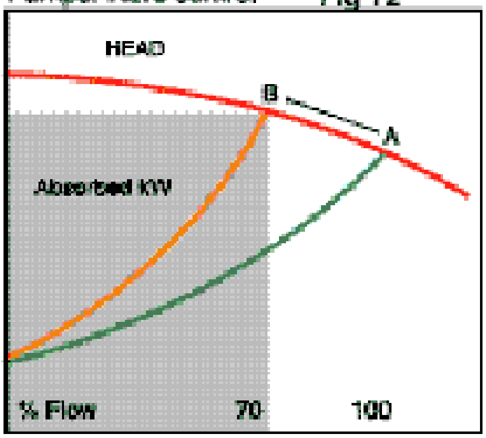
- Reduced Water Leakage
  Dual set points reduce water leakage. The water leakage in a distribution system is proportional to the pressure maintained in the system. Maintaining a constant pressure set point to meet the peak demands will lead to substantial water leakage.

- Eliminate Waterhammer
  The ramp up/down features of a VFD eliminate pressure surges. Waterhammer caused by hydraulic surges can be easily controlled using VFD technology. The properly programmed VFD system will start and stop pumps on a ramped or timed basis. The slow starting and stopping of a pump, coupled with varying the speed to maintain predetermined discharge pressure, can virtually eliminate hydraulic surges in the system, preventing waterhammer.

VFD vs. Control Valves

- VFDs offer cost savings by more efficient use of power and pump speed. The use of control valves on pumps has been popular as a way of controlling pressure in a distribution system despite their disadvantages. The control valve modulates, controlling pressure while the motor and pump run at 100% speed and develop about 5 to 8 psi head loss from inlet to outlet. As the valve ages, this head loss increases, causing pump efficiency to decline and leading to frequent valve failures.

Pumps: Valve control Fig 12



Pumps: Speed control Fig 13

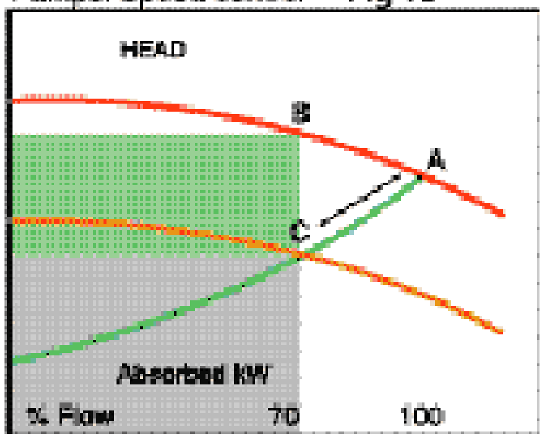
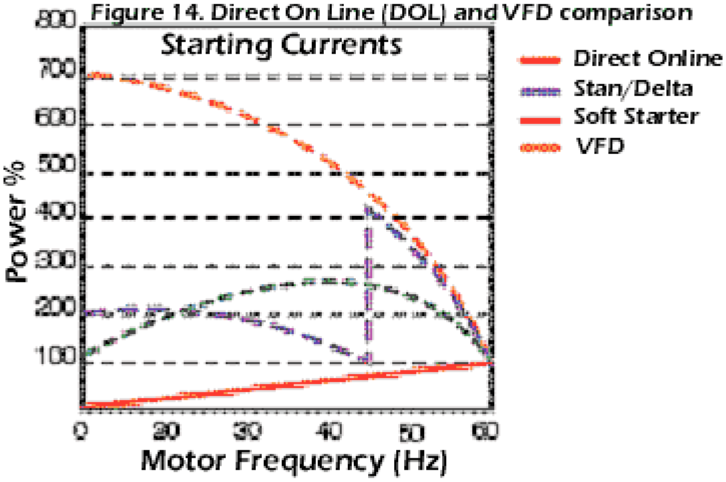


Figure 14. Direct On Line (DOL) and VFD comparison



VFDs offer many advantages over control valves, ranging from pressure control to energy savings. Varying the speed of the pump over the course of the day, to better match actual energy input demands to meet the system demands, can produce significant energy savings. Figures 1.2 and 1.3 show the pump curves depicting the distinct comparison of energy savings. The drawbacks of using the control valves for constant pressure are frequent valve failures that could lower pump efficiencies.

High Starting Currents

The power in-rush currents at the time of starting a pump are referred to as Direct On Line (DOL) currents. They typically range from 6 to 10 times its nominal current (Figure 1.4).

Several utility companies penalize pump users by charging under maximum demand charges. The high starting currents can be controlled by "soft starters" to some extent. VFDs eliminate the problem by starting the current at zero and raising it as the load is accelerated with no danger of exceeding full load current. This would cut the electrical charges, significantly eliminating the maximum demand charges and even in some cases qualify pump users for subsidies from utility companies.

Variable Frequency Drive (Low Voltage of below 600VAC)

- Principle
  Drives range in size from 3 hp through 800 hp. Although the sizes of these units vary, there are key components that can be common to all drives. These components include the following:

- Input power connectors
- Input power fuses
- Input line reactor
- Input rectifier circuit
- Input precharge SCR
- DC bus capacitors
- Microprocessor board
- Keypad display module
- Gate drive/interface board
- Power IGBT modules
- Output power connectors

An electrical diagram of the 6 pulse standard drive is illustrated in Figure 0-1. The drive consists of three main components: the converter portion, the DC Bus and the inverter portion. The converter or rectifier circuit converts the input AC fixed frequency fixed voltage source into a fixed DC bus voltage. The DC bus or link is composed of a large bank of electrolytic capacitors used to filter out the associated line ripple and store this energy for use by the output IGBTs. These IGBTs are controlled to convert the DC voltage into a 3 phase output that varies in frequency and voltage. This drive output is then used to control the speed of the connected motor.

SAN ANTONIO
4729 Shavano Oak, San Antonio, TX 78249-4020
210/ 492-4200 800/ 229-8965   FAX 210/ 492-4280
http://www.vfd.com

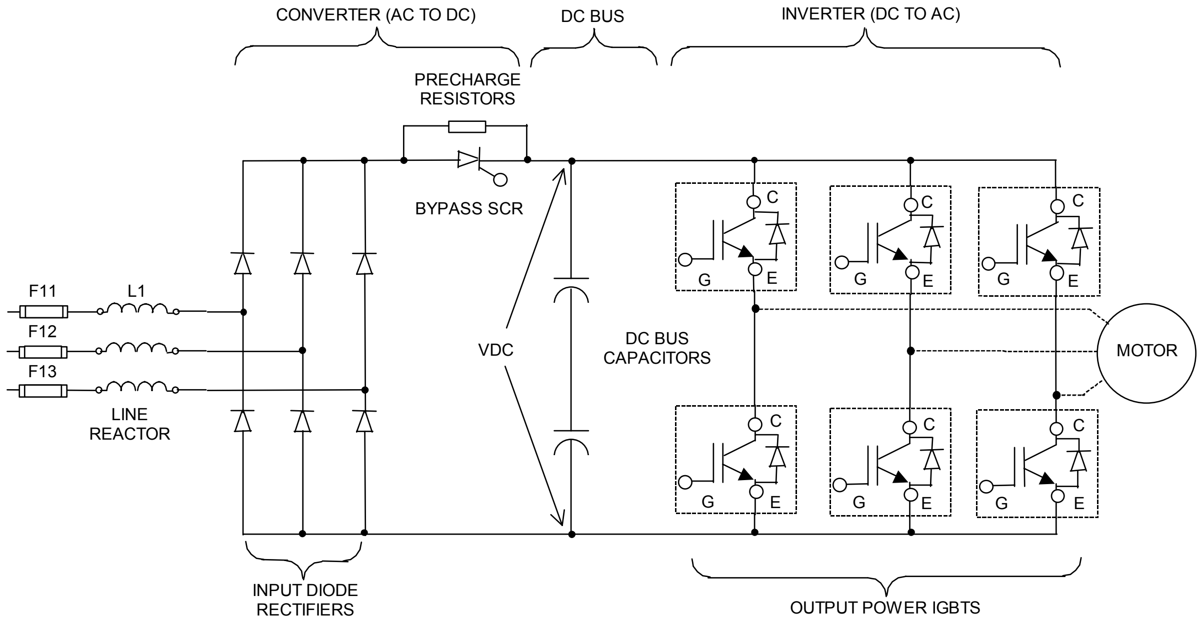


Figure 0-1. Power Schematic of the Standard (6-pulse)

In applications where input harmonics are required to be compliant with IEEE 519-1992 an 18-pulse (clean power) option is available. The input rectifier or converter portion is expanded from the standard 6-pulse to an 18-pulse section with the use of a patented 18-pulse autotransformer. External and internal views of a typical 18-pulse GT drive are shown in Figure 0-2. The power schematic of the 18-pulse is shown in Figure 0-3.

HOUSTON
One Park Ten Place, Suite 110
Houston, TX 77084
281/ 492-7090   888/ 492-7090
FAX 281/ 492-6994
http://www.vfd.com

AUSTIN
13740 Research Blvd., Unit L-8, Suite C
Austin, TX 78750
512/ 257-9435   888/ 257-9435
FAX 512/ 257-9437
http://www.vfd.com

Figure 0-2. External and Internal Photos of a Typical GT Drive

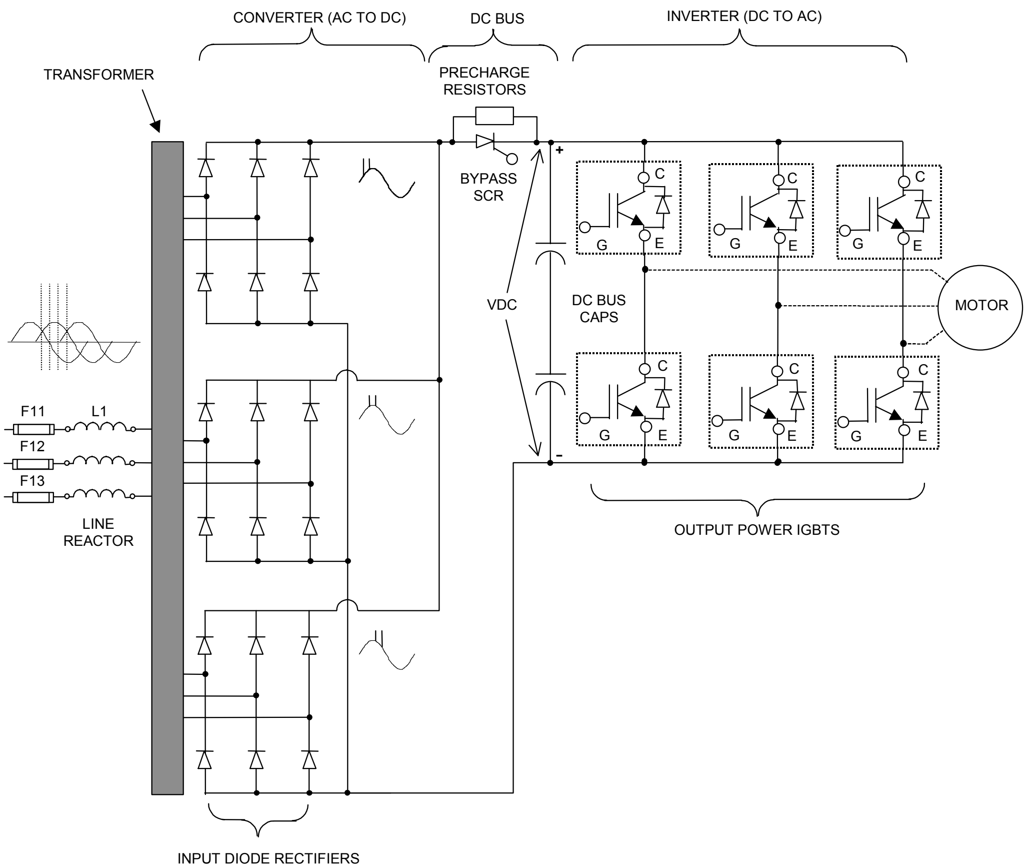


Figure 0-3. Power Schematic of the Clean Power (18-pulse)

The effect of varying the frequency is essentially the same as the effect of varying the speed. If the speed of a pump is changed, the flow, head and power will change according to the affinity laws. The laws state that the flow is proportional to the speed, and the head (pressure) is proportional to the square of the speed. The shaft power is proportional to the cube of the speed. Therefore, a reduction of 10% in speed will give 27% energy savings.

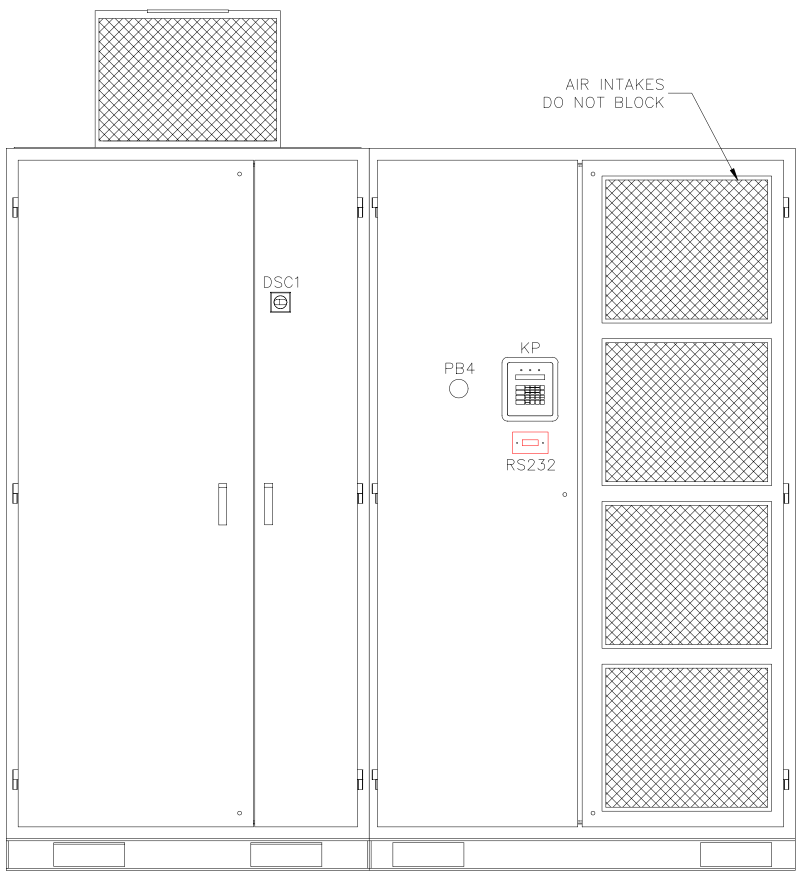
SAN ANTONIO
4729 Shavano Oak, San Antonio, TX 78249-4020
210/ 492-4200 800/ 229-8965 FAX 210/ 492-4280
http://www.vfd.com

Variable Frequency Drive (Medium Voltage)

Perfect Harmony is a series of pulse-width modulated, variable frequency AC motor drives designed and manufactured by ROBICON. The Perfect Harmony drive system addresses the following power quality issues:

- providing clean power input
- providing a high power factor
- providing nearly perfect sinusoidal output.

Illustration of a typical drive system.



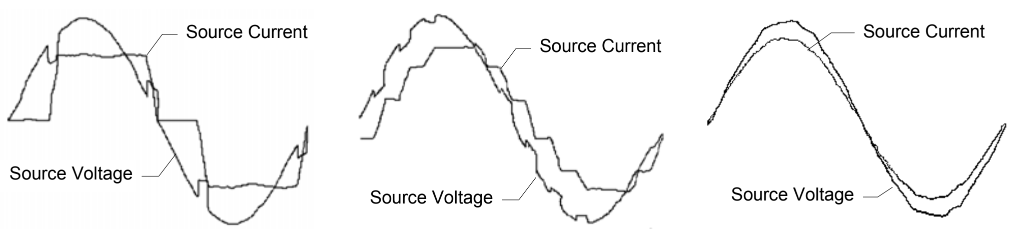
HOUSTON
One Park Ten Place, Suite 110
Houston, TX 77084
281/ 492-7090 888/ 492-7090
FAX 281/ 492-6994
http://www.vfd.com

AUSTIN
13740 Research Blvd., Unit L-8, Suite C
Austin, TX 78750
512/ 257-9435 888/ 257-9435
FAX 512/ 257-9437
http://www.vfd.com

The Perfect Harmony drive series meets the most stringent IEEE 519 1992 requirements for voltage and current harmonic distortion, even if the source capacity is no larger than the drive rating. This series protects other on-line equipment (such as computers, telephones, and lighting ballasts) from harmonic disturbances. Perfect Harmony also prevents “cross talk” with other variable speed drives. Clean power input eliminates the need for time-consuming harmonic/resonance analyses and costly harmonic filters. The illustration below input wave forms for typical 6-pulse, 12-pulse and Perfect Harmony series drives.

Total harmonic distortion of the source current is 25% for the 6-pulse, 8.8% for the 12-pulse, and 0.8% for the Perfect Harmony series drive. The corresponding voltage distortions with a typical source impedance are 10%, 5.9% and 1.2%, respectively.

> The above comparisons were done using a typical 1,000 hp current source drive (6-pulse and 12-pulse modes) and a Perfect Harmony series drive operating from a 1100 kVA, 5.75% impedance source.



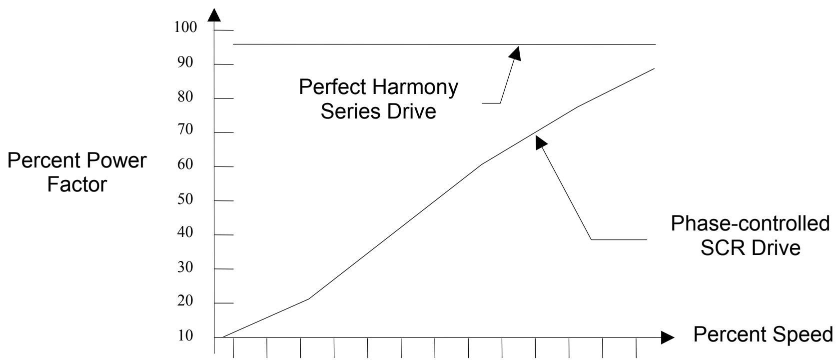
Typical 6-pulse Input Wave Form **Typical 12-pulse Input Wave Form** **Perfect Harmony Input Wave Form**

Figure 0-4. Harmonic Distortion Wave Form Comparisons

0.0.1. High Power Factor, Nearly Perfect Sinusoidal Input Currents

Power factor is a measure of the fraction of current which produces real power to the load. Typically, power factor is given as a percentage. A high power factor VFD (e.g., 95%) makes much better use of its input line current demand in producing real power to the motor than a VFD operating at a low power factor (e.g., 30%). VFD’s having low operating power factor often generate square-wave shaped line currents. This can lead to harmonics and other associated resonance problems.

The Perfect Harmony series draws nearly perfect sinusoidal input currents having a power factor that exceeds 95% throughout the entire speed range without the use of external power factor correction capacitors. This eliminates utility penalties for power factor and demand charges, and improves voltage regulation. In addition, feeders, breakers and transformers are not overloaded with reactive power. Low speed applications specifically benefit from the Perfect Harmony series since a high and stable power factor is maintained throughout the entire speed range using standard induction motors. The illustration below compares graphs of power factor versus percent speed for the Perfect Harmony series and a typical phase-controlled SCR drive.



2027334047 53 606773 80 87 93 100

Figure 0-5. Power Factor vs. Percent Speed Comparison

0.0.2. Nearly Perfect Sinusoidal Output Voltages

The design of the Perfect Harmony series of variable frequency drives inherently provides a sinusoidal output without the use of external output filters. This means that the drive provides a low distortion output voltage wave form that generates no appreciable audible motor noise. In addition, there is no need to derate motors (the drive can be applied to new or existing 1.0 service factor motors). In fact, Perfect Harmony drives eliminate harmful VFD-induced harmonics which cause motor heating. Similarly, VFD-induced torque pulsations are eliminated (even at low speeds), thereby reducing the stress on mechanical equipment. Common mode voltage stress and dV/dt stress are also minimized. A typical graph of the output current from a Perfect Harmony drive is illustrated below.

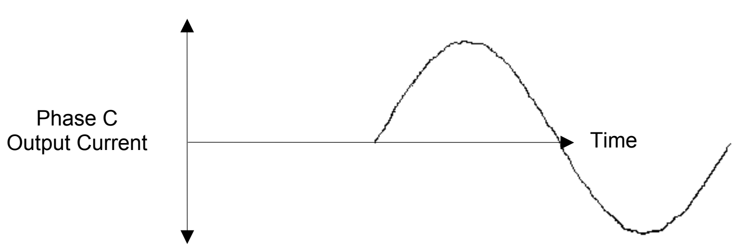


Figure 0-6. Nearly Sinusoidal Wave Form of Perfect Harmony Output Current

Some Things To Consider when Specifying a VFD

For a successful VFD installation and operation, choosing a suitable VFD manufacturer is difficult. The following are the factors to consider before selecting a vendor.

- Motor Cable Length
  VFD manufacturers publish a maximum cable length between the VFD and the motor to avoid the risk of stressing the motor and overheating the VFD. Many manufacturers offer output AC reactors to extend their product's published maximum length. To avoid this additional cost and voltage loss, look for a VFD with long standard (no additional filters needed) maximum cable length specifications.

- Power Factor
  The power factor of a VFD is an indicator of the harmonic currents that are generated by that unit. VFDs with a true displacement power factor of 0.90-1.00 have added filtration to their equipment to correct the effects of harmonics such as transformer heating and disturbance of sensitive metering equipment.

- Enclosure Ratings
  In existing plants, the layout of the control room may limit the application of VFDs. Under such circumstances, VFDs covered by NEMA 12 (typical for water/wastewater plants) enclosures can be installed next to the equipment.

- Multiple Motor Operation
  In some circumstances, it may be ideal to run several equal hp motors from one VFD. When one or more of the motors is switched on or off, excess energy flows back to the output of the VFD and can damage the unit. For this type of application, look for a manufacturer that has no limit to this type of switching but no additional isolation equipment.

- Software Enhancements
  There are some beneficial enhancements to VFDs for the water industry that are worth checking into. For instance, your application might require a constant torque start to overcome head pressure. A VFD that has load loss protection will shut down your motor if a coupling fails. Another desirable feature might be an internal PID controller to the VFD that takes two analog feedbacks and evaluates data to produce one of two established set-points.

- Protective Features
  Due to the nature of the technology, VFDs generate transients such as Radio Frequency Interference (RFI), voltage rise per time (dV/dt), high peak voltage and harmonics onto the AC line and motor cables. These transients can affect surrounding sensitive equipment (such as computers and monitoring equipment) and reduce motor life. Check with your supplier for RFI filters as well as built-in reactors that can reduce these effects.

- Serial Communication
  Some VFD manufacturers do not include an RS-485/-232 port as standard, so watch out for extra cost. Also, be sure your supplier provides the protocol needed in your application. Well-known protocols include Profibus DP, DeviceNet and Modbus Plus.

- Installation and Commissioning
  Ask your supplier to see a VFD instruction manual. Is it easy to read and understand? Can you easily find critical installation information such as wire gauge and tightening torques? Also, your supplier should be able to show you how to program a working VFD. Text keypads are much easier to program than numeric ones. Experiment with the keypad to determine how simple or complex the programming is. Ask about programming options to aid commissioning, such as PC software and application-specific macros.

- Service
  Ask about the warranty and service policy-sometimes an extended warranty is available. A 24-hour technical assistance number is important as is a local manufacturer's representative. Find out if the sales representative is capable and willing to technically support the product he or she is selling.

Conclusion

VFDs offer many advantages over the traditional methods of pressure control in a distribution network. They provide precise pressure control, reduce water leakage, increase pump life and result in significant energy savings. A careful selection of a VFD supplier should be made for trouble-free operation of the system and to enable you to reap the benefits of the VFD technology to the maximum extent.