Honeywell

Variable Frequency Drive (VFD)

APPLICATION GUIDE

CONTENTS

SAFETY

When Installing this Product...

1. Read these instructions carefully. Failure to follow them could damage the product or cause a hazardous condition.
2. Check the ratings given in the instructions and on the product to make sure the product is suitable for your application.
3. Installer must be a trained, experienced service technician.
4. After installation is complete, check out product operation as provided in these instructions.

> **WARNING**
> **Electrical Shock That Can Cause Death.**
> **Capacitor discharge can produce lethal shock.**
> Ensure that all circuits are completely safe before commencing work.

Each VFD has a bank of capacitors that, under normal circumstances, discharges shortly after disconnecting main power (five or 10 minutes). During normal operation, these capacitors charge to at least 500 Vdc and as high as 800 Vdc.

Inspection Procedure

IMPORTANT
Inspection and Repair are only to be undertaken by a competent person.

— Most VFD manufacturers include an LED that illuminates whenever the capacitor voltage is above 30 Vdc.
— Do not rely upon these resistors and LED circuits to indicate a safe condition. So far, we have not experienced a failure of the LED circuit or discharge resistors but this could happen.

The following is the correct procedure to follow:
Test Instruments Required: Standard Multimeter with Vac/Vdc range in excess of 600V.

IMPORTANT
Check test instruments immediately prior to commencing work by connecting to voltage supply.

Carry out necessary isolation and safety procedures for working on electrical equipment. Check for compliance with local requirements. A permit-to-work may be required. Where possible, remove fuses and lock off isolators.

IMPORTANT
If the LED is illuminated, do not touch any of the internal components of the VFD or associated wiring.

1. Disconnect power supply from VFD. All indicators, displays, and LED should extinguish after a few seconds.
2. Wait 5 minutes before taking further action.
3. Carefully remove any protective covers.
4. Do not touch any conductors within the VFD.
5. Confirm that the *LED charge* indicator is illuminated. This LED is bright and cannot be mistaken for another indicator.
6. If LED indicator is extinguished, identify DC bus circuit and check all busbars and terminals for voltage. Pay particular attention to terminals marked *P* and *N*.
7. Ensure that no voltages are present then use the voltage tester to check between conductors and *earth*.
NOTE: The voltage tester can discharge the capacitors by connecting it between busbars/connectors and *earth*.

Monitor the LED

It should be easy to see the level of illumination decay and within 1 or 2 minutes more, the LED should be extinguished. An LED maintaining illumination level can indicate damaged discharge resistors that create an open circuit. Also, an additional power supply may have been installed and is still powering the VFD. Carefully check for Vac supplies using the procedure outlined in the Installation Procedure section.

IMPORTANT
Recheck with multimeter before commencing work.

NOTE: If no Vac supplies are found, it is probable that discharge resistors are faulty.

INTRODUCTION

VFD Types

The following list gives mechanical, electrical and hydraulic VFD examples (many have a considerable mechanical content needing regular maintenance):

1. Mechanical Drives.
   a. Adjustable sheave belt drive.
   b. Clutch.
   c. Traction drive.
2. Electrical Drives.
   a. Eddy—current clutch.
   b. DC (rotating and solid state).
   c. Solid state Vac.
   d. Multi-speed motors.
3. Fluid drives.

Many of these can be replaced with a standard induction motor and a general purpose PWM VFD to provide a more reliable and cost effective solution to the VFD requirement. Using a VFD often provides energy conservation benefits and improvements in the accuracy of control as a bonus. Many opportunities for obtaining substantial savings are missed even though advice is available from numerous sources, including Government, professional bodies, consultants and equipment suppliers. The reasons for this include:

— Lack of awareness and/or skepticism regarding latest technologies.
— Overall financial and operational benefits are often not fully appreciated.
— Energy saving projects too often take second place to other production related expenditure.
— Lowest *first cost* takes precedence over *life cycle* cost (that is, initial cost plus running and maintenance costs).

Why Buy a VFD

Mechanical, electrical, and fluid power adjustable speed drives are available that offer some of the aforementioned benefits. None combine all of the advantages of a VFD:

1. Variable speed and flow capability with standard induction motor.
   a. Improved process control.
   b. Energy savings.
2. Reduced voltage starting characteristics.
   a. Soft start/smooth acceleration.
   b. Reduces power supply problems in the facility.
   c. Reduces motor heating and stress.
3. Used with standard AC induction motor.

Where are VFD Applications

Industry segments are important, because many applications are industry specific. Some *classic* VFD applications for various industries are provided below:

1. HVAC, fans and pumps.
2. Food Processing: agitators, mixers, conveyors for food transport, packaging and bottling, preparation machines (slicers, dicers, choppers), extruders, fans and pumps.
3. Petrochemicals: deep well pumps, oil field recovery, local distribution pumps, fans and pumps.
4. Mining and Metals: reheat furnaces, cooling beds, run in/out tables, fans and pumps.
5. Pulp and Paper/Forest Producers: washers, kilns, slitters, deckers, chippers, saws, sanders, peelers, de-barkers, fans and pumps, vacuum removal systems.
6. Machine Tool: replace spindle drives, grinders, saws, lathes, tool positioning drives, balancing machines, fans and pumps.
7. Transportation: material handling conveyors, cranes and hoists, small vehicle drives, fans and pumps.
8. Any machine or process that can be improved by varying speed or flow is a candidate for a VFD.

Benefits Summary

— Improved control.
— Reduced plant wear.
— Quieter operation at low load.
— Reduced complaints.
— Lower operating costs.
— Typical payback period is less than 2 years.

VFD MARKET

Energy Costs

The forces for industrial automation, requirements for ever increasing efficiencies from plant and machinery, together with demands for higher performance at a lower cost, continue to fuel rapid VFD market growth.

VFD Costs

Modern manufacturing techniques, using new technology Micro-Controllers, Digital Signal Processors, Application Specific Integrated Circuits (ASIC) and other highly integrated devices, have substantially reduced the VFD component count. Typically, VFD component counts have dropped from several thousand for early designs, to around 500 for modern machines. The result of this is not only smaller physical size, but also substantial reductions in overall cost and increase in reliability (see Fig. 1).

Other factors which have a lowering effect on market prices
— Wide VFD acceptance within industry and commerce.
— Larger volumes, produce benefits of scale: greater purchasing power by manufacturers and suppliers, larger investment in automated manufacturing processes.

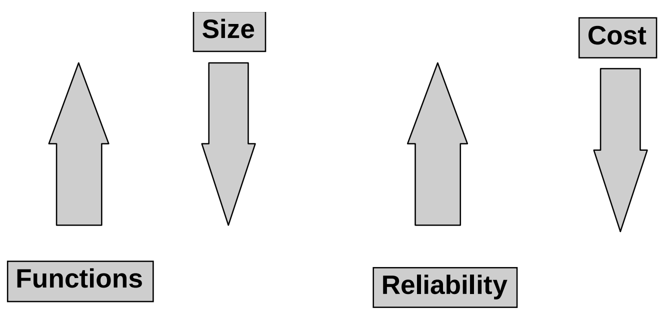


Fig. 1. Trends in the VFD Marketplace.

What's New

Another benefit of using advanced technologies in manufacturing and high performance chip sets, has been the availability to produce controllers with many more features.

In the early VFD days, more than 20 years ago, the machine had simple functionality, produced by the use of basic analogue technology. These machines had limited functions, providing the basics of speed control and soft start and stop.

Modern control of a general purpose VFD is digital, with what seems to be an ever growing list of functions:
— Multiple programmable digital inputs.
— Multiple programmable digital outputs.
— Multiple programmable analogue inputs.
— Multiple programmable analogue outputs.
— Closed loop high accuracy speed control.
— An array of motor protection functions.
— Simple plc. type functions.
— Simple but effective torque control.
— Communication bus.

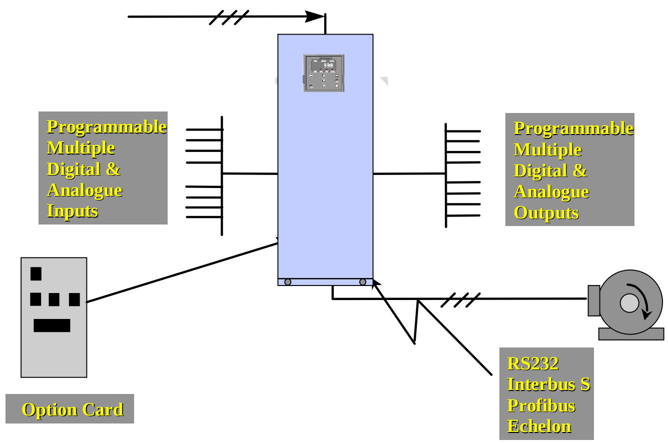


Fig. 2. VFD Functionality.

For non specialized use, there have always been four clearly defined areas of motor speed control, which require four different types of machines:

General Purpose AC Machine

Used on fans, pumps and machinery of all types, where *average performance* is required using either single or three-phase Vac supply driving a standard induction motor.

Flux Vector

High performance machine providing very high accuracy in speed and torque control, over wide operating range. Newer designs challenging the DC drive for High Torque at very low speeds. Special motors often required.

Spindle Drive

Very high performance machine used in mechanical handling and machine tool applications where high dynamic response is critical. These machines have many features of the Vector Flux VFD but often have much more input and output capability, to provide the necessary interfacing with the *outside world*. They almost always require a special motor.

DC Drive

DC drives are still prevalent in the drive industry, making up some 40% of the market. VFD performance has improved so much in the recent past, that DC drives are often replaced with AC machines that provide added benefits. There are applications, in particular very large, high-power, low-speed drives, where DC will be used for many years to come.

Advancements in design and expertise now allow the combination of functionality and performance of General Purpose, Flux Vector, Spindle Drive and to some extent the DC drive in the *one* package. However, the motor will have to be an AC type.

User Benefits

- One machine covers all applications.
- Lower spares cost.
- Fewer different variants for technicians to work with.
- Possible general reduction is costs: higher volume production.
- Interchangeability.

This *universal* approach is adopted by most high volume manufacturers as it is seen as the ultimate goal. (Fig. 3)

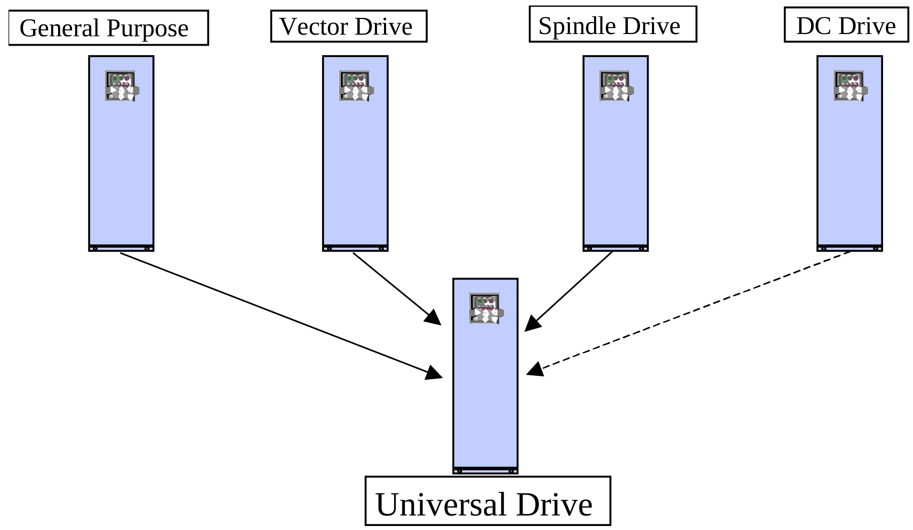


Fig. 3. Universal Drive.

MOTOR FUNDAMENTALS

Three-phase electric motors are very rugged machines that have to withstand almost endless abuse from end users and still continue to perform to specification. There are several variables of which the end user is often unaware. Many have significant effect on the general performance of the motor. The motor terminal voltage is a major variable that can have significant effect on the performance of the motor. Table 1 shows the effects of raising and lowering the motor terminal voltage, about its nameplate value. The power supply feeding the majority of domestic facilities is nominally 200 Vac 1 Phase and nominally 400 Vac three-phase for commercial and industrial applications. This power is transmitted at a frequency of 60 Hz. The vast majority of motors in industry and commerce are three-phase induction motors of the Squirrel Cage Design.

Table 1. AC Motors: Voltage Variation Effects (Constant Frequency).

	90% Rated Voltage	110% Rated Voltage
Torque (Varies directly as Square of Voltage)	-19%	+21%
Speed, Synchronous	No Change	No Change
Speed, Full Load (Induction Motors)	-1.5%	+1%
Current, Starting	-10 to -12%	+10 to +12%
Current, Full Load	+11%	-7%
Slip	+23%	-17%
Efficiency	-2%	+½ to +1%
Power Factor	+1%	-3%

Advantages

— Long life.
— High protection levels available.
— High efficiency: 80%+.
— Readily available replacements world-wide.
— Minimal moving parts therefore low maintenance cost.
— High starting torque, suitable for wide variations of applications.
— Simple to reverse.
— Low cost.

Disadvantages

— Designed for fixed speed operation.
— Designed to be run from sine wave power supply.

Voltage and Current Waveform Examples

No Load

Fig. 4 shows the current and voltage waveforms of one phase of a standard three-phase 10 Hp induction motor under no load conditions. Full load current of the motor is 13.5 amps from a 415 supply. It is clear from the graph that even under no load conditions the motor draws substantial current.

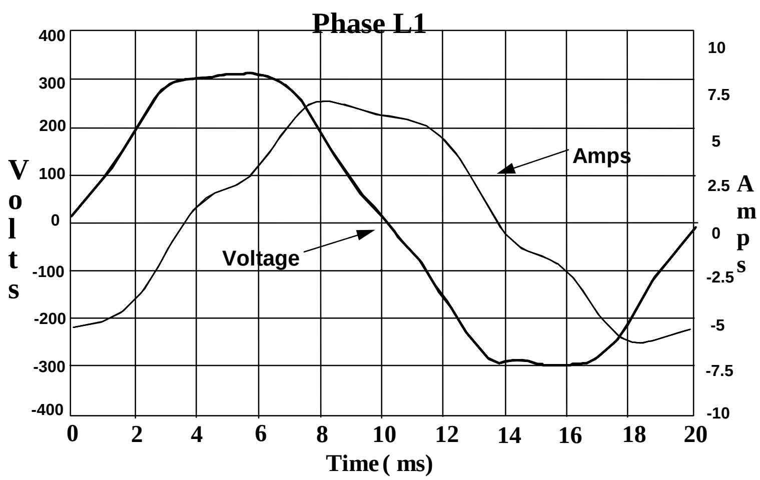


Fig. 4. Standard three-phase 10 Hp induction motor waveforms (no load conditions).

Note the scale on the right of the graph. The peak to peak current is 15 amps. Current lags substantially behind voltage. This demonstrates that the motor power factor is much less than unity. The majority of the current drawn is for the purpose of magnetizing the motor and is called *magnetizing current*. Note the shape of the voltage and current waveforms, both curves should be sine waves. It is likely that the reason for the distorted waveforms is load sharing of the same power supply that is non-sinusoidal and distorts the voltage waveform. This reflects in the distortion of the current waveform.

Full Load

Fig. 5 shows the results of increasing the load on the motor in the test above, to full load conditions. Current draw rose by a factor of three and the distortion factor has now increased substantially. Note the scale change on the right hand side of the graph and the peak to peak current is 50 amps. The current waveform moved towards the voltage, indicating an increase in power factor. However, the current still lags behind the voltage.

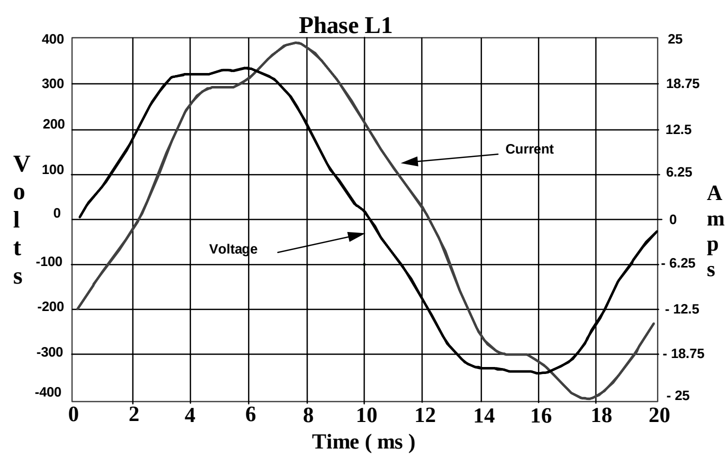


Fig. 5. Standard three-phase 10 Hp induction motor waveforms (full load conditions).

Sine Wave Supply Voltage to Frequency Relationship

The motor nameplate carries several important parameters: kW or HP, voltage, full-load current, full-load motor speed, and power supply frequency. Two of these, terminal voltage and power supply frequency are very important as they define the voltage to frequency ratio for the motor. This creates a constant flux (magnetic field) condition throughout the full speed range of the motor. The voltage to frequency relationship is a simple linear relationship. For example: If frequency changes from 50 Hz to 25 Hz, the voltage should change from 415V (three phase) to 207 volts. If the motor were connected to any sine wave supply, with a frequency other than that defined on the nameplate, the correct voltage for this frequency can be determined.

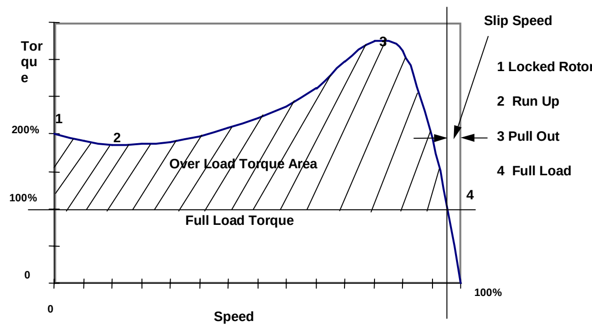


Fig. 6. Typical motor speed torque curve.

Motor Torque Characteristics

Fig. 7 shows the starting torque characteristics of a typical A/C induction motor. This is a torque curve of a general purpose motor. There are many other types, depending on load type and performance required. Point 1 is the locked rotor torque, typically 200% of normal full load torque. As the motor begins to accelerate the load, the torque production ability of the motor decreases. Then, at point 2, typically 20% of full speed, the torque has fallen to an approximate minimum of 175%. This point is called the run up point. The torque production ability of the motor increases from the run up point until about 90% speed, point three, maximum torque, the pull out point, is achieved.

From here, the motor rapidly reaches full load speed, point 4, which corresponds to the nameplate speed on the motor. If the load is very light, the motor will continue to accelerate to close to the synchronous speed, which in the case of a 4 pole machine on a 50Hz supply would be 1500 rpm.

NOTE: The difference between the synchronous speed and the full load speed is called *slip.* Slip is generally a few percent of the synchronous speed, equivalent to 40-50 rpm

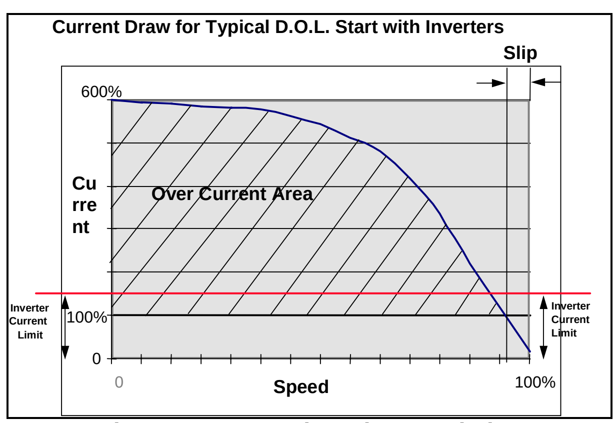


Fig. 7. Motor Starting Characteristics

When a standard induction motor is switched directly onto a 60 Hz power supply, there is a large inrush of current. This can exceed six times the motor nameplate full-load current. As the motor accelerates the load, this large current flow falls off rapidly until a point at which motor speed and load balance. This point is somewhere between no load speed and full load speed. See Fig. 7. Motors driven by a VFD have the large inrush of current controlled by the VFD. Only under worst case conditions will the inrush reach 150% of motor nameplate current. However, this setting is adjustable within the VFD and can be limited to a lower value.

Factors Affecting Motor Temperature and Insulation Life

As indicated earlier, three-phase electric motors are extremely rugged machines. With few moving parts sealed from the local environmental effects, except temperature, the motor can be expected to provide reliable service for many years. When discussing this subject with end users, often the comments made are significantly different. Where the motor is considered relatively unreliable and regularly *burning out*, random motor inspections are made on various sites. The majority are found to work at only 80% of full load. Fig. 8 indicates the life expectancy of Grades A, B, F and H types of insulation.

NOTE: Most modern motors are manufactured using Class F insulation.

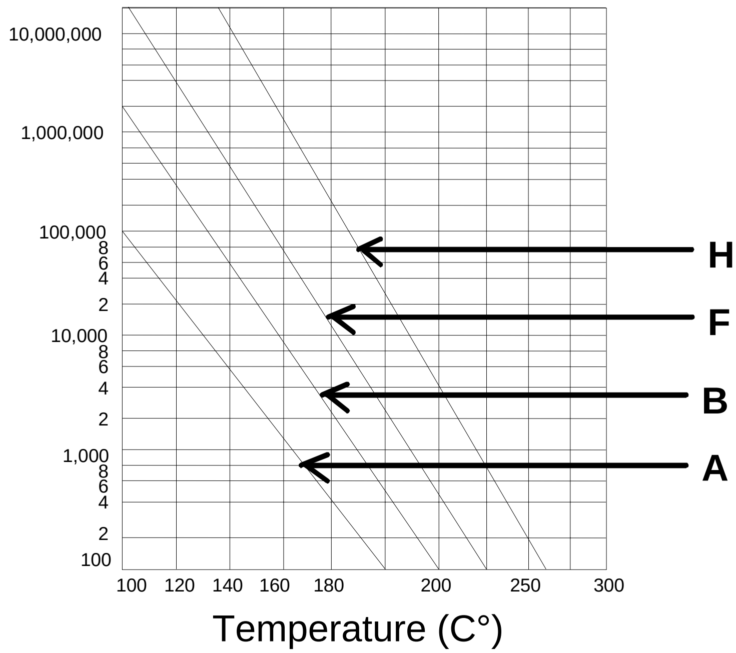


Fig. 8. Insulation life expectancies.

NOTE: The *Ten Degree Rule* indicates that a ten degree temperature increase cuts insulation life span approximately in half and vice-versa.

Clearly, with a life expectancy of in excess of 1,000,000 operational hours (over 100 years) at 284°F, motor burn-out should not be the problem it is often claimed to be. When investigations are made into a motor *burn out*, the failure can often be attributed to one of the variables indicated in Fig. 9.

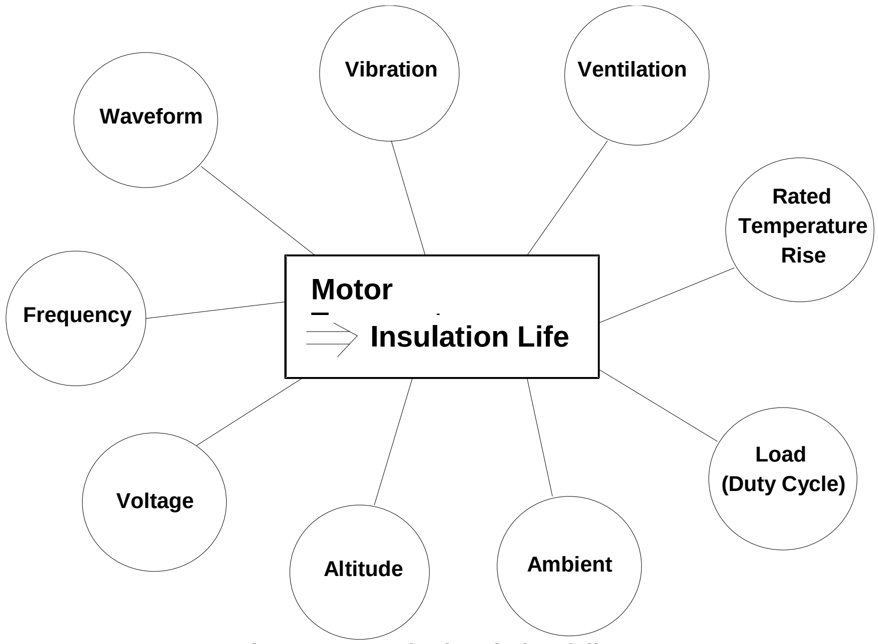


Fig. 9. Causes for insulation failure.

Three of the elements in Fig. 9 can be or are affected substantially by application of a VFD. Therefore, they have a bearing on the temperature of the motor and thus its life expectancy:

Vibration

Although a modern VFD produces good quality current waveforms, there is a small amount of additional vibration produced at the motor. Thus, there is potential for small reduction in the motor life expectancy. However, motors are often installed on inadequate frames or machinery that has a tendency to vibrate. Consequently, the life expectancy of the winding is affected far more by the installation than the VFD.

Ventilation

The installation of a VFD should have no affect on motor ventilation, as this is a purely mechanical function. However, a VFD tends to cause motors to run slightly warmer than they would if driven from a commercial power supply: typically 5 degrees Fahrenheit. Normally this is well within the motor design limits and there are no adverse effects from the small increase in temperature.

Rated Temperature Rise

Typically, motors are designed to produce an 176°F temperature rise at full load with nameplate conditions, in an ambient temperature of 104°F. As additional temperature rise caused by VFD application is only 5°F and experience shows that most motors are selected with 80% of design capacity and rarely run with an ambient temperature of 104°F. Again there is little effect on the life expectancy of the motor, when driven by a VFD.

Load (Duty Cycle)

Generally small motors from fractional Hp up to maybe 5 or 10 Hp can withstand many starts per hour, typically 100-200, without overheating. There is an increase in the motor temperature over that reached in a motor left running constantly. This increase in operating temperature is due mainly to:

- The surge current at start up, which may be as high as 5 or 7 times full load current.
- Periods when the motor is stopped, where the motor cooling fan is not running, therefore the body temperature will increase to compensate.

As increase in temperature reduces motor life, frequently starting even small motors can substantially reduce the life expectancy. As the motors increase in capacity above 10 Hp, the frequency of starts per hour should be reduced to 3 or 4 starts per hour for motors of 125 Hp to 250 Hp.

During starting, mechanical stresses increase rapidly with increases in motor sizes. Mechanical failure through metal fatigue is common on large machines that are started too frequently. When a VFD is applied to a motor, surge current is almost eliminated depending on the inertia of the load and the time required for the motor to reach full or required speed. The result is that there is virtually no limit to number of motor starts per hour, regardless of size.

Ambient Temperature

As indicated earlier, general purpose motors are normally designed to run at full load with nameplate conditions and an ambient temperature of 104°F.

Motors are often installed in areas where there is little or no ventilation. The heat losses from the motor may cause the surrounding air temperature to exceed the original design conditions of the motor. The application of a VFD in this case has little effect on life expectancy (see above).

Altitude

The altitude, height above sea level, has a bearing on motor temperature since the air density, and thus its ability to absorb heat, reduces with altitude. Generally 3280 feet is the height at which derating should commence.

Terminal Voltage

VFD control of the motor terminal voltage is direct. The VFD overall control strategy includes design to provide this function. As motor terminal voltage has a major impact on motor performance, great effort has been made by manufacturers to optimize voltage control under all conditions.

Power Supply Frequency

The motor design frequency is usually 50 or 60 cycles. When a VFD drives a motor, it is usually to control the motor speed. It therefore follows that the VFD has design functions embedded within its control strategy to ensure that the motor is not adversely affected by changes in the frequency supplied by the VFD.

Current Waveform

Manufacturers have taken major steps over the last few years to improve the quality of the modern VFD current waveform. Motors are machines designed to operate with a sine wave input. A few years ago, the VFD produced current waveforms that were coarse and anything but sinusoidal. The result of this was rough running and on some occasions overheating of the motors. A modern VFD produces current waveforms that show little distortion from the sine wave and thus motor and drive performance has dramatically improved. Motor losses and temperatures are both reduced.

Further Protection

Under all operating conditions the VFD monitors the speed and load imposed on the motor. A model of these conditions is continuously updated and checked against standard acceptable limits. In the event that these limits are exceeded, the motor is in an overloaded condition. Unless this overload is removed, the VFD takes the decision to trip the drive to safeguard the motor. If this motor model does not to provide the desired protection level, the VFD can take direct measurement of motor temperature via internal thermistors.

Differences Between Star Delta and Delta Star

Low power three-phase motors, 5 HP and below, are generally wound so the motor can operate on 200 or 400 Vac. To operate on 200 Vac, connect the motor in delta. To operate on 400 Vac, connect the motor in star. Select the correct VFD based on power supply voltage and phase number. Connect the motor to match the power supply voltage.

Motors above this capacity generally are wound to be operated in star mode for starting, to reduce surge current, and delta mode when the load is up to speed, to provide nameplate power output. Multiple contactors and various other devices are used to perform this change over function.

Under normal circumstances when a VFD is applied to a motor, connect the motor in Delta mode. The VFD will start the motor smoothly and without current surge. No changeover contactors are required.

Star Delta

Star Delta is a method to reduce applied voltage to the stator winding starting large motors (see Fig. 10). This reduces starting current. This also reduces locked rotor torque. Both power and current in Star are less.

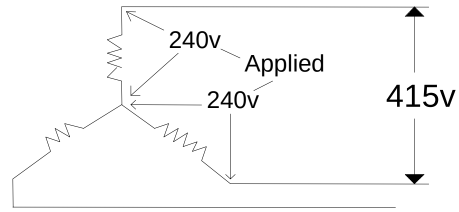


Fig. 10. 415V phase windings in Star.

Delta

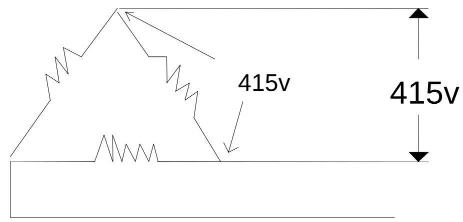


Fig. 11. 415V phase windings in Delta.

Full nameplate Power available in Delta (see Fig. 11).

Delta Star

A method to produce a Dual Voltage motor. See Fig. 12.

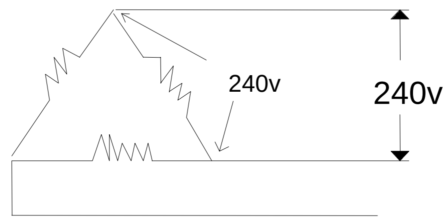


Fig. 12. 240V three-phase windings in Connect Delta.

Full nameplate Power available in Connect Delta.

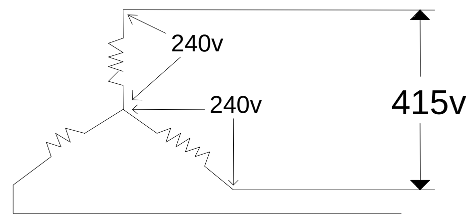


Fig. 13. 240V three-phase windings in Connect Star.

Full nameplate Power available in Connect Star (see Fig. 13).

Horsepower is the same in both cases, but current change in a ratio of 1.732 (square root of three). Delta is 1.732 times greater than Star.

Load Types

There are four basic load types:

Constant Torque

Care is required. Examples are: cranes, elevators, agitators, mixers, and conveyors. The torque remains constant throughout the range of speed of operation. This application is probably the most difficult for a general purpose VFD. It requires the motor to produce full load torque at zero speed. Rarely can a general purpose VFD provide this capability. Usually a Vector Type VFD would be applied, with some form of feedback of motor speed, such as an encoder. If accurate speed holding at very low speeds is not required a general purpose VFD could be used.

Square Law Torque Load

Usually a simple application. Examples are: fluid movers and reciprocating pumps. The torque demand increases with the speed of operation, but the power increases as the square of the increase in speed: hence the name Square Law. See Fig. 14. This is not usually a problem for a general purpose VFD. At the most critical speed, zero and just above, torque demand is low. Beware if the customer wishes to over speed the driven machine as the power requirement increases rapidly as the speed increases.

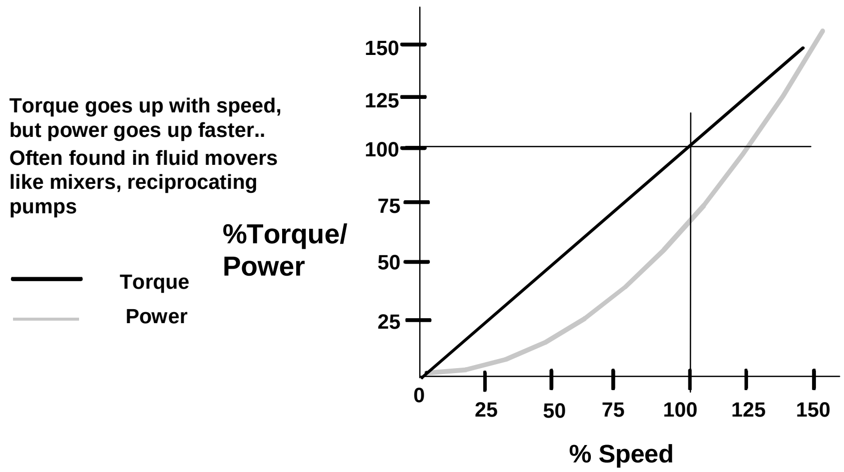


Fig. 14. Square law torque load torque/power curve.

Cube Law Torque Load

General HVAC and usually simple. Examples are: centrifugal fans and pumps. In the HVAC industry, it is generally easy to identify the type of load being driven by the motor. Most loads are of the fan or centrifugal pump types and therefore can be described as *cube law loads*. The torque and power requirement at zero speed is zero. See Fig. 15. Power requirement increases with the cube of the increase in speed. Therefore, there is a large increase in power requirement for a small increase in speed. For example: To double the machine speed would require eight times the power to drive it. Conversely, if the speed of the machine is halved, the power requirement is reduced to 1/8 of the original power.

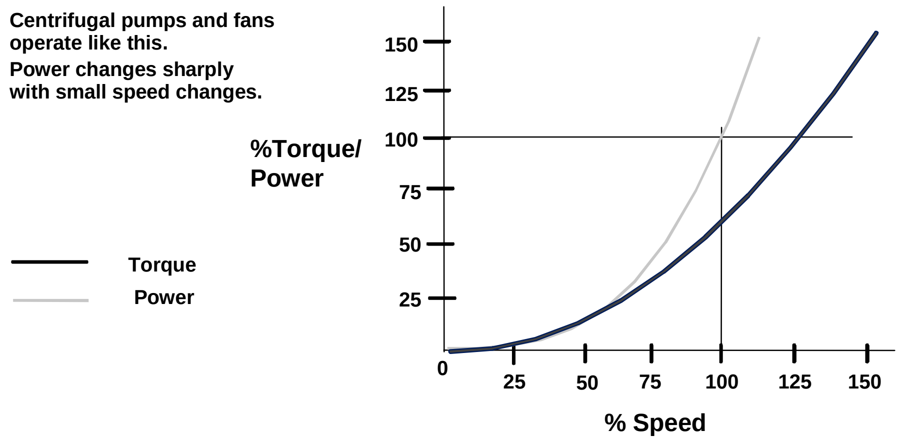


Fig. 15. Cube law torque load torque/power curve.

Constant Power Type Loads

Not usually encountered in HVAC industry. Examples are machine tools. Care must be taken at all times. If a mistake is made in type of load identification then the application will be at best troublesome and at worst a failure. See Fig. 16.

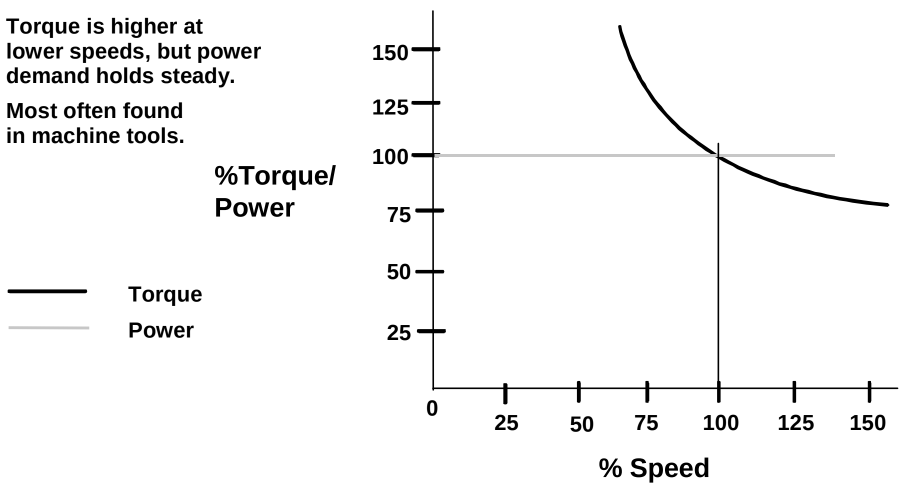


Fig. 16. Constant Power load torque/power curve.

Power Factor

Power factor is a term commonly encountered within the VFD or drives industry. Many VFD manufacturers claim that the power factor of their products is almost Unity and remains so across most of the load imposed upon the VFD. Most general purpose VFD manufacturers use the same type of input circuitry and therefore as electric machines, have similar power factors. Some factors affecting the power factor of the VFD:

— The power supply capacity of the transformer.
— The length of cable feeding the VFD.
— Load on the supply transformer.
— Size of AC line reactor and/or DC bus reactor in the VFD.

The power factor of the motor driven by a VFD varies according to the load imposed on the motor. This can range from 0.3 for a small motor on light load to 0.9 for a large motor on heavy load. The VFD will effectively isolate the motor from the power supply and a power factor of one will always be seen by the power supply. The power factor of an electric machine can be considered as the relationship between the total current drawn by the motor and the current drawn to produce useful power. See Table 2.

Table 2. Power Factor of Some Devices.

Device	Power Factor	Device	Power Factor
Incandescent Lamp	100%	Single Phase Induction Motor	60%-80%
Neon Lamp	40%-50%	Three Phase Induction Motor	70%-90%
Fluorescent Lamp (w/Stabilizer)	90%	Table Top Fan	60%-80%
Radio	100%	Ceiling Fan	50%-60%

Useful Formulae

Motor speed = (Supply frequency * 120) / Number of motor poles

The above formula provides the synchronous (no load) speed of the motor. However, as load is applied to the motor, it begins to develop slip. The actual speed deviates from synchronous speed. This can be positive slip or negative slip in order to develop torque.

Shaft Power in kW = (Nm * RPM) / 9549

Torque in Nm = (9549 * kW) / RPM

COS ϕ (PF) typically 0.8 and efficiency 0.8 for small motors

Electrical Power in kW = (V * I * PF * 1.73) / 1000

VFD FUNDAMENTALS

Construction

The majority of general purpose VFDs produced today have four fundamental sections (see Fig. 17). These are:

1. The input rectifier or converter.
2. The DC bus.
3. The output stack or VFD.
4. The controller.

The input rectifier or converter can be either three-phase or, in small machines, single phase. This input rectifier converts the Vac input into Vdc and charges the capacitors in this part of the circuit.

The DC bus acts as a small reservoir for power on which the output VFD draws. If any regenerated energy from the load remains, it is stored on the DC bus in the capacitors.

The *output stack* or VFD draws power from the DC bus and creates a synthesized Vac power supply, the frequency of which can be varied by the controller. The output of the converter is used to drive the electric motor.

Supervising the whole machine is a computerized controller, which is capable of making decisions based on the demands and on state of motor and load. It is driving and taking protective measures to ensure that no damage occurs to the machinery it is controlling or the VFD itself.

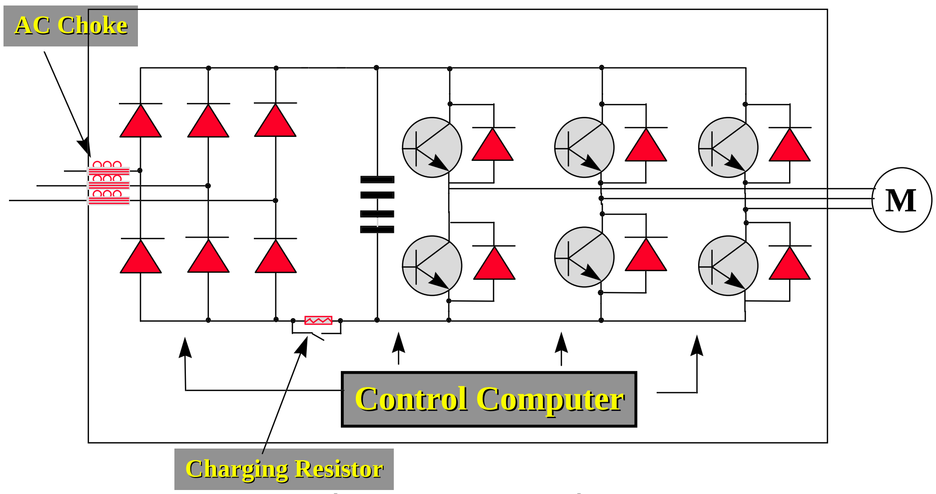


Fig. 17. VFD Construction.

Braking Resistor

Under normal circumstances, with the motor under load, the flow of energy through the system is from the commercial power supply to the VFD and from the VFD to the motor and finally from the motor to the load. There are operating conditions where the load tries to over run the motor. An example of this would be a high inertia load. For example: a large diameter fan, running at high speed, where the control system calls for the fan to run at low speed.

The VFD begins to lower its output frequency and the motor follows. However, due to the inertia in the fan, the fan resists the change in speed, causing the motor to run above the frequency output from the VFD. This situation will cause energy to flow from the load back through the motor and into the VFD. A general purpose VFD does not normally have the ability to pass this energy back into the commercial power supply. However, if required, additional equipment can do this.

The result of this regeneration is a build up of energy in the DC bus capacitors, which manifests itself as an increasing voltage. If this were allowed to occur unchecked, damage would occur to the components in the VFD due to exceeding the operating voltage limits. To ensure problems do not occur, the VFD has a bus voltage monitoring circuit. This circuit attempts to reduce regeneration until bus voltage falls to an acceptable level. If however it is important that the motor and load follow the control signal exactly, it may be necessary to add a braking resistor system to the VFD. (See Fig. 18.)

This would take the form of a power transistor, a power resistor and a control circuit, the layout of which is shown above. In the event that the DC bus voltage exceeds the threshold of the control circuit, the power transistor switches on. It also connects the positive and negative sides of the DC bus together, via a large power resistor. This action dissipates the excess energy as heat from the resistor. This resistor is subjected to high voltages and currents, so it is a highly stressed component and has to be carefully selected to ensure reliability.

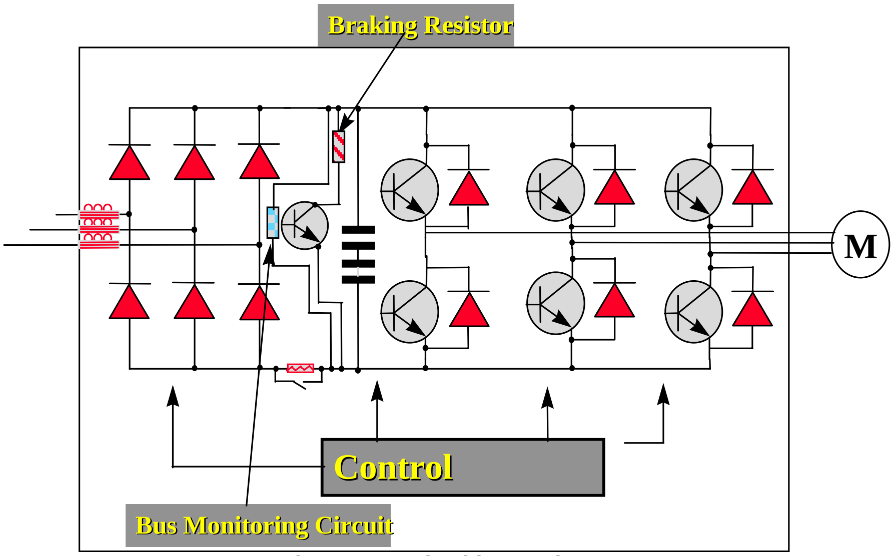


Fig. 18. VFD braking resistor.

Pulse Width Modulation (PWM) Control Principles

Various methods produce a synthesized three-phase power supply suitable for driving a standard three-phase electric motor. However, the industry has standardized on the PWM method of control. See Fig. 19.

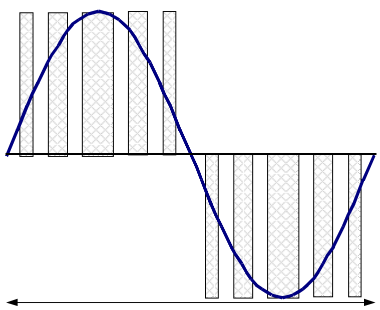


Fig. 19. Pulse Width Modulation.

VFD Voltage to Frequency Ratio.

When connected to a VFD, motor speed is no longer fixed by supply frequency, since the VFD can vary its output frequency. Under perfect conditions, at zero speed the terminal voltage would also be zero. Obviously if this was the case then the motor would produce zero torque and in many cases this would be unacceptable. Also at very low speeds the motor winding appears more like a resistive load than an inductive load. To overcome this problem with a general purpose VFD, a degree of fixed voltage boost is applied at zero speed. As the motor accelerates, a proportion of fixed boost is replaced by normal V/F ratio until, at some speed above zero, governed by the amount of fixed boost applied, all boost is replaced by the normal V/F ratio. If an excessive amount of fixed boost is applied, the motor can become overheated due to over fluxing. (See Fig. 20.)

It is also possible to program the drive to adjust the V/F ratio automatically according to the load applied to the motor. Within limits, as the current drawn increases the drive responds to this as an increase in load and to maintain torque and speed, the drive increases the terminal voltage, within predefined limits.

If the drive has been programmed correctly, the maximum terminal voltage will be reached at maximum speed. However, the application can require that the motor run over speed. Normally, 20% over speed is acceptable, providing the load can withstand the stresses caused by this additional speed. Fig. 20 illustrates that at maximum speed terminal voltage is at maximum. Therefore, there can be no increase in voltage due to speed increases. This point is called the field weakening point, as a constant motor flux can no longer be maintained. According to the V/F ratio, therefore the motor torque capability begins to reduce. If the motor continues to increase in speed then it passes into an area of operation called the constant power area.

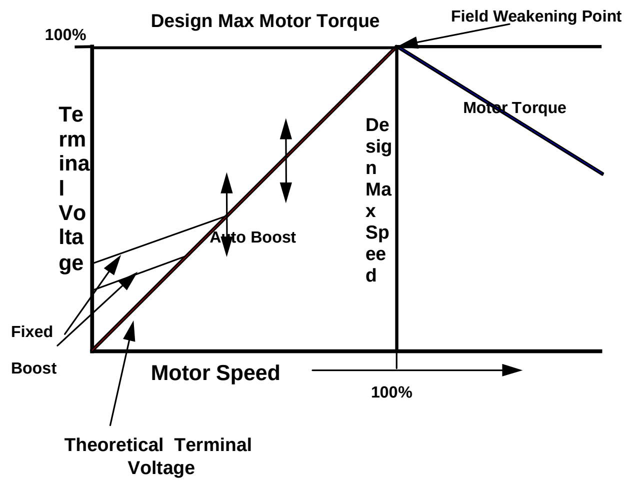


Fig. 20. VFD voltage to frequency ratio.

Charging Resistor

The charging resistor is included in the DC bus to provide current limiting during the initial power up stages of the VFD. When a fully discharged VFD is switched on to the power supply, the capacitors on the DC bus are seen by the power supply as a very low impedance load. If the design does not include a charging resistor, the current surge magnitude would be so high that the input bridge can be damaged, or require up-rating far beyond that required for normal running.

The power supply capacity, cable lengths have a bearing on the magnitude of this surge current. With the charging resistor in the circuit, the current surge is limited until the Vdc rises above about 380 volts. At this point, a contactor or solid state switch shorts out the resistor. The charging circuit is short time rated, repeated power down/up cycles will ultimately cause failure. Typically 10 power up/down cycles per hour are acceptable.

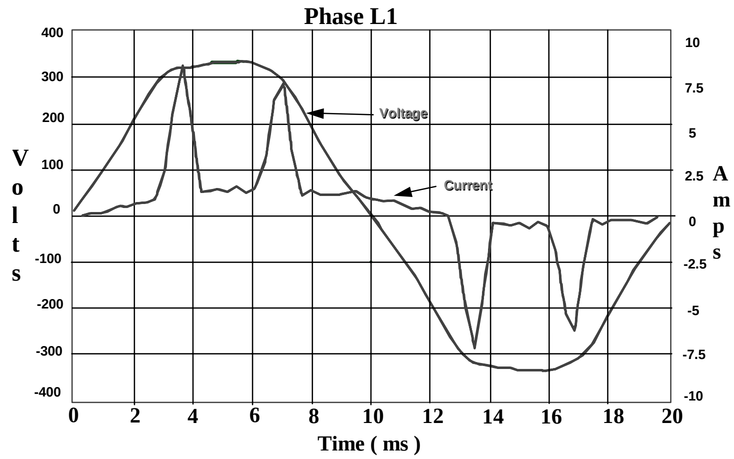
AC Line Choke

The AC Line choke design provides some smoothing on the DC bus and reduces the amount of ripple current that must be tolerated by the main capacitors. This has an effect of extending the life of these components. The choke provides a limiting function to the magnitude of the DC bus current during normal operation. This results in an improved overall power factor of the VFD and reduced harmonic currents flowing in the power distribution network.

NOTES:

— Be aware that if multiple VFDs or one large VFD installed on a distribution network that supports equipment that also produces harmonic currents, the effects are cumulative.
— If power factor correction equipment is also installed on the network, damage can occur to the correction equipment capacitors.
— Limiting the amount of harmonic current flowing in the network can require additional power line reactors, or under extreme conditions, a filter network.
— Only an Harmonic Survey can guarantee the quality of the power supply.

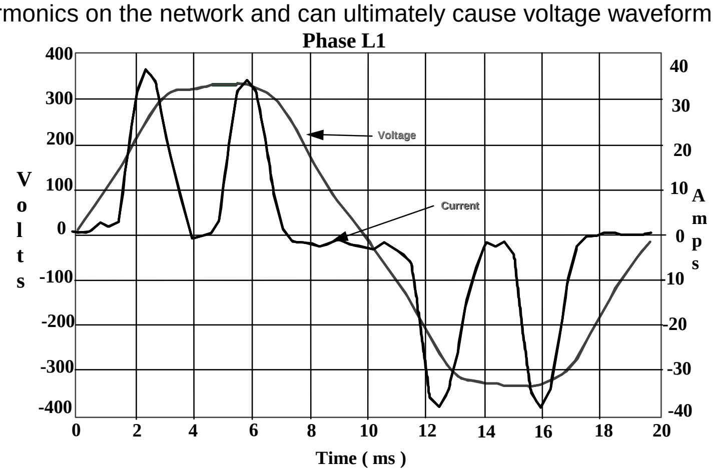
To illustrate this point, a test was carried out with a standard 4 pole three-phase motor connected first to no load and then full load, driven by a VFD. Fig. 21 and 22 show the voltage and current waveforms under these two conditions.



7.5 kW Motor No Load

Fig. 21. Motor voltage and current under no load conditions.

Note the shape of the current waveform in Fig. 21 with respect to the voltage. It is the non sinusoidal format of the current waveform that causes the harmonics on the network and can ultimately cause voltage waveform distortion.



7.5 Motor Full Load

Fig. 22. Motor voltage and current under full load conditions.

Note that the peak current in Fig. 22 has risen from 7.5 amps to almost 40 amps. Motor full load current is 13.5 amps.

Motor and VFD Tests

In the past, the VFD was seriously criticized for causing motor problems- in particular causing the motor to overheat to the extent where motor winding insulation was damaged, resulting in *motor burnout*. As a result, it was often recommended by suppliers/manufacturers/consultants to down rate a VFD driven motors by 10 percent.

Many advancements have been made in the control design of the modern VFD to an extent now that for centrifugal fan and pump type loads, no derating is required. The following sections contain results of a sequence of tests indicating the heating effects of running a standard 7.5 kW squirrel cage motor connected to the commercial power supply and to a general purpose VFD. The loading was provided by a calibrated dynamometer. Thermal imaging equipment was used to identify the *hot spots* on the outside of the motor body. Type K thermocouples were secured to the cleaned surface of the motor body at these points using epoxy resin and then thermal insulation applied.

Test 1. Motor Run with Varying Loads on Commercial Power Supply

Fig. 23 indicates performance of a standard squirrel cage motor driven directly by a commercial power supply at 100%, 66% and 33% load. On 100% load, motor body temperature rises quickly to 64°C, while ambient temperature remains stable around 20°C. When the load is reduced to 66%, body temperature quickly falls to 45°C, as expected under reduced load conditions.

Reducing load to 33% produced a further reduction in motor body temperature, to 40°C. However, the test was curtailed due to lack of time. It is evident from the slope of the graph at this load, that the motor temperature would have continued to fall several degrees before stabilizing at an estimated 38°C.

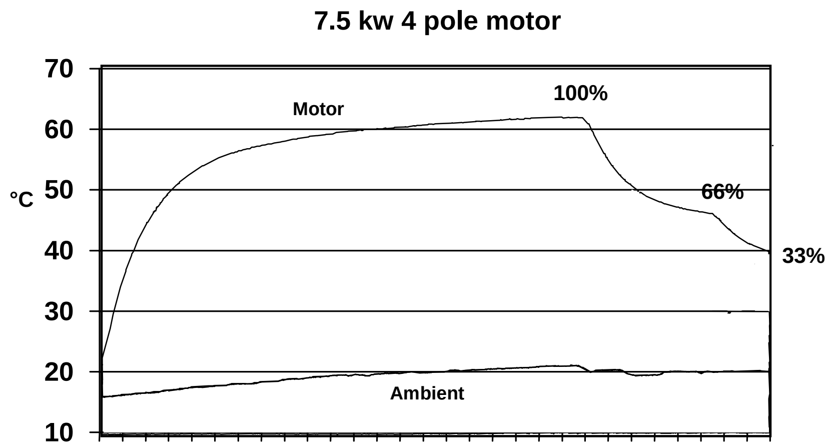


Fig. 23. Motor run at 100%, 66%, and 33% load on commercial power supply.

Test 2. Motor Driven by VFD with Varying Loads.

Fig. 24 indicates the results of a similar test to test 1. However, the motor was driven by a VFD running at 50Hz, rather than a commercial power supply. Early in the test, the VFD tripped. The diagnosed cause was VFD thermal overload. Caused by setting the VFD to a level too low for the load. This overload setting was adjusted and the test restarted. At 100% load, the motor body temperature reached 65°C when the load was reduced (see Fig. 24). However, had time allowed, the temperature would have probably reached 70°C. As the load was reduced to 66 percent, the motor body temperature fell to 46°C. Reducing the load to 33 percent caused the motor body temperature to fall to 38°C. During the test, ambient temperature was recorded and was similar to that of test 1.

A comparison between the two tests indicates that when the motor under test was run on a VFD, under maximum load conditions, at rated speed i.e. 50 Hz, the motor body temperature was increased by 5°C over that reached when run on the commercial power supply. This small increase in temperature is still within the operating range of the machine and clearly indicates that there is no need to derate a motor driven by a VFD, when the motor is run at full rated speed.

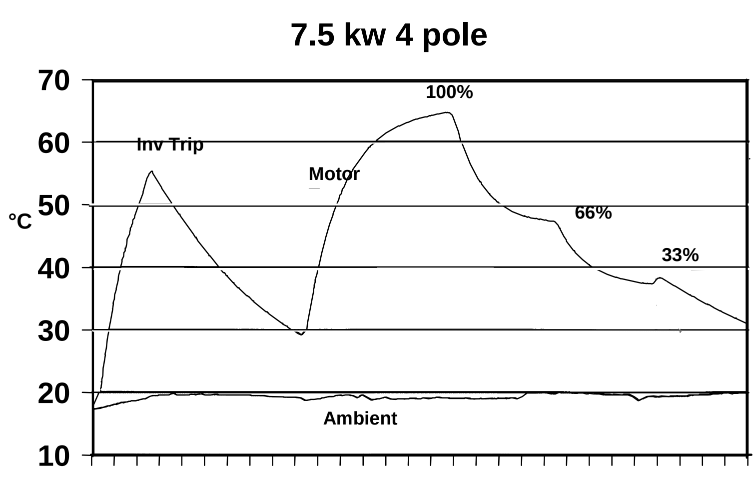


Fig. 24. Motor run at 100%, 66%, and 33% load on VFD.

Test 3. Motor Run on VFD with Fan Load Simulation.

The purpose of this test is to prove that the motor will not suffer harmful effects of overheating, when driving a fan or pump type centrifugal load at varying speeds. The dynamometer was configured to produce similar characteristics to those of a centrifugal fan. The motor was then run up to 50 Hz an the load adjusted to 100%. After a short time, it can be seen from Fig. 25, that the motor body temperature rose to a similar level as that reached in test 1 and 2 in the same time frame. The speed of the motor was then reduced in steps from 50 Hz to 40, 30 and 20 Hz. In each case the temperature of the motor body fell as the speed of the motor reduced. No auxiliary cooling was provided for the motor i.e. the only cooling air flow was provided by the shaft-mounted fan on the motor. Clearly, there are no harmful heating effects caused by driving a motor with a VFD, on centrifugal type loads and there is no need to derate the motor.

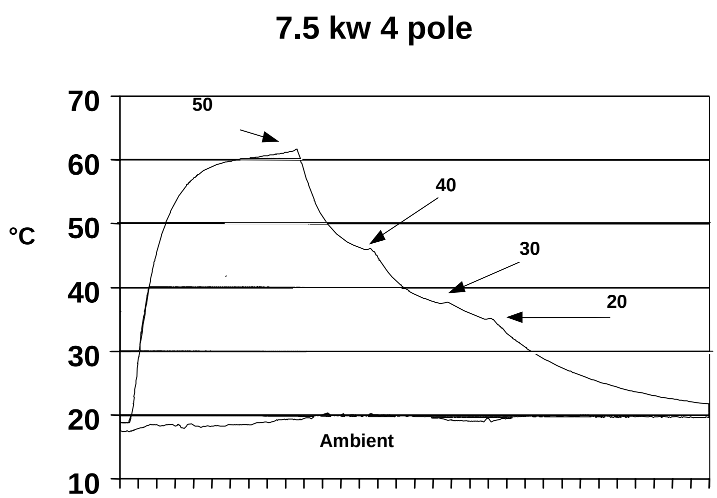


Fig. 25. Fan load with motor running at various frequencies.

Test 4 Motor Run on VFD with Constant Torque Load.

This test was by far the most arduous for the motor and VFD since the dynamometer was configured to hold the torque stable across a speed range from 50 Hz down to 15 Hz. This was not a test to prove the capabilities of the VFD to produce full load torque at reduced speeds, rather it was to show the heating effects under these operating conditions. Most modern VFDs can cause the motor to produce full load torque down to 1.5 Hz or less.

Time constraints limited the amount of test time at the higher speeds, thus not allowing the motor body temperature to stabilize at each step in the speed range, however a full load 50 Hz test had already been undertaken in test 2. It can be seen from Fig. 26 that under constant torque conditions, the motor body temperature will rise with each step reduction in speed.

30 Hz is probably the minimum speed at which a standard motor can be run continuously under full load torque conditions, however for short periods of time, much lower speeds at full load torque can be tolerated without adverse effects. If regular operation at speeds lower than 30 Hz and at full load torque are anticipated, then an auxiliary fan should be installed, in order to produce the desired cooling for the motor. Brooke Hansen and other motor manufacturers can provide standard motors with auxiliary cooling fan fitted as standard.

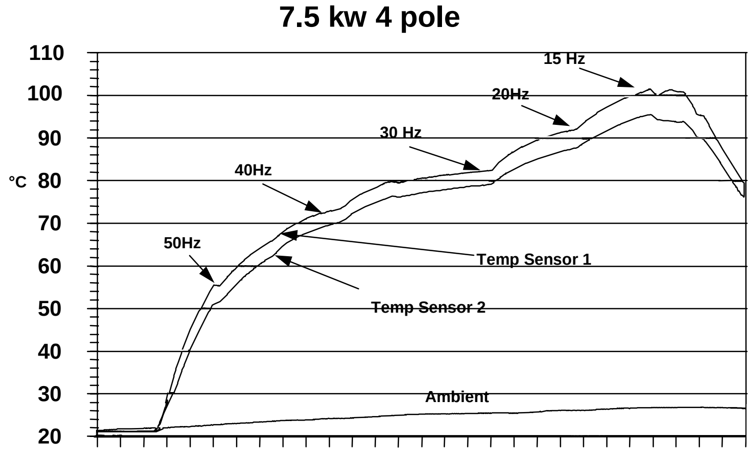


Fig. 26. Motor on constant full load torque.

Test 5 Motor Run on Old and Modern-Design VFDs at 50 Hz on Full Load torque.

As a final test, Fig. 27 shows a comparison in the heating effects of running a motor first on a 10 year old design VFD and a modern VFD. The graph shows that under similar load and ambient temperatures, the old design VFD caused the motor temperature to rise to 75°C whereas on the modern design, the motor temperature reached 68°C. The reason for this reduction in temperature is the improvement in the synthesis of the output waveforms, to the motor.

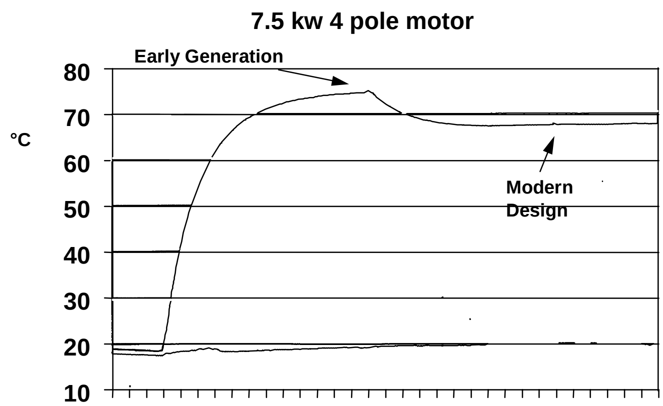


Fig. 27. Comparison of early generation and modern VFDs.

INSTALLATION GUIDELINES

General Guidelines

- Do not install a VFD in a hazardous or flameproof area.
- Do not install a VFD to drive motors installed in hazardous areas. This requires special testing and approvals.
- Every Honeywell VFD has a three-phase output.
- Do not assume that all three-phase AC motors can be driven by a general purpose VFD. Some types require a special VFD.
- Do get full motor name plate details - do not assume anything.
- Do not select VFD on Hp alone - some motors have high current to Hp ratio and the VFD could be too small if selected on Hp alone.
- On lightly loaded motors, do not select a VFD with capacity more than one frame size less than motor. If you do, expect problems.
- On very lightly loaded motors, do not select VFD on motor current drawn alone, i.e. 60 Hp VFD drawing 40 amps at 60 Hz may draw 60 amps at 10 Hz. If this situation arises, an output line reactor will be needed. Make allowance in proposal.
- Do not install a VFD in a hot, dirty or humid environment without special precautions.
- Do use shielded cable between the VFD and motor.
- Do not install control cables in same trunking, conduit as VFD power cables.
- Do include RFI filters on input to VFD.
- Do use shielded control cables as far as possible - and segregate from power cables at every opportunity.
- Do add additional input reactors, if VFD is installed within 92 feet of a power supply of 1 MVA or more.
- Do allow for output reactors if motor cable length is more than 320 feet or always if mineral insulated type cable is used.
- Do allow for correct sized earth cable as described later.
- Do allow for individual motor protection, if the VFD is driving more than 1 motor.
- Do interface any switches, isolators, contactors on output of the VFD, with the VFD control inputs.
- Do not feed a Star Delta starter with a VFD unless the VFD is held off until Delta sequence is complete and use *late make/early break* contacts.
- Do ensure when using Excel Classic type controllers, that transformers are connected correctly - otherwise 24 Vac can be output from DC analogue control terminals.
- On first time power up always disconnect VFD output cables. Transposed input and output cables can damage VFD.
- Beware: Installing a VFD on a fan supplying air to direct expansion refrigeration coils. Reduction in air flow could cause coil icing or liquid floodback to the compressor, which can cause mechanical failure.
- Do not mount sensors close to an electric motor driven by a VFD. The motor emits higher than normal electrical noise which may interfere with the accuracy of sensors.

Surveying

As with any system, it is crucial that the system is surveyed thoroughly to ensure that the application of the VFD is to be successful and provide trouble free operation. The survey should encompass six areas:

1. Location for the VFD.
2. The motor, control gear and power supply.
3. Mode of control.
4. Type of load.
5. The effect of varying the motor speed on the performance of the machine or service provided by the machine to be speed controlled.
6. Discussion with user.

VFD Location: Enclosures and Ventilation

The VFD is, by comparison with the motor, a relatively expensive machine. It should therefore be installed in a suitable environment. The VFD although very efficient still has some losses which manifest themselves as heat. The VFD should be installed in a well ventilated area, and obviously if installed within a cubicle, the cubicle must have sufficient through flow of air to cool the VFD or its surface area must be sufficiently large to provide natural cooling.

The ambient temperature (surrounding the VFD) must be below 122°F in order to provide correct reliable operation of the VFD. If the ambient temperature is liable to rise above 122°F then either derating of the VFD capacity will be required or additional cooling fans or possibly even a refrigeration unit will be required.

Where the environment is dusty and in particular if the dust is of a conductive nature, then the cooling air should be filtered prior to injection into the VFD enclosure. Again, if the environment is particularly dirty, the enclosure may be sized to provide sufficient natural cooling or a refrigeration unit may be installed. Refer to the technical manual for the individual machine for specific details on mounting and spacing between machines.

Under no circumstances must the VFD be installed within a hazardous area, an area where there is potential for presence of an explosive mixture surrounding the VFD. It may be that the VFD can be installed outside the hazardous area driving a motor within the hazardous area. In this particular circumstance, approvals and special testing are required.

Motor, Control Gear and Power Supply

Take the motor full name plate details, do not assume anything. If the name plate is missing then take full load current readings and measure the supply voltage.

Where there is a local isolator or contactors on the output of the VFD, try to ensure that these devices are interfaced with the VFD via *late make/early break* auxiliary contacts. This ensures that the VFD is aware that the switch is about to be opened before the main contacts open. If programmed correctly, it ensures trouble-free operation. During the opening of a switch controlling an inductive load, such as a motor, very high voltages can be created as the magnetic flux decays. Values as high as 4000 volts have been measured on a standard 400 volt circuit. If these high voltages are allowed to reach the VFD, unpredictable results may occur at the very least or possibly at worst, damage may occur to the power devices within the VFD.

What type of load is the motor driving - if its a fan or a centrifugal pump, then normally there will be no problems, however with process machines, the type of load characteristics can be very important e.g. grinding and mixing machines have very high starting torque requirements (and therefore current demand) whilst once up to speed, the current demand may only be 50% of motor nameplate current.

Beware of old motors. Many motors still in operation have not been rewound in 30 or 40 years of operation. The quality of the insulation materials used in old motors is not often able to cope with the stresses imposed by a VFD. If an old motor is being considered for speed control it would be wise to check if the machine has been rewound in that last 10-15 years. If it has not, then there is potential for a motor failure within a very short period after the VFD is installed.

Effects of Speed Control

Be aware that the system being served by the motor, which is being considered for speed control, may not be able to accept a varying volumes or special consideration may be required. Typical examples would be chilled water pumps feeding chillers and heating water pumps feeding boilers. Centrifugal or screw-type chillers usually have temperature control on the leaving water side of the machine. This will provide the feedback to the chiller so that it can reduce capacity without adverse effects. There is however a minimum flow rate that the machine will accept before problems occur. Laminar flow through the tube bundle is a typical example. Refer to manufacturers details carefully before considering this type of application - but it can be done successfully.

On chillers with reciprocating compressors, the temperature controls often placed in the flow on to the machine. In this case the temperature control system would not see the reduced flow and a trip on low leaving water temperature will occur. Special consideration is required.

Boilers are another example where if the flow rate through the machine is reduced too much, problems can occur. The boiler requires a minimum flow rate to produce turbulence within the heat exchanger in order to control *hot spots*. If the flow rate is reduced below this value then there is a possibility of *hot spots* occurring resulting in damage to the heat exchanger

IMPORTANT

Ensure that the user is fully aware of and agrees with the implications of applying speed control before proceeding.

EMC Wiring and RFI Filters

— Mount the RFI Filter as close as possible to the VFD input terminals, with cables as short as possible. Install at least one ferrite ring on the VFD output. Pass all conductors through the same ring. If possible, put one full turn of each conductor around the ring. If this is not possible and there are problems, add additional ferrite rings.
— Connect the filter to ground via its own earth strap, at least 1/2 in. (10 mm) wide and as short as possible.
— Use armored or shielded cable from the VFD to the motor. Connect the armor gland to the motor frame and the VFD main earth terminal with a heavy cable at least as large as the power conductors and as short as possible.
— Do not connect any signal 0V common to ground at the VFD. Ground at the controller end.

Line Reactors

Line reactors can be used on both VFD inputs and outputs.

Input Line Reactors

The installation of a large number of VFDs or other similar equipment can distort the current and voltage waveforms of the power supply, to the point which exceeds the power supply company guidelines or to the a level that other equipment served by this power supply is prevented from operating correctly. In such a case, including input line reactors provides additional smoothing to that provided by the DC choke. This reduces the overall VFD disturbance. Input line reactors can reduce the amount of radio interference produced by the VFD on the power line back into the distribution system. Tests have shown that typically 10 dB reductions in noise levels can be achieved, however the optimum situation is to install both input line reactors and RF filters.

Output Line Reactors

Reactors may need to be fitted on the VFD output for several reasons:

— If the VFD to motor cables are long, 320 feet or more, then capacitive leakage from the cables to earth can be so high that the VFD sees this as a fault and can trip on earth fault or over-current. It is difficult to be specific on this point as the capacitance varies according to: type of cable, proximity of individual conductors relative to each other, and the conductor shielding.

— With one large VFD driving multiple small motors, it is often specified that individual motors can be switched on and off the VFD without stopping the whole system. When the motor is disconnected from the VFD, a line reactor in the supply to each motor: acts as a current limiter, and helps absorb voltage spikes.

— Lightly loaded motors, when driven from a commercial power supply, can often mislead the surveying engineer into assuming that a VFD several frame sizes smaller than the motor can be selected for the application. Problems can occur when the VFD starts the motor. Even though the load is small, the motor current draw at low speed can be much higher than at full speed. This is due to the fact that the motor winding at low speed is a more resistive than inductive load. Typically, the VFD is unable to accelerate the motor due to over-current and it finally trips. Adding a line reactor to the VFD output reduces current magnitude and can *rescue* the situation.

— When sudden shock loads, contactors, or switches on the VFD output are encountered, an output line reactor installed can reduce the impact of these occurrences that cause trips or damage to the VFD.

— Mineral insulated cables from the VFD to motor have often been a problem. The conductors in these cables are so close to each other that higher than normal leakage losses occur. Also, there have been occurrences of gland failure at cable ends for no apparent reason. On installations where output line reactors have been installed together with mineral insulated cables, no problems have been reported. This may be a coincidence, as there is insufficient data to form a positive conclusion. It appears that the *softening* of the output pulses by the line reactor has a beneficial effect where mineral insulated cables are used.

RFI

Sources Of Emissions

VFD emissions fall into 2 categories: conducted and radiated (see Fig. 28). It is important to recognize that the VFD itself does not radiate much RF energy. Within 8 inches of the VFD, the field strength can be high and can interfere with the correct operation of sensitive equipment. Beyond the region shown in Fig. 28, the field strength quickly diminishes by the inverse cube law. Beyond 300 mm the field strength is generally insignificant.

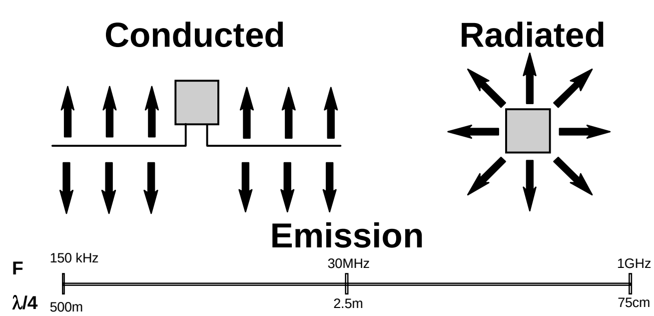


Fig. 28. Conducted and radiated emissions.

Routes for Emissions

The main route for the RF energy is out through the VFD output terminals. See Fig. 29.

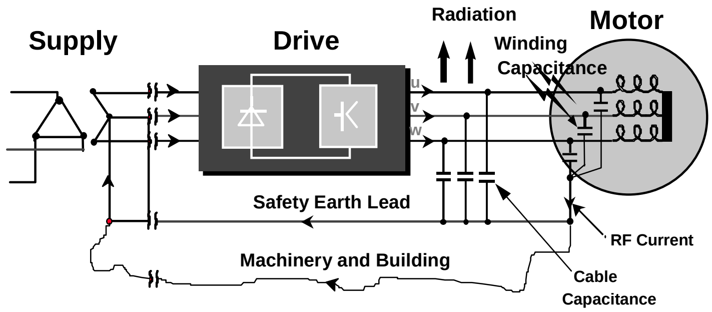


Fig. 29. Emission routes.

Without Input Filter

The VFD can be considered as a source of radio frequency (RF) current which leaves the output terminals. The capacitance of the output cable (motor cables) and the motor windings represents a relatively low impedance path to this *noise* current which flows back to the input terminals of the VFD via the main safety earth and then the input conductors. Any equipment coupled to the distribution network will effectively *see* this RF at its power supply input. If this path is not well defined and low impedance then the route back to the VFD input may be via unexpected path which may disturb nearby sensitive equipment.

To ensure the minimum possibility of disturbance to sensitive equipment, ensure that a low impedance path is provided for this current via a conductor at least the same cross section as the power conductors.

With Input Filter

When a correctly designed input filter is used with a VFD, then the path back to the VFD, for the RF current in the safety earth, is greatly reduced. The capacitors in the filter effectively provide a short circuit for the high frequency current.

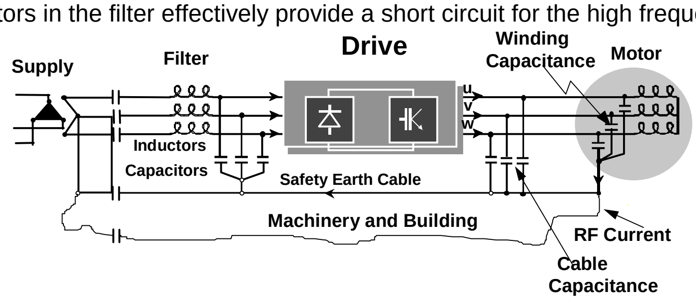


Fig. 30. Effect of an input filter.

Shielding Motor Cables

Where further reductions in RF emissions are required, shielded motor cables can be employed. Standard armored cable has proven to be adequate for this purpose, resulting in 1/30 of the original emissions. The motor chassis should be connected to the safety earth, in the normal manner, with the both ends of the armored cable also connected to the safety earth. The safety earth cable should then be taken directly to the VFD earth terminal, before progressing to the main distribution earth. See Fig. 31.

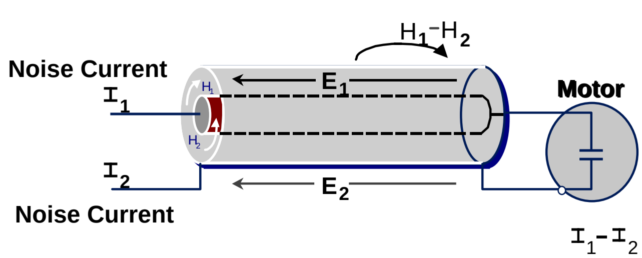


Fig. 31. Shielding motor cable.

Equipment Categories

Non Sensitive

Equipment falling into this category are simple electromechanical device:
— Relays.
— Contactors.
— Electric motors.
— Solenoid devices.

Care Required

Many electronic devices are insensitive to VFD emissions due to the spectrum at which this interference is generated and the ability for the target equipment to locally filter out the noise. Computers, and digital equipment generally working above 1 Vdc should not normally suffer from these emissions, unless they have circuits within them or externally connected, which fall into the following category. Many control systems have this combined categorization.

Sensitive

Any analog measuring circuit using low level signals:
— Thermocouples.
— Resistive temperature sensor.
— Humidity sensors.
— Strain gauges.
— pH sensors.
— Audio circuits.
— Proximity sensors.

Computer digital circuits, Ethernet and RS 232 have good immunity to VFD RFI, provided the cabling is correctly installed with high quality screening.

Very Sensitive

Systems that are specifically designed to be sensitive to electromagnetic radiation the band 100 kHz to 5 MHz:
— Radios designed to work in the long wave and medium wave bands.
— Inductive-loop pagers and communication systems.
— Power line carrier systems.

Radio receivers with input filters and shielded cables have little chance of problems outside a 3 to 9 foot radius around the system. Televisions, VHF radios, and mobile telephones using high frequencies are generally unaffected by VFD RFI.

General Wiring Standards

Sensitive equipment should not be installed within 1 foot of the VFD and its associated input and output cables. Parallel runs of any control signal cables and the input and output cables should be avoided. Where this is not possible then the control cables should be correctly shielded but not installed with 1 foot of the input and output cables of the VFD. See Fig. 32.

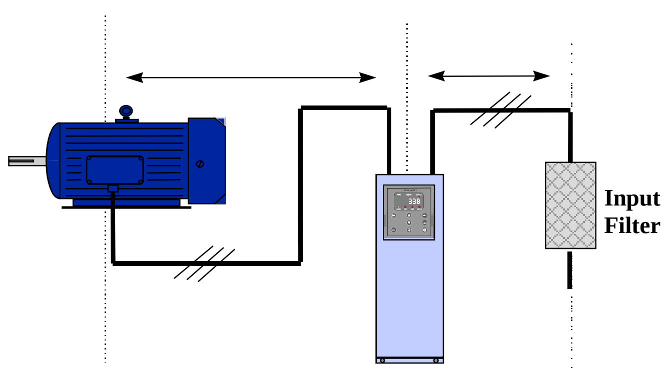


Fig. 32. Distances to keep as short as possible.

Where control signal cables need to cross VFD input and output cables this should be done at right angles with no parallel runs. See Fig. 33.

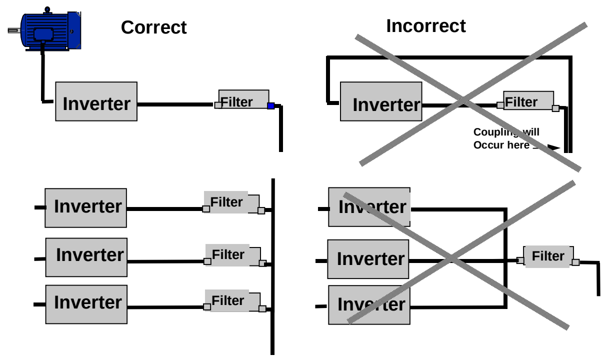


Fig. 33. Locating filter and VFD control signal cables.

Filter Location

Fig. 33 adjacent shows various VFD and filter installations. Where possible the filter should be installed as close as possible to the VFD and most importantly, the earth conductor from the filter to ground, should be at least the same cross section as the power conductors. The optimum configuration is 1 filter per VFD. VFD output cables should not be run close to the VFD input power cables as there will be some pickup from the output cable, even though it may armored or screened in some other way.

VFDs are a major source of interference. However, with good engineering practices, large numbers can be installed in proximity with sensitive equipment, with no adverse effect. As design technologies advance, more sophisticated control of the VFD output devices will make significant reductions in the area of RFI emissions. VFDs are here to stay for the foreseeable future, reducing plant running costs and enhancing our environment.

APPLICATIONS

Fig. 34 indicates the typical duty expected from a fan or a pump used in Heating, Ventilating and Air Conditioning (HVAC) applications (data supplied by the DTI) It can be seen from the graph that for the majority of the running life of this fan or pump, it has *over capacity*. The reason for this excess capacity is to accommodate fluctuations in loads due to weather conditions, changes in occupancy. The excess in flow is usually controlled either by throttling, using dampers or valves, or redirecting the excess capacity via by-pass ductwork or pipelines. The result of this is type of control is increased running costs and in some cases increased noise and vibration from the plant. This situation also often occurs in industrial applications, as the through-put of the process is inevitably variable. In many cases a VFD can be installed to control the speed of a motor and thus the capacity of the plant, providing reduced running costs and enhanced environmental conditions, as a result of reduced noise and drafts.

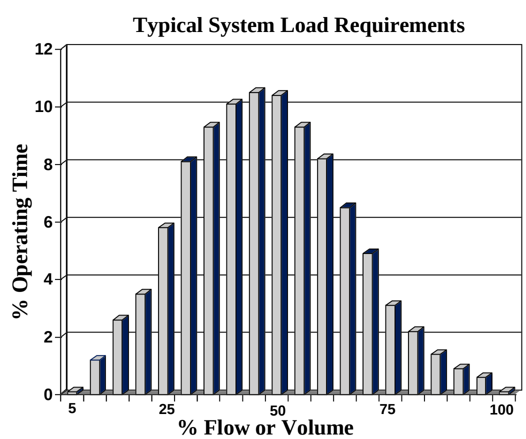


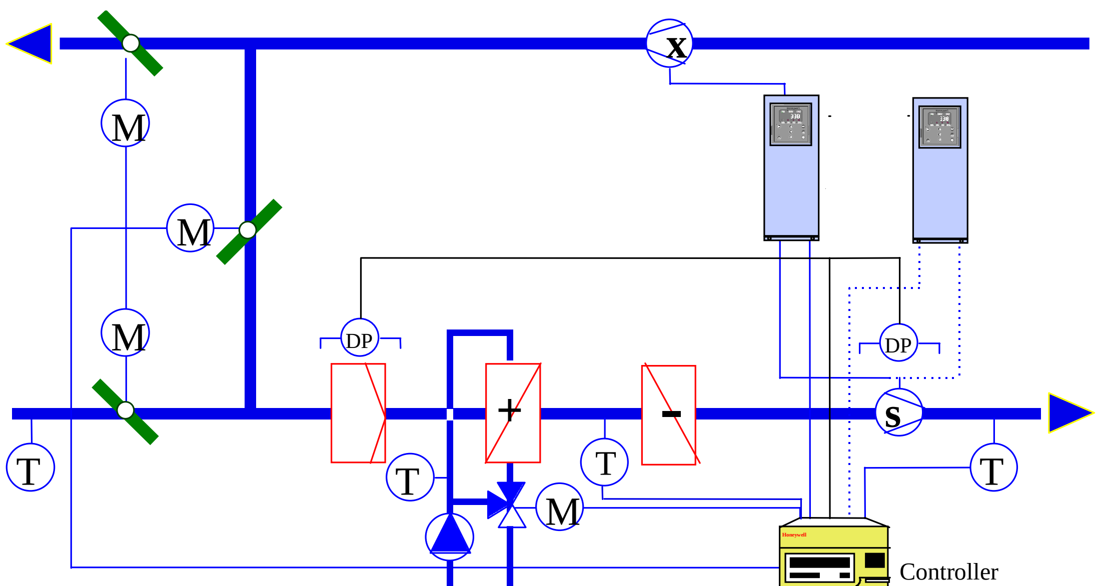
Fig. 34. Typical system load requirements.

APPLICATIONS

- Fans.
- Pumps.
- Mixers.
- Boilers.
- Compressors.
- Conveyors.
- Elevators.
- Machine Tools.
- Textile machinery.
- Paper and film manufacturing.

VFD OVERVIEW

Honeywell has long been aware of the full benefits of VFDs, and has installed them in a wide range of applications from fans, pumps, and compressors to machine tools, elevators and textile machines. The following applications are a sample of some of the installations and are intended to give an understanding of how a VFD can be utilized in the heating, ventilating, air conditioning (HVAC) and other industries. See Fig. 35.



NOTE: One inverter could be used, but two will provide better control

Fig. 35. Constant Air Volume (CAV) application diagram.

Application Description

A Constant Air Volume (CAV) System controls space temperature by altering the supply air temperature while maintaining constant airflow. The system design provides sufficient capacity to delivery supply air to the space for design load conditions. Only at maximum load conditions - full heating or full cooling - is maximum air flow required, at other periods it is perfectly feasible to vary the airflow while maintaining design conditions. Installing a VFD and linking into the existing temperature controls, allows the air flows to be varied relative to load conditions (see Fig. 36). The motor will only run at full speed when *full heating* or *full cooling* is called for.

Benefits

— Reduced running costs - typical savings 40% and 14 months payback, dependent on power consumption.
— Maintenance savings arise from running the motor at reduced speed which lowers the load torque; lessens mechanical stress on belts, bearings.
— Environmental comfort increased as a result of reduced air velocity - less draughts - and lower background noise levels.

VFD Features Used

— Soft Start - Reduced starting current and avoids pressure surges.
— Motor Speed Low Limit - Minimum air movement levels programmable.
— Automatic Continuous Operation - VFD will still run if control/speed reference signal is lost.

IMPORTANT

1. *Ensure minimum airflow is maintained.*
2. *Beware of low air quality: See CAV + Air Quality*

Operation (See Fig. 36)

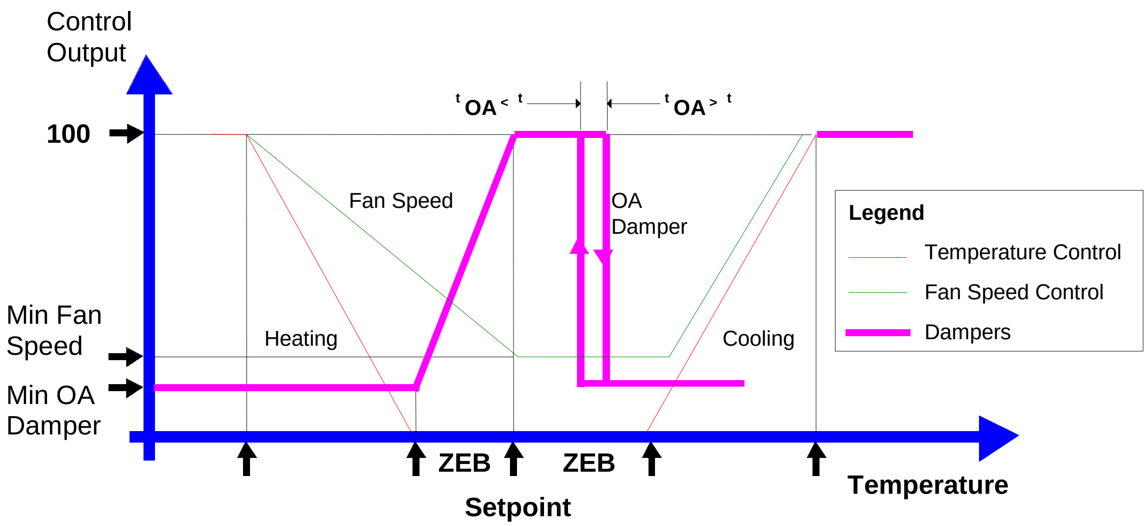


Fig. 36 Sequence of Control

Constant Air Volume with Air Quality Compensation (See Fig. 37)

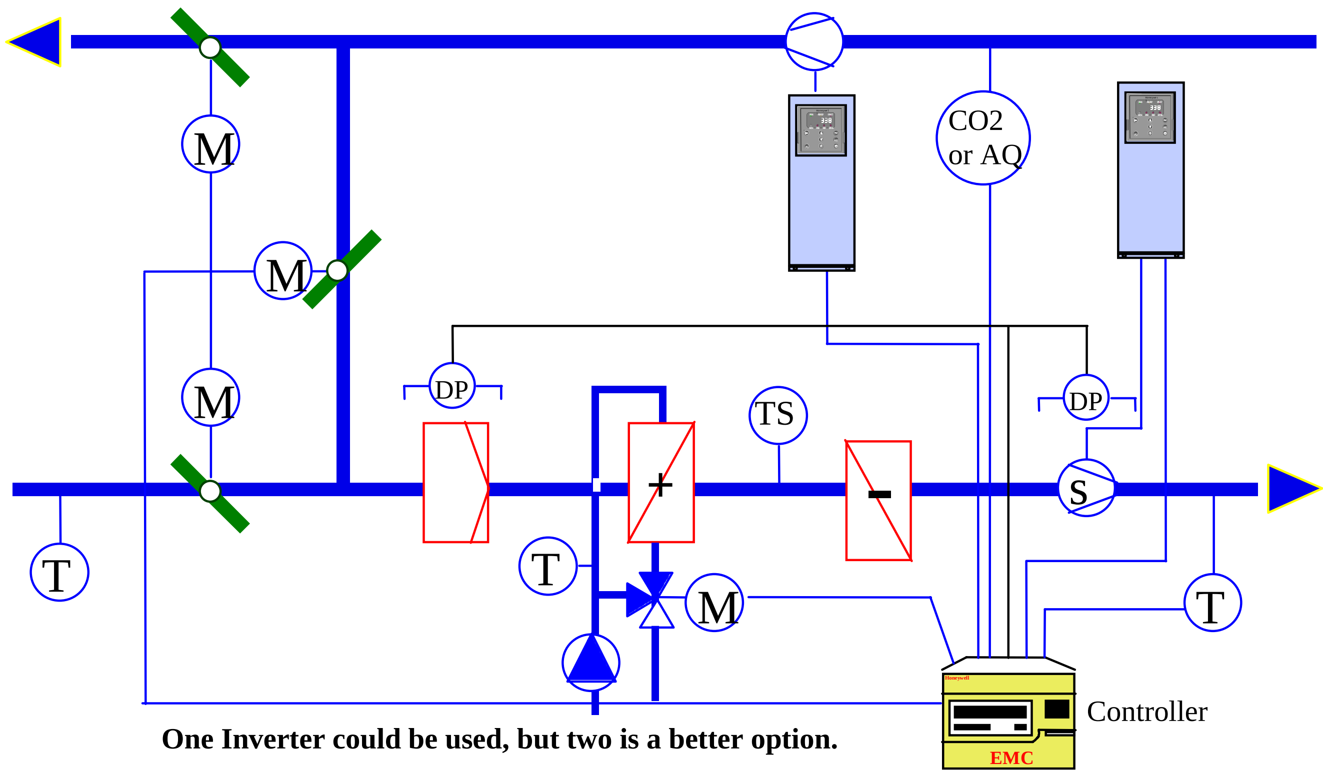


Fig. 37 Application Diagram.

Application Description

The application is as the previous standard CAV application, but with the addition of an air quality (AQ) or CO_2 detector fitted in either the extract duct or within the space. The air quality detector will control the dampers and the VFD in sequence.

As an example the temperature control could be satisfied with minimum heat output and supply/extract fan running at slow speed. With a large density of people in the space the air quality could be low (cigarette smoke, stale air and CO_2), while maintaining temperature control conditions.

The AQ detector could compensate for this by opening the fresh air dampers and increasing the fan speed in sequence. The control circuit will be modified to include two highest of two signal selector relays on the inputs to the VFD and the fresh air dampers.

Possible Usage

— Airport arrival and departure lounges.
— Theaters.
— Cinema.
— Lecture halls.
— Exhibition halls.

Benefits

— Reduced running costs.
— Maintenance savings due to reduced mechanical stress.
— Improved indoor air quality.

VFD Features Used

— Power failure recover.
— Speed search.
— Possible DC injection on start.
— Overspeed capability for increased performance.

IMPORTANT
Ensure minimum number of air charges per hour is still met, by using VFD low limit.

Operation

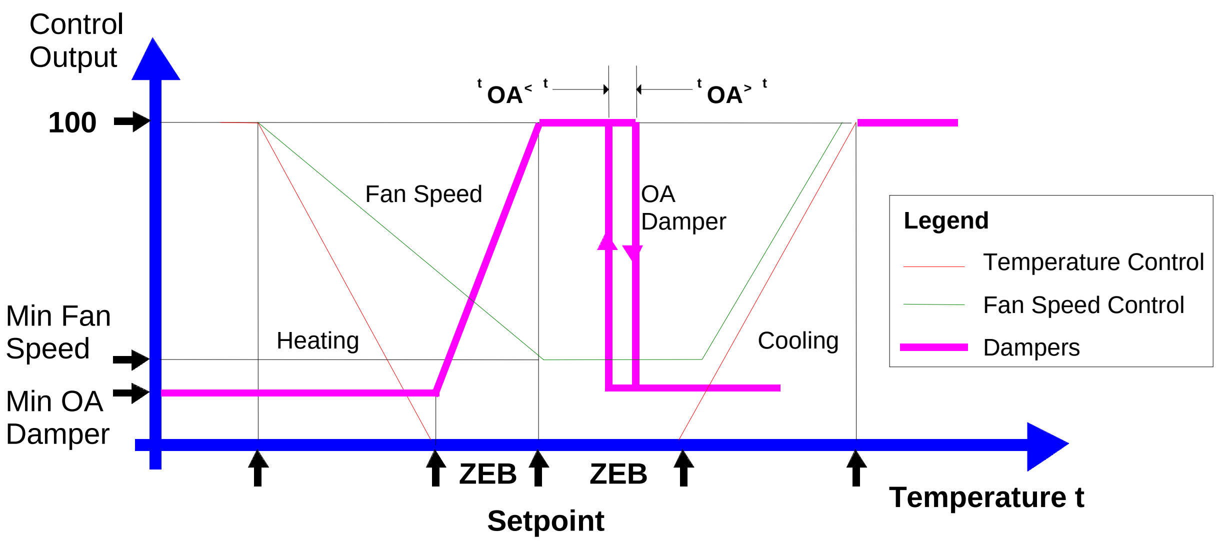


Fig. 38 Sequence of Control: Temperature.

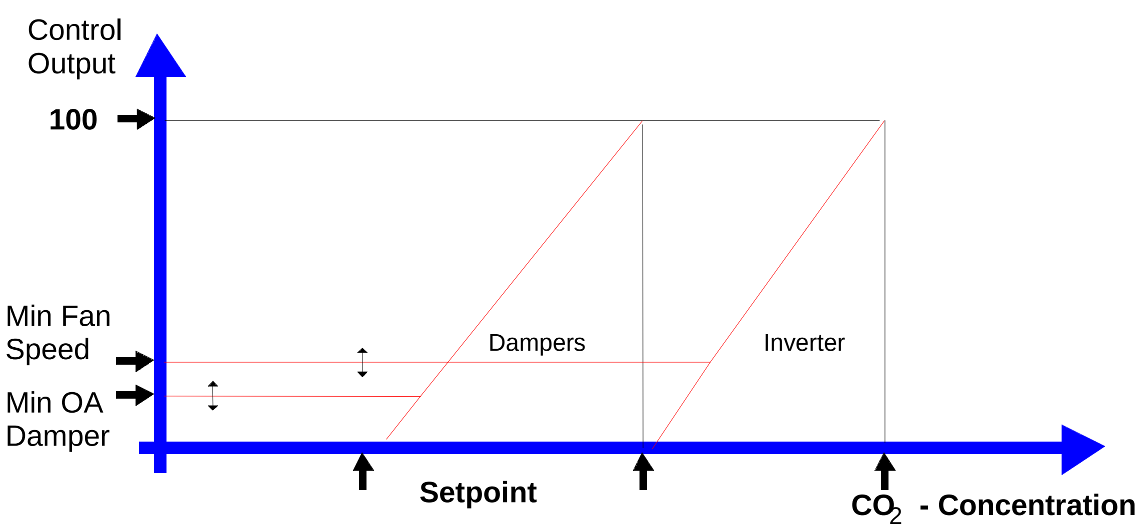


Fig. 39 Sequence of Control: Air Quality.

Variable Air Volume (VAV) Primary Plant Control (See Fig. 40)

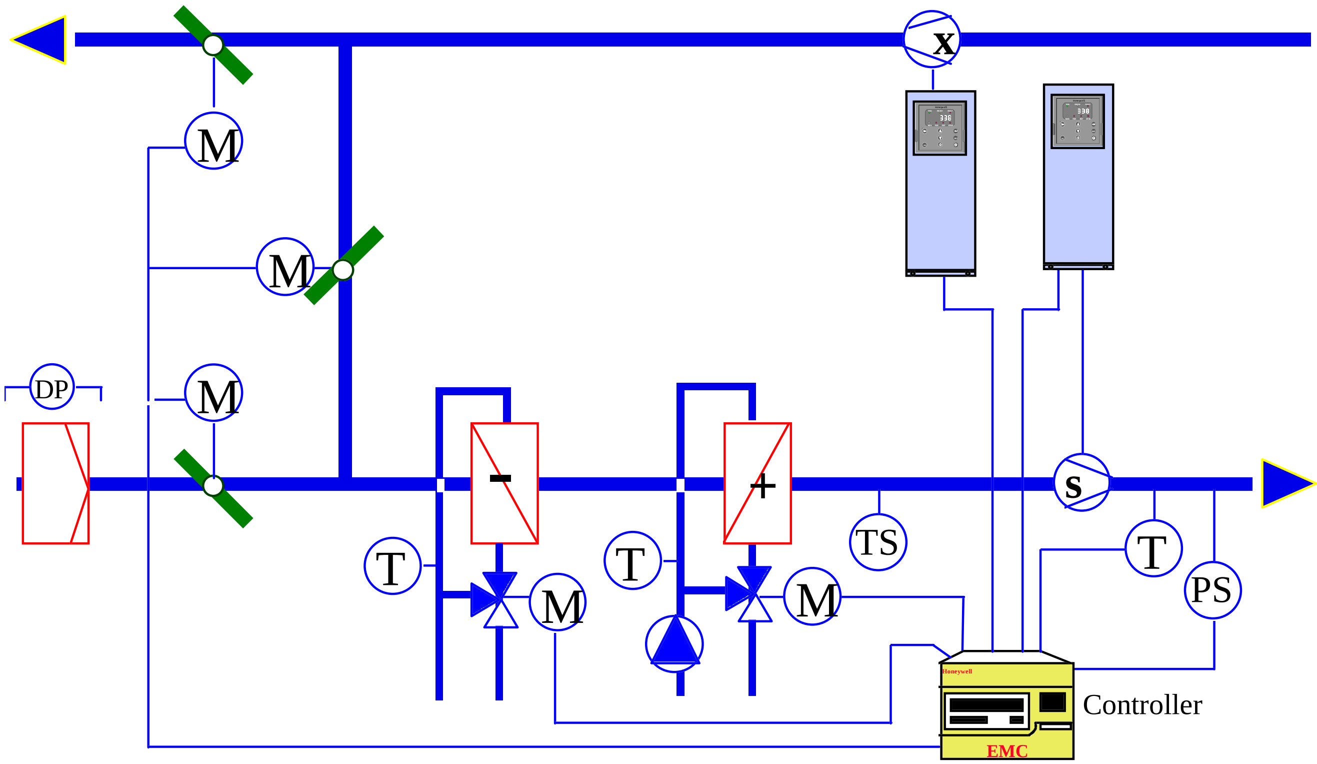


Fig. 40. Application Diagram.

Application Description

A Variable Air Volume (VAV) system controls the space temperature by varying the volume of supply air, rather than the supply air temperature. The interior zones of most large buildings normally require cooling only, because of occupancy and lighting loads. Air terminal units serve these zones and operate under thermostatic control to vary the airflow into the space to maintain the required temperature. The perimeter zones often have a variable load, dependent on the season and the losses through the building fabric. Heating in these areas may be supplied via reheat coils while the air terminal units maintain minimum airflow.

Airflow in the supply duct varies as the sum of the airflow through each unit varies. In light load conditions the air terminal units reduce airflow; as more cooling is required, the units increase airflow. When the VAV terminal unit dampers open, the static pressure drops in the supply duct; the sensor detects the pressure drop and the controller increases the speed of the supply fan. The opposite occurs when the VAV terminal unit dampers close.

A feature of VAV systems is that the minimum outside air delivered by the system is determined by the difference in air flow between the supply and return fans (and not the position of the outdoor air damper). To increase the volume of outside air, the return air damper is regulated. This airflow control provides a slightly positive building static pressure with respect to outdoor air, in a properly designed system. As supply air volume is reduced, so is return air volume. The return air fan is normally sized smaller than the supply air fan. Air velocity sensors are located in both the supply and return ducts, so the control of the return air fan mimics the supply air fan; the airflow in both ducts are controlled with a constant differential.

Benefits

– Reduced electrical running costs; especially when compared with the traditional guide vane control—with no energy savings—where the motor is running at full speed all the time.
– Maintenance savings arise from running the motor at reduced speed which lowers the load torque; lessens mechanical stress on belts, bearings.

VFD Features

— Soft Start: Reduced starting current and avoids pressure surges.
— Motor Speed Low Limit: Minimum air movements levels programmable.

Cooling Tower Fans (See Fig. 41)

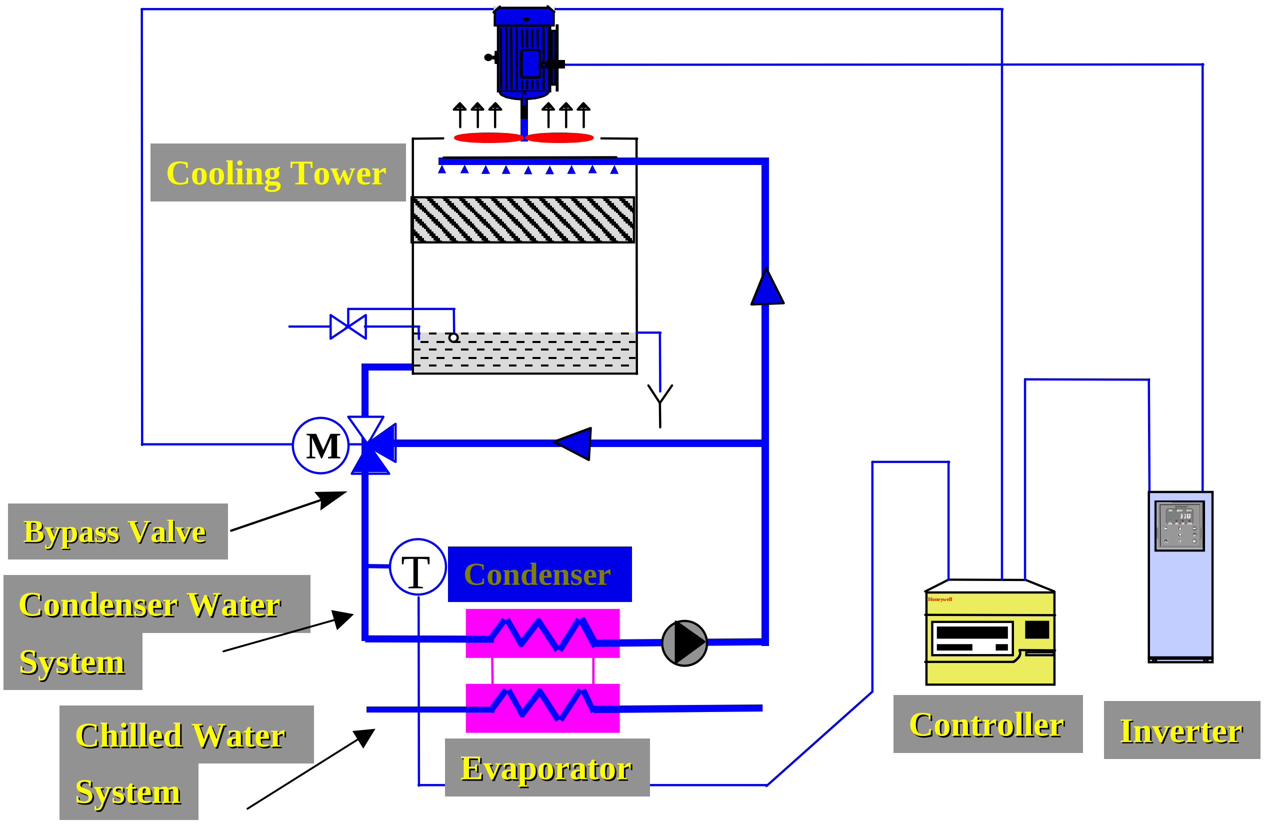


Fig. 41. Application diagram.

Application Description

A chilled water system is made of three main elements: refrigeration unit (water chiller), chilled water distribution network, and a means of dissipating heat collected by the system. The towers dissipate this collected heat by cooling the condenser water. The cooling effect in evaporative type cooling towers is dependent on the ratio of water to air contact and wet bulb temperature.

Traditionally when the condenser water is flowing fully over the tower the fan or fans are cycled on and off to control the water temperature. Partial load operating characteristics have a strong influence on operating costs. As most operation is at less than design load, fitting a VFD and varying the speed of the fan is a far more efficient means of controlling the condenser water temperature. For maximum chiller efficiency the condenser water temperature should be as low as can be used by the refrigeration system dependent on outdoor air conditions (i.e. wet bulb temperature).

When outside air wet bulb temperature is lower than design, the tower can cool water to a lower temperature, (but can never reach the actual wet bulb temperature). Therefore, the controller setpoint should be at the lowest setpoint attainable (by the tower) to save chiller energy and not waste fan energy trying to reach an unobtainable value.

Benefits

— Reduced wear and tear.
— Improved control (straight line)—more stable chiller operation.
— Fewer start/stops.
— Energy saving.

VFD Features Used

— Power failure recovery.
— Speed search.
— Possible DC injection on start.
— Overspeed capability for increased performance.

IMPORTANT
In multi-fan applications under VFD speed control, all fans should operate in unison.

Operation (See Fig. 42)

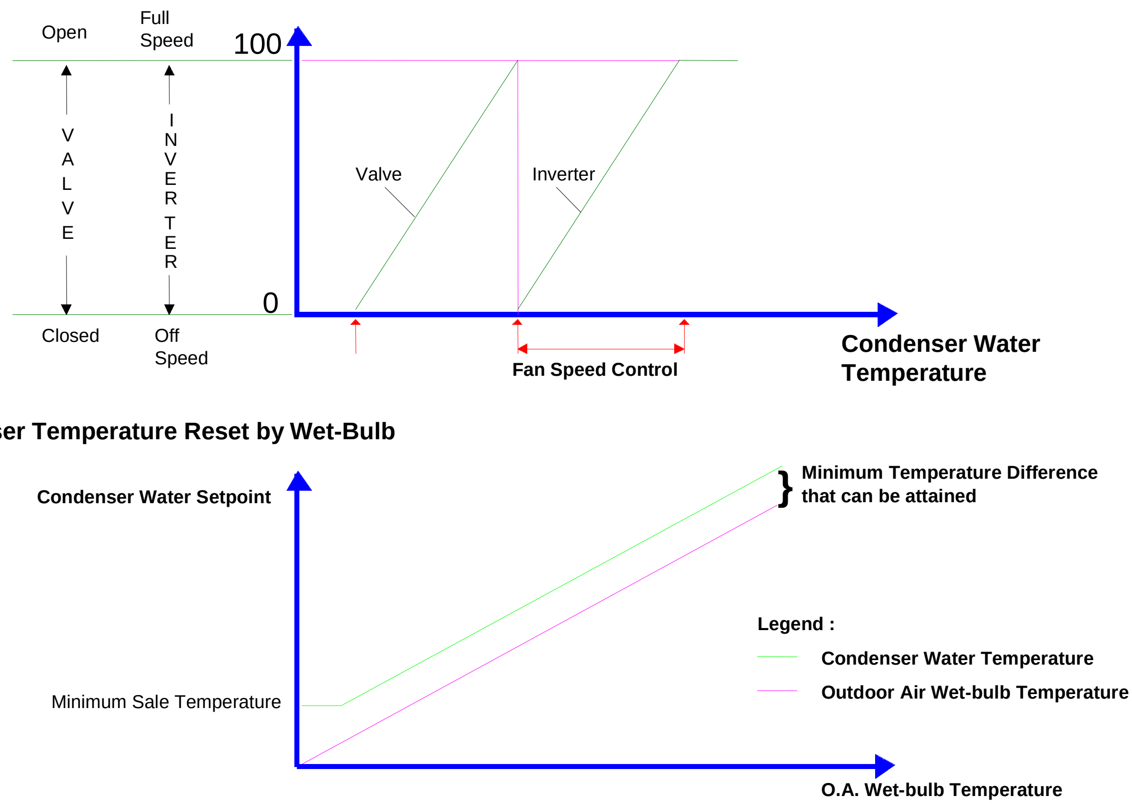


Fig. 42. Sequence of Control.

Primary Chilled Water Option 1 (See Fig. 43 and 44)

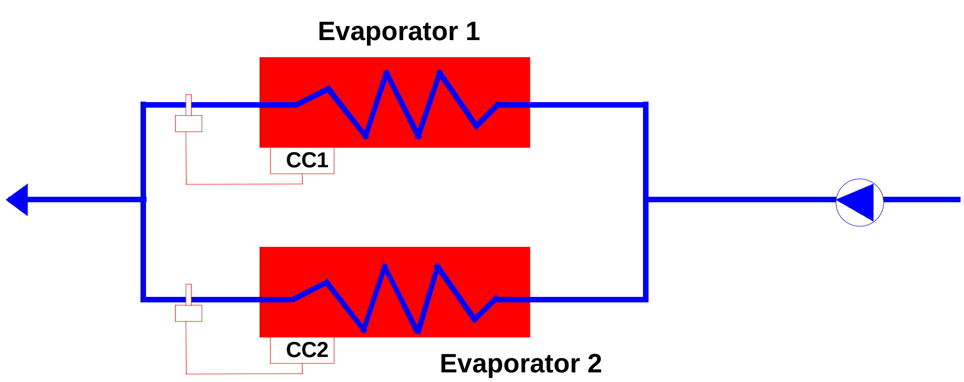


Fig. 43. Application without VFD.

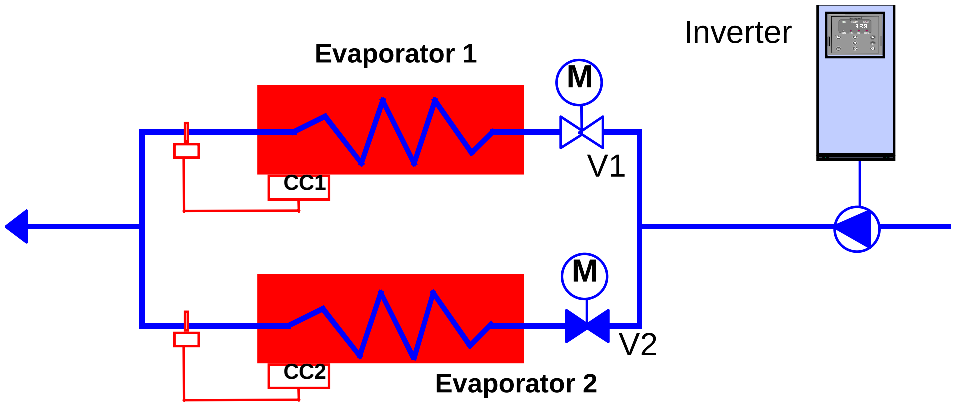


Fig. 44 Application with VFD.

Application Description

Chillers with evaporators piped in parallel (see Fig. 43) and controlling on either flow or return from the machine. Often, under light load conditions, chiller two will close down (to prevent short-cycling). This results in a rise in CHW supply temperature to the building, as 50% of water circulates through the *off* chiller (supply temperature is average of flow from the two machines).

A more energy efficient means of controlling the plant would be to install valves V1 and V2 and a VFD on the circulation pump (as in Fig. 44). Under light load conditions, one machine running and the other isolated, by closing valve V2 the VFD speed can be reduced to give the design flow rate through the “on” machine. As the demand increases the VFD speed can be increased to give full design flow for the two machines, the valve for number two chiller opened and the second machine started.

Benefits

— Energy savings: Chilled water pump and second chiller off for longer periods.
— Reduced maintenance: Fewer starts and stops and machine not having to run under light loads.
— Supply temperature to the building will be more stable.
— Reduced noise.

VFD Features Used

— Digital speed control.
— Auto-restart.

IMPORTANT

The VFD speed must be increased and full flow achieved, before the second valve is opened. Otherwise a flow failure trip may occur on the number 1 machine. It is also advisable to pulse this valve open as slowly as possible.

Primary Chilled Water Pump with DDC Control of Plant Option 2 (See Fig. 45 and 46)

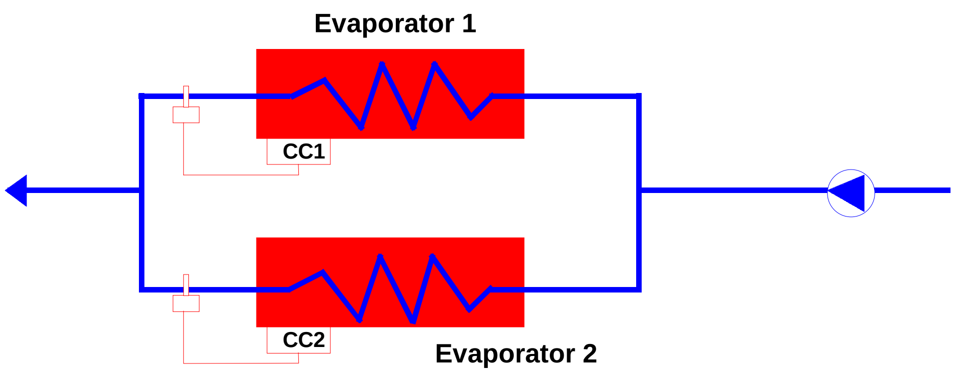


Fig. 45. Application without VFD.

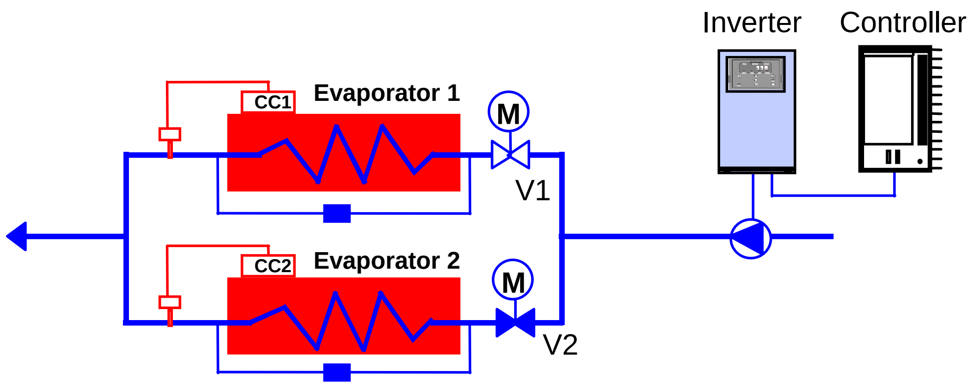


Fig. 46 Application with VFD and Excel Plus

Application Description

If the chillers in the previous example (option 1) are controlled on the flow from the machine and also have Direct Digital Control or a building management system installed on the air handling and chiller plants, an even more efficient and effective means of control is available.

The control software is made up of three elements :
— Safety factors, ensuring the minimum design flow rates for each chiller.
— Flow control for supplying the volume of water to suit the needs of the AHU. with the highest demand.
— Load control for sequencing the two machines.

The first element is the low limit control to set the minimum speed of the VFD (minimum design flow) while one machine runs and then increase the pump speed when both machines run to satisfy the minimum design flow rate (plus a 15% safety factor). This would act as a 2 position low limit.

The flow rates (pump speed) can then be varied to suit demand. This is achieved by inputting the feedback position of each AHU. bypass valve into a control loop. Using a predetermined setpoint, e.g. 85% open and P+I control, the output from each loop is fed into a load selector relay (highest signal). The output from the load selector is the control signal to the VFD. If this signal is higher than the low limit, the pump motor speed is increased and hence increase the flow rate. Conversely, as the AHU. with the highest demand begins to close its valve the flow rate would be reduced accordingly.

The third element in the control function is the load control or sequencing of the two machines. With one machine running its total load can be measured, as the chiller approaches full load e.g. 95% it can signal for the second machine to start. The total load of the machine can be measured by a current transducer measuring the current drawn by the chiller motor. Another possibility is by using pressure transducers to measure the differential pressure and by sensing the differential temperature across the evaporator and then calculating the instantaneous load. This later method is probably the safer as the differential pressure signal can be used as an input into the low limit flow control. The former is more accurate for starting the second machine at set load conditions. A variation of this system could be to have more than one chilled water pump and to sequence them on and off according to load.

Benefits

— Energy savings: Lag chiller will be off for longer periods.
— Reduced maintenance: Few starts and it is unwise to cycle chillers on and off under light load.
— Supply temperature to the building will be more stable.
— Reduced maximum demand: Fewer starts especially during winter.
— Reduced noise.

VFD Features

— Auto restart.
— Speed search.
— Overspeed.
— Overtorque protection.
— Stall prevention.
— Analog or digital control.

IMPORTANT

Very careful calibration of controllers is required to ensure that the chillers are safeguarded under all conditions. The chillers built-in controllers will still control at their original value. The supply temperature to building will not change. When starting the second chiller, the isolating valve must be opened as slowly as possible, to prevent the on machine tripping under low flow condition.

Secondary Chilled Water Pump Option 1 (See Fig. 47)

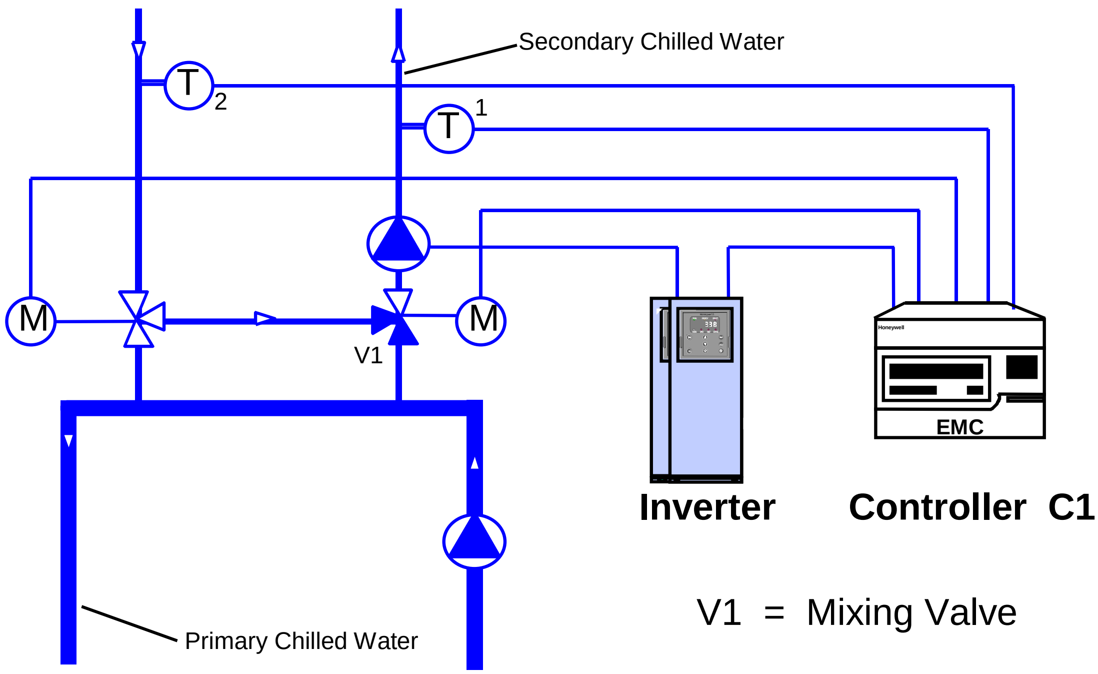


Fig. 47. Application diagram.

Application

Conventional Control Valve V1 is modulated by controller C1 with sensor T1 located in the secondary chilled water flow. The objective is to give a constant supply temperature at T1. The return temperature at T2 will vary relative to the load. Only at full load (hottest period of the year) will the return temperature be at design.

At all times a fixed speed circulating pump supplies the design water volume required to satisfy maximum load conditions. When full load capacity is not required (for most of the year) energy is continuously being wasted - a more economic system would be to install a VFD to control the pump circulating rate against the return temperature measured at T2. The controller setpoint would be the (design full load) return temperature.

As the flow rate is now being varied, the need for the three port valve is reduced, the bypass balancing values can be set down to a minimum.

Benefits

— Reduced noise from water pipework.
— Reduced maximum demand.
— Reduced wear and tear on machinery.
— Ability to overspeed the pump to increase capacity.
— Energy-saving on chillers.
— Energy-saving on heat loss through lagging. Return water temperature will be higher.

Secondary Chilled Water Pump with DDC Control Option 2 (See Fig. 48)

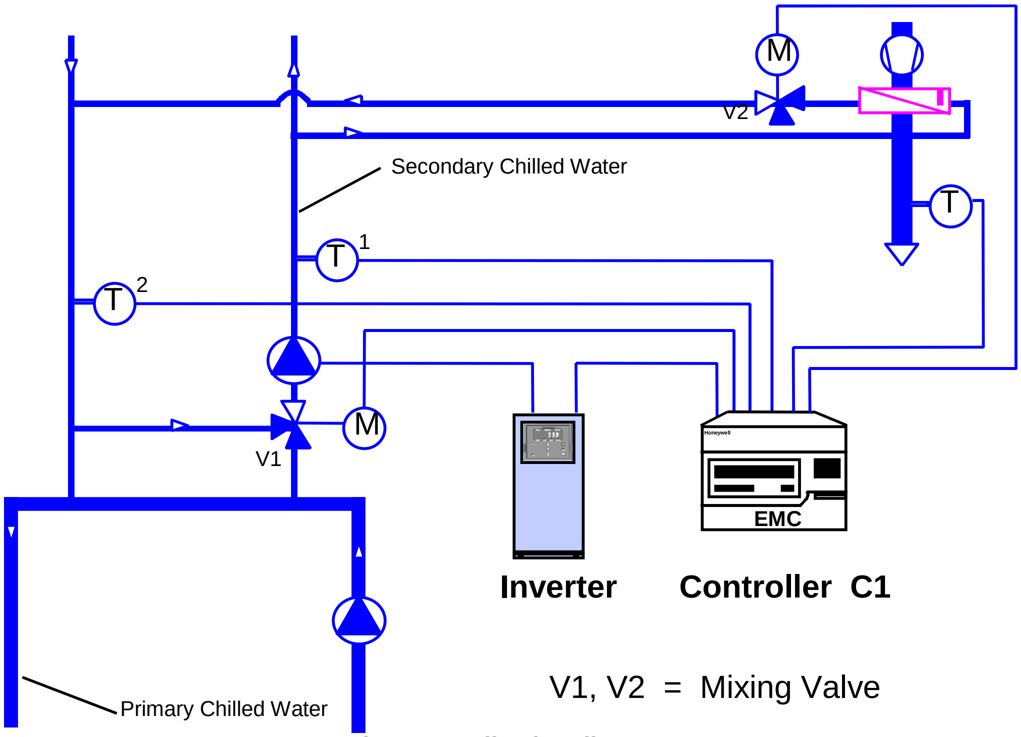


Fig. 48. Application diagram.

Application

If the existing plant is controlled by Direct Digital Control or connected into a Building Management System, an even more effective method of controlling the rate of flow of the secondary chilled water pump is available. The bypass port balancing valves can be set down to a minimum position and the VFD can be set for a low limit speed than will satisfy minimum requirements. The feedback position from each bypass valve can be used as an input to a control loop. Using a predetermined setpoint, e.g. 85% open and P+I control, the output from each loop is fed into a load selector (highest signal). The output from the load selector (equivalent to the AHU with the highest demand) is the input to the VFD. Any increase in valve position above 85% would cause the VFD to increase speed and hence increase the flow rate. Conversely as the AHU with the highest demand begins to close its valve it would cause the flow to decrease. Hence optimizing the pump flow volumes at all times.

Benefits

- Reduced noise from water pipework.
- Reduced maximum demand.
- Reduced wear and tear on machinery.
- Ability to overspeed the pump to increase capacity.
- Energy-saving on chillers.
- Energy-saving on heat loss through lagging as return water temperature will be higher.

VFD Features Used

- Auto restart.
- Speed search.
- Overspeed.
- Overtorque protection.
- Stall prevention.
- Analog or digital control.

IMPORTANT

Take care with choosing the setpoint for each control loop.

Heating Secondary Water Circuit (See Fig. 49)

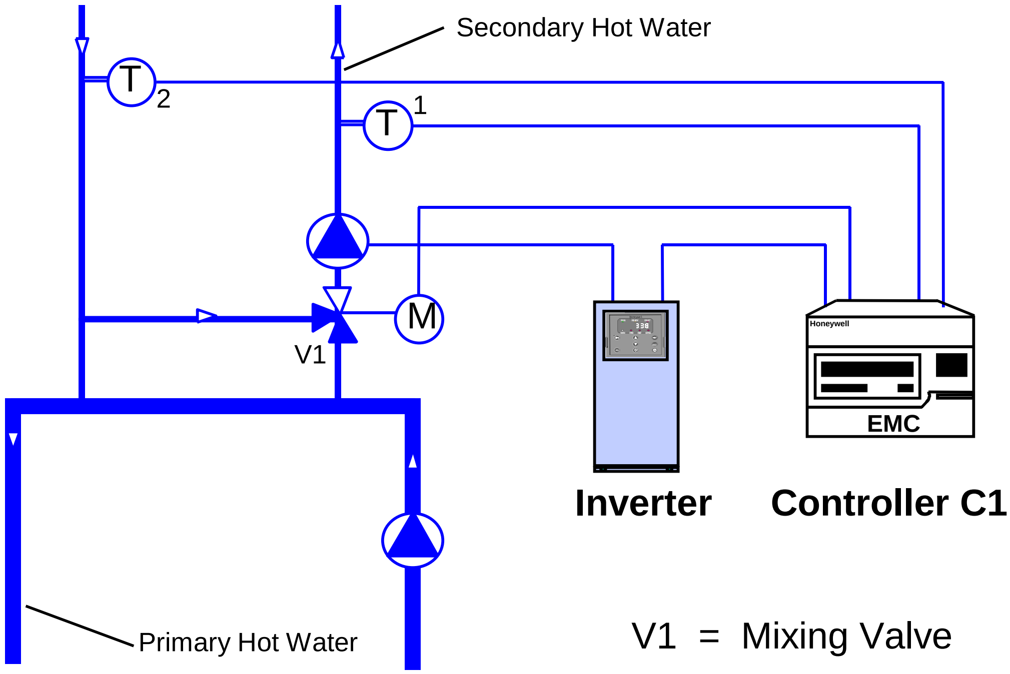


Fig. 49. Heating secondary water circuit application.

Application Description

Conventional Control Valve V1 is modulated by controller C1 with sensor T1 located in the secondary hot water flow. The objective is to give a constant supply temperature at T1. The return temperature at T2 will vary relative to the load. Only at full load (coldest period of the year) will the return temperature be at design. At all times a fixed speed circulating pump supplies the design water volume required to satisfy maximum load conditions. When full load capability is not required (for most of the year) energy is continuously being wasted - a more economic system would be to install a VFD to control the pump circulating rate against the return temperature measured at T2. The controller setpoint would be the (design load) return temperature. As the flow rate is varied, the need for three port valve bypass circuit reduces, and balancing values can be set down to a minimum. The circulated water volume is always at an optimum as setpoint is equivalent to full load conditions, thus energy consumption is at a minimum.

Benefits

— Reduced noise from water pipework.
— Reduced maximum demand.
— Reduced wear and tear on machinery.
— Ability to overspeed the pump to increase capacity.
— Reduced demand on the boilers.
— Energy-saving on heat loss from lagging: Return water temperature will be higher.

VFD Features Used

— Auto restart.
— Speed search.
— Overspeed.
— Overtorque protection.
— Stall prevention.
— Analog or digital control.

IMPORTANT

The setpoint of T2 must be carefully adjusted as under certain circumstances this may not satisfy the requirements of all of the air handling units served by the pump. In this case, the setpoint should be increased.

Steam Boiler Make-Up Pump (See Fig. 50 and 51)

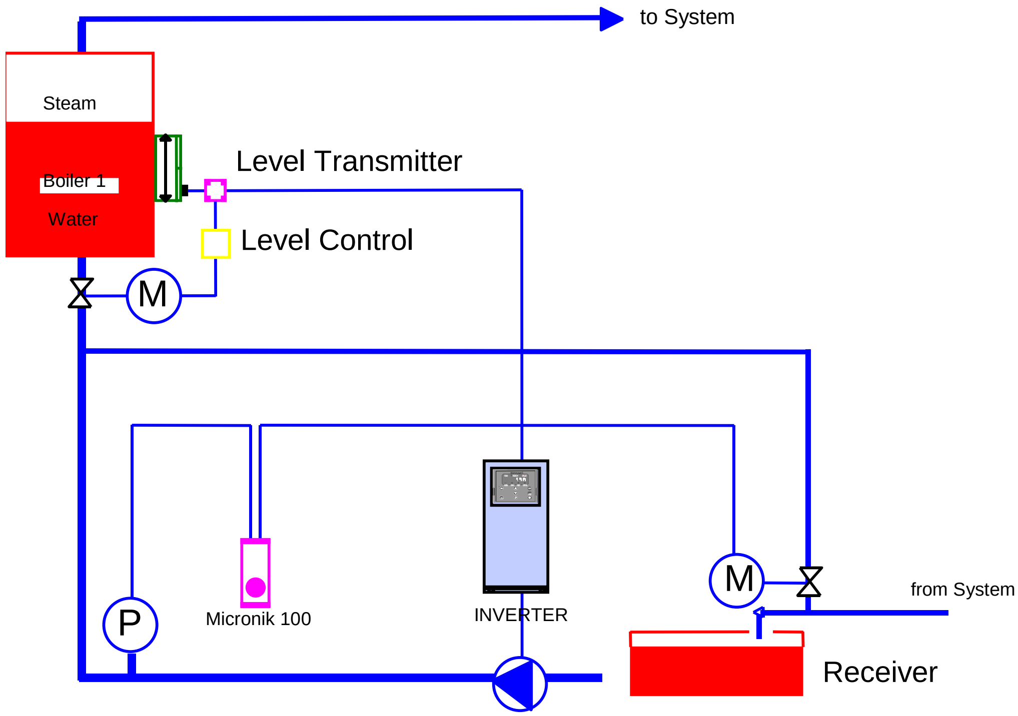


Fig. 50. Single boiler, single pump application.

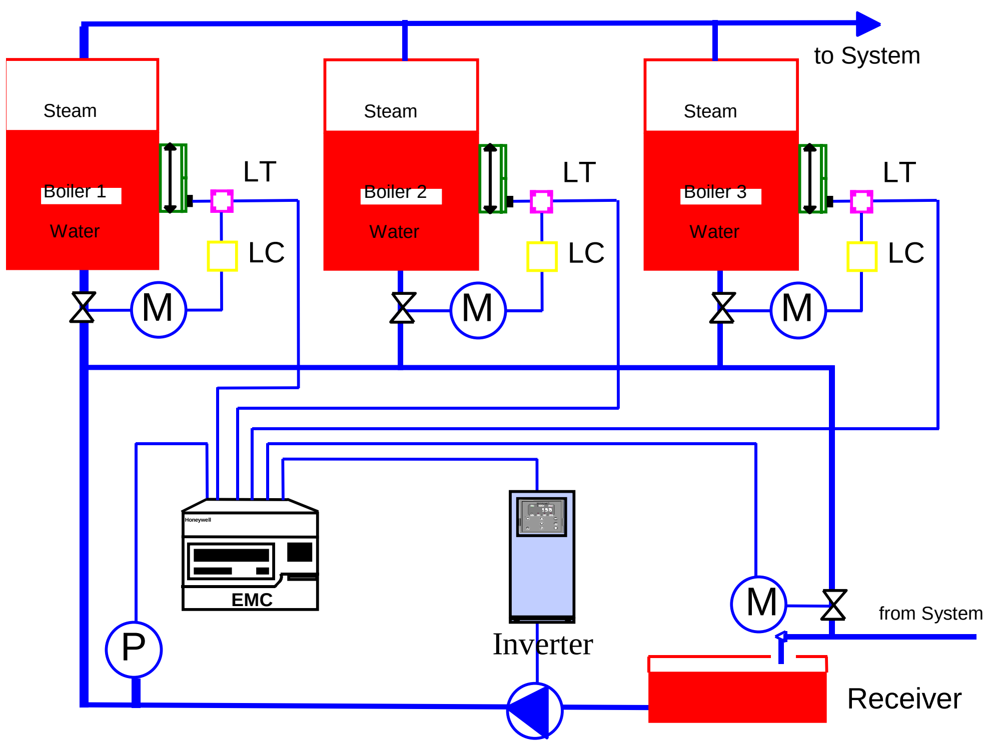


Fig. 51. Multi-boiler, single make-up pump application.

Boiler Flue Gas-Induced Draught (ID) Fan (See Fig. 52)

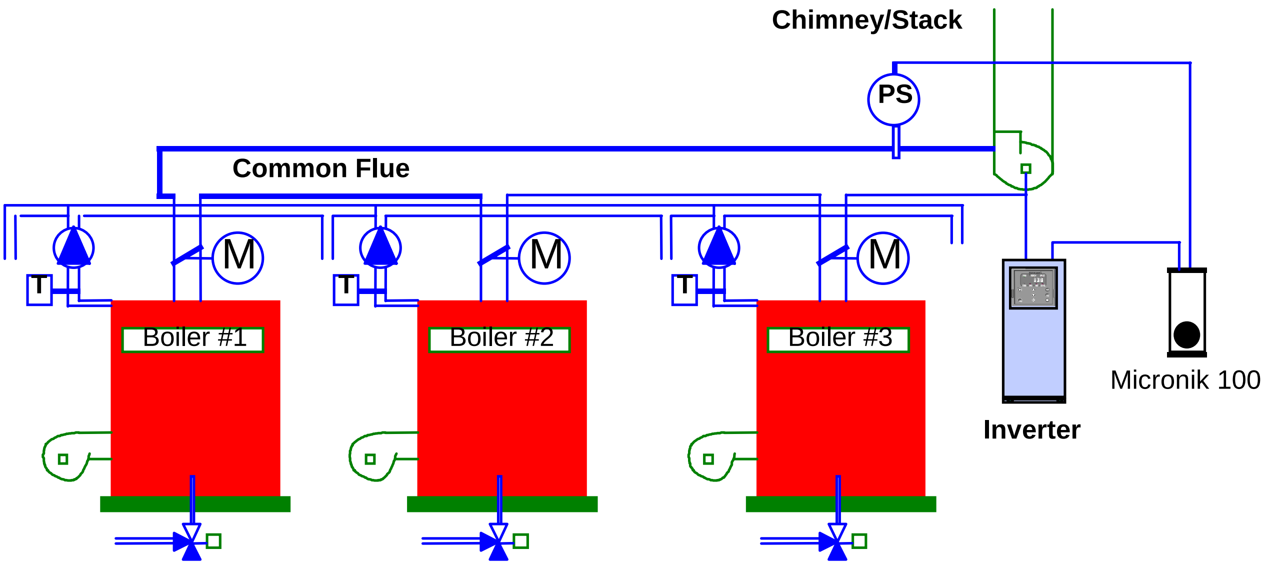


Fig. 52. Boiler flue gas ID fan application.

Application Description

Traditionally a damper in the common flue from all boilers is controlled by a static pressure sensor located before the ID fan. Individual dampers for each boiler are located in their own flue, these dampers close when the boiler is off line to prevent airflow through the boiler which can cause condensation and corrosion.

The common flue gas static pressure sensor detects the change in static pressure when the individual dampers close and modulates the common damper to prevent the induction of too much air into the on-line boilers. Only when all the boilers are on full load will the dampers be fully open.

Fitting a VFD to control the speed of the main ID fan will enable more precise control of the static pressure within the flue, thus reducing losses and preventing excess air flow through the on-line boilers. Thereby, matching the fan speed to the exact static pressure requirement, overcoming the need for the dampers, increasing the efficiency of the boiler and reducing electrical energy used by the ID fan.

Other Applications

— Process furnaces (metal refining).
— Hospitals.
— Incinerators (waste burning).

Benefits

— Reduced electrical energy.
— Prevents too much air from passing through *on-line* boilers, thus improving combustion efficiency.

VFD Features Used

— Power fail recovery.
— Auto restart on trip.

IMPORTANT

Careful commissioning is required to ensure efficient combustion is maintained and that emissions are kept under control.

Boilers and Forced Draught Fan (See Fig. 53)

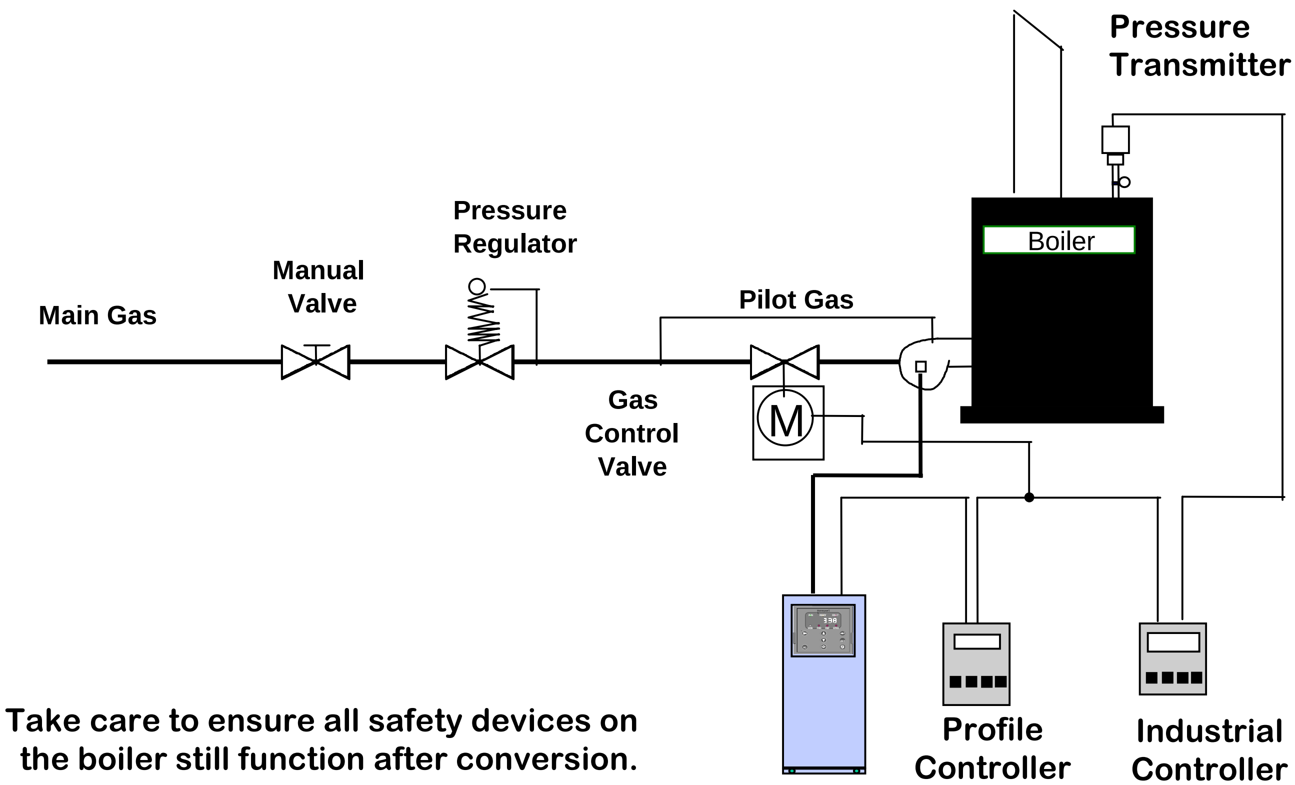


Fig. 53. Boiler with forced draught fan application.

Application Description

On large boilers modulating control is used to regulate the boiler output to match the building load. The steam pressure or hot water temperature is controlled by varying the volume of fuel (gas or oil) fed to the burner.

To maintain efficient combustion the volume of air supplied to the burner is regulated, relative to the amount of fuel. A simple combustion control system adjusts the air flow by means of a damper and linkage connected to the same modulating motor that adjusts the fuel supply. Fitting a VFD to the motor of the forced draught fan allows the fan speed to be varied relative to the volume of air required, giving more precise control and ensuring efficient combustion is achieved. Only when the boiler is at maximum load will the forced draught fan be running at full speed.

Other Applications

— Process furnaces.
— Incinerators.

VFD Features Used

— Power failure recovery.
— Auto restart on trip.
— Over speed.

Benefits

— Reduced electrical energy.
— Improved combustion control.

IMPORTANT
Careful commissioning is required to ensure efficient combustion and that emissions are kept under control.

Aircraft Passenger Jetty Loading (See Fig. 54)

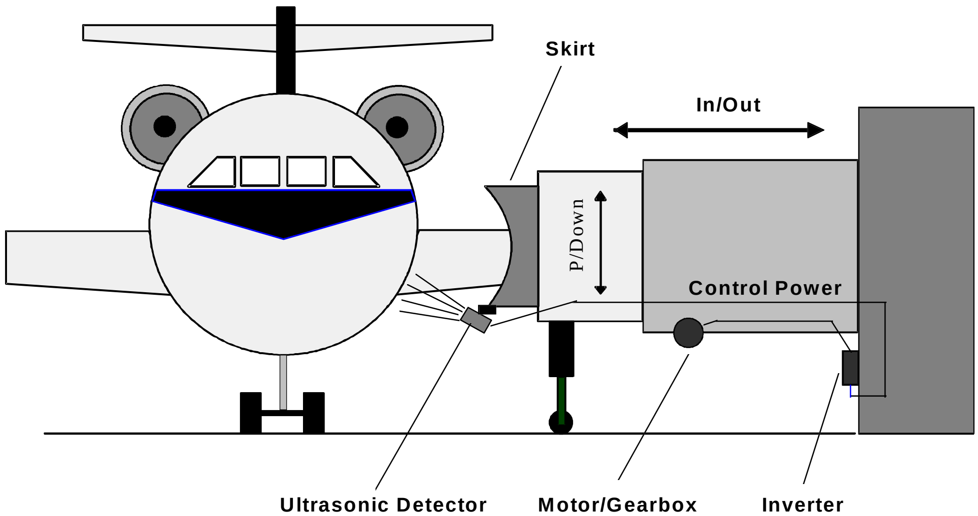


Fig. 54. Aircraft passenger jetty loading application.

Application Description

With the existing control system the jetty is started by hand and the operator drives the jetty out towards the aircraft. As the flexible skirt on the extremity of the jetty approaches the side of the fuselage, the operator stops the jetty and then slowly inches the jetty into its final docking position, where limit switches disable the control circuit and the motor powers down. Occasionally, the operator makes a mistake and the jetty skirt is driven into the fuselage at full speed. There is sufficient inertia in the equipment to damage the fuselage of the aircraft.

Fitting the VFD to the existing jetty motor allows smooth and progressive acceleration/deceleration with precise control even at low speeds. In addition an ultrasonic sensor is required to detect the proximity of the aircraft. Several control modifications are designed to prevent these accidents without loss of functionality and speed.

On start-up from a full retracted position, the VFD accelerates the jetty drive motor up to full speed within 4-6 seconds and the jetty extends as normal. As the jetty approaches the aircraft the ultrasonic sensor detects the proximity of the fuselage and signals the VFD to reduce speed (within 2-3 seconds) by 75 to 80% for the final docking phase.

The existing limit switches still operate and stop the jetty. This slower docking speed reduces the likelihood of damage to the fuselage. The reduction in human control also reduces the chance of accidents. The jetty control circuit is not disabled when retracting from the aircraft, as under some circumstances it is paramount to remove the jetty from the aircraft as quickly as possible.

Fit the VFD into the electrical circuits before the existing contractors. The VFD is then interfaced with these contactors to provide the normal start/stop functions, whilst retaining the existing limits and emergency control. Install the ultrasonic detector at a suitable angle to be able to detect all types of aircraft. It may be necessary to install a second detector to guarantee reliability. To enhance reliability the sensors should be mounted in a heated weatherproof box to prevent rain and frost affecting performance.

Other Applications

— Benefits.
— Reduction in potential damage to fuselage.
— Smooth acceleration/deceleration.
— Precise positioning.
— Shock free starting and stopping.
— Semi-automatic docking.

VFD Features Used

- Digital or analog speed control.
- Stall prevention.
- Forward - reverse.
- Variable torque.
- Overtorque trip.

IMPORTANT

Existing safety limits must not be altered.

Screw Press (See Fig. 55)

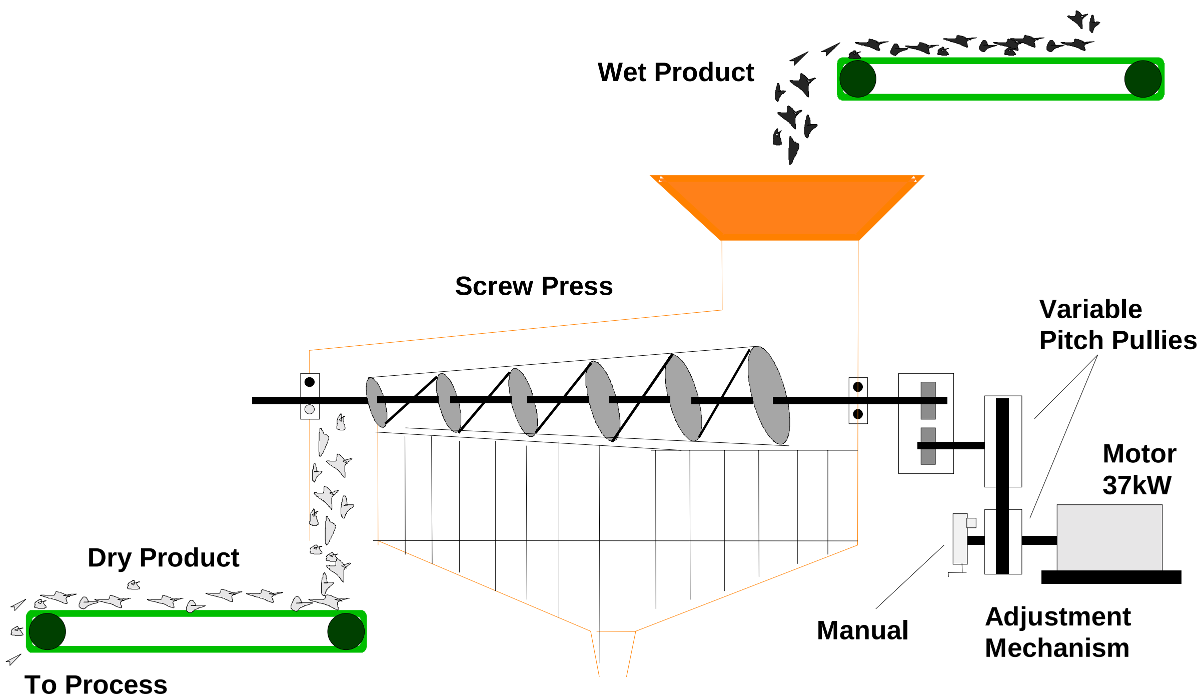


Fig. 55. Screw press application.

Application Description

A screw press is used to reduce the moisture content of a wet product. This application was used on a whisky distillery in Scotland. The product was the left over malted barley, after having the moisture removed by the screw press, it is then dried and used in cattle feed. Conventional control uses a set of mechanically variable pitch pulleys. The operator fixes the speed of the screw in order to meet the process requirements. However, differences in the wetness of the mixture means that the end product suffers from inconsistency. The mechanical speed variation is also unreliable and wear can take place thus changing the speed with respect to the adjuster position.

Modification

Replace the variable pitch pulleys with fixed pulleys (selected for the correct ratios), install VFD and vary speed electronically.

Benefits

- No mechanical speed variation to wear or brake-increased reliability and consistent control.
- Speed control can be automated since the VFD can be easily connected to a product sensor measuring wetness, thus providing closed loop control.
- Reduced possibility of damage to the screw press since the VFD can be programmed to maintain a fixed torque or to trip if overtorque conditions occur.

VFD Features Used

- Auto restart.
- Over speed.
- Over torque.
- Stall prevention.
- Analog or digital control.
- Forward/reverse for clearing blockages.
- Variable torque control.

IMPORTANT

Ensure that the VFD can handle the breakaway toque of the load. It may be necessary to select one size larger VFD than the motor to achieve this.

Elevators (See Fig. 56)

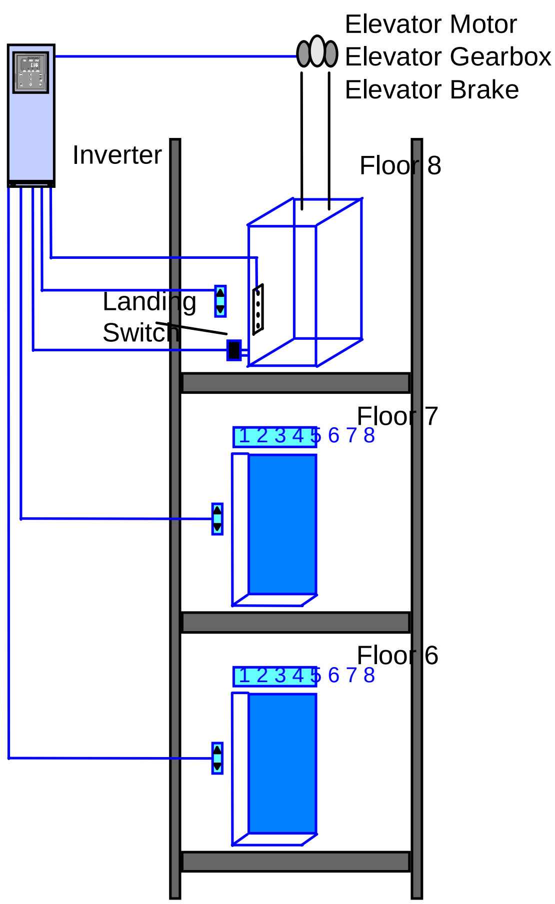


Fig. 56. Elevator application.

Application Description

As there are governing regulations covering equipment used in the transportation of people, this application requires the involvement of an organization already involved in elevator maintenance and installation. Small elevators tend to use single or two speed motors directly connected to the elevator gearbox. When the car approaches the landing a switch is made and the elevator motor is disengaged from the power supply and the car is brought to a halt by use of a brake. If the motor is 2 speed then a second speed phase is selected before the motor is disengaged from the power. This form of control is temperamental and the stopping accuracy (unpredictable) due to the temp of the brake, load and moisture, all affecting the accuracy of stopping.

Starting is also coarse as the motor is generally switched directly on to the power supply causing harsh acceleration. By interfacing a VFD to the existing control, smoother starting is achieved and stopping is more precise. These both to accuracy of approximately 1.5 mm. This is a fully controlled stop, so it is a repeatable process. It is not easy to give a design for a control interface as there are so many different possibilities, but the VFD application engineer should be conversant with the capabilities of the VFD to ensure that the correct mode of operation is employed.

Benefits

— Smooth start/stop.
— Accurate positioning.
— Easy retrofit.
— More reliable.
— Reduced wear on brakes.

VFD Features Used

— Digital control.
— Multi-fixed speed control.
— Auto restart.

IMPORTANT

1. *The deceleration phase generally is more arduous for the VFD as it has to absorb a large amount of energy from the car.*
2. *Under normal circumstances the VFD is NOT capable of handling this energy without tripping. A regenerative braking unit should be connected to dissipate this energy safely.*
3. *This is one of the most difficult applications as the performance has to be repeated many times throughout the working day. As many as 200 starts per hour are not uncommon.*

List of Abbreviations

AHU	Air Heating Unit
AQ	Air Quality
CAV	Constant Air Volume
CC	Chiller Controller
CHW	Chilled Water
DDC	Direct Digital Control
DP	Differential Pressure Sensor
HVAC	Heating, Ventilation, Air Conditioning
ID	Induced Draught
M	Motor
PS	Pressure Sensor
P + I	Proportional and Integral Control
T	Temperature Sensor
TS	Temperature Switch
TT	Temperature Transmitter
V	Valve
VAV	Variable Air Volume

PRE POWER UP CHECKS

1. Inspect internal condition of VFD for physical damage.
2. If the output (motor) cables from the VFD have been connected to the VFD terminals, disconnect them before powering up for the first time.
   NOTE It is very easy to confuse the input and output cabling resulting in one or more of the commercial electrical supply phases to be connected to the VFD output. If this occurs when power is applied, it is likely to damage to the VFD.
3. Make a general inspection of the internal condition of the VFD and its cubicle. Check for debris that can cause short circuits. Be aware that debris can fall down through the heat sink and become lodged in internal cooling fan.

POST POWER UP CHECKS

1. Power the VFD (with output disconnected).
2. Ensure that all input phases are present and the display is correct. Refer to the device technical manuals for details.
3. If all is well, power down and wait until the DC bus voltage has decreased to a safe level.
4. Reconnect the output cables.
5. Power the VFD again, ensuring that the *stop* command is present in the VFD terminal.
   NOTE: If the *start* command is present on the VFD terminal, the VFD will likely start the load using default parameters.
6. Program the following parameters before giving the *start* command:
   a. Motor name plate voltage.
   b. Motor name plate full load current.
   c. Acceleration ramp.
   d. Deceleration ramp.
   e. Any minimum or maximum speed limits.

   NOTE: Typical values for acceleration and deceleration times for first start:
   Up to 10 Hp: 30 seconds acceleration and deceleration.
   15 Hp to 50 Hp: 45 seconds acceleration and deceleration.
   60 Hp to 100 Hp: 74 seconds acceleration and deceleration.
   125 Hp to 160 Hp: 120 seconds acceleration and deceleration.
7. Use either the terminal *start* command or keypad command *forward jog*, and observe the direction of rotation. If the load rotates in the wrong direction, reverse the connection of the two cables on the VFD output. Reversing the cabling on the input of the VFD has no effect on direction of rotation at the output.
8. Start the machine with minimum speed reference and monitor the current drawn.
9. If the system will safely allow this, while monitoring current drawn, gradually increase the speed until maximum speed is achieved. Note any areas where overload or overcurrent occurs.
10. Reduce the speed reference to minimum and monitor the DC bus voltage as the VFD decelerates the load.
    a. If the deceleration rate is much too fast, an over voltage trip may occur immediately.
    b. If the deceleration ramp is only marginally too fast the over voltage trip may occur at some speed approaching zero.

    NOTE: In either case, the deceleration ramp should be extended. If there is a specific need to decelerate the load at a defined rate, this can require the addition of a braking circuit in order to dissipate regenerated energy.
11. Make several starts and stops to simulate what happens during normal operation. Include power down and power up during motoring. If the VFD trips, there is a problem with programming, cabling, or interfacing. A modern VFD should not trip.
12. Tune the primary control loop ensuring that the operation is stable and producing the desired results.
13. Check the operation of any bypass circuits or downstream switching to ensure that these functions work correctly without causing the the VFD to stress or trip.

TROUBLESHOOTING ON SITE

NOTE: Refer to the Safety section for guidance on safety.

With correct wiring, set-up and application, a modern VFD should rarely trip. Usually, if a VFD trips, the problem lies with the application or programming. However, situations can exist that cause operational problems, but do not cause the VFD to trip. These conditions can be difficult to diagnose.

Unstable Speed Control

If the speed reference value is available for display, this should be monitored when the VFD is not driving the motor and then when the motor is running. The displayed speed reference value will normally be available to a high degree of accuracy and therefore any deviation in this value will be immediately evident on the display. The VFD will attempt to follow this value. It is also be possible to monitor the input terminals for this speed reference, with an appropriate instrument - again any instability will be evident.

The reference value is normally Vdc or mA, so it is worthwhile to check reference terminals for any voltage level. Problems can occur with control instruments and with poor wiring, because Vac can be superimposed on the DC reference signal. Any level of Vac, particularly if it is at low frequencies, typically 60Hz power supply frequency produces modulation of the real reference signal causing instability.

In some cases, the level of induced Vac can be so high that physical damage can occur to the components on the control board of the VFD.

A simple check for stable control from the VFD is to install a temporary control potentiometer, (maybe 15 - 20K ohms in value) using the VFD power supply, usually 10 or 15 Vdc and 0V (ground). Connect the ends of the potentiometer to the DC power supply and to 0V ground and connect the wiper of the potentiometer to the voltage speed reference input. Vary the setting of the potentiometer and monitor the reference value on the VFD display for stability. Also monitor the display whilst the VFD is driving the motor - again it should be stable.

Where Vac is present on the speed reference lines, several courses of action can be taken:

1. Check for correct shielding and segregation of the control cables.
2. Check that correct input RFI filter has been applied.
3. Check for correct earth grounding on control and power cable shields.
4. Check for malfunction of control instruments.
5. Install filters in the reference lines to reduce the amount of Vac present.
6. Some VFDs have software filter options which can be enabled. However, these do cause delay in response and may not be acceptable.

Faults and Trips

Most VFDs have some form of error indication and an error log. The error indication is usually either on the VFD display, or an indicator LED (or relay output), or both.

Where an error log exists, it usually has the capacity for logging multiple errors and may also store other details that may have caused the trip. However, in most cases this information is only available on the last trip that has occurred and then only if the power has been maintained to the VFD.

Faults causing trips can be in 1 of 2 categories i.e. *minor* or *major*.

Normally resetting the VFD after a minor fault will not cause damage to the VFD or immediate damage to the motor.

Casual resetting of the VFD after a major fault, could cause serious damage to the VFD, and may cause damage to the motor and or cables between the motor and the VFD.

Examples of Minor faults would be:

— VFD overheat.
— Motor thermal trip.
— Loss of control loop.
— DC bus overvoltage.
— Loss of input phase.

Examples of Major faults would be:

— Instantaneous over current.
— Earth fault.
— Open circuit output phase.
— DC bus fuse open circuit.

Further inspection of the VFD technical manual will show any additional error messages.

Action if the VFD is Tripped

If the display indicates that the DC bus fuse has become open circuit, it is likely that one or more of the output power transistors have become short circuited or damaged in some way. Casual replacement of the DC bus fuse should not be made without full internal inspection and testing of power transistors (covered later in document.)

If the VFD is still powered, attempt to call up the motor voltage, motor current, speed, DC bus voltage and any other parameter available from the VFD. If this monitoring is available, log these parameters before powering down the VFD, as this important information may be lost. Also, if the VFD is fitted with a cooling fan, check if it is operating correctly.

If the error can be categorized as *minor*, the VFD can be reset. If the error can be categorized as *major*, it should be powered down at this stage.

Once the DC bus voltage has decayed to a safe level further work can continue.

The VFD should be inspected for internal damage, overheating. If no damage is apparent then the power can be reinstated. Care should be taken when restoring the power supply, as this will normally reset the trip and if the command to run is still present on the VFD, it will begin to accelerate the motor.

Minor Faults

VFD Overheat

This fault is usually caused by problems with cooling air circulation over the VFD heat sink or within the VFD chassis. It may also be caused through a combination of high motor load and high ambient temperature. The outcome of the above is that the VFD has sensed that its internal components have become overheated and has closed down, in order to prevent thermal damage.

1. Check for correct rotation of fans, both mounted on the VFD and any external cooling fans within the VFD enclosure.
2. Clean any air filters and heat sinks.
3. Check for any loose internal connections associated with remote mounted temperature sensors.

Motor thermal trip

The VFD has the capacity to monitor the motor load via the motor current and make an estimate of the degree of heating of the motor caused by this load. There is usually at least one parameter that allows the user to match the overload to the motor load conditions:

— Adjust the motor overload parameter to match the motor load condition, or
— Reduce the actual load on the motor until the overload condition is removed.

IMPORTANT

There may be an intermittent overload condition not present during inspection. Adjusting the motor overload parameter can result in a damaged motor.

The VFD may also have the ability to actually measure the motor temperature via sensors mounted within the motor body. If this option is available, there is usually no adjustment available. In this situation the only option is to reduce the motor load condition. It s also possible that the motor temperature sensors have become defective.

Loss of Control Loop

If the VFD is using a 4-20 mA source for speed reference, the VFD will normally monitor for a reference value below 4 mA. If this occurs, the VFD may respond by tripping, as it understands that the control loop has been lost and is therefore out of control. This will usually be caused by broken external cabling or a control instrument failure

DC bus over voltage

This problem can have several causes:

— Regeneration from high inertia loads.
— Excessively fast deceleration speeds.
— Open circuiting contactors or other types of switches between the motor and VFD.
— Regeneration from high inertia loads.

Under normal stable operation, the flow of energy is from the power supply through the VFD, to the motor and then out to the load. There can be situations where energy flow is reversed and the motor becomes a generator. This would occur if the load tries to *over-run* the motor, or the VFD tries to decrease the motor speed rapidly, and the load inertia is particularly high. In either case the *regenerated energy* flows back into the VFD. As it cannot flow past the bridge rectifier, it will be stored within the DC bus capacitors, causing a voltage rise. If this voltage rises to 740 volts the VFD will begin to ignore the speed reference and attempt to limit the DC bus voltage rise by reducing or stopping the rate of deceleration.

If this control loop is inadequate for the load, the DC bus voltage will continue to rise and at 800V (on a 400V VFD) the VFD will trip, to prevent over voltage damage occurring.

Extending the deceleration ramp time and or installing a braking unit would be options to prevent tripping. Also, it might be possible to use coast to stop, if the problem only occurred when the VFD was trying to bring the load to a halt.

Excessively fast deceleration speeds

If the deceleration rate is sufficiently short, it is almost guaranteed that an over voltage trip will occur, irrespective of the magnitude of the load. A motor without any connected load can regenerate a substantial amount of energy if attempts are made to bring it to a halt in one or two seconds. Simply extending the deceleration ramp times usually accommodates most problems in this area

Switches on output of VFD

Isolating switches or contactors will often be located in the output cables from the VFD. As when switching an inductive load, an arc develops at the point where the contact first breaks. This arc can cause high voltage spikes, as high as 3-4 kV, on the cables back to the VFD. The high voltage spike can completely disrupt the DC bus voltage monitoring circuit, causing a false high DC bus voltage trip.

To ensure optimum reliability, the switch on the output of the VFD must be interfaced with the VFD controls circuit, by a late make early break auxiliary contact. When programmed correctly, the VFD will see the opening of this switch and turn off - into a safe controlled state, thus preventing the trip.

Loss of input phase

A VFD does not usually have the ability to monitor the input power supply integrity. If the VFD is single phase input, loss of a phase will cause the VFD to close down safely and possibly log a power supply loss. If one phase of a three-phase input VFD is lost, there is usually sufficient capacity within the input bridge rectifier to cope with it. Heavy loading of the motor causes overheating of the input bridge rectifier and ultimately cause a trip on *VFD overheat*.

Some VFDs monitor the phases feeding the input bridge rectifier. If one phase voltage deviates from the acceptable limit, the VFD trips and record *phase loss*.

Major Faults

Instantaneous over current

This fault may be caused for various reasons:
— Motor phase to phase short circuit.
— Short circuit between two or more motor cables.
— Closing switches between VFD and motor while VFD still running.
— Acceleration rate too fast.

With short circuits, the VFD detects a low resistance between two or more phases that allows high current to flow at a level beyond the normal absolute rating of the VFD. High speed protection circuits have taken effect to protect the output power transistors of the VFD.

Earth fault

This fault will be reported if either the motor or motor cables have become shorted to earth. Most VFDs monitor the current balance between all three-phases and at maybe 40% imbalance on one phase, the VFD will trip and report an *earth fault*.

NOTE: With phase-to-phase and phase-to-earth faults, the speed of VFD response usually prevents any major damage from occurring in the fault area.

In some cases, there can be little or no apparent damage and even with a simple high voltage *megger* test the fault may not show itself. There can be situations where a high voltage *flash test* may have to be undertaken on the motor to identify the problem.

NOTE: The VFD should be disconnected from the motor when a megger test or high voltage test is to be undertaken. Failure to do so may cause damage to output transistors.

Open circuit output phase.

Many VFDs do not allow the motor to run with an open circuit on one of the phases to the motor. If the currents flowing in each phase do not balance to a reasonable level, the VFD will trip.

DC bus fuse open circuit

Most VFDs have a fuse located in the DC bus circuit. This fuse is usually a high speed semi-conductor protection fuse and is designed to protect the input bridge rectifier in the event of a major failure on the VFD output stage. If the fuse has become open circuit it should not be replaced without first checking the VFD power devices. It is unlikely that the fuse will have blown without some major component having failed elsewhere. See Fig. 57 for bridge rectifier and output power transistor testing information.

Closing a Switch on a Running VFD Output

There are no electrical defects in the circuit. It is caused by incorrect programming and application. If the VFD is running and a switch is closed in the output cables from the VFD, the motor and VFD will try to effect a *direct on-line (DOL) start*. Typically, surge currents in excess of 6 times full-load motor current flow during a DOL start. The VFD has a normal rating of 150% of its nameplate current for one minute and 200% current for 0.5 seconds. Under these conditions the VFD will trip.

Correcting the control wiring and reprogramming the VFD resolves this problem.

Testing Bridge Rectifier and Output Power Transistors

Diode and Power Transistor Test

IMPORTANT

Before undertaking these tests, ensure that main power to the VFD is isolated, additional power supplies are made safe, and the DC bus voltage has decreased to 0V. Remove any components from the connections shown to ensure readings are not misleading.

Table 3 and Fig. 57 indicate the various points for testing the power devices on the VFD. For this test, use a standard multimeter set to read resistance.

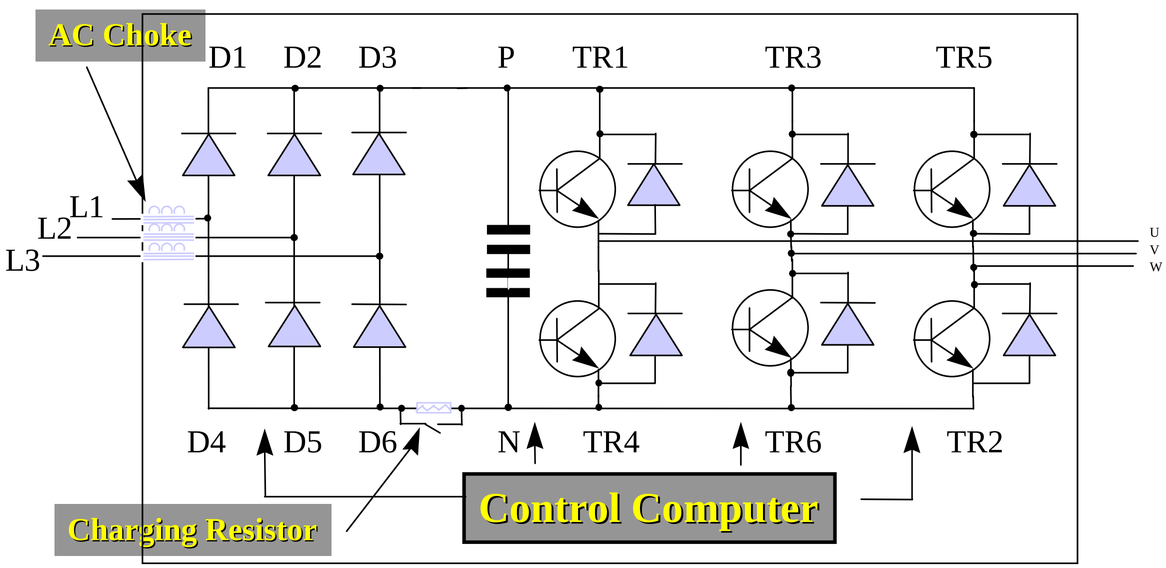


Fig. 57. Points for testing VFD power devices.

Table 3. Proper Power Device Test Readings.

		Tester Polarity +	Tester Polarity -	Measurement	Circuit Symbol	Tester Polarity +	Tester Polarity -	Measurement
Converter Module	D1	L1	P	Open	D4	L1	N	Closed
		P	L1	Closed		N	L1	Open
	D2	L2	P	Open	D5	L2	N	Closed
		P	L2	Closed		N	L2	Open
	D3	L3	P	Open	D6	L3	N	Closed
		P	L3	Closed		N	L3	Open
VFD Module	TR1	U	P	Open	TR4	U	N	Closed
		P	U	Closed		N	U	Open
	TR3	V	P	Open	TR6	V	N	Closed
		P	V	Closed		N	V	Open
	TR5	W	P	Open	TR2	W	N	Closed
		P	W	Closed		N	W	Open

Miscellaneous

Control Power Terminals

The VFD will generally have an on board power supply for use with external equipment e.g. transmitters. A simple voltage check of this power supply together with an other terminals that output voltages will give a good indication of the state of the control board.

Use of Multiple Auto Resets

Most VFDs have a function which provides auto reset in the event of a trip. This function is designed to enhance the reliability of the VFD service provided.

IMPORTANT

Use the auto reset function with caution.

Example: When an over current trip occurs, the over current condition causes abnormal heating within the input bridge rectifier and output power transistors. If the over current condition occurs repeatedly within a short space of time and the VFD is programmed to reset itself automatically. The reset can be programmed with insufficient time between resets to allow for cooling. This results in the power devices becoming thermally stressed, shortening their life expectancy.