APPLICATION GUIDE

Variable Frequency Drives
in
Retrofit or New Applications

Yorkland Controls Ltd. Environmental Solutions
www.yorkland.net Email: yorkland@yorkland.net
TORONTO + MISSISSAUGA + LONDON
(T) 416.661.3306 (F) 416.661.3320 Toll Free: 1-877-733-3833

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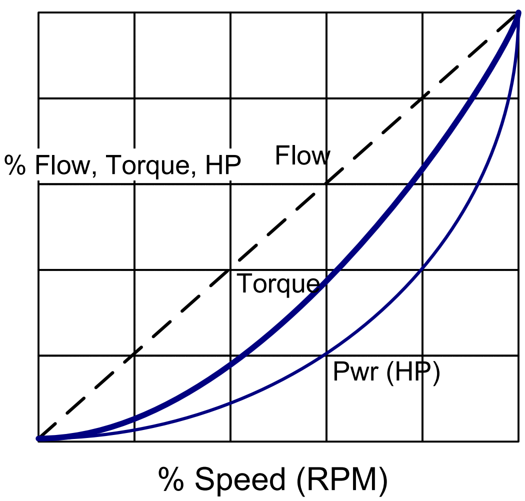
Application Guide #1

Variable Frequency Drives in Retrofit or New Applications

Energy Savings with Variable Frequency Drives – The Basics

AFFINITY LAWS

Most HVAC equipment is designed to perform during peak loads. These loads occur rarely during the operating year. Centrifugal pumps and fans ,therefore, are also sized to meet the maximum flow of the system. To control flow during off-max load conditions, flow control devices such as dampers, valves, inlet guide vains and bypass systems are used. These "throttling" devices are effective but not energy efficient. A typical duty cycle for pumps and fans is shown in table A. Using Variable Frequency Drives (VFD) varies the speed of fans and pumps so the units deliver only the required flow.
The physical properties of fans and pumps, referred to as the AFFINITY LAWS, allows the equipment to meet the partial load requirement and save energy. Figure 1 shows the relationship of Speed, Flow and Power.



Speed	Volume or Flow	HP
100%	100%	100 %
90 %	90 %	73 %
80 %	80 %	51 %
70 %	70 %	34 %
60 %	60 %	22 %
50 %	50 %	12.5%
40 %	40 %	6 %
30 %	30 %	3 %

Reducing the speed of a fan or a pump results in a large reduction in horse power.
For Example, at 50% flow, the horsepower required is 12.5% ($.5^3 = .125 = 12.5\%$).

It would actually cost less to run two 50 HP motors at 50% speed that it would be to run one 50HP motor at 100% speed.

Affinity Laws

1) Flow is directly proportional Speed $\quad \frac{Q_2}{Q_1} \quad \frac{N_2}{N_1}$

2) Torque required is proportional to speed squared $\quad \frac{T_2}{T_1} \quad \left(\frac{N_2}{N_1}\right)^2$

3) Horsepower required is proportional to speed cubed $\quad \frac{HP_2}{HP_1} \quad \left(\frac{N_2}{N_1}\right)^3$

Q = Flow
N = Fan Speed
T = Torque
HP = Horsepower

Duty Cycle

Establishing the number of hours (Duty Cycle) that a fan or pump runs at off peak loads is very important in establishing potential energy savings. Table A shows a typical duty cycle. In this example, the system will be operating ***below*** 70% flow for over 95% of the time. Most VFD manufactures have developed saving estimating software that assists in determining the savings by applying typical equipment duty cycles and throttling devices.

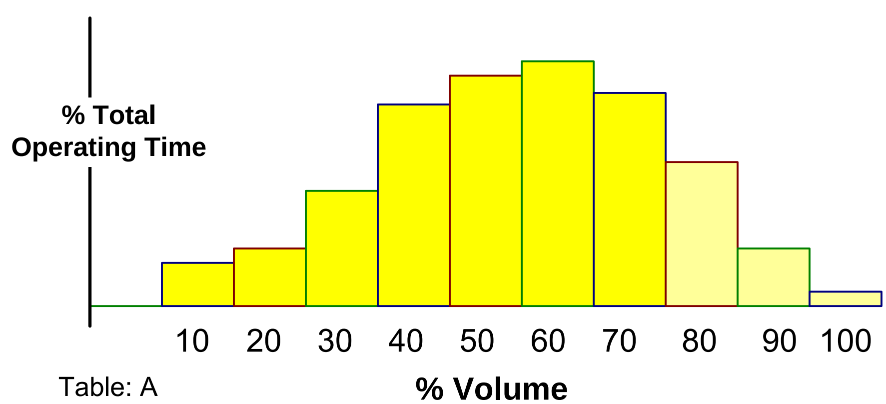


Table: A

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Centrifugal Pumps & Variable Frequency Drives - Basics

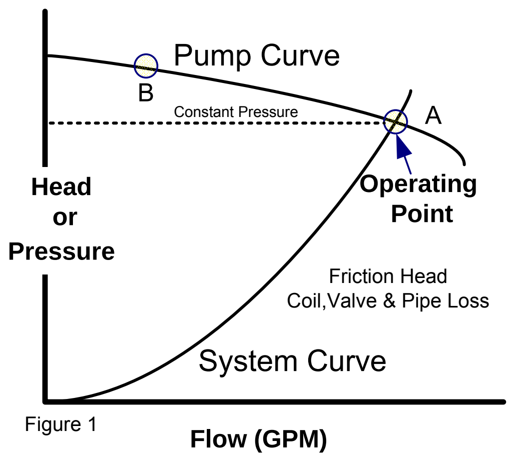

Figure 1

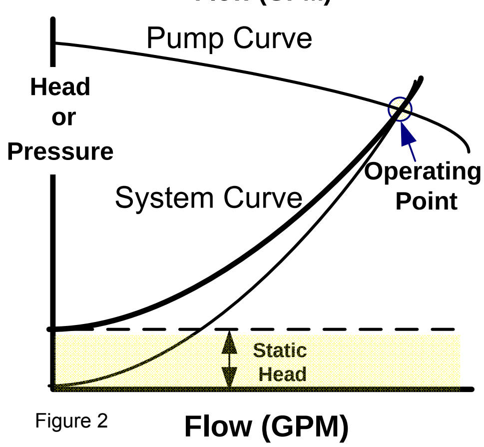

Figure 2

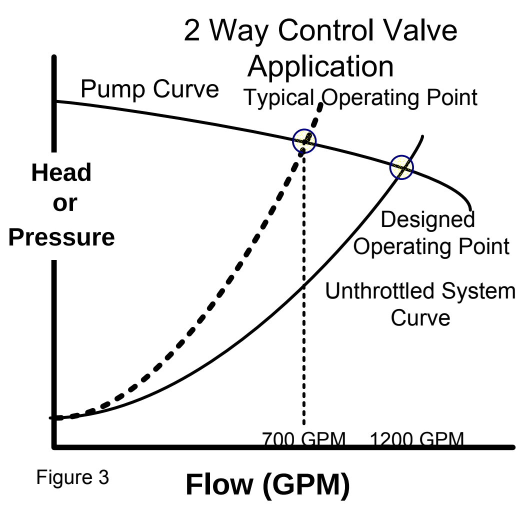

Figure 3

PUMP BASICS

The affinity laws apply to pumps as they do to fans. To understand VFD applications applied to pumps, it is a good idea to review the basics of how pumps are applied in general.

Figure 1 shows a pump curve relative to a hydronic system curve.
The pump curve describes the "head" (or pressure) versus flow characteristics of a particular pump. The curve shows that the pump will produce limited flow , at point "B", if it is applied to a system with a large differential pressure required to lift the water/glycol and overcome resistance to flow. Larger flow rates are achieved with this pump if pressure differential is reduced- as at point A.
To determine where along the pump curve the pump will operate requires information provided by the system curve. The system curve show the characteristics of the piping system. It shows the "friction head' as it increases with flow. Friction head is the measure of resistance to flow provided by the pipe, valves, elbows and other system components.

STATIC HEAD

The head required at zero flow is a called static head or lift. Figure 2 shows the combined friction and static head curve for the system. The static head is the amount of feet of elevation the pump must lift the water regardless of flow. Another way to look at is as the work needed to overcome gravity.
The intersection of the pump and system curves shows the natural or design operating point for the system. At this point pump pressure matches system losses. The intersection would generally be chosen to ensure that the pump is operating at or near its best efficiency.

FLOW CONTROL

TWO WAY CONTROL VALVES:

Most hydronic systems do not always work at design conditions. Systems with 2-way control valves vary the flow by modulating the valve to various positions. Closing the valve reduces flow and increases system friction in the system. Figure 3 shows a typical operating point when a particular flow is achieved by the control valve. Notice that the flow is achieved but at a increased system pressure.
Three way control valve systems maintain constant pressure by bypassing flow from pump discharge to the pump suction. While good flow is maintained, pump flow and energy consumption is also maintained – no energy savings. (Figure 1)

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Pumps & Variable Frequency Drives

PUMP ENERGY SAVINGS WITH VFDs

Applying a VFD to a pump to reduce speed and therefore flow, causes the pump curve to shift down as shown in figure 4. Since the operating point is still the new reduced pump curve and the system curve, the same reduced flow (note 700 GPM from 1200 GPM in figures) is achieved as with a valve. This flow is achieved but at a reduced pressure. Operating at reduced pressures can result in longer pump seal life, reduced impeller wear and less system vibration and noise.
Due to the affinity laws, power is greatly reduced at reduced flows thus offering significant savings. (figure: 5)

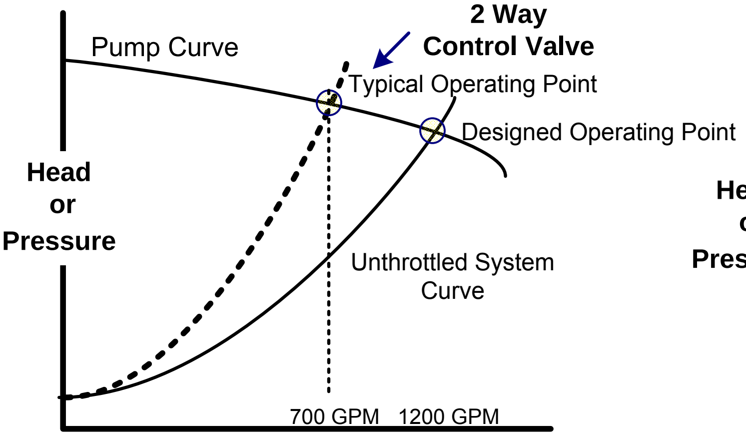


Figure 3

Flow (GPM)

VFD Application

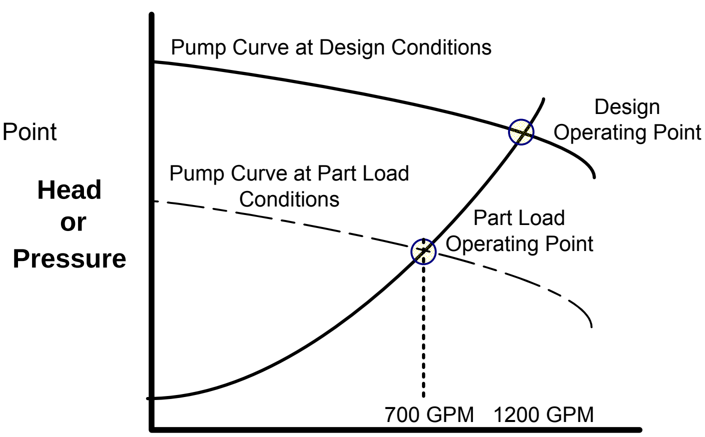


Figure 4

Flow (GPM)

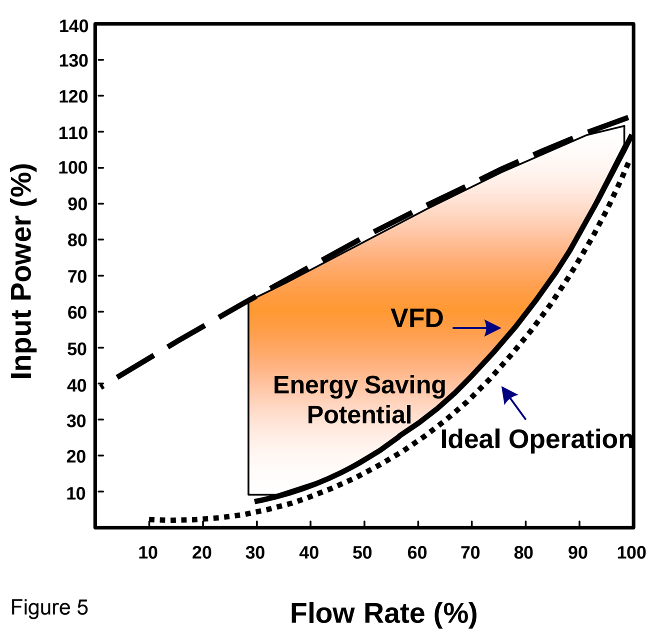


Figure 5

Typical Pump Applications

- Chilled and Hot water Pumps
- Condenser Water Pumps
- Booster Pumps

Pumps & Variable Frequency Drives

APPLYING VFDs TO PUMPS To REALIZE SAVINGS

As with most HVAC systems, original pump designs may be based on worst case maximum flow conditions for future expansion reasons, or the designer used the usual 15 to 20% over-sizing criteria.
When evaluating VFD retrofit opportunities for energy savings, one should look the system and pump curves and review the existing method of modulating the flow. (see figure 1)

BYPASS: If bypass control is used (example: 3-way valve at coils) the system is always at constant pressure.(See 'CP" in Figure 6). The savings potential can be quite large if there is no modulation present when VFDs are retrofitted.

2-Way VALVE CONTROL: If 2-way valves are used, the system operates along the pump curve from Operating Point to P3. These systems use less energy than constant pressure systems

If a VFD is being applied, the system will operate along the system curve from Operating Point to V3.

STATIC HEAD

Static Head can affect possible energy savings. If static head is high, the system curve can approach constant pressure. For example, in Figure 7, a pump curve is shown with three system curves – one with no static head, and two others different static heads. For a given flow rate, the difference between points A and B represent possible energy savings. Basically, the lower the static head, the greater the energy savings that can be achieved with VFDs.

DETERMINING PUMP & SYSTEM CURVES

Pump curves are readily available from pump manufacturers, however, system curves are more difficult to determine. One quick method can approximate the curve:
1. Determine the un-throttled (open) system flow rate at the location under consideration. (you may need to measure this at different locations or have a balancer establish this for you)
2. Measure the static head
3. Plot these two points on a copy of the pump curve.
4. Connect these points using a square function : Head = $Flow^2$

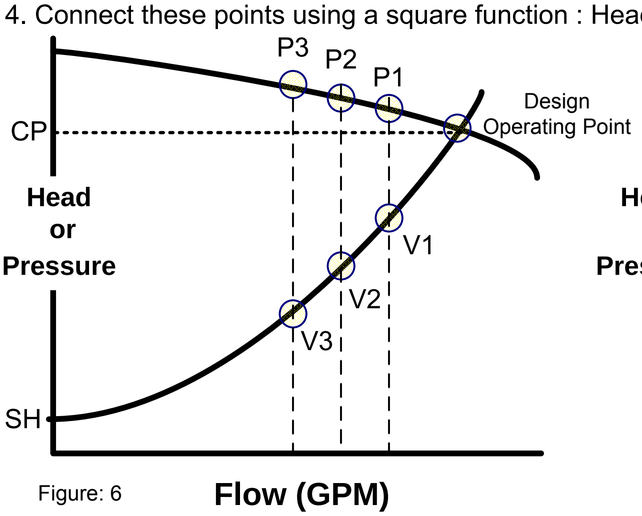


Figure: 6

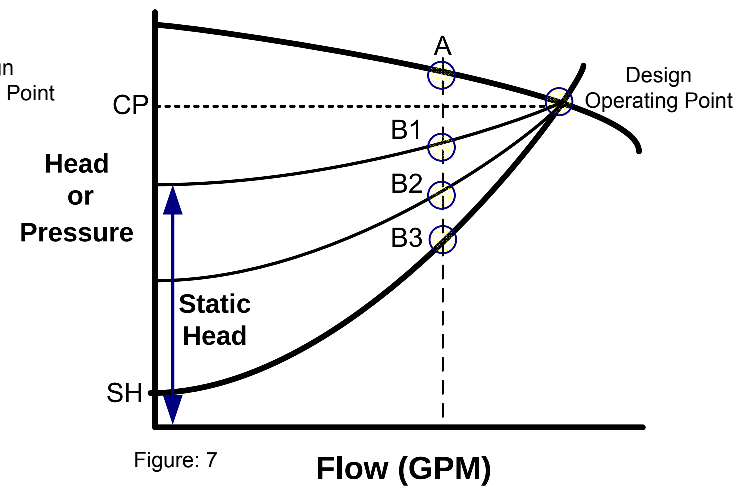


Figure: 7

P1, P2, P3 = Outlet Valve Flow Positions
V1. V2, V3 = VFD Operating Points
SH = Static Head
CP = Constant Pressure

Converting Constant-Speed Pumping to VFD Pumping

It is possible to convert constant flow systems to variable flow with the use of VFDs. Figure 1 & 2 show two piping arrangements of constant flow systems. In these constant flow systems, bypass valves control flow but at a constant pressure and speed - which does nothing to reduce energy at part load conditions. Graph 1 shows a typical curve for bypass valve flow control.
The basic steps to convert to a variable flow system are:

1. Review the system's pumping charts and system curves. If possible develop/measure your own system curves. Besure to review or measure the systems static head.
2. Review the type of valves. Three-way control valves may be converted to two way (see Figure 3). The existing 3 way valves – ideally should be equal percentage, and be able to control with the added pressure they will experience. If in doubt, 2-way valves may need to be installed.
3. Differential pressure sensor(s) need to be installed. The number and location of the sensor will depend on the piping system. These sensors would directly control the VFDs on the pumps.
4. Review to determine minimum flow requirements for the equipment (boiler & chillers). A new bypass arrangement may need to be installed to maintain the minimum flow requirements.

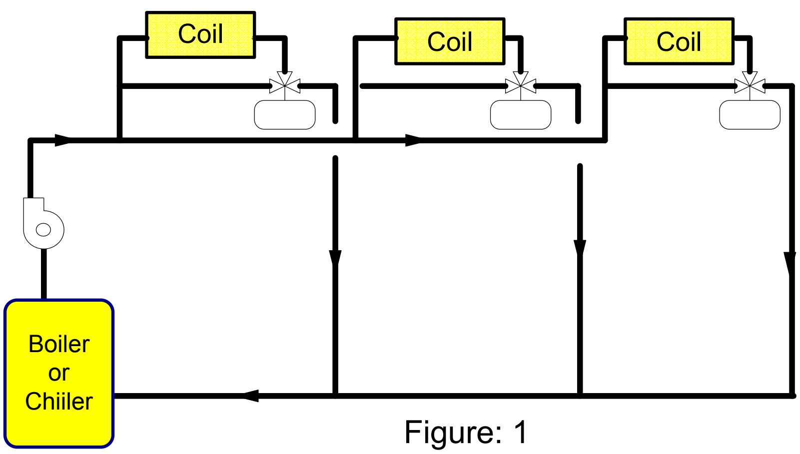
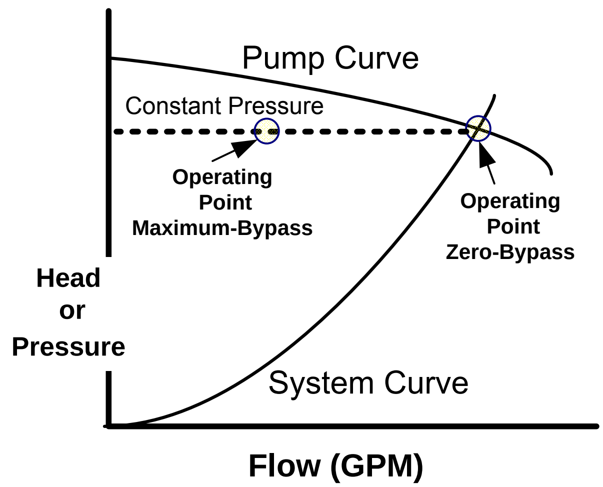


Figure: 1



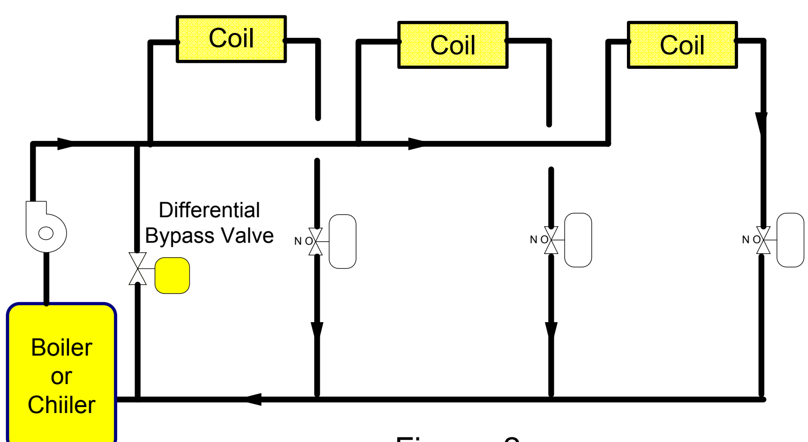


Figure: 2

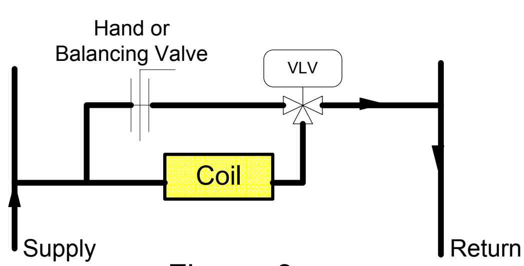


Figure: 3

3 way valve converted to 2 way operation

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Converting Constant-Speed Pumping to VFD Pumping

Figure 1 below shows a converted constant flow system to variable flow. The valves are 3 - way converted to 2-way (if possible). A differential pressure sensor (DP) is located at the end of distribution system to ensure minimum flow. In more complex piping systems, it may be necessary to have more than one differential pressure sensor. The location of this sensor is important as it allows the VFD controller to reduce the drive speed as flow is reduced. Placing it too close near the pump will lead to a reduction in the energy savings.
If it is located at the wrong spot (ie: at the pump), the tendency will be to have a higher setpoint at the controller to assure that there will be enough pressure at the farthest load during maximum load conditions. This higher than necessary setpoint can greatly reduce any potential energy savings.

The pressure sensor, in simple piping systems, may be directly connected to the VFD's internal controller. The DDC controller in the diagram is shown as an option. The addition of an optional DDC controller allows for control and monitoring of the equipment.

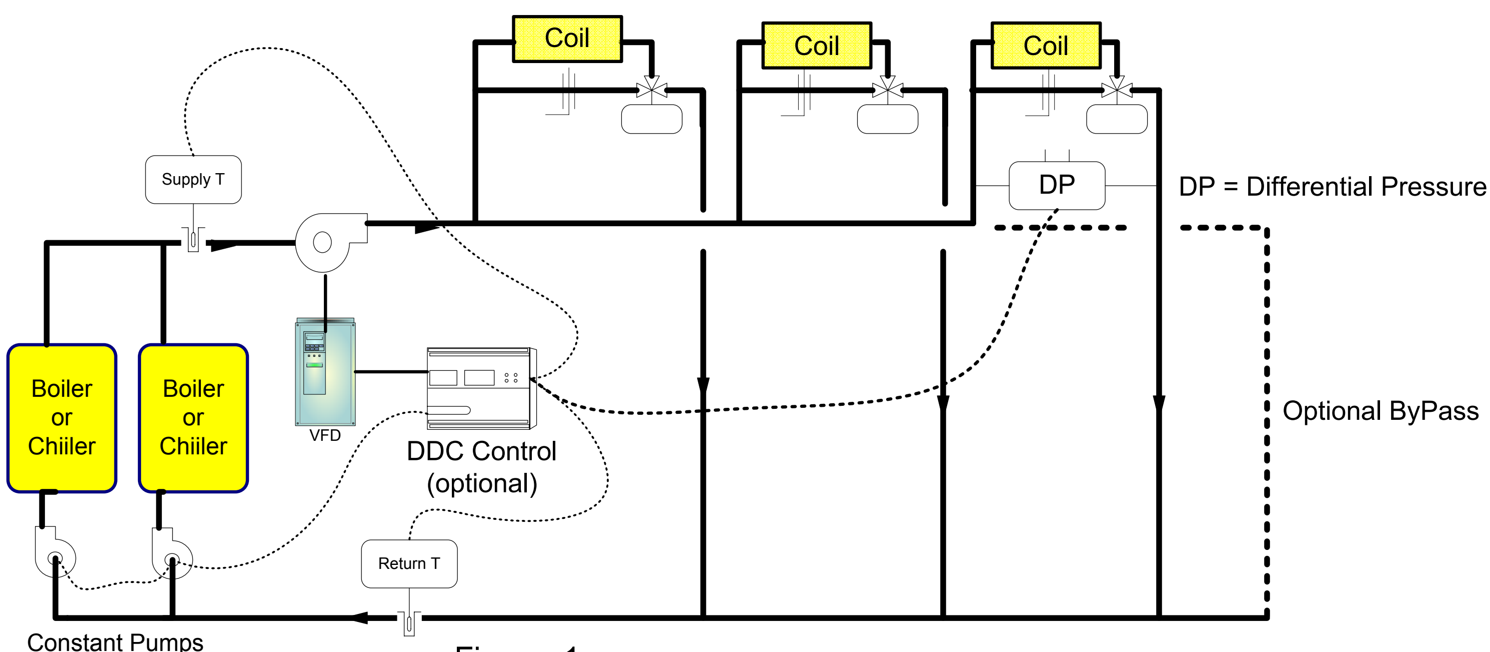


Figure: 1

Variable Frequency Drives & Centrifugal Fans

CENTRIFUGAL FANS

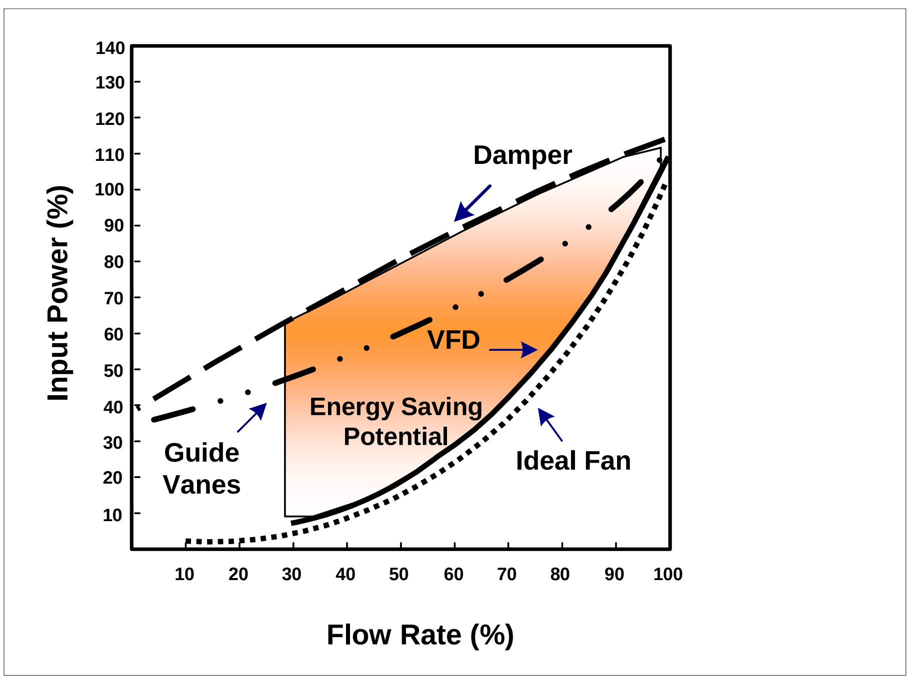
Three most common methods to control flow of fans are discharge air dampers, bypass dampers and inlet guide vanes. Figure 1 compares the power needs of these methods to direct control using VFDs.

Outlet dampers increase the resistance of the air flow much the same way a valve modulates the pump output. The fan remains at constant speed. These dampers are metal plates positioned in the air stream on the outlet of the fan. Volume is reduced by closing the damper. Closing the damper increases the system pressure which results in very little energy savings.

By pass dampers are least effective method of air flow modulation. The fan remains at constant speed. The air flow in these systems is controlled by bypassing the flow from the fan discharge to the fan intake. This type of control is simple and low in first cost, but does not conserve energy.

Variable inlet guide vanes directs air as air enters the fan. With these vanes, power requirements drop significantly as flow is decreased. The fan remains at constant speed. Volume is reduced by changing the vane position .Maintenance of these systems can be expensive as the operators an linkages are mechanical and need to be maintained.

Variable speed drives offer the greatest savings for fans. Power is greatly reduced (more than inlet vanes) as flow and speed decreases.



Typical Fan Applications

- Supply & Return Fans
- Exhaust Fans
- Boiler Combustion Fans
- Fume Hood Fans

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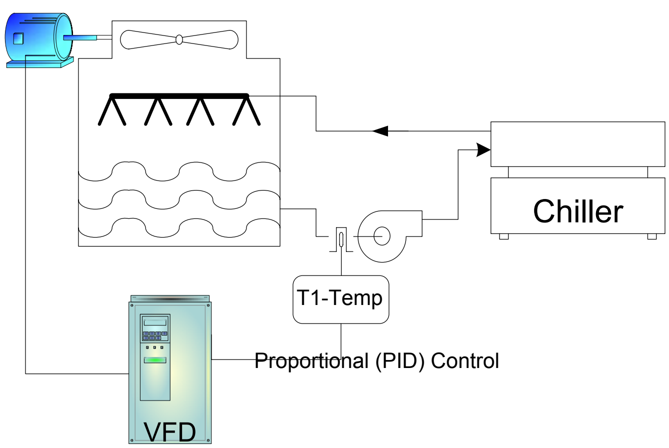
Variable Frequency Drives and Cooling Tower Performance

APPLICATION

Variable frequency drive (VFD) adjusts the speed of the fan(s) on the cooling tower by sensing temperature by way of the built in controller (PID).

ENERGY SAVINGS

Potential energy savings occur whenever the actual wet bulb temperature is lower than the design wet bulb.
A cooling tower is designed to remove heat from water at a specific rate via evaporative cooling. It should deliver "cooled" water to the system that should never exceed the design temperature. Since cooling is due to evaporation, the wet bulb temperature of the air is important. The cooling tower is thus designed to provide "cooled" water at the desired temperature at the highest wet bulb temperature that the cooling tower will experience.
Changes in the ambient wet bulb temperature causes the fan speed to be modulated and this reduces energy consumed by the fan(s) motor.

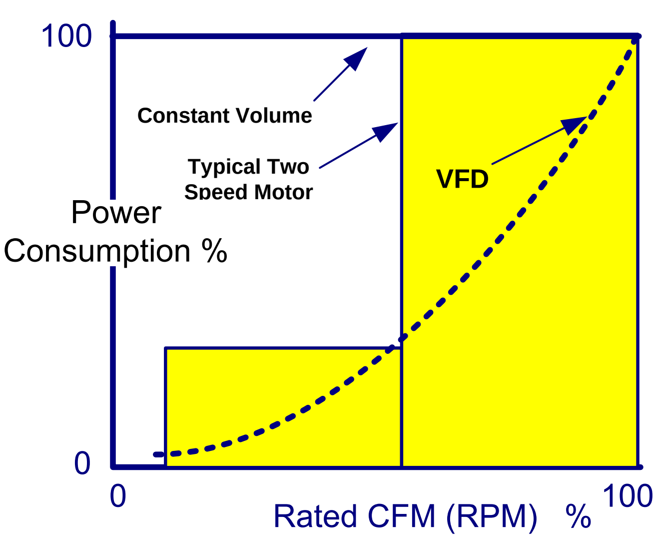


TOWER CONTROL

The VFD will run the fan at the lowest speed that will maintain the system output temperature. A temperature sensor located at the tower's outlet (T1) provides the signal that varies with water temperature. The set point controller (built in the drive or external) provides proportional accurate control of the cooling tower outlet temperature further, increasing the energy savings.

POWER SAVINGS

The relationship between power and speed of centrifugal fans is expressed in one of the affinity laws for motors. The power requirement of a fan varies as a cube of speed. The VFD allows the cooling tower fan to run at the desired speed to meet the cooling demand. ***Typically the fan will run at 40-70% of full speed, thus saving 50%*** or more of the energy consumed by a fixed speed (constant volume) system.



FEATURES	**BENEFITS**
Variable Speed	• Air flow is matched with actual demand • 60% Less fan energy than constant air flow systems • Reduces fan noise level • Accurate temperature control
High Efficiency	• Reduces the amount of make-up water required • Power consumption matches fan HP at all speeds at the most efficient point. • Reduce tower icing potential by running fan at lower speed
Soft Start	• Reduces line voltage fluctuation caused high demand • Increased life of fans, reducers, belts, bearings & starters

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Variable Frequency Drives and Cooling Tower Performance

RETROFIT

Increased system performance, energy savings and reduced maintenance costs are major reasons to consider retrofitting constant speed fans on cooling towers with VFDs.

When retrofitting, consider the following:

- Existing motors may be used with a VFD systems. Single and two-speed starters can be eliminated (a two-speed motor is permanently wired for high speed operation).
- Minimum speed of the VFD can be set to 20 to 25% for direct connected or belt driven fans. When a gearbox is used, minimum speed is more of a concern. The gearbox may depend on an oil slinger for lubrication. The VFD may be programmed to monitor the oil level & temperature of the gear box and increase speed to allow for more lubrication. The cooling tower manufacturer should be consulted for minimum speed recommendations.
- Consider vibration analysis on the fan and tower assembly. VFD controlled cooling tower fans operate over many speeds compared to constant or two-speed systems – mechanical resonance may develop at certain speeds. If the vibration is large enough, vibration switches are often wired to shut down the tower.
  Resonance speeds, when identified, can be programmed to be ignored or "locked out" in the VFD parameters, preventing vibration at these frequencies.
- VFD's are usually mounted away from the actual cooling tower, resulting in long lead lengths between the drive and the motor. For older motors, with lead lengths greater than 60 feet, a dV/dT (output) filter is recommended. Newer motors (usually approved for VFD operation) may have lead lengths in excess of 300 feet, with out the need for a filter. Have the motor manufacturer advise you of the lead length and carrier frequency restrictions.
- Industry standard communication field bus such as LON,BACNET, PROFIBUS, MODBUS and JOHNSON N2 OPEN are standard options on many VFD models. The communication options allow a management system to monitor data, energy usage, change drive parameters and remotely control the VFD.

CONTROL PARAMETERS

To achieve the desired water temperature, a temperature sensor (transducer) measures the actual temperature and compares it to the desired temperature setpoint. The VFD adjusts the speed accordingly. If the temperature is too high, the VFD will increase the airflow. If the temperature is too low, the VFD will decrease the air flow to reduce the cooling effect.

- The transducer/sensor is usually mounted on the outlet of the cooling tower. Mamac immersion type Model TE-213 is recommended as it provides the sensing signal (0-10 VDC or 4 – 20ma) to the VFD.
- Start with a control proportional band of 10 degs F to minimize fan cycling.
- Set motor acceleration and deceleration time to 90 sec to allow for soft start benefits.
- Carrier frequency may need to be adjusted to reduce noise and vibration.

VFD CONTROL FEATURES **(based on Johnson VS series drives)**:

- Terminals available for:
  - ϴ Low Level Alarms
  - ϴ Fan Vibration Shutdown
  - ϴ Other Sensors (OIL Temp Monitoring)
  - ϴ Fan belt breakage
- Optional Constant Speed Bypass
- Critical fan speed avoidance to avoid operation at the cooling tower resonant speeds.
- PID Control

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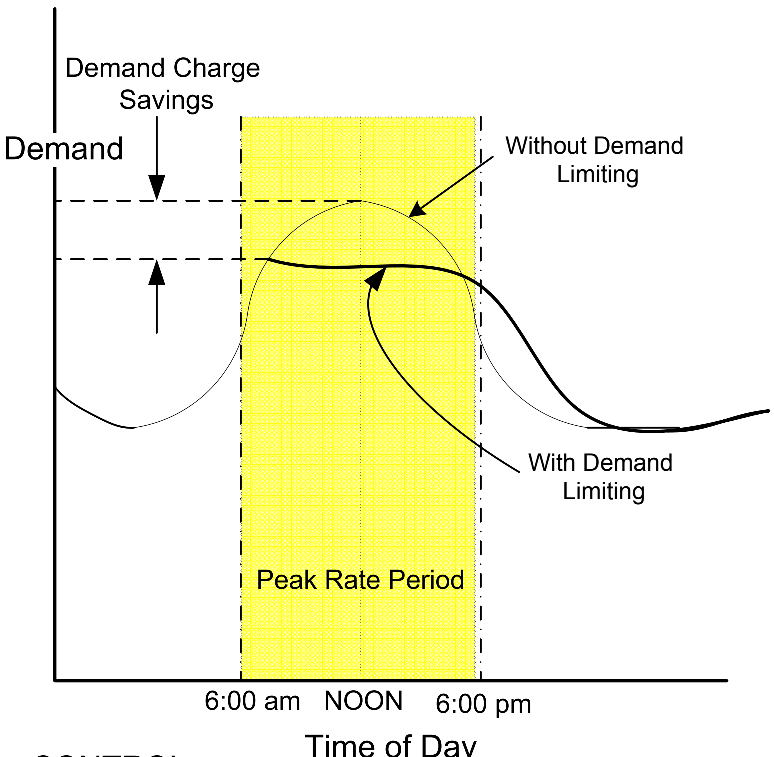
Demand Limiting Strategy Using Variable Speed Drives

DEMAND LIMITING

Demand Limiting is a common control strategy that reduces the utility bill by "limiting" the demand charges to a predefined level. Designated pieces of equipment is cycled off for relatively short periods of time to lessen the electrical demand.

Centrifugal loads in the HVAC system where variable speed/frequency drives (VFD) are present can have the speed reduced instead of having the equipment cycled off. The strategy make use of the "cubed" law between speed and power consumption, while maintaining comfort.



Utilities face shortages of generating capacity during high demand periods.. To encourage users to reduce energy consumption during these peak times, utilities charge a premium for electricity.

The demand limiting strategy is best implemented by a building automation control system that reduces the overall utility costs by controlling (reducing) the speed of the electrical equipment , or turning it off – typically for a 15 to 30 minute period – when the demand exceeds a predefined level. The predefined level is a level lower than the utility demand charge level.
Occupant comfort need not be sacrificed as overrides are implemented that allow equipment to resume normal operation, if space temperature exceeds pre-set limits.

CONTROL

- The control system should be capable of monitoring real time energy consumption.
- Building Automation System (BAS) Overrides should NOT be lower than the equipments' minimum speed.
- Ideally the VFDs being controlled should be compatible and networked with the BAS. Actual energy usage, KW and power can be read directly from the drive without the added expense of interfaces.
- Consider the **Johnson Controls VS Series** of drives for retrofit applications. The drives are Metasys N2 and LON ready.

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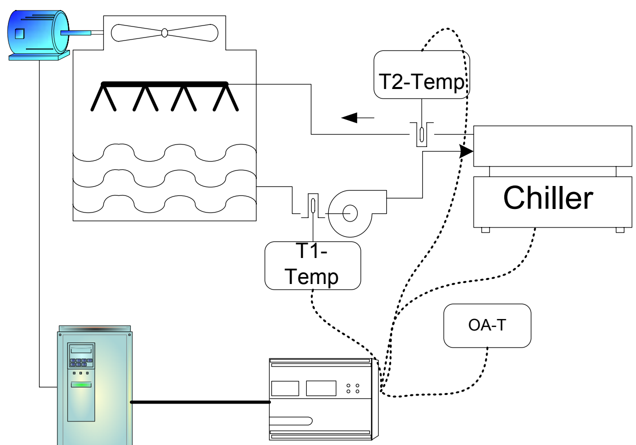
Variable Frequency Drives and Chiller Condenser Water Reset

COOLING TOWER OPERATION

The temperature of the water sent to the chiller condenser from the cooling tower is determined, largely by the ambient wet bulb temperature and the efficiency of the cooling tower (the amount of air drawn through the tower and the efficiency of air-water contact).

The cooling tower is specified to meet the design wet bulb temperature in any geographic area -- commonly 75° to 78°F. The cooling tower manufacturer then designs the tower to produce 85°F water under this condition for the design heat rejection level and water flow. The temperature difference between the water sent to the condenser (i.e. coming off the cooling tower) and this wet bulb figure (say 78°F) is defined as the approach temperature 7°F (= 85 - 78).



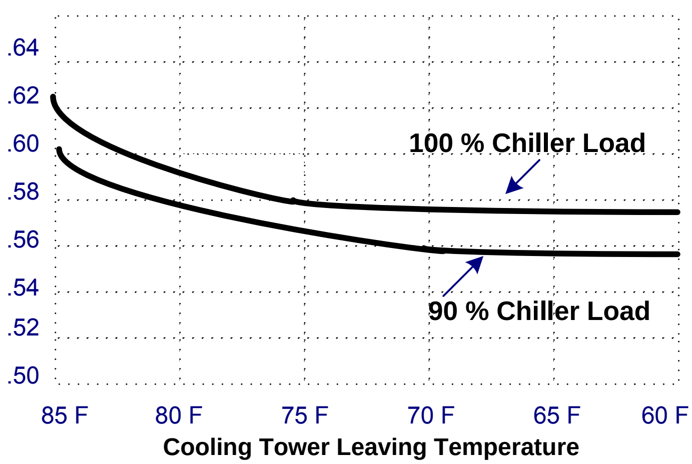


Figure 2

This design day wet bulb condition occurs relatively few hours a year. During dryer times, the cooling tower can produce colder water than 85°F. And, most chillers will operate with reduced power input if this water temperature is reduced (down to a given limit as specified by the equipment manufacturer). This concept is called "floating the condenser" and holds the potential of conserving energy and reducing operating costs.

Most of the energy consumed buy a chiller is used to move refrigerant from low pressure evaporator to high pressure condenser. As the pressure difference between the condenser and evaporator increases the compressor must do more work to move the refrigerant. Lowering the condenser water temperature decreases the pressure difference and the chiller does less work.

Some efficient chillers have a full load rating of 0.6 Kw/ton with entering water temperatures of 85° F. That same chiller can have a part load rating of 0.3 Kw/ton with 65°F entering water temperature. (Figure: 2)

CONDENSER WATER RESET

Cooling tower controls are usually set to produce water at 85 deg F. When ambient conditions are appropriate, the controls can be reset to product water that is cooler than 85 deg F. Depending on the chiller manufacturer, it may be possible to lower the leaving water temperature to 65 deg F – saving considerable energy.

There is a trade-off. In order to achieve the lower temperatures the cooling tower fan will run longer and harder. Therefore, the cooling tower fan can use up nearly 50% of the energy savings realized by the chiller. Using VFDs on the cooling tower fan provides better control and reduces the loss of potential energy savings.

CONTROL CONSIDERATIONS

Implementing Chiller Condenser Water Reset can be easier achieved with PLC type DDC controls, which use cooling tower supply and return temperatures to reset the condenser temperature and to monitor the load on the chiller. Additional sensors can monitor chiller load, control fan speed, and insure that the condenser water temperature doesn't drop too low.

- Use the DDC controller to control the VFD & calculate the reset setpoint of the condenser water.
- To ensure flow of refrigerant and maintain oil movement within the chiller, a minimum pressure differential must be maintained between the condenser and evaporator.
- Too low of condenser water will hamper return of refrigerant and actually reduce chiller efficiency.
- Implement a control strategy that optimizes the trade off between tower fan and chiller energy consumption.

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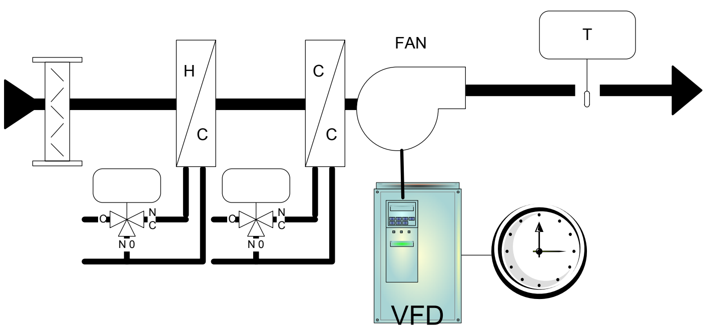
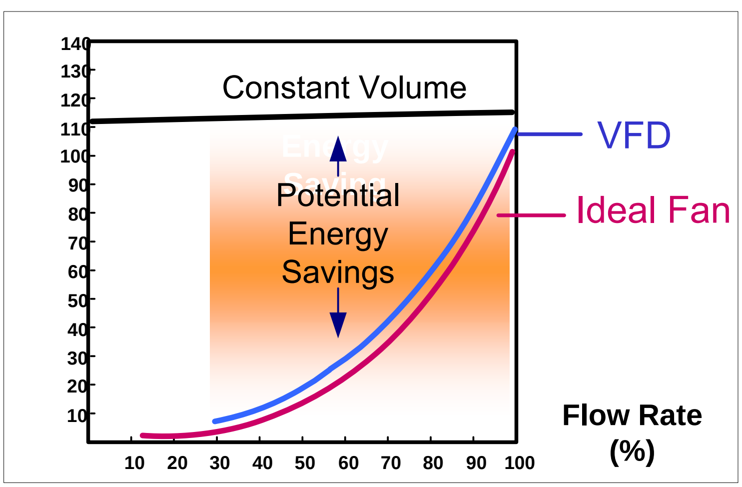
Make Up Air & Variable Frequency Drives

Make Up Air Units

Make Up Air Units (MUA) are used to bring in ‘fresh” conditioned air into a space to “make-up” the air that is exhausted from a building. In the case of condominiums and other high rise residential buildings, exhausted air from washroom exhaust, cooking exhaust, natural building ventilation systems is replenished by the MUA unit.
MUAs are usually designed for peak ventilation and occupancy periods are run at constant volume.

When VFDs are applied to MUA fan systems, potential savings are realized by reducing the speed of the fan during low occupancy periods. The chart below shows the relationship between power and flow. These physical laws of fans show that a 50% reduction in flow requires only 12.5% of the available horsepower. For a 50 Hp , this means that only 6.26 Hp is required.
Additional energy is saved by the REDUCED amount of air that is required to be heated or cooled.
Applying VFDs to MUA systems together with a good overall control strategy can realize substantial energy savings with payback less than 2 years.





Control Application & Considerations

Scheduling the MUA can be as simple has programming the VFD to several preset speeds that reflect the different occupancy periods in a building. The preset speeds are activated by time clock contacts or DDC control. The DDC control provides additional benefits which include VFD control, mechanical heating & cooling control with temperature setback.

For MUA units with electric or modulating gas heat, minimum flow must be maintained to prevent frozen coils or overheated heat exchangers. Verify minimum flow with the equipment manufacturer.

Lower minimum flows may be realized for MUA units with hydronic heating or cooling coils - increasing the energy savings.

ADDITIONAL FEATURES

ϴ VFDs can be interlocked with time clocks or exhaust fan contacts to enable the programmed speed. For example, the VFD may be programmed to run at 60% flow during weekdays from 2 to 4 PM and from 1:00am to 5:00am. And 100% flow at all other times.

ϴ Interlocking exhaust fans with the VFD allows the VFD to assume different speeds to match the number of exhaust fans that are turned on or off. (Volume Matching)

ϴ Indoor Air Quality (IAQ) sensors can be used to override and increase the speed of the the VFD when the carbon dioxide (Co2) increases above the override IAQ setpoint (800 to 1200 ppm Co2)

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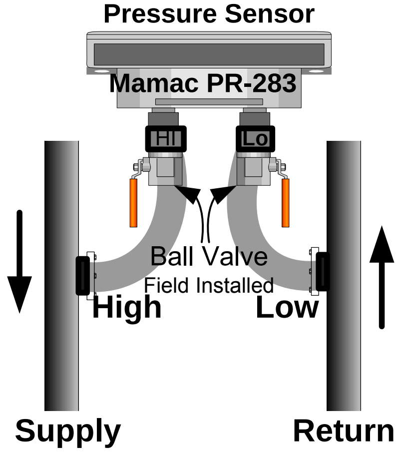
Application Guide # 9

Variable Frequency Drives in Retrofit or New Applications

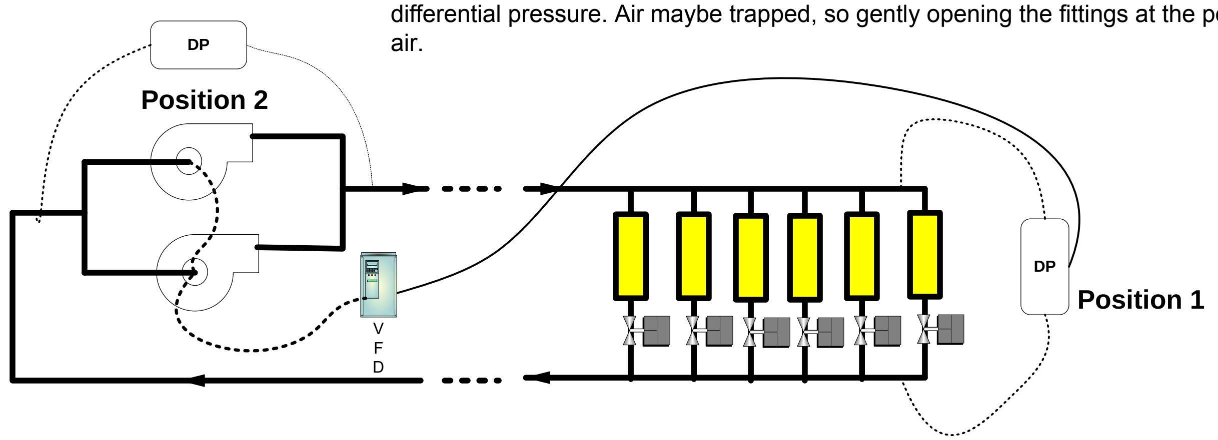
Applying Pressure Transmitters – “Wet - Wet”



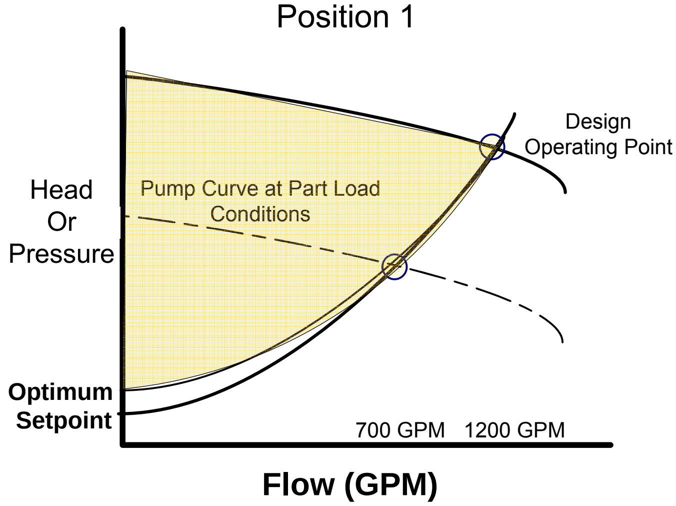
The location of differential pressure sensors, sometimes called wet-wet pressure sensors, is important when applying VFDs to pumps. The preferred location of the sensor is at the farthest point of the hydronic loop – see Position 1 in diagram 2. In this position pressure is measured at the load. There is no need to base the controlling setpoint to be based on “worst-case – maximum load, maximum pressure. In this best case condition the control curve – Figure 1 allows for a lower setpoint and thus maximizing energy savings (see shaded area)

Often, because of reducing installation costs, pressure sensors are placed at the pump – Position 2, in diagram 2. This location does not accurately represent the real “ part-load” conditions that occur. Thus, the setpoint is set higher to ensure that there will be enough pressure at the farthest load. The control curve in the worst-case setting is nearly linear and does not permit the discharge pressure to follow the system curve at lower load requirements.

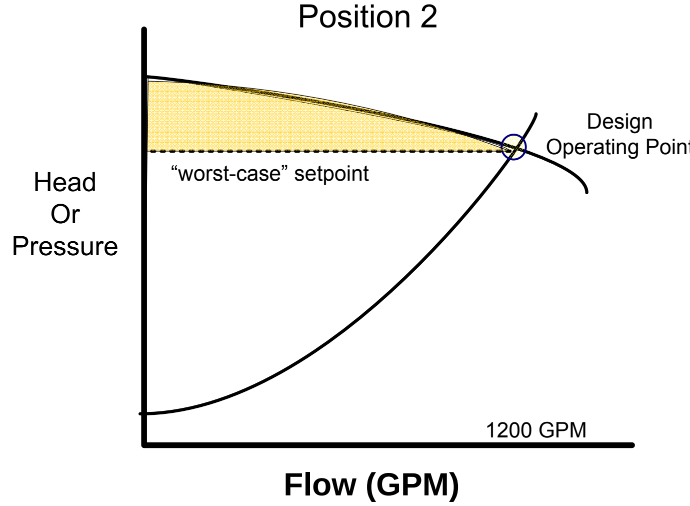
INSTALLATION TIP : It is always a good idea to install manual ball valves between the pressure sensor Hi & Lo pressure ports and the supply and return lines. This protects the transmitter from large pressure fluctuations that may occur during the construction or system retrofit process. After the system is fully installed, the ball valves are open so the sensor can then measure the differential pressure. Air maybe trapped, so gently opening the fittings at the ports will “bleed” any air.



VFD Application Sensor at Position 1



VFD Application Sensor at Position 2



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Variable Frequency Drives Saving Estimates

The following table was created as a guide to estimate energy savings through the application of VFDs. The table assumes 100 total Hp with 90% efficient motors. The assumed efficiency of the VFD is 97.5 %.

The following examples show how the table may be used.
Energy saving software (available from Yorkland) can be useful for more accurate estimates and various application comparisions.

	Non-VFD			VFD	
% of Total Fan/Pump HP On-Line	Operating Power kW	Operating Flow % of Design	% Fan Speed	Operating Power kW	Operating Flow % of Design
100%	78.70	100%	100%	80.8	100%
95%	73.40	96%	95%	69.50	95%
90%	69.00	92%	90%	59.40	90%
85%	64.60	88%	85%	50.40	85%
80%	60.30	85%	80%	42.50	80%
75%	56.00	80%	75%	35.40	75%
70%	51.80	76%	70%	29.30	70%
67%	49.00	73%	67%	25.60	67%
65%	47.70	72%	65%	23.90	65%
60%	43.60	67%	60%	19.30	60%
55%	39.60	62%	55%	15.30	55%
50%	35.60	57%	50%	12.00	50%
45%	31.70	52%	45%	9.30	45%
40%	27.90	47%	40%	7.00	40%
35%	24.00	41%	35%	5.20	35%
33%	22.70	39%	33%	4.60	33%
30%	20.50	36%	30%	3.80	30%
25%	16.80	30%	25%	2.60	25%
20%	13.30	24%	20%	1.80	20%
15%	9.80	18%	15%	1.10	15%
10%	6.40	12%	10%	0.50	10%
5%	3.10	5%	5%	0.00	5%

Example 1: 4 Fans at 20Hp (80HP total). The fan duty cycle is 75% (3 out of 4 fans usually run) at non-VFD – operating 250 days/year – 22 hours / day.
With the VFD the operation will be assumed at 60% fan speed. Fan runs 22 hours/day.
Energy Cost = .07Kw

Calculation: From table, 56Kw – 19.3Kw = 36.7kw in energy savings, 36.7kw x 80hp/100hp = 29.4kw. 29.4kw x 22 hrs = 647 kWh saved per day = $45.29 / day (647x.07) .

Savings per year = $11,322.50 ($45.29 x 250 days of operation/year)

Energy Saving Example

Example 2:

A 50 HP motor at $.07 / KwHr running 250 days per year for 10 hours per day. (2500 hrs).

Cost to run the motor at 100% speed = 35.6 kw (from chart) x 2500 x .07 = $6230

Cost to run the motor at the following duty cycle:

For 100 hp motor
100 % speed for 25% of the time: 80.08 kw(from chart) x (2500x .25) x .07 = $3535
80 % speed for 50% of the time: 42.50 kw x (2500 x .50) x .07 = $3719
60 % speed for 25% of the time: 19.3 kw x (2500 x .25) x .07 = $845

Total energy cost for 100 hp motor with VFD = $ 8099.00

Total energy cost for 50 hp motor with VFD = $ 8099 x $\frac{50}{100}$ = $ 4049.50

Savings to run a 50 hp motor with the above duty cycle = $6230.00 – $4049.50 = 2180.50

Modulating Supply and Exhaust Fans

Modulating Supply & Return Fans are used as a means of providing proper variable air volume (VAV) control as well as building pressurization. Many such VAV systems are still largely pneumatic with static to the downstream boxes being maintained by inlet guide vanes. To provide increased energy savings and energy comfort, these systems can be easily converted to VFD fan control of the supply and return fans and DDC control to coordinate any increased energy saving strategies. Figure 1 shows such a system.

To increase energy savings, the DDC controller can be programmed to reduce the flow from the return & supply fans for short periods of time. Coordinated with the building pressurization system, any temporary loss of space temperature may be avoided.

In Figure 1, the supply fan is controlled by the duct static pressure sensor, via the DDC, while the outside air and mixed air dampers are optimized to provide economizer control.. The return fan is modulated to stabilize building pressure at a slight positive. For simple supply and exhaust systems the building pressure and static pressure sensors may be connected directly to the VFD drive with an internal PID controller.

Typical Energy Savings are realized from converting pneumatic (or electromechanical) control to DDC control with VFD in the following ways:

1. Locking inlet guide valves mechanically open to allow the VFD to fully modulate the fans.
2. Free cooling by accurately modulating the economizer dampers and sequencing the mechanical equipment.
3. Controlling static and resetting the static pressure during short periods of time.
4. Accurate building pressurization.
5. Implementing other energy saving measures which include supply air reset, and night purge routines.

CONTROL CONSIDERATIONS

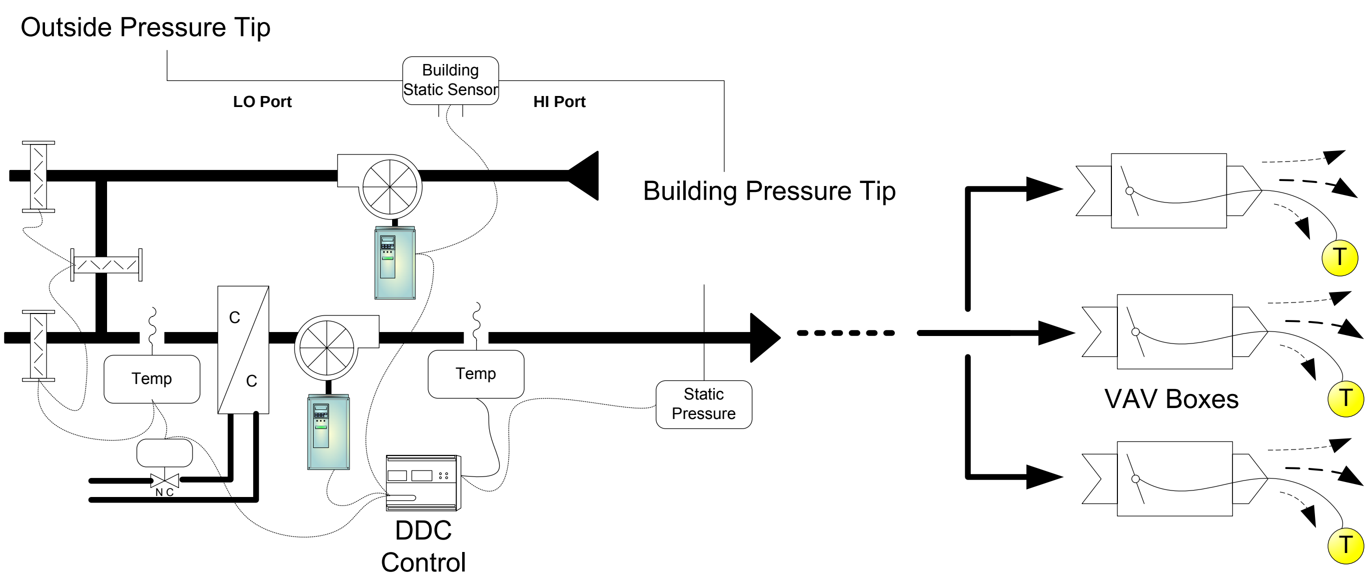
ϴ Placement of the indoor static pressure sensor is important as it should provide a stable signal. Entrances, dock, and other areas where large , sudden static pressure changes may occur should be avoided.

ϴ The outside reference static tip should be shielded from wind and rain.

ϴ When the exhaust fan is VFD controlled, consider a 2-position air damper to prevent the outside air from entering the building (infiltration) when the exhaust fan is off or a very low speeds.

ϴ For simple VAV systems, consider using drives with built in PID controls such as the **Johnson VS** series of drives.. This minimizes hardware and installation costs. Static sensors such as the **MAMAC PR-274** type provide a 0-10vdc control signal directly to the drive.

ϴ Duct mounted static pressure sensor should be mounted 2/3 of the distance of the distribution system.



VAV System Optimization

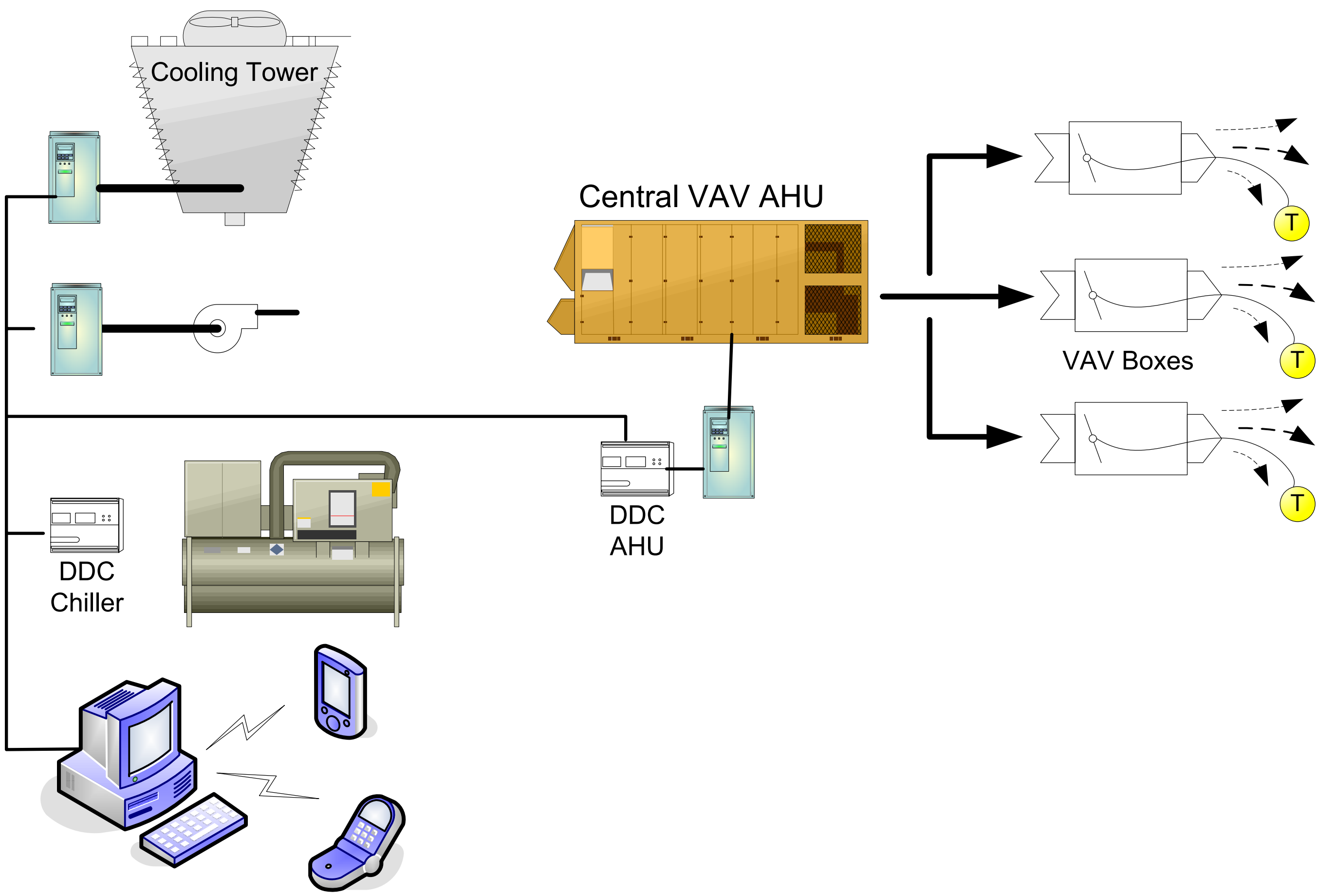
Variable Air Volume Systems (VAV) can be optimized to increase energy savings by maximizing the effeciency of the equipment at part-load conditions. The goal with the optimization strategy is to run each subsystem (chiller, cooling tower, Airhandler, etc) in the most efficient way possible while maintaining the current building load requirement.

As each VAV terminal controls the space temperature - based on flow – the "worst case" zone can easily be identified by an automation system. The supply fan speed can be reduced by resetting the static pressure (see following page). As the load drops and the fan meets a preset minimum flow, the system resets the air temperature up, so less chilled water is needed. In a variable flow chiller system, this reduces pumping energy.

If the system load continues to drop, the system will reset the chiller supply water temperature upward which will then reduce the energy requirements of the chiller. Changes in the chiller head pressure and loads can then reset the cooling tower fan speed.

The key to optimizing the system operation is communication and information sharing through the entire system equipment.

With the reduced cost of VFDs and Building Automation Systems, (BAS) complete system optimization can be implemented as a cost effective option.

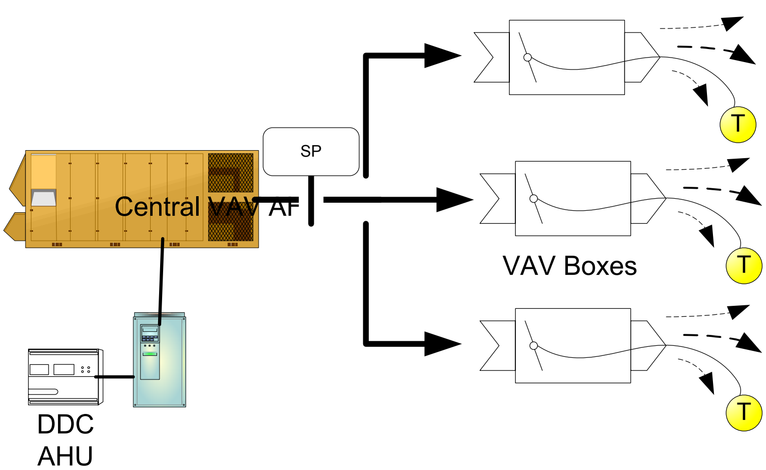


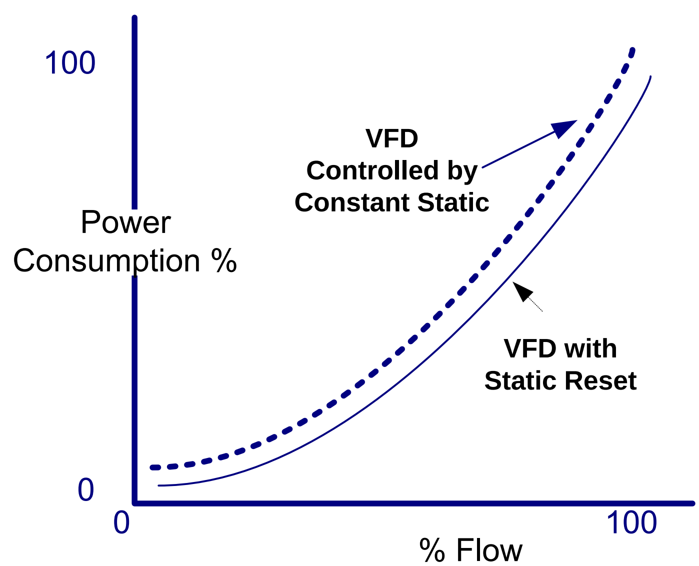
Static Pressure Reset

In VAV systems where the individual VAV boxes and the AHU are on a building automation system, additional savings can be achieved by implementing static pressure reset.
The static pressure sensor in a VAV system is typically located two-thirds of the way downstream in the main supply air duct for many existing systems. Static pressure is maintained by modulating the fan speed.
When the static pressure is lower than the setpoint, the fan speeds up to provide more airflow (static) to meet the VAV box needs, and vice-versa. A constant set point value is usually used regardless of the building load conditions.
Under partial-load conditions the static pressure required at the terminal VAV boxes may be far less than this constant set point. The individual boxes will assume a damper position to satisfy the space temperature requirements. For example, various VAV box dampers will be at different damper positions, (some at 70% open, 60% open, etc) very few will be at design, ie 95% -100% open.

RESET STRATEGY

Essentially, resetting supply air static pressure requires that every VAV box is sampled with the static reset set to the worst case box requirement. For example, each box is polled, every 5 minutes.
If no box is more than 95% open, reduce duct static pressure set point by 5%. If one or more boxes exceed 95% open, increase static pressure set point by 5%.
With a lower static set point to maintain, fan speed reduces. The result is increased energy savings in the 3 to 8% range. See figure below.
If the BAS system is already installed, implementing this strategy is relatively free.





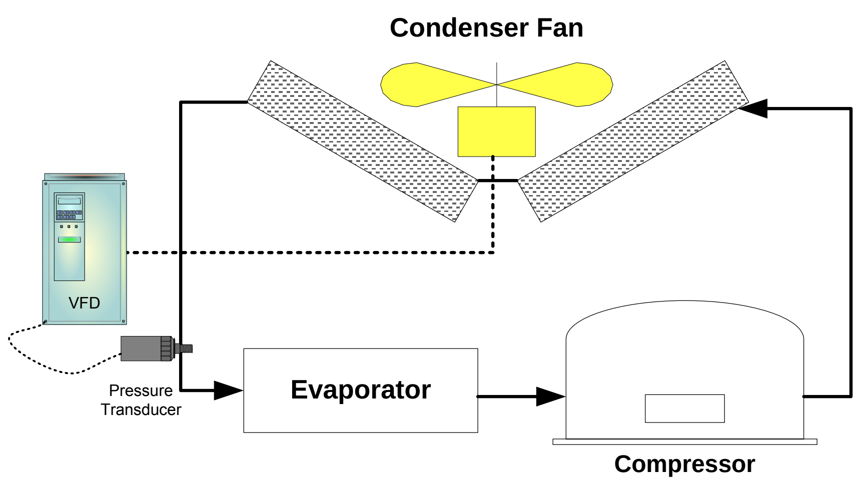
Head Pressure Control and Variable Speed Drives

Head pressure control is used in many refrigeration system where the application requires the system to operate most of the winter season.
Essentially, the head pressure control setpoint changes as the ambient (outside air conditions change).
Energy savings are realized if the condenser is allowed to operate at the lowest possible condensing temperature. The compressor does not need to work as hard and there are savings by employing a variable speed drive. Using accurate PID control increases the systems efficiency.

Another method to control head pressure is to allow the head pressure to “float” a fixed differential temperature above the ambient. The pressure is allowed to float based on the load.

Control Considerations

ϴ Pressure sensor is connected to the refrigeration system and wired directly to the VFD with a built in PID controller. This reduces material and installation costs.
ϴ Consider where the VFD is to be mounted. It may need to be housed in an outside air enclosure and need to operate in low ambient environment (-40 deg F)
ϴ The existing motor may need to be converted to 3 phase.
ϴ If the VFD is to mounted a fair distance away, consider an output filter even though the motor is inverter (VFD) rated.
ϴ For sleeve bearing motors, the VFD may be programmed to operate the motor at full speed for a few seconds to provide adequate lubrication of the motor.



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Application Guide # 14

Variable Frequency Drives in Retrofit or New Applications

AC Motor and Drive Guidelines with Long Leads

Output Line reactors and filters increase the life of ***existing motors*** in many VFD applications.
Below are some general “rules of thumb” of when and where to apply filters.

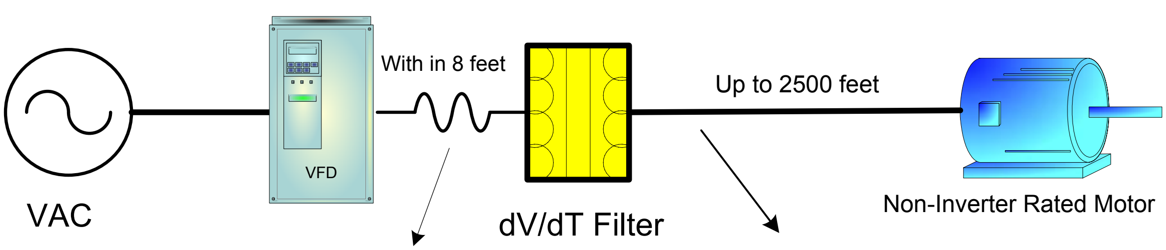
GUIDELINES

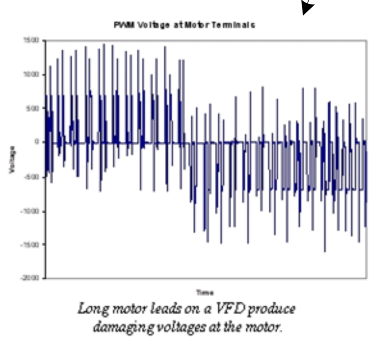
- Existing motor to be controlled by a VFD should have a service factor of 1.15 to higher
- Insulation Class of existing motor should be “F” or higher
- Conductor length from VFD to motor should be less than 150 feet with no output filters.(see Table 1 for guidance)
- Inverter (VFD) rated motors can operate at any distance from the drive. Check with manufacturer installation recommendations.
- With reactor installed at VFD output, lead length can extend from drive to motor up to 300 feet .
- With reactor installed at Motor terminals (motor input) the lead length can operate motor up to 650 feet.
- An Output Filter (dV/dT) specifically designed to strip the high frequency voltage transients that may harm the motor, can operate the motor to approximately 2500 feet. Note - the dV/dT filter must also be bypassed if the drive should fail.

For Standard Duty (Non-Inverter Duty) Motors with no dV/dT, as a general guideline, limit carrier frequency and cable length as follows □:

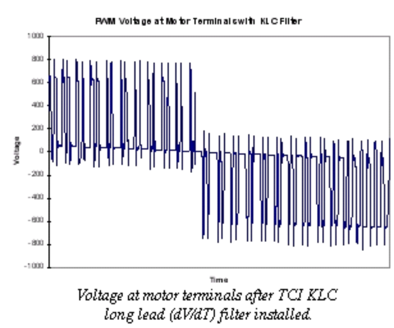
TABLE 1

Carrier Frequency	Max Cable Length in feet for 230V motors	Max Cable Length in feet for 460V motors	Max cable length in feet for 575 V motors
3	600	125	40
6	600	100	25
9	600	85	20
12	600	75	15





Before dV/dT Filter



After dV/dT Filter

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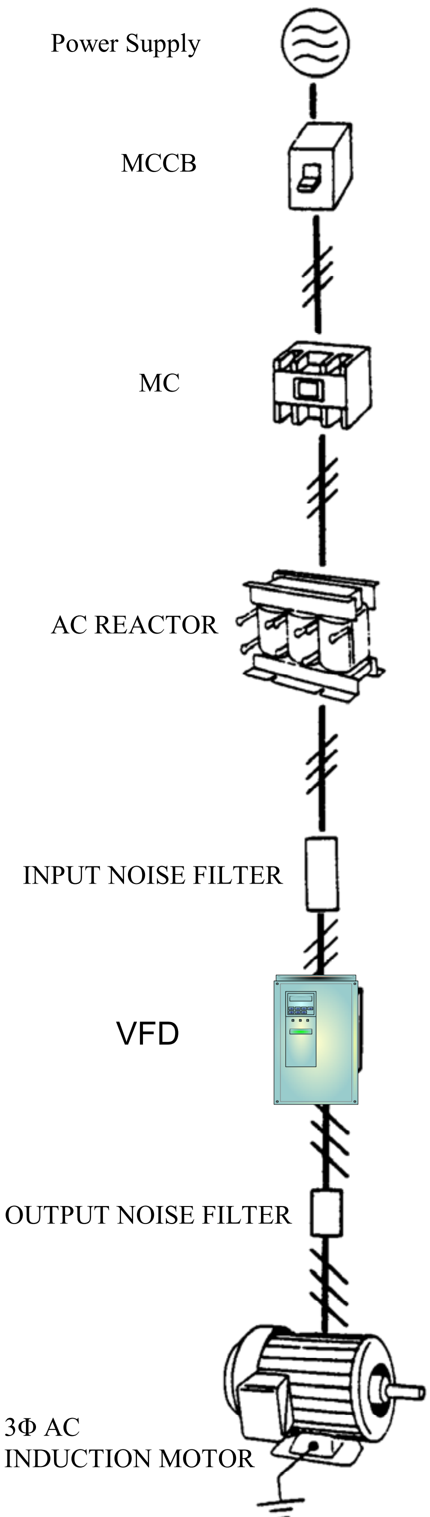
Variable Speed Drive Wiring Accessories



MCCB (molded case circuit breaker)
Do not use a circuit breaker for start/stop operation.
When a ground fault interrupter is used, select the one with no influence for high frequency. Setting current should be 200mA or above and the operating time at 0.1 second or longer to prevent malfunction.

MC (magnetic contactor)
It is not always necessary to have the MC on the input side. However, an input MC can be used to prevent an automatic restart after recovery from an external power loss during remote control operation.
Do not use the MC for start/stop operation.

AC REACTOR
When power capacity is significantly large compared to inverter capacity, or when the power factor needs to be improved, externally connect an AC reactor. Many VFD manufacturers install reactors in the drives. It is always a good idea to check.

Input Noise Filter
To comply with certain communication and interference regulations, input noise filters are to be installed. Many manufacturers include these filters.

Inverter (VFD)
Wire input to terminals L1, L2 and L3 for three phase input. Make sure to connect the ground terminal to an appropriate safety ground.

Output Noise Filter (EMI Suppression)
When used with output noise filter, radiated and conducted emissions may be reduced. dT/dV filters protect motors from EMI and voltage transients output from the drive itself. Not required if the motor is "inverter" rated.

Motor
When multiple motors are driven in parallel with an inverter, the inverter rated current should be at least 1.1 times the total motor rated current. Make sure that the motor and the inverters are separately grounded.

Preventive Maintenance of Variable Frequency Drives

Variable speed drives , like most mechanical equipment, should be inspected periodically. The table below shows the typical checks that should be performed.
The frequency of the inspections will depend on the installation, however, new installations should be checked every month for the first 6 months. Below are some general logical guidelines:

KEEP IT CLEAN & DRY
Most VFDs are enclosed in NEMA 1 (side vents for cooling airflow) or NEMA 12 (sealed, dust-tight).
Drives in the NEMA 1 class should be kept free of dust. Dust can cause a lack of air flow which reduces performance from heat sinks and circulating fans. In extreme cases, dust absorbs moisture which contributes to a shorter operating life or drive failure.
Drive manufacturers, including the Johnson VS series, allows the heat sink temperature to be monitored, while in operation.
Dirty, wet or other contaminated parts must be cleaned by vacuuming or wiping.

Normally, if the VFD is operated every day, the normal radiant heat should prevent condensation. Consider a NEMA 12 enclosure with a thermostatically controlled heater in locations where condensation is likely.

Check circulating fans for signs of wear or foreign objects.

CONNECTIONS
Inspect connections. Heat and mechanical vibration can lead to loose connections. (see table below)
Bad connections lead to arcing and causes nuisance trips.
Loose control connections can cause erratic operation. A loose reference signal from a controller or sensor can cause the drive to fluctuate.
With the drive off, check the tightness of all terminals. Be careful not to over-torque.

Measure the DC Bus voltage while the drive is in operation. Fluctuations in DC bus voltage may mean that the drive is under stress and will cause future trouble. Most manufacturers make the DC Bus voltage available to view on a keypad. If the bus voltage is erratic, consult the manufacturer before taking further action.

Component	Check	Corrective Action
External terminals, unit mounting bolts, connectors, etc.	**Loose screws**	**Tighten**
	Loose connectors	**Tighten**
Cooling fins	**Build-up of dust and dirt**	**Blow with dry compressed air of 39.2 ×10^4 to 58.8 x 10^4 Pa (57 to 85psi.) pressure.**
Printed circuit board	**Accumulation of conductive dust or oil**	**Blow with dry compressed air of 39.2 x10^4 to 58.8 x 10^4 Pa (57 to 85psi.) pressure.** **If dust and oil cannot be removed, replace the board.**
Cooling fan	**Abnormal noise and vibration. Whether the cumulative operation time exceeds 20,000 hours or not.**	**Replace the cooling fan.**
Power elements	**Accumulation of dust and dirt**	**Blow with dry compressed air of 39.2 x10^4 to 58.8 x 10^4 Pa (57 to 85psi) pressure.**
Capacitor	**Discoloration or odor**	**Replace the capacitor or inverter unit.**

Converting Heat Pump Systems

HEAT PUMP SYSTEMS

Heat pump loop systems may be converted to variable flow by installing a solenoid valve on each heat pump to stop the flow of water through the local heat pump (HP), when the unit is not operating.
This allows the pump head to increase and the VFD to modulate the pump speed to maintain a constant head (reduced flow). The result is a demand reduction and energy savings. Figure 1 shows the potential energy savings (shaded) on the pump curve.

CONTROL CONSIDERATIONS

A typical heat pump loop circuit ,such as shown in Figure 2, controls the heat pump loop at set point, by modulating valve (V1) for heating and sequencing the fluid cooler (cooling). With solenoid valves installed at each heat pump (HP), flow can now be controlled by the VFD controlling P1 & P2. The fluid coolers fan motor may also be controlled by a VFD – further increasing the savings.
The optional DDC Control, can integrate the complete loop by controlling the boilers, VFDs, fluid cooler sequencing and any additional pumps.
The differential pressure sensor DP should be installed at the farthest possible location of the system.
Pumps P3 & P4 are constant flow. They may also be controlled via a VFD, however, a complete review of the other heating loop requirements should be conducted.
In such a system, with various VFDs operating different pump sequences, installation costs can be reduced by installing VFDs with network capability.
For example, VS Drives with Metasys N2 communication bus, can be daisy chained instead of hardwired back to the controller(s).

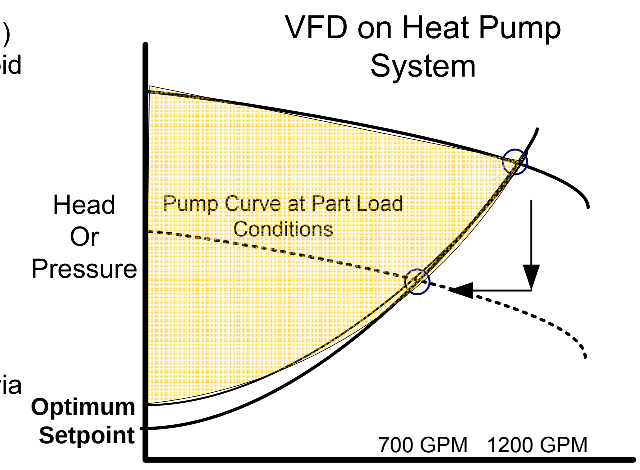


Figure: 1

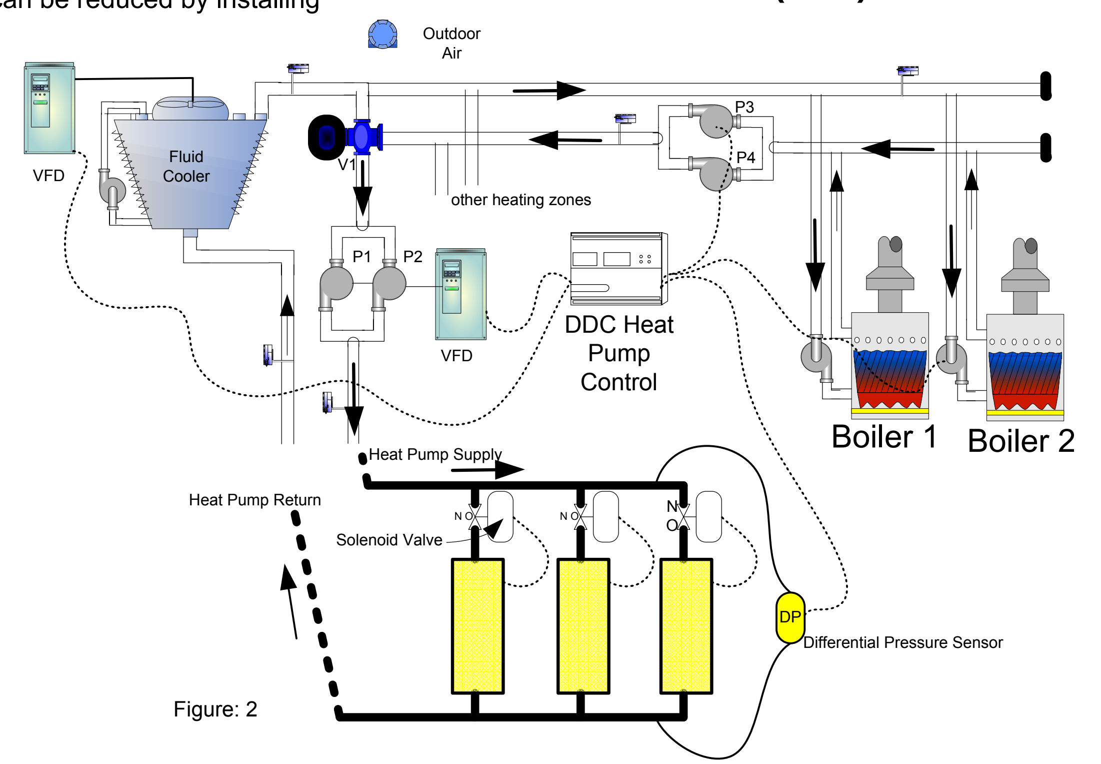


Figure: 2

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Parking Garages

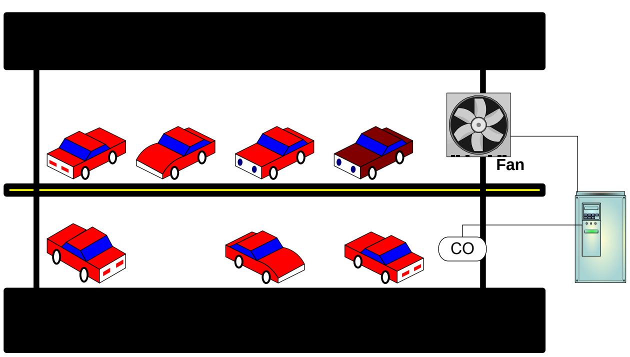
The concentration of carbon monoxide in car parks reaches a dangerous levels during peak traffic periods. However, conventional ventilation fans operate all day or in stages based on CO concentration resulting in a large waste of energy.

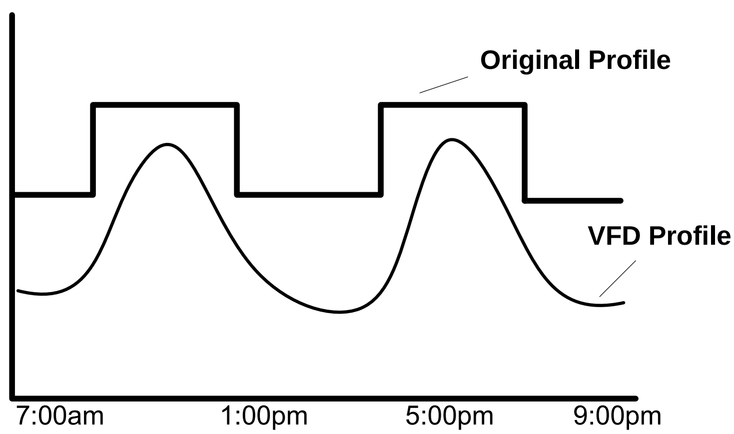
CO sensors are available on the market, which monitor CO concentrations. These sensors can be used with variable frequency drives to obtain optimum control with minimum energy consumption.

Automating the fan control with drives helps eliminate the potential danger of human error where fans may be unknowingly operated at low speeds during peak traffic times or of wasting large quantities of energy if left operating unnecessarily at full speed for longer than necessary periods. Even compared to automated two speed fan systems, large energy savings can be made.

Energy Savings

To calculate the potential savings over time, the actual load/time profile should be estimated. The load profile indicates the amount of flow the system requires to satisfy its loads during a typical day, month, year or time period under study. Diagram 1 below (Energy consumption over time) shows a typical load profile of a parking garage. The profile will vary depending on the specific needs of the system due location, safety margins used in the design phase and several other factors.





Diagram

Booster Pumps

Pressure booster pumps essentially add pressure to a commercial building's water supply at times when the water mains pressure is not sufficient. Most multistory apartment complexes, hotels, etc, require pressure booster pumps to supply adequate pressure to terminal units such as showers and bathrooms.

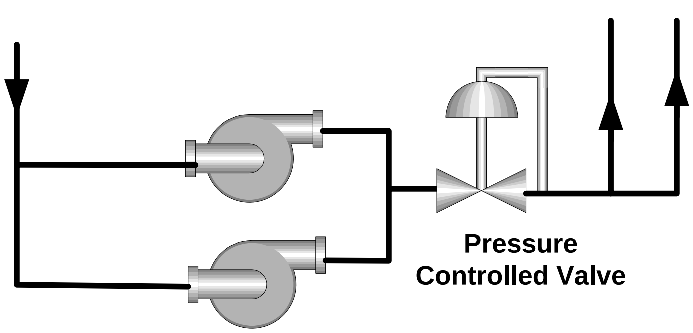
The pressure booster pumps need to be sized to maintain the design pressure while experiencing the maximum expected flow at the lowest suction pressure to the pump. A pressure control valve is used to balance the system and maintain the desired pressure in the system as the flow rate decreases or suction pressure varies to avoid over pressurization and control problems. In instances where the flow requirements vary significantly, multiple pumps are placed in parallel. As water consumption changes, additional pumps are staged on or off to maintain the pressure.

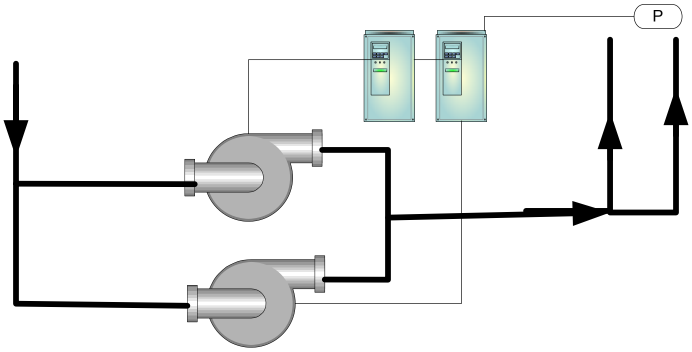
Variable speed drives can be added to pressure booster pumps as an alternative to using pressure control valves. This saves the energy and eliminates its cost and maintenance. The savings can amount to 20% or more, simply due to the safety factor used during the design of the system. If the suction pressure of the pump varies, the over-sizing of the pump required to handle the lowest suction pressure does not penalize the installation, when the suction pressure increases.

Control Considerations

ϴ The location of the pressure sensor is important. In the relatively small pressure booster-pumping systems found in commercial buildings, it is important to place the pressure sensor at the furthest possible location.

ϴ When the system becomes too large for one sensor, multiple sensors can be used, each placed in a critical area of the system. Where this is not possible, different setpoints can be established depending on the number of pumps operating.





Filters

Filter control systems are a type of constant air volume system often found in clean rooms, hospitals, laboratories, and other institutions where clean air is essential. They are employed wherever conditioned air must be filtered just before delivery to the occupied space in order to prevent contamination of a controlled space.

The supply fan blows the air across heating and cooling coils as required and through special micro filters. These filters remove contaminants from the air before it enters the controlled zone. Exhaust fans, sometimes also fitted with filters, remove the air from the zone and channel it to the outside. These fans
need to be sized to provide design flow even when the filter is dirty and has its maximum resistance.

Traditionally, no control is utilized in these systems. Once the system is balanced, no air flow capacity modulation is possible for the system or the fan. When the filters are new, the resistance of the filter is very low. This actually causes air to flow in excess of design conditions increasing energy consumption and decreasing the life of the filters. As the filters become clogged, the resistance increases to the filter's maximum rating level, then they are replaced. A differential pressure sensor is commonly utilized to monitor the filters and identify when the filters should be changed.

Using a drive in co-operation with a pressure sensor, the supply fan can maintain a precise flow rate. Since the system does not modulate, the pressure downstream of the filter is proportional to flow. As the filter becomes dirty and its pressure drop increases, the drive automatically increases the speed of the fan to compensate. In addition to allowing true constant air volume control, the drive saves energy and provides a soft-start increasing the life expectancy of the filters.

Less energy consumption occurs with clean filters, than would occur without the filter control strategy, because the drive will automatically maintain a reduced flow and lower fan discharge pressure when the filters are clean.
More energy consumption occurs with dirt loaded filters, than would occur without the filter control strategy, because the drive will automatically increase discharge pressure to overcome filter resistance and maintain a constant flow when the filters are clogged.
Dirty filters are recognized when the Drive speed reaches 80% to 100%.

The increase in energy consumption with clogged filters is more than offset by the reduction in energy consumption with clean filters. Pressure increase across a filter is not linear with filter dirt loading - 85% to 90% of the filter life occurs at less than 40% of the filter final pressure drop. Therefore, most of the filter life span contributes little to filter pressure drop increase.(see Figure 1). A strategy of keeping the flow constant, raising the fan discharge pressure only when needed, will produce energy savings as well as significantly extending the life of the filter. Typically, these systems are considerably oversized by a "safety" factor, which means design airflow is reached at less than 100% fan motor speed, adding to the potential savings.

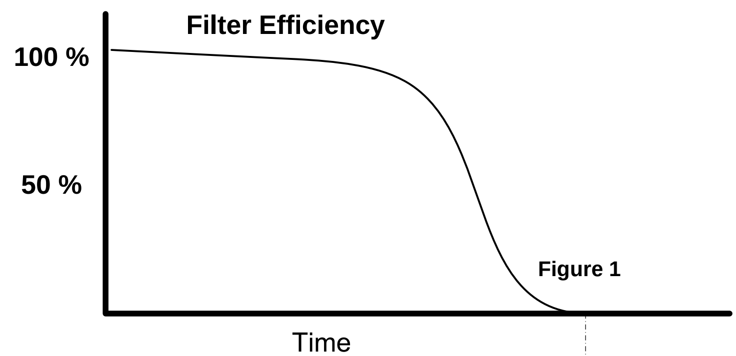
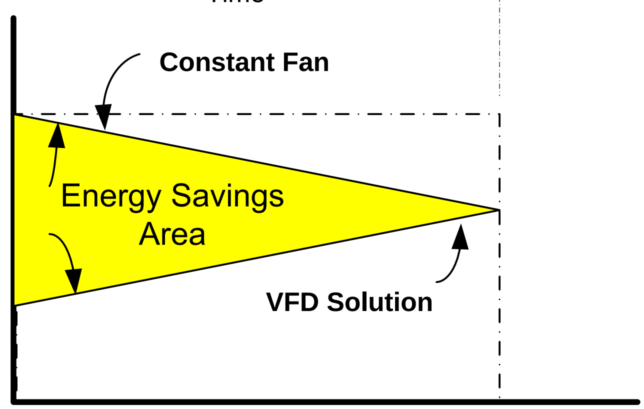
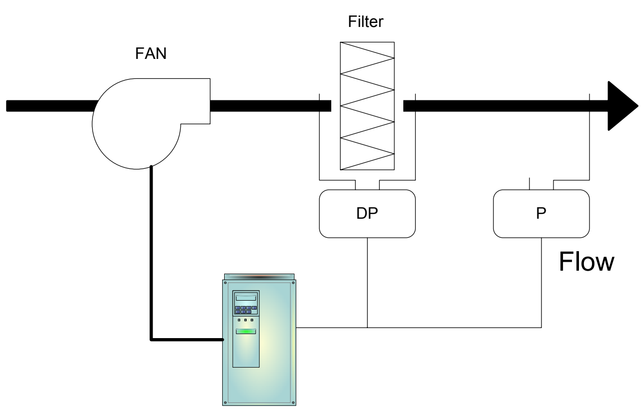


Figure 1



Energy Consumption over Time



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Swimming Pool Filtration System

Due to decreasing prices of VFDs, frequency converters are being used on smaller and smaller systems, such as swimming pool systems.

Nearly 40% of the total energy used by indoor swimming pools is consumed by the filtration and circulation pumps which are responsible for maintaining the cleanliness of the pool water.

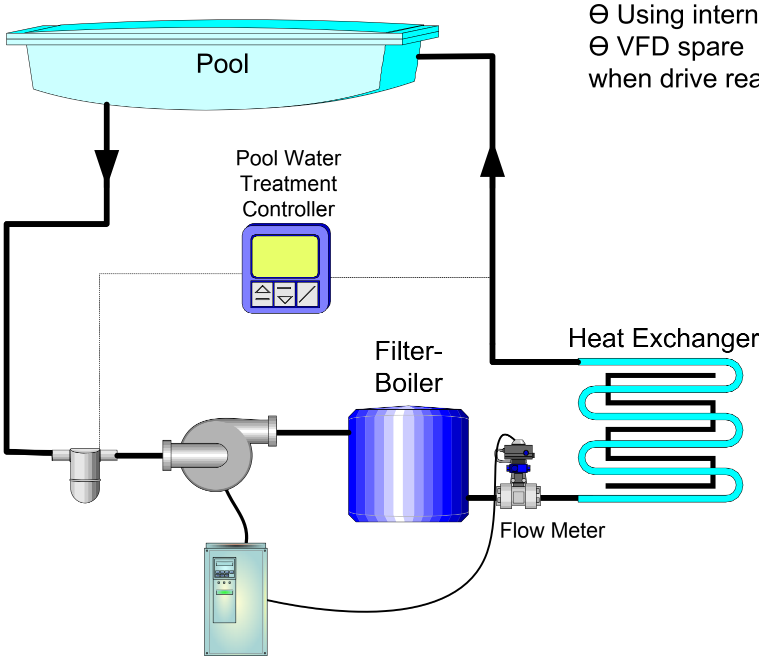
These pumps "recycle" the pool water by drawing it through a series of filters and chemical injection pools before returning it to the swimming pool. Filtration rates (set by government authorities) are intended to ensure proper standards of hygiene.

The filtration and circulation pumps must be capable of pumping a required volume of water in the worst case scenario - when the filters are clogged. New filters have a low resistance to flow is very low, so excessive amounts of water are circulated through the pool. The filters then experience a period of high wear until they become clogged and the flow rate they experience decreases toward design conditions. With public safety at issue, these pumps are usually oversized.

VFDs can be added to swimming pool filtration and circulation pumps very easily to eliminate the wasted energy due to the worst-case design philosophy and safety factor considerations. The VFD is installed along with a flow-meter to guarantee the appropriate water volume. The pump slows down to match actual demands.

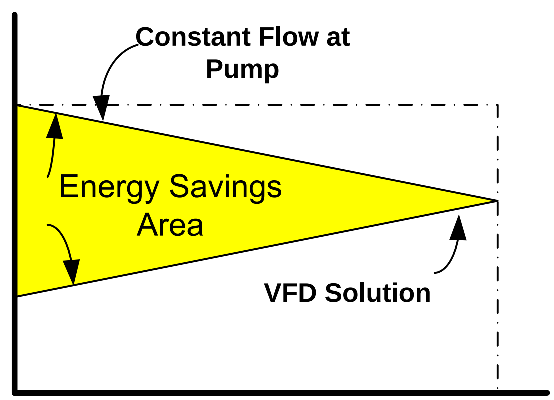
Initially, the drive will operate at a reduced speed while the filter is new and has a low resistance. As the filter becomes polluted, the drive will slowly increase the speed of the pump to maintain the design flow rate. When the pump nears a predetermined frequency, usually near maximum speed, the drive can signal an alarm indicating it is time to clean or replace the filters. This can also save on labor and material costs and time.

When the pump is not regulated the speed is always 100%, but the flow changes. Initially, when the filter is not clogged, flow rates will be higher than design, but the filter will become clogged faster. This results in more operating hours near design flow and pressure. When under drive control, the flow will always remain the same, but the pressure required to maintain that flow will vary.



CONTROL CONSIDERATIONS

ϴ Flow meter is to be installed to accurately regulate the filter pump.
ϴ Using internal VFD controller (PID) reduces costs.
ϴ VFD spare relay contacts can be configured to signal clogged filter when drive reaches 100% speed.



Energy Consumption over Time

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Bypass Considerations for Variable Speed Drives

WHY USE BYPASS

Although variable frequency controllers have become reliable devices in the last several years, some applications still require a back up system.

Some applications where bypass is required are those where downtime for any reason is unacceptable such as the ventilation of an operating room, computer room or clean room. Some industrial applications also require bypass to enable operation in the event of a drive failure, and typically are requested on centrifuges, induced and forced draft furnace fans and pumps.

In commercial buildings, fire and safety requirements often call for bypass as part of a drive package to insure the evacuation of smoke from a building after a fire. In such cases, bypass must allow for the remote control of the motor.

The bypass must switch the power supply to the motor between the VFD and the power line, but it also must be able to :

ϴ Protect the motor in both VFD and bypass modes.

ϴ Interface with safety controls.

ϴ Isolate the VFD for service while maintaining motor operation.

ϴ Meet code requirements as a motor starter.

It may be a requirement for a service person to troubleshoot or test the VFD when the motor is being operated in the bypass mode. This requires a disconnect or a contactor on the input of the VFD in addition to a main disconnect/ breaker.

Many bypasses are sized to handle only the full load current of a motor and not the locked rotor current. These are less expensive contactors or switches but cannot act as motor starters. A bypass which is not horsepower rated must only be switched when power is off and therefore requires a motor starter upstream.

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Controlling Duplex Pumps

Duplex Pump Control

Many dual pump systems, as shown in figure 1, are in operation today.
One pump acts as a primary pump and a second pump is provided as back up. When one pump fails, the backup pump is enabled, either manually or automatically. These systems usually rely on operators to periodically alternate which is the primary pump and which will be be standby.

With the reduced costs of controls and VFDs, inverters may now be cost effectively applied to duplex pumps to provide energy reductions and to provide automatic pump sequencing.

<u>Advantages</u>

ϴ Reduction in maintenance costs. VFDs are inherently soft start, increasing motor and linkage life.
ϴ Pumps can be alternated more frequently, say every 24 hours, increasing the life of the equipment.
ϴ On pump failure, the standby pump is automatically started with alarm indication.
ϴ Start-Stop and reset of pumps can be done by the VFDs.
ϴ Optional manual selector switch overrides the automatic pump alternation sequence.
ϴ In applications, where increased flow is required , on a temporary basis, the lead or primary pump may remain at maximum flow with the second "back up" pump enabled and varied to meet the system demand.

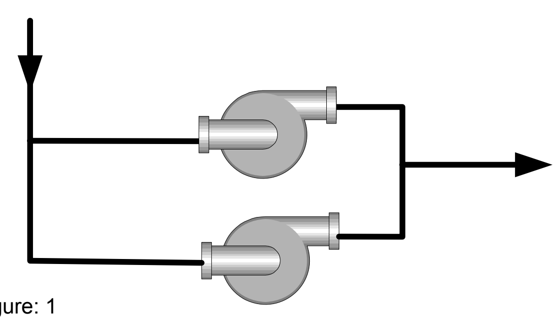

Figure: 1

Standby or "Lag" Pump

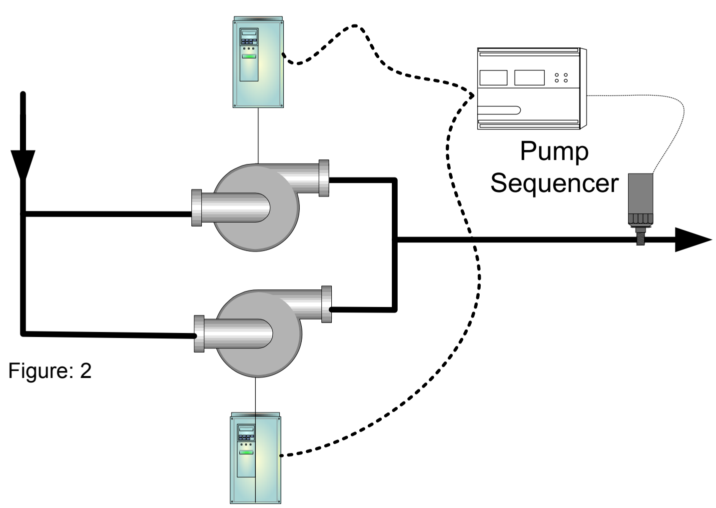

Figure: 2

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VFD Control Curves for Pumps and Fans

Control of flow for pumps and fans is straight forward .A controller (PID) sending a signal to the VFD (0-10vdc or 4-40ma). In direct one-to-one control, as the control signal increases, the flow increases. However, as shown in Figure 1, the relationship is not linear. A 30 % signal form the control, results in 50% flow. The resulting curve is typical for fans, and pumps. The non-linear characteristics reduce control accuracy, increased control overshoot which contributes to cycling.

Features, once found in more expensive controllers to compensate for the above non-linearity, are now built in to HVAC drive parameters.

The output parameters for the control signal and the frequency can be set (with in the drive) to create a curve found in Figure 2. The user sets the frequency that the drive is to operate at certain control signals.

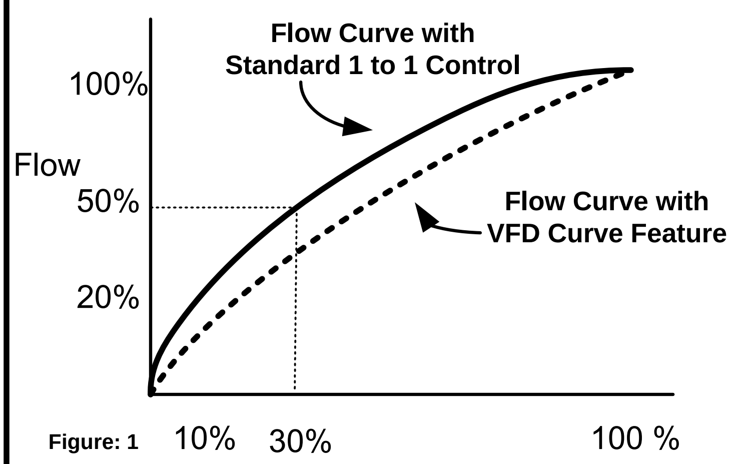

Figure: 1

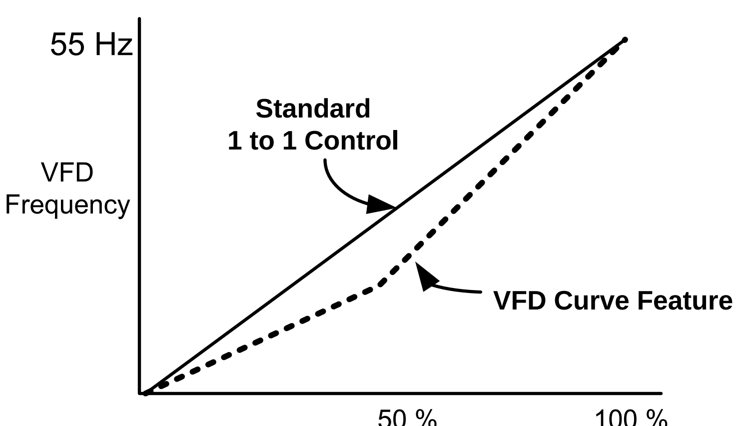

Figure: 2

EXAMPLE

With a one to one control relationship, a 30% signal to the drive, results in 18 Hz (30% of 60hz). The actual flow at 18 Hz is 50% flow.

With VFD parameters the following can be set:

Control Signal	VFD Frequency
0 VDC	0 Hz
5 VDC	12 Hz
10 VDC	55 Hz

The result would be linear flow resulting in more accurate and stable control. (see Figures 1 & 2)

CONTROL CONSIDERATIONS

ϴ Check with the VFD manufacturer to determine if custom control curves are part of their feature set.

ϴ Minimum flow should be considered when setting the custom curve. In fan applications, the “zero” signal from the control will not necessarily be at 0Hz. The drive will need to be set to a frequency which represents minimum flow.

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Constant Fan to Variable Flow Conversion

Constant fan systems, especially those where an air handler serves an large open area, may be converted to variable flow systems. Figure 1 shows a typical constant volume system. The room thermostat/sensor controls the mechanical heating and cooling equipment to condition the space. The *temperature in the duct therefore increases (heating) and decreases (cools)* with constant flow. Comfort is achieved by keeping the volume of air servicing the room constant while varying the temperature delivered.

Figure 2 shows how the system may be retrofitted to a variable volume system - with a variable speed drive controlling the fan speed. The discharge air sensor (DA-T) controls the mechanical equipment to keep the *temperature in the duct constant.* The room sensor controls the VFD. The principle of operation is very much like how a variable volume terminal box would operate. Temperature in the space is controlled by keeping the supply temperature the same and varying the volume of air delivered in to the space.

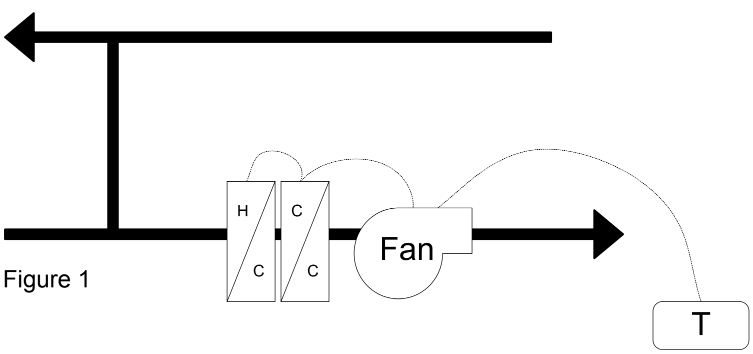

Figure 1

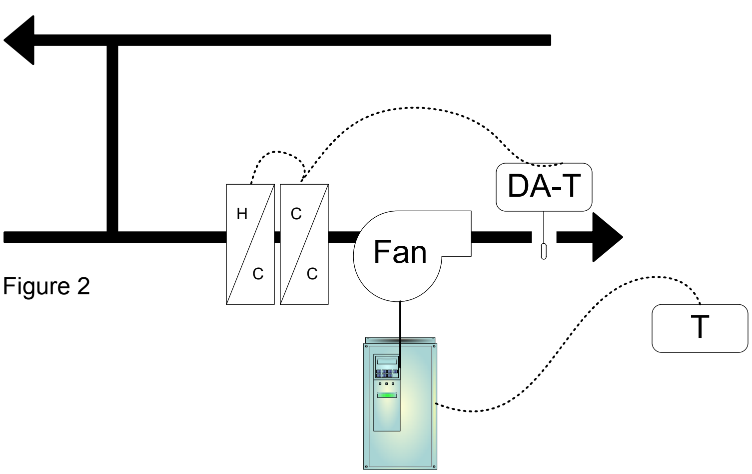

Figure 2

Control Application & Considerations

ϴ Supply air can be kept constant or reset based on the outdoor or return air conditions. In the winter months, typical supply air set points are 60 – 65 deg F, while in the summer, 55 deg F is adequate.

ϴ Minimum air flow requirements for the heating & cooling coils should be observed. Using DDC controls, the minimum fan speed set points maybe changed for heating mode and cooling mode.

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Multi-Motor Application

Multi-Motor Operation

One VFD may control multiple motors and is usually done because of budget considerations. When In the example below, a cooling tower with 4 equally sized motors are to be controlled by one VFD.

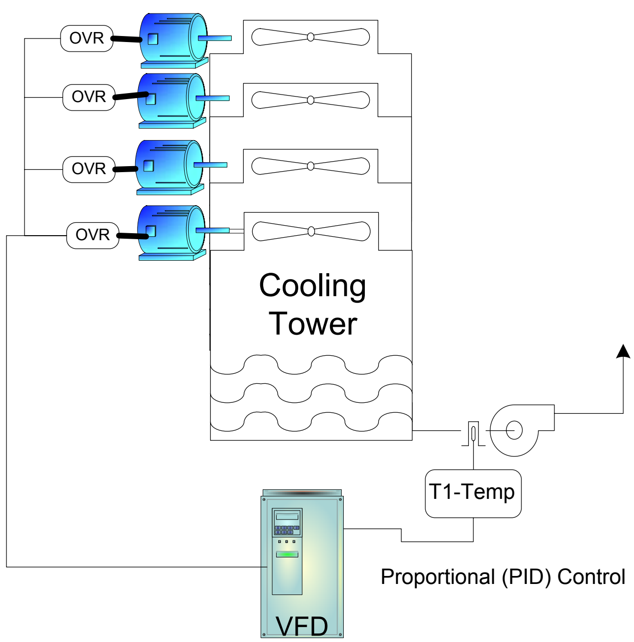
Application Considerations

ϴ Motors are to have the same capacity and operate at the same speed. In our example the 4 motors are 10 amps each.

ϴ The VFD parameters must be set to accommodate the total capacity. In our case the VFD parameter is set to 40 amps (10 amps x 4 motors). Individual VFD parameters that are meant for one motor should be turned off. For example slip compensation (calculating the difference between the field speed and rotor speed) should be set to off.

ϴ Each motor is to have its own motor overload protection. In our example, if the cooling tower fans were operating with a very light load, say 5 amps each, and if one of the 4 motors became jammed, the the amp draw on the jammed motor would need to surpass, 25 amps (40 amps – (3 x 5 amps)) before the drive saw any problem . This would cause damage to jammed motor .

OVR = Overload Protection



Variable Frequency Drives to Control Temperatures in Heating Loops

In many heating systems the hot water delivered to building heating loops typically have a constant running pumps which run through out the heating months. The temperature delivered to the building is usually at the same temperature as the primary heating loop. In these systems the building has a tendency to overheat since there is really no temperature control for the water supplying the zones. (see Figure 1).

Applying a VFD to the building pump (see Figure 2) and a temperature sensor, the hot water temperature to the building zones can be better maintained by varying the flow of water.

Energy Savings result from reduced electrical costs by reducing the speed of the pump and by better temperature control - preventing temperature over-shoot (over heating) in the zones. In many applications the pumps are oversized (10 to 15%), so even in maximum heat load conditions, the maximum pump speed with the VFD is less than before the retrofit.

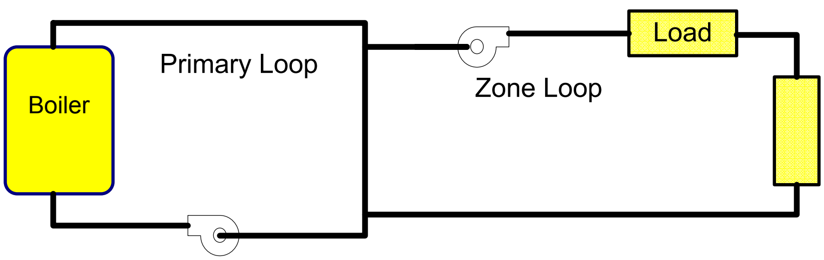


Figure 1

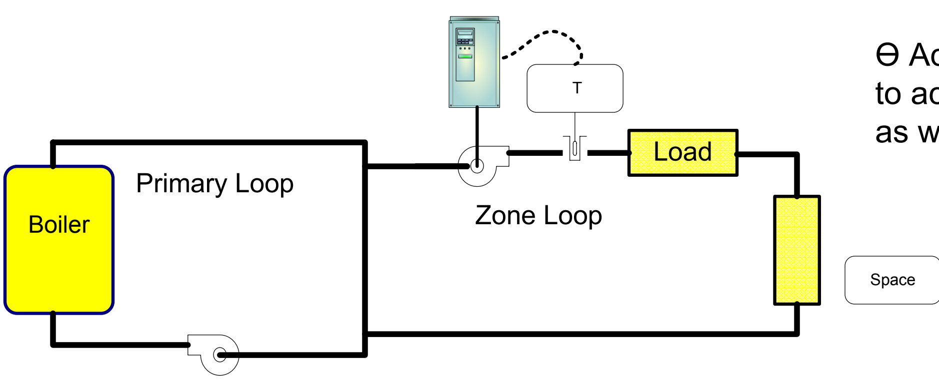


Figure 2

Control Application

ϴ A temperature sensor can be connected directly to the VFD built-in PID controller to control the water supply temperature to the zone(s)

ϴ The temperature of the water to the zones can have a different setpoint than the main boiler loop. Feedback from the zone (space) temperature can be used to further adjust the zone set point used by the VFD to control the hot water temperature.

ϴ Additional controllers may be added to account for outdoor air temperature as well as space temperature.

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Retrofitting Hydronic ByPass

Many variable flow hydronic systems utilize a by pass valve to balance pressure from the zones. Replacing these valves with a VFD to control pumps can save energy. For example, in Figure 1, as zones become satisfied, the differential pressure control (P) modulates the bypass valve open to decrease flow to the zone loops. As pressure in the zone loop decreases, the bypass valve closes to ensure proper flow out to the zones.

<u>VFD Application</u>

The bypass valve and electromechanical pressure control is replaced by a VFD to control the pump and a new differential pressure sensor (see Figure 2). The pump speed (flow) is modulated to maintain system pressure. Placing the differential pressure sensor as shown (farthest along the zone loop) can further increase control and possible savings. (see application guide # 3 & 9)

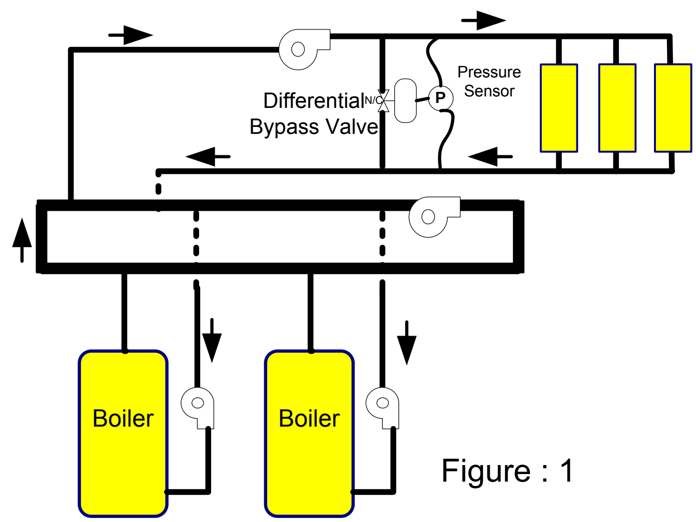

Figure : 1

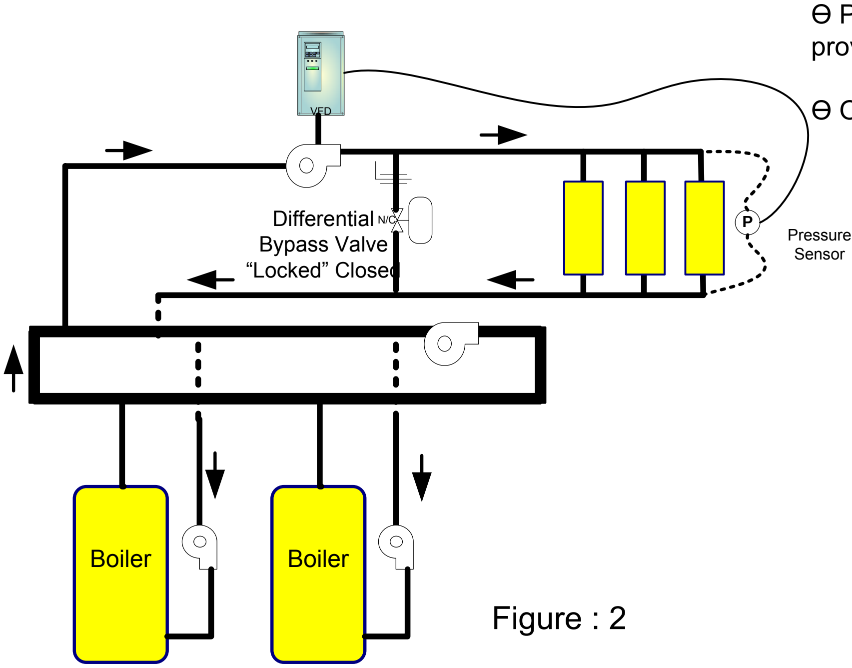

Figure : 2

<u>Advantages</u>

ϴ Decreased energy usage as pump speed varies with load.

ϴ Electro-mechanical valve and pressure control is replaced with more accurate and reliable pressure sensor.

<u>Control Considerations</u>

ϴ Review boiler manufacturer's specifications to determine "low or no flow" capabilities.

ϴ VFD minimum speed of the VFD must be greater than boiler manufacturer's flow specifications.

ϴ Placing the differential pressure as shown in figure 2 provides optimum control and savings

ϴ Original bypass valve is "locked" closed

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