



ENGINEERING BULLETIN

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Variable Frequency Drives

Purpose:

The purpose of this Engineering Bulletin is to help the EVAPCO sales team educate owners, engineers, operators and system integrators installing variable frequency drives of the nuances in applying variable frequency drive technology to cooling towers. This Engineering Bulletin presents some of the common mechanical and electrical issues encountered when applying pulse width modulated variable frequency drive (PWM VFD) technology to cooling towers and the necessary steps to take to ensure a trouble-free installation.

Following the recommendations of this Engineering Bulletin should ensure a successful application of PWM VFD technology in cooling tower service.

Background

A variable frequency drive, also known as a VFD or AFD (adjustable frequency drive) is a device that converts a fixed AC voltage and frequency and changes it into an AC adjustable voltage and frequency used to control the speed of an AC motor. By adjusting the voltage and frequency the AC induction motor can operate at many different speeds.

For a more detailed history of VFD's and a technical explanation, please refer to US Motors Application Guide for Adjustable Frequency Drives and AC Motors, Bulletin MP644-120 9/91¹.

On most HVAC cooling tower applications the need for tight capacity control is not required, however some users require more control than a two-speed motor can provide. Because most cooling towers are designed and manufactured to meet anticipated peak heat loads at worst case wet-bulb conditions, the majority of a tower's actual life is spent operating at much lower than design duty. Operating at reduced heat loads and wet-bulb temperatures affords the owner/operator an opportunity to save tower fan energy by reducing fan cycles of operation or fan speed.

Typical fan motor controls are on-off for a single speed motor, high-low-off for a multi-speed motor, or infinitely variable speeds, from 0 to 100%, for a motor connected to a variable frequency drive (VFD). The number of cooling tower cells, the sophistication of the system controls, and the cost will dictate the selection of fan controls; however, the most fan-energy efficient control option is the variable frequency drive. The use of a variable frequency drive on a cooling tower fan is also the most sensitive means to control leaving water temperature on critical process water applications.

The cost and functionality of state-of-the-art PWM variable frequency drives makes them a very attractive control option for owners and operators of cooling towers to save energy and reduce noise in non-peak periods. The use of VFD technology can also benefit the life of the mechanical components with fewer starts, smoother starts, and built-in motor diagnostics. VFD technology has particular benefit on towers operating in cold climates where airflow can be modulated to minimize icing and reversed at low speed for de-icing cycles.

Cooling Tower Applications

As with any technology, improper customer expectations, poor specifications and bad installation practices lead to problem VFD applications. Successful VFD installations cannot be made casually, all applicable VFD drive, motor and tower manufacturer recommendations, in addition to local electrical codes and best electrical grounding and conduit practices must be strictly followed.

Motor Concerns

On August 1, 2000, EVAPCO announced that all equipment whose motors will be driven by VFD's must be provided with inverter-duty motors in order to maintain the motor warranty. Motors utilized in VFD applications are not covered under warranty by either the motor manufacturer or EVAPCO unless inverter-duty motors are supplied.

The power supplied to the motor by a VFD is not smooth. The inverter within the VFD takes the 60 hz power then chops and re-shapes the AC sine wave. This simulated AC voltage contains spikes and irregularities that must be absorbed by the motor windings. VFD duty motors are built with heavy-duty windings and are equipped with extra heat dissipation features to handle the VFD application. In addition, spike resistant wire is utilized in our VFD duty motor design.

The type of motor, manufacturer of VFD, motor lead lengths (between the motor and VFD), conduit runs and grounding can dramatically affect the response and life of the motor.

The motor lead length restriction varies with the motor vendor. The US Motors Inverter Duty motor design has no restrictions on motor lead length. However, Baldor, another supplier of motors for EVAPCO puts restrictions on the distance from the inverter to the motor based on voltage:

460 Volt-100 feet or less

575 Volt-50 feet or less

Regardless of motor supplier, minimizing motor lead length between the motor and inverter is good engineering practice.

Although EVAPCO VFD (Inverter-Duty) motors have a 5 year standard warranty, this does not mitigate the reality that running a motor on a VFD will reduce bearing life. Motors operated in VFD service are more susceptible to bearing failure due to the high frequency switching and transient voltage spikes formed between the rotor and stator. An option is available (albeit an expensive one) for insulated bearings to protect the bearing from these shaft currents.

Cooling System Energy Savings-Do you really need a VFD?

Maximizing fan energy savings at the cooling tower does not always maximize total cooling system energy savings. In many cases, operating a fan at full speed and driving the condensing water temperature from the tower to the lowest temperature will save more net system energy at the compressor. This savings is more than what can be realized at the cooling tower fan motor.

Process cooling systems are generally where tight capacity control is required, and VFD's make the most sense. However, most HVAC applications do not require the strict capacity control found in process cooling systems. It is more common to use 2 speed motors or multi-cell cooling towers with single speed motors. Two cell cooling towers with 2 speed motors can have 6 stages of capacity control. The Two-Speed control panel will be less expensive than a variable frequency drive for the same application.

A typical sequence of operation during summer time:

1. Both fan motors on high speed-water on both cells
2. (1) Fan motor on high speed, (1) fan motor on low speed-flow through both cells
3. Both fan motors on low speed-flow through both cells
4. (1) fan motor on low speed, (1) fan motor off-flow through both cells
5. Both motors off-flow through both cells
6. Both motors off-flow through one cell

NOTE: System flow rate must not fall below minimum flow requirement for each cooling tower/cell.

Maximum fan energy savings is realized by operating all fans at the lowest possible speed to maintain the desired cold water temperature. On multiple fan tower systems, all of the variable frequency drives should be synchronized to speed up and slow down uniformly. When different motors are each on a separate drive control, the fans tend to ramp up and down, often fighting one another. This creates more continuous acceleration/deceleration forces on the fan blades and odd airflow/static patterns that fatigue the fan blades. The variable frequency drive needs a pre-set shut off speed to prevent water temperatures from becoming too cold and to prevent the drive from trying to turn a fan at near zero fan speed. At extremely low speeds with high inertia cooling tower fans, drives will suffer nuisance trips on over-current conditions. On gear boxes that are not designed for low motor rpm operation, the gears will lose adequate lubrication. Some gear drive manufacturers offer options that allow the gear drive to operate at any speed with proper gear lubrication.

The TEFC and TEAO motors used for typical cooling tower applications may lose proper cooling at very low fan or VFD speeds. EVAPCO should be consulted if minimum operating speeds below 25% are desired.

NOTE: Operating below 25% motor speed achieves very little return in fan energy savings and capacity control.

Specific Applications of the VFD

Cooling Tower Performance with a Variable Frequency Drive

Because of the increasing number of VFD applications, the question of capacity and power consumption at low fan speed is frequently asked. For estimating purposes, the unit capacity drops off linearly with fan speed and fan power is reduced by the cube of fan speed.

For example, if a unit produces 500 tons with a 50 hp fan motor at full speed, it will produce 250 tons at half speed. According to the fan laws, the unit will draw $(.5)^3 = .125 \times 50 \text{ HP} = 6.25 \text{ HP}$. Due to inefficiencies at low speed the motor will actually draw 7.5 HP. (15% instead of 12.5% of full speed nameplate hp). If more accurate data is required for less than full speed performance, contact the EVAPCO Marketing department.

NOTE: The recommended minimum cut-off speed for VFD belt or gear applications for 1800 rpm motors is 25% (30% for 1500 rpm gear drive and 35% for 1200 rpm gear drive). Speeds below these minimums may result in motor cogging and torque ripple, and in some gear drive systems, reduced lubrication capability. Operating at very low speed leads to excessive drive vibration and excitation of the tower's low structural resonant frequencies. Most VFD manufacturers are now providing good low speed motor control, but problems do develop and will be most evident in the lower speed operation.

Free Cooling and Winter Operation-Reverse Fan Operation at Half-Speed

EVAPCO's Induced Draft Cooling Towers are designed for year around operation. During free cooling and winter operation, ice may develop in the cooling tower. On induced-draft cooling towers, a reverse mode can be applied to de-ice the cooling tower. The VFD supplied on such projects should be designed with a reverse mode. The reverse mode must be locked out to operate at or below 50% of motor rpm only, any higher fan speed may damage the fill and eliminators.

Also, during free cooling/winter operation mode, the tower fan speed should be ideally set to cycle between 50% and 100% fan speed. Operating below 50% fan speed may allow water to come into contact with the inlet louvers and start ice formation.

EVAPCO's Forced Draft Cooling towers utilized in free cooling and winter operation will have a different control scheme. It is NOT possible to operate the centrifugal fan in reverse for de-icing. For these applications, it is essential to have a VFD that is programmed to operate down to 10% to allow the fans to always operate and reduce the possibility of splash-out and condensation on the fans, which lead to ice build up.

Gear Drives and VFD's-Gear Drive Chatter and Minimum Input RPM

Gear Drive Chatter

VFD's can have a negative impact on the mechanical performance of gear drive systems.

There are many VFD suppliers in the market, and certain manufacturers variable frequency drives create gear cogging and “chatter” at non-specific operating frequencies. These frequency bands vary with each VFD supplier and it is necessary for the drive supplier to lock out these bands so that the cogging is eliminated. **This is not a Cooling Tower manufacturer’s operational concern, but a normal system start-up routine.**

EVAPCO has strived to identify those suppliers with the best electronics that eliminate these cogging issues. In addition, we have tried to evaluate their design, but obviously due to competitive and proprietary reasons, we are unable to unlock the specifics of their design. Please contact the EVAPCO if you have any question about your drive supplier and design.

Many cooling towers are specified with commercial grade HVAC drives because the tower is considered a simple device. Always specify **Industrial Grade** variable frequency drives, it will be a better variable frequency drive and is usually designed to handle gear back lash, fan inertia, drag and coupling stiffness.

Gear Drive Minimum Input RPM

As mentioned before, if the drive control scheme allows low fan motor rpm operation, there will be a concern that the gear box is not receiving adequate lubrication. The standard gear box is lubricated properly down to 450 motor input rpm. Below 450 rpm, or 25% speed, oil cannot reach the upper output shaft bearings, therefore a gear box designed to operate below 450 rpm as standard is required.

Upon request, EVAPCO can supply a gearbox design that will provide proper lubrication (without an oil pump) for operation below 25% fan speed. This special design does require a price add and cannot be retro-fitted in the field.

Field Installation Procedures

The information just presented provides the ground work for VFD’s and Cooling Tower Applications. This next section provides the details of applying a VFD in the field.

Fixed speed fan systems are designed to operate resonance free at their prescribed operating speed. VFD systems can operate at all speeds from zero to full speed, creating the opportunity to strike a multitude of previously avoided system resonant frequencies. This may lead to unit vibration, fatigued structural components or gear noise. Further, all motor windings vibrate at 2x the power line frequency creating three simultaneous but variable excitation frequencies in the rotating equipment – one at fan operating frequency, one at motor operating frequency and one at 2x line frequency. Modulating VFD systems will strike every forcing frequency from 0 to 2x line frequency (0 to 100 or 120 Hz). Large structures (tower and building) inherently have low natural frequencies, within this operating range.

Owners and operators must expect that there are frequencies that must be locked out to prevent drive system and structural damage and noisy operation. *As part of the installation, resonant frequencies should be determined and locked out in the drive’s software.*

Not all resonant frequencies can be determined in advance because the tower's supporting structure, external piping and accessories contribute to the overall stiffness of the tower. Discovering resonant frequencies in an operating cooling tower does not necessarily indicate a cooling tower design defect; but rather, a failure to perform appropriate systems checks. This may cause premature equipment failure.

The VFD drive must also be adjusted so that the tower's fan drive train does not experience cogging or torque ripple. These torque fluctuations can occur at various frequencies over the operating speed range (ref. MG-1 Part 30, sect. 30.02.2.8)². If the cogging cannot be controlled with programmable drive settings, the drive should be programmed to skip the troublesome frequencies.

To check for other troublesome resonances in the field, a run-up and run-down test needs to be performed. Starting with the lowest operating frequency, step up fan frequency about 2 Hz at a time until full speed is reached. At each step, pause long enough for the fan to reach steady state. Note changes in unit vibration. Ideally, an accelerometer mounted on the bearing plate should be used to monitor the vibration levels. However great caution must be exercised with accelerometers. They are highly susceptible to electrical noise from the VFD, which creates both random and periodic spikes in the vibration spectrum.

If a "rough" or loud operating condition is encountered, quickly skip frequencies until the condition subsides. Note the beginning and ending band of the rough frequency range. Continue stepping through frequencies until full speed is reached. Repeat this process in reverse by stepping back down the frequency range to minimum speed. Some frequencies not detected on acceleration will arise on deceleration. Isolate the troublesome spots and approach them carefully from the top and bottom to try to determine the "edge" of onset. After the problem frequencies have been identified, a 2 Hz safety band on either side should be added and the frequency band programmed into the drive's lockout.

If a vibration problem is noted over a very wide frequency band(10 hz or greater), there is likely a problem with the VFD or the mechanical equipment. The Evapco Marketing Department and the drive supplier need to be consulted. Often alleviating the problem is as simple as correctly programming the VFD's torque profiles, carrier frequencies, and smoothing parameters. Persistent problems need further attention from Evapco and the drive manufacturer.

Motor noise or whine can be a serious problem with VFD's in sound sensitive locations. VFD driven motors normally exhibit a sharp tonal noise somewhere in the 2-8 kHz band that is 5-10 dB higher than the background sound levels. The noise does not indicate a motor problem. The noise is a consequence of the VFD's high frequency power switching. Most drives have programmable carrier frequencies or tone controls that allow some motor noise reduction. A higher carrier frequency reduces the audible noise but also reduces the current capability of the drive and increases the voltage spikes in the motor. The drive should be field programmed with the lowest tolerable carrier frequency for maximum drive and motor life.

Conclusion

The last page of this engineering bulletin includes a VFD Design Checklist. Use this checklist to help design, install or troubleshoot a VFD system.

References

- 1 US Motors-AC Adjustable Frequency Drive Applications Guide, Sept. 1991
- 2 NEMA Standard MG-1

VFD Design Checklist

As a minimum, a proper design and execution plan for cooling tower VFD operation should include:

- ث 1. **VFD (Inverter Duty) motors.**
- ث 2. **For induced-draft units, a VFD designed with reverse operating mode capability (with reverse mode locked out to operate at or below 50% of motor RPM only.**
- ث 3. **Consideration for fan motor lead length restrictions.**
- ث 4. **Final set-up and adjustment of the VFD performed on site by the VFD supplier or its authorized factory service technician.**
- ث 5. **Acceleration and deceleration profiles programmed to no less than 4 seconds, and ideally 10 seconds.**
- ث 6. **Coast down deceleration and stopping profile, rather than a powered or braked deceleration.**
- ث 7. **Upper speed limits capped at the line frequency.**
- ث 8. **Lower speed limit set to 25%.**
- ث 9. **The over-current trip limits set to no more than the service factor of the motor (1.15).**