Whitepaper

Automatic Energy Optimization

Introduction

Energy savings and precision system control are the main reasons to use adjustable frequency drives in heating, ventilating and air conditioning (HVAC) systems. Energy savings are significant because a slight reduction in the speed of a fan or centrifugal pump has a very large impact on its energy consumption. The efficiency of fans or pumps, along with the drive, remains high at reduced speeds. Motor efficiency, however, drops off as the motor becomes unloaded.

Drive manufacturers have attempted to improve the low speed efficiency of motors with a number of designs. Unfortunately, most of these products require tedious manual adjustment and still cannot optimize motor efficiency under all conditions.

The VLT HVAC Drive has a unique control feature called Automatic Energy Optimization (AEO). With this function, the drive automatically maximizes motor efficiency under any operating condition.

The following examines the reason for reduced motor efficiency at light loads and the way that AEO counteracts this natural tendency. The application and limitations of this function are also examined.

Motor operation

In an AC induction motor, torque is created on the motor shaft by a magnetic field within the motor. The strength of this magnetic field, and the resulting torque, varies with the load demand on the motor. A greater load requires more torque which means the motor draws more current from the supply voltage. Although the motor speed remains relatively constant, the current used can vary a great deal.

If full motor torque is not required, neither is the full magnetic field. The current that produces excess magnetic field provides no positive effect and also generates reactive current which wastes energy and introduces thermal stress. Excess current is even more pronounced at low torque where reactive current increases in comparison to real, or variable, current. This is the main reason why lightly loaded motors exhibit poor efficiency, as will be discussed in more detail.

To limit the current through the motor, the voltage to the motor is limited. While this seems simple, it isn't. Voltage reduced too much causes excessive motor slip which will cause a large current draw. The heat generated by this current can severely damage the motor. Because carelessly reducing the voltage too much can damage a motor, most drive manufactures avoid reducing the motor's voltage to the optimum level.

The relationship between voltage and frequency

For motors with constant torque loads, the motor's magnetization current should remain constant throughout the entire drive controlled speed range. Since the inductive reactance (X_L) of the motor's stator coils is proportional to the applied frequency, ($X_L = 2\pi fL$), a constant ratio between the applied voltage and frequency is necessary in order to maintain a constant motor current. This is the constant "volts to hertz" (V/Hz) ratio that is commonly mentioned in conjunction with adjustable frequency drives.

This is appropriate for drives which are designed for constant torque loads, such as conveyors, hoists and similar industrial applications. A constant value of V/Hz is shown in figure 1.

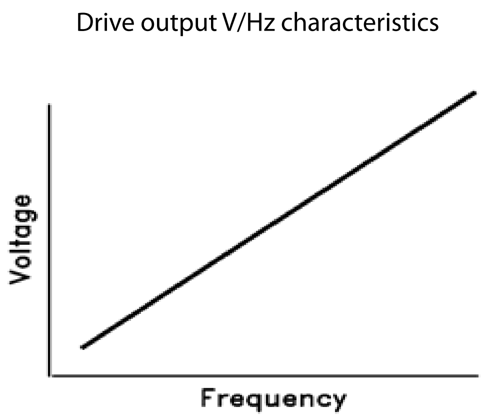

Figure 1. Constant V/Hz characteristics.

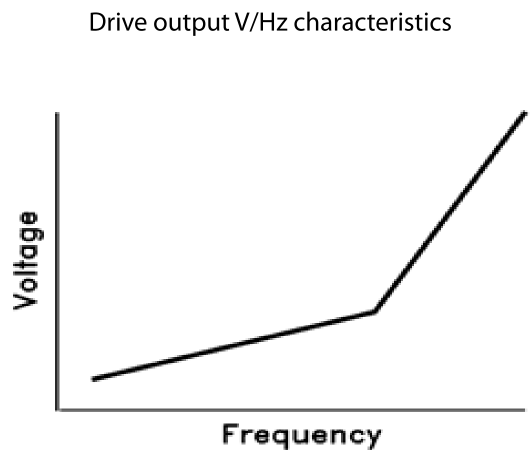

Figure 2. Approximate V/Hz characteristics.

When a drive with a constant V/Hz characteristic is applied to a variable torque load, the full magnetizing current provided at low speeds is greater than is required by the load. This over-magnetization, as mentioned, produces excess heat in the motor.

The solution is to determine what voltage the motor needs for proper operation. Since this requires specialized features, some drive manufacturers simply ignore it and their drives produce only a constant V/Hz ratio over the entire speed range. While this doesn't maximize the motor's efficiency, it does avoid under-magnetizing the motor and creating excessive slip.

Because variable torque loads are all somewhat different, a fixed V/Hz pattern will not work for all loads. When an attempt is made to improve motor efficiency, the actual adjustment of the V/Hz profile is often left up to the end user. This method (shown in figure 2), requires the user to define an intermediate point in the drive's V/Hz profile. What this requires is extensive experimentation and evaluation over the speed range and load of the system. In addition, if the system characteristics change, it is necessary to repeat the process. Clearly, this isn't a very practical solution.

Some drive manufacturers offer the user a choice between a number of pre-defined variable torque V/Hz profiles. While this simplifies the procedure, it is still necessary to manually run the motor throughout its operating speed range and determine the lowest V/Hz profile that will drive the load without excessive slip or motor heating.

Again, the load characteristics of the application can change due to seasonal change-over or alteration of the building's HVAC system. In this case, the manual profile procedure must be repeated. Because of the work involved, most users simply choose a high V/Hz profile, knowing that it will drive the load. This results in high cost energy being wasted.

Automatic Energy Optimization

The best solution to fitting the voltage to the frequency/power curve would be if it were automated. This is exactly what the VLT HVAC Drive does. The VLT HVAC Drive uses the unique Automatic Energy Optimization control process which automatically ensures—without user interaction—that the voltage and frequency relationship is always optimum for the motor's load.

In order to automatically provide the correct voltage at any operating frequency and load, the drive continuously monitors the motor and responds to changes. The VLT HVAC Drive's unique VVC^{+} control process is central to this. Current is monitored so that both the real current (that which varies with load) and the reactive current (that which magnetizes the motor stator) are known at all times.

The result is that the drive automatically maintains peak motor efficiency under all conditions. During initial acceleration, up to 110% output voltage is applied to provide additional torque to overcome the inertia of the load. This also provides the soft start and smooth ramp up characteristics of adjustable frequency drives designed for HVAC use. After the motor reaches the desired speed, the VLT HVAC Drive automatically detects the steady-state load level and reduces the output voltage to maximize motor efficiency. If the load changes, such as when a valve in a pumping system suddenly opens, the drive detects the load change and immediately increases the output voltage to maintain control of the motor.

In addition, the VLT HVAC Drive Automatic Motor Adaptation (AMA) function, which accurately determines critical motor parameters, allows the drive to calculate the current readings to determine the amount of magnetizing current required by the load. The result is exceptional low load motor performance, an area where most drives can do very little. The VLT HVAC Drive can actually reduce the reactive portion of the motor current. This component, often 25% of motor current and much greater at low load, is typically ignored by other adjustable frequency drive manufacturers.

Automatic energy optimization allows the VLT HVAC Drive to control voltages over a wide range in order to match the drive output with the load. The range of voltages over which AEO operates can be seen in figure 3. As shown, AEO allows the drive to reduce the motor's voltage by as much as 50% in order to save energy. The variable V/Hz feature saves an additional 5% of energy in a typical HVAC application.

Advantages of AEO

Automatic energy optimization's major benefit is in variable torque loads. As the motor's speed is decreased, the load on the motor drops dramatically. If a constant V/Hz ratio is supplied to the motor, its efficiency will suffer. Knowing how much the motor voltage can be reduced before motor performance begins to suffer is difficult to determine manually. AEO calculates this automatically and continuously. If the load profile changes, AEO responds to the change and adjusts the voltage supplied to the motor.

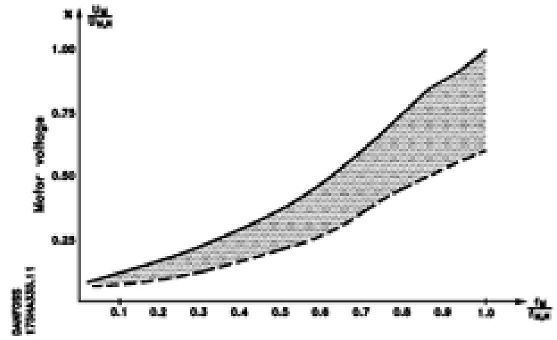

Figure 3. AEO operational range and savings.

Even without change in speed, AEO still produces energy savings. To provide an operational safety margin and ensure against design error, most motors for HVAC systems are sized larger than is needed to drive the load.

As a result, even under full speed, full flow conditions, the motor operates at less than full load. Without the voltage reduction that AEO provides, the motor is operating inefficiently. With the VLT HVAC Drive, it is common to notice an output voltage from the drive which is less than the motor's nameplate rating, even when the drive is producing full frequency. Rather than being an indication that something is wrong, this is savings derived from AEO compensating for a motor oversized for the application.

Variable speed, constant volume applications benefit from AEO as well. An example of such an application is a fan system for a clean room. Here, the purpose of the drive is to maintain a constant air flow, even as the micro-filter for the air becomes dirty. As the filter becomes clogged, the drive automatically increases the speed of the fan. AEO ensures that sufficient torque is always available on the motor shaft while maintaining maximum motor efficiency.

Although maximizing the motor's efficiency is the main goal of AEO, other benefits are also provided. Heat generation in the motor, the primary cause of motor failure, is reduced. By reducing the thermal stress on the motor, motor life is extended. Reduced motor heat generation also reduces the ambient motor heat load on the building. In instances such as large motors in temperature controlled areas, additional saving in cooling costs can be significant.

Reduced current flow also has an additional benefit. This is reduced energy losses in the adjustable frequency drive and all other components supplying current to the motor, such as transformers or line reactors.

Multiple motor operation

In applications where multiple motors are present but only one is controlled by the drive at any time, such as alternating pumps, AEO will maximize the efficiency of whichever motor is currently in operation. AEO's dynamic control technique automatically responds to the on-line motor and applies current in response to the motor load.

Because AEO tailors the drive's output voltage to the specific requirements of the motor, it cannot perform reliably in simultaneous multiple motor applications. If two or more motors are connected simultaneously to the output of a drive, AEO can provide only an output voltage that is correct for the average of the motors. As a result, motor voltage may be too high for one motor and too low for another. Because of the problems that under-magnetizing a motor can cause, this is to be avoided. When multiple motors are controlled simultaneously by a single drive, the VLT 6000 is set up to follow a pre-programmed, variable torque V/Hz curve.

Summary

Motors in HVAC systems are seldom fully loaded. This is because the motor is generally oversized for the application and because the motor load drops dramatically as flow rates are reduced. Normally, motor efficiency is low at low loads.

To improve motor efficiency, some adjustable frequency drives require the system operator to adjust the drive's output V/Hz characteristics. These manual methods are both cumbersome and inaccurate. As a result, they are seldom used. In addition, if system requirements change, the operator must repeat the adjustments.

The unique VVC^{+} algorithm of the VLT HVAC Drive monitors in detail the current demands of the motor. Through this, the drive determines the motor's load and the automatic energy optimization feature ensures that the motor receives the ideal voltage at all times. This ensures peak motor and system efficiency even at low speed operation. All of this is accomplished automatically and without need for user intervention.