Active energy control—optimum solution for maximum savings

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Saving energy is more than the right thing to do

Energy costs continue to increase. At the same time, there is increased pressure to reduce utility bills without sacrificing operations or comfort.

For over 40 years, variable frequency drives (VFDs) have been a critical component of commercial and industrial systems' efforts to improve energy efficiency. Today, their fundamental usage has remained the same, while technology has evolved and improved—yielding drives that are better able than ever to reduce energy consumption and improve reliability while extending equipment life.

On the whole, VFDs are designed to optimize energy use. How a VFD optimizes energy use differentiates the technology from various manufacturers.

Today, new algorithms are delivering significant energy savings and stability, and establishing a new level of efficiency for commercial buildings. A novel control algorithm for VFDs reduces the input power of an induction motor used to drive a variable torque load, like a fan or pump. The algorithm dynamically adjusts the motor's operating point based on its load conditions, and providing power savings and improving energy efficiency.

Finding new motor efficiencies through VFDs

VFDs for induction motors use power electronics switching technologies to supply AC power of variable frequencies to motors. This allows direct control of motor speed and improves efficiency. The output voltage waveform of a typical VFD is typically based on pulse-width modulation (PWM). The amplitude, duty cycle, and periodicity of the PWM waveform decide the effective voltage and frequency of the VFD output. The voltage and frequency output from the VFD, together with the motor load, are the most important factors that determine the operating point of a VFD-driven motor.

For industrial applications with constant load requirements, a constant volts per hertz (V/Hz) ratio provides a constant torque for the load. The constant V/Hz ratio corresponds to a linear V/Hz curve, established by connecting two points, (0 Hz, 0V) and (f_{rated} , V_{rated}) with a straight line, where f_{rated} and V_{rated} are the rated frequency (50 Hz or 60 Hz typically) and the rated voltage correspondingly. Typically, these two parameters can be found on the nameplate of an induction motor. When a linear V/Hz curve is applied, the voltage for a specific commanded reference frequency f_{ref} is equal to f_{ref} $*V_{rated}$ $/f_{rated}$.

For many hydraulics and heating, ventilating, and air conditioning (HVAC) applications where induction motors are used to power pumps and fans, the torque needed to drive the motor loads is variable based on the shaft speed of the motor, which is determined by the frequency of the VFD output. The relationship between the shaft speed and the other key parameters for a pump or a fan is expressed in the well-known affinity laws: the flow is proportional to the shaft speed; the head/pressure is proportional to the square of the shaft speed; and the power is proportional to the cube of the shaft speed. Based on the affinity laws, the torque needed to power a fan or pump at a lower reference frequency is lower than that for a higher reference frequency.

For these applications, a linear V/Hz curve typically provides a voltage higher than necessary, especially when the reference frequency is significantly lower than the rated frequency of the motor. Many VFDs provide a squared V/Hz curve for such applications. When a squared V/Hz curve is applied, the voltage for a specific reference frequency is typically lower than the voltage output based on the linear V/Hz curve.

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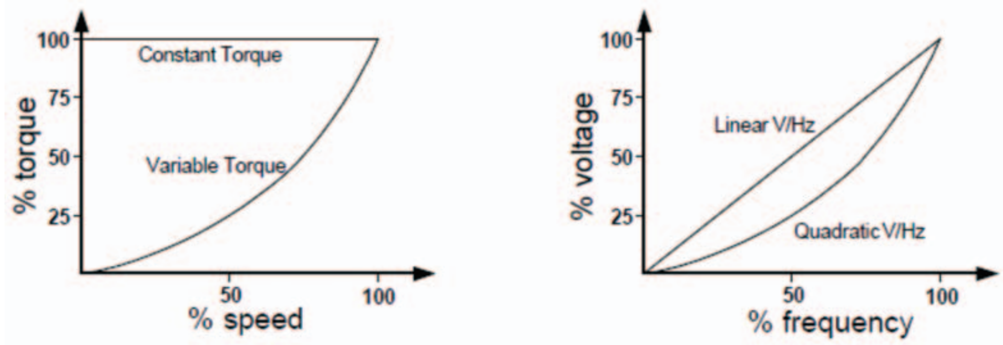

Figure 1.

Figure 1 illustrates the load characteristics for both constant torque load and variable torque load, as well as the voltage/frequency curves for both linear V/Hz control and quadratic (squared) V/Hz control.

The main benefit of reducing the input voltage to an induction motor is the consequent reduction in the motor core losses. Those losses are typically proportional to the square of the input voltage. Applying unnecessarily high voltage to the motor generates excessive motor core losses in the form of heat and noise.

Both linear and square/quadratic V/Hz curves are static V/Hz control methods. By "static" we mean that the voltage output only depends on the reference frequency, without any considerations based on the actual motor load. If the motor load is low, the static voltage generated by either curve may be more than adequate to the power load, hence generating unnecessary core losses. However, if the motor load is higher than what the static voltage can handle, the squared V/Hz control method may endanger the motor stability and cause it to overheat or stall.

These concerns are the major motivation for the design of dynamic V/Hz control methods (active energy control). The active energy control method takes into account the real-time operating parameters of the motor when determining the output voltage of the VFD. The control algorithm monitors the motor load and motor current, as well as other parameters, to find an operating point that both optimizes energy usage and assures motor stability.

Active energy control establishes a new level of efficiency and savings

The energy-optimizing algorithm is started when the drive is commanded to start the motor following a reference frequency, or when a new reference frequency is entered by the user. To assure the stability of the motor, the algorithm initially sets the drive output voltage at the same level as the voltage based on the linear V/Hz method for the same reference frequency. It then begins to reduce the voltage incrementally to optimize the energy usage. Meanwhile, the algorithm monitors several real-time parameters of the motor to prevent the motor from entering conditions that may lead to instability. When the motor enters the optimal zone of operation, the drive output voltage stays at the same level until there is a change triggered by commands to the drive, such as a change in the reference frequency or a change in some real-time parameters. After the output voltage stabilizes, the drive keeps monitoring the real-time parameters of the motor to prevent instability conditions.

There are two major design goals for the energy-optimizing algorithm:

- Determining the optimal output voltage based on the reference frequency and the dynamic real-time parameters of the motor
- Assuring the stability of the motor

Reducing the voltage output to the motor reduces the motor core losses. However, excessive reduction in the supplied voltage may cause the motor current to rise, which leads to potential motor instability and an increase in other losses, such as motor copper loss. The algorithm monitors the motor slip and motor current to ensure that the voltage is not reduced to an excessively low level.

Another factor that may lead to motor instability is changes in the motor load. A slower change in the motor load causes the motor slip and motor current to change, and the algorithm will adjust the voltage output based on these changes. An abrupt increase in the motor load is the most challenging for motor stability. If the algorithm detects a rapid increase in the motor current or motor slip, it quickly increases the output voltage to assure stability of the motor.

Demonstrated results—real energy savings

Test results underscore the stability of the algorithm by abruptly changing the reference frequency or motor load. The performance advantage of active energy control is compared with other V/Hz control methods.

1. Stability Test

   The most challenging scenarios for maintaining the stability of the V/Hz energy optimizing algorithms are abrupt increases in reference frequency or the motor load. If an algorithm does not increase the output voltage to the motor promptly enough as a response to such changes, the motor may become unstable, especially after the algorithm reduces the voltage to a minimal level that is capable of handling the load before the change in the reference frequency or the load.

   The active energy control algorithm had been tested for incremental frequency changes ranging from ±1 Hz to ±15 Hz with no instability conditions appearing. We also tested for abrupt changes in motor loads again with no instability conditions, including overcurrent trip, motor stall, or overload.

2. Energy Savings Tests

The first set of testing was conducted in a lab environment using a 50 hp motor driving a generator that powers resistor banks. The resistor values are selected to emulate typical fan or pump loads. At 60 Hz, the output power level of the motor is selected at 37.5 hp. At any other reference frequency, the output power was adjusted based on the frequency value and the affinity laws. We measure the input power to the drive using a three-phase power meter, compare it with the power value when the linear V/Hz mode is used, and calculate a percentage value of power savings for each frequency we test. For comparison, we also calculate the power savings in percentages achieved by square V/Hz mode and flux optimization mode over the linear V/Hz modes. **Figure 2** shows the results.

In **Figure 2**, we can see that the active energy control algorithm achieves higher percentages of energy savings compared with existing static and dynamic V/Hz control algorithms. The percentage of saving is more significant at lower reference frequencies.

The second set of tests was performed at a waste water treatment plant driving a centrifugal pump. Both the motor and the VFD are rated at 50 Hz for this particular installation. In this instance, the VFD input power is taken for both linear V/Hz mode and the active energy control mode for 25 Hz, 30 Hz, 40 Hz, 45 Hz, and 50 Hz. The percentages of savings are calculated and plotted in **Figure 3**.

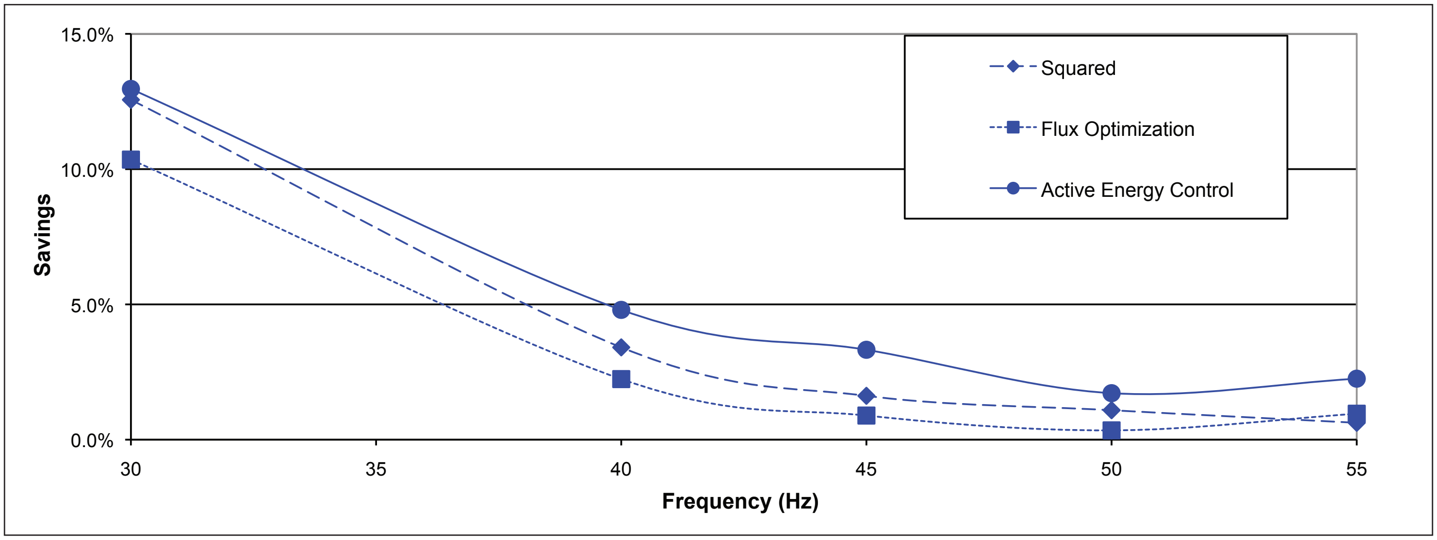

Figure 2. Energy Savings of the Active Energy Control Algorithm

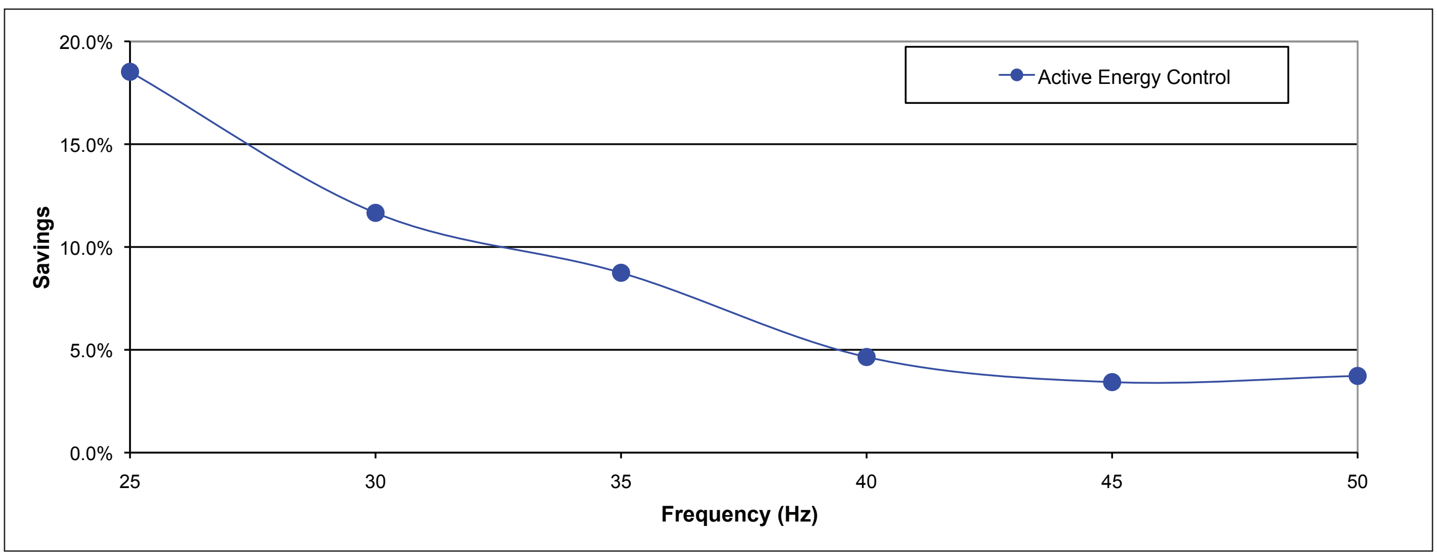

Figure 3. Energy Savings of the Energy Optimizing Algorithm Over Linear V/Hz Mode Under Various Frequencies (Pump Testing)

In **Figure 3**, we can see that the testing results match those shown in our lab testing very well, and verify the energy-saving capabilities of active energy control.

Lastly, we confirmed our test results by using a third-party test provider. In this instance, we compared our performance vs. competitive drives and their energy control algorithms. The VFD is used to power a motor, which in turn drives a Size 24½ blower. The motor size, 20 hp, is suggested by the blower manufacturer. Input power values of the drive are taken between 30 Hz and 55 Hz for various V/Hz control modes. The following figure shows the energy savings percentages compared with the input power of the linear V/Hz mode. Also included in the comparison are the results for a different vendor's flux optimization mode and a dynamic V/Hz control mode from another vendor.

The testing results presented in **Figure 4** show that the active energy control algorithm outperforms both the flux optimization mode from a different vendor and a dynamic V/Hz control mode from another vendor.

Conclusion

The design and implementation of the active energy control algorithm of Eaton's H-Max drives provides a competitive edge over other manufacturers' variable torque drives. Experimental results demonstrate that the algorithm is capable of both assuring motor stability and achieving superior energy savings compared with other static or dynamic V/Hz control methods. Utilizing active energy control, we go beyond drive efficiency and ultimately improve efficiencies of the motor and the application, in general providing superior energy savings to our customers.

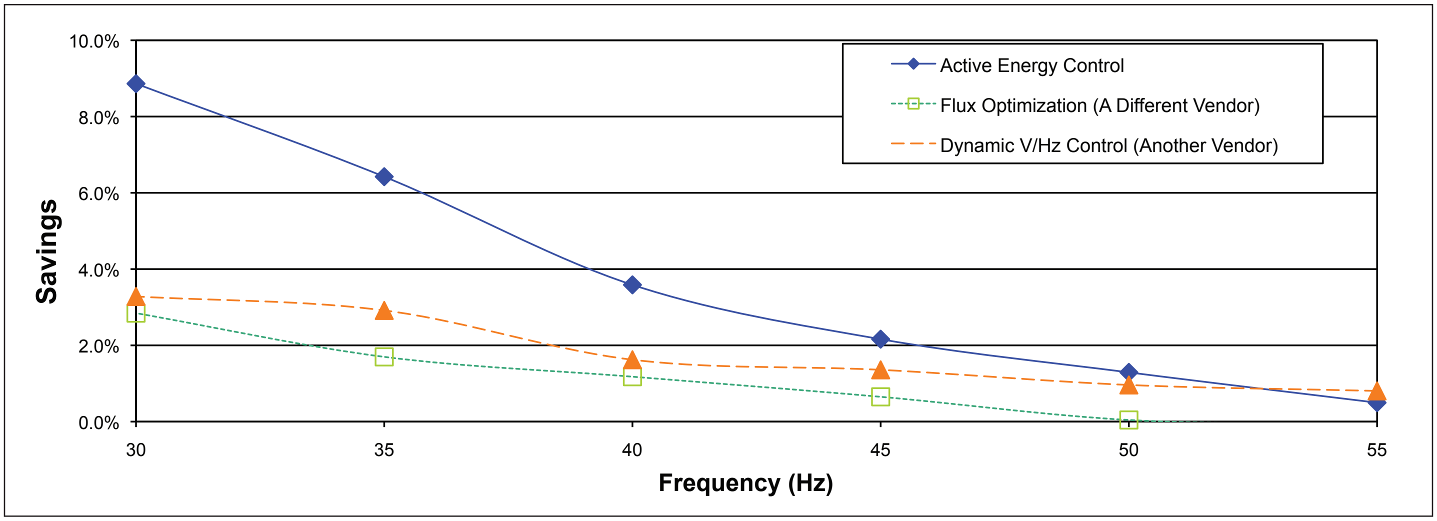

Figure 4. Energy Savings for Various Dynamic V/Hz Modes (Compared with Linear Mode)

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