

Product & Technology Review

Motor Voltage Controllers

Power conditioning devices intended to save energy and reduce current for motors. Models are available for a range of motors, from single-phase fractional horsepower motors all the way up to three-phase motors with horsepower in the hundreds. Motor voltage controllers are sometimes referred to as Nola controllers.

Manufacturers

There are many manufacturers of motor voltage controllers, with more entering the market regularly. One source reports over sixty manufacturers. Marketing of motor voltage controllers varies considerably. Some manufacturers promote the product as a power factor improvement and motor energy saving device, with soft start as an extra feature. Others market the product as a soft starter and give only scant mention to the load-based voltage control as an extra feature.

Some manufacturers have only 120-volt, single-phase fractional horsepower controllers targeted toward residential consumers for plug-in products like refrigerators. Others serve commercial and industrial markets with three-phase integral horsepower motors up to 575 rated volts. There are some manufacturers that serve both the single-phase and three-phase market.

Technology History

The motor voltage controller works on a principle credited to Frank Nola of NASA who obtained several related patents in the late 1970s and early 1980s. Because of his contribu-



This illustration is representative of a motor voltage controller.

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tions, a common generic name for this controller has become “Nola controller.” The device may also be called a power factor controller because of its tendency to reduce reactive power more than real power. This was the key benefit promoted when it first entered the market, although it is easier and less expensive to correct power factor with capacitors. Now it is promoted primarily for energy saving.

A Nola controller is essentially an electronic soft starter that can chop (i.e. reduce) voltage not only during starting, but during operation at low-torque load. The controller typically calculates power factor from the current and voltage and determines torque loading from that, then supplies reduced voltage as appropriate. At low load, reducing the voltage reduces reactive current and increases efficiency.

Manufacturers generally do not market the product by any of the generic names. They typically brand the product as a distinct new technology with revolutionary performance attributes.

Technology Function and Application

Motor voltage controllers are intended to save energy by reducing voltage when motors are operated below their rated load. Motors have an output power rating, expressed in horsepower or kW. The power rating is not the highest power the motor can produce but a nominal power that the manufacturer identifies as the size or rating they will cover by warranty. It is close to the highest power the motor can sustain continuously without over-heating and compromising its life expectancy.

Another nameplate parameter is the utilization voltage, which is the ideal voltage for operation at rated power. At any load up to the rated load, the motor runs fine and without harmful stress at utilization voltage $\pm 10\%$. However, somewhat higher efficiency and power factor can be obtained if an under-loaded motor is operated at reduced voltage. This led to the invention of the motor voltage controller.

How does a motor operate below its rated load?

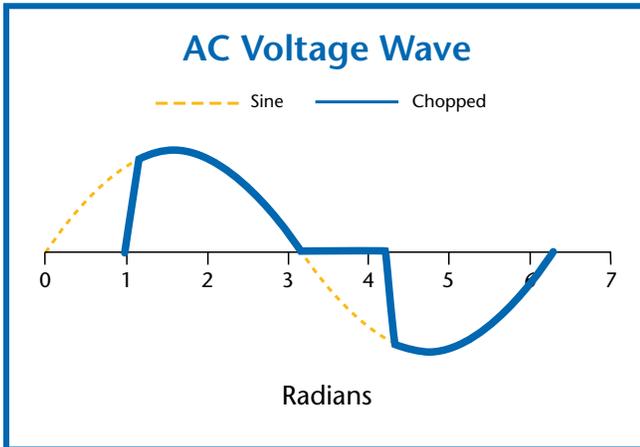
A popular belief is that a motor always delivers its rated horsepower to the shaft. In fact an AC motor is caused to rotate at a nearly constant speed related to the 60 Hz AC line frequency. If the load's resisting torque is reduced because, for example, no log is being fed to a saw blade, the motor speed will increase very little. What happens is the motor will relax its torque force to balance the reduced torque requirement of the load. Power transfer is proportional to speed times the torque force, so power output is reduced when the load's torque requirement is reduced.

Motor voltage controllers only regulate voltage, unlike adjustable speed drives, which regulate voltage and frequency. Motor voltage controllers typically use current and output voltage sensors to determine motor load, and then automatically adjust output voltage to an optimum level for the load. They usually save energy at low load and no load. In order for them to save the double digit amounts some manufacturers advertise, the motor has to be operating at idle or very low load almost all of the time.

The reduced voltage that motor voltage controllers provide to motors has harmonic distortion. This is because motor voltage controllers ordinarily reduce voltage by “chopping” it with power semiconductors called silicon controlled rectifiers (SCRs). SCRs remain off through the early part of the half cycle, and then turn on for the remainder of the half cycle, producing a distorted sine wave as shown in bold in Figure 1. Chopping has the desired effect of reducing the average or root mean square (RMS) value of the voltage. The voltage wave would appear more complicated for three-phase line to line power.

Figure 1.

Chopped Voltage for a Single Phase Motor



Unfortunately, chopping the voltage wave introduces voltage harmonics that reduce motor efficiency and sometimes produce an audible buzz. The efficiency reduction due to voltage harmonics somewhat diminishes the potential efficiency improvement at low load resulting from the RMS voltage reduction. The various harmonics all try to turn the motor at different speeds and directions and essentially fight the fundamental frequency.

Voltage harmonics from a motor voltage controller are primarily an issue for the motor being controlled. To a lesser degree voltage harmonics are introduced system-wide. This occurs because the motor draws current harmonics in response to its chopped voltage and these current harmonics act across the system, contributing to voltage distortion on the line side of the controller. A report by the Electric Power Research Institute (EPRI) notes that motor voltage controllers are a concern of electric utilities because of the harmonic distortion they contribute to the electric power system. (EPRI 2003)

Single-phase, fractional horsepower motors have more potential for savings at low load than larger motors. However, refrigerators and fans are about the only single-phase motors that run enough hours annually to warrant consideration of voltage control. Tests on refrigerators have found considerable savings in some cases and none in others. The greater likelihood for good savings is with older

What are harmonics?

Harmonics are integer multiples of fundamental frequency. For example if the line frequency is 60 Hz, the 2nd harmonic is 120 Hz, the 3rd harmonic is 180 Hz, and so on. Two hundred years ago the mathematician Joseph Fourier showed that any shape of distorted wave could be disaggregated into the series of a fundamental sine wave plus various sinusoidal harmonics of that wave at various amplitudes. This has proven very important in electrical theory because electrical conductors and devices respond to the various harmonic components as if they were indeed distinct frequencies.

models. This may be because newer models are more carefully engineered to not oversize the compressor motors. One investigator reported testing a residential fan that slowed dramatically and began to buzz when powered by a popular mass-marketed motor voltage controller. This is plausible because low-efficiency single-phase motors have considerably higher speed sensitivity to voltage than the nearly constant speed larger three-phase motors.

Energy Savings Claims

Manufacturers usually claim "up to" a certain percent savings. Some product literature suggests savings of 40% or more. It is important to recognize that "up to" designates a maximum but not a minimum. Some product literature qualifies prospective savings with "...in appropriate applications."

It is important to understand how a savings figure is defined. Because the greatest savings occur at low load, the savings percent is usually based on the power saved with the device in the circuit at idle or some low load, divided by the power consumed with the device bypassed at the same idle or low load. It is rarely based on the savings expressed as a percent of the rated power. For example, if a motor runs idle nearly all the time, it may only be using about

4% of the energy it requires at rated load. The motor voltage controller may drop this energy down to 3% and the controller manufacturer can correctly say it saved 25% of the energy. That might sound impressive, but it is a large percent of a very small number, so in reality you are saving very little energy.

Some product literature claims that the controller precisely meters out the exact right amount of power when a motor is serving a light-torque demand. It is often stated or implied that an uncontrolled power bus somehow forces full-rated power into a lightly loaded motor. This is simply incorrect. Oregon State University's Motor Systems Resource Facility (which is being renamed Wallace Energy Systems and Renewables Facility), tested an energy efficient motor at rated load at full voltage, then load was reduced by reducing torque demand of the dynamometer with no change in applied voltage. At 25.4% load and full voltage, the motor input wattage dropped to 26.1%, i.e. nowhere near full-load power.

Non-Energy Benefits

If the prospective energy saving economic benefit for a motor voltage controller is found to be marginal for a specific application, consider the additional benefits of the soft start capability. Soft-starts will reduce mechanical shock to the load and reduce voltage sag during motor acceleration.

Independent Testing Results

Several motor voltage controllers have been tested by independent labs. Results have been variable depending upon the product manufacturer and even more on the motors selected for testing. Advanced Energy of Raleigh, NC, evaluated four 20-HP motor voltage controllers in its motor lab in 1999. This was done as a research project for Duke Energy. Each controller was from a different manufacturer and two motors (one standard and one energy-efficient) were tested with each controller. In all tests with the controller in the circuit at 50% and higher loading, more energy was used. At 25% loading all but one of the devices produced savings. The amount of savings varied con-

siderably between motors and devices. Simple payback (based on actual product cost and \$.05 per kWh energy) was calculated for each device at the load for which it produced the most savings. Based on continuous operation at exactly that load, the best performing device had a 44-year simple payback. Evaluators concluded that "the voltage controller devices have limited energy savings potential."

Bonneville Power Administration, EPRI, Portland General Electric, and Tacoma City Light sponsored a motor voltage controller study in 1994 at the Motor Systems Resource Facility. About 6% energy reduction was observed at about 5% load, but this was only about 0.4% of the motor's full-rated load. Power factor was improved slightly below 40% load. The study's report (Test Evaluation of a Reduced-Voltage Induction Motor Controller) concludes that the particular technology under evaluation was likely best for standard efficiency motors that run idle or at low power for much of the time and need the additional benefit of electronic soft start.

Cost

Cost varies considerably. Advanced Energy of Raleigh, NC, purchased four 20-HP motor voltage controllers from different manufacturers at a price ranging from \$2,000 to \$2,600. In three-phase applications, they should be comparable to, or somewhat more than, the cost of electronic soft starters.

Alternative Products and Strategies

Motor voltage controllers are advertised for saving energy and improving power factor in motors that spend significant time running at low loads. Savings can also be achieved in these situations by upgrading to NEMA Premium™ motors. Use the MotorMaster+ software tool (available free from U.S. DOE – www1.eere.energy.gov/industry/bestpractices/software.html#mm) to identify NEMA Premium motors that have comparatively high efficiency at 25% load to ensure that the savings advantage is strong at the lower loads. Among motor

models that exactly equal the NEMA Premium standard, there is over a five-point spread in efficiency at 25% load.

If you determine that a candidate motor always runs well below its rating, you can probably save more energy by downsizing the motor. This will also reduce starting current and reactive power. However, be careful of downsizing if your motor operates in a dirty environment. Oversized motors tolerate dirt obstructing the cooling passages and surfaces better than right-sized motors.

To improve power factor, the alternative is properly sized capacitors. They will provide high power factor at full load and almost completely eliminate reactive current at low and idle power. Correcting power factor can free up capacity on your distribution system. However, correcting power factor will bring only negligible improvement on your electric bill unless your power company charges a power factor penalty. See *References* for more information on power factor.

Additional Reviewer Comments

If you are considering a motor voltage controller, some tests beforehand can determine if a motor is a good candidate. If it is, and you install one, some comparative tests afterwards will verify the magnitude of savings.

Testing will require a good power analyzer that measures real power, power factor, and harmonic levels. Ideally it will use a power logging feature to determine a load duration profile. Cheaper watt meters may not read true power accurately at low loads because of the low power factor. Be sure to take measurements on the input (line side) of the device to accurately measure power and power factor the way your utility meter sees it. Never use an ammeter alone to compare before and after energy use – that has been a popular but invalid demonstration in retail marketing of motor voltage controllers to homeowners who do not understand that change in current is not always a valid indicator of change in power consumption.

It should be qualified that not all statements contained here are certain to pertain to all mo-

tor voltage controllers. The numerous manufacturers often claim innovative and proprietary features that increase performance or achieve faster and better control for rapidly changing loads or loads that challenge stability. These may include claims such as very fast (fraction of a cycle) response to load changes or reduced harmonics. It is certainly possible to design a motor voltage controller with advanced power electronics or electronic filtering to reduce output and input harmonics, although this would involve more costly power electronics.

When we have looked at independent lab test results of motor voltage controllers they show savings generally anywhere from zero to about 7% at idle and very low loads if you define the savings as a percentage of rated load energy. The savings are less if the motor is more efficient to begin with, and much less (or non-existent) if the motor is operating above 50% load much of the time. In fact, energy use is liable to increase slightly at loads above 50% due to the power consumed by the electronic controller.

Motor voltage controllers save more energy for some motors than others. One factor is that motors vary in their losses, and a greater portion of losses in some motors is associated with the magnetic properties of the motor's iron core (hysteresis and eddy current losses). These motors have more potential for savings from voltage reduction. Another factor may be that the harmonics that motor voltage controllers create at the motor terminals reduce potential savings more in some motors than others.

Motor voltage controllers may be good energy saving choices for applications like saws and chippers, elevator MG sets, escalator motors, and any motors that run idle or very lightly loaded much of the time. However, do the math and determine your prospective life-cycle economic benefit.

Conclusion

Most manufacturers of motor voltage controllers claim to use a unique approach to controlling motor voltage at low loads and indeed the details vary from product to product. The efficacy of each unit that we have reviewed,

however, seems to be fairly similar. If the claims they are making sound too good to be true, be wary. The conditions necessary for cost-effective application of a motor voltage controller are extensive and will be difficult to find.

The more of the following questions you answer “Yes” to, the greater your prospects for savings by some sort of system upgrade:

- Do you have a significant capacity in rotating equipment that must run considerably unloaded much of the time?
- Is your power factor low?
- Are your motors old or less efficient than the NEMA Energy Efficient or NEMA Premium levels?
- Would it be useful to add a soft start to your motor?

Determine the load profile and compare cost and prospective power savings from a motor voltage controller and alternatives such as upgrading to NEMA Premium motors and downsizing where appropriate, adding power capacitors, or adding a conventional soft start. Carefully review the terms of any energy savings “guarantee” and benchmark the energy used by the motors under study with a power analyzer. After implementation, use the power analyzer to verify the expected energy reduction.

Additional Information

Northwest businesses and utilities can contact the EnergyIdeas Clearinghouse for additional information on this or other energy efficiency technologies or products. Contact:

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Note: Product & Technology Reviews are peer reviewed by objective industry professionals prior to publishing.

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WSUEEP07-016