

## Characterizing the Performance of Motor Voltage Controllers

**Background** Preserving fossil fuels and reducing air pollution are high priorities for environmentalists, the government, and many businesses. Provocative environmental concerns, such as the greenhouse effect, have spawned new niche industries that innovate energy-saving technologies. One such industry has developed a highly commercialized energy-saving device for common motor-driven residential appliances, such as refrigerators, washing machines, and air conditioners. Called motor voltage controllers (MVCs), these devices control the voltage to motor-driven appliances depending on the loading of the motor. Other features of the device may include soft-start capability, surge protection, and power-factor improvement.

The theory of operation is simple: Motors used in appliances are designed to deliver full power at a terminal voltage of about 115 volts RMS. However, when a motor is less than fully loaded, applying a rated terminal voltage produces more magnetizing current than is required to drive the load. MVCs are designed to reduce the power consumption of a motor by reducing the RMS voltage when the motor load decreases, thus reducing the core losses associated with the excess magnetizing current. Figure 1 shows the output of a typical MVC connected to a motor loaded at 25 percent of its rating. Note the notches in the output voltage, which result in a reduction in RMS voltage of the MVC output compared to its input.

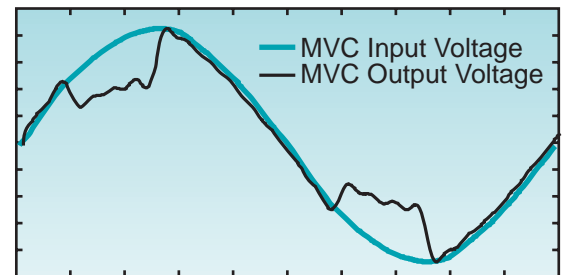


Figure 1. Input and Output Voltages of a Typical Motor Voltage Controller

The application of MVCs is ideal for older, low-efficiency appliance motors. However, today's appliance motors are energy-efficient, and many run at full load so that an MVC may not achieve its purpose and in fact may be counterproductive. Additionally, because MVCs are nonlinear devices, one concern of electric utilities is how much harmonic distortion MVCs contribute to the electrical system, and does such a contribution offset any savings in power consumption.

**Objective** The objective of the tests performed at the University of Tennessee was to characterize the energy-savings performance and harmonic emissions of three commercially available motor voltage controllers.

**Test Setup** Three single-phase off-the-shelf MVCs were tested using the setup shown in Figure 2. A variable AC voltage source was used to power a single-phase, one-half-horsepower, high-efficiency, permanent-split capacitor motor, which is typically used in residential appliances. The motor

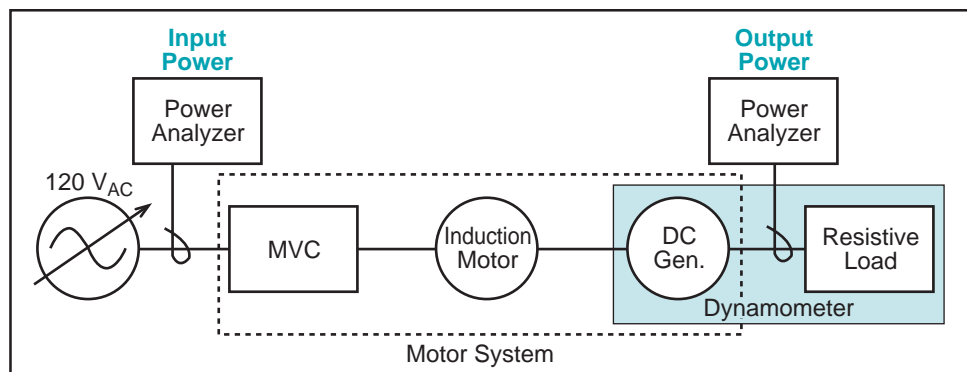


Figure 2. Test Setup

shaft was connected to a dynamometer (combination of DC generator and resistive load). The voltage at the source was held at 120 Vac during all trials. By varying the resistive load of the DC generator, the load on the induction motor system was varied from zero to 100 percent in 25-percent increments. This setup enabled both input and output powers to be conveniently measured with electrical instruments. The five trials were conducted for each MVC and once without an MVC in the circuit. During each trial, the input and output power of the motor system were measured using two power analyzers as shown in Figure 2. Efficiency was then calculated for each trial by dividing the output power by the input power. Additionally, the harmonic current distortion was measured at the voltage source during each trial.

## TEST RESULTS

Table 1 shows the measured input and output power, calculated efficiency, and measured current distortion of the motor system without an MVC installed. Table 2 shows the same parameters of the motor system with each of the three MVCs installed. Table 3 shows the RMS output voltages of the three MVCs for all trials. Figures 3 and 4 show efficiency and current distortion for all trials. As shown in Figure 3, the efficiency of the system increased as the motor load increased, leveling off above 75-percent load with no MVC in the circuit. However, the efficiency of the system with an MVC *did not* level off at 75-percent load but rather decreased about nine percent for all tested MVCs. As shown in Figure 4, the correlation between current distortion and motor load varied widely over the four test conditions.

## DISCUSSION

One of the three MVCs demonstrated an appreciable increase in system efficiency at a 25-percent motor load. With MVC 3 installed, the efficiency increased about seven percent. The other two MVCs demonstrated modest increases in efficiency at 25-percent

Table 3. RMS Voltage at the MVC Output at Different Motor Loads

Motor Load (%)	RMS Voltage (V)		
	MVC 1	MVC 2	MVC 3
0	113	106	73.8
25	113	106	94.6
50	113	106	103
75	111	105	109
100	107	117	114

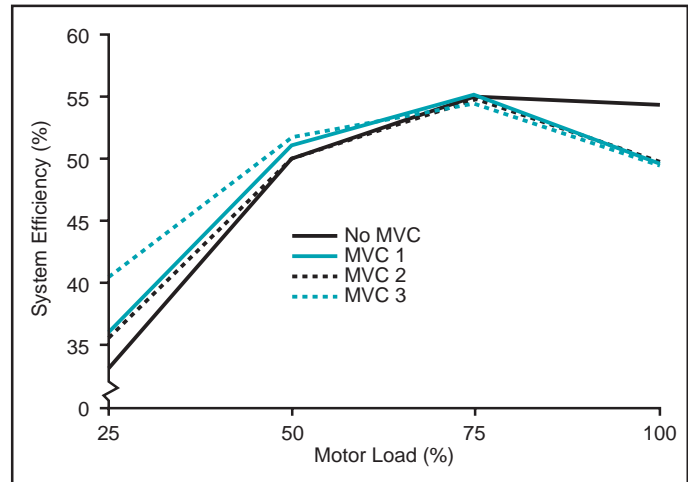


Figure 3. System Efficiency at Different Motor Loads

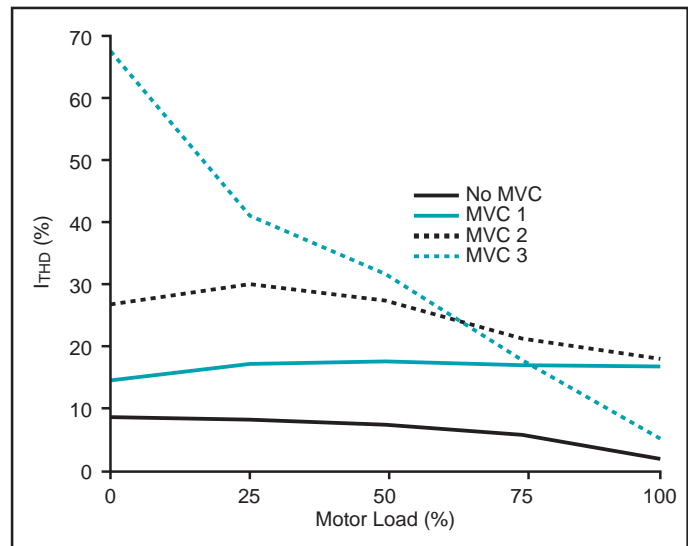


Figure 4. Current Distortion at Different Motor Loads

Table 1. Input Power, Output Power, Efficiency, and Current Distortion without an MVC at Different Motor Loads

Motor Load (%)	Input Power (W)	Output Power (W)	Efficiency (%)	Current THD (%)
0	142	0	0.0	8.7
25	265	88	33.2	8.1
50	383	190	49.9	7.3
75	488	268	54.9	5.7
100	679	369	54.3	2.1

Table 2. Input Power, Output Power, Efficiency, and Current Distortion with Different MVCs at Different Motor Loads

Motor Load (%)	MVC 1				MVC 2				MVC 3			
	Input Power (W)	Output Power (W)	Efficiency (%)	Current THD (%)	Input Power (W)	Output Power (W)	Efficiency (%)	Current THD (%)	Input Power (W)	Output Power (W)	Efficiency (%)	Current THD (%)
0	125	0	0.0	14.5	125	0	0.0	26.8	58	0	0.0	67.2
25	253	91	36.0	17.1	253	90	35.6	30.0	217	88	40.6	41.3
50	372	190	51.1	17.4	380	190	50.0	27.3	369	191	51.8	31.6
75	483	266	55.1	17.0	498	273	54.8	21.3	490	267	54.5	18.0
100	746	370	49.6	16.8	740	368	49.7	18.2	746	369	49.5	5.2

motor load (about three percent). Any difference in efficiency at 50-percent motor load and above was either negligible or negative. The decrease in efficiency at maximum load is caused by the losses inherent in the MVC. Testing other types of motors typically used in residential appliances, such as standard split-phase and capacitor-start/capacitor-run motors, yielded about the same results.

With the exception of MVC 1, current distortion tended to decrease as the motor load increased. At a low motor load (25 percent), the harmonic distortion of the motor system ranged from 8.1 percent for the non-MVC system to 41.3 percent for MVC 3. At a 25-percent motor load, the high current distortion may contribute to power-system losses, reducing any gain in efficiency an MVC may bring.

### **SIGNIFICANCE**

Motor voltage controllers may increase the efficiency of induction motors that are lightly loaded and have high core losses, which is often the case with older appliances. However, many of today's appliances have high-efficiency motors that operate at near-full load. For example, connecting an MVC to a new energy-efficient refrigerator with a fully loaded motor may actually increase energy consumption. While test results suggest that MVCs can increase efficiency at low motor loads, electric utilities must resolve several questions before recommending MVCs to their residential customers. First, is the average savings in efficiency for older appliances worth the expense of the MVC? Second, will any savings in energy efficiency at the appliance be offset by losses in the electrical system caused by increased current distortion? Third, will a lower RMS voltage at the appliance motor decrease the life of a motor? The answers to these questions depend upon the electrical environment of each customer and the type and age of the appliance.

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