True RMS vs AC Average Rectified Multimeter Readings when a Phase Cutting Speed Control is Used

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Introduction

There are two methods commonly used in Digital Volt Meter (DVM) AC measurements, one is AC average rectified measurement and the other is True RMS measurement. True RMS is a consistent and standard way to measure and compare dynamic signals of all shapes and sizes. In other words, RMS measurement is equivalent to the heating potential of a dynamic waveform .[1]

While a non-true RMS or AC rectified average multimeter may not be accurate to measure non pure sinusoidal waveform due to different hardware architecture being used to extract the signal, an AC average rectified multimeter can be calibrated with a fixed form factor to measure RMS value of pure sinusoidal signal.

In this white paper, a comparison between the motor voltage measured using a True RMS DVM meter and a DVM using averaging rectified voltage measurements is presented and the resulting airflow affect if the wrong meter is used is presented.

Why RMS?

The purpose of RMS value is to simplify power calculations by providing equivalent DC voltage that would develop the same average power in resistive load.

The formulas below compare the calculations of an RMS meter compared to an average rectified measuring meter when measuring pure sinusoidal AC voltage.

$$V_{RMS} = \sqrt{\frac{1}{T}\int_0^T v^2(t)dt}\ ;\text{ Which is }\frac{V_{pk}}{\sqrt{2}} = 0.707V_{pk}\text{ for pure sinusoidal wave.}$$

$$V_{AVE} = \frac{1}{T}\int_0^T |v(t)|dt\ ;\text{ Which is } 0.637\ V_{pk}\text{ for pure sinusoidal wave.}$$

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[1] True RMS Definition, application note 106, Linear Technology

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Therefore in non-true RMS meter reading, the value is calibrated by a form factor of 1.11, which is coming from $\frac{0.707}{0.637} = 1.11$, but this is only accurate for a pure sinusoidal waveform[2].

Experiment

To understand the difference between true RMS and AC rectified averaging digital multimeter, an experiment is prepared using the equipment listed below:

1. A Hoffman Controls model 706-123SB phase cutting electronics speed controller was used to generate a non-pure sinusoidal waveform from the AC incoming line voltage. (Any phase cutting AC speed control can be used)

2. An EBM Fan D4E250-CA01-01 blower/ fan was used to simulate normal operating condition.

3. A Fluke 73III AC average rectified digital multimeter

4. A Fluke 179 True RMS digital multimeter

5. An APC Variable AC power Supply

Electrical connection diagram:
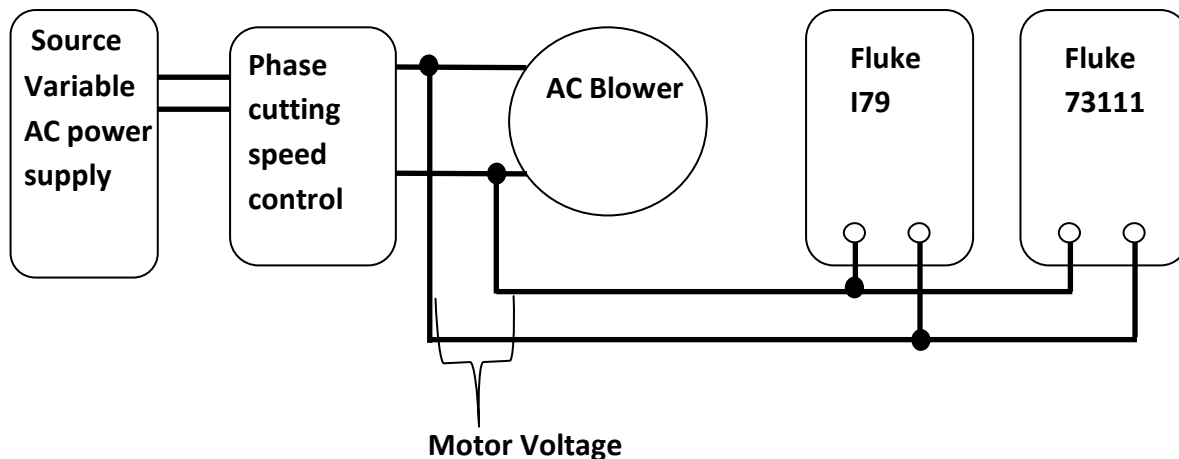
[2] Fundamental Electrical and Electronic Principle 3rd edition by Christopher R Robertson, Newness 2008.

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Equipment setup Left to right, phase cutting speed controller, Fluke 179 DVM, Fluke 73III DVM. Meters are connected in parallel to measure the output voltage from speed control.

Phase cutting Speed Controller   **Fluke 179**   **Fluke 73III**
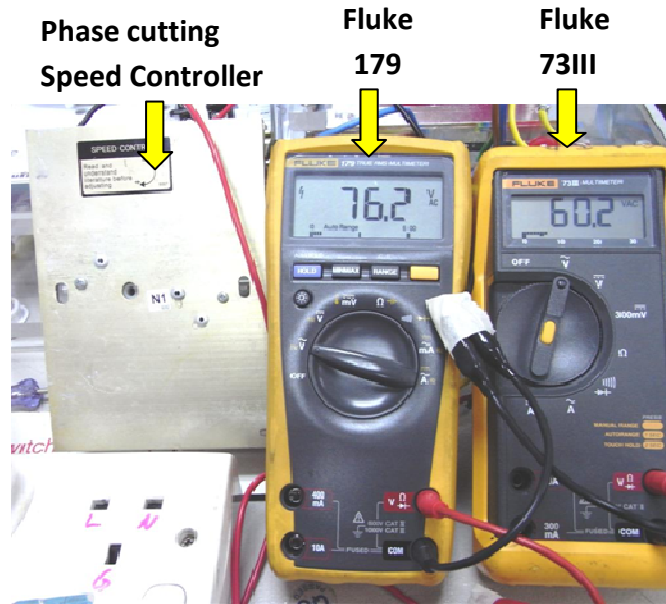
Experiment One

A stable AC input voltage of 230VAC/50Hz was fed into a phase cutting speed controller. The voltage from the phase cutting speed controller was adjusted from 35 Vrms to 230 Vrms in 10 VAC increments measured with the Vrms meter. At each voltage both Vrms and Vavg values are recorded.

Comparison graphs were plotted to analyze the correlation between Vrms and Vavg readings. The top graph uses the X axis to indicate the Vrms measurement at each set point and the Y axis to indicate the Vave measurement at each set point. A 1 to 1 correlation line is drawn on the top graph for reference.

The bottom graph shows that the difference between Vrms and Vavg measurements is not linear from the minimum voltage set point to the maximum voltage set point. Both graphs indicate Vavg measurements always result in lower values than Vrms measurements at the same set point. At the maximum voltage a full AC sine wave is measured, and the difference between the Vrms and Vavg

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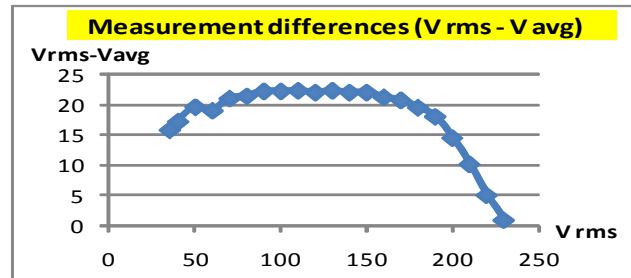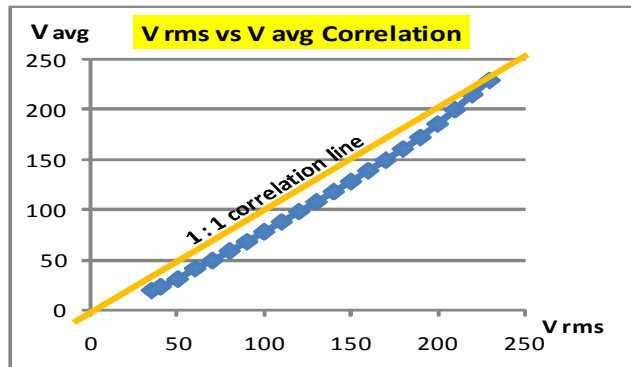
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measurement is approximately zero. This is expected because the Vavg multimeter is calibrated at full sine wave. The measurement from low voltage set point to high voltage set point varies from approximately 16 VAC to maximum of approximately 23 VAC then gradually drops to zero at full voltage. The 1 VAC variation at maximum voltage is a result of using a phase cutting controller and rounding.

Motor Voltage Experiment result

Fixed AC source at 230VAC/50Hz

V rms	V avg	V rms- V avg
(V)	(V)	(V)
35	19.2	15.8
40	22.8	17.2
50	30.4	19.6
60	41	19
70	49	21
80	58.6	21.4
90	67.8	22.2
100	77.8	22.2
110	87.7	22.3
120	98	22
130	107.7	22.3
140	118	22
150	128	22
160	138.8	21.2
170	149.3	20.7
180	160.5	19.5
190	172	18
200	185.5	14.5
210	199.8	10.2
220	214.9	5.1
230	229	1

full waveform (Max Speed)

V rms vs V avg Correlation

1 : 1 correlation line

Measurement differences (V rms - V avg)

These results are consistent and repeatable within the test fixture and instrument tolerances, and can be used as a quick guide to differentiate between true rms and average rectified multimeters.
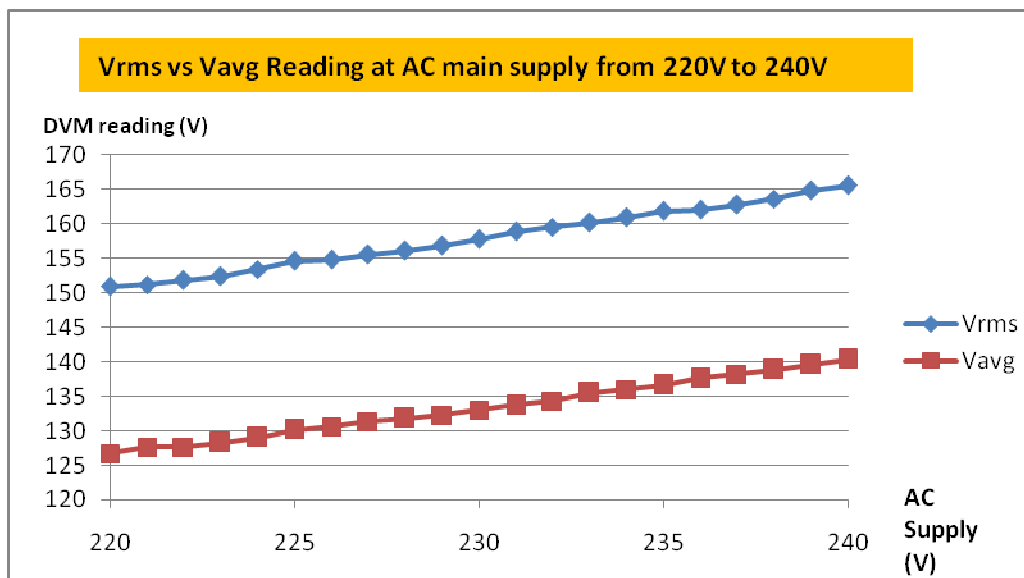
Experiment Two

In this experiment the same set up is used. The phase cutting speed control is NOT adjusted. The incoming line voltage is adjusted +/- 10 volts of nominal AC incoming voltage using a phase cutting speed control. The True RMS and averaging meters were used to measure motor voltage. The purpose of this experiment is to show the effect that fluctuating incoming voltage has on the motor voltage. The second purpose is to show that the True RMS and average meters continue to provide different readings.

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To simulate 115 VAC operations the incoming voltage was adjusted from 105 VAC to 125 VAC in one volt increments. The readings for both Vrms and Vave were plotted on the graph below. The motor phase cutting speed control was adjusted to approximately mid range. This was an arbitrary setting to simulate a typical speed control adjustment.

Vrms vs Vavg Reading at AC main supply from 105V to 125V
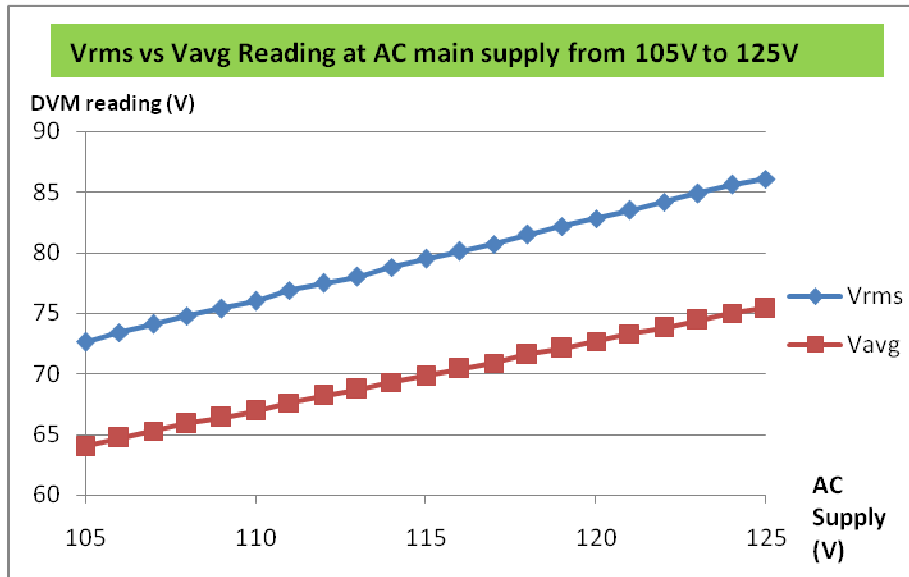
To simulate 230 VAC operations the incoming voltage was adjusted from 220 VAC to 240 VAC in one volt increments. The readings for both Vrms and Vave were plotted on the graph below. The motor phase cutting speed control was adjusted to approximately mid range. This was an arbitrary setting to simulate a typical speed control adjustment.

Vrms vs Vavg Reading at AC main supply from 220V to 240V

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Conclusions

When measuring voltage from a phase cutting speed control, a True RMS meter must be used to obtain consistent correct voltage measurements. The correlation factor between Vrms and Vave is neither linear nor constant.

Experiment two illustrates the linearity between the two meter readings is closer, but still not consistent. A true Vrms meter should be used.

The experiment also illustrates that fluctuation of incoming voltage does affect the output motor voltage of phase cutting speed controls. This is important because motor/fan speed affects air flow. Without stable voltage the air flows are affected. This can lead to compromised barrier protection.

ESCO has published an additional technical paper titled *Understanding Airflow Stability Behavior with Incoming Power Voltage Fluctuations*. This paper further explains the affect of incoming voltage and possible solutions.

References

1. True RMS Definition, application note 106, Linear Technology
2. Fundamental Electrical and Electronic Principle 3rd edition by Christopher R Robertson, Newness 2008.