

Appendix H

Measuring Power regulated by Zero Crossing SCR Controllers

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January 31, 2001

Revised December 29, 2004 for general use.

What is a Zero Crossing SCR Controller?

A zero crossing SCR controller is used to regulate the power delivered to a resistive load. The controller uses two Silicon Controlled Rectifiers (SCRs) connected back to back in opposite directions and a zero crossing detector. The zero crossing detector detects the zero crossing of the AC voltage input and allows the SCRs to conduct starting with a zero crossing of the voltage. This avoids harmonic problems associated with the phase angle fired SCR controller.

A variable time base firing circuit is used to provide precise control of power delivered to a resistive load. Zero crossing controllers are not intended for use with inductive loads such as motors. A zero crossing controller is either conducting with full voltage applied to the load or it is not conducting. On or Off. The variable time base circuit controls the proportion of **ON** time to **OFF** time.

Typical Zero Crossing SCR Controllers

All zero crossing controllers operate over some fixed number of cycles of the AC voltage. 180 cycles is typical for many. There are essentially two types: time proportioning and variable time on over the duration of the 180-cycle period.

The second is the simpler case. For the 180-cycle period (3 seconds at 60 Hertz) the controller works as shown in the chart below:

Full Off	0 cycles conducting out of 180
Lowest power	1 cycle conducting, 179 off.
1/4 power	45 cycles on, 135 cycles off
1/2 power	90 cycles on, 90 cycles off
3/4 power	135 cycles on, 45 cycles off
Highest Power (without full on)	179 cycles on, 1 cycle off
Full on	180 cycles conducting, 0 off

The time proportioning zero crossing controller proportionally spreads the on/off time over the 180-cycle period thus applying more even power to the load. The chart below gives an example a time proportioning zero crossing controller.

Full Off	0 cycles conducting out of 180
Lowest power	1 cycle conducting, 179 off.
1/4 power	1 cycle on, 3 cycles off for the 180 cycle period
1/2 power	2 cycles on, 2 cycles off for the 180 cycle period
3/4 power	3 cycles on, 1 cycle off for the 180 cycle period
Highest Power (without full on)	179 cycles on, 1 cycle off
Full on	180 cycles conducting, 0 off

Typical Applications for Zero crossing Controllers

Almost all applications of zero crossing controllers involve control of heaters. Examples of heating applications include: Dryers, kilns, ovens, environmental chambers, extruders, molding equipment, distillation equipment.

Industries that use zero crossing controllers include glass, plastics, lumber, food, chemical, petroleum, metal, textiles, pulp, paper, etc. Almost all industry involved in manufacturing of base materials and finished goods use heaters in their process. Zero crossing controllers are often used to control these heaters.

Zero crossing controllers accept an analog signal input to control the power applied to a heating load. The source of this signal is very often a power (or watt) transducer. The watt transducer provides the feedback signal to the zero crossing controller to enable it to deliver constant power to the load.

Transducers

The typical watt transducer is designed to filter the AC ripple that is the result of the instantaneous multiplication of AC voltage and AC current. For a single-phase load powered from a 60 hertz source the ripple will be at 120 hertz and have a minimum peak to peak value that is twice the actual power. To filter this AC component the watt transducers average the reading over 200 to 400 milliseconds. This totally filters the ripple.

A watt transducer measuring the power regulated by a zero crossing controller must 1) filter the normal 120-hertz ripple and 2) also filter the step changes in power from 0 to full scale as regulated by the controller.

That means the watt transducer must average the power over the entire period of 180 cycles, be able to handle the worst case -- 1 cycle on and 179 cycles off, and still provide a smooth output.

The "rule of thumb" in the past was to provide an averaging period 10 times the duty period of the zero crossing controller. So if the duty cycle of the controller is 180 cycles or 3 seconds at 60 hertz, the transducer should have an averaging period of 30 seconds.

The Vice-President of Manufacturing at Ohio Semitronics, Inc. recently asked me to check to see if this "rule of thumb" of 10 times the duty period is really necessary. Using an HDR model ZF1 single-phase zero crossing controller, which has a time base of 160 cycles and is time proportioning, I tested a PC5-7EA with various averaging filters and compared the result with a PC5-8E with a fixed ten second averaging filter.

Recommended Watt Transducer Models

As of January 31, 2001 the only watt transducers series to recommend is the PC5 series.

The GW5 family, which includes the AGW, GH, and AGH, is more difficult to provide with long period averaging time. These are not recommended for use on zero crossing controllers.

The DW5, DWV, and DMT series of watt transducers have programmable response time but the response time of these transducers does not affect the averaging time. These are not useable on zero crossing SCR controllers.

One of the most important considerations (other than averaging time) of selecting a watt transducer is repeatability. The repeatability of the PC5 watt transducer for the same conditions is excellent.

Accuracy is often a concern because the PC5 series is rated at $\pm 0.5\%$ of full scale. In the case of a zero crossing SCR controller, one is dealing with either full power or zero power. Therefore the overall accuracy of a PC5 being used on a zero crossing SCR controlled load is $\pm 0.5\%$ of reading + any zero offset error.

What averaging period should one select?

As a result of my tests, the "rule of thumb" of 10 times the duty period is not needed. An averaging time a little longer than the duty period provides good smooth output from the PC5 watt transducer on a single phase load. Because the zero crossing controller is either on or off, the same will apply to a three phase load.

The chart below gives averaging times available for PC5 series watt transducers.

Averaging Time	Option
No averaging	Y18*
25 mS	Y19
50 mS	Y20
100 mS	Y21
200 mS	Standard Model
500 mS	Y22
1 S	Y23
3 S	Y24
5 S	Y25
10 S	Y26
15 S	Y27

(mS -- milliseconds, S -- seconds)

(* Best to use 0 to 5 volt output with Y18)

The HDR ZF1 zero crossing controller operates over a 160 cycle period or $160\text{cycles}/60\text{cycles/sec} = 2\frac{2}{3}$ seconds. For this application we recommend a 5-second averaging period, which is option Y25. You the customer should make the final decision. You may want a shorter or longer averaging period.

The longer the averaging period, the longer the output response of the transducer will be. Some may not be able to tolerate a 5 or 10 second wait for the output of the transducer to rise to full output.

The bottom line is that you are safe using option Y25 for most zero crossing applications.

Special Considerations

The above is based on the North American power generation frequency of 60-Hertz. If the transducer is destined for a country using 50-Hertz power the averaging time may have to be longer.

The HDR ZF1 zero crossing controller operates over a 160 cycle period or $160\text{cycles}/50\text{cycles/sec} = 3.2$ seconds. For this application recommend a 5-second averaging period, which is option Y25. You the customer should make the final decision. You may want a shorter or longer averaging period.

Several industries including the paper industry generate their own electric power at 25-Hertz. Because they use dryers, which use heaters, zero crossing controllers are used. The same example now becomes:

(continued on page 4)

The HDR ZF1 zero crossing controller operates over a 160 cycle period or $160\text{cycles}/25\text{cycles/sec} = 6.4$ seconds. For this application use a 10-second averaging period. This however also requires a specially built PC5 watt transducer for use on 25-hertz. Please check with us at Ohio Semitronics, Inc. for Y option number and cost.

(Continue on page 5 for the test and test results)

Test Results

Test Setup

Equipment used:

PC5-7EA with a switch selectable averaging filter installed. (Not an option)
(EX185, EA, and Y47 - depending on the vintage - designate a 0 to 20 mADC output.)
0 to 20 mADC is proportional to 0 to 1500 watts.

PC5-8E with a fixed 10 second averaging filter.
4 to 20 mADC is proportional to 0 to 3000 watts.

HDR Power Systems zero crossing controller model ZF1

500-watt lamp (rated 500 watts at 130 volts)

Dataq DI-190 two channel data acquisition card.

My desktop computer.

WinDaq data acquisition software from Dataq.

The Setup:

The current inputs of the watt transducers are connected in series such that all three current inputs are used on each watt transducer.

The voltage inputs of the watt transducers are connected in parallel such that all three voltage inputs are used on each watt transducer.

The output of each watt transducer is loaded with a 250 Ω resistor.

In this manner the actual scale is:

PC5-7EA 0 to 5 volts ~ 0 to 500 watts

PC5-8E 1 to 5 volts ~ 0 to 1000 watts.

Both watt transducers are connected between the ZF1 and the lamp so that both are measuring exactly the same load.

The ZF1 is equipped with a potentiometer to permit manual adjustment from zero to 159/160 of full power.

Procedure:

Run the lamp at three power setting for each averaging period of 500 mS, 1 S, 3 S, 5 S, and 10 S. The power settings are approximate at 1) full scale, 2) mid-scale, and 3) low scale.

Record the outputs of the transducers using the data acquisition card and software.

At each power setting allow the lamp to run at the desired setting until the watt transducer outputs reach a stable reading, remove the voltage supply until the watt transducer outputs reach a stable reading, reapply voltage supply until the watt transducer outputs reach a stable reading, record the curve. The object of removing and reapplying the voltage supply is to illustrate the response time of the transducers.

The Results

The results are displayed on the attached 15 graphs (Not included with this paper. Please contact Ohio Semitronics, Inc. if you want copies of the graphs.)

The upper graph depicts the output from the PC5-7EA.

The lower graph depicts the output from the PC5-8E. In all cases the averaging filter on the PC5-8E is fixed at 10 seconds. Use this for comparison against the PC5-7EA

The turn OFF and turn ON points are marked on all sheets. This gives one a graphical display of the response time of the transducer.

The scale on the graphs is 0 to 5 volts; each horizontal division represents 0.833 seconds.

The graphs clearly illustrate that an averaging period of 5 seconds provides adequate filtering for the zero-crossing controllers. (Please contact Ohio Semitronics, Inc. if you want copies of the graphs.)

Developments Since this was Originally Written Zero Crossing Controllers with DC Components

Added December 29, 2004

Since this paper was written, we at Ohio Semitronics, Inc. have encountered zero-crossing controllers that control by the half cycle rather than a complete cycle. This means that DC components exist.

Where DC components exist transformer coupling can not be used.

A directly connected PC5 series watt transducer can handle this situation so long as:

1. The voltage is monitored in front of the controller. The voltage sensing in a PC5 is transformer coupled and thus must have an AC input
2. The current sensing is direct. No current transformer is used. Current may be sensed on either side of the controller.

This works because PC5 series watt transducers use hall effect sensors for multiplication. The hall sensor is placed in a magnetic circuit such that the sensor is excited by a current proportional to the measured voltage and that the sensor is responding to the magnetic flux in the magnetic circuit. That flux is proportional to the current. The output of the hall sensor in the magnetic circuit is proportional to the product of the excitation current and the magnetic flux.

The directly coupled PC5 will provide an output proportional to power even when there are DC components in the current. The maximum current that the PC5 series can handle when directly connected is 25 amperes. If you have current that exceeds 25 amperes please contact Ohio Semitronics, Inc. We can build a transducer to handle higher currents.

The same filtering circuit is required. Specify "Y25" for a five second averaging filter.

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