Zero-Voltage Switching vs. Random-Voltage Switching

Introduction . . . .

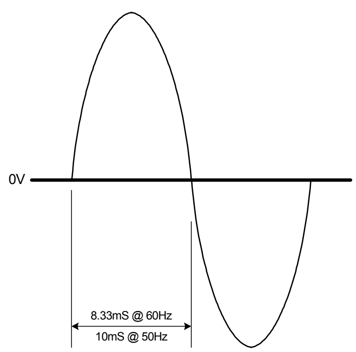
Many Artisan products offer a choice between zero-voltage and random-voltage switching on their solid state AC outputs, most notably the 4310 and 4710 timers. This application note will explain the difference between these two output types, and give guidelines for choosing between them dependant on the application. This choice is predominantly dependant on the characteristics of the load the timer is switching.

Some Basics . . . .

AC Voltage vs DC Voltage

This first section explains what AC voltage is and the difference between it and DC voltage. If you already have a working knowledge of this please feel free to advance to the next section.

AC stands for *A*lternating *C*urrent, while DC stands for *D*irect *C*urrent. An AC circuit changes polarity frequently, here in the US it changes 60 times per second, and is generally written as 60Hz, or 60~, or even 60 cps (cycles per second). This means that the voltage polarity changes from +/-, to -/+, and back to +/- 60 times per second. Outside of the US, 50Hz AC power is commonly found, naturally it changes polarity 50 times per second. A typical AC voltage waveform is found to the left and this is what you would see if you connected an oscilloscope across the AC outlet in your home. Please note how the voltage crosses through 0V every 8.33 milliseconds (10 mSec for 50Hz).



Conversely, DC voltage does not change polarity. This kind of power is created from batteries or DC power supplies, typically used in products like your cell phone or the PC on your desk.

Zero-Voltage and Random-Voltage Switching

When the timing circuit determines that the output should be turned on, it sends a signal to another component which controls the AC output switch. In a zero-voltage circuit, this component *waits until the AC voltage is at 0V* before turning the output on. This means that the energizing of the external load can occur up to 8.33 mSec after the timing circuit determines that the timing period is over. This small delay (0.00833 sec) is not noticeable in virtually all applications, and controlling the AC voltage level when the load turns on can have significant benefits.

Random-voltage switching operates like it states, it energizes the output switch whenever the timing circuit signals it to do so, meaning that the external load can turn on at any point in the AC voltage waveform. This type of output uses a control device similar to the zero-voltage circuit but this device is simpler as it does not need to sense the AC line voltage.

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Types of Loads

The most important factor to consider when choosing the type of output for an application is the type of load the timer is switching, and to determine this we must define some basic electronic concepts. The basic building blocks of electronic circuits are resistors, inductors, and capacitors, and their characteristics are used to describe most electrical loads.

Resistors - This type of component *resists* current flow like an adjustable valve in a water line. As the voltage across a resistor goes up or down the current flow changes accordingly in a linear fashion.

Inductors - An inductor is created by winding a wire around a metal core, and when current flows through the wire it *induces* an electro-magnetic field, thereby turning the metal core into a magnet (an electro-magnet). This is the basic operating principle for relays, solenoids, and electric motors. The magnetized metal opens the valve, moves the relay contact, or rotates the shaft.

Capacitors - Capacitors store electric charge, and they are characterized according to their *capacity* to do so. They are not prevalent in load circuits except when used in electrical motors to help them start turning or to keep them running.

Inrush Current - Inductive and capacitive loads draw higher current when they are first turned on because the electrical energy they need to store or create causes the current to *rush in* when the voltage is first applied. Most lamps also have inrush current, but for a different reason. The resistance of the tungsten filament is very low when it is cold, so current flows quickly when power is first applied. Once the filament heats up it's resistance increases and the current drops down to its normal level. For this reason they are called non-linear resistive loads.

Here is a chart of various types of loads and their general characteristics in terms of these definitions. Inrush current is shown as a multiplier of the normal running current, an inrush rating of 8-10 for a 1 Amp load means that the load can draw 8-10 Amps when first turned on. These are generalizations for basic load types, it is the customers responsibility to gather the electrical data for their particular load.

LOAD	Res	Ind	Cap	Inrush	Description
Heater	Y	N	N	None	Current proportional to voltage, linear
Lamp (std)	Y	N	N	10-20	Non-linear resistive load
Lamp (LED)	Y	N	N	None	Similar to a heater, no inrush
Relay	Y	Y	N	4-6	Inductive and resistive
Solenoid	Y	Y	N	4-6	Inductive and resistive
Motor (no cap)	Y	Y	N	6-8	More inductive than resistive
Motor (w/cap)	Y	Y	Y	8-10	Same as above, higher inrush (cap)
Transformer	N	Y	N	30-40*	Virtually all inductive

* = Under special conditions, see next section for details

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Putting it all Together

There are two distinct advantages in using zero-voltage switching:

Reduced Inrush Current - Turning the load on at 0V reduces the inrush current below what you would experience with random-voltage switching. With any load which produces inrush currents, the first AC voltage cycle requires the highest current, so starting the current flow at 0V will naturally reduce it. This has two affects, it extends the operating life of the product by reducing the current pulses through the solid state output, and it reduces the amount of EMI and RFI produced when turning the load on.

Reduced EMI and RFI - EMI is *E*lectro-*M*agnetic *I*nterference. High inrush currents flowing through the wires cause an electromagnetic field, similar to the current flowing through an inductor. These EM fields radiate *out* from the wire, and can caused improper operation of sensitive electronic components. RFI is *R*adio *F*requency *I*nterference. RFI is produced when the voltage in a circuit changes very rapidly, such when a random-voltage switching output turns on at or near the peak AC voltage. This sharp voltage rise can cause high-frequency ringing which can also interfere with the operation of sensitive electronic equipment.

For these reasons, zero-voltage AC switching should be used for any load which has inrush current.

But as with most things *there are exceptions*, and here are two to consider:

High Current Resistive Loads - Even though linear resistive loads have no inrush current, the sharply rising voltages associated with random-voltage switching of high current resistive loads can cause interference with sensitive circuitry. *Zero-voltage switching should be used for high current resistive loads*.

Transformers and Power Supplies - Transformers can exhibit extremely high inrush currents (30-40 times normal) when turned at 0V, This is due to the saturation characteristics of the ferrous metal core material, and *random-voltage switching should be used for transformers and for power supplies with transformers at the AC input*. The *optimal* solution is to turn the timer output on at the peak AC voltage, but this is not currently available in our standard timer line. Artisan makes custom products with this feature, please contact us if you would like to utilize this technology in your transformer or power supply switching application.

It is the *customers* responsibility to analyze their application and perform the necessary tests on the selected timer to determine its suitability for use in their product.

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