Analysis and Simulation of Current Zero Crossing Time Interval Under Different Loads

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ABSTRACT
This paper discusses the use of zero-crossing in switching for three types of loads, namely resistive, inductive, and capacitive. The switching process using zero crossings and not using zero crossings was simulated with MATLAB software and then the simulation results were analyzed. The results of the simulation and analysis show that in resistive loads with zero-crossing the switching process to break the connection between the voltage source and the load there is no voltage at the terminals so as to prevent the occurrence of arcs in the switch device. Whereas inductive loads, the use of zero-crossing is able to prevent the arcs going from source to load, but unfortunately because the current and voltage are in different phases, so when switching at the zero voltage point the current is not at zero, so the reverse current will be able to cause the arcs in the switch device. In capacitive loads, the addition of zero-crossing will prevent the occurrence of arcs in the switch device. When the voltage is switched at zero, it means that the voltage on the capacitive load is also at zero. The reverse voltage of a capacitive load is determined by the final voltage of the source. The time interval for a voltage to zero is also shown in the simulation so that it can be used by electronics practitioners in building electronic devices that use switching for large currents.

Keywords: *Zero crossing, MATLAB, Different loads.*

1. INTRODUCTION

Nowadays, more and more inductive loads are connected to the electric power grid and switched regularly such as water heaters, coolers, air conditioners, and so on. Relays are used in these devices to obtain switching between different modes of operation. In general, relay switching is out of sync with the power grid. This causes the relay to switch at a certain phase on the grid voltage. Thus, voltage flickers can be routinely experienced in the power grid during interruptions of heavy loads caused by the surging of the relay contacts[1]. The worst case is switching the relay at 90 degrees to the mains voltage[2], which can cause the mains voltage to flicker and affect the operation of network-connected electrical and electronic devices and cause malfunctions, communication errors, system shutdown or restart, and so on [3]. Figure 1 shows an electric arc between the contacts and the relay which is switched off at the 90 degree phase of the mains voltage. At the same time, the mains voltage is at 160V as shown in Figure 2. Figure 3 shows a sudden 152V change in the mains voltage waveform when the relay is switched ON.

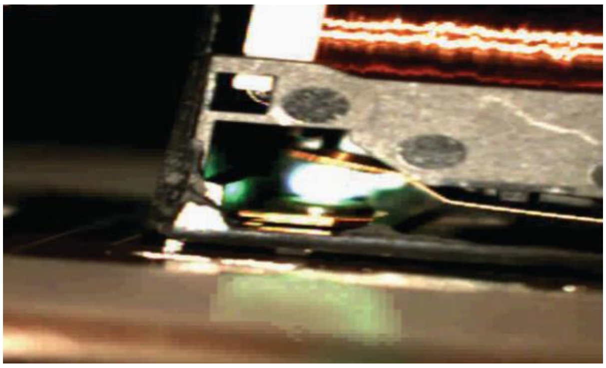

Figure 1. Electric arc between relay contacts

IEC61000 was published to determine the reliability of electrical and electronic devices to repetitive electrical fast transients. Generally, what is done is to modify the electrical and electronic devices under test when they fail to be on the EFT test. Except, there has been little effort at reducing or eliminating sources of EFT interference which is generally caused by switching inductive loads and switching relays[4].

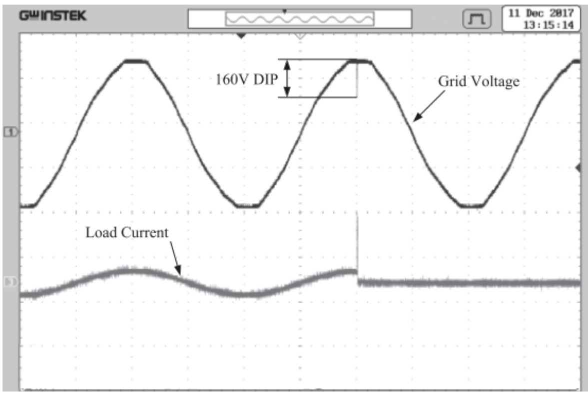

Figure 2. A sudden change in voltage when the relay switches OFF

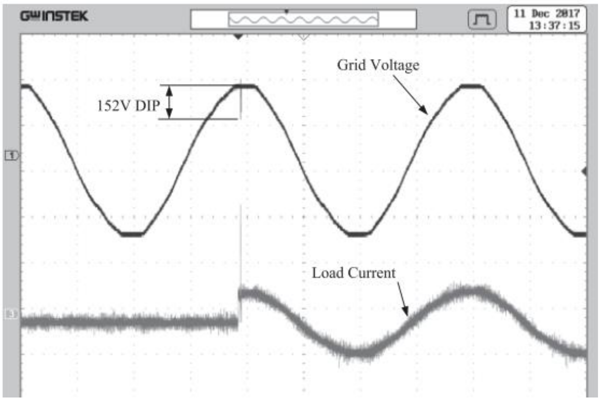

Figure 3. A sudden change in voltage when the relay switches ON

Currently, most control schemes of relay switching on the device do not consider the grid voltage phase. With such a control scheme, it is very easy to switch off the relay at high grid voltage, which results in a change in grid voltage caused by leakage inductance from the grid power line. An electric arc during relay switching will cause contact oxidation and a reduction in relay life. Also, the oxidation layer on the relay contacts will cause a high impedance to the relay contacts, which generates additional heat. The additional heat will increase the relay contact temperature and affect the elasticity of the contacts. Finally, the relay failed to switch on. This is why most relay manufacturers can only guarantee 100K switching times. This is far from the life of mechanical switching, with more than 1M switching times[5].

And this makes it possible to switch the relay on or off as long as the mains voltage passes zero. There is no effect on the grid voltage in this condition, and no arc occurs during relay switching[6]. However, this rarely happens because the delay time of the relay action is not taken into account in the control signal. The zero-crossing switching control scheme on the relay is applied to a three-phase high-voltage power grid system[7]. And it only considers the effect of the limit temperature on the control of the zero-crossing relay. It does not take into account the effect of the different mounting positions of the relay. Furthermore, the consistency of the delay relay time is not considered in mass production.

In this paper, the simulation of switching from AC voltage sources to electrical loads of resistive, inductive, and capacitive types is simulated using MATLAB software. This switching uses two strategies, namely by using a zero-crossing unit and without using it. This paper presents and discusses the waveforms of various types of loads and their effects on the switching process. The time interval from the switching process to a zero point is also presented so that this simulation and analysis can be used in various real implementations in electronic devices.

2. RELAY SWITCHING TECHNOLOGY

Relays are used to switch many electrical devices ON and OFF connecting and disconnecting devices from an AC power source, in response to a control signal. One category of electrical devices that are generally controlled by relays is electronic ballasts which switch ON and OFF in response to a sensor device such as motion detection. Figure 4 shows a block diagram of the relay switching technology proposed by [3]. Zero crossing detection circuit will cause the synchronous circuit to know the points of the mains voltage passing zero. Synchronous circuits generate synchronous signals from the grid voltage. The synchronous signal provides a time delay compensation circuit to trigger the switching relay. Then the switching relay can operate at a voltage passing zero to obtain slight voltage swings and eliminate fast transients in the network.

When switching an electrical device such as an electronic ballast or a lamp ON and OFF with a relay, the relay contact must be made at or near a certain point in the case of an AC voltage waveform i.e. at the zero-crossing point. If contact is made or broken at random points along the AC voltage waveform, contact may occur when the waveform is at a voltage level appreciable causing a high temperature electric discharge which is often called arcing[8]. Arcing causes contact erosion and reduces relay life. A consideration that must be taken in designing a circuit that switches the relay ON and OFF near the zero-crossing point is the turn-on and turn-off times of the relay, which are also referred to as the "make" and "break" times of the relay[9].

When the ON/OFF control signal is switched to OFF, the delay at the relay breaking contact is indicated by the TOFF time. Since the voltage of the waveform does not approach zero voltage, the relay contact is broken at this point can damage the relay. Many relays have the same on and off time (TON = TOFF). The purpose of the delay time compensation is to provide a delay time for the relay to switch from the released state to the operating mode and vice versa. It can provide relay switching at the exact time the network voltage passes zero.

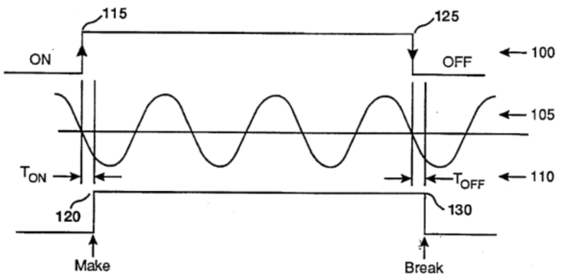

Figure 4. "Make" and "break" times

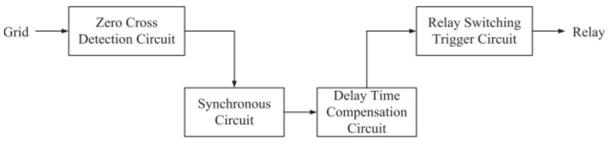

Figure 5. Block diagram of the new switching technology

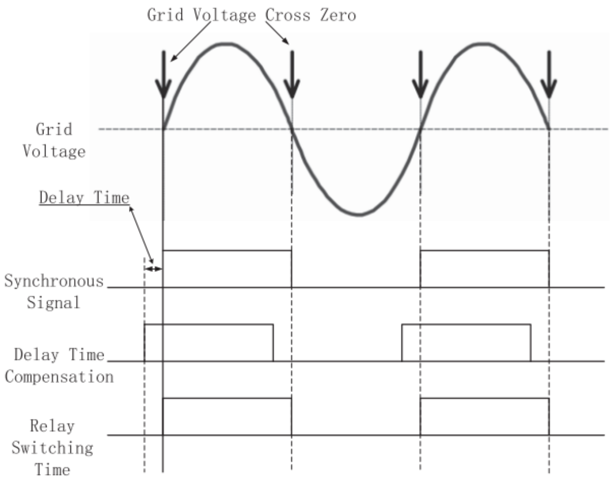

Figure 6. Operational of the new relay switching technology

3. ZERO CROSSING ON SWITCHING

The system proposed in paper [10] is illustrated in Figure 7. The power line is connected in parallel with switches and loads and a zero crossing detector. A voltage of 0 volts at the load is detected with the Zero Crossing Detector. Then the microcontroller starts the timer function to delay the quarter period of the power line. After the delay is complete, the microcontroller activates a switch that disconnects the voltage from the power line to the load. The shape of the signal is described in Figure 8.

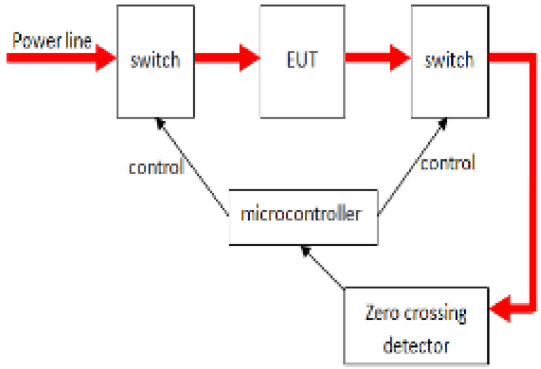

Figure 7. System block diagram

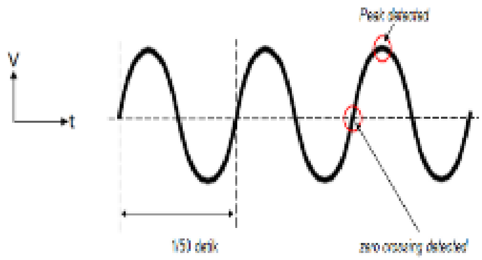

Figure 8. Power line signal

Two switches/relays are used, the first is located between the power lines and the load, and the second is located between the load and the Zero Crossing Detector. The first relay is used to disconnect the load/EUT (Equipment Unit Test) from the power line. The second relay is used to disconnect the ZCD from the EUT so that the ZCD does not become a load to the EUT after being disconnected from the supply. Both the first and second relays are triggered at the same time. The type of relay used is SRD. The ZCD circuit which is used to determine the time when the AC voltage passes 0 volts, can also be used to detect 0 volts. The output of this PWM circuit will change every time the voltage passes 0 volts. The SCD circuit is shown in Figure 7. A combination of resistors and diodes is used to protect the OP-AMP from overload. In this system, the microcontroller has three functions, namely: receiving input from the ZCD, making delays and controlling switches.

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3 conditions of EUT were used in the experiment for overall system performance, namely: capacitive loads, no load, and inductive pump loads. The capacitive load was chosen because it can store energy in the form of voltage. Until all three supplies are cut off, the load will still contain the final voltage level.

The response of the relay circuit is shown in Figure 9. X-Axis is time (5 ms/div) and y-axis is voltage 5V/div. The yellow line is an external trigger, while the blue line is a response from the relay. There is a time delay between trigger and response of 4 ms, indicated by the two white dotted lines. The reason is that the mechanical relay takes time to connect and disconnect. Based on the datasheet, the maximum time required is 10 ms, depending on the power of the trigger. In this system, the trigger is directly from the microcontroller pin, which is 5 Vdc. If the trigger doesn't change, neither does the delay time.

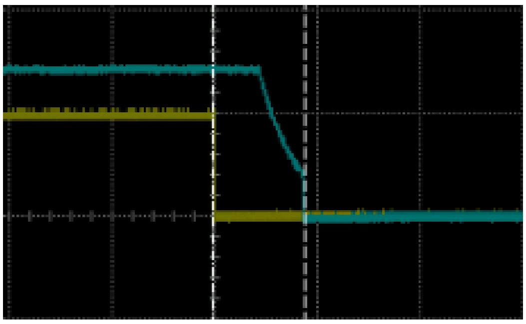

Figure 9. Response of the relay circuit

The response of the ZCD circuit is shown in Figure 10. The x-axis time (0.1 ms/div) and the y-axis voltage (10V/div). The blue line is the ZCD input, while the yellow line is the output. The input is a sine wave of the power line whose frequency is 50 Hz. Both the input and output signals pass the value 0 at the same time. The rise time of the output signal is less than 12 us, so it can be ignored.

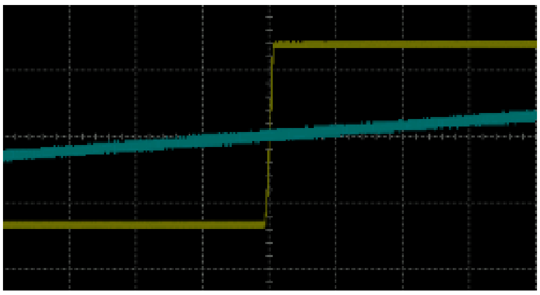

Figure 10. ZCD circuit response

4. SIMULATION AND ANALYSIS OF SWITCHING AT DIFFERENT TYPES OF LOADS

The results of the voltage and current waves on the three types of loads namely: resistive, inductive, and capacitive are described in this section. In the simulation in MATLAB, the switch component used to disconnect the voltage source is ideal, so there is no snubber circuit in this block. This block is purely a deal switch that disconnects and connects. Current sensors and voltage sensors are installed to determine the waveform in conditions before switching and after switching. Current sensor to determine the amount of current flowing to the load. Then the voltage sensor is useful for measuring the terminals on the load. The load used is purely resistive by using two resistors in parallel. The voltage source is 50V with a frequency of 50 Hz.

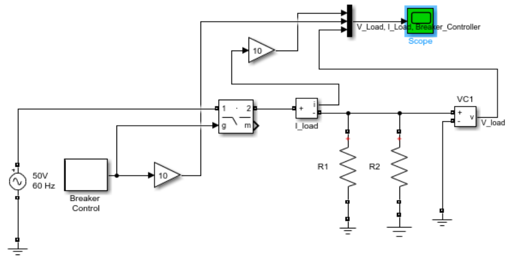

Figure 11. Simulation of a switched resistive load from a power source without containing a zerocrossing detector

The simulation of the process of switching the resistive load circuit without using zero crossings is shown in Figure 12. It can be seen that the switch is turned off at 0.04 s. At this time the voltage and current are not at zero. In this condition, the switch or breaker will become a load because the load resistor has been disconnected. The voltage will drop across this breaker, where the value of the breaker resistor is infinity if the breaker is completely open. When the breaker is not fully open, or the voltage is too high in this condition, arcs appear.

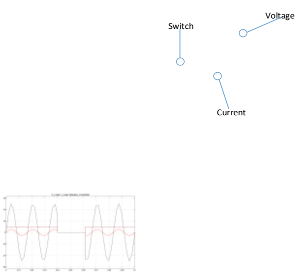

Figure 12. Waveforms of load voltage, load current, and switch control on a resistive load that is disconnected without zerocrossing

The addition of a zero crossing unit carried out in the resistive load switch process is shown in Figure 13. The zero crossing unit is used to detect the position when the AC voltage source is zero. When the command to turn off the switch is carried out, the switch does not turn off immediately but waits until there is a trigger from the zero crossing CCunit.

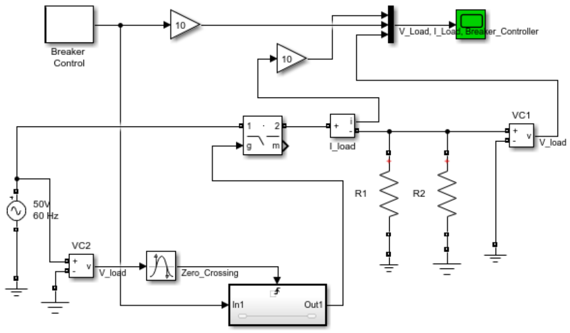

Figure 13. Simulation of a switched resistive load from a power source containing a zerocrossing detector

The waveform of the voltage, current, and switching time of the process of turning off the switch equipped with a zero crossing unit on a resistive load is shown in Figure 14. Here it can be seen that when the switch command turns off, the voltage from the source is not directly cut off but the voltage is followed up to the zero point. Likewise, when turning on the switch, the voltage is awaited to start from zero. So that in the switch process there is no sparks.

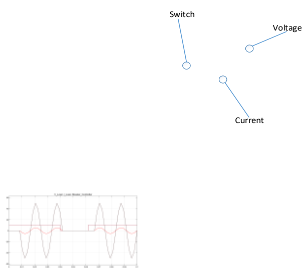

Figure 14. Waveforms of load voltage, load current, and switch control on a disconnected resistive load containing zerocrossing

The process of switching on an inductive load without using a zero crossing unit is shown in Figure 15. In an inductive load there must be a resistor in parallel with the inductive load. This is a mechanism where when the switch is turned off the energy stored in the inductor will be released so that a path must be provided. If this path is not provided, then according to the nature of the inductor, this stored energy will be released in the form of a voltage that continues to increase or rise so that it will penetrate the air to look for objects around it to release its energy.

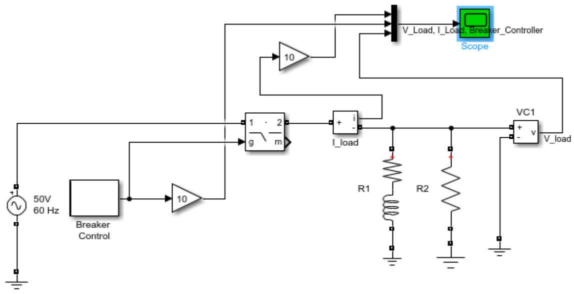

Figure 15. Simulation of an inductive load switched from a power source without containing a zerocrossing detector

The waveforms of voltage, current, and switch for switching an inductive load without using a zero crossing are shown in Figure 16. Current and voltage are not in phase. During the switching process to disconnect the voltage source to the load, the voltage that is in a high level condition is immediately turned off. The level of this voltage condition is not the same as the high current level, because it is not in the same phase. The source voltage is the same as the load voltage. Due to the inductive nature of the load the current flowing to the load is counteracted by the energy generated from the inductive load.

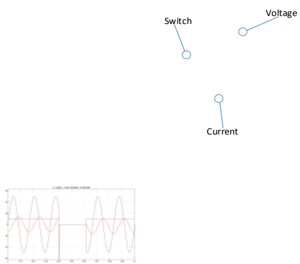

Figure 16. Waveforms of load voltage, load current, and switch control on an inductive load that is disconnected without zerocrossing

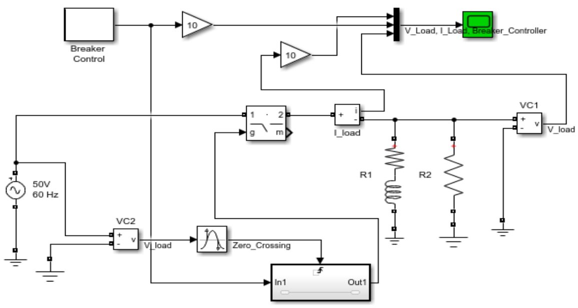

Figure 17. Simulation of an inductive load switched from a power source containing a zerocrossing detector

In the voltage, current, and switching waves in the inductive load using zero crossing, the load termination has been carried out at the zero point. But the current is not directly cut off at the zero point either. This is not a problem with the switching device, because this current is the load current. Generally, the installed load is parallel to the others so that through the load this current will flow until the energy in the induced load runs out. But if there is no other load path to flow, then one alternative to release energy from this inductive load is through a switching device. There is a reverse voltage from the load to the source through the switching device.

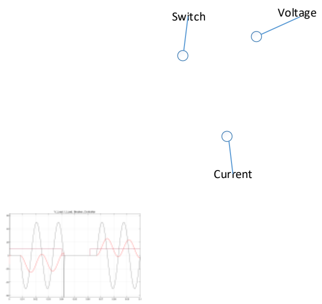

Figure 18. Waveforms of load voltage, load current, and switch control on an inductive load disconnected by zerocrossing

In capacitive load switching, the energy stored in the load is lost if the switching process is carried out at a zero voltage level. This greatly makes the switching device safe from the reverse voltage caused by the energy stored in the capacitive load. In addition, the addition of zero crossing is also very useful during the switching process to connect to the load. Without zero crossing, when the switch is on at a high voltage level, a high current will occur instantly. So there will be a spark jump in the switch. But with zero crossing, the current flowing to the load is not high or the capacitive nature of the load has no influence in determining the current rate.

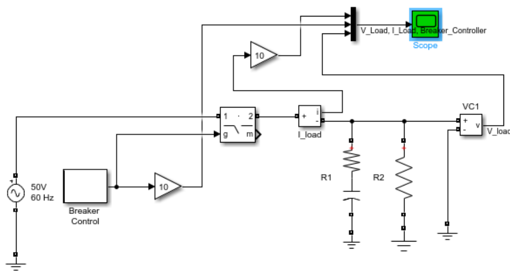

Figure 19. Simulation of a switched capacitive load from a power source without containing a zerocrossing detector

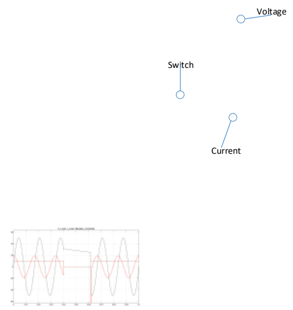

Figure 20. Waveforms of load voltage, load current, and switch control on a capacitive load that is disconnected without zerocrossing

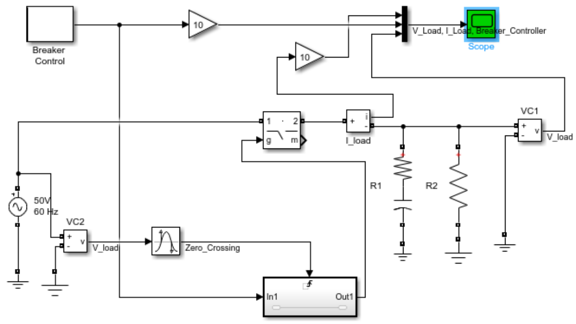

Figure 21. Waveforms of a switched capacitive load from a power source containing a zerocrossing detector

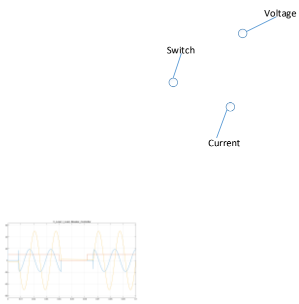

Figure 22. Waveforms of load voltage, load current, and switch control on a capacitive load disconnected by zerocrossing

5. CONCLUSION

From the simulation on the switching process of three types of loads, namely resistive, capacitive, and inductive, it is known that the use of zero crossing can prevent the occurrence of sparks in the switching device. It can be shown that when the AC voltage source at time t is at a high voltage level, then the energy released in a switch device should not exist. So that in the switching process, imperfect open contacts will force the voltage source to release the voltage drop on the device. If the voltage source has a high voltage value, the oxidation process and sparks will occur in the switching device. This simulation also shows the time span required for an AC voltage source to reach zero. So that this simulation can be used as a reference by practitioners in making various electronic devices or electrical controls that involve switching.

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