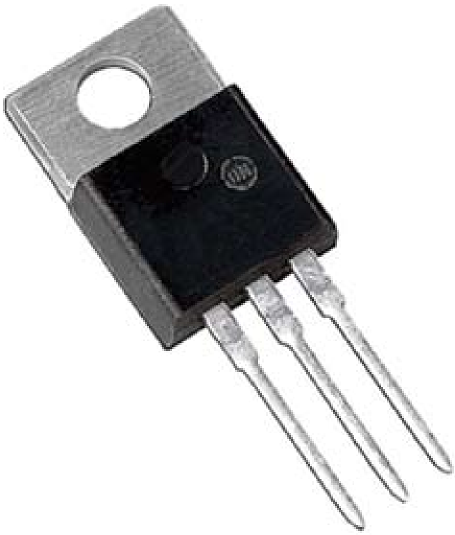
EXOTIC TRIACS: THE GATE TO POWER CONTROL

Learn about the use, operation and limitations of thyristors, particularly triacs, in power control



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Modern power control systems use electronic devices like thyristors for power switching, phase control, chopper, etc. These devices also find applications in inverter design, brilliance control in lamps, speed control of motors, etc. The electronic power control circuits are designed to control the distribution or levels of AC or DC power sources. Such power control circuits can be used to manually switch power to electrical devices or to switch power automatically when parameters such as temperature or light intensities go beyond preset levels.

Thyristors belong to a group of components known as silicon-controlled switches (SCS) or silicon-controlled rectifiers (SCR). As the name implies, their main function is to turn on/off a current. As in diodes, current flow in thyristors is only in one direction. The symbol of thyristor indicates that it is a diode-like device allowing current flow from the anode to cathode. A third terminal called 'gate' controls the flow of current in the device.

The thyristor family includes SCRs, diacs, triacs and more exotic members like quadracs, alternistors, opto-triacs and MOS thyristors. Majority of these devices can handle high current but only a small current (a few micro-amperes) is needed to switch on the device. Instant switching action makes thyristors a suitable alternative to mechanical relays in power control circuits. SCRs and triacs are the main solidstate devices used in medium- and high-voltage applications.

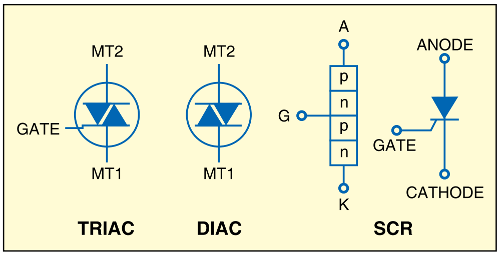

Fig. 1: Symbols of triac, diac and SCR

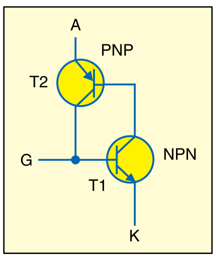

Fig. 2: Internal features of SCR

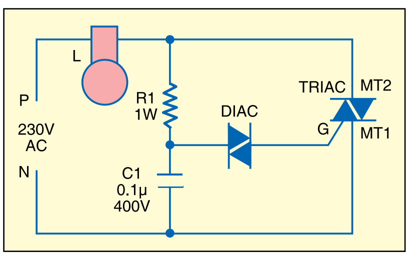

Fig. 3: Switching on of a lamp through diac and triac

Silicon-controlled rectifiers

SCRs can be seen as conventional rectifiers controlled by a logic gate signal. These four-layered, three-terminal silicon rectifiers can be controlled through their gate terminal.

Normally, an SCR acts as an 'open switch' and in the 'off' state, the device restricts current flow. When the gate-to-cathode voltage exceeds a certain threshold, the device turns on and conducts current in the anode-cathode direction. The SCR then 'self-latches' into 'on' state and stays 'on' until the anode-to-cathode current falls below the minimum holding value. At this point, the SCR turns off and again becomes an open switch.

In 'on' state, the SCR exhibits low impedance, which is maintained as long as the current in the terminals is above the holding current limit. In 'off' state, the SCR has high impedance, which is maintained as long as the applied voltage is below the 'break-over voltage.'

SCR in action

When in action, SCR is like two overlapping transistors—the n-p junction of a pnp transistor overlapping the n-p junction of an npn transistor.

When a trigger current is applied to the gate terminal (see Fig. 2), T1 conducts and its collector current provides bias to T2 and it also conducts. At the same time, the collector current of T2

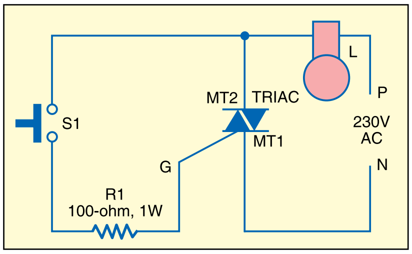

Fig. 4: Simple lamp control circuit

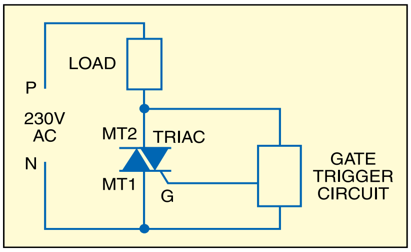

Fig. 5: Phase triggering

provides more base current to T1. This positive feedback effect ensures that both transistors are conducting. Once this condition is attained, T1 and T2 remain latched and no more gate current is required.

If the voltage between the anode and cathode rapidly increases, capacitive coupling may induce enough charge into the gate to trigger the device. This is referred to as 'dv/dt triggering.' This may not switch the SCR into full conduction rapidly and the partially triggered SCR will dissipate more power possibly harming the device.

Diac—the follower of triac

Diacs are bidirectional trigger diodes designed to trigger triacs or SCRs. These, like four-layered diodes, remain non-conducting until their break-over voltage is reached. At this point, they turn on fully and remain 'on' until the applied voltage or circuit current is reduced below the holding values.

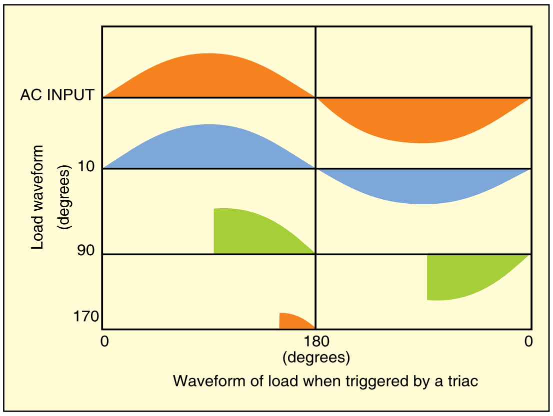

Fig. 6: Waveforms of AC and load

Basically, a diac, when connected across a voltage source with a current-limiting resistor, acts like a high impedance until the applied voltage rises to above 35 volts. Thereafter it acts as a 30V zener diode and conducts. The remaining 5 volts develop across the current-limiting resistor.

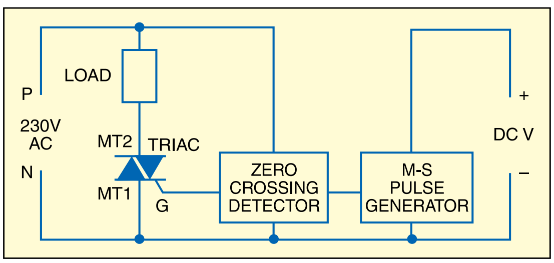

Fig. 7: Burst triggering of triac

In the avalanche state, the diac exhibits negative resistance characteristics and the voltage across it snaps back typically about 5 volts, which is sufficient to trigger the triac or SCR. If the forward current falls below the minimum holding value of 30 volts (typical), the diac will turn off. The main drawback of the device is that it cannot be triggered at just any point in the AC power cycle. It triggers at its present break-over voltage only.

Diacs are used in AC power control circuits to provide trigger pulse to triacs for their proper operation. As shown in Fig. 3, a diac-triac combination can be used to switch on a lamp.

During each half cycle of the waveform, capacitor C1 charges depending on the value of R1. When the voltage in the capacitor rises to the breakdown voltage of the diac, it conducts sending a positive pulse to the gate of triac. The triac and lamp then turn on and remain 'on' until the waveform crosses through zero voltage again.

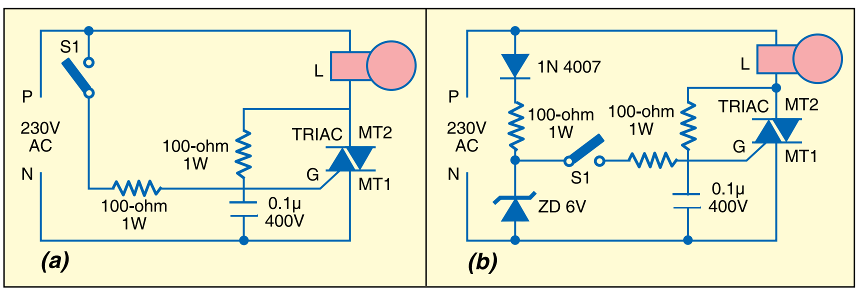

Fig. 8: (a) AC line triggering and (b) line-derived DC triggering

Triac—the back-to-back SCR

Triac, or TRIode for alternating current, is an electronic device equivalent to two silicon-controlled rectifiers joined in inverse parallel (but with polarity reversed) with their gates connected together. The resulting bidirectional electronic switch can conduct current in either direction when triggered.

Like SCRs, triacs are also three-terminal devices. Their MT1 and MT2 terminals (main terminals 1 and 2) pass current in either direction, while the third terminal G (gate) sends trigger pulse to the device.

Triacs can be triggered by either a positive voltage or negative voltage applied to their gate electrode. When the voltage on the MT2 terminal is positive with respect to MT2 and a positive voltage is applied to the gate, the left SCR in the triac conducts. If the voltage is reversed and a negative voltage is applied to the gate, the SCR on the right conducts. Minimum holding current 'Ih' must be maintained to keep the triac conducting. AC or DC pulses can trigger the triac. Four modes of triggering are possible:

1. Positive voltage to MT2 and positive pulse to gate
2. Positive voltage to MT2 and negative pulse to gate
3. Negative voltage to MT2 and positive voltage to gate
4. Negative voltage to MT2 and negative voltage to gate

Working of the triac is simple. (See Fig. 4.) Normally, the triac remains an open switch with the lamp turned off. When switch S1 is 'on,' R1 provides gate current to the triac, so the triac self-latches shortly after the start of each half cycle and the lamp is provided with full power.

Gate triggered

The gate terminal of the triac is used to trigger the device into conduction. The higher the current into the gate, the smaller the forward break-over voltage. Thus applying a sufficient pulse of current to the gate will switch the device into 'on' state. Once triggered, the device continues to conduct until the current through it drops below a certain threshold value.

Two modes of gate triggering are employed in power control circuits: phase triggering and burst triggering.

Phase triggering. In phase triggering (Fig. 5), AC power is applied to the load via a triac. The triac is triggered at any point during each half cycle through a variable-phase-delay network and a trigger pulse generator. Fig. 5 shows the mode of phase triggering.

The triac unlatches at the end of each AC half cycle as the instantaneous supply voltage (and thus the load current) briefly falls to zero. If the triac is triggered after the start of each half cycle with zero phase, the load voltage equals the full supply voltage. If the triac is triggered with 90° phase delay, the load voltage equals half the supply voltage, so the load consumes one-fourth of the

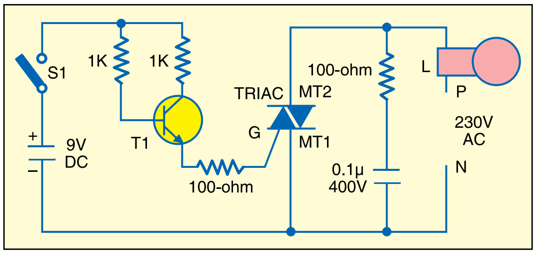

Fig. 9: DC triggering

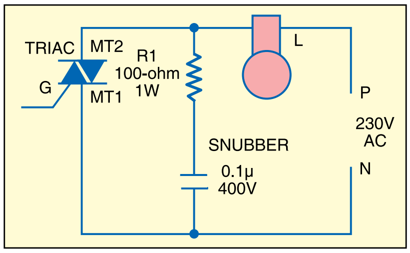

Fig. 10: R-C snubber

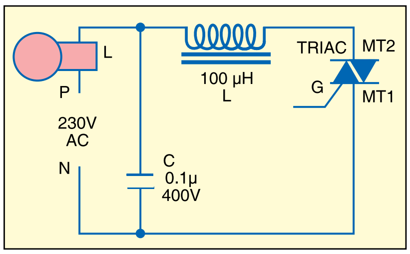

Fig. 11: L-C RFI suppressor

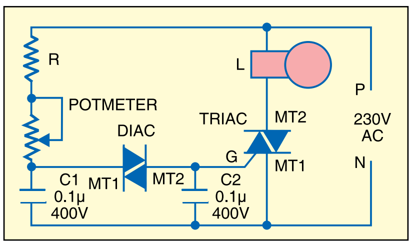

Fig. 12: Lamp dimmer with a capacitor (C2) to eliminate backlash effect

power. If the triac is fired with 180° delay, the load voltage will be zero and the load consumes only negligible power. The waveforms of AC and loads are shown in Fig. 6.

Phase triggering is highly efficient to vary the load power over a wide range as in lamp-brilliance control circuits. Since switching occurs at the AC frequency, lamp brightness can be varied without flicker. But one major drawback of phase triggering is that when power increases from zero to a high peak value especially with 90° delay, high-current surge generates radio frequency interference (RFI). So phase triggering is not suitable for high-current loads.

Burst triggering. More efficient power control is achieved through burst triggering in which power bursts of complete half cycles are fed to the load at regular line-frequency-related intervals. Thus if the burst is repeated at 8-cycle intervals, the load voltage is proportional to the full supply voltage if the burst is of 8-cycle duration, half voltage (equivalent to quarter power) at 4-cycle duration or 1/16th of the voltage (equivalent to 1/256th power) at one half-cycle duration. The burst firing method is shown in Fig. 7.

The advantage of burst firing is minimum RFI since the switching of power to the load is very near the start of line half cycles, when the line voltage and load current are nearly zero. The zero-crossing detector circuit gated by a mark/space ratio pulse generator enables the gate of the triac at the start of the line half cycle.

The zero-crossing detector-mark/space pulse generator circuit outputs only if it is 'gated' on and the line voltage is below 7 volts. The triac is then triggered and switches power to the load. The mark/space generator requires 12V DC, which can be obtained from a DC power supply or rectified power from AC line. The burst fire method is efficient but enables power consumption of the load only in a number of half-cycle steps.

AC/DC triggering

Synchronous/non-synchronous triggering is possible in triacs by applying AC power line voltage to the gate of the triac. In synchronous switching, the triac turns on at the same point in each AC half cycle just after the zero crossing point. In non-synchronous switching, the switching is not always synchronised to the fixed points of AC cycle and RFI will be very high particularly at the point of initial power-'on.' The low RFI in synchronous switching makes it advantageous especially for higher-power load circuits. Fig. 8 shows two methods of triac switching using AC line voltage.

Transformer-derived DC or battery power is used in DC triggering through a transistor switch or by electronic devices like ICs. If a transistor is used, external sensor circuits can be interfaced and the load switch-'on' can be controlled by external parameters like light and heat. The simplest way of DC triggering is shown in Fig. 9.

Triacs need some care

Triacs have some inherent drawbacks that reflect in their working. Careful designing of triac-based circuits results in a better working performance. The main drawbacks of triacs are rate effect, RF interference and backlash effect.

Rate effect—a snubber will cure it. Between the MT1 terminal and gate of a triac, an internal capacitance exists. If the MT1 terminal is supplied with a sharply increasing voltage, it causes enough gate voltage breakthrough to trigger the triac. This condition is referred to as 'rate effect'—an unwanted effect caused mainly by the high transients in the AC line. Rate effect also occurs when the load is switched on due to high inrush voltage. It is severe particularly in driving inductive loads such as motors because the load current and voltage are out of phase.

An R-C snubber network minimises the rate effect and makes the switching clean. It is connected between MT1 and MT2 terminals of the triac as shown in Fig. 10.

Radio frequency interference (RFI)—a filter will suppress. Unwanted RF generation is another major problem encountered in triac switching. Each time the triac is gated on its load, the load current switches rapidly from zero to a high value depending on the load resistance and supply voltage. This fast switching action (taking only a few microseconds) generates a pulse of RFI. It is the least when the triac is triggered close to 0° and 180° zero-crossing points but maximum in a 90° waveform. This is because switch-'on' current is minimum at 0° and 180° zero-crossing points. Switch-'on' current is maximum at 90° producing very high RFI.

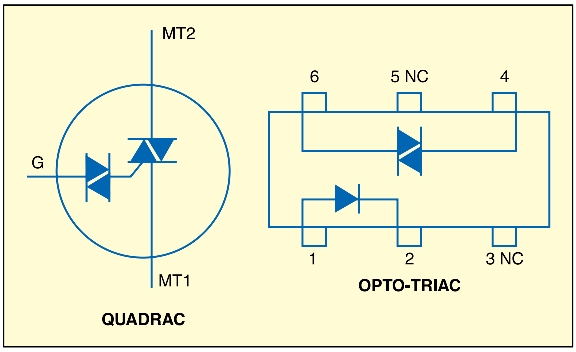

Fig. 13: Internal view of quadrac and opto-triac

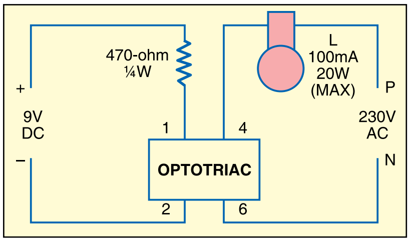

Fig. 14: Driving a load (20W-100mA) directly using an opto-triac

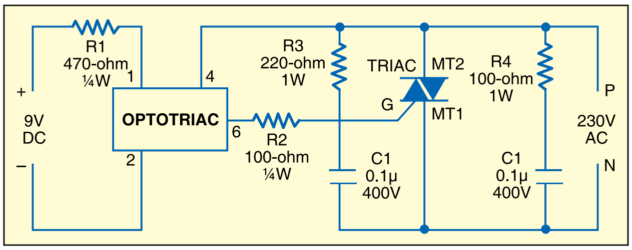

Fig. 15: Driving AC load using opto-triac and a slave triac

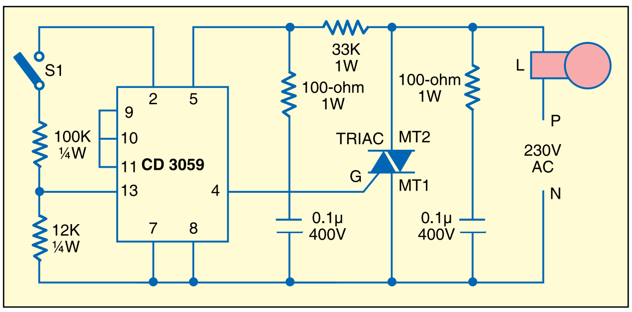

Fig. 16: Driving load using triac and triac-drive IC

The strength of RFI is proportional to the length of the wire that connects the load to the triac. RFI is annoying particularly in lamp dimmer circuits and can be eliminated using a simple L-C RFI suppression network (see Fig. 11).

Backlash effect—makes a lamp lazy. A serious control hysteresis or backlash develops in triac-controlled lamp-dimmer circuits when the gate current is controlled by a variable potentiometer. When the resistance of the potmeter increases to maximum, brightness of the lamp reduces to the minimum. Thereafter, the lamp never turns on until the resistance of the potmeter is reduced to a few ohms, say, 50 to 70 ohms. This occurs due to discharging of the capacitor connected to the diac.

When the triac fires, the capacitor discharges via the diac and generates the backlash effect. This problem can be easily rectified by connecting a 47- to 100-ohm resistor in series with the diac or adding a capacitor (C2) to the gate of the triac. This capacitor (C2) will slow down the backlash effect and the full turn effect can be obtained. The connection of the capacitor is shown in Fig. 12.

Versions available

More and more versions of triacs are available nowadays to make the power control circuits run perfectly.

SCRs and Their Details

Type of SCR	Voltage and current rating	Pin assignment (front view)
2P4M	500V-2A	KAG
2P5M	600V-2A	KAG
2P6M	700V-2A	KAG
5P4M	500V-5A	KAG
5P5M	600V-5A	KAG
5P6M	700V-5A	KAG
3P2M	300V-0.47A	GAK
3P4M	500V-0.47A	GAK
TYN 412	600V-12A	KAG
TYN 416	600V-16A	KAG
TYN 604	600V-16A	KAG
BT 169	400V-0.5A	KAG
BT 151	650V-12A	KAG
C 106	600V-4A	KAG
MCR 100	600V-0.8A	KAG
CYN B 25	1000V-25A	KAG
CYN B 40	1000V-40A	KAG
BT 136	600V-4A	MT1 MT2 G
BT 138	600V-12A	MT1 MT2 G
BT 139	600V-16A	MT1 MT2 G
BTA 23	800V-12A	MT1 MT2 G
BTA 22	800V-10A	MT1 MT2 G
BTA 40	800V-40A	A1 A2 G
BTA 41	800V-40A	A1 A2 G
BTB 41	800V-40A	A1 A2 G

Examples are Alternistors, quadracs and opto-triacs.

Alternistors. Alternistor is the trade name of a new-generation triac with improved 'turn off' (commutation). These devices are made especially for controlling highly inductive loads such as motors. Alternistors have a built-in snubber network to reduce the rate effect. These trigger in the fourth quadrant with negative voltage and positive gate current.

Quadracs. These are specially made triacs having an inbuilt diac-triac combination. This eliminates the use of an external diac, making the circuit simple.

Opto-triacs—illuminating triacs. Opto-triacs are photosensitive triacs with an inbuilt LED and semiconductor triac portion in a single package. These are available in various voltage and current ratings (MOC series). Opto-triacs can be interfaced with triac-controlled circuits so as to get total AC isolation from the remaining circuitry. The output current of the device is limited to around 100 mA and it can handle brief surge current of 400 mA to 1A.

Opto-triacs can be directly used to drive an AC load with 100mA current and 20-watt power rating (maximum). In order to drive high-power devices, a slave triac should be used.

Opto-triac cannot drive heavy-current loads directly. So a slave triac must be used in conjunction with the opto-triac to drive heavy loads as shown in Fig. 15. In the circuit, R3-C1 network provides phase shift to the triac's gate and R4-C2 act as the snubber network, and hence the circuit can be used to drive inductive and non-inductive loads.

ICs for triacs

Special triac-driving ICs are available to 'gate' triacs through zero-crossing method. These ICs have an inbuilt AC rectifier circuit, zero-crossing detector, gating circuit and high-gain differential amplifier in a single package. CD3059 and TDA1024 belong to this category.

When pin 13 of the IC is biased through S1, the triac is triggered through the zero-crossing method provided pin 13 is biased above pin 9. The internal differential amplifier of the IC enables the gate of the triac through output pin 4.

Solidstate switches make it easy

AC switching using solidstate switches like SCRs and triacs makes the circuit design simple and also reduces the cost. Moreover, it avoids relay chattering and arcing. It is necessary to identify the device before designing the circuit. The table given here will allow you to select the SCR or triac easily. ●

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