



## TRIAC analog control circuits for inductive loads

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### **Introduction**

The TRIACs of today are well suited to the requirements of switching inductive loads.

TRIAC control circuits must be particularly well tuned to be both economical and applicable to inductive loads.

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The purpose of this document is to present different methods of TRIAC control with their applications and to analyze their relative advantages and disadvantages.

A simple circuit offering all the guarantees of reliability is proposed for inductive loads.

# 1 Triggering methods

## 1.1 Triggering with synchronization on the TRIAC voltage

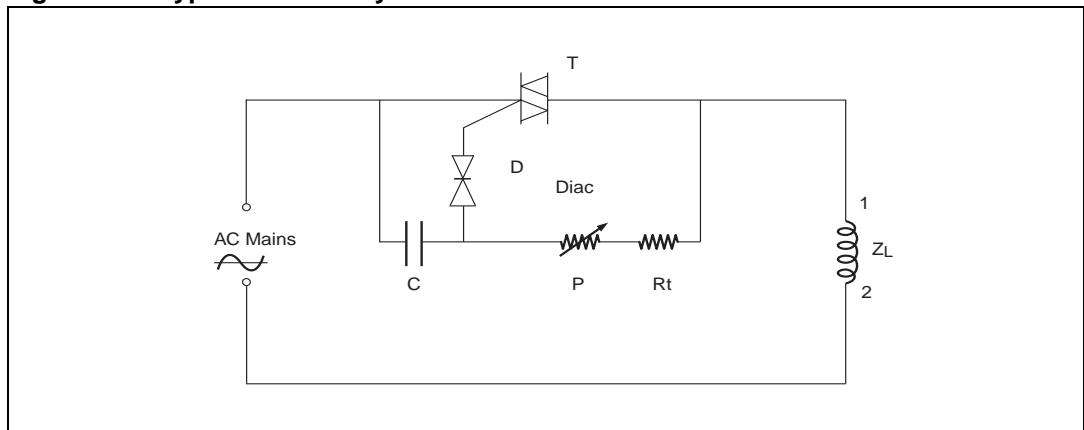
The triggering circuit with synchronization across the TRIAC (See [Figure 1](#) and [Figure 2](#)) turns on the component at an angle  $\beta$  after the current drops to zero, such that

$$\beta = \omega \cdot T_r.$$

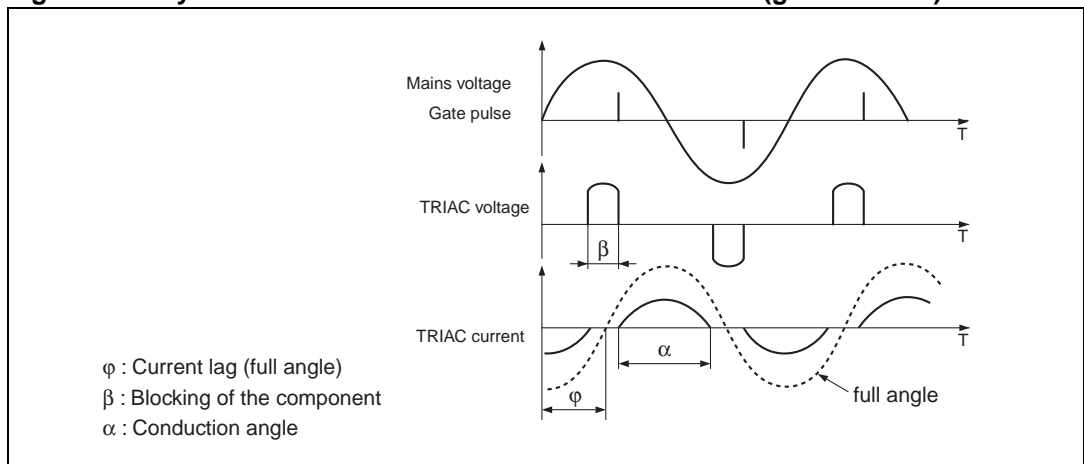
Time  $T_r$  is defined by the time constant  $(P + R_t)C$ .

$$\omega = 2 \cdot \pi \cdot f \text{ with } f = \text{mains frequency.}$$

**Figure 1. Typical circuit - synchronization across the TRIAC**



**Figure 2. Synchronization across the TRIAC - waveforms (general case)**



This is the simplest possible circuit but in certain cases it can have an important drawback.

For example, consider a highly inductive load ( $L \omega / R > 4$ ) where the TRIAC is turned on with a considerable delay  $\beta$ , perhaps  $100^\circ$  after the mains voltage zero as in [Figure 3](#).

If the TRIAC is turned on at point A, the conduction ( $\alpha$ ) lasts up to about  $150^\circ$ . The TRIAC turns off at point B at  $\alpha + \beta = 250^\circ$  after the zero voltage point. At that instant a negative voltage is applied to the triggering circuit which turns on the TRIAC at point C after an angle  $\beta$  of  $100^\circ$ , that is,  $350^\circ$  from the starting point.

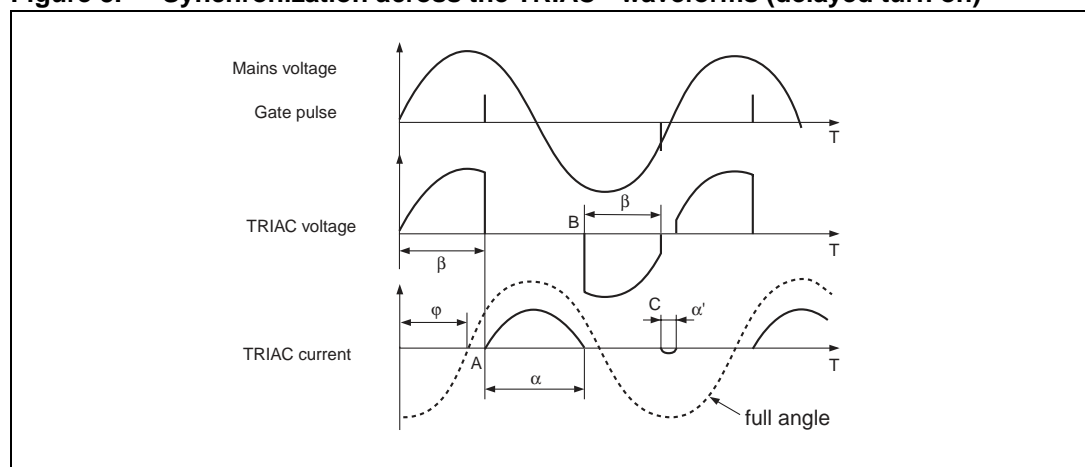
The second turn-on occurs at a very low voltage and the angle  $\alpha'$  is much smaller than  $\alpha$ . The following period begins under similar conditions and the unbalance persists. This type of asymmetrical operation is not only unacceptable but can be dangerous (high current due to load magnetic saturation due to the dc content of the waveform).

The unbalance is illustrated for a particular case, starting from zero of the mains voltage. Other causes also produce this behavior

- variation of the load impedance, for example, with motors, due to torque variation
- modification of the control turn-on angle

This phenomenon is due to the fact that the circuit does not take its time reference from the mains zero voltage. Rather, the synchronization is taken from the voltage across the TRIAC, which is dependent on the load current, that is, on the load phase shift.

**Figure 3. Synchronization across the TRIAC - waveforms (delayed turn on)**



To sum up, this first very simple triggering circuit, synchronized by the voltage across the TRIAC, has the following characteristics:

- Advantages:
  - Simple design and low cost
  - Connection by two wires, without polarity issue
  - Absence of a separate power supply
  - Little power dissipated in P and R<sub>t</sub>
- A serious disadvantage:
  - Because of its principle, this circuit cannot be used for highly inductive loads with a narrow conduction angle because it can result in unacceptable asymmetrical operation.

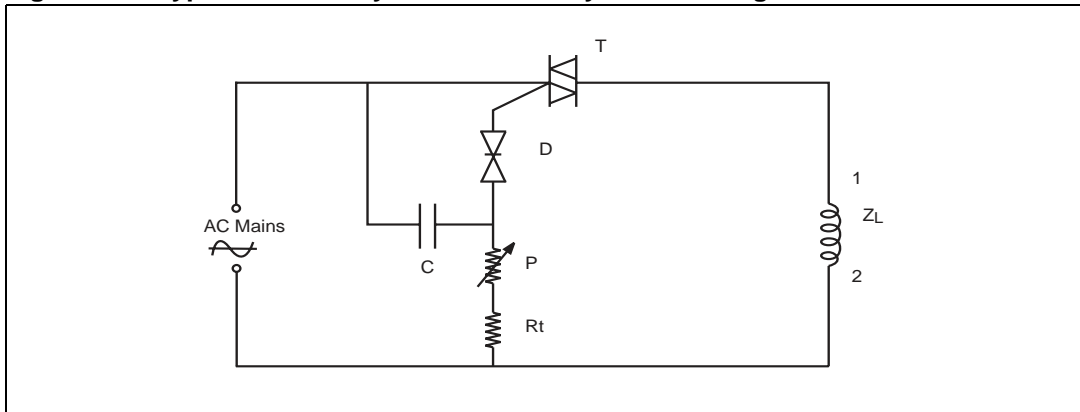
This very simple triggering circuit should be reserved for low-cost applications with the following characteristics:

- Resistive or slightly inductive loads
- No stringent requirements concerning the accuracy of regulation
- Highly inductive loads where the power varies between 85 and 100% of the maximum power

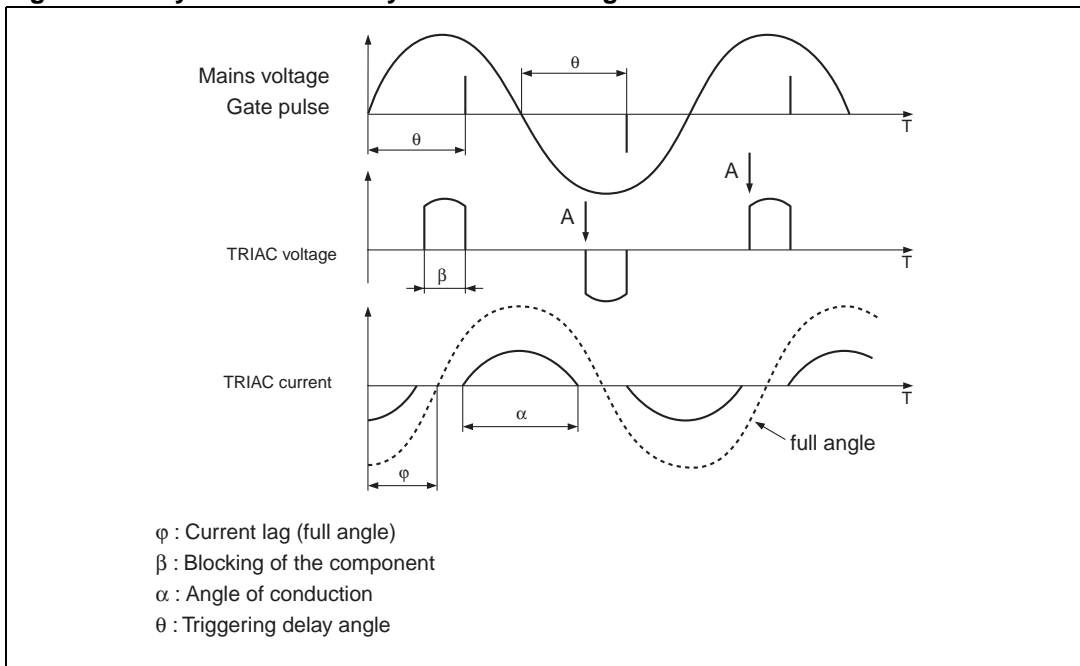
## 1.2 Triggering with synchronization by the mains voltage

This triggering circuit of [Figure 4](#) is synchronized by the mains voltage. The pulses are always shifted by 180° with respect to each other, whatever the type of load.

**Figure 4. Typical circuit - synchronization by mains voltage**



**Figure 5. Synchronization by the mains voltage - waveforms**



Angle  $\theta$  is the delay between the mains zero voltage and the triggering pulse. It can be adjusted by means of potentiometer, P, from 0 to 180° to vary the load voltage. The current in an inductive load (L.R) lags the voltage by an angle  $\phi$ : ( $\tan \phi = \omega \cdot L / R$ ).

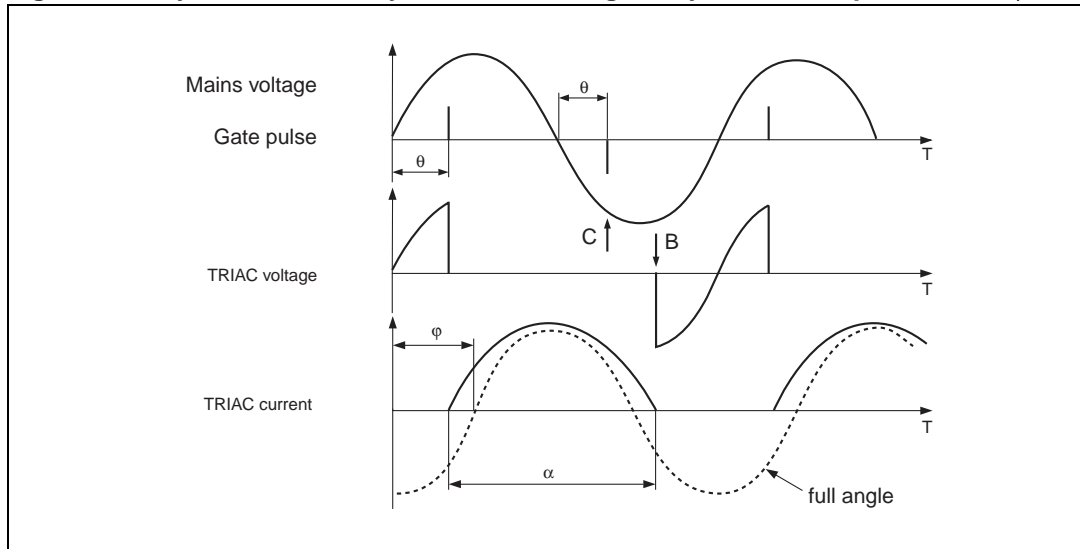
For triggering angles,  $\theta$ , higher than  $\phi$ , operation is perfectly symmetrical and stable.

This simple circuit can still present the risk of a fault in the case where  $\theta$  is smaller than  $\phi$ , as shown in [Figure 6](#).

As an example, take the case of a highly inductive load and an angle  $\theta = 60^\circ$ . The TRIAC is turned on at point A ( $60^\circ$ ). It conducts over more than 180°, up around  $230^\circ$ . It is blocked at point B: ( $290^\circ$ ).

The second triggering pulse occurs at point C when  $\theta + \alpha = 240^\circ$ . It has no action on the TRIAC which is still conducting. The TRIAC is not turned on for the next half-wave. As in the previous case, the operation is totally asymmetrical, and thus unacceptable.

**Figure 6. Synchronization by the mains voltage - asymmetrical operation  $\theta < \varphi$**



To prevent this fault, it is necessary to limit the turn-on angle to maintain  $\theta > \varphi$ . This is possible for loads whose L and R parameters remain strictly constant.

Experience shows that for the majority of inductive loads used in industrial applications (like motor controls and transformers) the values of L and R are not constant and vary a great deal during operation. For these types of applications it is not possible to limit the turn-on angle without considerably reducing the voltage excursion.

To sum up, this simple triggering circuit, synchronized by the mains voltage, is more developed than the previous one. It has the following characteristics:

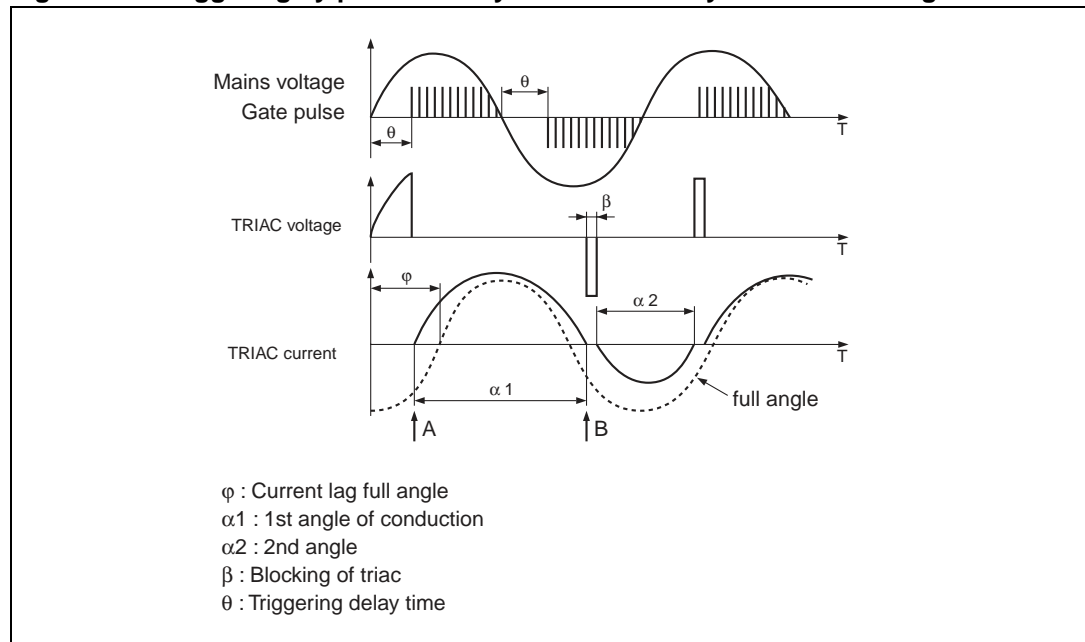
- Advantages:
  - Simple design
  - More accurate control than the previous circuit
  - No auxiliary power supply or transformer required
- Disadvantages:
  - Connection of the circuit by 3 marked wires, instead of 2 without polarity in the previous circuits
  - Higher power dissipated in passive components P and  $R_t$  (since the mains voltage is continuously applied across them)
  - Operation becomes completely asymmetrical if the control angle  $\theta$  is less than  $\varphi$ .

This triggering circuit can be used only for applications in which the phase shift of the load remains constant (air inductor) or if operation is restricted to values of  $\theta$  much higher than  $\varphi$ , that is, for low load voltage operations.

### 1.3 Triggering synchronized by the mains voltage and suitable for industrial applications

This new circuit is derived from the previous one by improving the triggering pulse generator. The improvement consists of maintaining the triggering signal during each half wave between values  $\theta$  and  $180^\circ$ . This is done simply by sending a pulse train after the initial pulse so as to maintain the triggering order, as shown in [Figure 7](#).

**Figure 7. Triggering by pulse train synchronization by the mains voltage**

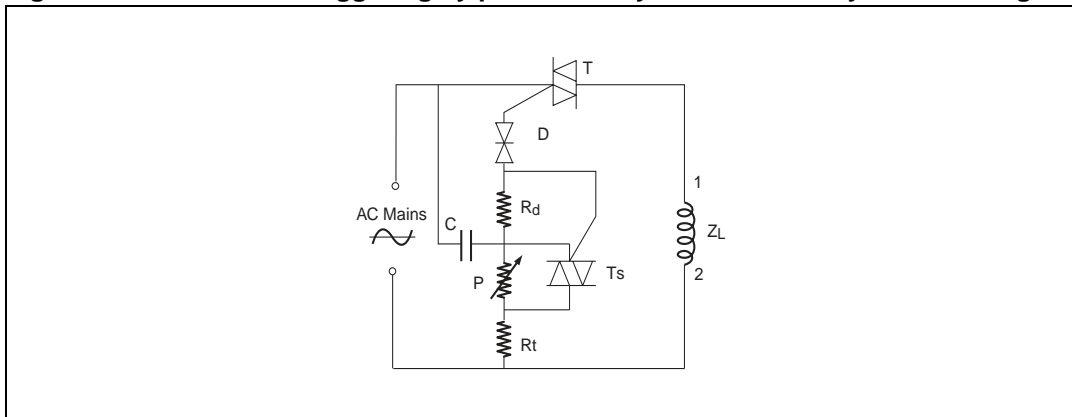


For example, suppose that angle  $\phi$  is equal to  $85^\circ$  and  $\theta$  is equal to  $60^\circ$ . At the first pulse, the TRIAC is turned on at point A ( $60^\circ$ ). It conducts for angle  $\alpha 1$  greater than  $180^\circ$  and close to  $240^\circ$ . It is blocked at point B, but is immediately triggered at point B' by the next gate pulse. During the first half-waves, operation is slightly asymmetrical but gradually the durations of conduction become balanced (refer to the dotted line curve in [Figure 7](#)).

[Figure 8](#) gives the circuit diagram. A small sensitive auxiliary TRIAC,  $T_s$ , is used to produce the required pulse train. The delay time constant, defined by capacitor C, compensating resistor  $R_t$  and potentiometer P, sets the angle  $\theta$ . The capacitor charges from 0 V. DIAC D triggers TRIAC T as soon as the capacitor voltage reaches the DIAC breakover voltage ( $V_{bo}$ ). This time is the same for both half-waves, it just depends on  $V_{bo}$  symmetry.

A first pulse is applied to the gate of the main TRIAC, T. A voltage pulse occurs across  $R_d$  and triggers sensitive TRIAC  $T_s$ . Once turned on, this  $T_s$  bypasses potentiometer P. Thus the remaining charging cycles of the capacitor have a much shorter time constant  $R_t \cdot C$ .

**Figure 8. Circuit with triggering by pulse train synchronization by mains voltage**



This results in a train of pulses being applied to the gate of TRIAC, T. In this way T is retriggered into conduction instead of remaining blocked as in the previous circuit.

The pulse train continues until the mains voltage crosses the zero point, at which time TRIAC Ts, supplied through a resistive load, turns off.

For the following half-cycle, the time constant is once more determined by the capacitor and the potentiometer. This half cycle is then symmetrical to the previous one..

To sum up, the improved triggering circuit synchronized by the mains voltage has a number of advantages.

- Low cost
- Excellent control accuracy
- No need for auxilliary power supply
- Operation with all types of loads (different  $\cos \varphi$  or variable  $\cos \varphi$  values)
- No risk of failure over the whole adjustment range

This circuit has been developed by the STMicroelectronics applications laboratory and used with success for a wide range of equipment.

## 1.4 Conclusion

The tricky control of an inductive load requires a critical choice of triggering circuit. The first two circuits described here give the user a very limited adjustment range. A universal circuit can be obtained by taking into account two main factors:

- To reach perfect symmetry of the first gate pulses in positive and negative half-cycles, the triggering circuit should be synchronized by the mains voltage.
- The phase angle variation allows perfect symmetry of the current if the TRIAC is continuously triggered.

The circuit described in the [Section 1.3: Triggering synchronized by the mains voltage and suitable for industrial applications on page 6](#) combines these two principles in a very simple way. It allows complete variation of power with an inductive load without particular problems. It can thus serves as the basis for a universal circuit for control an inductive load by phase splitting.

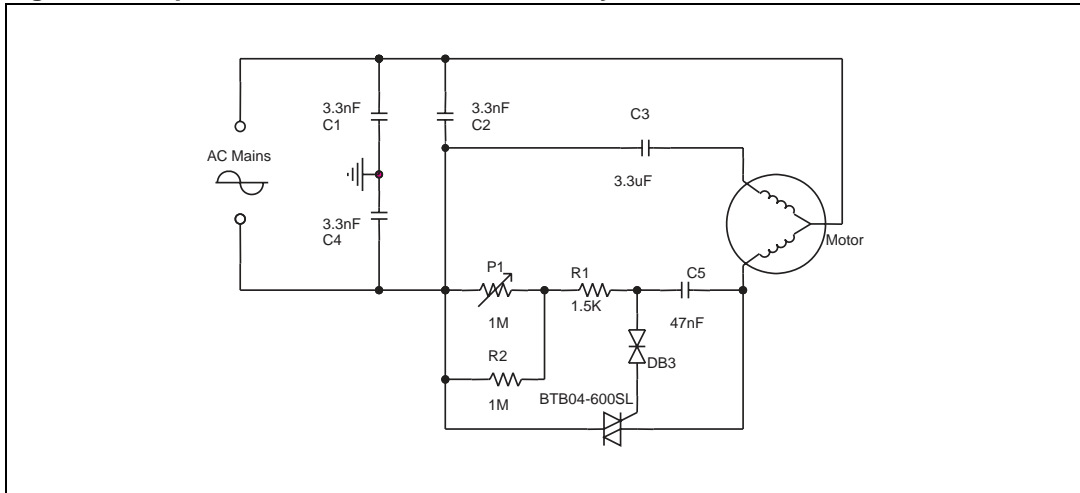
## 2 Application examples

### 2.1 Synchronization across the TRIAC

The schematic in [Figure 9](#) is used to set the speed of a low-power induction motor, such as those which can be found in fan applications.

Capacitors C1, C2 and C4 are used to filter the noise coming from TRIAC commutations. C1 and C4 capacitors have to be from Y2 technology, whereas C2 has to be from X2 technology.

**Figure 9. Speed-control circuit for a small asynchronous motor**





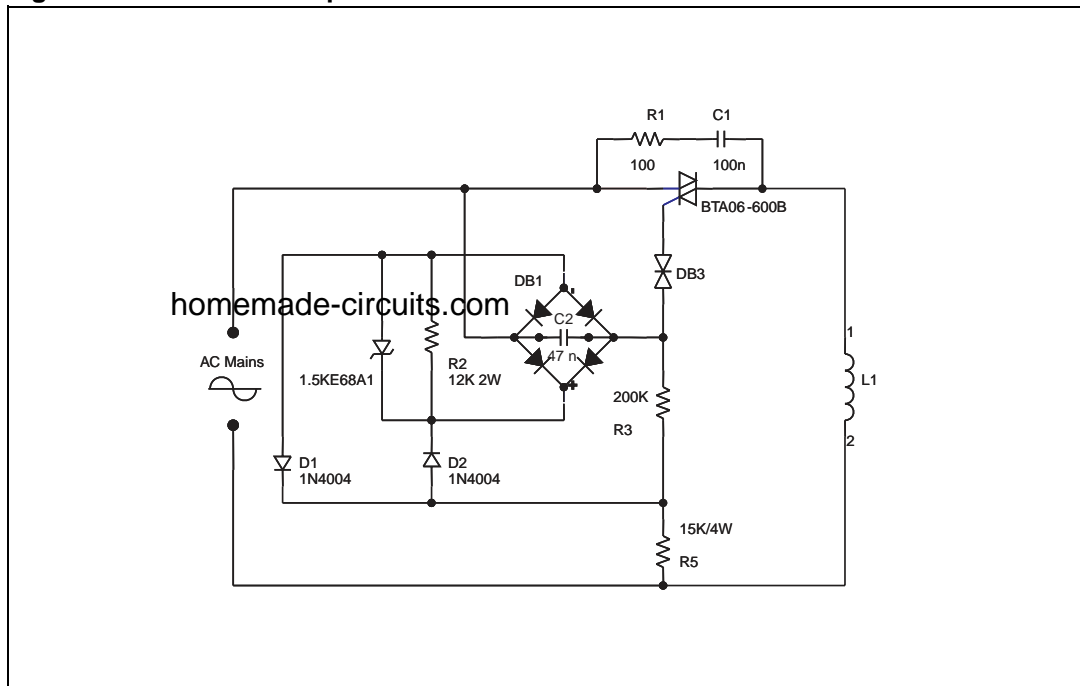
## 2.2 Synchronization by the mains voltage

The schematic in [Figure 10](#) shows a step-down circuit used to approximately divide by two the rms voltage between the line input and the inductive load (L1). C2 and R3 provide a turn-on delay of approximately 7 ms.

The diode bridge, with diodes D1 and D2 and R2 resistor are used to discharge C2 at each line zero voltage. This resets the voltage charge at each new half line cycle, and keeps the same turn-on delay.

The Transil reduces the power dissipation through R3.

**Figure 10. 220/110 V step-down circuit**

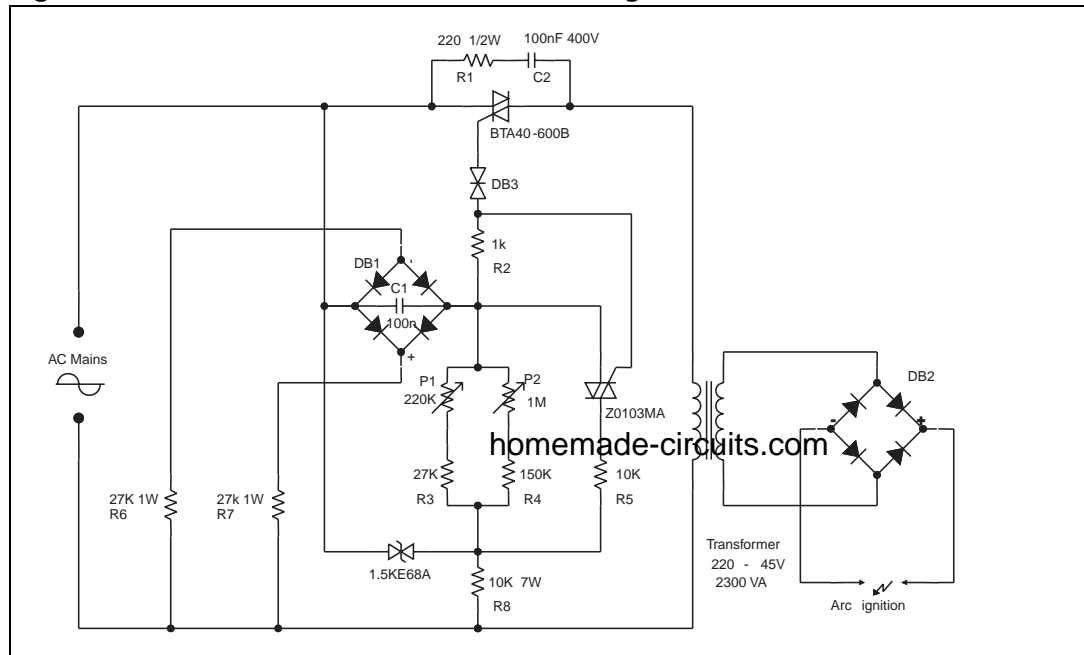


### 2.3 Pulse-train triggering circuit

The schematic in *Figure 11* shows a typical circuit for welding equipment. Potentiometer P2 is used for accurate control of the maximum turn-on delay. DB1 diode bridge and R6-R7 resistors are used to discharge C1 at each line zero voltage. This resets the voltage charge at each new half line cycle, and keeps the same turn-on delay.

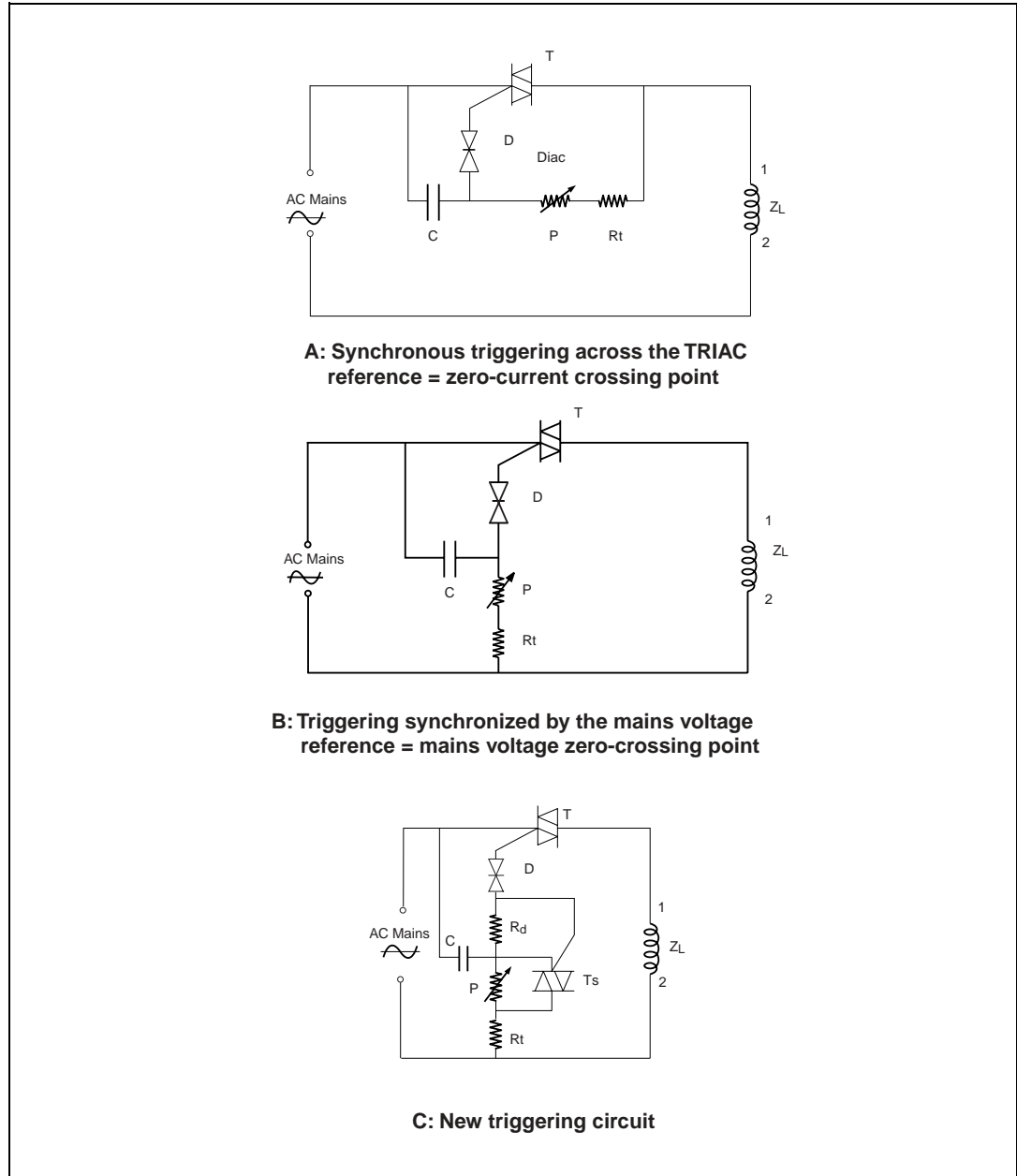
The Transil reduces power dissipation through both potentiometers.

**Figure 11. Power variation circuit for arc welding transformer**



# Appendix A Solutions summary for inductive load control

Figure 12. Different triggering circuits



## A.1 Triggering synchronized across the TRIAC

See [Figure 12](#) part A for the schematic diagram.

### A.1.1 Resistive load

Current and voltage are in phase, good synchronization. No fault over the whole adjustment range.

### A.1.2 Inductive load

The current lags by  $\pi / 2$ . Two cases should be considered:

- Broad conducting angle; narrow lag angle.  
The time separating two conducting periods is very brief. The positive and negative currents are very similar. Certain applications are covered by this case (for instance speed-control circuit for ac motors).
- Narrow conducting angle; broad lag angle.  
The flow of current in one direction is a function of the control and thus of the duration of the current flow in the previous polarity.  
The TRIAC can be triggered at the end of the mains half-cycle. In this case no current flows through the circuit and it acts as a rectifier.

### A.1.3 Circuit characteristics

Advantages of the circuit are as follows:

- Connection by two wires without polarity
- Low power dissipated by the passive components
- Excellent power variation circuit for resistive or slightly inductive loads
- With highly inductive loads, the circuit can only operate satisfactorily within the limits of a slight decrease in the conduction angle.

Disadvantages of the circuit are as follows

- For inductive loads, there is a large current dissymmetry for a variation towards the narrowest conduction angles. For this type of application the circuit cannot be used at all.

## A.2 Triggering synchronized by the mains voltage

See [Figure 12](#) part B for the schematic diagram.

### A.2.1 Resistive load

No fault over the whole adjustment range.

### A.2.2 Inductive load

The following two cases should be considered:

- Turn-on delay angle  $\theta >$  load lag,  $\varphi$  (in full-cycle control)  
Correct synchronization of the triggering pulses enables balanced conduction for all variations up to the load lag angle. Some applications use this principle (for example, 200 V – 100 V rms step-down circuit).
- Turn-on delay angle  $\theta <$   $\varphi$ .  
Triggering occurs before the lag angle is reached. The TRIAC will conduct for an angle  $\alpha > 180^\circ$ . It is blocked after the gate pulse of the following half-cycle. The current does not flow for next bias cycle. The circuit thus acts as a rectifier.

### A.2.3 Circuit characteristics

Advantages of the circuit:

- Accuracy of the triggering pulses.
- Current operation with a resistive load (but circuit complex, previous circuit preferred)
- Excellent operation for power variation circuits limiting conduction to small angles with inductive loads.

Disadvantages of the circuit:

- Connection by 3 wires - it is necessary to have access to the mains terminals.
- Power is dissipated permanently by the passive components.
- Impossible to adjust the delay angle to values close to or lower than the load phase shift. This circuit cannot be used for inductive loads where a variation close to the highest conduction angle is required.

## A.3 New triggering circuit

See [Figure 12](#) part C for the schematic diagram.

### A.3.1 Resistive load

No problem over the whole adjustment range.

### A.3.2 Inductive load

Operation in the two possible cases:

- Delay angle  $\theta > \varphi$   
Balanced conduction due to good synchronization of the triggering pulses
- Delay angle  $\theta < \varphi$   
For a conduction angle higher than  $180^\circ$ , the TRIAC turns off after the 1st pulse of the following half-cycle. It is immediately retriggered by the next repetitive pulse. The two currents are modified until a balance is reached.

### A.3.3 Circuit characteristics

Disadvantages of the circuit:

- Connection by 3 wires - it is necessary to have access to the mains terminals.
- Power is dissipated permanently by the passive components.

Advantages:

- Accuracy of the triggering pulses
- Correct operation for resistive loads
- No bad operation with inductive loads
- Power variation over the whole range
- Good balance between positive and negative current cycles

### 3 Revision history

**Table 1. Document revision history**

Date	Revision	Changes
February-1989	1	First Issue
1-Apr-2004	2	Stylesheet update. No content change.
30-Jan-2008	3	Reformatted to current standards. Complete technical update.
16-Sep-2008	4	Updated graphics and explanatory text for <a href="#">Figure 9</a> , <a href="#">Figure 10</a> , <a href="#">Figure 11</a> , and <a href="#">Figure 12</a> .

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