NEW TRIACS: IS THE SNUBBER CIRCUIT NECESSARY?

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When driving an inductive load, triacs are designed with RC snubber. These commutation aid networks are badly optimized in most of applications.

The subject of this paper is, first of all, to analyze the functions of snubber circuits for triacs and to propose calculation methods.

But today snubber circuits must be reconsidered by taking into account the progress of the triac technology. This article explains how it is now possible to reduce or to eliminate the snubber, and thus simplify the AC switch function, thanks to the high performance in commutation of the SNUBBERLESS™ triacs.

INTRODUCTION:

The triac is today the only bidirectional device able to control various loads supplied by the domestic and industrial mains. It is often designed with a network made of a resistor R and a capacitor C, the SNUBBER circuit.

This circuit improves the operation of the triac in its environment but what is its real function?

USE OF THE SNUBBER CIRCUIT ASSOCIATED WITH TRIACS.

The main function of this circuit is to improve the switching behavior of the triac at turn off: we will explain how and suggest some methods to define it.

**Fig. 1:** Synoptic of application circuit with triac.
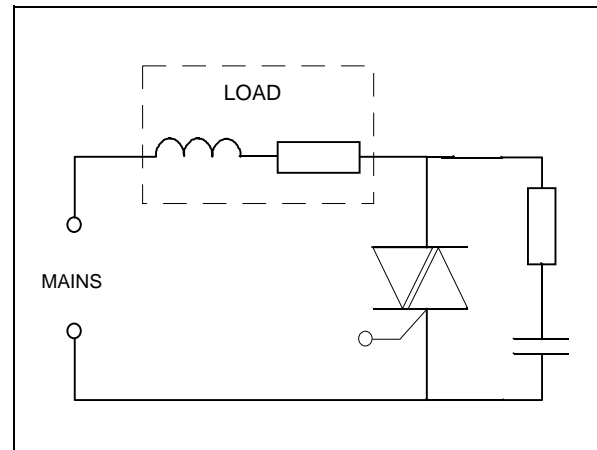
DESCRIPTION OF THE TRIAC COMMUTATION.

The triac is a device similar to two back to back Silicon Controlled Rectifier (SCR) with a common control area.
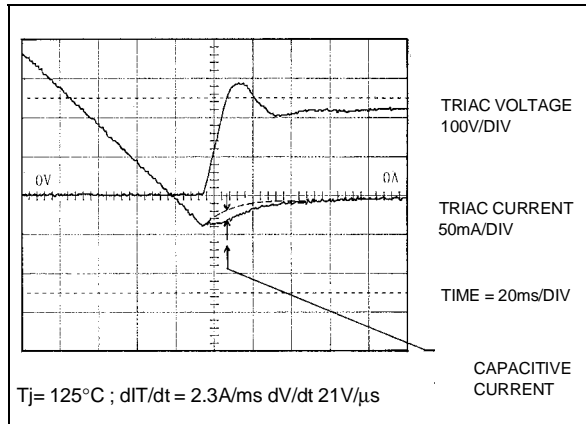
At turn off the commutation of the triac is the transient phase during which the load current is passing through zero and the supply voltage is reapplied to the triac terminals.

Fig. 2: Example of triac structure and its equivalent simplified circuit
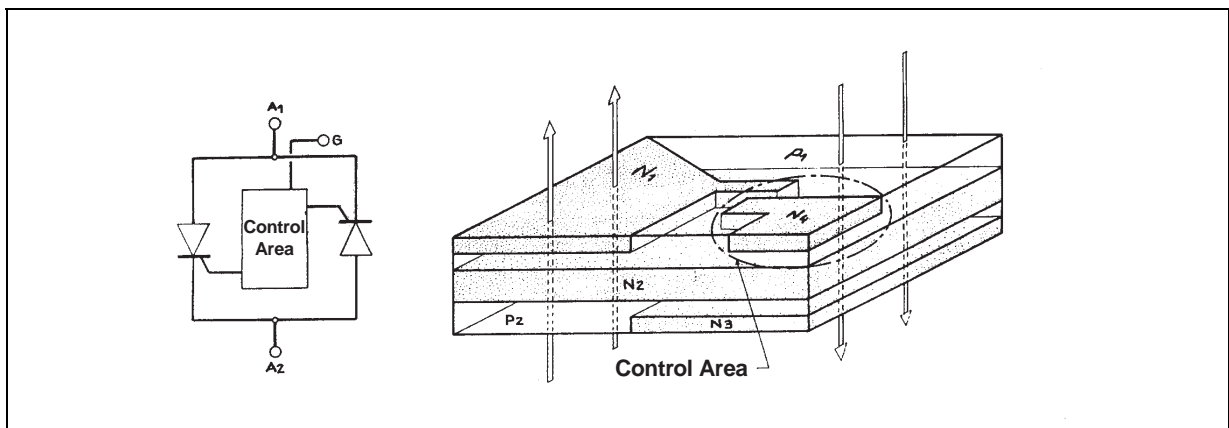
Fig. 3: BTB10-600BW commutation on inductive load.


Tj= 125°C ; dIT/dt = 2.3A/ms dV/dt 21V/μs

PARAMETERS OF COMMUTATION.

For a given device and a determined junction temperature the risk of a spurious firing is possible. It is linked to:

- The rate of removal of the triac current dI_T/dt before zero crossing because it determines the quantity of stored carriers which could be injected in the gate area or the opposite thyristor ;

- The rate of rise of the reapplied triac voltage, dV/dt, which creates a current through the gate because of the junction capacitance.

The parameters which characterize the performance of the triac commutation are the critical rate of removal of the current $(dI/dt)_c$ and the critical rate of rise of voltage, $(dV/dt)_c$: above these values the triac fires again spontaneously.

**Fig. 4:** Spurious firing at commutation for a BTB06-600S

Tj = 100°C; dIT/dt = 1.8A/ms dV/dt 17V/μs
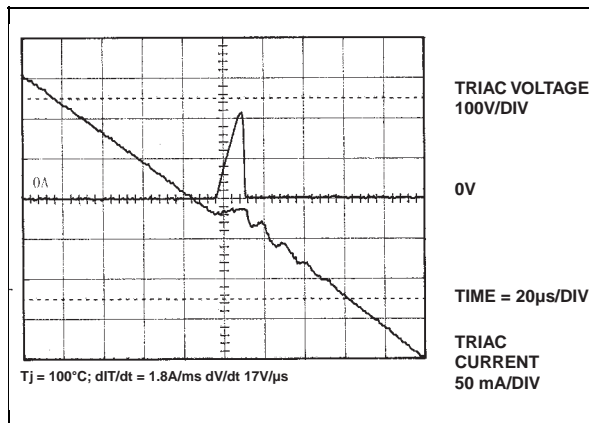
MAIN HYPOTHESIS ON COMMUTATION:

The analysis of commutation shows that :

- At turn off a recovery current, I_R, appears commonly when $dI_T/dt > 0.1$ x $(dI/dt)_c$; (see fig. 3).

- The circuit voltage V_a is reapplied to the device when $I_T = I_R$;

- The spurious firing is possible as far as there is a reverse current (made of recovery or capacitive current) : mean while **each dV/dt** is able to provoke the triac refiring; (see fig. 4).

Fig. 5: Application circuit (a) and its equivalent diagram at commutation (b).
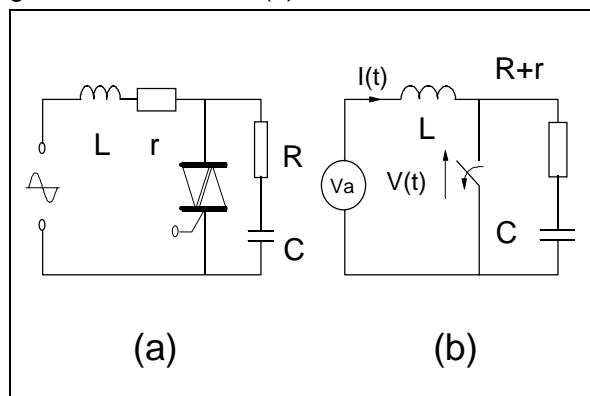
AIM OF THE SNUBBER CIRCUIT.

The today method to choose a triac on inductive load consists in :

- selecting a triac with an RMS current, I_{+TRMS-}, suitable with dI_{+T-}/dt of the circuit ; for conventional triac, the specified $(dI/dt)_{+c-}$ is linked to the current rating by the formula:

-

$$(d\,I/\,d\,t)_c = 2 \; x \; \Pi \; x\,f\,x\,\sqrt{2} \;\; I_{TRMS}$$

This value must be higher than the dI_T/dt of circuit.

- limiting the maximum reapplied dV/dt below the specified value $(dV/dt)_c$: this is the main function of the snubber circuit.

CHOICE OF THE SNUBBER CIRCUIT.

The aid circuit makes up a resonant circuit with the load. At turn off it limits the slope of reapplied voltage dV/dt but generates an overvoltage V_M. Its choice results of a compromise in order to respect $(dV/dt)_c$ and repetitive peak off state voltage V_{DRM} triac specification. There are two possibilities:

1/ for low V_{DRM} the resonant circuit must be damped, reducing both V_M and dV/dt (§ 2 of annex);

2/ with higher voltage possibilities the circuit can oscillate and the capacitor adjusts mainly the dV/dt (§ 3 of annex)

Today we use commonly triacs with V_{DRM} = 600 V or more. Therefore we suggest the second way because capacitor is smaller (reduced 4 times).

THE DISADVANTAGES OF THE SNUBBER CIRCUIT.

The snubber circuit improves the triac behavior but it imposes to the device stresses which limit its use.

At turn on the discharge of the capacitor creates a pulse current with high repetitive dI_T/dt which can destroy the triac by local over heat near the gate. It is recommended to limit the amplitude of current with a resistor higher than 50 Ohms and the turn on dI/dt below 20 A/µs.

Fig. 6: Triac turn on with snubber circuit.
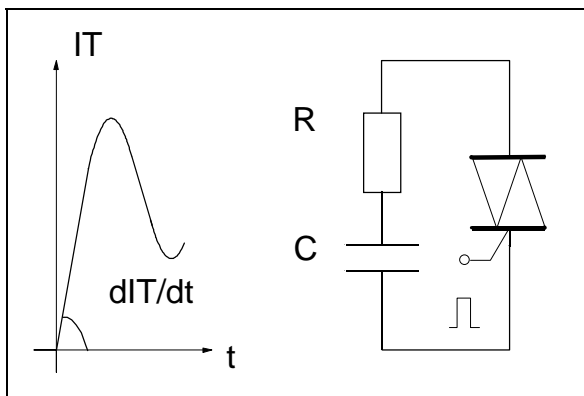
The current, which flows through the snubber circuit when the triac is off, decreases the off state quality of the switch: this leakage current (several mA) could create problems for small loads like electro-valves, micro motors...

PROGRESS MADE ON TRIACS.

PREDOMINANCE OF $(dI/dt)_c$ AND LIMITATION OF dV/dt:

The study of the commutation behavior of triac can be made thanks to the curve of the critical commutation performance of each sample : $(dI/dt)_c$ versus various reapplied $(dV/dt)_c$.

Fig. 7: Critical $(dI/dt)_c$ versus $(dV/dt)_c$ for BTB10-600B sample.
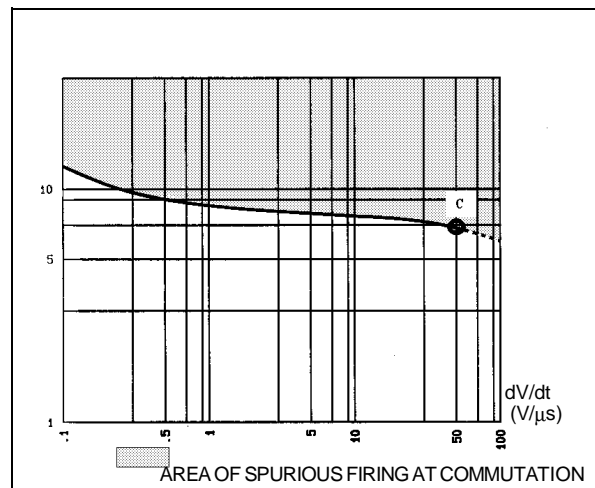
For a conventional triac (I_{GT}> 25 mA) the critical $(dI/dt)_c$ is not much sensitive to the $(dV/dt)_c$: so it represents the **most significant** parameter to characterize the triac behavior in commutation (fig.7).

Without snubber circuit the $(dV/dt)_c$ is limited by the junction capacitance of the triac (point C).

In order to improve the commutation behavior of the triac and to eliminate the snubber circuit the parameter $(dI/dt)_c$ has to be increased on all range of dV/dt.

We also notice the efficiency of the snubber circuit in commutation $(dI/dt)_c$ is lower than two by reduction of dV/dt from its natural limitation (point C) to 0.1V/µs.

PERFORMANCES OF THE SNUBBERLESS TRIACS:

This analysis permitted the development of new triacs with better performances in commutation: the SNUBBERLESS triacs which have got a new design with improved triggering mechanism and better decoupling of single integrated thyristors.

For same size and gate sensitivity the improvement ratio on $(dI/dt)_c$ is higher than 3.

Fig. 8: Comparison between conventional and snubberless 10 A triacs.
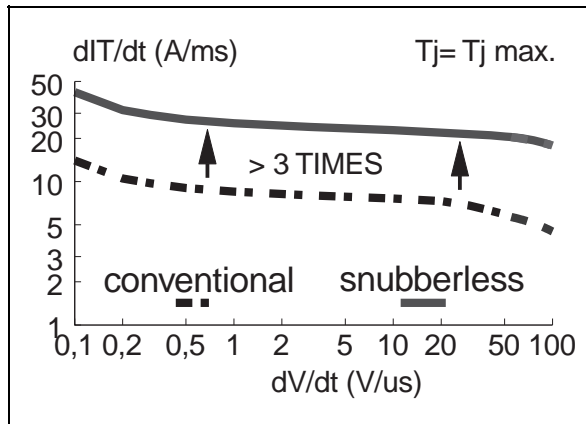
So we can specify now the commutation behavior with $(dI/dt)_c$ for a value dV/dt from 0 to its natural limitation by the junction capacitance **(without snubber circuit)**.

CURRENT RANGE (A)	TRIAC SUFFIX		dI/dt on 50 Hz sine pulse (A/ms)
	BW	CW	
6	5	3.5	2.7
10	9	5.5	4.4
16	14	8.5	7
25	22	12	11.1

CONSEQUENCES ON APPLICATION CIRCUITS.

The SNUBBERLESS triacs offer application advantages :
- The function of commutation aid of the snubber circuit disappears : so, it can be removed;

- In application the dI_T/dt through the triac is not adjustable because it is given by the circuit (V_a and L); its measure permits the choice of this triac with the commutation parameter, $(dI/dt)_c$.
- The commutation behavior is no longer linked to the current range, and the high $(dI/dt)_c$ performance allows a reduction of the die size. For instance, a universal motor of 1200 W - 220 V can be driven by a BTB10-600 BW (*) instead of the BTB15-600B(**).

(*) 10 Amps SNUBBERLESS triac with V_{DRM} = 600 V and I_{GT} = 50 mA; specified at 9 A/ms without snubber.

(**) 15 Amps conventional triac with V_{DRM} = 600 V and I_{GT} = 50 mA; specified at 6.7A/ms with dV/dt limited to 10 V/µs.

IS IT ALWAYS POSSIBLE TO REMOVE THE SNUBBER CIRCUIT ?

The answer is not in the affirmative because sometimes it has other functions :
- improvement of the triac immunity against transients in the off state ;
- compensation of latching current at turn on (not dealt in this paper).

Switching on and voltage perturbations can provoke overvoltages and fast voltage variations across the triac :
- this one could break over when the overvoltages are higher than its repetitive peak off state voltage, V_{DRM};
- due to the junction capacitance fast voltage variations create a gate current and could trigger the triac; the device limit is the rate of rise of the off-state voltage, dV/dt.

The snubber circuit can improve the triac behavior in off-state. But its efficiency is linked to the values of series inductance L at the oscillation frequency of perturbations (typically higher than 100 kHz).

We could add a saturable inductor in series with the triac when L is too low: particularly this is the case of resistive load.

IMPROVEMENT OF THE IMMUNITY TO TRANSIENT VOLTAGES (STATIC DV/DT):

When the circuit has its specific overvoltage suppressor, as clamping diodes (TRANSIL™), the aim of the snubber circuit is to reduce only dV/dt for triac voltage lower than V_{DRM}. It must be damped, limiting its overvoltage and the current in the suppressor.
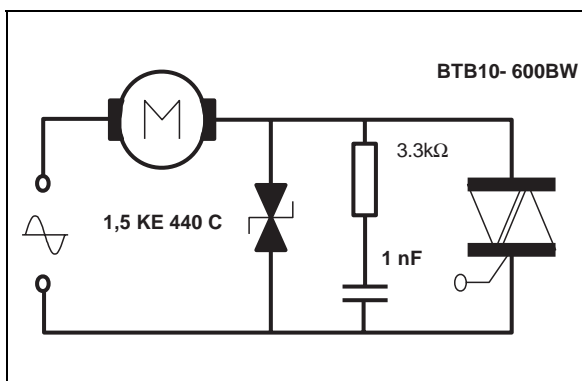
The § 2 of annex permits to choose the values:

$$C > 3 \; x \; (V_{DRM})^2 \; / \; (L \; x \; dV/dt)^2$$

$$R < 0.8 \; x \; L \; x \; (dt/dt)/V_{DRM}$$

For a 1200 W motor with L (100 kHz) # 5 mH a BTB10-600BW triac needs a snubber circuit of 3.3 kΩ and 1nF (fig.8).

Fig. 9: Example of improved off-state immunity for triac

PROTECTION AGAINST OVERVOLTAGES :

The snubber circuit could be a simple circuit in order to reduce overvoltage V_M. It must operate as a low pass filter with minimum resistance (50 Ohms) avoiding turn on current stresses.

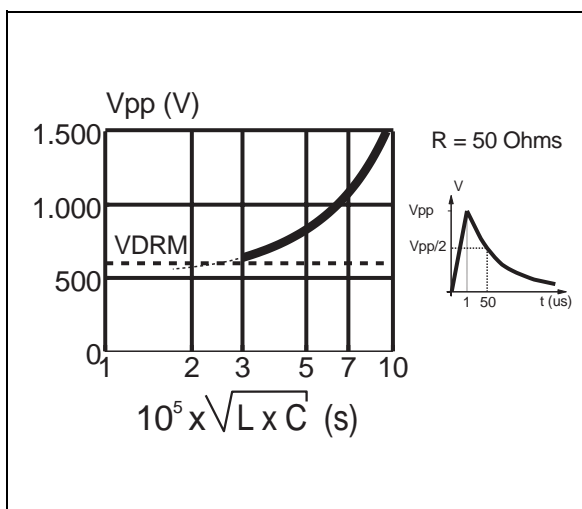**Fig. 10:** Snubber circuit efficiency against overvoltage V_{PP}(Triac voltage<600V).

Figure 10 shows the maximum allowed overvoltage Vp versus $\sqrt{LxC}$ remaining the triac voltage below 600 V.

But the efficiency of this circuit is poor and we prefer use other ways of overvoltage protection: input filters and suppressor (see fig.9).

CONCLUSION :

Used today as turn off commutation aid circuit, the snubber circuit can be well optimized thanks to higher blocking voltage V_{DRM}: we obtain a reduction of the capacitor size.

But with the SNUBBERLESS triacs, the aid function of the snubber circuit disappears. Because of the improvement of the commutation performance (higher critical $(dI/dt)_c$) these new triacs offer a cost reduction by decreasing their size, and permit to eliminate the snubber circuit in most of applications.

The snubber circuit, associed to a serial inductance, reduces the off state voltage variations. Its efficiency against overvoltage is poor and specific protection devices are preferred.

REFERENCES :

- Improvement in the triac commutation 1989. P.RAULT SGS THOMSON-Microelectronics.
- Analysis and design of snubber networks for dv/dt suppression in triac circuits (RCA) AN 4745 - 1971 JE WOJSLAWOWICZ.
- For energy conversion and motor control - triacs or alternistors. Pierre RAULT and Jean Marie PETER ; THOMSON CSF for PCI September 1982.

Annex :

DETERMINATION OF THE COMPONENTS OF SNUBBER CIRCUIT.

. 1 SNUBBER CIRCUIT OPERATION

The load inductance L and the snubber circuit make up a resonant circuit across which the mains voltage is reapplied at turn off. The RC circuit limits dV/dt but generates an overvoltage V_M which must be lower than V_{DRM}.

We can analyse V_M and $(dV/dt)_{max}$ with their relative parameter versus the damping factor F of the resonant circuit LCR:

Fig. A1: overvoltage (e) versus damping factor F.
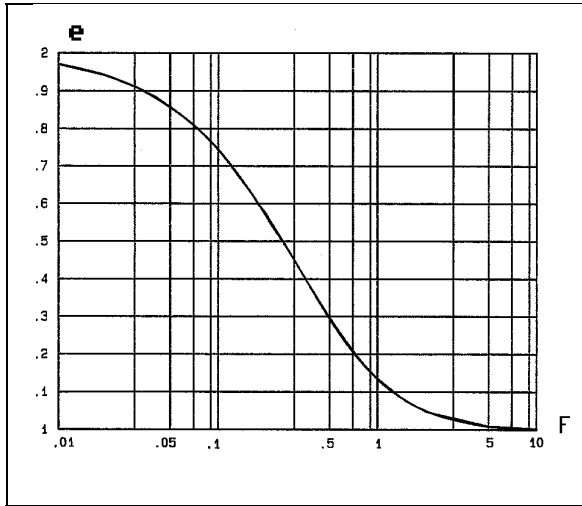
Fig. A2: rise slope (δ) versus damping factor F.
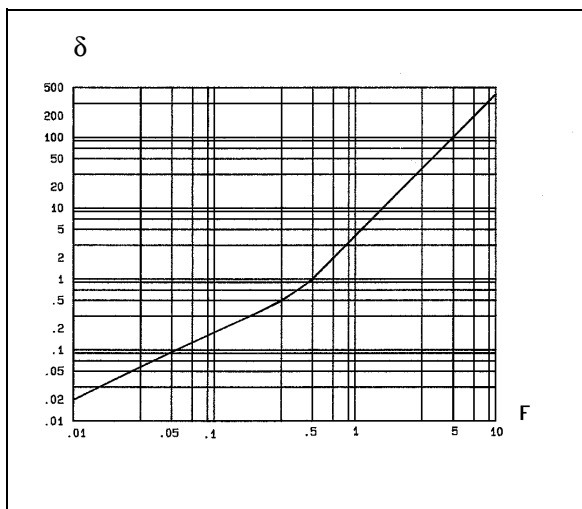
$$e = \frac{V_M}{V_a}$$

$$\delta = \frac{R \ x \ C \ x \ (dV/dt) \ max}{V_a}$$

$$F = \frac{R}{2} \ X \ \sqrt{\frac{C}{L}}$$

These curves show there are two intervalles where variations if F -due to the tolerance of the components- don't almost modify the overvoltage value :

$$F > 0.5 \ and \ F < 0.1$$

Therefore these are the two methods in order to choose the snubber circuit.

. 2 DETERMINATION OF THE SNUBBER CIRCUIT WHEN F > 0.5:

V_M is limited first of all (e < 1.3) thanks to the capacitor C; the resistance R sets the slope $(dV/dt)_{max}$.

$$R \ x \ \sqrt{\frac{C}{L}} > 1$$

$$(dV/dt)_c > \frac{V_a \ x \ R}{L}$$

However F must be low (F = 1) in order to reduce the capacitor and the resistor dissipation power P_R:

$$C > \frac{4 \ x \ V_a{}^2}{L \ x \ (dV/dt)_c{}^2}$$

and

$$R < \frac{L \ x \ (dV/dt)_c}{V_a}$$

with

$P_R < 2.C.Va^2.f$

$V_M/V_a < 1.2$

$V_a = V_{ac} \ x \ \sqrt{2} \ x \ \sin\phi$

$V_{ac} = R_{MS}$ mains voltage

f = mains frequency

$\cos\phi$ = power factor of load

L = inductance of load when zero crossing

r = resistance of load

An inductive load of 2000 VA - cosϕ = 0.6 on 220 V - 50 Hz mains can be controlled with a triac specified @ $(dV/dt)_c$ = 10 V/µs by using :

C = 30 nF and R = 3.5 kOhms

with

L = 100 mH

r = 40 Ohms

P_R = 0.23 W

V_M = 332 V (choose a triac with V_{DRM} = 400 V)

. 3 DETERMINATION OF THE SNUBBER CIRUIT F< 0.1:

dV/dt is optimized first of all (δ < 0.18) thanks to the capacitance C; V_M is only set by the resistance R:

$$R \times \sqrt{\frac{C}{L}} < 0.2$$

and

$$(dV/dt)_c > \frac{V_a}{L \times C}$$

The resistance value has to keep a sufficient value (F = 0.05) in order to limit stresses on triac at turn on (see 1.5)

$$C > \frac{V_a^2}{L \times (dV/dt)_c}$$

and

$$R + r < \frac{0.1 \times L \times (dV/dt)_c}{V_a}$$

with

$P_R < 2.C.V_a^2.f$

$e = V_M/V_a < 1.9$

$V_a = V_{ac} \times \sqrt{2} \times \sim\sin\phi$

With the same load 2000 VA - cosϕ = 0.6 on 220 V - 50 Hz mains and with the same triac :

C = 10 nF and **R = 300 Ohms**

P_R = 0.08 W

V_M = 525V (choose a triac with V_{DRM}=600 V)

. 4 COMMENTS :

Today the triac offers blocking voltage V_{DRM} up to 800V: so we suggest the second method because the capacitor is smaller, (reduced by 4) and the reapplied slope dV/dt is less sensitive to damping factor variation and so better controlled.

These values obtained by calculation are slightly overrated because the real slope of the reapplied voltage is limited also by the junction capacitance of triac.