Snubber Circuits

Table of contents

What is a snubber circuit?

Snubber circuits are necessary to maintain the safe function and longevity of power switches. These circuits provide greater efficiency, they raise the possible switching speed and reduce the EMI. For easy understanding it can be said that a snubber circuit is a protection circuit of power switches.

Why should snubber circuits be installed?

In the real world a switched load appears as an impedance. So when these loads are switched, there are unwanted voltage transients or surge currents which have a negative effect on the switching elements and the controlling circuit. These effects can have immediate or time delayed consequences which can lead to malfunction or even defects of the switching elements and the controlling circuit. If snubber circuits are well designed, they can reduce or even eliminate these effects. Therefore it is necessary to use snubber circuits with relay contacts because electric arcs can be minimized and a longer life of the contacts can be achieved. In addition the number of switching cycles can be increased which will allow savings in material and maintenance costs. If SCRs (SemiConductor Relays), especially thyristors and triacs, are used it snubbers are necessary to control the rise of the voltage along the anode to cathode track. If this voltage rises to fast it can lead to unwanted turn-on of the device. If this happens, a faultless action of the device can't be guaranteed anymore and it could fail.

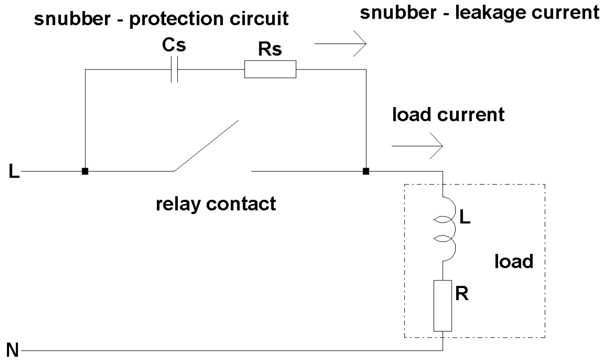
Functionality of a snubber circuit

The snubber circuit absorbs the energy which is stored in the load. To keep the switching device within its safe operating range, it is necessary to protect the switch. If the load is inductive, the switch-off can be problematic because the self-induction wants to maintain the current flow which leads to voltage transients which can be in the range of kilo- to megawatts. These voltage transients should be avoided with relay contacts because they induce an electric arc which causes migration of the contact material and may lead to the destruction of the contact.

Placement of the Snubber Circuit

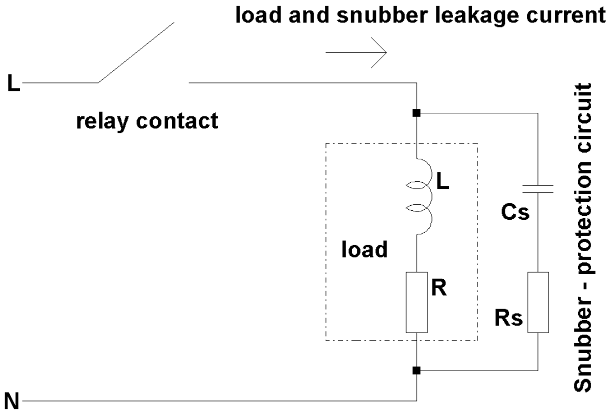
For the placement of the snubber, the type of load must be known. Because of the fact, that the protection circuit has to be designed according to the load, it is impossible to design a universal protection circuit.

For an inductive load the snubber must be connected either in parallel to the switch, or in parallel to the load. A simple snubber consists of a resistor and a capacitor. If the snubber is connected in parallel to the switch, the current flows through the protection circuit at switch-off and then decays. Because of the connection in parallel to the switch, there is a constant current flow through the snubber when the switch is open. To keep this current flow to an acceptable level, a well designed circuit is needed.



Connection of the snubber circuit in parallel to the switch

If the snubber is connected in parallel to the load, the current flow is also stopped through the switch and the snubber circuit becomes active. In contrast to the first method there is no current flow when the switch is open but there is a leakage current when the switch is closed. In this arrangement the current flow caused by transient voltages can not flow over the neutral wire which can lead to improved EMI.



Snubber circuit connected in parallel to the load

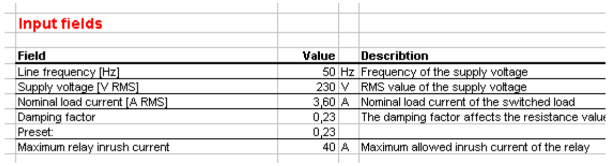
It is up to the designer to decide whether the protection circuit is connected in parallel to the switch or to the load. The sole factor to be considered in this decision is the length of time the switch is open or closed to keep the loss as low as possible. In both methods the protection circuit has the effect of converting the electrical energy into heat and therefore to reduce or eliminate the electrical arc. In general the protection circuit should be placed as near as possible to the switch or load depending on the method.

Design process of a relay contact protection circuit with the template

With the provided Excel spreadsheet it should be easy and simple for the designer to calculate the optimum values for a particular application. The calculation is provided for inductive loads. In the beginning the designer has to decide about the type of placement. According to this the correct Excel spreadsheet has to be chosen.

After choosing the type of placement the frequency and the RMS value of the switched voltage have to be inserted in the relevant fields.
The next step is to find out the nominal current of the load. This current value can be found in the datasheet of the switched device or it must be measured. The value is needed for the calculation of the parameters of the protection circuit. The calculation assumes that the load is a pure inductance, so all parameters are calculated for the worst case.

Keep in mind that the calculation of the protection circuits via the Excel spreadsheets can only be done for inductive loads.

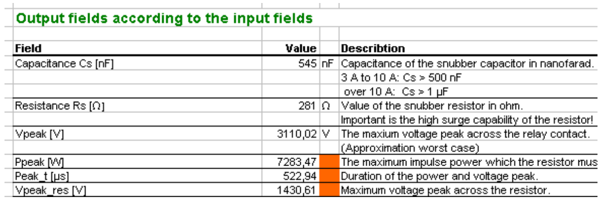


Input fields

Field	Value		Describtion
Line frequency [Hz]	50	Hz	Frequency of the supply voltage
Supply voltage [V RMS]	230	V	RMS value of the supply voltage
Nominal load current [A RMS]	3,60	A	Nominal load current of the switched load
Damping factor	0,23		The damping factor affects the resistance valu
Preset:	0,23		
Maximum relay inrush current	40	A	Maximum allowed inrush current of the relay

To complete the input fields the maximum relay current must be entered if it is provided in the datasheet of the relay supplier. The field “Damping Factor” is preset and can not be changed. This constant controls the duration of the voltage swing and therewith the time in which the stored energy must be dissipated. The damping factor which is the outcome of the chosen values has to be compared with the preset value. This is done later after the values are chosen.

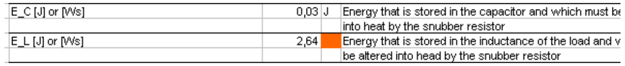
In the example an inductive load with a nominal current of 3.6 ampere at a supply voltage of 230 volts and 50 Hz is assumed. The results of the calculations can be read in the output fields.



Output fields according to the input fields

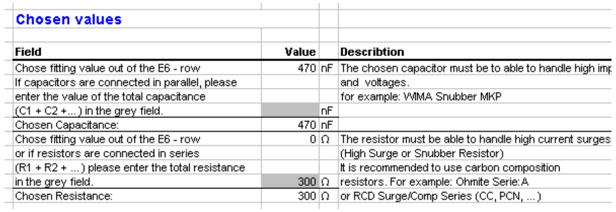
Field	Value		Describtion
Capacitance Cs [nF]	545	nF	Capacitance of the snubber capacitor in nanofarad.
			3 A to 10 A: Cs > 500 nF
			over 10 A: Cs > 1 µF
Resistance Rs [Ω]	281	Ω	Value of the snubber resistor in ohm.
			Important is the high surge capability of the resistor!
Vpeak [V]	3110,02	V	The maxium voltage peak across the relay contact.
			(Approximation worst case)
Ppeak [W]	7283,47	🟧	The maximum impulse power which the resistor mus
Peak_t [µs]	522,94	🟧	Duration of the power and voltage peak.
Vpeak_res [V]	1430,61	🟧	Maximum voltage peak across the resistor.

For these inputs we receive as a result a capacitance of 545 nF and a resistor value of 281 Ω. The next field gives information about the maximum voltage through the relay contact. This value is the absolute maximum of a transient. This voltage transient can occur if the switch is turned off when the current through it is a maximum. In this moment the stored energy in the inductance has the highest value. Without a snubber circuit the voltage transient would be in the area of Kilovolts to Megavolts, this would lead to an electrical arc. So the protection circuit can decrease or even eliminate these arcs.
Some fields which are very important for the choice of the devices in the protection circuit are the next fields. They contain the maximum power peak in the resistor and its time and the resulting voltage across the resistor. These indicators are very important to choose the correct resistor. The snubber resistor has to be a type which can handle high current surges. These resistors are often called “high surge” or “high current surge” devices. For this application carbon composition resistors are best suited because they consist of a homogeneous mass which can handle high current pulses. In the datasheets of these resistors the amount of energy which can be altered into heat per impulse is given in Joule [J]. The stored energy can be read out of the following fields.



E_C [J] or [Ws]	0,03	J	Energy that is stored in the capacitor and which must be
			into heat by the snubber resistor
E_L [J] or [Ws]	2,64	🟧	Energy that is stored in the inductance of the load and v
			be altered into head by the snubber resistor

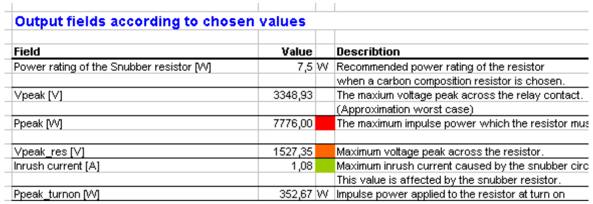
These details make it easy to choose the correct resistor for the particular application. As examples the series “A” of Ohmite and the series “CC” and “PCN” of RCD can be mentioned.
The calculation example earlier showed that we require a capacitance of 545 nF and a resistor value of 281 Ω. However because we cannot purchase these exact values it is necessary to check the effect on the output which is inherent to the deviation of the available values and the calculated ones.
In the section “Chosen Values” you can enter the real world values of your resistor and capacitance. These values should be as close to the calculated ones as possible.
You can choose a capacitance out of the E6 – row, or enter the value of a parallel connection of capacitances (C1 + C2 + …) in the grey field below. A parallel connection of capacitances doesn’t change anything regarding the withstand voltage or maximum voltage rise.
For the resistor you can also choose a value out of the drop – down menu. If you choose a series connection of resistors you can enter the total resistance (R1 + R2 + …) in the grey field below.



Chosen values

Field	Value		Describtion
Chose fitting value out of the E6 - row	470	nF	The chosen capacitor must be to able to handle high imp
If capacitors are connected in parallel, please			and voltages.
enter the value of the total capacitance			for example: WIMA Snubber MKP
(C1 + C2 +…) in the grey field.		nF	
Chosen Capacitance:	470	nF	
Chose fitting value out of the E6 - row	0	Ω	The resistor must be able to handle high current surges
or if resistors are connected in series			(High Surge or Snubber Resistor)
(R1 + R2 + …) please enter the total resistance			It is recommended to use carbon composition
in the grey field.	300	Ω	resistors. For example: Ohmite Serie:A
Chosen Resistance:	300	Ω	or RCD Surge/Comp Series (CC, PCN, …)

In the example a series connection of two 150 Ω resistors is chosen. This gives a total value of 300 Ω.
The next step is to revise the deviation of the new output from the calculated output and to interpret it correctly.

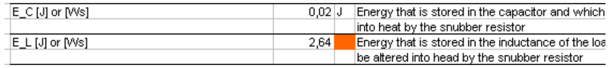


Output fields according to chosen values

Field	Value		Describtion
Power rating of the Snubber resistor [W]	7,5	W	Recommended power rating of the resistor
			when a carbon composition resistor is chosen.
Vpeak [V]	3348,93		The maxium voltage peak across the relay contact.
			(Approximation worst case)
Ppeak [W]	7776,00	🟥	The maximum impulse power which the resistor mus
Vpeak_res [V]	1527,35	🟧	Maximum voltage peak across the resistor.
Inrush current [A]	1,08	🟩	Maximum inrush current caused by the snubber circ
			This value is affected by the snubber resistor.
Ppeak_turnon [W]	352,67	W	Impulse power applied to the resistor at turn on

For the given application we should use a resistor with a power rating of 7.5 watts. We take two 150 Ω resistors with a rating of 5 watts each. So we obtain a total power rating of 10 watts. This value could be seen as a recommendation, because the current surge capability of the resistor is crucial. Pay attention to the lines with the red marking. If the marking is red, the obtained

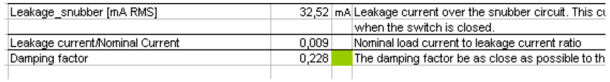
values are relatively high and the capabilities of the used devices could be exceeded.
As mentioned before, the maximum impulse energy that a snubber resistor can handle without any damage is given in the corresponding datasheets. Therefore you can read the stored energy which must be converted into heat.



E_C [J] or [Ws]	0,02	J	Energy that is stored in the capacitor and which into heat by the snubber resistor
E_L [J] or [Ws]	2,64	🟧	Energy that is stored in the inductance of the loa be altered into head by the snubber resistor

The stored energy in the capacitance changes with its value.
It may be that in those datasheets diagrams are given, which contain information about how long the maximum voltage can be applied across the resistor.
The field "Duration of the Peak [µs]" gives an approximate time in which the highest power and voltage peak dissipate. You should not under-size the snubber resistors because this would shorten the lifetime of these devices. If the load is, for example a motor, the snubber resistor's power ratings have to be even higher, because the kinetic energy, which is stored in the rotation of the motor, has also to be converted by the snubber resistor.

The deviation of the chosen values from the calculated ones can have an impact on the characteristics of the protection circuit. You should check the deviations from the calculated conditions concerning leakage current and the damping factor.



Leakage_snubber [mA RMS]	32,52	mA	Leakage current over the snubber circuit. This cu when the switch is closed.
Leakage current/Nominal Current	0,009		Nominal load current to leakage current ratio
Damping factor	0,228	🟩	The damping factor be as close as possible to th

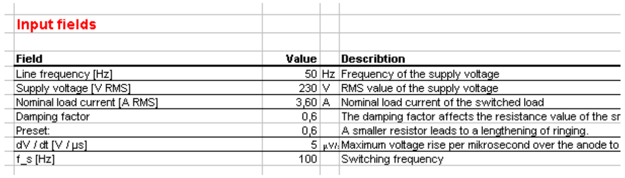
The snubber capacitance and the snubber resistor form a high pass which leads to a current over this circuit when alternating voltage is applied. The occurrence of this leakage current is dependent of its placement as stated in chapter "Placement of the Snubber Circuit". When the values are chosen inappropriately, the leakage current and the current consumption increases. The calculation is designed such that the amount of leakage current is one hundredth of the nominal load current. Unfortunately this effect can't be avoided. If the snubber circuit is over-sized the leakage current would rise and the protection circuit would loose its efficiency.

For the choice of the snubber capacitor, it's necessary to use devices declared as snubber capacitors because they need to have high impulse stability. As an example the "Snubber MKP" series from WIMA should be mentioned. These polypropylene film capacitors offer very good electrical characteristics and are well suited for this application.

Design - template for a thyristor/triac snubber circuit

As mentioned above, thyristors and triacs need snubber circuits to control the voltage rise to defend them from unwanted turn-on. As before, the load inductance and the protection circuit form a RLC – oscillating circuit. Because of the fact that the turn – off can only be achieved when the current falls below a certain boundary, the stored energy in the inductance is a minimum. Therefore the requirements the protection circuit devices have to face are not as high as before. None the less the devices should be explicit snubber devices and should be chosen carefully. Again it can be said that if kinetic energy is stored in the load, the required power ratings of the resistors should be raised. This decision is up to the designer.

For the principle design of the snubber circuit the provided Excel spreadsheet for the thyristor/triac snubber design can be used. Again the nominal voltage and its frequency, and the nominal current must be entered.



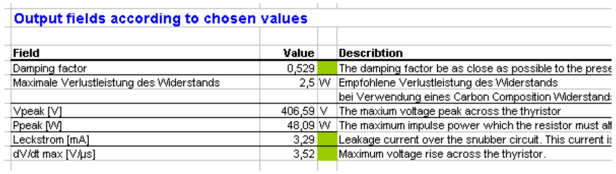
Input fields

Field	Value		Describtion
Line frequency [Hz]	50	Hz	Frequency of the supply voltage
Supply voltage [V RMS]	230	V	RMS value of the supply voltage
Nominal load current [A RMS]	3,60	A	Nominal load current of the switched load
Damping factor	0,6		The damping factor affects the resistance value of the sr
Preset:	0,6		A smaller resistor leads to a lengthening of ringing.
dV / dt [V / µs]	5	µV/	Maximum voltage rise per mikrosecond over the anode to
f_s [Hz]	100		Switching frequency

Furthermore the damping factor can be chosen. A higher damping factor leads to a shorter swing time of the oscillating circuit, in return the time in which the energy must be converted decreases. Shortening this time could lead to higher maximum power ratings.
For the calculation of the maximum power rating of the resistor, the switching frequency has to be known. It must be entered in the field "Switching frequency" in hertz.

Again the results can be taken from the „output fields".

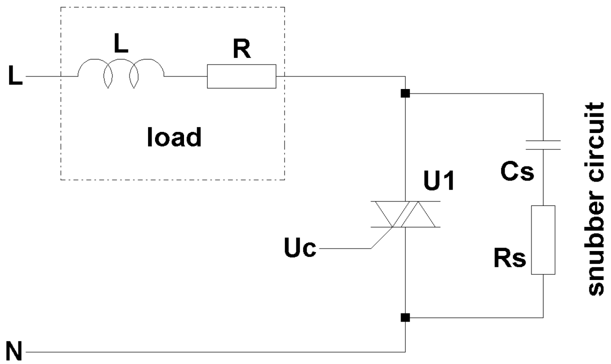
In the following chapter the values can be chosen from the E6 – row or they can be entered into the designated grey fields. As before the changes which can occur due to the deviation of the values have to be checked and compared with the calculated values.



Output fields according to chosen values

Field	Value		Describtion
Damping factor	0,529	🟩	The damping factor be as close as possible to the prese
Maximale Verlustleistung des Widerstands	2,5	W	Empfohlene Verlustleistung des Widerstands bei Verwendung eines Carbon Composition Widerstand:
Vpeak [V]	406,59	V	The maxium voltage peak across the thyristor
Ppeak [W]	48,09	W	The maximum impulse power which the resistor must al
Leckstrom [mA]	3,29	🟩	Leakage current over the snubber circuit. This current is
dV/dt max [V/µs]	3,52	🟩	Maximum voltage rise across the thyristor.

In particular the values in the „leakage current [mA]" and „dV/dt max [µs]" lines have to be compared to the calculated ones.



Thyristor/triac with snubber circuit

With this application note the design template the user should be qualified to calculate values for a suited snubber circuit. The choice of suitable snubber devices for the underlying application lies in the hands of the designer. The operation and durability of the snubber circuit is up to the quality and the maximum limitations of the devices. The devices have to be adapted to the given application to ensure these qualities. Please note that the shown circuits and therefore calculated values are not suited for certain applications.

Bibliography

Templeton, George. „*RC Snubber Networks For Thyristor Power Control and Transient Suppression*“, AN1048/D, ON Semiconductor, June 2008

„*RC Snubber Networks For Thyristor Power Control and Transient Suppression*”, AN-3008, Fairchild Semiconductor, 2002

„*Application Guide Snubber Capacitors*”, Cornell Dubilier Electronics, Inc., 2010

Todd, Philip C. „*Snubber Circuits: Theory, Design and Application*”, Unitrode Corporation, 1993

„*RC Snubber Circuit Design For TRIACs*”, AN437, STMicroelectronics, October 2007

„*An Introduction to Carbon Composition Resistors*”, Welwyn Components Limited,

Keuter, Wolfgang. „*Das Stellen und Schalten von Wechselgrößen*”, Hüthig, 1982, ISBN 3-7785-0761-3

Minovic, M. „*Schaltgeräte – Theorie und Praxis*“, Hüthig & Pflaum Verlag, 1977, ISBN 3-8101-0035-8

Table of revision

0100

Engineers	Peter Reiter/Thomas Platzer
Date	15/10/2010
Issue of change	Compilation
Description of change	