Störbeeinflussung durch nicht beschaltete Lasten / Kontakte

EMC Interference caused by switched loads

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Werden elektrische Lasten über elektromechanische Kontakte geschaltet, so werden sehr steile Spannungs- und Stromflanken EMV mässig wirksam. Dies wird durch die Einschalt- und, insbesondere bei induktiven Lasten, die Ausschaltvorgänge, verstärkt noch durch das unvermeidliche Prellen der Kontakte, bewirkt. Nicht nur, dass die Ein- und Ausschaltvorgänge den Kontaktabbrand verursachen, sondern sie erzeugen auch hochfrequente Energien, die zu un-berechenbaren Funktionsstörungen führen.
Beschaltungsmassnahmen werden aufgezeigt.

When an electrical load is switched by electrome - chanical contacts fast rising voltage and current fluctuation will occur, i.e. EMC interference. This is caused during the inrush and especially by inductive loads at the cut off point. This problem increases due to the inevitable contact bounce.
The inrush and cut off events are not only responsible for the contact erosion but also for the generation of HF interference energy, which leads to unexpected malfunctioning. Connection methods to avoid these problems are explained as follows.

A typical example is a relay which features these effects by demonstrating an inductive load and the electromechanical contact and the corresponding interference **[1]**.

The principle

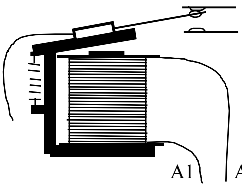


Fig. 1 Typical relay's configuration

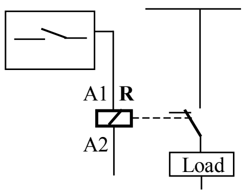
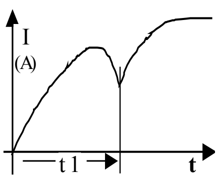


Fig. 2 Diagram principle

Switching on

When power is applied to the coil (A1, A2) a current begins to flow through the relay coil. The resulting force from the magnetic field pulls the armature closing then the magnetic circuit and therefore opening the NC contact and closing the NO contact.
In DC relays, the maximum current is reached after this event. In AC relays (contactors), the initial high inrush current drops to the considerably lower operating current.



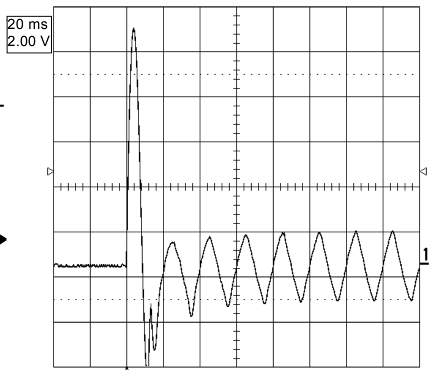


Fig. 3 Typical inrush current DC relays **Fig. 3a** AC relays

This means, that by commutating an inductive DC load there is almost no spark and therefore no electromagnetic interference (EMI), as in the case of AC relay (contactors).

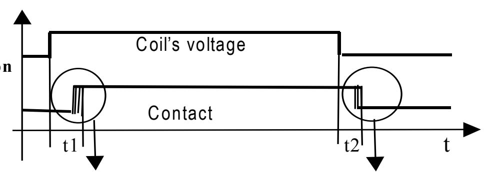
Switching off

If the current in the relay coil is interrupted, the armature returns to its initial position after the delay time (off delay time); the NO opens and the NC closes. However the magnetic energy in the relay coil (inductivity) must be consumed somewhere, in other words, the current in the coil reduces to zero according to an e–function. If this is not possible, self-inducted voltages generate to the corresponding current values.
This is what causes problems when switching an inductance load with an electromagnetic contact.

Switching behaviour of contacts

From a mechanical point of view, electromagnetic contacts are to some extent flexibly arranged masses. That says it all. When the contact bounces or moves it begins to oscillate; which means that for a short time it opens and closes until it reaches a steady state (relays in a range from 0,2 to approximately 5ms) **[2]**.

Fig. 4
Relay function



Contacts bouncing :

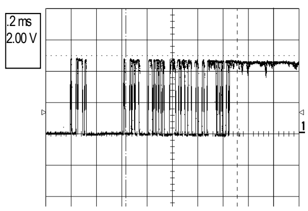


Fig. 4a Switching-on

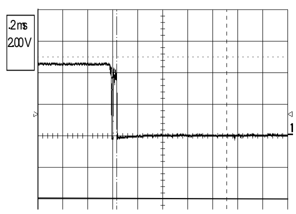


Fig. 4b Switching-off

The events described below have the following results:
In a switching on event, very fast electric state change are forced on a conductor: voltage spikes, with values equivalent to the values of the mains, are always tied with electric fields and therefore currents, and with them their magnetic fields associated. The bounce intensifies the EMI effects.
It is now, in principle, a matter of an harmonics event, that in effect corresponds to a frequency spectrum that can reach up to VHF and UHF range.
Side effect radiation causes inductive disturbance in adjacent conductors (inductive and capacitive coupling).
The temporary interdependence across long wires can be sufficient to activate control inputs of, for example PLC's, with a corresponding parallel control signal, and also the inputs of fast counters, positioning equipment, etc..

Types of loads

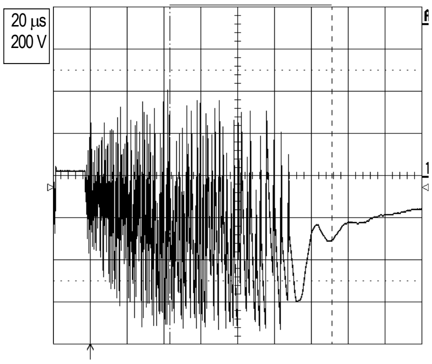
Electrical loads are be classified as follow:

- Resistive load, e.g. incandescent lamps, heating installation
- Inductive load, e.g. relays, contactors, electromagnetic valves, magnetic couplings
- Capacitive load e.g. compensated lamps, capacitors

Whilst behaving normally in steady state, the situation during switching on and off changes:

- Every conductor qualifies as a complex circuit of capacitance, inductance and pure resistance
- An incandescent lamp shows an inrush current up to twenty times larger
- A motor will generate an inrush current of four to eight times the nominal operating current and additionally there is still a switching off peak current of higher energy.

When switching on with an electromechanical contact one contact softly touches the other and a spark is generated, and it causes some molecules from the surface of the contact to melt and to settle either on the other contact or on the housing. In technical words, melting material and migration **[3]**.
When switching off something similar. In that particular instant when the contact surface separates, a high current density take place and for a short time the switching off voltage overcomes the gap and produces a spark with the same effects, which again means contact melting and material migration. **[3]**
This phenomenon is obviously highly dependent on the switching current and voltage, in other words, the load.
Depending on the type of load, capacitive or inductive, these effects can be even stronger.
If follows that the switching off operation (the actual opening of the contacts) may not happen immediately because the arc might not be extinguished (load curve). This occurs especially with inductive loads.
What does that have to do with Electromagnetic interference (EMI)?
Premature locking, reliability and maintenance of a contact are one thing. Another theme is EMI.
It is known that electric sparks can produce high frequency oscillations which qualify as data transmission **[4]**. In our case the data obtained has a very simple name: "EMI interference".
It must be borne in mind that the duration of one simple switching event is certainly short (around 100µs), however the apparent HF effect can indeed be significant.



The picture shows the voltage on a switched industrial DC24V relay's coil.
During 120µs high frequency oscillations takes place a with a frequency rate up to 1MHz and an amplitude of around 1000 Vpp.
Peak values up to 2000V are possible depending on the layout.

Fig. 5 Switching-off voltage

Because in a complex facility such switching events can overlap with other phenomenon, something must be done in order to smooth this generated distortions.
Note: By coupling several switching process, it is possible to bypass conventional and time delay measurements e.g. 5 ms at the PLC input.

Connection

In principle, if a disturbance-causing load is to be connected, then it makes sense to minimise the disturbance emitting cause.
Frequently one speaks about the use of a suppressor circuit, which comes down to the same.

– Capacitive load

Neither a parallel diode or a RC-module helps in this case. A measurement of help is provided by the provision of resistors in series or by means of a small choke to avoid the high inrush current and therefore the spark that causes the EMI and the resulting melting of the contacts. If nothing else is possible, it may be necessary to use sequenced starting such as soft start or star-delta starter used in motors.
If a load is to be switched with a small relay over a long cable run, a small series resistor is recommended.

– Inductive load

The goal here must be to ensure that the stored magnetic energy does not extinguish itself in the arc during the opening of the contacts.
This can be accomplished with a freewheeling diode (DC) or an RC-module (DC/AC) parallel with the load.
Using a diode will still incur steep voltages rise but at the height of the operating voltage, an RC-module will smooth voltage slope.
Sparking during switching off can be avoided if the voltage rise rate is slower than the speed of the contact.
This way the full switching load capability of the contact can be achieved or even exceeded – the same as with ohmic load.
Because with RC–modules a reduced the flank slope is achieved, the distorting frequency spectrum is strongly limited (to a few hundred Hertz) thereby preventing the emission of glitches from connected conductors as well as non-conductors.

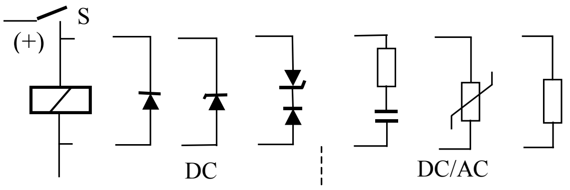


Fig. 6 Types of connection, e.g. an industrial relay (inductive load)

Comment

Obviously, it is possible to switch, for example an RC-module, parallel to the contact. However that could lead to possibly inadmissible residual currents that can cause a malfunctioning in event of a fault. This is definitely not recommended. The connection should come, for obvious reasons, if possible, from the source.
In principle, the connection should extend the off delay time of a relay, contactor or electromagnetic valve.
A diode across a DC coil's relay generate an off delay time that is from 3 to 5 times longer, which means that instead of the usual 10ms (industrial relay) it is now 30ms. This has to be considered in the logic.
The simple connection option with a resistor – inexpensive and reliable – is appropriate in cases of low operating voltages and for short start-up time, therefore it is only used in the automobile industry.
There are, of course, others connection combinations possible, for example with Zener diodes or a combination of diode plus RC-modules.
Usually the RC-module is of small dimensions if the life expectancy of the contact is to be achieved. RC-modules are relatively expensive (see appendix).
The load should never be connected with just a simple capacitor, this may help with the switching off but problems could arise at the time of switch-on.
Figure 7 shows the voltage curve at the relay coil of a standard industrial DC24V relay with a diode. It clearly shows that the off delay time is approximately 30ms (1V over the diode = current in the coil). The figure 7b shows the voltage curve with an RC-module (0,25µF + 470Ω). Despite the relatively large RC-module it can be seen that still quite high self-inductive peak (70V) arises. It is important to point out the damp sine oscillation curve produced with a resonance frequency of approximately 125Hz. The relay closes after a standard off delay time plus approx. 4ms because the current is practically zero. With such steep flank, no more sparks occur and no electromagnetics distortions!

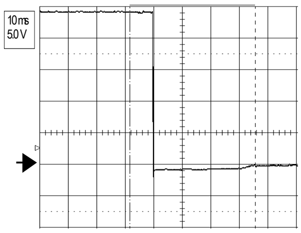


Fig. 7a Diode connection

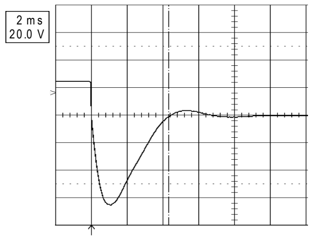


Fig. 7b RC connection

Calculating the suppressor circuit

When calculating the components for a protective circuit, in particular diodes or VDR's, is important to consider that any additional energy released by neighbouring equipment during the interruption of a higher circuit, for instance during a fuse failure, must be absorbed.

RC-modules

If an RC-module is chosen, as well as considering the EMI aspect, the life expectancy of the contact must also be considered. To achieve sufficient EMI suppression, small capacitances are enough (<0,1µF). However, if the contact's life expectancy or a higher switching off voltage is considered, then a larger capacitance is necessary. For appropriate dimensions, the following simple proceeding can be recommended:

Capacitance in [µF]:
Corresponding current in [A] (≥0µ1).

The operating voltage selected is probably either AC125V or AC250V.
Resistors for operating voltage up to 60V: 100Ω;
for voltage up to 250V: 470Ω.
Note: Inductance of the parallel RC-module can show resonance effects with unwanted consequences (see appendix).
If the RC-module is used, the capacitor should be X2 type and the resistor be of the pulse-withstanding type e.g. carbon composition resistor.

Diodes

Decisive for the design criteria is forward current and the reverse blocking voltage. The permissible forward current should at least correspond to the maximum operating current. The off-state voltage should be at least twice the $U_{operating}$, but never under 200V. Problems can be encountered because diode with low reverse voltage can be overloaded due to external coupling. In general, it is recommended to use the well known and low price 1N4007 diode with reverse voltage of up to 1000V and

peak current over 10A/10ms.
Transients over 1000V will also affect the diodes. A diode performs satisfactorily in standard application up to 24V/1A enhancing the life expectancy of the contact.
By choosing a Zener diode, the peak current given in the data sheet has to be considered. In case of doubt the introduction of a suppression diode (pulse-withstand type) should be taken in consideration. A combination of circuits can be implemented to reduce the off delay time.

Varistors

When using varistors the main design criteria should be the maximum operating voltage, e.g. 1,5 x $U_{operating}$. Usually the AC voltage is imprinted on surface of the components. It is important to bear in mind that under no circumstances are VDR`s suitable to limit the supply voltage. In addition, VDR's should not normally be switched in parallel. It is important not fit an under sized unit (e.g. small diameter) as this causes premature dying and failure. Therefore, a varistor with a diameter smaller than 10mm should not be used.
Example:

A 10mm type AC275V is able to bear a single pulse of over 60A/1ms once, but only approximately 7A/1ms for an unlimited repetitive period. The continuous energy dissipation of a 10mm type amounts to just 400mW.

Summary

In principle, all inductive loads switched with contacts should be connected in control systems. This practice avoids the disturbing influences and substantially extends (with correct dimensions) the life expectancy of the contacts.
The correct connection saves time and money on laborious error tracing and corrective measurements and maintenance which may be needed later. Additionally, many EMI problems are avoided.

Appendix A
Interference's influence through not connected loads/contacts

Contact bounce comparison according to a 3 pole 10A industrial relay

Sample 11 pol. Standard **Sample Min. Ind. Relay**

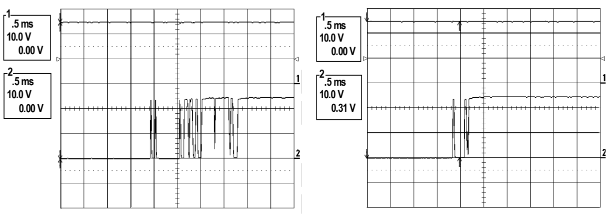


Fig. A1 Switching-on

Sample 11 pol. Standard **Sample Min. Ind. Relais**

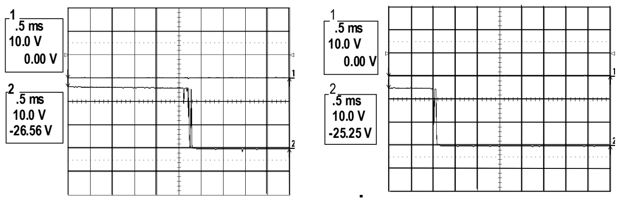


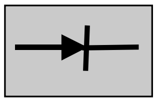
Fig. A2 Switching-off

Comment

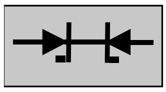
The two graphs show the response behaviour based on a typical sample. Even though a lot of scattering is to be expected over the series, there are considerable temporary variations due to differences in the design.
It is certain that these differences not only affect the noise behaviour and the noise spectrum, but also the life expectancy of the contacts with electrical load.
Such differences suggest thus also different qualities. Also, attention must be given to the fact that bouncing and the resulting noise spectrum can change during the life span.

Overview of the most usual connections

Diode: Only **DC**

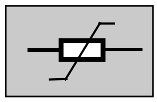


Low price
Very effective for the contact's life expectancy up to approx. DC24V/1A
Min. reverse recovery (<1V)
Extend off delay time in a factor of 3...10



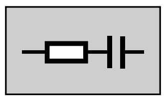
Diode solution for **DC** and **AC**
Minimal reverse recovery voltage
Approx. 1,5 x $U_{operating}$

Varistor: For **AC** and **DC**



Good price
Good effectiveness for EMI
Medium reverse recovery voltage
(approx. 2 x U_O)
Effective pulse spike limitation
Short off delay time
Low effect on life expectancy extension
Capacitive load

RC-Module: For **AC** and **DC**



Relatively expensive
If correct applied very effective in the life expectancy of component
Relative high reverse voltage
Minimal interference frequency spectrum
Medium off delay time
Resonance effect must be taken into account during leakage current damping

Note:
There are also other circuits possible. In the low voltage range it is found resistors that are simply switched in parallel. An RC-module with a diode allows minimal reverse voltage of a resistor, etc.

Varistors (VDR) typical capacitances

The varistors are classified according to their diameter, in other words, to their power capability.
They are distributed by different manufactures and have compatible characteristics.

Selection:

05mm/0,01W **AC30V**/DC38V	**700pF***	**05mm**/0,10W **AC275V**/DC350V	**50pF**
07mm / 0,02W / **AC30V**/DC38V	**1200pF**	**07mm**/0,25W **AC275V**/DC350V	**95pF**
10mm/0,05W **AC30V**/DC38V	**2750pF**	**10mm**/0,40W **AC275V**/DC350V	**195pF**
14mm/0,10W **AC30V** / DC38V	**4950pF**	**14mm**/0,60W **AC275V**/DC350V	**320pF**
20mm/0,20W **AC30V** / DC38V	**9350pF**	**20mm**/1,00W **AC275V**/DC350V	**630pF**

*Nominal data by 1kHz **[5]**

The capacitance helps to limit the high frequency spectrum, however it produces inrush current peak when switching on.

Example to limiting with VDR:

Type: **10mm** AC 30V/DC38V: **93V / 5A**
10mm AC 275V/DC350V: **710V / 25A**

By frequent switching, it has to be ensured that the medium switch-off energy does not exceed the maximum stress of the VDR because this would reduce the life expectancy.

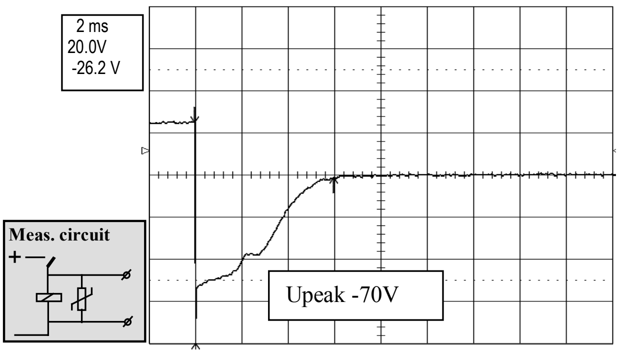


Fig. A3 Peak voltage with varistor. Self inductive voltage measured in a standard 3 pole industrial relay, DC24V. Wired with a VDR Type: 20mm/ AC30V (DC38V).

Comparison - energy consideration in inductors

Example of industrial relay / PLC input

Formula: $X_l = \sqrt{Z^2 - R^2}$; $X_l = \omega L$; $W = 0{,}5\,L\,i^2$; **[6]**

$W = i\,u\,t$ **[6]**

Three pole standard – industrial relay (11 pin)

AC230V version:

Typical values

Current consumption at 230V/50Hz:	10mA
Ohmic resistance:	6,28kΩ
Resulting inductivity:	**70,4H**

The maximal energy is:

$W = 0{,}5 \times 70{,}4H \times (0{,}01A \times 1{,}414)^2 = 0{,}00703Ws$

W = 7,0mWs

DC24V version:

Typical values

Current consumption by AC 30V:	12,5mA
Current consumption by DC24V:	57mA
Ohmic resistance:	419Ω
The inductivity comes to:	**7,5H**

The maximal energy is:

$W = 0{,}5 \times 7{,}5H \times 0{,}057A^2 =$ 0,0122Ws

W = 12,2mWs

Energy needed to activate a PLC's input:

Typical values:

Pick up voltage:	16V
Input current:	5mA
Control pulse:	10ms

The energy results:

$W = 16V \times 0{,}005A \times 0{,}010s = 4\ 10^{-4}Ws$

W = 0,8mWs

Comparison

Result: $W_{Relay} >> W_{Pick\ up}$ **!**

Frequency consideration when connecting inductive loads with RC-modules

The nominal inductivity values, depending on the type or model used, can have a deviation of up to 25%. The frequency consideration is not just a matter of EMI. An RC-module can show resonance in the range of the frequency and/or possible existing harmonics waves (2^{nd}, 3^{rd} harmonics) causing an AC relay to hum or not to open. In extreme cases, a relay connected with long lines could even actuate.

The resonance frequency is given by:

$$f = 1 / (2\pi\sqrt{C\,L}) \quad [6]$$

Example industrial relay

Three pole standard industrial relay (11 pin)

AC230V version:

Current consumption at 230V/50Hz:	7,1mA
Ohmic resistance:	7,4kΩ
Resulting inductivity:	**100,4H**

With a connection of:

10nF - resulting resonance frequency is:	**159Hz,**
100nF - resulting resonance frequency is:	**50,25Hz**

DC24V version:

Current consumption at AC30V:	12,5mA
Current consumption at DC24V:	57mA
Ohmic resistance:	419Ω
Resulting inductivity:	**7,5H**

With a connection of:

10nF - resulting resonance frequency:	**580Hz**
100nF - resulting resonance frequency:	**184Hz**

→ **These frequencies leads to practically no radiation and no cross modulation!**

If the frequency is selected low enough, i.e. a slower du/dt which means a larger C, then the contact can open, and no more spark at switching off will occur. This applies also for DC loads.

→ **Longer contact life expectancy!**

Resulting reverse voltage

Calculating the resulting reverse voltage with an RC-module can be done simply by comparing the energies (neglecting the resistances):

$$W_L = W_C \qquad 0{,}5\,L \times i^2 = 0{,}5\,C \times u^2\ ;$$

$$\text{From that:} \quad u = \sqrt{i^2 \times L/C} \quad [6]$$

Reset delay time with /without connections. Typical values

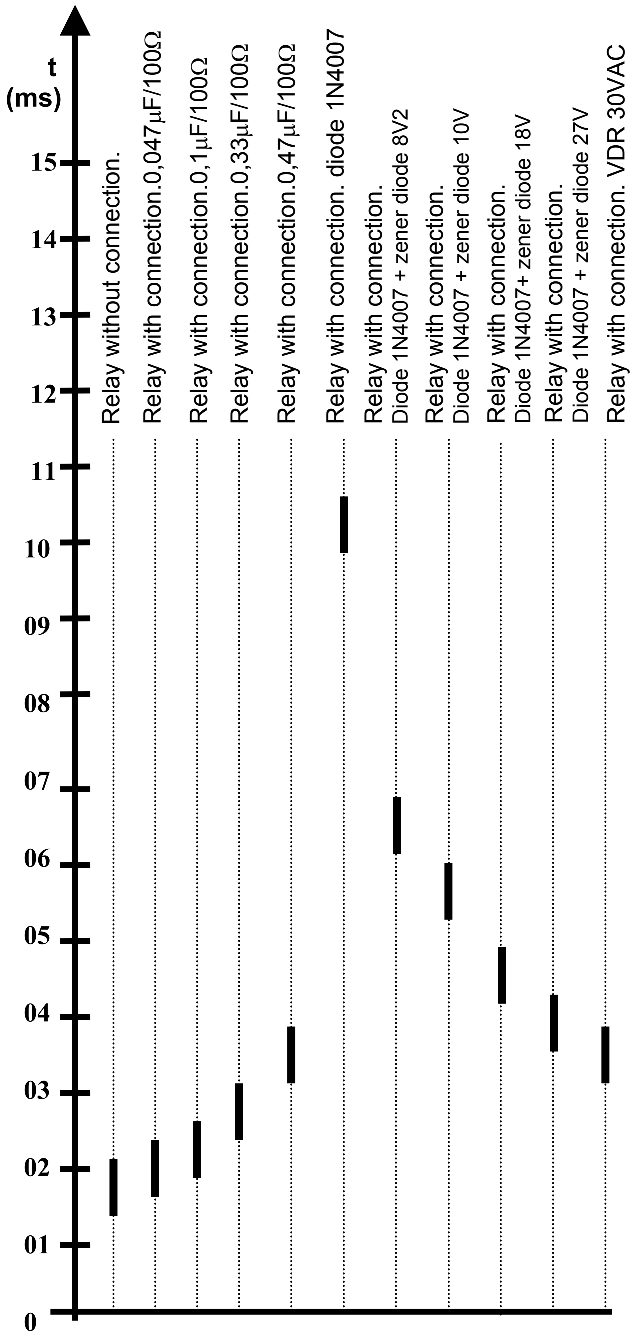


Fig. A4 Off delay time with/without connection as example an industrial relay (according to measurements on a miniature industrial relay. Type: 2 poles 10A)

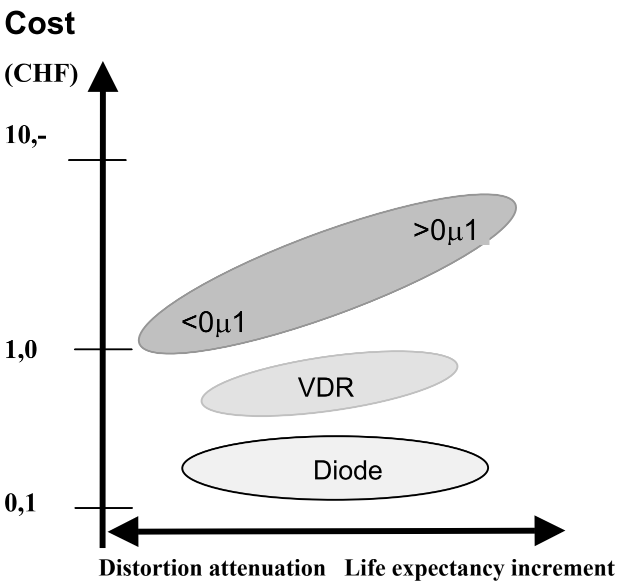


Fig. A5 The different connection Cost / efficacy relationship

Note:

Diode

Diodes work very well up to DC24V, 1A (electromagnetic valve etc.), beyond this value arc suppression is not sufficient.

VDR

VDR work in the first instance through their self capacitance, but in the long term it can give switching on problems.

RC-Module

RC-modules work very well. To avoid distortions it only requires small capacitances. A minimum of 0,22µF should be provided to increase the life expectancy.
As a rule of thumb, approximately 1µF / A should be used.
The resistor should not be too large. The maximum inrush current before activation of the contact must be considered.
Resistors values from 47Ω to 470Ω are usually not critical.

Literature

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