

## PROBLEM WITH OUTPUT RELAYS USED IN MICROPROCESSOR-BASED PROTECTION DEVICES: WHAT TO DO?

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*Друга публікація автора на тему про невідповідність параметрів субмініатюрних вихідних реле мікропроцесорних пристроїв релейного захисту реальним умовам експлуатації і стандартам, що діють. У даній статті пропонуються заходи по уточненню стандартів, а також приводяться конкретні технічні рішення цієї проблеми.*

*Вторая публикация автора на тему о несоответствии параметров субминиатюрных выходных реле микропроцессорных устройств релейной защиты реальным условиям эксплуатации и действующим стандартам. В данной статье предлагаются меры по уточнению стандартов, а также приводятся конкретные технические решения этой проблемы.*

### INTRODUCTION

Conversion from electromechanical and static to microprocessor-based protection devices (MPD) is frequently accompanied by a number of the technical problems, usually unknown to the consumer [1]. One of these problems is nonconformance of subminiature electromechanical relays (SER), used as output elements of MPD, to the parameters specified in the MPD data sheet, actual standards, and real operation conditions. This problem has been investigated by the author in [2]. After the publication of the results of this research the author discovered an earlier publication [3] in which experts from Vector Power Solutions Ltd, General Electric and National Grid Transco also noticed these discrepancies. In addition, the author has received responses to his article [2] from experts of SER Manufacturers, from the Technical Committee 94 (All-or-nothing electric relays) of the IEC; and from other specialists. Thus, we can assume that the existence of this problem is confirmed and recognized by the international engineering public.

The purpose of this publication is researching ways to solving this problem.

#### 1. NONCONFORMANCE PARAMETERS OF MPD OUTPUT CONTACTS TO PARAMETERS OF SER

1.1. As MPDs are devices that work only in emergency modes, the frequency of their operation and total number of operations for all service life are very insignificant (we shall show,  $10^3$  operations) in comparison with the normal number of the operations allowable for SER ( $10^5 - 10^6$ ). As erosion of contacts at switching has a cumulative character it is abundantly clear that SER manufacturers set limitations on the switching ability of contacts, proceeding from what is accepted as usual for them (that is a large) number of operations. It is therefore possible to expect that for a number of operations 100 - 1000 times less than what is usually accepted for SER, "the top rod" in limitations on their switching ability can be essentially increased.

1.2. An especially heavy mode for SER contacts it is considered a mode of switching of inductive loads at DC voltages as high as 125 V and 250 V (standard voltages

of a DC system on substations and power stations). According to the data sheet on SER, used today in MPD, none of them can be used for work in such conditions. This limitation is absolutely correct in the formal view and completely supported by manufacturers. However, when taking into consideration this question it is necessary to take into account, that "switching" for SER must be understood as a "full cycle", that is both part of the "switching" cycle inclusive: and making and breaking of a circuit. Actually, in the full cycle mode in MPD works only the contacts of the internal SER which intended for control of other (outside) auxiliary relays.

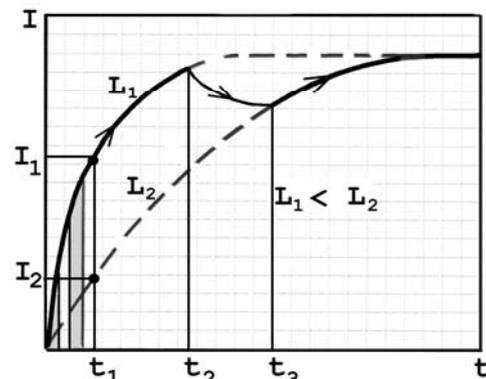


Fig. 1. Dependence of current ( $I$ ) breaking at contacts bouncing during making process from inductance ( $L$ ) of load.

$I_1$  – current breaking at low inductance of load;  $I_2$  – current breaking at high inductance of load;  $t_1$  – bouncing period;  $t_2$  – start moving of core in trip solenoid;  $t_3$  – stop moving of core in trip solenoid

The most powerful MPD contacts are intended only for turning-on (making) without breaking the trip coil of the high-voltage circuit breaker (CB). Disconnection (break) of the trip coil circuit from the DC power supply is carried out by own powerful auxiliary contacts of the CB. Hypothetically only, making of contacts does not affect the electric arc between the contacts and consequently there should not be any special limitations for turn-on of inductive load at a DC voltage of 125 - 250 V. The problem appears because the actual contact making process is accompanied by repeated impacts (making) and

bounces (breaking) of contacts. In other words, there is no "pure" turn-on without turn-off – it simply does not exist. Even single breaking at mentioned above conditions (an inductive load of 10 – 15 A at DC voltage 125 - 250 V), will produce a high energy electrical arc between SER contacts which may weld them together. In addition, at enlarging of load inductance, the more energy exuded on contacts increases the probability of welding. For this reason, the DC switching capability specified in the data

sheet on SER for active load at voltages up to 30 V only, may not even close them to required values. This is also the reason that there are not any separations between various kinds of switching modes because of the danger of even single switching-off with a powerful arc on contacts. It is interesting that this approach is accepted not only by SER manufacturers, but also by the corresponding committee on standardization at the IEC.

Table 1

Switching capability of subminiature electromechanical relays using in MPD

Subminiature Electro-magnetic Relay Type	Maximal Switching Power (for resistive load)		Rated Current & Voltage (for resistive load)		Make Current for Inductive Load (L/R) In Mode with Very Infrequent Making Cycles ( $\leq 1000$ )			
	AC	DC	AC	DC	125 VDC		250 VDC	
					10 ms	25 ms	10 ms	25 ms
ST	2000 VA	150 W	8 A; 380 V	5 A; 30 V	?	?	?	?
JS	2000 VA	192 W	8 A; 250 V	8 A; 24 V				
RT2	2000 VA	240 W	8A; 250 V	8A; 30 V				
RYII	2000 VA	224 W	8A; 240 V	8A; 28 V				
G6RN	2000 VA	150 W	8 A; 250 V	5 A; 30 V				
G2RL-1E	3000 VA	288 W	12 A; 250 V	12 A; 24 V				

However, by more detailed consideration of this problem, it would appear that this situation is no so unequivocal, and more likely paradoxical, because at turn-on of the inductive load by relay contacts the current through the contacts increases smoothly. Increasing inductance causes the current to increase more slowly. At the same time, contact bouncing with impact occurs only at the initial stage of the making process, prolonging a very much limited time period, usually not exceeding 3 -

4 ms for subminiature relays and not dependent on load inductance. This brings about a paradoxical situation: the more inductance of load, the less the value of current that is broken off by contact bouncing during the making process (fig. 1). This means that the standard reasoning stated above in that specific situation is not relevant and the real capacity of the SER contacts making an inductive load may be much higher.

Table 2

Switching capacity of contacts depending on the type of load for control electromagnets, valves and solenoid actuators

Utilization Category	Type of current	Switching capacity of contacts in the mode of normal switching					
		Make (switching ON)			Break (switching OFF)		
		current	voltage	cosφ	current	voltage	cosφ
IEC 60947-4							
AC-15	AC	$10 I_N$	$U_N$	0.3	$10 I_N$	$U_N$	0.3
DC-13	DC	$I_N$	$U_N$	-	$I_N$	$U_N$	-
Switching capacity of contacts in the mode of infrequent switching							
AC-15	AC	$10 I_N$	$1.1 U_N$	0.3	$10 I_N$	$1.1 U_N$	0.3
DC-13	DC	$1.1 I_N$	$1.1 U_N$	-	$1.1 I_N$	$1.1 U_N$	-
Switching capacity of contacts for 1000 making cycles							
DC-13	DC	?	?	$L/R \leq 10$ ms	-	-	-
	DC	?	?	$L/R \leq 20$ ms	-	-	-
	DC	?	?	$L/R \leq 40$ ms	-	-	-

$I_N$  and  $U_N$  rated values of currents and voltages of electric loads switched by relay contacts

Because MPD are very important and crucial devices which determine working ability of a major sector of the economy, urgent research for functioning SER contacts in this specific mode is necessary. On the basis of this research SER companies-manufacturers should add technical specifications to relays in a mode of very infrequent making of inductive loads at DC voltages of 125 and 250B (tab. 1). If, besides bringing MPD manufacturers to audit technical specifications and eliminate obvious

mistakes regarding switching capability of the output relay contacts described in [2], there can be a difference between the parameters written in the specifications of MPD and SER, will actually not too great.

## 2. NONCONFORMANCE TO ACTUAL STANDARDS IN MPD OUTPUT CONTACT PARAMETERS

Some standards considered as universal, for example IEC 60947-4, and also the new 3 edition of IEC standard 61810-1 (presently applied at the stage of consideration) the relay contacts switching capability (in category DC-13), when corresponding to a mentioned mode, consider separately make and break inductive loads. According to these standards the switching capability of these contacts for make and for break is identical and equals 100% of rated current in a mode of normal switching, and 110% in a mode of infrequent switching. Such ratios ob-

viously specify that at their definition the phenomenon of bouncing contacts and probability of circuit breaks with an inductive load at a full current were taken into account. That is, without taking into account the conclusions formulated in 1.1 and 1.2. In a concrete considered mode, it is possible to allow, apparently, considerably higher currents at make contacts. In our opinion, these standards should be edited by adding, in view of the above mentioned reasons, a special switching mode, used in MPD (tab. 2).

Table 3

Parameters of some modern thyristors, suitable for using as output elements of MPD

Thyristor type		BTW69-1200	40TPS12	CS 60-16io1 CS 60-14io1 CS 60-12io1	70TPS16 70TPS12
Max. repetitive off-state peak voltage, V	$V_{DRM}, V_{RRM}$	1200	1200	1600 1400 1200	1600 1200
Max. on-state rms current, A	$I_{T(RMS)}$	50	55	75	75
Peak, ½ cycle (sine) non repetitive surge current, A	$I_{TSM}$	580	500	1500	1200
Max. peak forward on-state voltage (voltage drop), V	$V_{TM}$	1.9	1.85	1.4	1.4
Max. holding current, mA	$I_H$	150	150	200	200

### 3. IMPROVEMENT OF MPD BY MANUFACTURERS

Carrying out of all the necessary stages of SER testing in the specified mode, entering corrections into the technical documentation, and especially correction of standards, is a long enough process, which can take years. During this time the problem may be solved by MPD manufacturers independently, with no connection to this process. We shall consider probable ways for solving this problem.

3.1. Using of compact relays intended specially for switching inductive load at 125 – 250V DC. For such ability the contact system of the relays incorporated a blow-out magnet, placed between contacts. Magnetic field of the magnet interacts with DC arc between contacts and rapidly repulsing it away from the contacts at their breaking. Many companies produce such relays today, fig. 2. Some of them are suitable for installation on the printed-circuit-board (PCB). For example, the JC2aF-H73 type, produced by Matsushita, IG2C-24VDCM type, produced by Kuhnke, etc. Application of such relays can appear effective not only for making of the CB trip coils used in usual schemes, in view of what was stated above, but much more for making of these coils in a special schemes with the forcing capacitor which creates a high current pulse through the coil (and contacts, of course) in the initial stage of the making process for it acceleration, fig.3. For this specific but widely used scheme, mentioned above, the reasoning regarding small current value is that breaking by contacts at bouncing in the initial stage of the process is not so relevant, therefore using of such relays may be very effective.

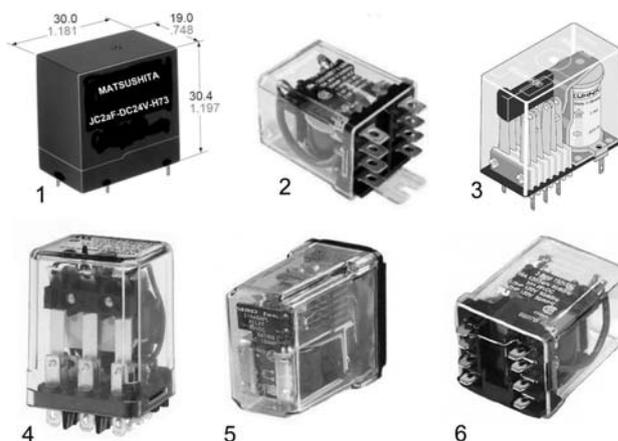


Fig. 2. Compact relays with blow-out magnets suitable for switching inductive load at 240 VDC:

- 1 - JC2aF-DC24V-H73 type (Matsushita); 2 - 300 series (Magnecraft); 3 - IG2C-24VDCM type (Kuhnke); 4 - KUEP-3D17-12 (Potter & Brumfield); 5 - 219 series (Magnecraft); 6 - A283 series (Magnecraft)

3.2. It is desirable to wider usage thyristors for currents of 30 - 70A and voltages of 1200 – 1600V, complete with varistors, as the powerful output contact of MPD which intended only for making (without breaking) the trip coil of the circuit breaker. Modern thyristors with such parameters (tab. 3), have small sizes (fig. 4), and in view of the short duration of current passing through them, can be used without Heatsink.

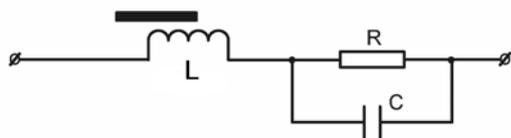


Fig. 3. A circuit diagram for forcing switching of the CB tripping coil ( $L$ )

Thyristors should be chosen with a hold current of not less than 50 – 70 mA and they should not remain in the conductive condition under action of small-current so-called "supervision relays", supervising serviceability of all trip circuits by means of having a small current passing through it (approx. 15 – 20 mA). Thyristors have the best overcurrent and overvoltage capability in comparison with power transistors, IGBT, FET.

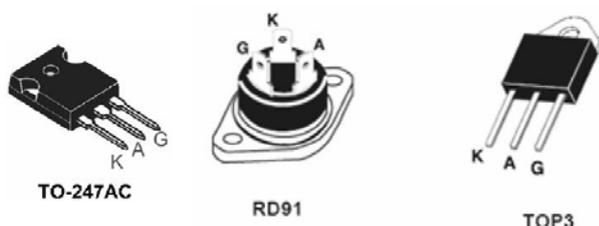


Fig. 4. Modern thyristors for switching current 30 – 75 A at 1200 – 1600 V, made in a compact cases

3.3. In perspective, the decision should be, in MPD, to use hybrid devices containing a SER contact and a solid state switching element, connected in parallel. One of these devices is suggested by the author in fig. 5.

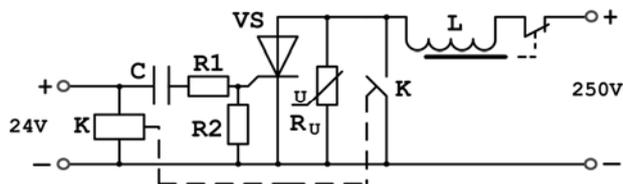


Fig. 5. Circuit diagram of hybrid element intended for energizing trip coil at 250 VDC

In this device the control signal is put to a winding of the SER and simultaneously charges capacitor  $C$ , through a limit resistor ( $R1$ ) and the gate circuit of thyristor  $VS$ . The thyristor instantly opens by means of this charging current (with a delay of some microseconds) and picks-up the CB trip coil  $L$ . Contact  $K$  closes and shunts the thyristor through 7 – 10 ms (the own time of operation of the SER). The current of trip coil  $L$  flows to a circuit of contact  $K$ . At the beginning of this process there is an opening of contacts at bouncing, inter-contact resistance, and the voltage on the contacts start increasing. This voltage is put to thyristor  $VS$ . At an increase in this voltage of up to 5 – 7 V the thyristor again instantly opens as this time the capacitor  $C$  has not yet been completely charged and charging current continues to flow through the gate of the thyristor. The capacity  $C$  and resistance  $R1$  leave this condition in order to guarantee a thyristor gate current of about 50 – 70 mA during 15 - 20 ms, that is, before the full termination of contact bouncing. Thus, during the

contact making process there is no break of the trip coil circuit and there is no arc on the contacts. After full charge of the capacitor, the current in the thyristor gate circuit stops, is finally locked and no longer influences the condition of the load (trip coil) circuit. At disappearance of the control signal at the input of the device the capacitor is discharged through the coil of the relay  $K$ .

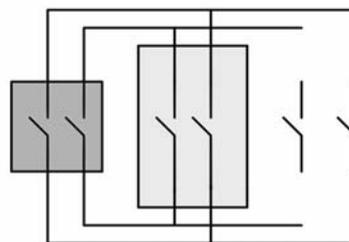


Fig. 6. Connection in parallel-in pairs contacts from the relay of various types for excluding of bouncing

3.4. As the basis of the problem of switching-on of the trip coil is the bouncing of contacts, accompanying short-term breaks of current during the making process, the natural solution of this problem could be to compensate these breakages with a combination of two contacts connected in parallel with the various parameters of vibration which are not conterminous on a phase (fig. 6).

It is abundantly clear that if connected in parallel-in pairs, contacts of relays of various types, with various mechanical properties of contacts, we can predict with practically full confidence that it is possible to guarantee unconformity in the phase of bouncing that is absent of breaks of circuit during the switching-on of inductive load. MPD manufacturers can take arms on this principle, using in the their products usual SER as described above, and SER manufacturers can produce relays containing, in the single case, two contacts with different rigidities or weights, in which vibration at bouncing does not coincide on a phase, having connected both these contacts in parallel.

3.5. Power reed switches with increased switching capability have now appeared in the market (fig. 7) and the relays on which they are based could be used with success as output contacts in MPD.

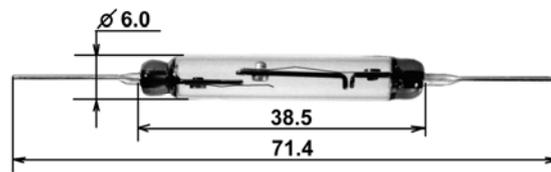


Fig. 7. Power reed switch R14U and R15U (Bestact™, produced by Yaskawa) with two-stage contact system for switching inductive load

Such reed switches with a rated current of 5A are capable not only to make, but also to break circuits with inductive loads at 230V DC. For example, they are capable of switching-off 0.4 – 0.6 ADC with a constant time of 40 ms. That it is quite enough for their usage as the auxiliary contacts of MPD intended for control by external auxiliary relays. The operating time of these reed

switches does not exceed 5 ms, bouncing time not more than 2 ms; switching cycles number 50 - 100 million. It is obvious that when reducing the requirement of the number of switching cycles 10.000 times, we should expect an additional increase in their switching current (that should be confirmed with the manufacturer, of course). When choosing auxiliary output relays for MPD it is necessary to take into account that some of them will be used for switching of the coils of the external electromagnetic relays at 125 – 240 V DC, and some others for switching of low-voltage and low-current signals on logic inputs of other MPD. Usually that is not taken into account in any way by manufacturers of MPD, however, it is known that for switching powerful loads and for switching low-current, low-voltage signals contacts should have different properties and should be made from different materials. This is reflected in the technical specifications on SER. For example, a relay with powerful contacts will have limits on the lower threshold of a switched current and voltage, and this threshold frequently lays within the values used in practice for small level control signals. Therefore, two types of SER corresponding to two types of loads should be used as auxiliary output relays in MPD, as mentioned above.

3.6. Modern high-voltage IGBT transistors can be successfully used as powerful output auxiliary relays of MPD. The small sizes (plastic case TO-247 and similar types), have high values of collector current, high withstanding overvoltages, high power dissipation, and high allowable working temperatures of the crystal (tab. 4), making such transistors rather attractive elements for switching inductive loads (coils of external auxiliary relays) with a consumption of 0.1–5 A at 250 VDC. For overvoltage protection when switching inductive loads, such transistors can in addition be protected by varistors with a clamping voltage of 500-700V. As is known, some problems may arise when using IGBT transistors represented by the correct organization of their control circuits, however, today these problems are successfully solved and there are numerous drivers for controls of IGBT transistors on the market which are made as small modules, fig. 8. In such drivers, all necessary element are contained inside for reliable switch-on and switch-off IGBT transistors.

Single modules of this type and two IGBT transistors, form analogues of high-quality changeover contacts, galvanically isolated from the internal control circuits of the MPD.

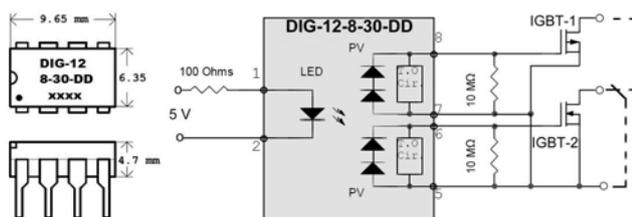


Fig. 8. Modern galvanic isolated driver for controls of pair IGBT transistors, formatives single changeover contact

There are in the market also completely assembled modules (solid-state relays on basis of IGBT technology)

ready to use at 250 VDC. These modules have the biggest sizes (58.4 x 45.7 x 22.9 mm) than the single IGBT with the driver but can be used in MPD of anyone design as do not demand the printed circuit board or any addition elements for their installation, fig. 9.

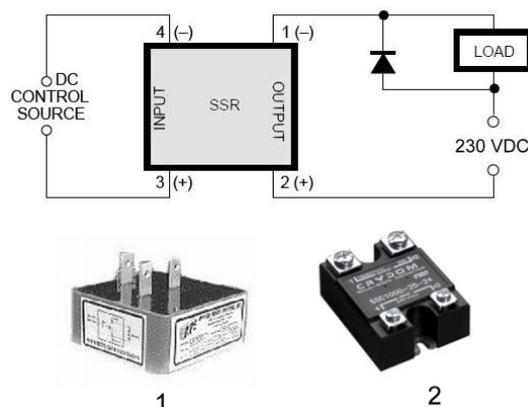


Fig. 9. Solid-state modules for switching of inductive load at 250 VDC:

- 1 – APSW-DC75 type (Applied Power Systems);
- 2 – SSC1000-25 type (Crydom)

Both these modules have a high current and over-voltage capability (75A, 1500 V - for 1, and 25A, 1200 V – for 2), that made them suitable for usage in MPD.

#### 4. IMPROVEMENT OF MDP BY THE OPERATIONAL STAFF OF POWER SYSTEM

One elementary solution of the problem of MPD output contacts, including switching-on the CB trip coil, could be to use an external power amplifier of an elementary type, inserting it between the output contact of the MPD and the trip coil (fig. 10).

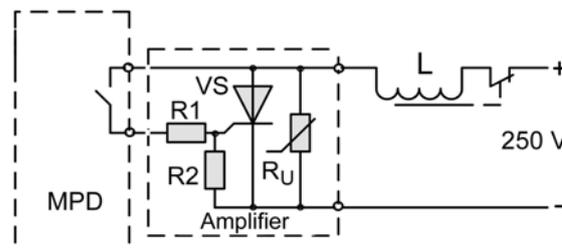


Fig. 10. Simple switching amplifier on single thyristor for trip coil energizing

When the single output MPD contact must switch-on group of trip coils belonging to different circuit breakers, it is possible to use a power demultiplexer on thyristors (fig. 11) connected to the output of the above mentioned amplifier.

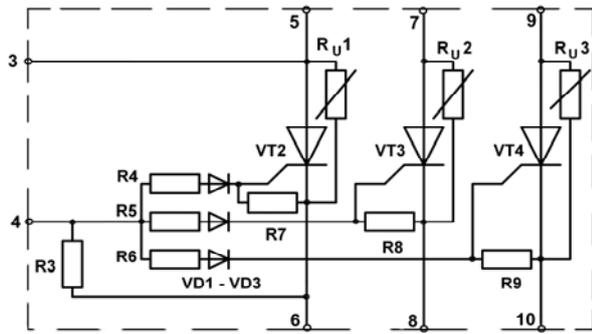


Fig. 11a. Power demultiplexer on thyristors for switch-on the group of trip coil

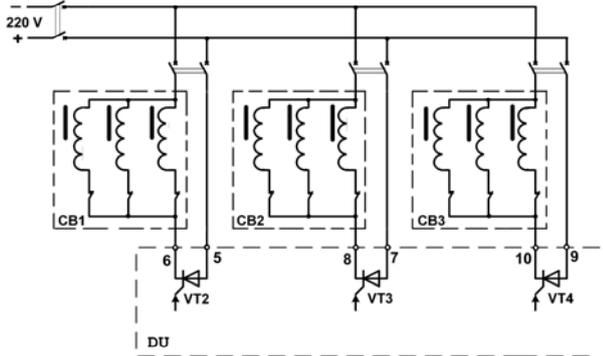


Fig. 11b. Circuit diagram for external connection of power demultiplexer (DU). CB1, CB2, CB3 – three phase circuit breakers

For contacts of auxiliary relays (which require not only switching-on, but also switching-off the inductive load) arc protective modules of the passive type, connected in parallel to contacts of the relay, can be used, for example an RC-circuit of self-made or industrial types (fig. 12), manufactured by many companies.

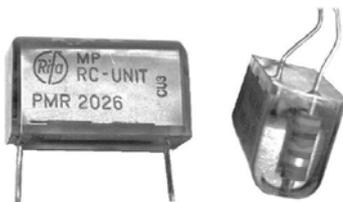


Fig. 12. Passive arc-protective module contains series connected R and C elements (produced by RIFA)

More effective protection of relay contacts against an electric arc is provided by protective modules of the active type, containing semiconductor elements such as transistors (fig. 13).

Naturally, modules of this type are much more complex and expensive than modules of the passive type. Even a more simplified version of such a module (USA Pat. 5703743) contains two transistors (IGBT and FET types), one triac, three diodes, and three Zeners.



Fig. 13. Smart (active type) arc-protective modules SEL-9501 and SEL-9502 types (produced by SEL)

A more sophisticated updating (USA Pat. 6956725) consists of the current transformer, a rectifier bridge, and some capacitors and resistors in addition to the above-listed elements. Such modules are sold in the open market by Schweitzer Engineering Laboratories and can be successfully used by any consumer used MPD. The choice of type of protective module depends on the concrete parameters of the switching load. At "light" loads, with the time constant not exceeding 7-10 ms, elementary RC-modules can be used, and for heavy loads with  $R/L = 30 - 50$  ms, active type modules are more suitable.

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