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NONCONFORMANCE IN ELECTROMECHANICAL OUTPUT RELAYS OF MICROPROCESSOR-BASED PROTECTION DEVICES UNDER ACTUAL OPERATING CONDITIONS

Gurevich Vladimir, Ph.D
Israel Electric Corp., Central Electric Laboratory
POB10, Haifa 31000, Israel
Fax: (++1) 603-308-5909, E-mail: gurevich2@bezeqint.net

Мікропроцесорні реле захисту швидко витісняють традиційні електромеханічні і навіть електронні пристрої захисту практично у всіх областях електроенергетики. У статті розглядається одна з численних проблем мікропроцесорних реле: невідповідність параметрів вихідних елементів цих реле, виконаних на основі мініатюрних електромеханічних реле, реальним умовам експлуатації: комутації індуктивного навантаження (котушок вимикачів) при напрузі постійного струму 220 В і так звана "суха" комутація кіл управління. Запропоновано простий і надійний підсилювач спеціальної конструкції для збільшення комутаційної спроможності вихідних реле.

Микропроцессорные реле защиты быстро вытесняют традиционные электромеханические и даже электронные устройства защиты практически во всех областях электроэнергетики. В статье рассматривается одна из многочисленных проблем микропроцессорных реле: несоответствие параметров выходных элементов этих реле, выполненных на основе миниатюрных электромеханических реле, реальным условиям эксплуатации: коммутации индуктивной нагрузки (катушек выключателей) при напряжении постоянного тока 220 В и так называемая "сухая" коммутация цепей управления. Предложен простой и надежный усилитель специальной конструкции для увеличения коммутационной способности выходных реле.

Microprocessor-based relay protection devices are gradually driving out traditional electromechanical and even electronic relay protection devices from virtually all fields of power and electrical engineering. Whether this is good or bad may be open to debate (the advantages of microprocessor-based protection means over the traditional are far from being absolute or obvious) yet we must acknowledge that this is the general trend. While acknowledging this trend we must also note that microprocessor-based protection means do have several specific drawbacks. In this paper one of these problems will be discussed.

1. Microprocessor-based relay protection devices (hereinafter MRPD) with different functionalities (differential, distance protection, generators protection, capacitor banks protection, etc.), made by different leading companies in the world such as ABB, General Electric, Areva, Alstom, Cooper, and Crompton Instruments, were analyzed for compliance of output of the electromagnetic relays used in these MRPD, with the standard requirements and parameters set forth in the manufacturers' specifications and the actual operating conditions in the power systems.

2. It was established that in all types of MRPD electromagnetic relays of the same class were used as output elements: subminiature relays with one make or changeover contact enclosed in a sealed plastic box having dimensions of about 30 x 10 x 12 mm (Fig. 1). These are G2RL, RY6100 G6RN, RTE24012, ST2, JS and similar relays made by the Schrack, Omron, Matshshita, and Fujitsu companies. Normally the ***maximal values*** of switched voltage and switched current are marked on the bodies of the subminiature relays, in contrast to the maximal switching power and the type of current to which these current values are related, which are usually omitted. This creates a problem when choosing the relay since maximal switched power is not equal to the multiple of maximal switched voltage and maximal switched current. For adequate evaluation of the switching ability of such relays the accompanying technical documentation needs to be analyzed.

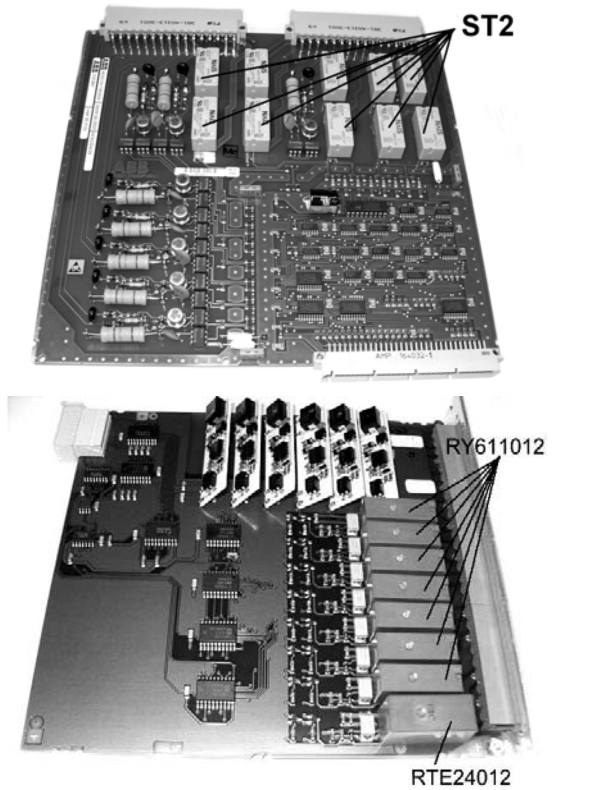

Fig. 1. PCB boards of MRPD with output electromechanical relays of different types

The results of our analysis of technical documentation accompanying these subminiature electromagnetic relays are presented in Table 1.
As can be seen from the table, all of the relays have limited DC switching ability and are only suitable for switching of merely active loads.

Table 1

Switching capability of subminiature electromechanical relays using in MRPD

Relay Type (Manufacturer)	Maximal Switching Power (for resistive load)		Rated Current & Voltage (for resistive load)		
	AC	DC	AC	DC	for 250 V DC
ST series (Matsusita)	2000 VA	150 W	8 A; 380 V	5 A; 30 V	0.40 A
JS series (Fujitsu)	2000 VA	192 W	8 A; 250 V	8 A; 24 V	0.35 A
RT2 (Schrack)	2000 VA	240 W	8A; 250 V	8A; 30 V	0.25 A
RYII (Schrack)	2000 VA	224 W	8A; 240 V	8A; 28 V	0.28 A
G6RN (Omron)	2000 VA	150 W	8 A; 250 V	5 A; 30 V	-
G2RL-1E (Omron)	3000 VA	288 W	12 A; 250 V	12 A; 24 V	0.30 A

This can be attributed to very hard DC operation conditions of relay contacts with inductive loads, resulting in considerable overloads that are likely to cause a breakdown of the very small dielectric gap between the relay contacts which maintains arching on the contacts, as well as nonoccurrence of periodic current zero crossing, characteristic of AC. Voltage across the contacts may become six-fold the value of the nominal voltage. When the voltage over the contacts exceeds 50 V a strong spark is generated at switching such a load that causes strong erosion of the contacts. As the applied voltage is increased (to 100-150 V), the spark at the relay contacts is changed to a stable arc, which totally melts even powerful contacts (rated for nominal currents of 10-15 A) within 0.5-1.0 seconds at a current of 0.5-2 A. Therefore the switching ability of DC relays is much lower than that of AC relays (Fig. 2), however, according to the manufacturers of MRPD, subminiature relays installed in MRPD are designed for the direct making of tripping coils in high voltage circuit breakers - CB (for line protection) or for the making of lockout relays – powerful intermediate latching relays with a manual reset (for transformer protection), namely for engaging inductive loads in 220 V DC circuits – the heaviest duty for relays. What are these loads under actual operating conditions?

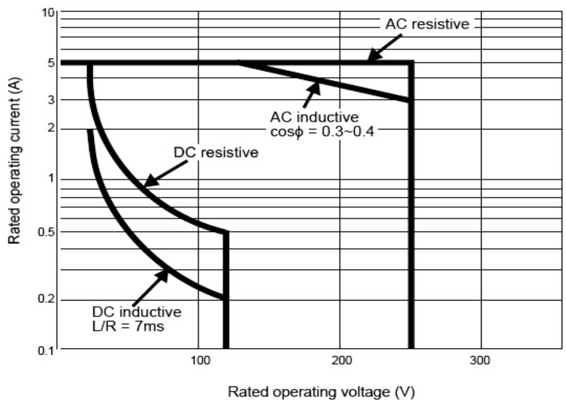

Fig. 2. Typical relations between commutation parameters (voltage, current) and load characters for relay contacts

Table 2 includes the results of analysis of tripping coil parameters for different types of circuit breakers made in different countries.

As can be concluded from the comparison of the abovementioned relay parameters (Table 1) and the parameters of the tripping coils of CBs (Table 2), the switching ability of subminiature relays for DC circuits (0.3 – 0.4 A) not at all sufficient for the direct making of tripping coils of CBs (the required currents are 1- 6 A). Connecting of lockout relays between output MRPD relays and high voltage CB still does not provide a solution since the self-current consumed by the coil of lockout relay (2 A for the HEA type relay and 2.8 A for a modern HEA63 relay made by General Electric) falls into the same range of currents of tripping coils of CBs.

The situation becomes even more complicated because switching of ***the DC inductive load*** for these relays cannot be foreseen at all, so subsequently the use of these relays for direct switching of tripping coils of CB's, as well as intermediate lockout relays, results in the generation of loads beyond those allowed.

3. What do the standards and technical documentation related to MRPD say?

According to the ANSI/IEEE C37-90-1989 and IEEE Standard for Relays and Relay Systems Associated with Electric Power Apparatus [1]. Part 6/7: Make and Carry Ratings for Tripping Output Circuits establishes that the making current and the carry current accompanying it for 4 seconds that is provided by the contacts of the input relays controlling the tripping coil of CBs shall at least 30 A. Why is this current value so high in comparison with the actual currents in disconnecting switches? Because the AC tripping coil (a solenoid with a movable core) has considerable starting currents (up to 10-fold) caused by a low initial impedance of a solenoid with an extended core. For devices with alternating operation current such requirements are quite justified.

It is reasonable that in the view of this requirement MRPD manufacturers included this parameter in the standard provided by their MRPD devices. In this way the MRPD specification with regard to this parameter totally complies with the standard requirements. However the situation is different for the MRPD themselves, since the specifications for specific types of output electromagnetic relays do not mention at all the capability to switch 30 A of current, even if it is AC.

Here we should be more precise and mention that specifications for some types of special extended power subminiature relays (not used in MRPD) mention the ***inrush current,*** i.e. short duration making currents reaching values of up to 30 A. These relays are as if specifically designated for use in MRPD. Maybe if MRPD manufacturers were requested to use these relays this would provide a solution to the problem?

The issue turns out to be not so simple, as there are some other standards related to the relay switching modes [2, 3, 4, 5]. In particular the IEC 60947-4 [4] standard, in which the switching modes of relays and contactors are divided into so called ***"categories of application",*** specifies requirements for contact relays operating in these modes. In particular the contacts designated for controlling the electrical magnets of other intermediate relays, contractors, solenoids and valves are classified as AC-15 for AC and DC-13 for DC (Table 3).

From the Table 3 it follows that increased (ten-fold) switching current of the relay at closing (making capacity) with respect to nominal current, is allowed only for AC. In switching of DC circuits this increase does not exceed 10%. This is accounted for by fact that not all making of relay contacts is terminated after the initial contacting of those contacts. Actually the making process is always accompanied by the contacts bouncing after their first closing. Relay contacts make several open-close cycles of contact bounce before coming to rest in the final state, Fig. 3 [6].

Table 2

Parameters of tripping coils of high-voltage circuit breakers

Circuit Breaker Model	Circuit Breaker Kind	Trip Coil	
		Rated Voltage, V DC	Rated Current, A
ELK SD14 (ABB)	SF_6 , 170 kV, 4000 A	220	2.3
B3-S101 (ALSTOM)	SF_6 , 170 kV, 2000 A	220	0.7
CPRG180/10-360 (AEG)	Generator CB for 13.8 kV	110	2.0
3AP1F1 (Siemens)	Oil CB, 245 kV, 3150 A	220	5.8
BBP-6-10/630 (Russia)	Vacuum CB, 10 kV, 630 A	100	5.0
ВБГ-35 (Russia)	SF_6 , 35 kV	220	2.5
BBOA-15-14/12500 (Russia)	Air CB, 15 kV, 12500 A	220	4.5

Table 3

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

Utilization Category IEC 60947-4	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
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	-

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

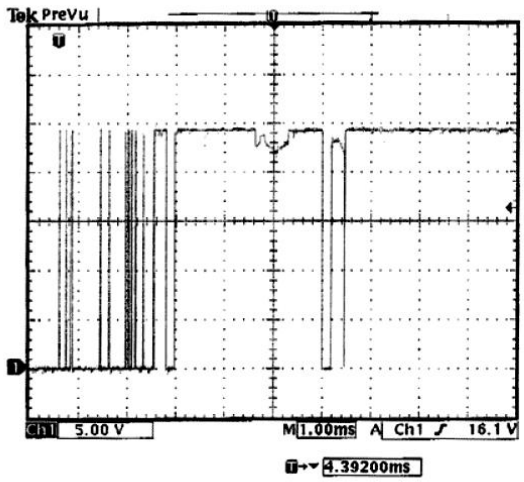

Fig.3. Oscillogram of relay making process with real measured relay contact bounce

This contact-bounce interval is in addition to the relay's operate and release times, which can measure (upon the type of relay) from ones millisecond for small relays to tens of milliseconds for lager relays. Therefore, all other factors being the same, the making power of the contacts of a DC load relay is much lower than that of an AC one.

From the above it follows that short duration making currents of 30 A (3.75 IN) for subminiature relays may be allowed only in AC circuits (even though this restriction for the use of relays is not pointed out in any of the specifications, for obvious reasons!). That is quite reasonable since there is no DC making currents at solenoid and control coil activation. From here it also follows that when the tripping coil of the CB is controlled by DC 220-250 V circuits, the allowed value of making current for contacts is only 110% of the nominal value, namely within a range of 0.35 – 0.45A, which is much lower that the actual currents.

In actual operating conditions output relays of MRPD are operated relatively rarely (only in case of failures in the networks), which postpones detection of switching problems. This saves MRPD manufacturers from customers' claims. Because of erosion that is intensified at each relay operation the contacts surface condition is gradually deteriorated and their resistance and heating increased, which results in welding of the contacts during the next switching. In the course of the above research we have approached many manufacturers of subminiature relays with a request for an opportunity to use their relays for making without breaking currents of inductive load at a voltage 220 V DC and we received the following answers:

a) The danger of welding of contacts may be very great because of bouncing;

b) The relay to be used only in the authorized modes specified in the technical specifications.

Moreover, in some cases, for example for accelerated (forcing) operating of the CB (used in some types of Siemens CBs, for example) a special circuit is used (Fig. 4) that provides higher making current of up to 75 A. Direct connection of contacts of subminiature relays in such circuits is prohibited.

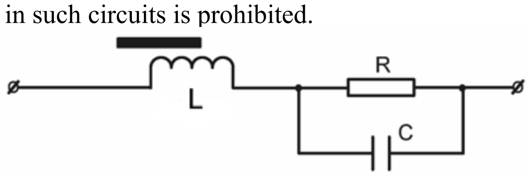

Fig. 4. A circuit diagram for forcing switching of the CB tripping coil (L)

4. There is an additional problem: the electrical strength of the insulation of the inter-contact gap of the output relays [7, 8]. Standard IEC 60255-5 [8] does not define the test voltage that must be withstood by the open contacts of output relays and suggests that the MRPD manufacturer and the consumer agree on it, in accordance with the specific operating environment. Such an approach is reasonable since only in some cases are the contacts of output MRPD designated to switch inductive loads under a constant voltage of 220-250 V. However, a circuit that includes the contacts of an input relay is a powerful DC network of substations. Powerful electrical devices connected in the circuit (intermediate relays, contactors, solenoids) have high-inductance control windings, whose switching results in generation of significant overvoltages. Therefore a question arises; to which type of switching devices should the output MRPD be attributed? Their requirements will be determined accordingly. On the one hand, they are the internal elements of measurement relay (MRPD is a measurement relay), to which the IEC 60255-5 standard applies. On the other hand, they can be easily attributed to electromechanical relays and contactors. There is a separate standard for each type of switching device (see list of references). Some of these standards include a great number of requirements; from the design parameters of the electric strength of the relay insulation, to the point of the gap between the contacts, and the distance between the outlets of the relay mounted on the printed board. In order to make things easier, some standards and instruction manuals for relays offer a simplified formula for defining the minimal needed values of the test voltage for industrial relays maintained for 1 minute: $U = 2U_N + 1000$ (but not less than 1500 V for apparatus with nominal voltage above 60 V). For a voltage of 250 V this yields a value of 1500 V. The analysis of technical parameters of a great number of industrial relays shows that for this class of relays the maintained test voltage is within the range of 1500 – 2500 V, whereas in the subminiature relays used on MRPD these values do not go beyond 1000 V, in other words they do meet even the lowest level of requirements for the strength of inter-contact gap of industrial relays. The problem is not only in the contact gap, but also due to the insufficient distance between the pins of the subminiature relays. Under real conditions of operation (moisture, dust) there is a high probability of breakdown for some types of subminiature relays between the pins on the surface of the PCB board. Therefore manufacturers of MRPD sometimes make special rabbets on a PCB board between the relay pins in order to prevent such breakdowns. Unfortunately, sometimes not only the subminiature relays, but also other components of the MRPD, chosen for reason of miniaturization rather than reliability, are also involved. Fig. 5.

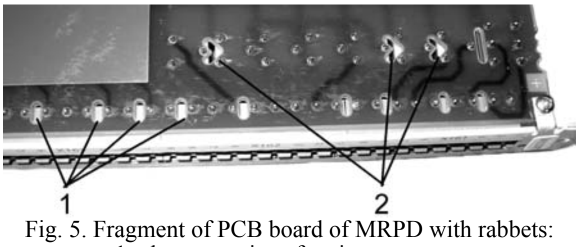

Fig. 5. Fragment of PCB board of MRPD with rabbets:
1 – between pins of main connector;
2 – between pins of output relays

5. Not all contacts of output relays are designated for switching high power loads. Some of them are used as so called “dry” contacts in electronic control circuits of other microprocessor protection devices, local controller or data transmission devices. A circuit or a contact is called “dry” when the currents switched by it are so small that the contacts are completely free of sparks at switching. This also turns out to be faulty terminology since in the absence of a spark the oxide films on the coating are not destroyed, which results in significant deterioration of the contact quality. When the coating thickness is too large the contact resistance is so increased that “dry” circuit switching becomes virtually impossible [9]. This is particularly relevant for miniature relays with low contact pressure and small contact shift, and that is the reason for limiting the lower boundary of switched current or power. This value may be different for different types of contact coatings. For example, in the mentioned ST2 type relay the minimal allowed value of current is 100mA. Obviously, this relay cannot be used for reliable switching of a “dry” circuit. When ordering MRPD, the minimal switched current and voltage should be included as the most important values in the technical specifications, and compliance should be inspected and verified by opening of the MRPD.

6. With regards to the problem of correctness of the technical parameters represented in the MRPD specifications, it should be mentioned first of all that the values for specific parameters of a particular MRPD are often provided in different documents that are essentially distinct, and secondly that in some cases such incorrectness verges on absurdity. For example, one of the specifications for MRPD drawn up by one of the major companies (“Output relays” section) says:

Making capacity: 1000 W (VA) at L/R = 40 ms

This entry has several major mistakes:

a. Making capacity does not provide information about restrictions in relay use because of undefined current and voltage.

b. Switching ability of the DC and AC relay contacts for active load is different by about an order of magnitude (see above), therefore the value 1000W(VA), stipulating for equal power values for both DC and AC, is incorrect.

c. The inductivity of the load in the form of an L/R ratio is given only for DC. For AC the inductivity of the load is expressed in terms of the power factor (PF) or cosφ.

d. Assuming that the term “Making capacity” means “Switching capacity” the value 1000 does not match the actual parameters of any relay used in MRPD. For AC it is a twofold underestimation (exactly), whereas for DC it is a 5-fold overestimation.

e. As mentioned above, switching of the ***inductive DC load*** is not stipulated for the mentioned subminiature relays, and is not mentioned at all in the specifications.

The specifications for another microprocessor relay made by the same company read:

Brake capacity DC: 50W (resistive),
62.5 W (inductive L/R=50 ms)

This entry is unreasonable, since the allowed break capacity of the inductive DC load, being higher than that of the active load, contradicts all postulates of electrical engineering. Moreover, the same specifications say:

Make & Carry: 30 A for 3sec;
Carry: 250 A for 30 ms

We could not find any mention of 30A, and all the more of any 250A currents, in any of the specifications for the mentioned types of subminiature relays.

These are only a few examples of incorrect information included in such important documents as technical specifications.

7. The problem becomes even more complicated since at infrequent protection operation the mentioned discrepancies in MRPD are not detected at once. Under these conditions MRPD can function well for a couple of years, during which the output relay contacts accumulate defects that eventually lead to a sudden failure, resulting in serious damage. Provided the device can operate for several years without visible faults, it is difficult to present a claim to the manufacturers of MRPD. It is also quite difficult to determine the exact working life of a relay operating under such conditions, and to predict when damage is due.

8. What can be done in this situation? The MRPD manufacturer should be requested to install several output relays, complying completely with the standard requirements for industrial relays. It should be noted that in the past this approach was very popular in semiconductor protection devices (Fig. 6), however at present it is not practicable, as this would require a major change in the MRPD structure, and an increase in size.

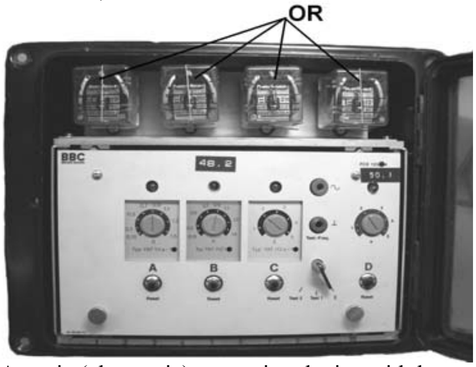

Fig. 6. A static (electronic) protection device with large-output electromechanical relays of industrial type, placed in separate cell (OR – output relays)

The problem could be resolved by having the user connect external power amplifiers between the MRPD output relay and the tripping coil of the CB. This amplifier would have to be simple, fast-acting, jam-resistant and highly reliable under actual operation conditions.

9. We have analyzed the technical parameters of various strong-current solid-state relays (SSR) made by the leading companies in the world (ABB, Tyco Electronics, Crouzet, Teledyne, Magnecraft, Celduc, Crydom, Comus, etc.) and determined that each production sample SSR has at least one or more parameters that do not comply with the requirements essential for their use as a power amplifier of output MRPD relays. Such parameters as maximal DC voltage withstood over the main electrodes in a cut-off state, which must be at least 1500 V; making current in DC circuits with an inductive load, which must be at least 5 - 10 A; operational suitability in DC circuits (many SSR can be operated only in AC circuits); and make-time which must be not more than 1ms.

10. Due to unavailability, in today's market, of power amplifiers confirming to the requirements of combined operation with MRPD, we have developed an amplifier conforming to these requirements. Due to its simple structure (Fig. 7), in-house making of this amplifier by the electric power companies is quite possible.

The main switching element of the device is a particularly small-sized thyristor VT designed for current up to 30A and voltage up to 1600 V. It has additional protection against spikes by means of an varistor RV with clamping voltage of 1200 V (at nominal mains voltage of 250 V this provides high reliability of the varistor). With the help of a special normally closed high voltage optical coupler Opt the thyristor is forcedly blocked in the OFF-state in order to prevent its accidental switching by induced voltage or noise signal. The thyristor is switched ON by the control current flowing in the thyristor control circuit at closure of contact K of the output relay MRPD. Capacitor C (0.01 μF 1600 V) is used as an additional filter preventing the noises reach the thyristor. Unfortunately only a few of the thousands of electronic components available in the market comply entirely with the requirements. In the first place this relates to the thyristor VT (type 30TPS16, STMicroelectronics) and optical coupler Opt (type TLP4597G, Toshiba). In order to provide higher reliability and faster response of the device it is recommended to use only these elements.

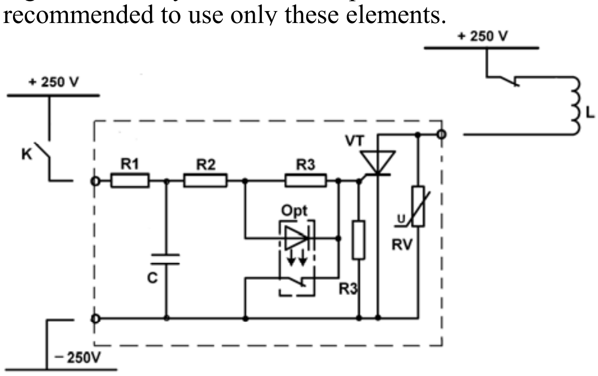

Fig. 7. Switching amplifier for output MRPD relays:
K – contact of output MRPD relay ; L – tripping coil of CB

11. In order to enhance the general reliability level of the operation of electronic equipment having electrical contact with DC 250 V mains, it is advisable to install special protective devices for protection of sensitive electronic equipment (the mentioned MRPD, for example) from spikes, generated at switching of inductive loads (intermediate relay windings and contactors, solenoids of actuator component drives, etc.) at the electronic equipment termination point. Protective device of Limitor-VTS type (ABB Stotz-Kontakt GmbH) includes a powerful varistor and a fuse disconnecting the varistor from the mains in case it is damaged (and also generating a visual or distant failure alarm signal) is a good solution.

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