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Peculiarities of the relays intended for operating trip coils of the high-voltage circuit breakers

Parameters of the subminiature electromagnetic relays used as output elements in microprocessor relay protection, do not correspond to technical specifications on these relay protection. The reasons of this discrepancy are analyzed. Contradictions and discrepancies of the international standards in this area are considered. It is shown, that absence of clearness in standards and mistakes in technical specifications of microprocessor protection manufacturers do not allow to estimate technical parameters correctly and lead to decrease in reliability of relay protection.

1. Introduction

As it is known, the switching capacity of relay contacts is determined by the area of contact surface, contacts mass, contact force and contact gap. The higher values that these parameters have, the higher the switching capacity of the contacts is. This is why powerful contacts differ from low-power ones, first of all in regards to their dimensions and secondly in regards to their gaps. A larger and more powerful coil is needed to create a large contact force and to move heavier contacts at a greater distance. Thus, one can state that for switching more powerful loads a larger relay is needed, Fig. 1.

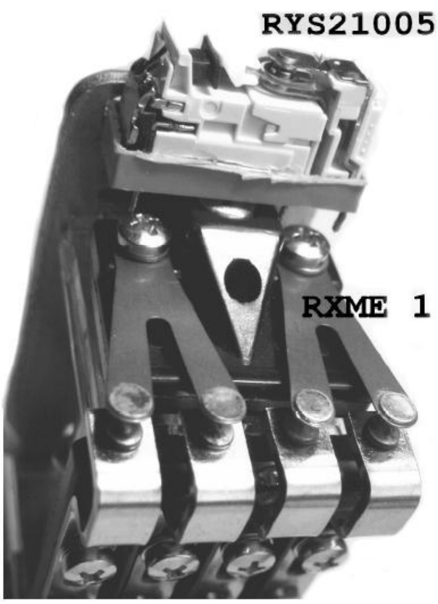

Fig. 1. Subminiature relay RYS 21005 type located on V-shaped double break high power contacts of the auxiliary relay RXME-1type intended for controlling of CB trip coil

In old electromechanical protective relays as an element switching trip coil of high-voltage circuit breaker (CB) one used a special embedded auxiliary latching relay, with manual resetting and with an embed flag (target) indicating relay condition. This relay is called «auxiliary seal-in relay with target» and it has powerful contacts with big gap. They are especially meant for energizing up to 30A with DC voltages of 250 V.

In next generation protective relays – electronic analogues (or «static»), made up of integrated microcircuits and transistors, there is still tendency to use large embedded output (trip) relays with powerful contacts meant for switching the circuit breaker trip coil, Fig. 2.

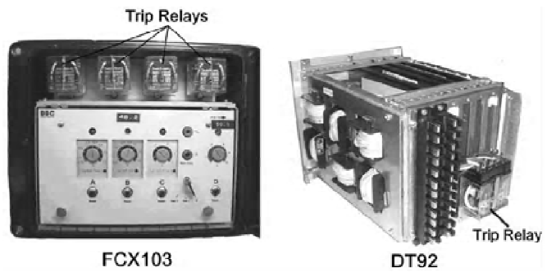

Fig. 2. Solid-state protective relays on discrete components with embedded power output relays

A new reality has appeared in the transition to the newest relay protections – microprocessor-based ones [1, 2]. Hard competition in the market and a desire to maximally reduce the size of microprocessor-based protection devices (MPD) has resulted in the usage of subminiature electromagnetic relays as output elements, Fig. 3.

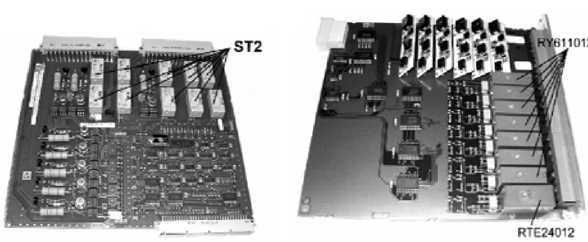

Fig. 3. Printed circuit boards of the microprocessor-based protective relays with output electromechanical relays different types

2. The object of article

The object of article is the analysis of conformity of parameters of the subminiature electromechanical relays, used as output elements in microprocessor based protection devices, to actual operation conditions and to the main standards requirements.

3. The analysis of actual operation conditions of the output relays in microprocessor protection devices

According to manufacturer documentation these relays are meant for applications in such systems as industrial automation, electronic power supplies, TV sets, domestic appliances, computers and communication systems, timers, etc. In the technical characteristics of these relays the switching capacity in DC is limited as a rule to 28–30 V and to be used only for purely active (resistive) loads. At the same time, the maximum switching power in DC (sometimes it is curved lines of switching capacity in DC) enables calculating the maximum switching current at 250 VDC, Table 1. As is clear from the table, values of these currents, even with purely resistive loads, are 20–40 times less than in AC. Regarding the switching of inductive loads in DC, this capability is not provided in technical specifications at all.

How did manufacturers of MPD manage to use miniature (i. e., low-power) relays for direct switching of CB trip coil? Is it the case that requirements to control contacts of trip coil may have been reduced? By no means! In technical specifications of all MPD, manufacturers guarantee current switching of not less than 30A at 250VDC. Probably miniature relays themselves attained such perfection that now they are able to switch inductive loads (coils) with current 30A 250VDC? Alas, technical specifications of subminiature relays used in MPD do not say anything about such abilities of miniature relays. However, engineers of manufacturing companies of these relays to whom the author addressed direct inquiries are categorical in rejecting such abilities of relays used in MPD. Then it is clear that manufacturers of MPD make such important and expensive (10–15 thousand USD) devices like MPD with trivially improper elements? Reports about tests of output relays switching capacity which were submitted on our demand by the world's largest manufacturers of MPD say that these relays have stood to the tests successfully and are acknowledged valid for application. Then where is the logic? Perhaps manufacturers of MPD conduct these tests improperly? On the contrary, MPD with these miniature output relays have functioned successfully in many world power systems for many years. Then maybe real operation conditions of these relays are much easier than requirements mentioned in technical specification? Let us try to sort this situation out. First of all, we will examine real parameters of CB trip coils, Fig. 4.

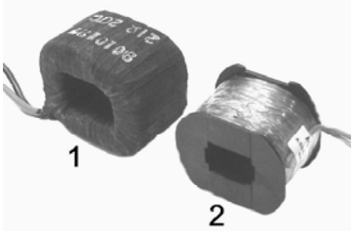

Fig. 4. Trip coils of the CB on 160–170 kV from different manufacturers: 1 – Hitachi Kokubo Works (GE-Hitachi, USA); 2 – AQ Trafo AB (Sweden)

Table 4 shows the results of measurements of general parameters of trip coils (L1, L3, L4) of high-voltage CB of several types, and also coils (L2) of special high-speed auxiliary latching relays with position fixing and manual release (lockout) which is sometimes included between protective relay and circuit breaker.

Table 2. Main parameters of trip coils to the high-voltage CB of some types and to the lockout relays

Parameter	*Unit*	*L1*	*L2*	*L3*	*L4*
Current, I	A	1,25	2,5	5	12
Inductance(coil on core), L	H	0,5	1,0	1,0	0,22
Resistance, R	Ω	200	100	50	22
Time Constant, τ = L/R	ms	2,5	10	20	10
Magnetic Energy, E	J	0,4	3,12	12,5	15,8

The analysis of coils parameters given in the table may lead to some interesting conclusions.

Firstly, a lockout relay is the load for contacts of miniature output relays not less than CB trip coils, Fig. 5. Experiments with the relay made by the author showed that even powerful contacts of the relay (contact diameter of 6 mm, and the gap between contacts was about 8 mm) are not able to break current (with arc) their own control coil series-connected with normally closed contacts 250VDC. Only two pairs of series-connected NC contacts (see the circuit in Fig. 5.) were able to break the arc appearing at disconnection. In next modification of this relay (HEA62) even for two pairs of such powerful contacts one decided to make switching process easier and to shunt coil with special arc-suppressing circuit composed of diode and resistor. Manufacturer data given in Table 3

Table 1. Switching capability of miniature electromechanical relays using in microprocessor-based protection devices as output relays

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

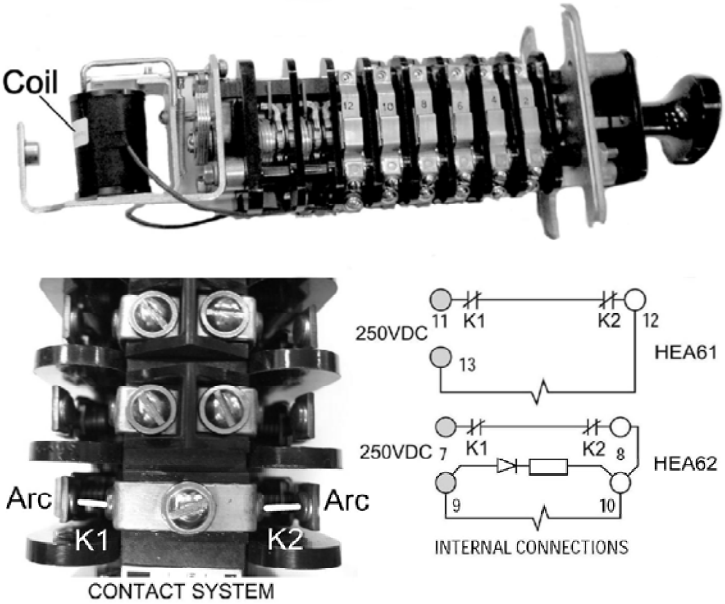

Fig. 5. Latching hand reset auxiliary relay (lockout) 12HEA61 type

[3] give a visual idea of the degree of load type influence on the switching capacity even of such powerful contacts.

Secondly, the time constant, $\tau = L/R$, which usually characterizes load type, is not a sufficiently informative value to allow conclusions of the real switching capacity of contacts. For example, Table 2 shows that in the *L*2 and *L*4 coils with the same *L/R* considerably different energy is reserved which is evaluated with equation [4]:

$$E_L = \int_0^I i d\psi = \int_0^I L i di = \frac{LI^2}{2},$$

where: ψ – magnetic-flux linkage; *L* – load inductivity; *I* – current in load.

Exactly this energy of magnetic field is released on the contacts during the switching process. This means that the relay contacts will be wear out differently during switching of *L*2 and *L*4 coils with the same *L/R* value.

Table 3. Switching capabilities for power contacts of lockout relays

Load	Current (A) for Number of contacts, connected in series		
	1	2	4
250VDC, inductive	0,7	1,75	6,5
220VAC, resistive	25	50	–
220VAC, inductive	12	25	40

Thirdly, the switched current value without indication of other parameters of inductive load (as for example, in Table 3) is not a sufficient parameter for unambiguous evaluation of the contacts switching capacity. For example, the current in the *L*2 coil is only two times stronger than in the *L*1 coil, whereas the energy reserved in *L*2 is almost eight times higher than the energy released during switching in *L*1. Experiments on these coils with fixing of arc power on contacts verified these conclusions.

Based on the above, one proposes using this load magnetic field energy as an index characterizing inductive load. In our concrete case for nominal voltages 250VDC and 125 VDC these values will be:

$$E_{250} = 0{,}125 I\tau,$$
$$E_{125} = 0{,}062 I\tau,$$

where: *I* – current in load in amperes; τ – load time constant in milliseconds.

Thus, examination of real parameters of CB trip coils and high-speed lockout relays may lead to the conclusion that they are really serious inductive loads for contacts of protection devices, output relays.

In justifying the ability of miniature electromagnetic relays to control trip coils of high-voltage CB, the manufacturers of MPD usually refer to the fact that contacts of these relays just TURN ON the trip coil of circuit breakers. Turning off of the coil is accompanied by intensive arcing is implemented by auxiliary normally-closed contacts of the CB itself, but not by the contacts of the miniature relay. This is why it is possible to turn on powerful trip coils of high-voltage CB by means of low-power contacts of miniature relays. Is the statement unambiguous? It is well known that contact closure of electric appliances is accompanied by numerous contacts' springing after first closure and further repeated closures (the process is called «bouncing»). This fact is reflected in technical literature and standards, Fig. 6. This means that there is no «pure closure» of contacts without numerous breakings in process of relay actuation. Surely, the period of contacts being turned off (i.e., with arc burning) is minor during rebounds, but small distances between contacts in this period and the attendant compression makes the risk of contacts sticking very real. That is why in existing standards there are no great

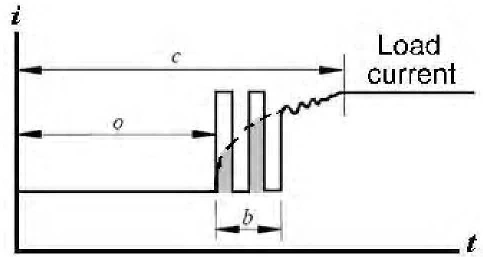

Fig. 6. Oscillogram of relay making process with contact bounce (according to IEC 61810-7): *o* – time period from coil energizing up to first contact closing; *b* – bounce time; *c* – time to stable closing

differences between the turning ON and turning OFF of circuits with inductive loads in direct current by the evaluation of contacts switching capacity. For example, for application category DC-13 (control of electromagnets, coils of solenoids and valves) according to the IEC 60947 standard the current of contacts both turning ON and turning OFF should not exceed a nominal (continuous) current, while for contacts functioning with AC, a 10-fold value of turn-ON current is accepted, Table 4.

However, the above is not the reason to conclude unambiguously that miniature relays' contacts realizing activation of trip coils of circuit breakers or coils of powerful high-speed auxiliary relays are really subjected to significant overloads. The thing is that during the activation of inductive loads the current in it grows not linearly but exponentially. This means that the load circuit breaks during contacts bouncing happen when the current is less than nominal (see Fig. 6).

On the other hand, the fact that output contacts of miniature relays in protection devices do not fail when activated for the first time, but function for a long time in real operation conditions also does not prove that these contacts function in the mode that is normal for them. It depends on the fact that even when contacts have visible arc switching failure (i. e., non-closure or non-breaking of contacts) this does not take place immediately. Rather a long process of defects accumulating on the contact surfaces takes place as a result of intensive evaporation of contact material from one contact and the transference of it to the other contact. Transient resistance of contacts increases and so does their temperature. In miniature relays this leads to the fusion of the plastic case near contacts, contamination of contacts and further growth of transient resistance. After several thousands of these occurrences in simple relay the final welding of contacts disintegrates or a break in one of contacts takes place which appears as an absolute relay failure. As electromagnetic relays are usually meant for hundred thousands or even millions of cycles, the operating regime in which the relay fails after several thousands of commutations instead of million commutations is not acceptable and is not allowed by relay manufacturers. On the other hand, output relays in protection devices do not function with such intensity. The maximum number of actuations of these relays during their entire service life hardly exceeds several thousands. Then it is clear why relays functioning in the regime, which is abnormal for them, nevertheless provide serviceability of protection and even meet tests at factories of MPD manufacturers. MPD manufacturing companies submit always these two facts in extenuation of using miniature relays for the direct breaking of high-voltage CB. However, does it really mean there is no problem in the question? The process of relay contacts failure in the operating mode is statistical and the moment of failure depends on the number of accumulated defects and their size. This in turn is determined by concrete parameters of trip coils, frequency of MPD actuation, physical properties of the contacts construction, and the dispersion their parameters during relay assembling. The longer the relay functions, the higher the possibility of its failure and thereby the failure of protection of important power objects. Thus, the matter is not that miniature electromagnetic relay used in protection device fails right after the first actuation or after definite number of actuations, but that in the process of operation there is a steady erosion of its reliability and the strong possibility of failure grows.

4. The analysis of the international standards and the technical specifications

The above discussion brings into question the methods of miniature relays testing in conditions not provided and not authorized officially by the manufacturer, about validity criteria, etc. Perhaps, we will manage in answering to these questions and clarify the situation with

Table 4. 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 rated values of currents and voltages of electric loads switched by relay contacts

Table 5. Scope and object of the standards IEC 60947-5-1 and IEEE C37.90

IEC 60947-5-1	IEEE Std. C37.90
Control circuit devices and switching elements intended for controlling, signaling, interlocking, etc., of switchgear and controlgear. Also applies to specific types of switching elements associated with other devices (whose main circuits are covered by other standards).	Standard specifies for relay and relay systems used to protect and control power apparatus. It does not cover relays designed primarily for industrial control, for switching communication or other low-level signals, or any other equipment not intended for control power apparatus.

the help of international standards in this area. What are the standards? Judging by the names, for control relays of circuit breakers trip coils two general standards suit: IEC 60947-5-1 standard (Low-voltage switchgear and controlgear. Part 5-1: Control circuit devices and switching elements. Electromechanical control circuit devices) [6] and IEEE C37.90 standard (Relays and Relay Systems Associated with Electric Power Apparatus) [7], Table 5.

The definitions given in both standards are very close; however the application area of C37.90 standard is seen as the part of wider application area of 60947-5-1 standard. A rather strange limit of C37.90 standard draws attention: exclusion of industrial automation relays and other relays not meant especially for power devices control from the area of its cover. What serious fundamental differences exist between industrial automation relays meant for control of powerful contactors coils, coils of solenoids and valves of control systems of manufacturing processes and relays meant for trip coils of circuit breakers? They have the same voltage, the same current, the same capacity! This limitation of C37.90 is not so harmless as it seems and has far-reaching consequences, as on one hand the standard describes procedure of examination of relays meant for activation of trip coils of CB, and on the other hand it excludes from the consideration relays of industrial purpose not meant specially for power devices control. This means that this standard cannot be applied to MPD in which miniature output relays are used (originally meant for industrial automation, communication equipment or other similar equipment, but not for power devices control) as elements directly controlling trip coils of CB.

There are not less strange differences in the methods of testing of relays offered by these standards, see Table 6.

Why does C39.70 standard prescribe testing switching capacity of contacts specially meant for switching CB trip coils (i.e., significant inductive loads) on purely resistive load? Why is the turn-on current strictly specified as 30 A in this standard while the trip coils of modern breakers are meant for much lower current? Why are the criteria for relay applicability not discussed during testing? Another question that needs answering is why does switched current in IEC 60947-5-1 standard not exceed 1.1A during testing? Why isn't there a separate mode of load make without breaker (i. e., typical mode of functioning of trip relay contacts)?

An analysis of the standards' requirements for the testing of relay insulation and withstanding voltage also evokes bewilderment. For example, in IEC 60947-5-1 the list of relay parts is given with the test voltage attached. It

Table 6. Making and breaking capacities for DC load test according to IEC 60947-5-1 and IEEE C37.90 standards

	IEC 60947-5-1	IEEE Std. C37.90
1	Load type: air-cored inductor in series with a resistor, L/R<300 ms	Load type: active resistor
2	Switching current for Utilization category DC-13, Designation N300 – 1.1 A Any other types of applications shall be based on agreement between manufacturer and user.	Making current – 30 A
3	Number of operation – 5000 at 10 s interval	Number of operation – 2000 in sequence: 0,2 s – ON, 15 s – OFF
4	Acceptance criteria: – no electrical or mechanical failures; – no contact welding or prolonged arcing; – withstanding the power-frequency test voltage of $2U_{NOM}$, but not less than 1000 V.	Acceptance criteria: not specified

appears that this list contains no relay output contacts! IEC 60255-5 [8] considers it possible to test these contacts, but it assumes the necessity of coordinating the test voltage between manufacturer and customer.

As practice shows, in many cases the customer knows nothing about this article of the standard and does not coordinate anything with the manufacturer apart from the requirements to output relays contacts. This is why the manufacturer may indicate in technical documentation that the parameters of the protection device are in full compliance with requirements of the standard without any additional provisos.

C37.90 treats testing of output contacts of protective relays completely differently. It supports such testing, but in processes of relay manufacturing, that, in fact, it does not allow customers to test this most important parameter of relay on their own. Why? Unfortunately, the author did not manage to get clear answers to these questions even from the IEEE group responsible for this standard. Moreover, MPD manufacturers actively use these standards, refer to them in their documentation and conduct their own test based on them.

A very confused situation has emerged not only in the sphere of standards, but also in the sphere of the type tests of protective relays, conducted both by relay manufacturers and International Certifying Centre KEMA. The author was permitted to get acquainted with type test protocols of different types MPD conducted by KEMA, Siemens and ABB companies, and he discovered many strange things there, too.

For example, at Siemens switching capacity of output relays of MPD is examined using AC (instead of DC!), and at KEMA this type of MPD testing is not conducted at all. At ABB the company tests of these contacts were conducted for protective relays of previous generations (SPAD, SPAU, SPAC series, for example) in which large auxiliary relays were used with rather powerful contacts, which were good in switching of trip coils. For protection devices of the next generation (which we are discussing) in which miniature relays were first used, such tests are even not provided in the list of test types.

Lack of preciseness in international standards results in mistakes in technical specifications of modern MPD. The author has analyzed many technical specifications of such devices, manufactured by world benchmark companies in the field, on switching capacity of output relays including: 7SD61, 7SA522 (Siemens); MiCOM P541, P546 (Areva); T60, D60, L90 (General Electric); REL561, REL670 (ABB); BEI-GPS100, BEI-CDS240 (Basler) and others. All of them contained mistakes and inaccuracies, or just lacked the most important parameters to avoid unambiguous conclusion about such relays' applicability. As an example one may consider the set of parameters given in the relay specification of Areva Company, Table 7 [9]. The author repeatedly addressed Areva and asked for explanations of these strange parameters. The first time the author got different information having no relation to the questions, and later he got no answers at all.

Conclusions

1. Currently there are no unambiguous proofs that contacts of miniature electromagnetic relays widely used in microprocessor-based protection devices function in

Table 7. The switching parameters of the output relays stated in the specification of microprocessor relays produced by AREVA

Protective relays types: Distance Line Protection (MiCOM P443) and Current Differential Protection (MiCOM P541…P546)	Parameters specified in documentation	Our comments
Standard general purpose contacts:		1. For such making capacity at 300 V rated voltage will obtain Making Power: 250A*300V=75.000 W (75 kilowatt!). Very difficult give credence to such capability for subminiature electromagnetic relays. 2. Higher braking capacity for DC inductive load (62,5 W) in comparison to lower breaking capacity for DC resistive load (50 W) contradicts to known theory and practices.
Rated voltage	300 V	
Continuous current	10 A	
Short-duration current	30 A for 3 s	
Making capacity	250 A for 30 ms	
Braking capacity:		
DC resistive	50 W	
DC inductive (*L*/*R*=50 ms)	62.5 W	
AC resistive	2500 VA	
AC inductive (PF=0,7)	2500 VA	
High break contacts for tripping:		
Rated voltage	300 V	
Continuous current	10 A DC	
Short-duration current	30 A DC for 3 s	
Making capacity	250 A DC for 30 ms	
Break capacity:		
DC resistive	7500 W	
DC inductive (*L*/*R* = 50 ms)	2500 W	

the modes acceptable for them and ensure necessary reliable when switching trip coils of circuit breakers.

2. Manufacturers of miniature electromagnetic relays used in microprocessor-based protection devices should include the following parameter in technical specifications of their relays: Make without break of inductive loads at 125VDC and 250VDC in the infrequent switching mode. International standards dealing with the switching capacity of relay contacts should be amended with the parameter specifying: Make without break of inductive loads, which is in compliance with real parameters of trip coils of circuit breakers or powerful auxiliary relays. These standards should be mutually coordinated.

3. The author offers for consideration the possibility of replacing of the $\tau = L/R$ parameter with the parameter characterizing switching energy E for a different rated voltages. One should create a standard (or add a separate paragraph to existing standards) for typical symbols of set of most important parameters of relay contacts switching capacity, obligatory for inclusion in technical documentation and examples of such parameters recorded in the technical specification.

4. Requirements for the testing of relay contacts specially meant for energizing the trip coil of circuit breaker (IEEE St. C37-90) should be brought into conformity with real service conditions. Contacts applicability criteria in the testing process should include analysis of their condition to ensure the necessary reliability of switching.

5. Manufacturers of microprocessor-based protection devices should revise technical specifications in the part concerning parameters of output relays and bring them into conformity with reality.

6. Consumers of microprocessor-based protection devices should more carefully analyze specifications of the equipment bought, and demand from manufacturers test record sheets of compliance with standards requirements.

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Параметры субминиатюрных электромагнитных реле, используемых в качестве выходных элементов в микропроцессорных защитах, не соответствуют техническим спецификациям на эти защиты. Анализируются причины этого несоответствия. Рассматриваются противоречия и неточности международных стандартов в этой области. Показано, что отсутствие четкости в стандартах и ошибки в технических спецификациях производителей микропроцессорных защит не позволяют правильно оценить технические параметры и приводят к снижению надежности релейной защиты.

Параметри субмініатюрних електромагнітних реле, використовуваних як вихідні елементи в мікропроцесорних захистах, не відповідають технічним специфікаціям на ці захисти. Аналізуються причини цієї невідповідності. Розглядаються протиріччя й неточності міжнародних стандартів у цій області. Показано, що відсутність чіткості в стандартах і помилки в технічних специфікаціях виробників мікропроцесорних захистів не дозволяють правильно оцінити технічні параметри й приводять до зниження надійності релейного захисту.