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# Hybrid Reed - Solid-State Devices are a New Generation of Protective Relays

*Author's* approach allows viewing the problem of re-equipment of relay protection in a new way. In the author's opinion combination of reed switches with magnetic circuits and semiconductor elements opens new avenues in development of the promising protective relays featuring reliability, simplicity and low cost. Examples of protective relays made with these elements are given below.

Research and development in the field of electromechanical protective relays has not been conducted for tens years, this in contrast to electromechanical auxiliary relays for industrial purposes. For a long time all the efforts of researches and developers in the field of protective relays have been directed exclusively to microprocessor devices. While at the first stages of the process of replacement of electromechanical relays with microprocessor based devices, voices in support of electromechanical relays were heard, after tens years of intensive wear out and rusting of out-of-date electromechanical relays and problems in maintenance, the voices of the supporters of such relays have virtually disappeared. Thus, quite legitimate and clearly negative relation of maintenance staff to the out-of-date and extremely worn out electromechanical relays is covered usually with all kinds of not microprocessor-based protective relays. Leading manufacturers worldwide support such relation and tendencies because of the super-profits made from manufacturing microprocessor-based relays.

Usually, very few people pays attention to that actually so-called microprocessor protective relay is not a relay, but a certain multipurpose device which combines function of many devices in one design, frequently these functions are not related neither to relays nor to relay protection. For example, actually such important and attractive functions, as recording of emergency modes, ability of remote data transmission by means of optical communication, etc., are carried out much better, by a variety of specialized devices available in the market than by microprocessor relays. Tens of companies offer multi-channel (12, 24, 36 and more channels) microprocessor-based recorders of emergency modes that are able not only to write down these modes, but also to analyze them, to calculate distance to the point of damage, to transmit data through GPS or a computer network etc. Also a variety of modern communication and data transmission systems available today in the market have a lot of remarkable properties. In addition, combination of different functions of several types of protection in one microprocessor device is more harmless because damaging any electronic component used in the microprocessor, memory, the power supply, etc. will cause simultaneous malfunctioning of all types of protection of important power objects and not just a failure of a single protection function.

In connection with stated above, it is obvious that the entire set of the modern equipment which perform the same set of functions as the combined microprocessor device, and not only a single protective relay function (current, voltage, power) will be taken into consideration (in comparison with combined microprocessor device). Such approach [1, 2] allows to view the problem of re-equipment of relay protection in a new way. Besides, the development of the elements base, including powerful semi-conductor and electromechanical switching elements, has never been ending.

This paper is devoted to research and development of new generation characteristics of protective relays created on the basis of hybrid-reed – solid-state devices.

In the last years small- size thyristors and transistors in standard cases TO-247, TO-220 (with parameters given at tables 1 and 2), intended for soldering on the printed-circuit-board have appeared, with switching current of tens of amperes at a voltages of 1200 - 1600 V. Various companies manufacture miniature high-speed (shares of milliseconds) vacuum reed switches with withstanding voltage of 1000 - 2500 V which can serve as precision threshold (pickup) elements in the protective relays (with parameters given at table 3). Japanese company Yaskawa

Table 1. Main parameters of the modern power thyristors, suitable for mounting on PCB

| Parameter/Thyristor type | 30TPS12 | 25TTS12 | 70TPS16 | CS 60-16io1 | BTW69 -1200 | CS 29-12io1C |
|---|---|---|---|---|---|---|
| Case | TO-247AC | TO-220AC | SUPER 247 | PLUS247 | TOP3 | ISOPLUS 220 |
| Max. off-state peak voltage, V | 1200 | 1200 | 1600 | 1600 | 1200 | 1200 |
| Max. on-state rms current, A | 30 | 25 | 70 | 75 | 50 | 35 |
| Peak, ½ cycle surge current, A | 300 | 300 | 1200 | 1500 | 580 | 200 |
| dv/dt, V/µs | 500 | 500 | 500 | 1000 | 1000 | 1000 |
| di/dt, A/µs | 150 | 150 | 150 | 150 | 50 | 150 |
| Leakage current (t = 25ºC), A | 0.5 | 0.5 | 1.0 | 0.2 | 5 | 2 |
| Holding current, mA | 100 | 150 | 200 | 200 | 150 | 50 |
| Turn-on time, µs | 0.9 | 0.9 | - | 2 | - | 2 |

Table 2. Main parameters of the modern power high-voltage IGBT

| **Parameter/Transistor type** | **IXSK35N1 20AU1** | **APT35GN1 20N** | **FGA25N120 ANTD** | **IXGH25 N160** | **FGA50N10 0BNTD** |
|---|---|---|---|---|---|
| Case | TO-246AA | TO-247 | TO-3P | TO-247 | TO-3P |
| Max. collector-emitter voltage, V | 1200 | 1200 | 1200 | 1600 | 1000 |
| Continuous collector current, A | 35 | 94 | 25 | 75 | 50 |
| Pulsed collector current, A | 140 | 105 | 90 | 200 | 100 |
| Total power dissipation, W | 300 | 379 | 312 | 300 | 156 |
| Collector-emitter ON voltage, V | 4 | 2.5 – 4.7 | 2.15 | 2.5 – 4.7 | 2.0 |
| Turn-ON delay time, ns | 80 | 24 | 50 | 47 | 140 |
| Turn-OFF delay time, ns | 900 | 300 | 190 | 86 | 630 |

Table 3. Main parameters of high-speed vacuum high-voltage reed switches

| **Parameter/Reed switch type** | **MRA5650G** | **KSK-1A75** | **HYR2016** | **HYR1559** | **MARR-5** | **R1-48C** |
|---|---|---|---|---|---|---|
| Contact form | NO | NO | NO | NO | NO | NO |
| Max. switching voltage, V | 1000 | 1000 | 1000 | 1500 | 1000 | 250 |
| Max. switching current, A | 1 | 0.5 | 1 | 0.5 | 0.5 | 1 |
| Max. switching power, W | 100 | 10 | 25 | 10 | 10 | 70 |
| Dielectric strength, V | 1500 | 1500 | 2500 | 1500 | 2000 | 780 |
| Operate time, ms | 0.6 | 0.5 | 0.8 | 0.4 | 0.75 | 0.35 |
| Release time, ms | 0.05 | 0.1 | 0.3 | 0.2 | 0.3 | 0.03 |
| Dimensions, mm | D = 2.75, L = 21 | D = 2.3, L =14.2 | D = 2.6, L = 21 | D = 2.3, L =14.2 | D = 2.66, L = 19.7 | D = 2.7, L = 20.5 |
| Pull in value (AT range) | 20 – 60 | 15 - 40 | 15 - 70 | 15 - 50 | 17 - 38 | 27 - 80 |

and its branches manufacture a series of middle- size powerful reed switches for switching of current of up to 5 A at a voltage of 250 V (Fig. 1).

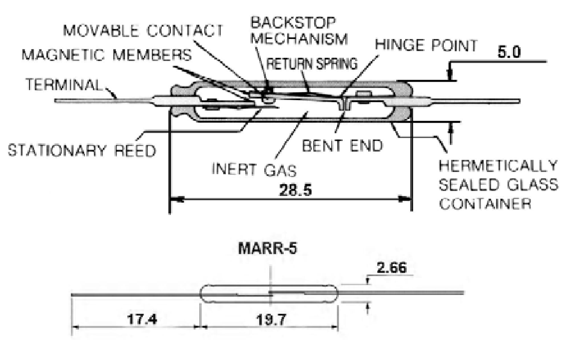



Fig. 1. Modern reed switches, recommended for use in the relays. At the top: gas filled power reed switch R15U (Yaskawa); at the bottom: miniature high-speed vacuum reed switch MARR-5 (Hamlin Inc.)

When using reed switches it should be always considered, that their high reliability will be guarantied only while observing the restrictions imposed by the switching ability determined in the technical specifications. Similarly to the semi-conductor switches, the reed switches quickly fail even at a short-term exceeding of the allowed switching parameters. At the same time, even though modern reed switches are electromechanical elements, their reliability and number of switching cycles is closer to that of semi-conductor elements, and so are many of their parameters, such as electromagnetic interferences, surge withstand capability, etc., the last considerably surpass. Because of extraordinary features of the reed switch relays, not owned by usual electromechanical relays, such as high speed, precise and stable pickup value, and high release factor on an alternating current, etc. [3], a lot of devices for protection and automation system in the industry, power engineering and military techniques [4, 5] were developed on their basis .

One can even speak about «Renaissance» of electromechanical protective relays [6]. Moreover, as it became evident protective relays based on reed switched with the parameters unattainable for microprocessor-based devices can be constructed [7].

Combination the reed switches with magnetic circuits and semiconductor elements open new avenues in development of interesting and promising devices distinguished in the simplicity and low cost. For example, such a simple device, as reed switch with two operating coils (Fig.2,a) can be the basis for creation of the differential protection, logic elements, threshold summing element, etc. Reed switch with a special magnetic circuit (Fig. 2,b) appears to be insensitive to aperiodical component of current in the coil. Reed switch, connected with to a simple circuit diagram (Fig.2,c), responds to the voltage asymmetry. In the circuit diagram (Fig. 2,d) reed switch pickups only at a fast change of current (voltage) in a control circuit which is distinctive for emergency mode and do not respond at slow changes of the current, related to the changes in load. In addition the reed switch also directly respond to the magnetic field of the current passing in bus bar without additional windings (Fig.2,e).

Let's consider concrete examples of the most widespread kinds of protective relays based on the suggested technology.

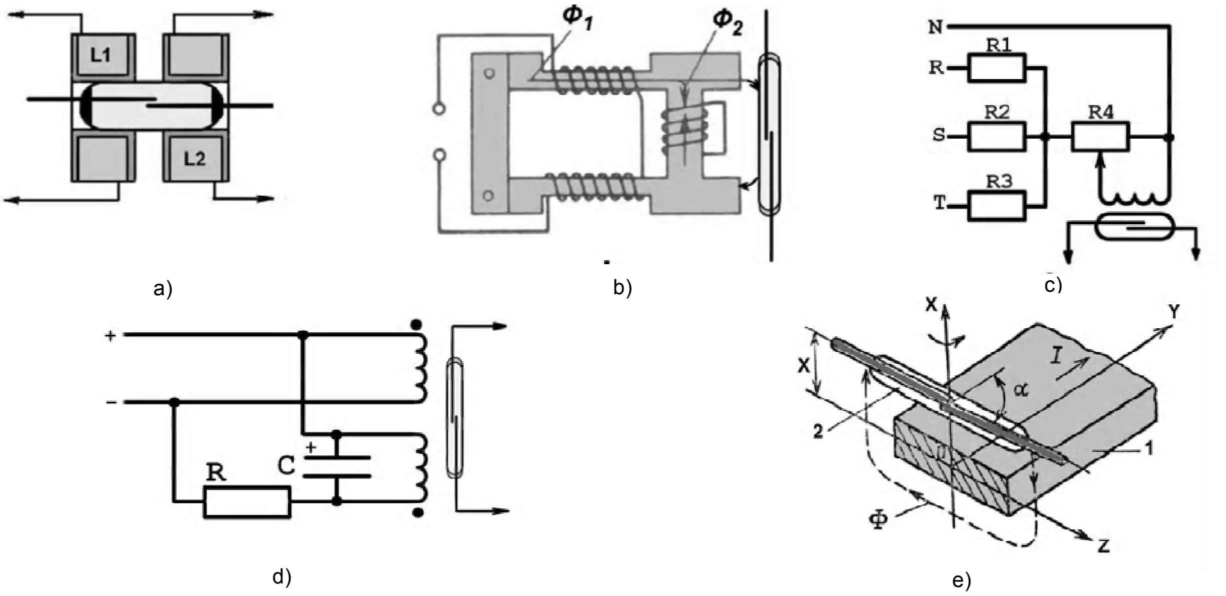



Fig. 2. Examples of various applications of reed switches in the protection devices.

Instantaneous current relay (Fig.3). The over-current relays without time delay are widely used for protection of electric networks and electric equipments against overload. This version of relay is intended for direct energizing of the trip coil of the high-voltage circuit breaker (CB).

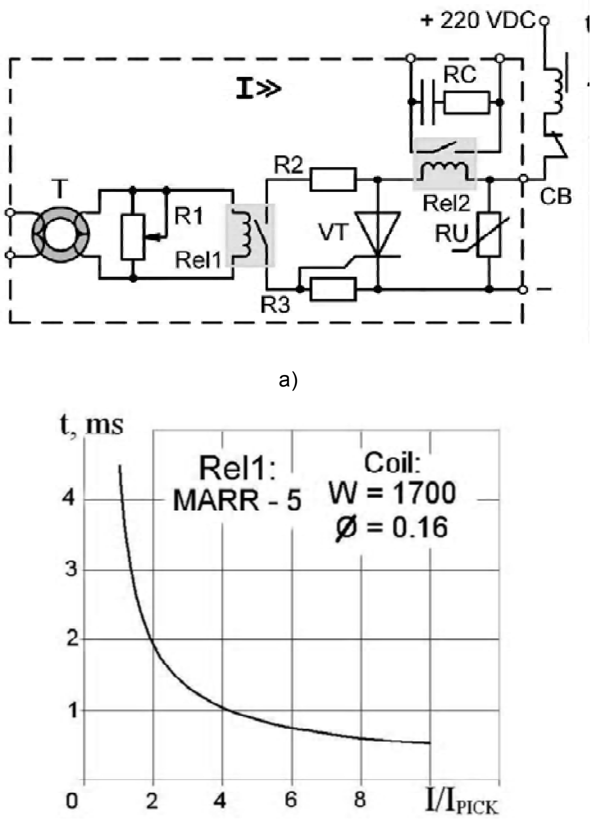
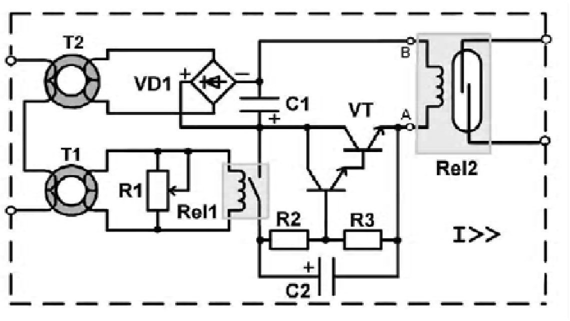


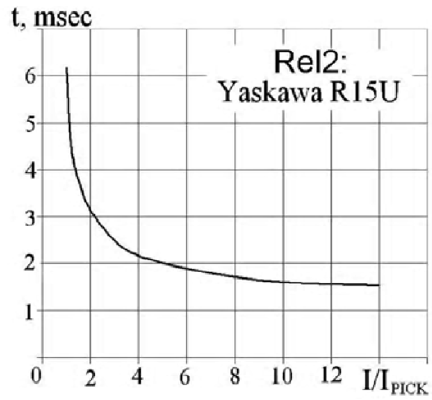

Fig. 3. The simplest hybrid protective relay: instantaneous current relay. The basic circuit diagram (a) and experimental time-current characteristic curve (b), where $I/I_{PICK}$ – multiples of pick-up setting

Sensitive threshold (pickup) element of the device is the Rel1 relay made with a miniature high-speed vacuum reed switch. Its coil contains 2050 turns of 0.16 mm wire. At pickups this reed switch starts to vibrate at a double current frequency . Upon the first closing of the circuit by the reed switch, thyristor VT will turn-ON and energize CB trip coil. The thyristor only switches this coil ON, it is switched OFF by the own auxiliary-contact of the CB. Rel2 is an intermediate relay, intended for signaling or blocking circuits and it uses a medium capacity reed switch such as GC1513. Its coil has very low resistance and it is designed for short-term carrying of a direct current in a range from 0.5 up to 15 A (typical currents of CB trip coils of various types) at which this reed switch operation is reliable. Adjustment of pickups (coarsening the relay) is carried out with the help of potentiometer R1. In the relay thyristor such as 30TPS12 (in TO-247AC case) is used with rated current 30A and the maximal withstanding voltage of 1200V and miniature vacuum reed switch such as MARR-5. The input CT is made on a low-frequency ferrite ring with the external diameter of 32 mm. RC-circuit serves for protection of the auxiliary contact (reed switch) from spark erosion at switching of inductive loads. Varistor RU such as SIOV-Q20K275 protects the device from spikes in the DC circuit. Its clamping voltage does not exceed 350-420V DC. This voltage level should be higher than the rated voltage of a DC network, but lower than the maximal withstanding voltages of the thyristor and the reed switch. As shown in experimental time-current characteristic curve, the relay speed is higher than that of the electromechanical, static or microprocessor-based devices, it does not need replenishment, is insensitive to high-frequency interferences and spikes in a current circuit, and remains reliable at strong distortions of current [7].

Instantaneous current relay with high release ratio (Fig. 4). In this relay design a powerful reed switch such as R15U (Yaskawa) is used as a contact of tripping output relay Rel2 instead of power thyristor VT. The second CT (T2) serves as an energy source necessary for operation of the power reed switch.




a)




b)

Fig. 4. Instantaneous current relay with high release ratio: the basic circuit diagram (a) and experimental time-current characteristic curve (b) where $I/I_{PICK}$ – multiples of pick-up setting

Vibrating reed switch (Rel1) does not affects the operation of relay Rel2. Therefore a special active filter can be used between pickups element Rel1 and output relay Rel2. The filter formed with capacitor C2 (22 uF), resistors R2, R3 and transistor VT which can be any low-power transistor for voltages not less than 100B with current gain ($h_{FE}$) not less than 100, for example, such as ZTX753, ZTX953. With a low-power Darlington transistor (for example, such as ZTX605), as shown in Fig. 4, the capacity C2 can be considerably reduced. By means of this filter the current pulsation in reed switch circuits of Rel1 will be transformed to a stable current in the coil circuit of relay Rel2. The release ratio of reed switch Rel1 is close to 0.99 at alternating current. For lower release ratio of the relay (0.7–0.6) it is enough to connect the Rel1 coil through rectifier bridge, and to transfer capacitor C2 to a different location: in parallel to this bridge. Since the capacity needed to feed the powerful reed switch is much greater than for a miniature reed switch, CT (T2) is formed with two identical transformers, similar to transformer T1 in which the secondary windings are connected in parallel, and the primary winding - communicating, covers both ferrite rings. The total power consumed by the relay from the current circuit (at a current 5A) does not exceed 4 W. The winding of relay Rel2 consists of two coils placed on the reed switch and connected between them in series. Each of them contains 7600 turns of a 0.08 wire. Experimental time-current characteristic curves (Fig. 4), was obtained for a series of consecutive pickups of the relay, during the time intervals between which the charge of capacitor C1 was kept unchanged. At the first pickup of the relay with not charged capacitor the time delay is approximately twice long, Such acceleration of operation in case of repeated pickups at short circuit is a positive property of the protective relay. Even in view of increasing the operation time at the first pickup, the relay speed still remains very high. Modern IGBT-transistors (Table 2) and complete modules used for their operation (so-called «drivers»), allow to realize a very simple switching output unit of the relay on a contactless basis (Fig. 5).

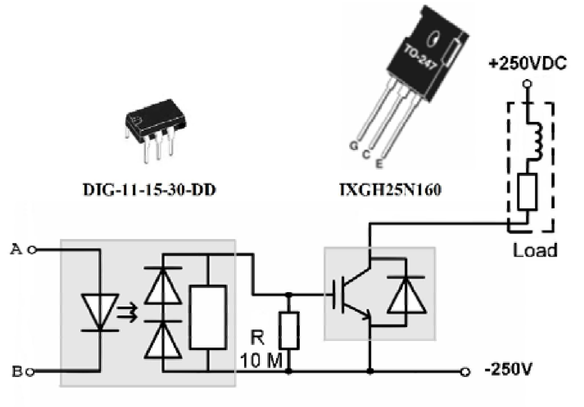
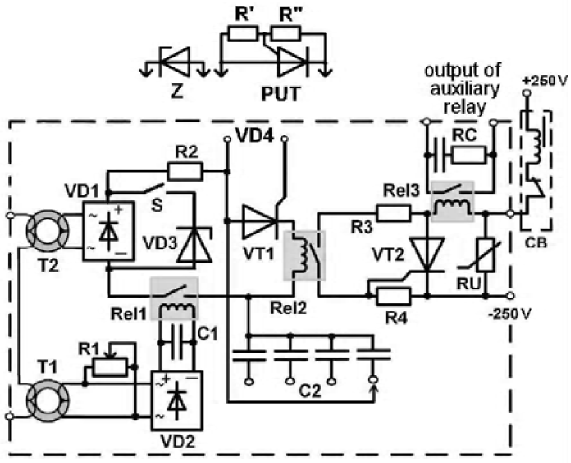
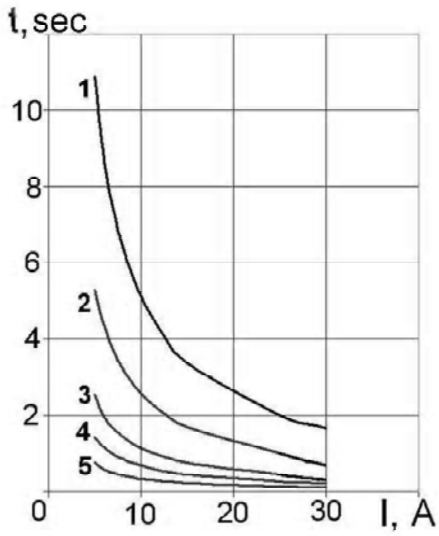



Fig. 5. An embodiment of circuit of output switching unit of the relay based on the modern IGBT-transistor (IXGH25N160) and specialized driver with the dynamic discharging (DIG-11-15-30-DD) for this transistor control

Current relays with independent and dependent time delay (Fig. 6). Similarly to the above design, the relay contains two independent current transformers: the first one (T1) is used as a source of control value for pickups module on reed switch (Rel1) and the second (T2) - for feeding of time delay unit. When the microswitch S is switched ON , the Zener diode VD3 is connected to the output of rectifier bridge VD1 and provides a constant level of a voltage (on an input of the time delay unit time) which is independent from the input current in the current pickups range. In this case the relay works with the constant time delays which are determined by capacitance C2 and resistance R2. As this capacitance is charged up to the certain voltage value, turn- ON thyristor VT1 and capacitance C2 are completely discharged through low resistance (81 Ohm) winding (2050 turns by a wire 0.16) of relay Rel2, activating the reed switch. In order to turn this device into a relay with time delay depending on the current it is necessary turn the microswitch S OFF. In this way the voltage charge of capacitor C2 will depend on the input current level: the higher is this current, the higher is the voltage applied to capacitors C2 and the shorter is the time of their charging up to a voltage level at which thyristor VT1 turns ON, forming a typical time-current characteristic curve (Fig. 6), the specific relay of such kind. If second reed switch, is removed from the center of the coil and mounted in the coil of relay Rel1 (so that its pickup will be 10–15 times higher than that of the first reed switch) and is connected in parallel to reed switch of the relay Rel2, the device will pickups instantaneously at high rates of the input current and energize the trip coil of the CB during 3 - 4 milliseconds. Turn ON thyristor VT1 was used as the threshold element VD4, standard Zener diode was used in the relay prototype, however the best results can be obtained with so-called «programmable unijunction transistor» (PUT), e. g. 2N6027, 2N6028 types. This element of the structure and characteristics is similar to a thyristor with very low leakage current (microamperes) through gate junction that allows more efficient use of capacitance C2. Its turning-ON voltage can be adjusted i.e. «programmed» by means of resistors R' and R".



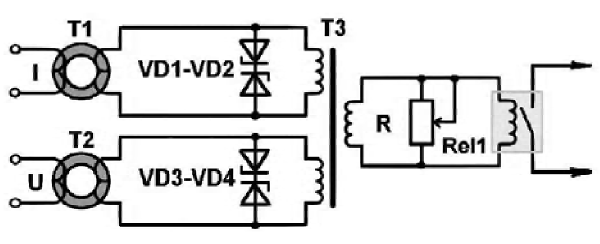

a)



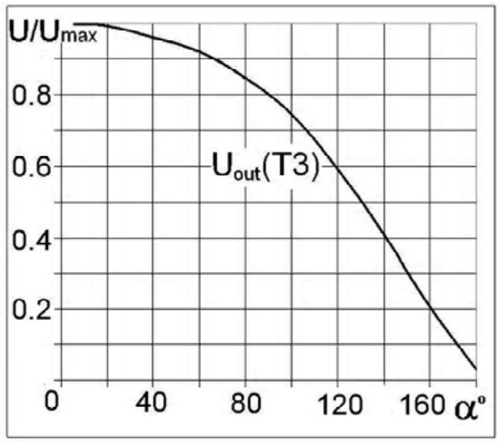

b)

Fig. 6. Universal protective current relay with the time delay: the basic circuit diagram (a) and set of experimental time-current characteristic curves (b). For the relay with the dependent time-current characteristic curves the various values of capacity C2 (in uF) are as follows: 1 – 4400; 2 – 3200; 3 – 2200; 4 – 1000; 5 – 300.

Relay of a power direction (Fig. 7). Even such complex function as detection of power direction can be realized very simply by means of hybrid technology. As it is known, the power direction is determined by the angle of phase displacement between the current and the voltage, therefore, actually, the power direction relay responds to the change of angle between the current and the voltage. It turned out, that application of two equivalent phase-shifted voltages to two primary windings of the intermediate transformer T3, cause the output voltage on the third winding to depend very strongly on the phase displacement between these voltages (Fig. 7). It is necessary only to exclude the change effect of the input voltage supplied from current transformer (T1) and voltage transformer (T2) at a level of the output voltage of transformer T3. The simplest solution of this problem is provided by means of two back-to-back connected Zeners as it is shown on Fig. 7. Pickups relay can be adjusted by means of potentiometer R.



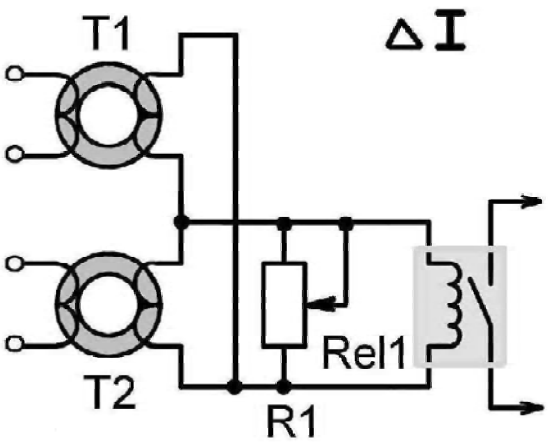

a)



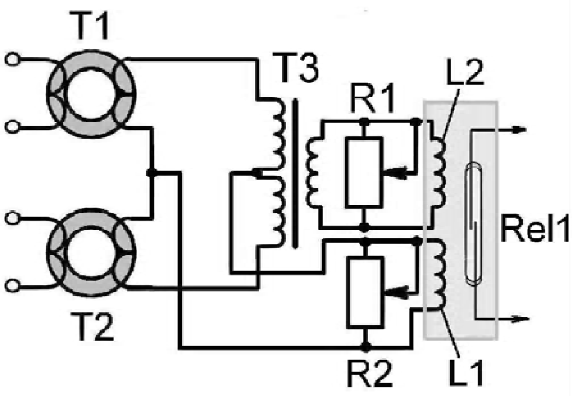

b)

Fig. 7. The relay of power direction: basic circuit diagram of measuring the threshold module (a) and experimental dependence of an output voltage of transformer T3 on an angle shift between two voltages on its primary windings (b).

Relay of differential protection (Fig. 8). The use of two current transformers (T1 and T2), connected to the input of pickup module of any of the devices described above allows to realize a two-input relay of differential protection (Fig. 8, a). Interesting opportunities are provided with use of two separate intermediate transformers with the secondary windings connected in series in this device. To allow more complex functions, such as coarsening the relay sensitivity with increasing the current carried directly through protected object (so-called «restraint»), intermediate transformer T3 is included in the relay. In addition, the output reed relay Rel1 consists of two windings: L1 - differential and L2 – restraint, which shift the working point of the relay proportionally to the current carried directly through protected object (Fig. 8, b).




a)




b)

Fig. 8. Measuring modules for the relay of differential protection: a – the simplest embodiment, b – an embodiment with restraint

## Conclusion

Description of quite interesting and promising devices based on the suggested elements could be continued. However, the purpose of this publication is not to present the advantages of reed switches, but to prove that on the basis of a combination of modern reed switches and modern power semi-conductor elements a new generation of hybrid protective relays not including complex mechanisms can be easily created that can replace the out-of-date electromechanical relays at the upper level with retaining their high noise and surge stability, maintainability and other positive features. The use of the new generation of the relays would allow sparing considerable financial expenses connected with necessity of purchasing the expensive microprocessor-based protective devices. Thus, further perfection of automatic control systems in electric networks by equipping them with microprocessor recorders of emergency modes, optical communication systems and other modern systems can be gradually accomplished, during accumulation of financial resources independently of the relay protection. In the author's opinion the examples of the protective relays developed and tested by the author can support our conclusion.

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*Автор предлагает новый взгляд на проблему реорганизации релейной защиты. По его мнению, комбинация герконов, магнитных цепей и полупроводниковых элементов позволяет создавать новые типы защитных реле, отличающиеся надежностью, простотой и низкой стоимостью. В качестве примера приведены описания конкретных конструкций защитных реле, выполненных на этой элементной базе.*

*Автор пропонує новий погляд на проблему реорганізації релейного захисту. На його думку, комбінація герконів, магнітних ланцюгів і напівпровідникових елементів дозволяє створювати нові типи захисних реле, що відрізняються надійністю, простотою й низькою вартістю. Як приклад наведені описи конкретних конструкцій захисних реле, виконаних на цій елементній базі.*