Device of Protection of Relay Protection

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***Abstract*- The problem of protection of relay protection is discussed in the article. It is shown that the relay protection of power objects really requires protection. From what and as it is necessary to protect a protective relay it is told in the article.**

Keywords*- *Relay Protection; Cyber-Security; Digital Protective Relays; Reed Switches; Electromechanical Protective Relays

I. INTRODUCTION

Relay protection is the most important system, the reliability and correct performance of which influence reliability of power supply to customers. However, regardless of its name (protection), relay protection cannot protect from emergency modes. In other words, it cannot *prevent* an emergency mode in a power supply system, but can only limit its negative effect on this system in time and in space, i.e. limit material damage caused by an incident and nothing more [1]. Everything mentioned above is related to an intact protective relays and its proper functioning. However, protective relay like any other complex technical device can fail. Moreover, in case of emergency a faulty relay will not limit its effect on the power system in time and in space. However, this situation can be predicted and the probability of its occurrence is considered when designing relay protection of power systems. In fact, use double protective relays; in critical systems they use different types of protective relays so that in case one type fails, another will be actuated, or a relays connected in another location of the power system, etc.

It is known that protective relay has two kinds of failures: a so-called “non-operation” and an “unwanted operation”. The measures mentioned above allow compensating the damage caused by non-operation of a specific relay to some extent, but they can do nothing with unwanted operation of relay. As [1] mentions, these circumstances result in a new situation, when a malfunctioning relay can generate a faulty command to disconnect a high voltage circuit breaker because of an unwanted operation, which leads to termination of normal functioning of power system. Moreover, it results in not only disconnection of thousands of consumers, but also in a danger of a large system incident and also to power system collapse, caused by unexpected overflows of power during such disconnections in a complex and branched system. As mentioned in [2] failures of relay protection were responsible for 25-28% of large system incidents, which happened in the world. If we consider that relay protection is also responsible for 50-70% of transformation of simple emergency modes into a power system collapses [2], we can make a conclusion that relay protection is responsible for almost all of the system incidents.

II. PROBLEM WITH RELIABILITY OF DIGITAL PROTECTIVE RELAYS

Modern tendency of substitution electro-mechanical protective relays (EMPR) by digital protective relays (DPR) accompanied by reduction of reliability of power system [3]. This is explained by a set of reasons among which the most important one is a significant increasing of DPR susceptibility to cyber-attacks and intended electromagnetic destructive impacts (IEDI) [3].

A solution could be the incorporation of the best parameters of DPR (wide functional capabilities, special protection characteristics, which are not present in EMPR, etc) with the best properties of EMPR (noise resistance, resistance to cyber-attacks and IEDI). Is it possible to create such a hybrid device at all? The practice says yes. It is known that in many power systems installation of the very first samples of DPR was backed-up by EMPR connected in parallel [4]. According to [5] this technical policy, which based on backing-up DPR with an EMPR connected in parallel with additional time delay of 0.1 sec, is up-to-date and justified today. The author of [5] states that:

A 10-year experience of using DPR and EMPR in modern substations of Velikiy Ustyug power lines of Vologdaenergo showed that this is the only way to establish a modern substation with modern and extremely reliably relay protection…Under no conditions should we allow stopping producing electro-mechanical protection relays, kits and boards”.

But are these statements fair enough? First of all, it is obvious that in case of parallel connection of DPR and EMPR we are only talking about reduction of accidents of “non-operation” of protection but not about “unwanted operation”. However, it is the latter case, which is the most dangerous and as of today we’re not protected from this type of malfunctioning. Besides, according to the Theory of Reliability if we connect both relays parallel, the probability of “unwanted operation” will increase. Secondly, modern EMPR are not “modern” in a sense in which the author [5] refers to them, i.e. new and the most advanced for today. It is rather an opposite situation: the so called “modern” EMPR were designed dozens of decades years ago, which means that they are aged today.

III. SOLUTION FOR THE PROBLEM

We think that the solution of this problem rests in another plane. In [6] we offered an idea of accelerated actuation of EMPR rather than delayed actuation mentioned in [5]. At the same time both relays (DPR and EMPR) are not connected parallel, but in series, Fig. 1. Under the normal mode of operation DPR is deactivated and in case of emergency EMPR is the first to be actuated (as a starting unit of DPR) and actuates DPR to allow its further normal operation.

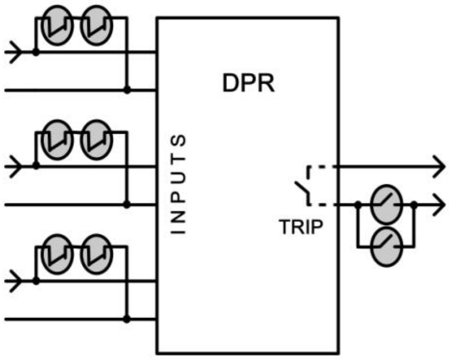

Fig. 1 Application of EMPR based on high speed reed-switches to shunting sensitive inputs of DPR and block its output (trip) contact

An instantaneous (several milliseconds) current (voltage, power) relay can be used as a starting unit (SU) of this kind. This SU cannot be actuated by a cyber attack; it is far more resistant to IEDI compared with DPR. If we shunting the sensitive inputs of DPR by normally closed reed switches of SU, this can prevent high-voltage impulses from entering the sensitive inputs of DPR and its damage by IEDI. Connection of reed switches of such SU in series with DPR's trip contact will prevent unauthorized actions of relay protection affected by cyber interference from outside.

Thus, if the SU not actuated, DPR will not be able to influence the operational mode of a power system even if it will actuate by a cyber attack or affected by IEDI. If the SU will actuate by overcurrent, for example, nothing will prevent us from using special protection characteristics and broad functionality of DPR.

Obviously, the so-called "modern" EMPR cannot act as instantaneous SU of DPR. An instantaneous hybrid Fast Overcurrent Relay (FOR) studied in [7] in detail is more suitable to act as a SU, Fig. 2.

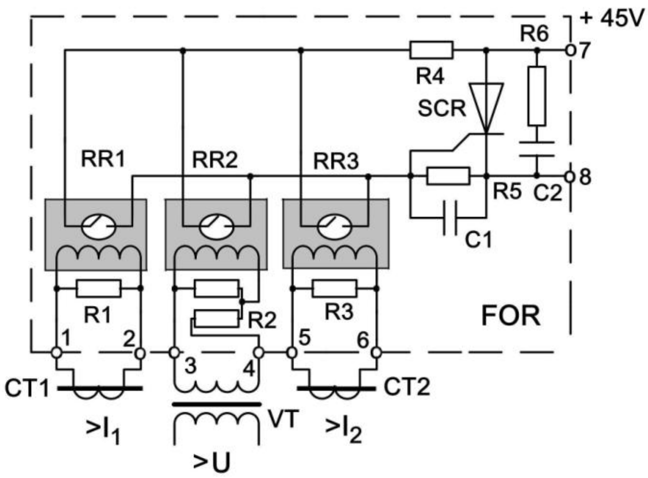

Fig. 2 Starting unit (SU) based on hybrid Fast Overcurrent Relay

When this device reaches a threshold value of current, the members of reed switch of one of relays RR1 – RR3 start vibrating with 100 Hz frequency. Their first closure results in opening of SCR thyristor connected in series with the DC load, which remains turned on even in period when vibrating reed switch is open. The reed switch continues vibrating until relay protection disconnects a damaged circuit with abnormal current (as a rule, this takes from several milliseconds to several seconds). Such principle of a SU has several advantages:

- accurate and stable threshold of pick-ups with a possibility to adjust it by changing the reed switch's position in a coil or by changing a resistor R1;
- quick operation (fractions of a millisecond);

- high reset coefficient (close to 1);
- full galvanic separation with high level of insulation (kV) from input current circuit;
- hermetically sealed contacts; no need to clean and adjust them.

Miniature vacuum reed switches with withstanding voltage of not less than 1 kV and having their own operate time of about 1 ms (Table I) can be used as sensitive threshold elements in the SU (Table I).

TABLE I MAIN PARAMETERS OF VACUUM NORMALLY OPEN HIGH-VOLTAGE REED SWITCHES OF SEVERAL TYPES

Parameter/Type	MRA5650G	KSK-1A75	HYR2016	HYR1559	MARR-5	KSK-1A85
Contact type	NO	NO	NO	NO	NO	NO
Switching voltage, V	1000	1000	1000	1500	1000	1000
Switching current, A	1	0.5	1	0.5	0.5	1
Switching power, W	100	10	25	10	10	100
Dielectric strength, V	1500	1500	2500	1500	2000	4000
Operate time, ms	0.6	0.5	0.8	0.4	0.75	1.0
Release time, ms	0.05	0.1	0.3	0.2	0.3	0.1
Balloon dimensions	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 = 2.75, L = 21
Sensitivities, A	20 – 60	15 - 40	15 - 70	15 - 50	17 - 38	20 – 60

An assembly including a reed switch and a current coil with several winds of a thick wire is located into a ferromagnetic screen.

Table II shows parameters of several types of thyristors which are more suitable to be used in a SU. In order to reduce noise resistance of a SU, it includes additional RC-elements.

TABLE II THE MOST IMPORTANT PARAMETERS OF SEVERAL TYPES OF POWERFUL THYRISTORS INTENDED FOR MOUNTING ON PRINTED CIRCUIT BOARD

Parameter / Type	CS 20-12io1	CLA50E1200HB	25TTS12	30TPS12	BTW68-1200
V_{RRM}/V_{DRM}, V	1200	1200	1200	1200	1200
$I_{T\ (RMS)}$, A	30	79	25	30	30
$I_{T\ (AV)}$, A	19	50	16	20	19
I_{TSM}, A	200	650	300	250	400
I_{GT}, mA	65	50	60	45	50
I_L, max., mA	150	125	200	200	40
I_H, max., mA	100	100	100	100	75
dv/dt, V/µs	1000	1000	500	500	250
T_{GT}, µs	2	2	0.9	0.9	100
T_J, ℃	-40 +125	-40 +150	-40 +125	-40 +125	-40 +125
Case type	TO-247	TO-247	TO-220AC	TO-247AC	TOP3 ins.

A starting unit controls by operation of final control relays connected according to a diagram in Fig. 3.

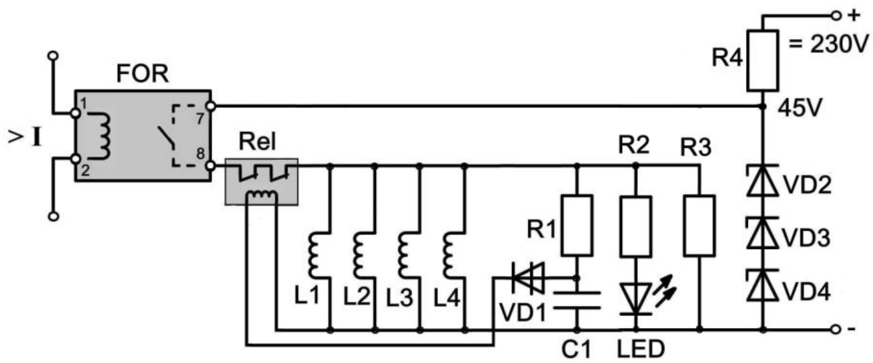

Fig. 3 A diagram of connection of final control reed relays (L1 – L4 – control windings of these relays the contacts of which are shown in Fig. 1)

All the elements of this layout are fed from stabilized voltage divider on VD2 – VD4 Zener diodes, which supplies 45 V and protects from voltage surges and spikes from the main supply circuit. This voltage (45 V) is also applied to the elements of the SU. When it gets actuated, voltage is supplied to control windings of all final control reed relays, which are actuated within

2-3 milliseconds and de-shunting (unblock) the DPR, which allows its normal operation. Simultaneously a capacitor C1 starts charging through R2 resistor.

In about 10 s the voltage on a capacitor reaches the value of D1 (Trigger Diode) opening (breakover) voltage through which C1 capacitor is quickly uncharged to the winding of electromagnetic relay Rel. As a result, the relay is actuated for a short time period opening its contacts, which are normally closed and break the feeding circuit of final control relays' windings for about 100-300 msec.

When this happens, the thyristor of the FOR SU is closed and the device returns to its initial condition (standby mode). Since time is required for DPR's operation under emergency mode of a protected object (usually not more than several seconds), 10 seconds is more than enough to return to a standby mode for a full finish of a cycle of DPR's normal operation. Since the total current consumed by L1-L4 windings of a final control relay can be less than the latching current (I_L) and the holding current (I_H) of thyristor, the circuit in Fig. 3 is supplemented by a powerful resistor R3, which increases the total current flowing through the thyristor to 250-300 mA. Though there are special thyristors with increased sensitivity and small latching and holding current rates, which do not exceed 10 mA in the market (TS820-600, TIC106, BT258-600R, X0402MF, MCR708A1, etc) we do not recommend using them in this device, since it can lead to reduction of its noise resistance.

Gas-filled reed switches Bestact R15U by Yaskawa Company, which block output contact (trip contact) of DPR can be successfully used as contact of final control relay, Fig. 4; they are intended for current rates of up to 30 A at 240 V and has operate time, which does not exceed 5 ms.

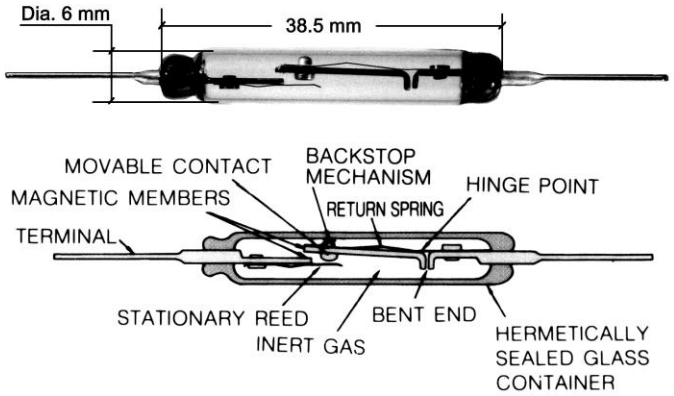

Fig. 4 A powerful gas-filled reed switch Bestact R15U by Yaskawa Company with a two-stage switching

High-voltage vacuum normally closed reed switches of different types, Table III, can be used in a SU for shunting of sensitive (non-current) inputs of DPR.

TABLE III MAIN PARAMETERS OF SOME TYPES OF CHANGEOVER REED SWITHES

Parameter / **Type, Manufacturer**	**GC 1917** **Comus**	**HSR-830R** **Hermetic Switch, Inc.**	**HSR-834** **Hermetic Switch, Inc.**	**HSR-V933W** **Hermetic Switch, Inc.**
Max. switching power, W	60	25	100	100
Max. switching voltage, V	400	250	500	500
Max. switching current, A	1	1	3	3
Dielectric strength, V	1000	1000	1000	1500
Operate time, ms	4.0	3.6	2.0	4.2
Release time, ms	0.15	4.2	1.0	3.7
Balloon dimensions, mm	D=5.6, L=36	D=5.3, L=32	D=5.3, L=34	D=5.3, L=33

Obviously, that according to the Theory of reliability, connection of additional contacts (even those that are highly reliable) in series with trip terminals of DPR's or parallel to its inputs will result in a certain reduction of reliability of relay protection. How much? It is very difficult to answer this question today, as there is no adequate information due to lack of experience of using such devices. However, should it be necessary, this reduction of reliability can be simply compensated by using two reed switches connected in series or parallel as additional contacts, Fig. 1. The probability of such failures as "unwanted operation" in electromechanical relays is much lower than the probability of "non-operation". That's why their parallel connection (unlike ordinary parallel connection of DPR) will definitely increase reliability of relay protection. For normally closed additional contacts shunting DPR's inputs, improvement of reliability can be achieved by connection of these contacts in series, Fig. 1.

The capacitor of a R1C1-circuit as well as other elements of the device is improved and has a higher (5-fold) margin in terms of working voltage, Table IV.

TABLE IV MAIN PARAMETERS OF SOME TYPES OF HIGH-QUALITY CAPACITORS FOR RC CHARGING CIRCUIT

Capacitor Type	Manufacturer	Capacity, Voltage	Dimensions, mm	Min/Max Temperature, ºC
B43504B2477M	EPCOS	470 μF, 250V	Dia. 30 x 30	-40 +105
B43505A2477M	EPCOS	470 μF, 250V	Dia. 30 x 35	-40 +105
EETHC2E471CA	Panasonic	470 μF, 250V	Dia. 25 x 30	-40 +105
MAL215933471E3	Vishay	470 μF, 250V	Dia. 25 x 40	-25 +105
MCHPR250V477M25X41	Multicomp	470 μF, 250V	Dia. 25 x 41	-25 +105
381LQ471M250J022	Cornell Dublier	470 μF, 250V	Dia. 25 x 30	-40 +105

As a voltage divider three Zener diodes connected in series were selected with a stabilization voltage of 15 V and 10 Wt power each. With a rather low own energy consumption of the circuit, high voltage margin prevents Zener diode's heating, improves reliability of their operation and allows improving absorption of high energy overvoltage impulses. Parameters of the most suitable Zener diodes for these purposes are listed in Table V.

TABLE V MAIN PARAMETERS OF SOME TYPES OF 10 W, 15 V ZENER DIODES

Parameter / Type	NTE5191A	1N2979
P_D, W	10	10
V_Z, V	15	15
I_{ZM}, mA	560	560
I_{ZT}	170	170
Z_{ZT}, Ω	3	3
I_R, μA	10	5
T_{OPR}, ℃	-65+175	-65+175
Case type	DO-4	DO-4

The following types of devices can be recommended as VD1 trigger diode (Fig. 3) with an opening (breakover) voltage of 24-36V and current rate of 1-2A: NTE6407, DB3, BR100/03, CT-32, HT-32 and others. As an electromagnetic relay Rel (Fig. 3) we can recommend Full Size Cristal Can Relays with two changeover contacts (two normally closed contacts are used to increase reliability), which switches 2-5 A current with a coil for 24V DC. As an example, the following relays can be mentioned: REN33, REN34, REK134, RES48, 782XDXH, H782, B07, FW, SF, G2A-434ADC24, HGPRM-B4C05ZC, 2B-7506 and others.

There is no need for fine-tuning of a pick-up threshold of this device. It is important that its actuation is always earlier than that of DPR under any suspicious regime in a control circuit, since unwanted operation of the device as a result of incorrect setup does not influence operation of DPR protected by the device.

IV. CONCLUSION

Modern digital protective relays (DPR) need to be protected from cyber attacks and intended electromagnetic destructive impacts (IEDI). Simply backing up the DPR by other DPRs or by electromechanical protective relays (EMPR) may prevent "non-operation", but may not prevent "unwanted operation" - especially different kinds of DPR malfunctions. The protection device that is described in the article may solve the problem. The use of highly reliable components in this device chose with multiple margins in terms of current, voltage and power and which allow operation under a wide range of temperatures, a limited number of such components, perfect galvanic separation and doubling of the most important elements ensure high reliability of DPR under powerful electromagnetic noises, cyber-attacks and IEDI corresponding to reliability and noise resistance of electromechanical relays.

DPRs protected by the described device can be connected in parallel to protect the most important power sector facilities. When using this device it is possible to connect additional EMPR parallel to DPR with a 0.1 second delay [5].

Obviously, specific circuit configurations can be different from those described in this article. However, the suggested solution will definitely increase reliability of DPR-based protection.

The simplicity of the described device makes it possible to quickly arrange its production at any enterprise manufacturing electronic devices.

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Dr. V. Gurevich is author of 9 books, more than 160 articles and more than 100 patents.