Volume 13 Issue 48
Originally issued as F15

Global Journal of Researches in Engineering
Electrical and Electronics Engineering
Volume 13 Issue 15 Version 1.0 Year 2013
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

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GJRE-F Classification : *FOR Code: 090905*

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Abstract - **A new way for protecting digital protective relays from cyber attacks and intentional destructive electromagnetic impacts is describe in the article.**

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I. Introduction

The modern trend of the replacement of electromechanical protective relays by digital protective relays (DPR) has exposed a serious problem, which was not known before in the field of relay protection. This problem is the possibility of an intentional remote destructive impact (IRDI) on the relay protection in order to disable it or force it to perform functions that are not related to the current mode of operation of the electric equipment being protected. DPR is the most critical link in the structure of modern power supply systems [1] because, on the one hand it is the most susceptible to IRDI, while on the other hand it is directly related to power circuit breakers, which influence the configuration of the power system. This is why IRDI in the form of cyber attacks and intentional destructive electromagnetic impacts (IDEI) [3] are targeted at DPR [2]. Special research conducted by B5 CIGRE and presented in its report confirmed the relevance of the problem and reached the conclusion that the expansion of the application of the most advanced standard IEC 61850 with its GOOSE-messages as well as modern Ethernet technologies in relay protection result in increasing of its susceptibility to IRDI [4]. The Smart Grid [5] technologies are equally dangerous in this regard.

II. The New Way for Highly Efficient Compound Protection of DPR

The recent appreciation of the problem of DPR's cyber safety has resulted in intensification of multiple investigations related mainly to sophistication of computer communication protocols designed for relay protection and improvement of their cryptographic security. Until recently, different specialists have concentrated all their efforts into just this area. As for IDEI, unfortunately this problem has not been seriously addressed yet. At the same time, 17 years ago when the DPR's problems were just emerging, the author offered a general idea of highly efficient compound protection of DPR from cyber attacks and IDEI by means of hardware facilities instead of software tools. The suggested protection device implements a principle of by-passing the sensitive DPR's terminals by means of responsive electromechanical reed-switches [6]. The idea of implementation of responsive electromechanical reed-switches was further developed in more details [7, 8].

As mentioned before, the task of increasing the reliability of relay protection cannot be fulfilled by combining DPR's functions with those that have nothing to do with relay protection, such as monitoring of the functionality of electric equipment, remote control of circuit breakers, etc. The DPR should be used solely to solve problems of relay protection. Moreover, there are many specific devices in the market that can be used to solve other problems, such as the monitoring of electric equipment. These devices may vary from the simplest relays that control the continuity of the circuit breaker trip coils to sophisticated complex units that ensure online control of gas composition dissolved in the transformer's oil or the level of partial discharges in the insulating material. As for remote control of circuit breakers by means of DPR, this type of application will make it difficult to distinguish between authorized and unauthorized access, this is why use of this type of DPR should be eliminated. Moreover, with separation of the functions, the hardware facilities ensure easier protection from IRDI also of remote control of circuit breakers [9].

III. Device for DPR Protection from IRDI

The general idea behind the suggested hardware-facilitated method of protection of DPR from IRDI is to use an electromechanical reed-switch starting unit (SU) in combination with DPR and connected functionally in series with it as well as an electromechanical action element (RR1 – RR7), which ensures the blocking of the sensitive inputs of DPR and

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disconnection of its output circuit, Fig. 1. The reset of the actuated SU is performed upon the circuit breaker's actuation and backed-up by RESET command at the end of a preliminary set-up time period.

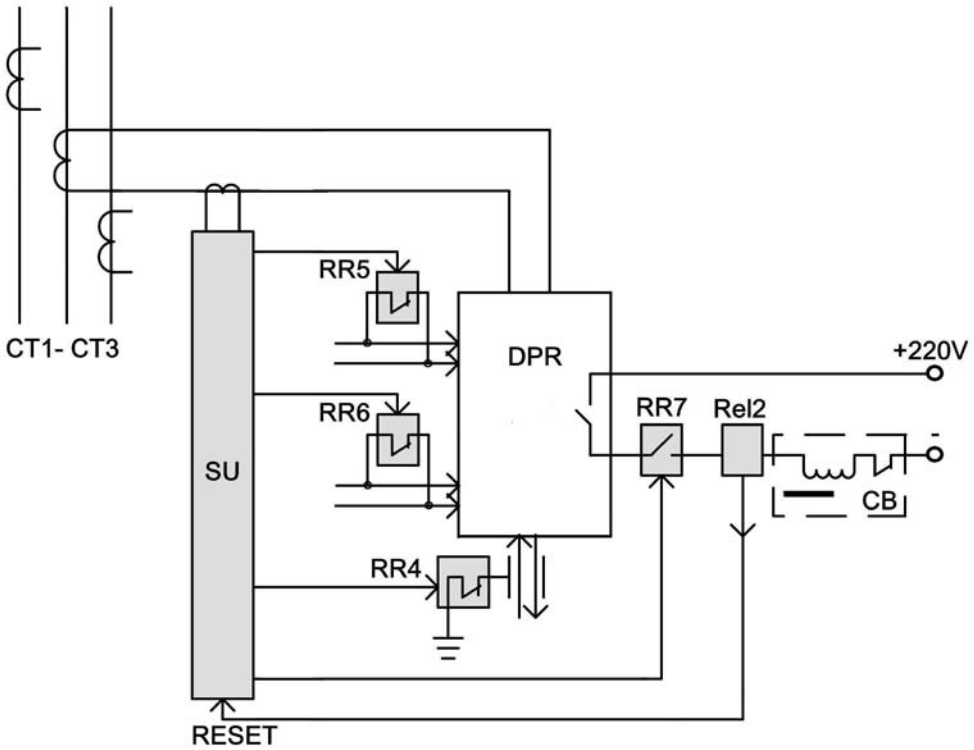

Figure 1 : A structural diagram of DPR protection from IRDI

Without current and/or voltage actuation of this SU, DPR will not be able to influence the operation mode of the power system, even under IRDI. If the SU is actuated and DPR enabled, nothing will interfere with using specific features and wide functional capabilities of DPR. At the same time, unnecessary actuation of the SU itself does not influence the operation of the relay protection and thus there are no specific requirements as to the accuracy of the SU actuation. The only thing that is important is that it should always be actuated before DPR, i.e., its settings should be a little bit lower than required for the controlled parameter. If the SU actuation was unnecessary and DPR was not actuated, the device would automatically reset. The main technical requirements for this device are its high reliability, insensitivity to short electromagnetic impulse (micro- and nanosecond range) and high-frequency interferences, resistance to substantial over-voltages, high level of galvanic insulation from external circuits and high speed of response to actuation (several milliseconds).

This article provides a description of an improved device designed to protect DPR from IRDI, which satisfies the above conditions, Fig. 2.

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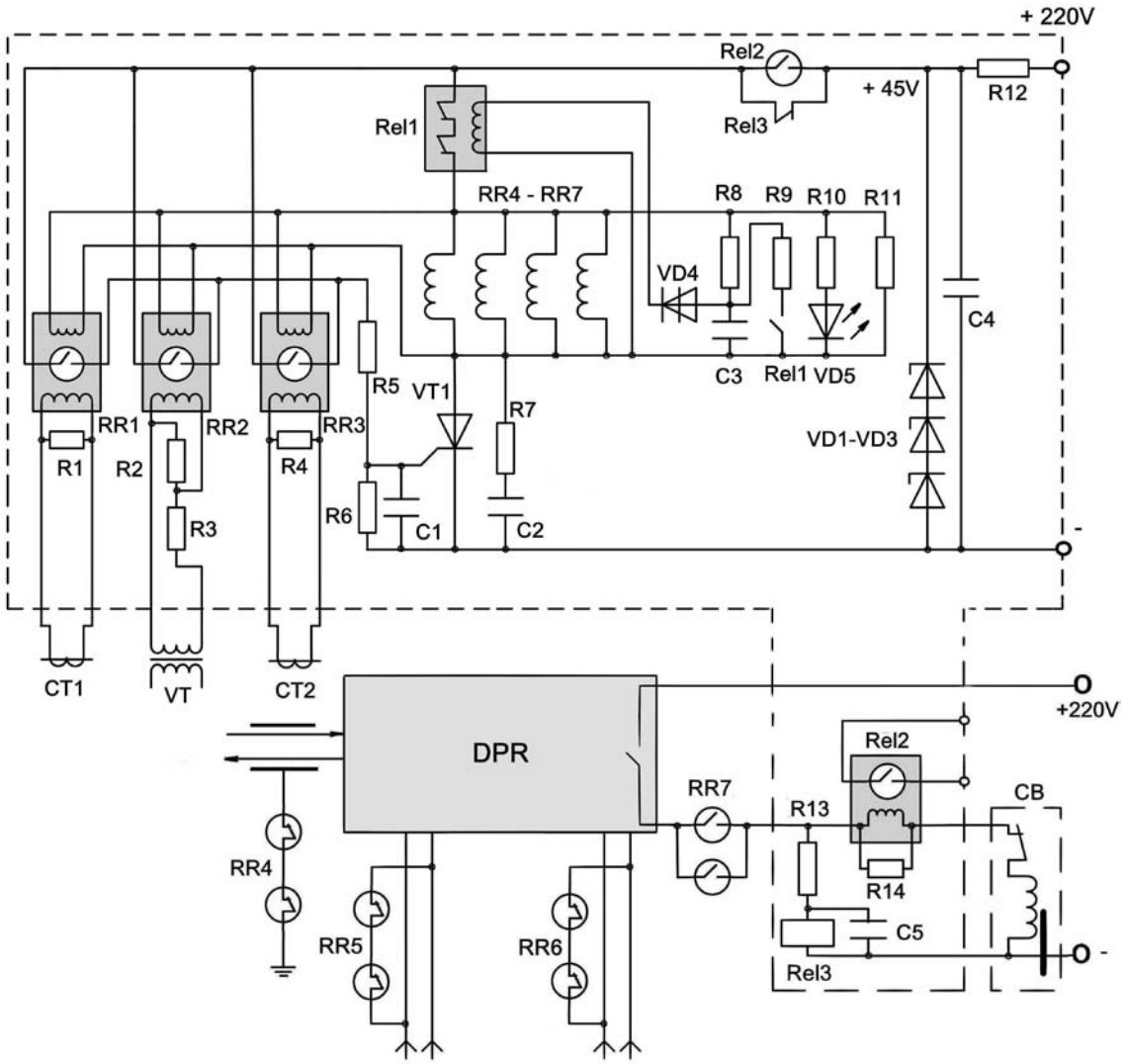

Figure 2 : A diagram of improved device protecting DPR from IRDI

The principle of operation of this device is as follows. In its initial state under the normal operation mode of the protected object, all the input reed-switches (current and voltage sensors, etc.) RR1- RR3, are in the released state. The thyristor VT1 is in the off state; the control coils of the reed-switches RR4-RR7 are not energized. The normally closed contacts RR5 and RR6 short circuit the logical inputs of DPR, the RR4 terminals short circuit the communication channel, while the RR7 terminals open the output circuit of DPR. Under these conditions the DPR is fully blocked both in inputs and in outputs and no IRDI can result in its unnecessary actuation and unauthorized actuation of the CB trip coil. Bypassing both the logical inputs of DPR and the communication channel also increases its operational vitality under the impact of a powerful electromagnetic impulse.

In case of the emergency mode in the protected object at least one of the controlled parameters (current, voltage or power) will drastically change. This change leads to actuation of at least one of the reed-switches RR1- RR3 within one millisecond or less. When actuated, a reed-switch of a corresponding input starts vibrating at a doubled frequency. During the first event of the switching of the reed-switch's terminals, the thyristor VT1 will switch on within several micro-seconds and the control coils of the reed-switches RR4-RR7 will be powered. Actuation (opening) of RR4-RR6 reed switches takes place during 2 – 4 milliseconds, while the switching on of the power terminals of the RR7 reed-switch (Bestact R15U reed-switch type) does not take longer than 5 milliseconds. Thus, the total response time of the unit to an emergency mode does not exceed 6 milliseconds, which is quite acceptable considering the DPR's own actuation time of 30-40 milliseconds. Under this mode of operation of DPR protection device, the DPR will be fully unblocked and returned into its normal mode of operation, retaining all its settings and features.

As can be seen in the diagram (Fig. 1) each of input relays (sensors) is equipped with a second

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winding on the reed-switch, which receives power from the constant voltage source upon thyristor's VT1 switching on. Due to the additional magnetic field created by this winding, the reed-switch of the actuated relay stops vibrating and enters a steady on state.

After the DPR performs the time delay set-up by its feature, its internal output relay will energize trip coil of the CB. Current flowing in the circuit of the CB trip coil results in actuation of the reed-switch relay Rel2 with a powerful Bestact R15U reed-switch and switching on of its terminals connected in parallel to the normally closed terminals of Rel3. Rel3 is actuated with a small time delay (about 10-20 milliseconds). This time delay is necessary in order for Rel2 terminal to switch on before Rel3 terminal switch off.

At the end of actuation cycle of the CB circuit breaker, its interlock will switch off and the circuit of the trip coil will be interrupted. At the same time Rel2 is released and its contact interrupts the anode circuit of the thyristor VT1, which is then immediately switched off, cutting off current from the control coils of RR4-RR7 relays and addition DC coils of RR1-RR3 relays. The device is totally returned to its initial state and is ready for a new cycle of operation.

If actuation of the device was unnecessary and DPR did not generate a command to disconnect the circuit breaker, the supply circuit of the thyristor VT1 will be interrupted for a short time by a normally closed contact of Rel1 relay upon the charging of C3 capacitor through resistor R8 and switch on of VD4 dynistor diode. The capacity of this capacitor and resistance of the resistor ensure a time delay of several seconds, which exceeds the maximum possible time necessary to fulfill the full cycle of DPR operation in order not to interfere with its operation should it be required. Actuation of Rel1 relay is temporary, since immediately upon its actuation and the opening of the normally closed contacts in the thyristor's circuit, its normally open terminal will switch on and discharge the C3 capacitor through a low-Ohm R9 resistor, ensuring its full discharge and return into initial state. At the same time the VD4 dynistor diode will close and current on the Rel1 relay's coil will be cut off. This is how a forced reset of the device to its initial state happens, if its actuation is unnecessary.

The R11 resistor is needed to increase the current rate flowing through the power thyristor VT1 and its reliable maintenance in a conducting state. The LED VD4 serves as an indicator of the device's condition.

In order to increase the reliability of the device and its resistance to IDEI, only a few solid-state elements are used. They were selected with very big reserves for the device's maximal values in marginal current and voltage rates that are not used in usual industrial applications. For example, the VT1 thyristor with its actual operational voltage of 45 V was selected for maximum voltage rate of 1200 V; with its actual operational current rate of fractions of Ampere, it can work under current of tens of Ampere and conduct short-term impulses of hundreds of Ampere. The Zener diodes VD1-VD3, as well as the VD4 dynistor diode, are also selected with very large power reserves. The auxiliary relays Rel1 and Rel3 are selected as sealed with high power contacts. The general recommendations for selection of hardware components of protection device and even some specific types of recommended components are listed in [8].

IV. Resume

The described solution is designed to prove the technical possibility for implementing digital relays protection from intentional remote destructive impact by means of hardware components rather than software tools. It can serve as a starting point for detailed developments of a device suitable for industrial production. Further efforts should be aimed at developing structural designs of input reed-switch relays (current and voltage sensors) with adjustable threshold of actuation. The experience of development of such devices is mentioned in [10].

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