Reliability of microprocessor-based protection devices - myths and reality

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This is the second part of a two-part article "Reliability of microprocessor-based relay protection devices - myths and reality. Part 1 was published in EngineerIT May 2008.

Microprocessor-based protection devices (MDs) of all types are supplied with what is called switchmode power supplies in which the input voltage (AC or DC) acts on the rectifier and the filter then interrupts with the high frequency (tens-hundreds kilohertz) with the help of a powerful switching transistor, which turns the supply into high-frequency AC. This high-frequency voltage is transformed by the high-frequency transformer to a low voltage (mostly, 12 V), which is rectified, filtered and stabilised. Further lower voltages are formed from this DC voltage (5 V, for example), necessary for MPD functioning. Microprocessors are usually rather sensitive to a level of a feed voltage and can perform unpredictable operations at the voltage reduction below a certain value. With MPD a constant monitoring of the level of a feed voltage of the CPU is carried out. As mentioned above, the integrated circuit of ADM 691-695 can be used for the continuous monitoring of the power supply voltage level. As well as with the watchdog timer, the ADM 691-695 chip generates a signal for locking the CPU at an inadmissible voltage supply reduction. The locking signal remains until the voltage level is restored. Is it possible to count such voltage level monitoring as self-diagnostics of the power supply, raising it functioning reliability? Hardly, therefore it is the internal technological locking only which prevents failures in the CPU. Such monitoring has no relation to the reliability of the power supply.

It is our contention that power supplies are the most unreliable unit of the MPD. First, elements of the power supply work in a high load mode; they are constantly subjected to the influence of high values of a voltage and a current, voltage spikes, dissipating high power on the elements. Secondly, they contain many aluminum electrolytic capacitors that do not carry high frequency currents on which switching power supplies work well, and are frequently the reason for the total breakdown of the power supply (and, consequently, of the whole MPD). Can monitoring of an output voltage level in this case help? Can it indicate in advance the deterioration of a capacitor and thereby prevent the sudden MPD failure?

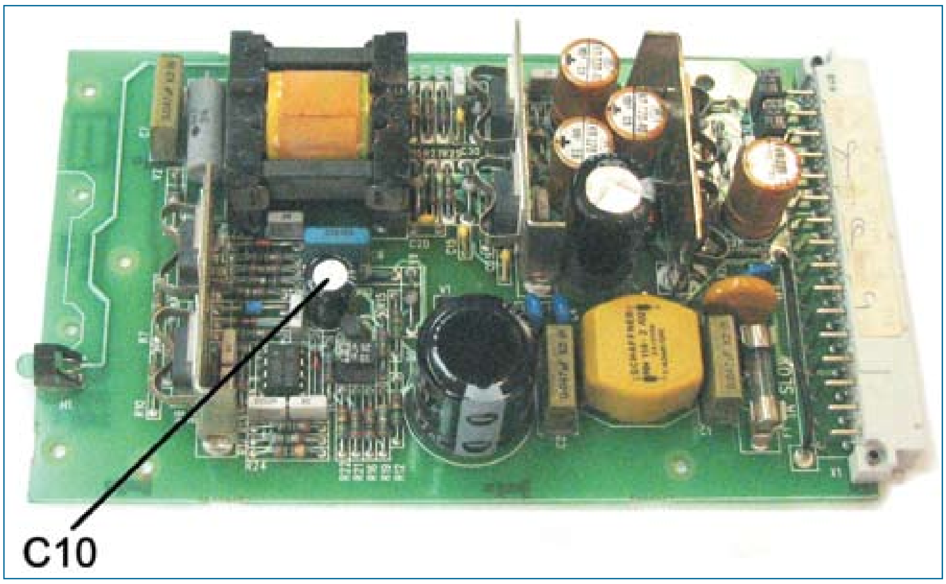

Fig. 8: Units of digital inputs of various configurations from MPD series REL316.

Output electromagnetic relays

As shown in previous research [28, 29] conducted by the author, contacts of miniature electromechanical relays (usually used in all types of modern MPDs as output elements) directly control the trip coils of high-voltage circuit breakers or the coils of auxiliary relays with a significant overload. Therefore reliability of these relays is essentially reduced in comparison with the value specified by the relays manufacturer. On the other hand, in promotional brochures of various manufacturers about MPD advantages it is usually emphasised that serviceability of such important elements as output relays is continuously supervised by means of a self-diagnostics system of the MPD. It is impossible to check the serviceability of the electromechanical relay in a working MPD if the contacts are inserted directly into the circuit of the trip coil of the high high-voltage circuit breaker. The serviceability of contacts of the output relays can in this case not be checked. What check is possible? Only the relay coil!. This is what the MPD manufacturers have implemented: the supervision of the continuity of the relay coil. This is done by passing a constant weak current through the coil. However, it is the contacts, not the relay coil that is not the unreliable part of the electromechanical relay. This is not mentioned in the specification and is mostly overlooked.

Units of digital and analogue inputs

The digital inputs unit is a set of powerful resistors, opto-couplers, electronic filters, multiplexers, etc., mounted, usually, on a common PCB together with the output relays (Fig. 8). The analogue inputs unit is a set of voltage and current transformers mounted on a separate PCB, (Fig. 9). In [30] it is noted that these units are only partly covered by self-diagnostics, without any explanation of how it is performed, but in [31] it is stated that they are not covered at all by self-diagnostics. PCBs of analogue and digital inputs in the MPD have, as a usual, various configurations (Fig. 8). The given type of

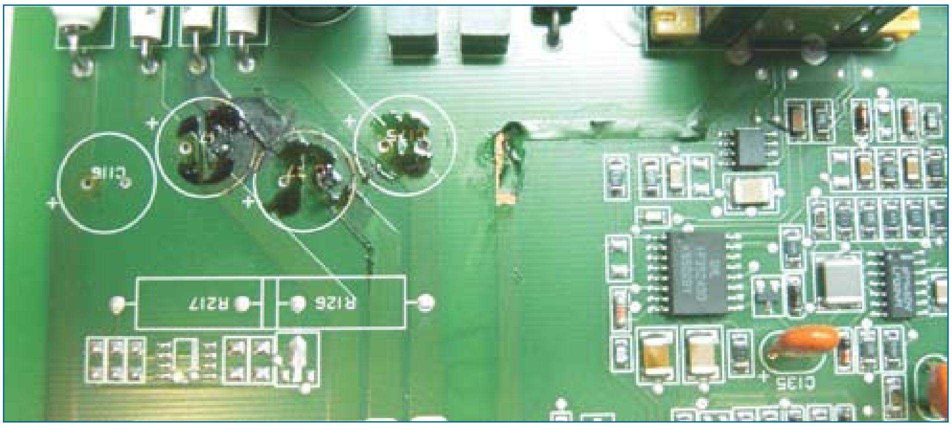

Fig. 9: Units of analogue inputs MPD containing voltage and current transformers.

the PCB established in the given MPD should be entered into its memory.

To clarify the situation and to place points above i, we have replaced one such PCB (in MPDREL316 type) the type of which is stored in the MPD's memory, with a PCB of another type (Fig. 8) without changing the data in the MPD memory. Apparently the MPD is loaded into a normal operating mode without noticing the substitution of the PCB. It is clear that it will not function correctly. What can be said about self-diagnostics of serviceability of internal components of these units in such a situation? Further comment is unnecessary.

In conclusion of this section it is necessary to note that, contrary to popular belief, internal self-diagnostics are not in fact the means intended for decreasing the MPD failure rate, ie., for increasing its reliability. The purpose of self-diagnostics is locking the MPD and delivering an alarm signal before the occurrence of emergency mode in a power network, instead of during a MPD failure.

Myth 4: MPDs are essentially more reliable in comparison to the previous generation's protection devices, as they contain considerably fewer components and these components are less subject to deterioration. MPDs also contain fewer internal connections [32]

Regarding the claim that MPDs contain fewer components than relay protection devices of the previous generation, it turns out that actually the number of components making up some MPDs is more than the number of components of protective relays of previous generations. As for the claim of more intensive physical ageing of elements of the protective relays of the previous generation, this theory also does not bear scrutiny. The comparison is made between the modern elements and technologies used in MPD with materials (impregnation and cover varnishes, plastics, insulation materials, contact and anti-corrosion materials) that were in use in the USSR 50 years ago and employed in the protective relays for many decades. As already stated, old electromechanical relays manufactured in the west (BBC, Westinghouse, General Electric, etc.) in which high-quality materials and coverings were applied, still work successfully and show no signs of ageing.

Over the past decade materials used in the manufacture of components and micronisation of components have advanced, yet the problem of ageing of components remains. Even high-quality electrolytic capacitors of Japanese manufacture start to change the parameters after 7 - 10 years of operation under the high-frequency used in MPD's switching power supplies. As a result a change of parameter of one such capacitor only, (Fig. 10), completely stops power supplies functioning. For example, power supplies such as SPGU240A1, used in MPD, types SPAC, SPAD, SPAU, SPAJ have been shown to cause this.

In some cases leaking capacitors can destroy the copper tracks on PCBs.

Another problem is the aspiration of manufacturers for MPD miniaturisation at any cost. This has led to using electronic elements in MPD working with an overload and dissipated increased value of heat that does not promote an increase in MPD reliability and reduction of elements ageing. Over-heating of ditital input circuits is a major issue. (33)

Multilayered PCB MPD involves a huge number of contact transitions (crosspieces) between layers. From the author's personal experience there have been cases of faulty MPD actions due to the increase of transitive resistance of these transitions.

The design of many types of MPDs come with a motherboard with multicontact sockets and functional boards with the reciprocal sockets connected to a motherboard. Instead of a motherboard, flexible multicore trunks connecting separate PCBs are sometimes used. These contact connections do not always provide a reliable transfer of low-voltage/low-current signals between boards. Contrary to the widespread myth, MPD contains many more interconnections than the relay of the previous generations.

Another problem with MPDs that manufacturers prefer not to mention

In view of the increased sensitivity of modern microelectronics to electromagnetic radiations, there is a problem for MPDs with respect to electromagnetic compatibilities. Many experts have noted the frequent incompatibility between real parameters of grounding systems in substations and the requirements showed by MPDs [34, 35] and, as result of this, on MPD failures. But little is known by the experts in the field of relay protection about the problem of "electromagnetic terrorism", the powerful electromagnetic radiations [36] that intentionally impact on electronic devices, and also about the problem of hacker attacks (cyber security problem) [37]. These problems were unknown in relay protection and became

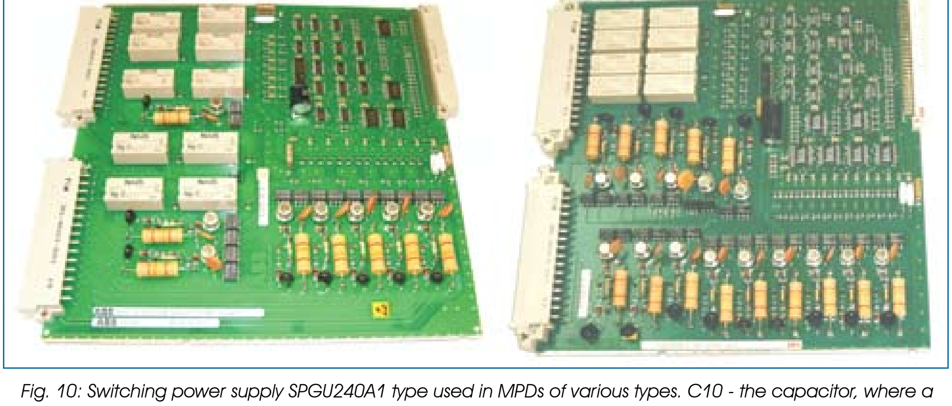

Fig. 10: Switching power supply SPGU240A1 type used in MPDs of various types. C10 - the capacitor, where a change of parameters results in full loss of working ability of the power supply.

a reality only with MPD applications, as their sensitivity to electromagnetic noises is 10,000 times higher than in electromechanical relays [34]. The built-in MPD software is also subject to external influences. And if, in addition to all the aforesaid, one takes into account that one MPD carries out the functions of 3 - 5 EMRs, the situation with MPD reliability is aggravated even more, as damage of one of the common MPD elements is equivalent, in consequence, to the simultaneous damaging of several kinds of protection at once. In this connection in [38] transition of microprocessor protection is offered to provide additional independent, simple, inexpensive, not microprocessor reserve protection in cases of extreme situations.

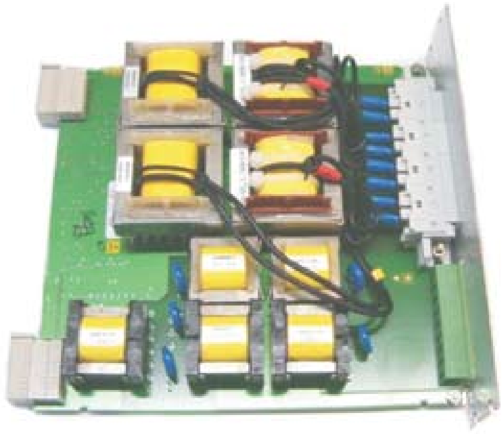

Fig. 11: Destruction of copper tracks on the printed circuit board due to electrolyte leakage.

Conclusions

- Reliability of MPD is lower than reliability of electromechanical relays and electronic relays on discrete elements.
- Built-in self-diagnostics MPD is ineffective and is not a means of increasing MPD reliability.
- Nanotechnologies, used in manufacture of MPD's elements, lead to the occurrence of problems not known in relay protection. Ignoring these problems can lead to catastrophic consequences. Decision-makers in the field of relay protection and the personnel in power companies should be aware of these MPD features.
- The recording function of emergency modes in power networks and data transmission function on modern connection channels are not direct functions of relay protection and for this reason there are separate microprocessor devices which carry out these functions more efficiently than MPDs. As opposed to relay protection, failure of these devices does not lead to heavy failures in power systems. Therefore for relay protection devices the focus should be on other demands of reliability and, accordingly, to use other approaches at the design stage, directed at increasing reliability and decreasing vulnerability.
- Those responsible for making the decisions on reconstruction of relay protection and ways of further development should understand precisely the properties and features of the MPD, taking into account not only widely promoted MPD advantages, but also the serious shortfalls, one of which is reduced reliability.
- Reliability of MPD is lower than reliability of electromechanical relays and electronic relays on discrete elements.
- Built-in self-diagnostics MPD is ineffective and is not a means at all for increasing MPD reliability.
- Nanotechnologies, used in the manufacture of MPD elements, leads to the occurrence of new problems for relay protection. Ignoring these problems can lead to catastrophic consequences. The managers making the decision in the field of relay protection and the personnel of the power companies should be informed about these MPD features.
- The recording function of emergency modes in power network and data transmission functions on modern connection channels are not direct functions of relay protection - for realisation of this there are separate microprocessor devices which carry out these functions far better than MPDs. Compared to relay protection, failure of these devices does not lead to failures in power systems. Therefore for relay protection devices the focus should be on demands for reliability and alternate approaches should be used during design, directed at increasing reliability and decreasing vulnerability.
- Those responsible for making the decisions on reconstruction of relay protection and ways of further developments should understand exactly the properties and features of the MPD, to take into account not only of widely-promoted MPD advantages, but also the serious shortcomings, one of which is lowered reliability.

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