Testing HEMP Resilience of Electronic Equipment Used in Power Industry: Is It Essential?

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***Abstract* - Military electronic equipment is a subject of various tests determining its resilience to high-altitude electromagnetic pulse at nuclear explosion (HEMP) on special test benches (HEMP simulators). Recently, it has become very important to ensure HEMP protection for civil systems that are part of a country's infrastructure, primarily, those of the power industry. In the USA for example, a special Directive signed by President D. Trump on March 26, 2019 is devoted to this issue; activities of SC77C Committee of International Electrotechnical Commission; activity of WG C4.54 group within CIGRE. Since military men have extensive experience in the area of establishing HEMP protection and testing of electronic equipment, it is often brought to civil equipment without considering its specific features. Is this correct? The article discusses this issue and suggests that it is not feasible to test electronic equipment used in the power industry on military test benches.**

***Keywords* – HEMP, electronic equipment, protection means, power industry, resilience testing**

I. INTRODUCTION

Electronic equipment used in the power industry is represented by digital protection relays (DPR), multiple controllers, systems of automation, measurement, monitoring and data transfer, as well as the SCADA system. As a rule, these are placed in a controls cabinets (Fig. 1).

Fig. 1. Electronic equipment controls cabinets used in the power industry

The design of these cabinets is suboptimal in terms of protection from HEMP electromagnetic pulse, and thus requires significant adjustments described in [1,2]. These adjustments could result in rather significant complication of the cabinet's design and consequently, in cost increase. That is why it is taken for granted that the fact that efficiency of these adjustments needs to be definitely checked and confirmed experimentally.

II. ISSUES WITH TESTING ELECTRONIC EQUIPMENT USED IN POWER INDUSTRY ON HEMP SIMULATORS

Testing HEMP-resistance of such equipment can be performed in accordance with -standard [3] on test benches, which were initially built to test military equipment (Fig. 2) and are described in [1].

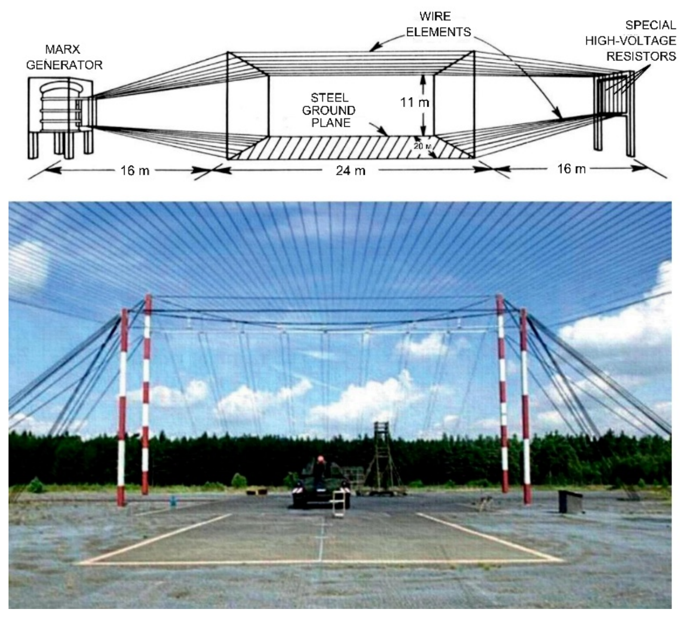

Fig. 2. Typical design of a guided-wave test bench to simulate HEMP impact (in particular, E1 component of HEMP).

A modern HEMP simulator of the most common guided-wave type consists of two main parts: a source of high-voltage pulses and an antenna system, which create an electric field pulse (matching E1 component of HEMP) within the operational volume of the simulator where a test object is located (Fig. 2). Usually, a pulse voltage generator (PVG), assembled according to the Marx design, is used as a source of high-voltage pulses. A so called bottom "plate" of this simulator represents a metal grid placed in a concrete foundation, while the top "plate" represents rows of stretched wire supported by insulated supports.

Since electronic equipment placed in cabinets is connected with other devices by means of multicore control and power cables, and these other devices may often be located dozens and hundreds of meters away from the cabinets, the test should be run over the whole system rather than on a separate control cabinet (Fig. 3).

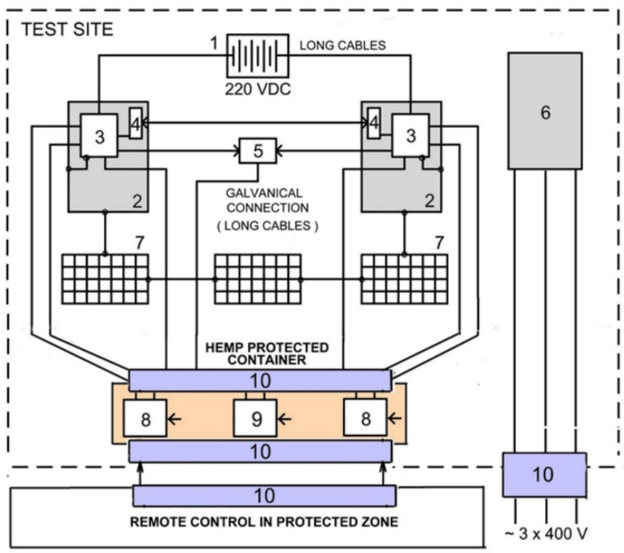

Fig. 3. Layout of the test-bench. 1 – Mobile battery 220V;2 – Electrical cabinets distanced from one another; 3 – Tested electronics (such as Digital Protective Relays - DPR); 4 – Communication devices; 5 – Lockout relay controlled via DPR output circuits; 6 – Battery charger; 7 – Set of metal meshes comprising the ground system model; 8 - simulators of different modes of EUT operation synchronized or not with HEMP initiation system; 9 – EUT status recorders; 10 – HEMP Filters

The main idea of the test process was to gradually disconnect differentprotection elements under continuing electromagnetic pulse impacts in order to determine the minimal (optimal) number of protection elements, which would still maintain the efficiency of electronic equipment functioning (Fig. 4).

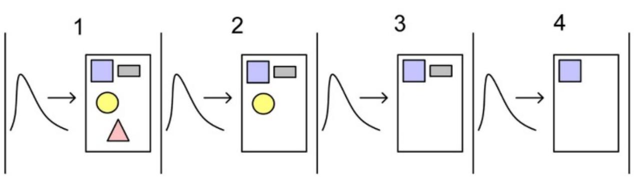

Fig. 4. Stages of electronic equipment testing with gradual disconnection of different protection elements and repeated generation of the test pulses.

This approach would allow to find an optimum solution for the problem of electronic equipment protection and reduce costs. However, research has challenged this seemingly logical test program [2]. Indeed, even the smallest change in the internal wiringin the cabinet, e.g. increase of the length of connecting wires between the protection element and the electronic equipment's input terminal under protection from 25cm to 50cm results in full loss of protecting capability by protection elements (e.g. varistors). Is it really possible to maintain strongly identicalwiring and short connecting wires in all the cabinets with different electronic equipment inside? The answer is pretty straightforward: not at all.

Another problem is that it is impossible to simulate HEMP impact on hundred-meter long control cables using a test-bench with 15 by 20 meters bottom plate (or similar to that). How would you accommodate long cables in such a restricted area? If a zigzag pattern is used, the pulse induced in oppositely directed parts of the zigzag will be mutually compensated. If they are placed in concentric circles, the impact of the test-bench's electric field onto this cable will be significantly higher compared to the real situation. Combination of the two is both too complicated for calculations and almost unpredictable.

Earthing of cabinets and electronic equipment inside them is another issue to be addressed. This issue is determined on the one hand by the difference between electromagnetic pulse of lightning (LEMP) and that of a high-altitude nuclear explosion (HEMP), and on the other hand, by the design of the test-bench with an earthed bottom plate. LEMP is a local pinpoint electric discharge between two electrodes: a cloud and an object with earth potential (or earthing system). Whereas HEMP is not a pinpoint, but a rather extensive physical process determined by electrons quickly flowing towards earth and covering an area of thousands of kilometers. The nature of these events is absolutely different and thus the response of electrical conductors to their impact will also be different. For example, imagine a long metal rod placed on two insulators with negligibly small capacitance to earth (Fig. 4). In case LEMP impacts one of its ends and the other end will be earthed, a current pulse determined by high potential difference between the rod's ends will run through the rod.

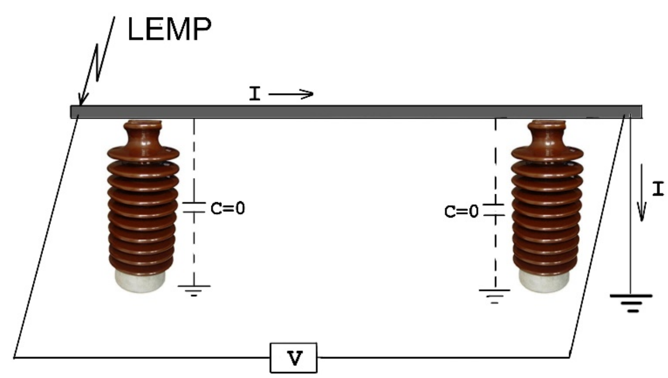

Fig. 5. LEMP impact onto metal rod

Will there be a potential difference between the rod's ends and will a current pulse run through it, if the right end of the rod will be disconnected from the earth? The answer is obvious: No. Thus, earthing is very important upon LEMP impact.

Now, let us address the effect of earth upon HEMP impact (Fig. 6).

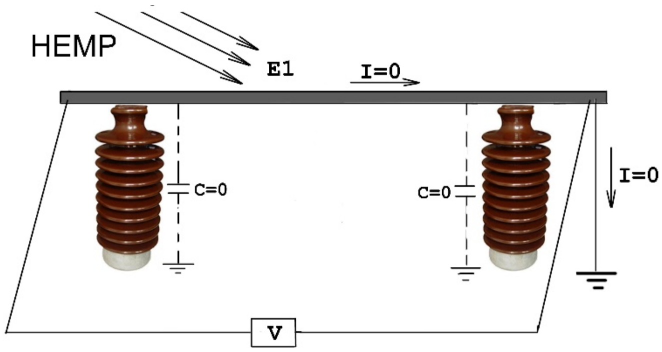

Fig. 6. Impact of HEMP (its E1 component, to be precise) onto a metal rod

Upon HEMP impact, high potential difference occurs between the rod's ends regardless of whether or not the earthing is available. There will be no current, even if the earthing is there, since this potential difference is irrelevant to the earth potential. This is very similar to a battery insulated from the earth (e.g. hanging on an insulation strand) (Fig. 7). The potential difference between the battery's terminals will not depend on the earth availability. In addition to that, earthing of one of the terminals will not lead to current occurrence in the earth circuit. This means that upon HEMP impact an insulated rod will be as indifferent to earthing as an insulated battery.

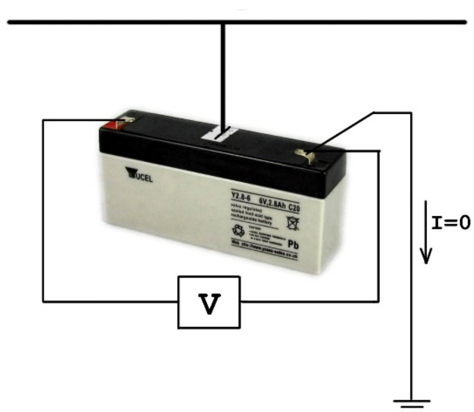

Fig. 7. Current rates and voltages in the battery insulated (hanging on insulation strand) from the earth

Now, let us return to the HEMP testing bench (fig. 2). Since the pulse of high density electric field occurs here between the top insulated electrode and the bottom earthed electrode, obviously the test object placed between these electrodes will respond like being struck by LEMP (Fig. 5) rather than by HEMP (fig. 6). In other words, this test bench simulates a lightning strike, but not the impact of a high-altitude nuclear explosion. In addition to that, earthing (e.g. connection to the bottom plate potential) of the test object (e.g. a control cabinet) and switching on of protection elements - voltage suppressors (varistors) between circuits of electronic equipment and the earth (grounded bottom plate) will significantly weaken the impact of the test pulse (like earthing upon a lightning strike) and this can be wrongly perceived as an efficient protection against HEMP.

III. THE DIFFERENCE BETWEEN POWER INDUSTRY ELECTRONIC EQUIPMENT AND MILITARY ELECTRONIC EQUIPMENT

What should we do with testing of military systems on such benches? The fundamental difference of military systems (armored fighting vehicles, aircrafts, missiles), which are obligatory subjected to such tests, is that each one of these systemsare enclosed and autonomous and all of their cables run inside, without stretching for hundreds of meters outside. Secondly, all copies of the same type are manufactured based on the same drawings with strict adherence to the same technology. They feature negligibly small differences both in terms of component parts and in terms of assembly, which is performed using the same wire harness that has been previously prepared on a special templates. Thirdly, the circuits of internal electronic equipment are irrelevant to the earth and its potential. These features of military equipment make it possible to test it on existing test benches and extrapolate the findings obtained for one sample over the total batch of this type.

Cabinets with electronic equipment used in the power industry may differ in terms of design, may contain long cables stretching outside for hundreds of meters and running inside, and may be equipped with obligatory earthing.

Since we are talking about a very short pulse (2.5/25 ns), which affects electric circuits similar to a high-frequency signal with a frequency of up to 100 MHz, obviously variations of internal layout and external cables, as well as different types of equipment used in cabinets and different combinations of this equipment, will heavily influence high-frequency properties, and consequently equipment sensitivity to HEMP and efficiency of protection elements [2], that it doesnot make any sense to extrapolate the findings obtained for one cabinet to other cabinets. Moreover, existing test benches do not provide a real picture for equipment using external earthing.

This challenges feasibility of electronic equipment testing on test benches which simulate HEMP. In my opinion, as of today we have already accumulated certain experience in the field of development of protection means for electronic equipment -; there are descriptions of component parts and materials which are different from those used in military equipment in terms of their cost. Of course, efficiency of these protection measures will be much lower than that of armored fighting vehicles or missiles, but in its combination its will be enough for preventing damage to the majority of types of power industry electronic equipment.

Simultaneously, we must question feasibility of testing power industry electronic equipment to determine its resistance to high-amplitude current pulse (several kiloamperes), which is also stipulated by [3], and a corresponding military standard MIL-STD-188-125-1. Indeed, the normal values for pulse current suggested in these standards are intended and used to check HEMP filters, which need to allow high-amplitude current pulse through them without any damage or malfunctioning. However, the standards do not mention that the normal values are intended for just checking the filters only, and thus, they are automatically extrapolated on all types of equipment. It should be noted that input circuits of power industry electronic equipment, both logic and analogue, as well as supply circuits, feature high impedance, therefore dozens of kilovolts will be necessary to generate a current rated several kiloamperes in these circuits. Special testing equipment makes it possible to generate such kind of a pulse voltage and current, but this voltage will surpass the standards' requirements to voltage amplitude, wherethe input and output terminals of electronic equipment are needed to sustain. Consequently, any attempts to test resistance to current pulse will result in unreasonably high pulse voltage affecting the equipment and leading to its damage. Therefore, in my opinion, these types of tests should be excluded from the testing program of power industry electronic equipment.

IV. CONCLUSIONS

In my opinion the strategy should be to use all known [1, 2] protection measures (which ensure partial protection of each, if used separately) in each cabinet, but only for critical kinds of equipment and without any additional complex tests on HEMP simulating test benches and pulse current generators.

The need to use the aggregate of protection measures is stipulated by the inability to forecast the minimum amount of protection elements suitable for any and all situations after conducting tests on 1-2 certain constructed cabinets with certain equipment on the HEMP-simulating test bench.

Therefore, protection should be designed for the worst case and accommodate all necessary protection means. Cost reduction should be achieved through protection of only critical, but not any equipment, rather than through partial use of protection elements and measures.

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