Establishment of Inventory of Electronic Equipment Replacement Modules as a Way to Improve the Survivability of the Power System

Preliminary Communication

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Abstract *– The article discusses a way to improve the survivability of the power system affected by the High Altitude Electromagnetic Pulse (HEMP) through establishment of inventory of electronic equipment replacement modules, particularly those of digital protective relays. It is shown that the known methods of spare parts quantity optimization cannot be used in this case. Thus, another method is offered. Specific principles of the storage of replacement modules are discussed as well as the ways of their realization.*

Keywords *– High Altitude Electromagnetic Pulse (HEMP), Intention Destructive Electromagnetic Interferences (IDEI), Spare Parts, Tools and Accessories (SPTA).*

1. INTRODUCTION

The problem of Intention Destructive Electromagnetic Interferences (IDEI) in electric power systems has recently become extremely relevant due to two modern trends, i.e., expanded use of microelectronics and microprocessor equipment in the electric power industry on the one hand, and intensive development of the means for remote destruction of electronic instruments on the other hand [1]. The most powerful IDEI is represented by the High Altitude Electromagnetic Pulse (HEMP), especially its E1 and E2 components [1], which neither affect people nor result in mechanical destruction of surface facilities, but cause multiple electric disruptions of low-voltage microelectronic components of modern electronic systems of protection, control and management that are widely used in the electric power industry. The trend of increasing the dependence of the electric power industry on these systems leads to a situation where their mass failure can result in total power system collapse, so that the issue of improving the survivability of the power system in case of mass failure of microelectronic systems is gaining special significance.

2. OPTIMIZATION OF INVENTORY OF ELECTRONIC EQUIPMENT REPLACEMENT MODULES

One of the efficient ways to improve the survivability of the power system is to ensure quick restoration of damaged equipment by using spare parts, tools and accessories (SPTA). However, establishment of SPTA inventories requires significant investments, especially in case of extremely complex electronic digital systems of protection, automation and management that are widely used in power systems. That is why all over the world people are looking for optimum inventory of SPTA, which will enable us to combine the required reliability at minimum investment.

Establishment of these SPTA inventories is a common problem, which is well known in different areas of engineering. The problem has been well studied theoretically using different mathematical methods of optimization [2-9]. The known methods of optimization of SPTA inventories are based on statistical analysis of failures of elements, replacement modules and complex items. In other words, the quantity of necessary SPTA kits is calculated based on the fact that failures of electronic equipment are single accidental events, which happen with a certain frequency governed by statistical laws of random variables distribution. The necessity of increasing the number of SPTA kits in order to ensure restoration of workability of equipment affected by the HEMP is practically assured. But how should we increase this number? Obviously, the HEMP impact onto the energy system will result in simultaneous mass failures of electronic equipment that do not comply with any statistical law. Besides, a usual and rather long process of ordering and obtaining a new SPTA kit to replenish inventory after using up kits prepared earlier is not suitable in this situation. So, the expansion of SPTA inventory by 1.5-2 times (this is what short-sighted managers sometimes do) does not solve the problem, while the expansion of inventory, which supposes that all types of electronic equipment will be backed by SPTA, is unreal due to economic reasons. That is why an absolutely different approach should be employed in order to calculate the optimum SPTA kit.

The method offered is based on three main principles:

1. Not all electronic devices should be equipped with SPTA. These should be only those that are considered as critically important devices (CID), the lack of which makes even partial operation of electric energy facilities impossible, where only critically important objects (CIO) should be selected.
2. Full and not partial SPTA kits should be established for CID.
3. Inventories of SPTA kits for CID should be supplemented regardless of availability of SPTA kits which are already stored in warehouses.

Thus, optimization of SPTA inventories in this case is based on calculation of the number of CID necessary to supplement CIO in a specific energy system.

3. THE PROBLEM OF SPTA STORAGE

The problem of SPTA storage requires us to address two problems, i.e., where SPTA should be stored and how.

Today, SPTA kits of many energy systems are stored in warehouses, which are often remotely located from energy facilities. When necessary, the kits are obtained by repair departments or directly by the operating team. Should urgent restoration of CID be necessary after the HEMP impact, there appears a problem of urgent delivery of critically important goods to critically important objects as there is a probability that the impact of a powerful electromagnetic pulse will result in failure of microcontrollers, which manage operation of modern transport vehicles.

According to [3], electric communication systems use two levels of SPTA, i.e., "SPTA-0" and "SPTA-G" kits. SPTA-0 kit is an integral part of a device (CID in this case) and should be stored at a site (CIO in our case). SPTA-G kits (group kits) are used to replenish SPTA-0 kits and they are stored at a large service center (or in a warehouse). Both SPTA-0 and SPTA-G should be checked and tested before depositing for storage. This approach to SPTA storage for necessary restoration of the energy system after the HEMP impact is fully justified for many reasons. It is also efficient in the electric energy industry as it allows avoiding the problem of urgent delivery of SPTA to CIO for CID restoration. Storing of CID's SPTA kits at a site does not require us to address this problem. When organizing storage of CID's SPTA kits in this way, another problem can be solved, i.e., the problem of their configuration and setup prior to installation into the equipment. This requires significant time investments, participation of highly skilled staff as well as employment of special electronic equipment and computers (which can also be damaged). An example of this type of CID is represented by modern digital protective relays (DPR), the lack of which makes it impossible for a power system to operate. In case of mass DPR failure as a result of the HEMP impact, it will be extremely difficult to ensure the simultaneous set-up of dozens of DPR's SPTA kits at many remotely located sites. That is why SPTA of DPR considered as CID should not only be stored near the operating DPR, but should also be pre-programmed, set up and configured for quick replacement of failed blocks of specific DPR working with certain settings and adjustments.

The second question that needs to be addressed is: How should we store CID's SPTA kits? The problem is that the HEMP creates the electric field density of up to 50 kV/m at ground surface. This density can create the difference in potentials at the outputs of relatively small electronic components (within one printed circuit board). This difference in potentials is enough for electric disruption of p-n junctions (the thinnest layers of insulation in microprocessors) or to erase information stored in memory cells. This means that CID's SPTA kits should be stored in HEMP-resistant containers.

What should be the features of these containers? Let us consult the MIL-STD-188-125-1 standard [10], which stipulates the requirements for shielding performance of critically important objects from the HEMP impact (Table 1).

Table 1. Minimum requirements for shielding performance of critically important objects from the HEMP [10]

Frequency	Shielding performance [dB]
10 kHz	20
100 kHz	40
1 MHz	60
10 MHz	80
1GHz	80

At the same time, [1] provides data about the spectral density of radiation of various types of the HEMP. (Fig. 1).

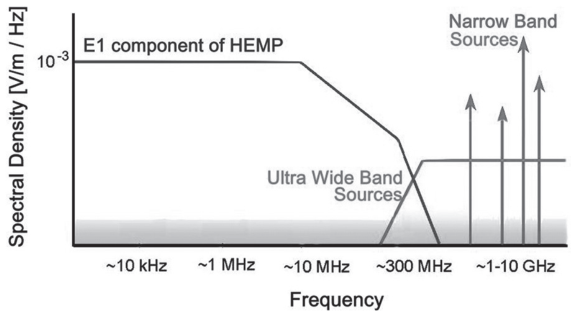

Fig. 1. Spectral density of radiation of different IDEI sources [1].

These data show that the density of radiation of the E1 component of the HEMP remains the highest at frequencies lower than 10 kHz and drops down dramatically at frequencies higher than 300 MHz. Other sources of IDEI (not the HEMP) create a relatively high density of radiation in the range of higher frequencies up to 10 GHz. That is why efficient protection should be ensured in the frequency range from several kHz to 10 GHz.

It is known that the skin depth of metals is determined by skin effects and that it depends on the frequency: the higher the frequency (f), the shallower the skin depth (Δ), i.e., the thinner the screen wall:

$$\Delta = 503\sqrt{\frac{\rho}{\mu_m f}} \quad (1)$$

where: Δ - is the skin depth,
ρ - is the electrical resistance of metal,
μm - is the magnetic permeability of metal,
f - is radiation frequency.

The "skin depth" is defined as the surface layer of metal where the density of an electromagnetic field is reduced by e = 2.718 times. According to [11], this layer will account for almost 86% of energy coming from the surface. Table 2 shows the results of calculation based on the above mentioned formula for the most widely used metal shield, i.e., aluminum.

Table 2. The skin depth of aluminum wall shield for different frequencies

Freq.	1 kHz	10 kHz	100 kHz	1 MHz	10 MHz	100 MHz	1 GHz
skin depth [mm]	2.6	0.83	0.26	0.083	0.026	0.0083	0.0026

It is obvious from the table that the aluminum container with the wall thickness of not less than 3 mm can ensure rather efficient weakening of radiation of all HEMP types.

What does the market of protective containers offer today? First of all, the market offers large and heavy thick-wall metal containers, Fig. 2, equipped with protected ventilation systems and filters for input cables. For information about manufacturers of such containers, see [12]. These containers are widely used in the army and obviously ensure reliable protection of equipment located inside. Unfortunately, these are very expensive means of protection, which will unlikely be used for SPTA storage in the electric energy industry.

Fig. 2. Large metal containers protecting from HEMP and equipped with ventilation systems and filters to connect input cables [12].

Another variety of a protective container is represented by a room without windows, the walls and doors of which are covered with copper sheets (these rooms are offered by the Holland Shielding Systems company). These protective containers also ensure perfect shielding (from 40 to 120 dB in the frequency range from 10 kHz to 10 GHz). However, they are also as expensive as those mentioned above.

Simple, reliable and very cheap containers protecting from the HEMP are represented by (according to their manufacturers) Faraday bags of different sizes with a metallized layer, Fig. 3. For information about manufacturers of such bags, see [12].

Fig. 3. Faraday bags with metallized layer intended for protection of small electronic devices from HEMP [12].

As a rule, manufacturers of these bags declare high level of radiation weakening reaching as high as 40-45 dB. However, they decently conceal the frequency range for which these measurements were obtained. Can metallized layer with a thickness of several micron efficiently weaken electromagnetic field in the frequency range from several kHz to several Ghz? Table 2 provides a decisive answer to this question: No, it cannot!

Another variety of protective container, which is also widely represented in the market and promoted as a reliable means of protection from HEMP is represented by a tent, produced from the same (as Faraday bags) metallized plastic or at best woven from fiber containing metal yarn, Fig. 4. For information about manufacturers of such tents, see [12].

Special portable metal containers with thick walls, which ensure very efficient shielding are also widely represented in the market, Fig. 5. For information about manufacturers of such containers, see [12].

Unfortunately, these containers are very expensive for SPTA storage and their internal chamber is not big enough.

The most suitable containers are those made of aluminum and welded from aluminum sheets in the shape of simple boxes with covers, Fig. 6. For information about manufacturers of such containers, see [12].

These containers with a wall thickness of 3/16 inch (4.8 mm) ensure rather acceptable level of shielding: not less than 50 dB in the frequency range from 100 kHz to 1 GHz (76 dB at 300 MHz; 66 dB at 1 GHz). They are produced by several companies, including Montie Gear, EMP Engineering, etc. in standard or customized sizes.

Fig. 4. Protective tent produced from metallized fiber [12].

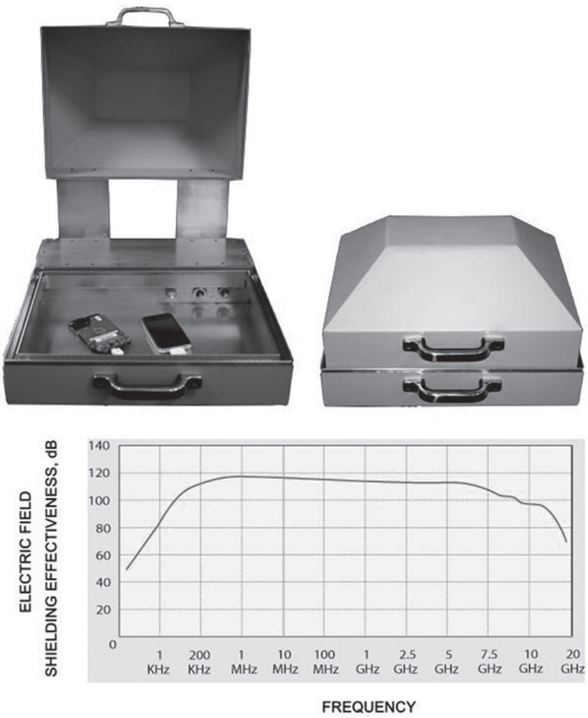

Fig. 5. Protective container which possesses very high shielding performance [12].

It should be noted that these simple containers of necessary sizes can be produced at any workshop that has welding equipment. At the same time, in order to prevent the impact of an electromagnetic field of the upper part of the frequency range on stored electronic devices

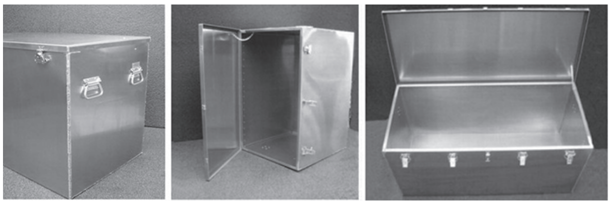

Fig. 6. Inexpensive protective containers for SPTA storage made of sheet aluminum [12].

(which can penetrate into the inner cavity of the container through vents created by a poorly attached cover), it is recommended to locate extra sensitive electronic devices (such as printed circuit boards with microprocessors and memory cells) into the aforementioned metallized Faraday bags before putting them into the container.

4. CONCLUSIONS

One of the ways to quickly restore the electric energy system workability after any type of the HEMP impact is to create special SPTA kits for electronic equipment. The known methods of SPTA inventory optimization are not acceptable for the situation under discussion. In order to ensure quick restoration of the energy system's electronic equipment, it is necessary to establish full SPTA kits for critically important devices (CID) located at critically important objects (CIO) in the electric energy industry. Both CID and CIO should be determined in advance.

The SPTA kits for CID should be independent of total inventory of SPTA stored at warehouses. The CID's SPTA kits should be preliminary checked, set-up, and configured; they should be stored in close proximity to CID they are related to.

The CID's SPTA should be stored in closed containers protecting them from the HEMP and other IDEI types. These containers can be produced by welding aluminum sheets with a thickness of about 5 mm. Extra-sensitive blocks containing microprocessors and memory cells should be preliminary put in metallized Faraday bags.

5. REFERENCES

[1] V. Gurevich, "Cyber and Electromagnetic Threats in Modern Relay Protection", CRC Press, Boca Raton, USA, 2014.

[2] V. Zhdanov, "Automation of Stock Establishment in SPTA Kits: Methods and Techniques", Components & Technologies, No. 5, pp. 173–176, 2010. (in Russian)

[3] Industry Standard 45.66-96. "Spare Parts, Tools and Accessories of Electrical Communication Means". Industry Standard. M. Center of Scientific and Technological Information "Informsyaz", 1997.

[4] A. A. Zatsarinny, A. I. Garanin, S. V. Kozlov, "Calculation of SPTA Kits in Protected Automated Information Systems", Systems and Means of Informatics, Vol. 23, No. 1, pp. 113–131, 2013. (in Russian)

[5] R. V. Dopira, A. P. Lysiuk, D. V. Tsybenko, "Method of Calculation of Spare Parts Supply System for Wide-Area Radio-Electronic Facilities", Software Products and Systems, No. 1, pp. 128–130, 2009. (in Russian)

[6] National Standard RV 20.39.303-98., "A Comprehensive System of General Requirements", Apparatus, Instruments, Devices, and Equipment Designed for Military Application. Requirements to Reliability. Composition and Order of Task. M. IPK, Izdatelstvo Standartov, 1998.

[7] M. E. Trimp, R. Dekker, R. H. Teunter, "Optimize Initial Spare Parts Inventories: an Analysis and Improvement of an Electronic Decision Tool", Econometric Institute Research Papers, No. EI 2004-52, 2004.

[8] MIL-STD-1388-2. "Requirements for a Logistic Support Analysis Record", Department of Defense, 1993.

[9] R. E. Love, B. F. Stebbins, "An Analysis of Spare Parts Forecasting Methods Utilized in the United States Marine Corps", Naval Postgraduate School Monterey CA, USA, Master's Thesis, 1987.

[10] MIL-STD-188-125-1. "High-Altitude Electromagnetic Pulse (HEMP) Protection for Ground-Based C4I Facilities Performing Critical, Time-Urgent Missions, Part 1: Fixed Facilities", 1998.

[11] N. M. Nekrasova, L. S. Katsevich, I. P. Yevtyukova, "Industrial Electroheat Installations", Gosenergoizdat, Moscow-Leningrad, 1961. (in Russian)

[12] Gurevich V. Protection of Power Substation Equipment Against Electromagnetic Pulse – Infra-Engineering, Moscow, 2016, 297 pages, (in Russian).