Protection of Diesel Generators from Electromagnetic Pulse (HEMP)

Vladimir Gurevich

Central Electric Laboratory, Israel Electric Corp.

Abstract **-Modern backup power sources, based on diesel generator sets without any special protection, will likely be damaged under the impact of High-altitude Electromagnetic Pulse (HEMP) over spacious areas. They will be incapable to perform in critical situations for which they have actually been designed. This article suggests practical protection measures for microprocessor-controlled diesel generators of various capacity and purpose.**

Keywords **-electromagnetic pulse, HEMP, diesel generator, protection, microprocessor, controller**

I. INTRODUCTION

The electromagnetic pulse that occurs during the high altitude (40-400 km) nuclear explosion (HEMP) creates the electric field density of up to 50 kV/m at the ground surface. This creates extreme danger for all types of electric and electronic equipment [1]. The problem of diesel generator (DG) protection from HEMP becomes particularly relevant as DGs act as backup power sources. They are designed to power up critical loads in emergency situations. Consequently, they need to be absolutely ready for use even under HEMP conditions.

At present there are thousands of DGs with the power rating from several kilowatts to dozens of megawatts. Some of them are small open-design portable devices that can be stored in a metal container protected from electromagnetic emissions. These can be used when necessary after removing from a container. Generally speaking, these low capacity DGs have a simple design without sensitive electronics and are relatively inexpensive. Thus, it is unnecessary to use any special measures to protect these DGs (except for locating them into a metal container).

II. INCREASED SUSCEPTIBILITYOF MEDIUM- AND HIGH-POWER DGs

Medium-power industrial DGs (from dozens to hundreds of kilowatts) are large and heavy devices that are intended for transportation. More often than not, they are confined in a casing with several sensors and microprocessor-based controllers that control the DG's operation, measure and display various parameters, as well as protect it from overload and emergency modes. Protection from emergency modes in high power (1-50 MW) DGs is performed by digital protective relays (DPR) of the same type as those used at conventional power plants. They are usually confined in standard relay protection cabinets that are installed inside the DG casing. These cabinets are usually of the same type as those used in the electrical energy industry at power plants and substations.

Use of microprocessor-based controllers and DPR that are especially susceptible to HEMP [2] in medium- and high-power DGs results in a sharp reduction of DG's efficiency as a backup power source for critical loads. Accordingly, they need to be urgently addressed. It should be noted that there are two absolutely different modes of DG use (from the protective measures perspective). One mode presupposes storage of de-energized DGs at warehouses, whereas in the other mode, they are constantly connected to local consumer's electric network, and can automatically start at any time should it become necessary to re-energize the circuit or to flatten the load peaks. Let us address possible protection measures for medium-power DGs (the most widely spread) in both situations.

III. PROTECTION OF DE-ENERGIZED MEDIUM-CAPACITY DGs AT WAREHOUSES AND OPEN-AIR SITES

It should be immediately stressed that storing of DGs at centralized warehouses (as customarily happens) is incorrect. DGs are backup power sources that should be ready for use within the shortest possible time after emergency occurrence (HEMP impact in our situation). As HEMP impact is all encompassing and creates problems for transport, communication systems and computerized warehouse equipment, it becomes obvious that we need to aim at decentralization of backup of DGs storage places, moving these places as close to potential consumers as possible.

The easiest solution to protect internal equipment of de-energized DG from HEMP is to put metal casing on top of the DG. However, this approach has some serious drawbacks. First of all, the casing for a medium capacity DG (5-8 meters long; 1.5-2 meters wide; 3 meters high) should be designed with special stiffeners. It should also be welded from sufficiently thick metal to provide for the necessary rigidity of the structure. This casing will be extremely heavy, consequently a user will need a crane to remove it from the DG and prepare the DG for startup. However, this can hardly be a reasonable approach in a critical situation. Moreover, DGs need to be switched on from time to time to check their operability during a storage period. Rarely will it be practical to provide a crane every time you need to lift the protective casing in order to perform a test run of a DG. On the other hand, medium- and high capacity DGs are usually equipped with a metal casing. Nevertheless, it should be noted that this casing has many cut-outs, holes and blinds that drastically reduce its screening properties.

Taking the above mentioned into account, I suggest the following concept of medium capacity DG protection:

1. Improvement of screening capacity of DG's own casing by closing all the cut-outs, holes and blinds with removable metal patches, some of which can easily be removed (if necessary) when preparing the DG to startup.
2. Mounting of protecting ventilation panels based on so called "waveguides below-cutoff" onto vents to take the cooling air in and out.
3. Disconnection of the central controller's terminal (when storing the DG), which connects it with multiple internal sensors and instruments by means of a cable harness.
4. Connection (by means of alligator clips) of all the power leads of the generator's rotor and stator into a point of common coupling and connection of this point with the DG chassis.
5. Removal of the electronic unit from the automatic power switch at the generator's input and placing it into the screened casing.
6. Mounting of an electromagnetic filter and varistor-based non-linear voltage suppressors into the mains of the internal battery's charger, which remains connected to the external 220 VAC while stored.

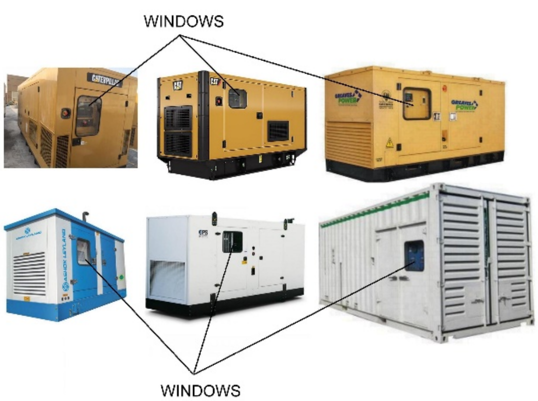

Fig. 1. Windows in front of controllers' screens cut out in casings of most DG types.

Initially, this long list of protective measures may seem excessively difficult and expensive to implement in practice. In fact, this is not true. The purpose of this article is to describe simple and affordable measures which can protect a DG from HEMP impact.

IV. PRACTICAL IMPLEMENTATION OF DG PROTECTION

a. Mounting of protecting metal panels

When deploying paragraph 1 of the suggested concept, a special emphasis should be placed on the window which is cut out in the DG casing in front of the microprocessor-based controller's screen. These windows are present in most DG types, Fig. 1. They are intended for visual monitoring of the controller's readings. However, they pose the biggest danger from the point of view of the DG susceptibility. These windows should be tightly closed with a welded on or bolted metal plate 1 (Fig. 2), contoured underneath with conductive rubber. The controller's readings are not taken continuously. When the DG is started, it is sufficient to read its parameters by opening the door in the DG's casing, which is located near the controller. Should it be absolutely necessary, it is possible to weld a small door opposite the controller's screen (instead of the steel plate) or use conductive glass to cover the windows, or glue a transparent conductive film [3] to the ordinary glass. However, one needs to understand that all of those alternative options will be less efficient than the first option.

Another protection measure is to mount a detachable metal panel into the cut-off in the DG's casing, designed for power cables running out of the DG to be connected to an external load. When storing the DG, these cables need to be dismantled and the cut-off closed (Fig. 2). Another cable cut-off, which connects the internal battery's charger of the DG to external 220 VAC, should also be closed with a permanent metal panel 3 (Fig. 2).

Fig. 2. Metal plates mounted into cut-offs in the medium-capacity DG casing. 1 – in front of main controller's window; 2 – detachable panel for power cables; 3 – permanent panel with a power connector 4 - to connect 220V power cable running between the internal charger and the external 220V line.

Obviously, connector 4 should meet at least IP67 requirements. These connectors are available from several companies and can be easily bought on the market (Fig. 3).

Fig. 3. Inexpensive IP67 connectors manufactured by Mennekes and SCAME companies suitable for DG.

b. Mounting of electromagnetic filter and varistors

There is a metal container inside panel 3 where an electromagnetic filter and varistor are mounted (Fig. 4).

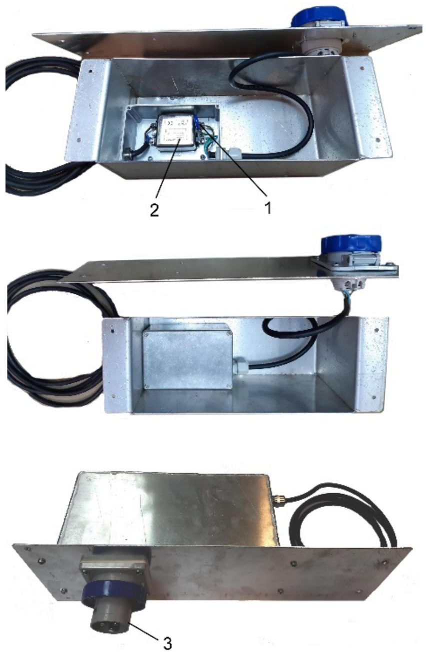

Fig. 4. Electromagnetic filter 2 with varistor 1 mounted in a double metal module attached inside of a permanent panel (3, Fig. 2); 3 – power connector

The electromagnetic filter with an input varistor is connected between the power connector 3 and the internal cable running to a 220V input terminal of the DG's charger. Furthermore, there are two additional varistors connected directly to the input and output of the charger (Fig. 5).

Our research found [4] that NBM-06-471 (manufactured by Coselcompany) filters feature the best specifications at low cost and thus they are recommended for use in DGs. As for varistors, there are several models on the market mounted inside a section of a standard terminal block, designed to be mounted on a DIN rail (Fig. 6).

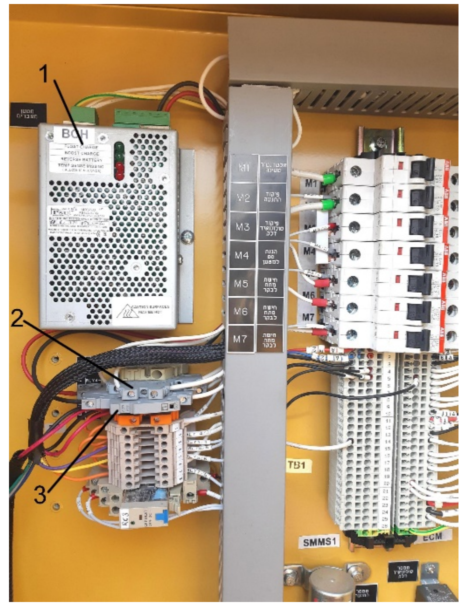

Fig. 5. Connection of additional varistors (2 and 3) at the input and output of the charger 1 inside the DG casing.

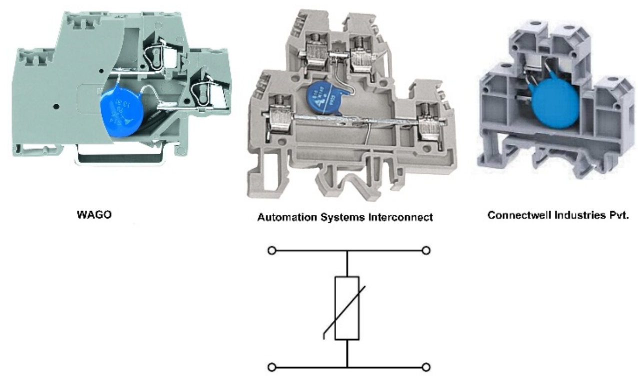

Fig. 6. Varistors from various manufacturers mounted inside a standard terminal block, designed to be mounted on a DIN-rail and connection diagram.

c. Main controller protection

On the one hand, the main controller of a medium-capacity DG is its major element compulsory for DG operation. On the other hand, this controller with multiple long cables connected to it, which act as antennas absorbing electromagnetic energy from internal space of the DG's casing, is the most HEMP-susceptible element of the DG. The simplest, most reliable, cheapest and most affordable controller protection would be to disconnect the connector with cables during the storage period (Fig. 7) (in addition to closing the window in front of the controller in the DG's casing).

d. Mounting of ventilation blinds

There are large-size cut-offs (0.5–2 square meters each) in the DG casing (on the side or on the roof) to draw in and exhaust outside cooling air, which is drawn through the inner space of the DG by a powerful fan. These cut-offs may be closed with blinds or may remain fully open (if they are located on the roof). However, large area non-metal cut-offs in the metal casing bring its shielding properties to zero.

Fig. 7. Disconnection of cable harness from the main controller as protection from HEMP impact

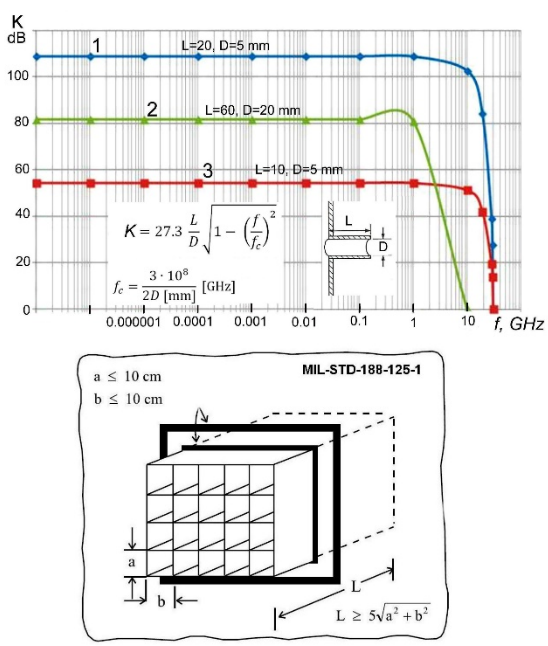

Fig. 8. Calculation of waveguides below cut-off and attenuation curves introduced by these units [5] with different geometric sizes (left) L – length of round section waveguide; D – diameter of the waveguide; f – frequency of emission; f_C – cutoff frequency, at which the waveguide stops attenuating the electromagnetic wave; the ratios for effective waveguides below cut-off recommended in the US military standard [6], which stipulates protection of electric equipment from HEMP (below).

In order to improve the DG casing shielding properties, these cut-offs need to be closed with special ventilation blinds based on so called "waveguides below-cutoff". They allow air flow in, but obstruct the passage of the electromagnetic wave. The waveguide below-cut-off is just a metal tube with a specific ratio between its internal diameter and the length (Fig. 8). This ratio provides maximum attenuation of the electromagnetic wave.

There are many ventilation blinds based on waveguides below-cutoff on the market, including small-size designed for cabinets with electronic equipment and tailor-made (Fig. 9).

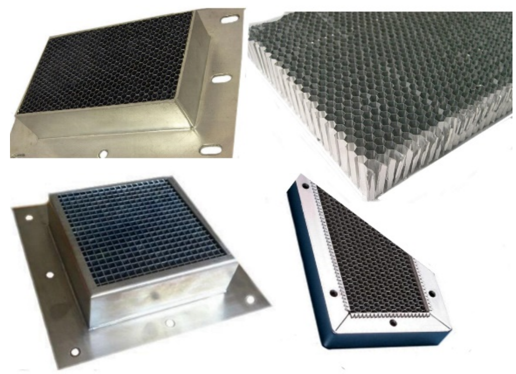

Fig. 9. Ventilation blinds based on waveguides below-cutoff.

These ventilation panels are available from multiple manufacturers, such as Holland Shielding Systems, MAJR Products Corp., Micro Tech Components GmbH, Parker Hannifin Corp, EMC EMI Ltd, Kemtron Ltd, Foshan Huarui Honeycomb Technology Co., Ltd, Foshan Alucrown Building Materials Co., Ltd, Arrow Dragon Metal Products Co. Ltd., and many others.

There is a concern that closing of ventilation cut-offs in the DG casing with shielding screens, nets and honeycomb structures will inevitably result in air flow resistance and deterioration of DG cooling. If the cells of these screens are too small, they can be plugged with dust and dirt and further aggravate the situation. In order to avoid significant deterioration of cooling, the section area of the cells should be significantly large. Simultaneously, in order to have these cells act as waveguides below-cutoff, their length should be increased proportionally to section area increase. The honeycomb structures with adequate cell diameter, with thickness and panel size parameters suitable for DG, are also manufactured by multiple companies, e.g. Arrow Dragon Metal Products Co. Ltd.

In order to compensate for increased resistance to air flow, the aggregate area of the honeycomb structures closing the cut-off in the DG casing should be increased in such a way to make their total area larger than the area of the cut-off itself. This is achievable when using the box with all the walls made of the same cells (Fig. 10), instead of the flat ventilation plate covering the cut-off.

Fig. 10. Mounting of box-shaped honeycomb ventilation panels on the DG casing's roof.

In this case the area is increased due to the box's side walls, which also allow the air movement.

This idea has been tested in real conditions. In order to perform the test, a DG with ventilation panels attached to it was loaded to full power (Fig. 11) for one hour and the temperature measurements were taken by the standard temperature gauge and the inner controller (Fig. 12). The results of the test found that the DG temperature at full load was not rising due to installation of honeycomb ventilation panels.

Fig. 11. Load resistance used during DG testing The controller display shows voltage (400V) and current (448A) parameters used during testing.

Fig. 12. DG with ventilation panels attached to it (shown by arrows) during testing. The controller's display shows an 88°C temperature, which corresponds to a full load of DG without additional ventilation panels. This temperature remained unchanged during testing.

Electromagnetic features of fabricated ventilation panels (in this case – their ability to weaken electromagnetic emission) were also experimentally tested (Fig. 13).

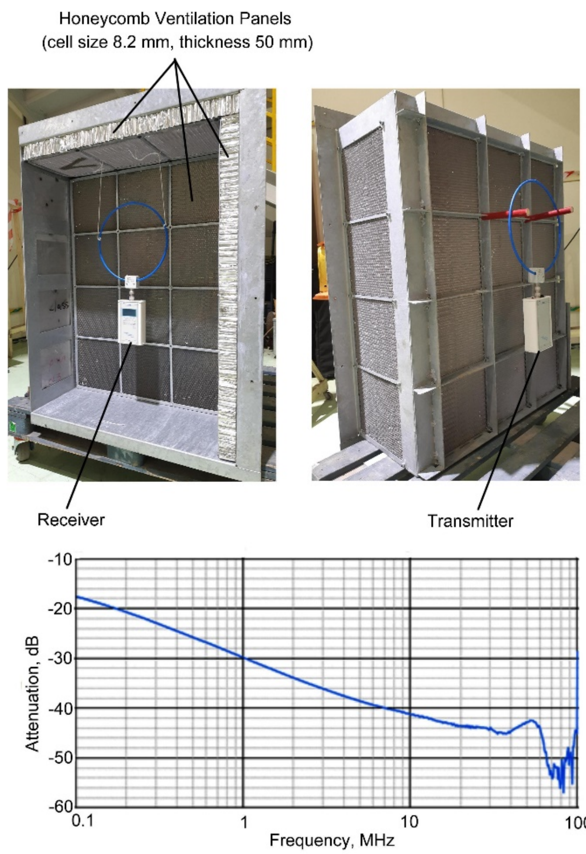

Fig. 13. Measuring attenuation of electromagnetic emission introduced by properly sized honeycomb ventilation panels by means of a SEMS system.

The findings confirmed quite satisfactory electromagnetic properties of these ventilation panels.

e. *Protection Of* DG *Connected To Consumer's Network*

There are two options here:

a. Immovable DGs located in a permanent place. These switch on automatically whenever necessary;
b. Transportable DGs that are arranged temporarily to power up a consumer. These are intended for frequent start-ups and for continuous operation during specific limited periods. In some circumstances, these DGs can be switched on in advance as a response to intelligence data about a danger of pending electromagnetic impact. Thus, they can be working during the HEMP impact.

In the first case, the most efficient protection is achieved when locating a DG in a closed container made of reinforced concrete with fine mesh reinforcement or a metal-sheet fabricated container. These containers should have no windows and their vents intended for cooling air take up and bleeding as well as the exhaust gas holes need to be closed with honeycomb panels. The panels that close the vents are clearly seen in Fig. 14.

Fig. 14. Protective containers for immovable DGs. The vents are closed with honeycomb panels.

In addition to the above-mentioned honeycomb panels, the DGs located in a protective container should be equipped with special HEMP filters installed between the power leads of the DGs and the load located outside the protected area. These filters designed for full load current (Fig. 15) are rather large and heavy. They need to be attached in the protective container in such a way that only the filters' exit cables free from pulse overloads and powerful high-frequency signals could enter the protected area.

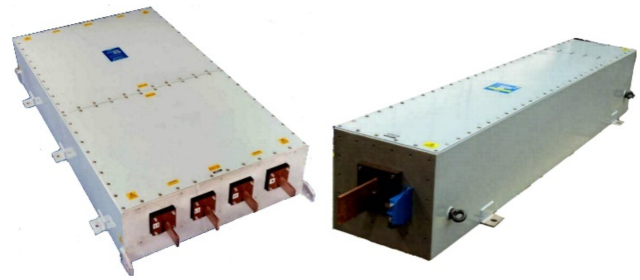

Fig. 15. Powerful HEMP filters for power circuits rated 800 and 1,200 A

The same is applicable to all control cables that also need to be run through corresponding filters before entering the protected area. All these filters need to be located in a separate container, Fig. 16.

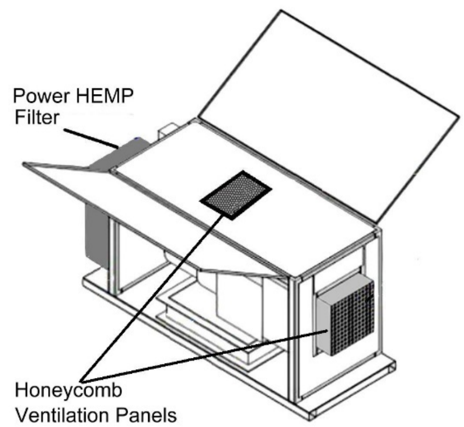

Fig. 16. Protective container for immovable DG

1 – filter block; 2 – honeycomb panel closing the opening for air bleeding and the exhaust pipe; 3 – honeycomb panel closing the outside air inlet opening.

Actually, these protective containers will fit not only for immovable, but also movable DGs of relatively low capacity (up to 100-200 kW). This type of protected DG is produced by some companies, e.g. EMP Engineering. The price of a 60 kW DG in a protected container is $85,000 US. Both these DGs and those located in immovable protective containers can work efficiently during the HEMP impact.

Since HEMP impact is global and affects large regions and sometimes even whole countries, the approach to backup DGs use should be different from that employed for man-induced or natural disasters,as the latter are: 1) limited in space; and 2) this space is not known in advance. Unlike local man-induced or natural disasters, locations for DGs installation in case of global HEMP impact can be determined in advance. Consequently, one of the approaches to protect heavy and large movable large capacity DGs (more than 0.5 - 1 MW), without protective containers, intended for operation at different consumers' during HEMP impact, is early location of fully equipped empty protective containers at critical loads, which will be powered from backup DGs during HEMP impact. Moreover, the DGs need to be delivered to the site and installed in the previously prepared protective containers.

Early transfer of critical loads to DG power and their disconnection from a centralized power supply in case of HEMP danger gives an additional positive effect. This is due to significant risk reduction of power system damage when it is off (disconnected). Thus, this approach may be demanded in practice.

A more complicated and less reliable solution to ensure efficiency of large DGs that have no special protective container during possible HEMP impact, is to use well-known standard approaches to protection of electric and electronic equipment of power plants and substations [1], in addition to installation of honeycomb structure blocks on vents, power filters and weld sealing of a window in front of the controller. The above-mentioned known protection measures include [1]:

- Use of shielded control cables inside the DG casing;
- Use of metal (instead of plastic) cable ducts;
- Use of filters embedded into control cables or ferrite filters put onto the control cable harness;
- Installation of excess voltage suppressors that employ zinc-oxide varistors or powerful avalanche diodes in all the power and control circuits;
- Introduction of a high-frequency choke into the grounding circuit.

It should be accepted that this solution is the most difficult to employ for a consumer having unprotected DGs. However, in some cases it can be the preferred approach. For example, when the above-mentioned protective measures will be adopted by a DG manufacturer during order performance.

V. CONCLUSION

Technical measures of DG protection from HEMP discussed in the article touch upon DGs of various typical sizes and purpose. Adoption of these measures is fairly easy for semiskilled technical staff and doesnot require high investments.

In fact, DGs will not perform properly in case of HEMP impact without these investments.

REFERENCES

[1]. Gurevich V. Protecting Electrical Equipment. Good Practices for Preventing High Altitude Electromagnetic Pulse Impacts. – De Gruyter, Berlin, 2019. – 386 p.

[2]. Gurevich V. Digital Protective Relays. Problems and Solutions. – Taylor & Francis Group, Boca Raton-London-New York, 2011, 404 p.

[3]. Gurevich V. I. Basic HEMP Protection Means for a Power Substation: A Quick Guide. – International Journal of Research and Innovation in Applied Science, 2017, vol. II, issue IV.

[4]. Gurevich V. Selection of LC filters to ensure HEMP protection of electronic equipment. – Interference Technologies, May 12, 2020.

[5]. Ivko A. Shielding of electronic equipment as a method of ensuring electromagnetic compatibility. – Modern Electronics, 2015, No. 8, pp. 86 – 90 (Rus.).

[6]. MIL-STD-188-125-1. High-Altitude Electromagnetic Pulse (HEMP) Protection for Ground-Based C^4I Facilities Performing Critical, Time-Urgent Mission. Part 1. Fixed Facilities, US Department of Defense, 1998.