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Protection of Diesel Generators from an Electromagnetic Pulse (EMP)

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Strictly as per the compliance and regulations of :

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I. Introduction

The electromagnetic pulse that emerges during the high altitude (40-400 km) nuclear explosion (HEMP) generates the electric field density of up to 50 kV/m at the earth surface. This creates extreme danger for all types of electric and electronic equipment [1]. Thus, the problem of diesel generator (DG) protection from HEMP becomes particularly relevant. First of all, DGs act as backup power sources and are designed to power up critical loads in emergency situations. Consequently, they need to be 100 percent ready for use even after the HEMP. Secondly, DGs are often stored outdoors (outside of the buildings that can partially mitigate the HEMP impact).DGs stored outdoors may also become a target for Intentional Destructive Electromagnetic Interferences (IDEI), which can be produced by portable devices that generate pulse emissions of several Gigawatts in the directional antenna [1].

Nowadays there are thousands of kinds 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 removal from the container. Generally speaking, these low capacity DGs have a simple design without sensitive electronics and are relatively inexpensive. Thus, it makes no sense to use any special measures to protect these DGs (except for metal enclosure).

II. Increased Susceptibility of Medium- and High-Capacity DGs

Medium-capacity industrial DGs (from dozens to hundreds of kilowatts) are large and heavy devices that are intended for transportation. As a rule, they are confined in a casing with many sensors and microprocessor-based controllers that control the DG's operation, measure and display various parameters, as well as protect them from overload and emergency modes. Protection from emergency modes in high capacity (1-50 MW) DGs is performed by digital protective relays (DPR) of the same type as those used in the electric industry in conventional power plants and substations. They are usually confined in standard relay protection cabinets that are installed inside the DG's casing. These cabinets are usually of the same type as those used in the electric energy industry in power plants and substations.

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

III. Protection Of DGs Stored De-Energized Outdoors

It should be immediately stressed that it is inappropriate to store DGs at centralized warehouses (as it usually happens). DGs are backup power sources that should be ready for use within the shortest possible time after emergency occurrence (after HEMP in this 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 DGs storage places, moving them closer to potential consumers.

The easiest solution to protect internal equipment of de-energized DGs from HEMP is to put metal casing on top of the DGs. However, this approach has some serious drawbacks. First, the casing for

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medium capacity DGs (5-8 meters long; 1.5-2 meters wide; 3 meters high) should be equipped with special stiffeners. The metal casing should be made of sufficiently thick metal welded together to provide for the necessary rigidity of the structure. Such casing will be so heavy that a user will need a crane to remove it from the DGs and prepare the DGs for a start up. However, this can hardly be a reasonable approach in a critical situation. Moreover, this casing will protect the DGs from 5 sides. And what about protection from the bottom ? What about inevitable multiple and large gaps between the casing walls and the foundation of the DGs? On the other hand, medium- and high capacity DGs are usually equipped with their own metal casing. Nevertheless, it should be noted that such casing has many cutouts, holes and blinds that drastically reduce its screening properties.

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

1. Improvement of screening capacity of the DG's own casing by closing all the cutouts, holes and blinds with removable metal patches that can easily be removed when preparing the DGs to startup.
2. Disconnection of connectors of all the electronic appliances and sensors from internal wiring and cable harness.
3. Installation of the same type of connectors' counterparts with short-circuited pins into connectors both on the side of electronic appliances and sensors and on the side of cable harness. Points of common coupling of all the cable harness wires should be connected to the DG's chassis.
4. Short-circuiting 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's chassis.
5. Removal of the electronic unit from the automatic power circuit breaker at the generator's output and placing it into the screened casing.

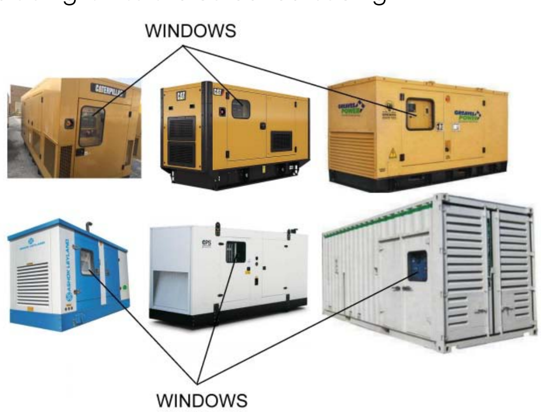

Fig. 1: Windows in front of controllers' screens cutout in casings of most DG types

When deploying clause 1 of the suggested concept, a special emphasis should be put on the window, which is cut out in the DG's casing in front of the microprocessor-based controller's screen. Such windows are present in most DG types, see 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's susceptibility to HEMP.

These windows should be tightly closed with a welded-on or bolted steel plate contoured with conductive rubber gaskets. The controller's readings are not taken continuously. When the DG is started, it is enough 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 these alternative options will be less efficient than the first option.

The second approach to improve the screening ability of the DG's casing is to close the air intake and exhaust apertures and blinds, see Fig. 1, with a solid steel plate fixed with welded bolts and contoured with conductive rubber gaskets. These screening plates should be removed before the DG start-up. Another large opening in the DG's casing is the cutout designed to connect external power cables to the DGs. This opening should also be closed by a removable bolted steel plate.

Fig. 2: Standard connectors of various types used to connect sensors to the DGs

When deploying other methods of the offered concept (related to disconnection of highly sensitive electronic equipment from internal electric circuit), it should be kept in mind that each point of intrusion into the internal arrangement of the DGs should be registered in the check list and each procedure of disconnection and restoration of circuits should be marked in this check list.

Fig. 3: Widely used DG controller, type EMCP 4

In order to connect multiple DG sensors to the cable harness, standard connectors (Fig. 2) are used. Subsequently, it is easy to buy mating parts to these standard connectors and use them as caps to short circuit the terminals of sensors and wires in harnesses.

Different types of DGs use different types of controllers. Producers of these controllers often use their own, non-standard connectors to connect external circuits. For example, one of these connectors, marked as 160-7689 in the documentation, is used in a well known EMCP 4 controller, which is widely used in various types of DGs, see Fig. 3. Some diesel units have another non-standard connector marked as 9X-4391. However, non-standard connectors are not really a problem as they (and many other types of connectors used in DGs) are readily available as spare parts and can be purchased both from a controllers' manufacturer and on the web, say eBay (see Fig. 4) at a relatively low price (50-60 USD).

Fig. 4: Non-standard 160-7689 and 9X-4391 connectors of DG controllers, which are readily available in the market

IV. Protection of DGs Connected to Consumer's Network

There are two options here:

- Immovable DGs located in a permanent place. These start-ups automatically whenever necessary;
- Transport table 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 started 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 the DGs in a closed container made of reinforced concrete with a fine mesh reinforcement or a metal-sheet fabricated container. These containers should have no windows and their vents should be intended for cooling air intake and release, the exhaust gas holes also need to be closed with special honeycomb structure blocks. These blocks that close the vents are clearly seen in Fig. 5.

Fig. 5: Protective containers for immovable DGs. The vents are closed with special honeycomb structure blocks

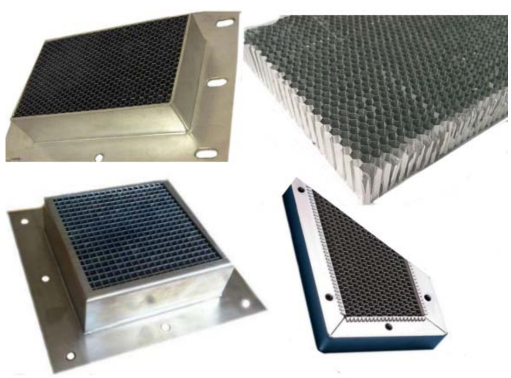

Fig. 6: Honeycomb structure blocks designed to close the vents

The honeycomb structure blocks (Fig. 6) are made of round or rectangular (sometimes hex-shaped) section pipes welded alongside. The purpose of these blocks is to ensure cooling air (or exhaust gases) circulation and prevent electromagnetic emissions from penetration into the protected area.

It is commonly known that the hollow metal pipe acts as a waveguide that conducts the high-frequency electromagnetic wave. Nevertheless, in order to have this pipe act as a waveguide, it should have specific geometric dimensions that are related to the wave length. If the dimensions of the pipe (waveguide) are different, it can cause significant wave decay (up to 80-100 dB). In other words, it does not conduct the electromagnetic wave. The waveguides that do not conduct electromagnetic waves at a frequency rate lower than the defined value (also known as the cutoff frequency) are called waveguides-below-cutoff. The size of waveguides-below-cutoff (i.e. the size of pipes used to produce the honeycomb structure blocks in our case) is determined by known formulas, see Fig. 7.

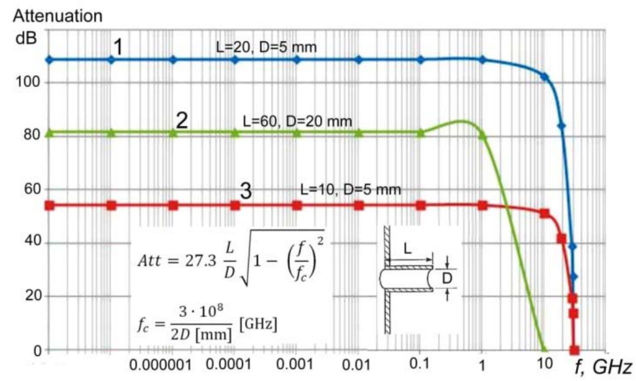

Fig. 7: Correlation between the index of electromagnetic emission attenuation by waveguides-below-cutoff and their geometrical dimensions and frequency. L– length of round section waveguide; D– diameter of the waveguide; f– frequency of emission; fc – cutoff frequency.

The curves in Fig. 7 (determined by [4] using these formulas) show that the ability of waveguides-below-cutoff to weaken the electromagnetic emissions is maintained in a wide range of frequencies up to the cutoff frequency.

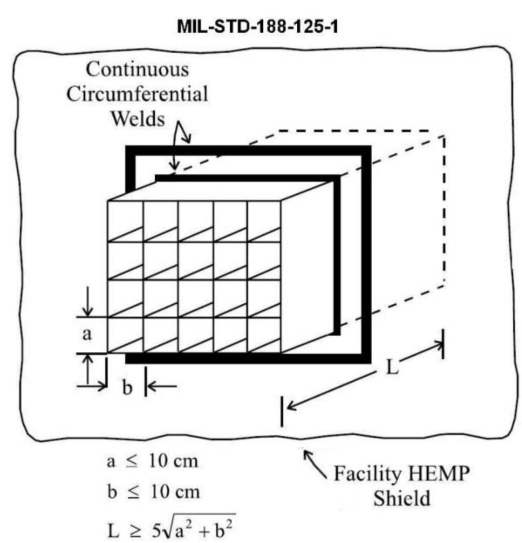

Fig. 8: The ratios to select the size of simple rectangular section pipes for the honeycomb structure [5].

In order to ensure the reliable operation of the waveguide-below-cutoff, it is necessary to select its cutoff frequency with a one and a half period margin in relation to the maximum working frequency. The military standard [5] suggests the ratios for selection of the size of simple rectangular section pipes for the honeycomb structure, see Fig. 8. In addition to the above mentioned honeycomb blocks, 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 which are designed for full load current (Fig. 9) are rather large and heavy. They need to be attached to the protective container in such a way that only the filters' exit cables are free from pulse overloads and powerful high-frequency signals can enter the protected area.

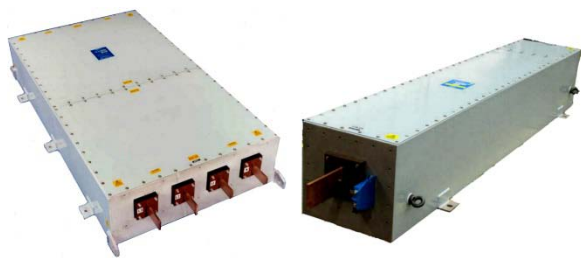

Fig. 9: Powerful HEMP filters for power circuits rated 800 and 1,200 A

The same is applicable to all control cables that also need to be run through corresponding filters before entering the protected area. All such filters need to be located in a separate container, see Fig. 10.

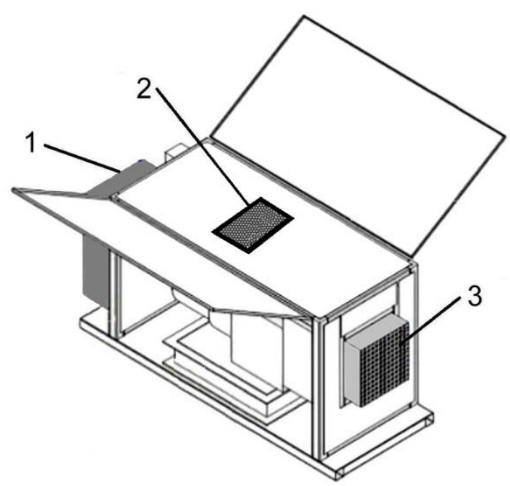

Fig. 10: Protective container for immovable DGs. 1 – filter block; 2 – honeycomb structure block closing the opening for air bleeding and the exhaust aperture; 3 – honeycomb structure block closing the cooling air intake opening.

Actually, such protective containers will fit for not only immovable, but also movable DGs, but 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 such DGs and those located in immovable protective containers can work properly during the HEMP impact.

Since HEMP impact is global and affects large regions and sometimes even entire countries, the approach to backup DGs use should be different from that employed for man-induced (technological) or natural disasters, as the latter are: 1) limited in space; and 2) this space is not known in advance. Unlike local technological 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 casing under the 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 controller. The above mentioned known protection measures include:

- use of shielded control cables inside the DG's casing;
- use of metal (instead of plastic) cable trays;
- 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.

Obviously, such a solution [1] is the most difficult to employ for a consumer having an unprotected DG. However, in some cases it can be the preferred approach, e.g. if the manufacturer of the DGs will initially adopt the above-mentioned protective measuresat the order processing stage.

V. Conclusion

Technical measures of DG protection from HEMP discussed in the article touch upon DGs of various typical sizes and purpose. Adoption of such measures is fairly easy for semiskilled technical staff and does not require high investments. In addition, it should be considered that DGs would not perform properly upon HEMP impact without such investments.

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