International Journal of Electrical and Electronics Research ISSN 2348-6988 (online)
Vol. 5, Issue 3, pp: (6-12), Month: July - September 2017, Available at: www.researchpublish.com

Facilities Ensuring Substation Direct Current Auxiliary Power System Survivability under Electromagnetic Pulse (HEMP) Part 1 Stationary Substations

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Abstract: **High Altitude Electromagnetic Pulse (HEMP) is a challenging agent aimed to destroy the most critical types of electric equipment in the most important components of national infrastructure. The article examines the measures to keep the substation direct current auxiliary power system (DCAPS) running upon HEMP, and describes the method to effectively protect the DCAPS operating equipment, using special elements and redundant power supplies based on diesel generators and compact DC power supplies.**

Keywords: **Power Substation, Electromagnetic Pulse, HEMP, Direct Current Auxiliary Power System.**

I. INTRODUCTION

High Altitude Electromagnetic Pulse *(*HEMP), as well as special high-power sources for distance destructive electromagnetic emission, are the most up-to-date and effective means to destroy the electronics of power systems, communications, water supply systems and other critical parts of national infrastructures without direct damage to the population [1, 2]. Thus, this kind of weapon is deemed as the most promising and is in rapid evolution in all developed countries.

Direct current auxiliary power system (DCAPS) is the most important component of any substation. All other substation systems and equipment (such as power equipment, relay protection, automation, control, communication, emergency, etc.) rely upon its operability. DCAPS failure makes the whole substation completely inoperable and "invisible" for the central control room. Therefore, DCAPS above all others needs the special facilities to ensure its operation upon HEMP. Such facilities can be categorized as follows: 1) facilities protecting operational equipment against HEMP; and 2) DCAPS redundant power supplies starting after HEMP in order to restore substantiation operability upon DCAPS failure.

II. PROTECTION OF DCAPS OPERATING EQUIPMENT AGAINST

Primarily, the special protection measures are required for electronic battery chargers (BCs) supplying power to DC current carrying buses, feeding numerous consumers and ensuring battery floating charge. A regular BC is the metal cabinet containing many electronic elements and cables (input AC supply triple cable, output two-core DC cable and emergency control cable). From the protection point of view, such a cabinet is basically identical to control, relay protection or an automation cabinet, therefore it can be protected against HEMP using the same means and methods as was proposed in [3 – 6] earlier. Briefly, it should be noted that such means include measures to improve the cabinet screening ability, special screened control cables, HEMP ferrite beads installed on control cables, surge overvoltage protection elements and improvement of the cabinet ground system, including usage of the so called "special floating ground" and disconnectable grounding [4]. Considering the fact that besides BCs, DCAPS also contains a DC control power distribution panel, AC distribution panel feeding the BC and battery bank, the DCAPS protection must span beyond the BCs cabinet protection. Furthermore, DC flowing through the power cables makes the strong neutralizing impact on inductive elements of standard HEMP filters and significantly reduces their effectiveness. Consequently, DCAPS protection has certain peculiar features.

Therefore, I suggest the following additional measures for DCAPS protection:

1. Special chokes acting as HEMP filters in power cables should be connected to the BC and battery bank.
2. Block varistors with high dissipated pulse energy should be installed on DC buses and in the triple AC power circuit of the BC.
3. Block varistors with medium dissipated pulse energy should be installed in BC cabinet and on the battery bank.

One possible type of DCAPS scheme equipped with mentioned protections is shown in Fig. 1.

Here, the chokes installed in the battery bank circuit limits the HEMP current pulse amplitude, which otherwise can be too high due to the very low internal impedance of batteries. The need to install the chokes in the BC DC circuit arises as the external DC circuit is connected directly to the inner rectifier bridge of the BC through thyristors, which are prone to failure upon the high amplitude current pulse if the chokes are not installed. Such chokes can be less powerful than the chokes used in the battery bank circuit. External AC cables are connected to BC input transformer windings, characterized by the very high impedance upon the very short current pulse, so such a circuit does not require any additional current limiting chokes.

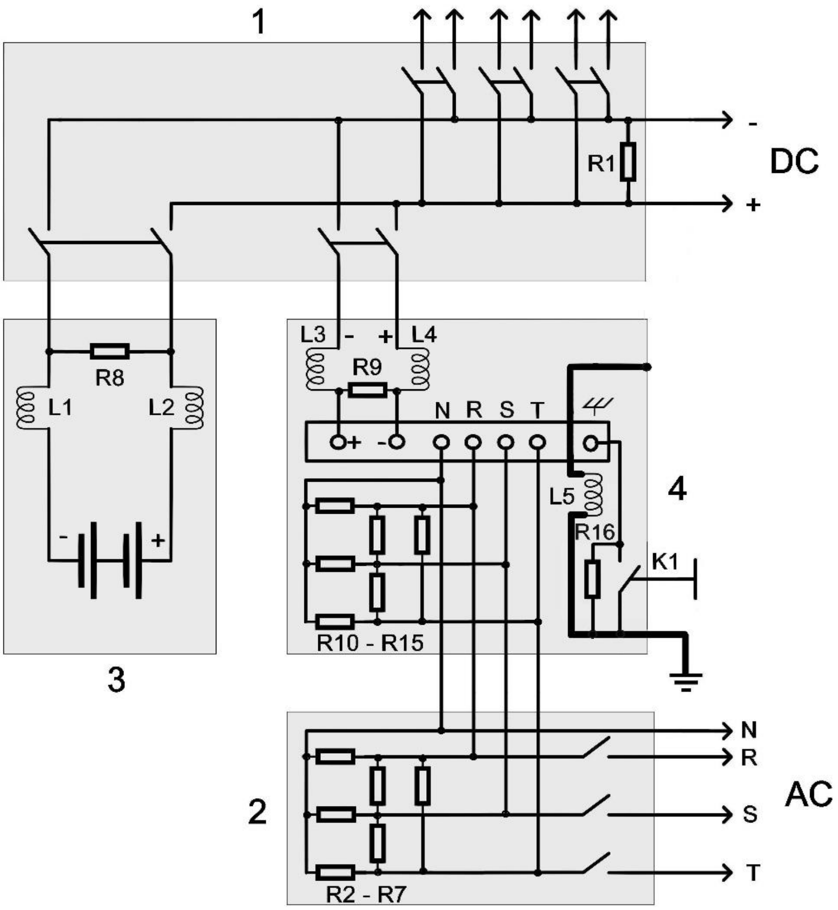

Fig. 1. Layout of protection elements in DCAPS. 1 – DC distribution panel; 2 – AC distribution panel; 3 – battery bank; 4 – charger (BC); R1 – R8 – block varistors with high dissipated energy; R9 – R15 - block varistors with medium dissipated energy; L5, R16, К - elements of the grounding system of the cabinet and internal zero potential circuit (local ground) of charger (so-called «special floating ground», in detail presented in [4]).

High-power chokes suitable to be used in DCAPSs as HEMP filters are manufactured by the American company CWS, see Fig. 2.

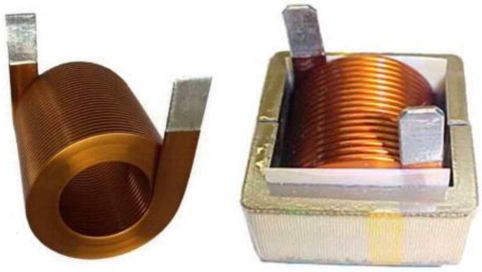

Fig. 2. High power cored and coreless chokes equipped with helical coil manufactured by CWS using the tailored material based on the special technology

Table 1 shows basic parameters of certain cored chokes Series ES.

TABLE 1. BASIC PARAMETERS OF CHOKES

Choke Type	Max. Continuous Current, A	Inductance at Full Current, µH	Resistance (Impedance)			Dimensions, mm
			DC, mΩ	1 MHz, kΩ	1 GHz, MΩ	
EK55246-341M-40AH	40	162	13.4	1.0	1.0	58 x 58 x 35
ES55242-140M-200AH	200	9.9	1.1	0.062	0.062	57 x 57 x 38

It is recommended to use high energy block varistors by EPCOS, Semicode, Dean Technology, Inc., Dongguan Uchi Electronics Co., etc. built in standard enclosures with maximum dimensions of 135 mm x 118 mm x 27 mm, see Fig. 3. Such block varistors are capable of transferring single current pulses of 8/20 ms with an amplitude up to 100 kA and dissipating energy of 2kJ – 3kJ, or even up to 10kJ. Pulse response time is 15 ns – 25 ns, according to manufacturer’s data. Varistors of this type should be outsized (by nominal voltage) as they are designed to ensure protection against HEMP high-voltage pulse rather than against surge overvoltage which is normally present in the system. For example, for DCAPS with the nominal voltage of 250VDC, such block varistors can have 420VDC (varistor actuation residual voltage or clamping voltage is 840V).

Fig. 3. Block varistors with high dissipated energy and pulse currents up to 100 kA.

Upon HEMP, residual voltage of 840V does not damage the wire and power cables isolation, as they are designed to withstand the much higher pulse voltages of several kilovolts. On the other hand, such a big safety factor ensures reliable and damage-free varistor operation within the long period. Additional mounting holes available on the enclosure of varistors of this design allow the direct fixing of them to the inner cabinet walls. In this case such walls act as cooling bores, further improving the reliability of devices continuously operating under the applied service voltage.

As medium dissipated energy block varistors, it is also recommended to use varistors made by the above-mentioned manufacturers (Littlefuse company in addition), see Fig. 4. Such varistors designed for installation inside the BC cabinet or directly on the battery bank buses are tolerable to single pulse currents up to 30 – 40 kA, have lower dissipated pulse energy (300J – 500J), smaller maximum size (usually, 60 mm x 55 mm x 14 mm) and lower redundant operating voltage, e.g. 320VDC (varistor actuation residual voltage or clamping voltage is 650V).

Certain information sources emphasize rapid response of avalanche diodes and diode-based suppressors compared to varistors. Unfortunately, the manufacturers of such elements do not produce them for required pulse currents and dissipated pulse energy and do not produce them in enclosures suitable for mounting in power cabinets. Thus, at the present time the varistors are preferable.

Fig. 4. Block varistors with medium dissipated energy and pulse currents up to 40 kA.

III. REDUNANT POWER SUPPLIES FOR DCAPS SYSTEMS

DCAPS redundant power supply is designed to restore the DCAPS operability upon HEMP in case of failure of operating DC current feeding the BC, or in case of damage of some DCAPS components despite the implemented protection measures.

Two alternatives of independent redundant power supplies, with minimum power required to ensure operability of critical DCAPS loads of 5 kW are considered: 1) based on the fuel cell, and 2) based on the diesel generator.

Fuel cell (FC) is the chemical source of current converting the fuel energy directly into the electricity without the combustion stage. As for the amount of energy, the FC is significantly more effective (efficiency up to 40%–50%) compared to combustion engine (efficiency up to 12% – 15%). Besides, the fuel cell is environmentally friendly as it does not inject contaminators into the atmosphere in contrast to the combustion engine. But, are these useful FC properties important in case of redundant power sources, since they are regularly inactive and actuated only upon the emergency and for a limited time only? The answer is quite obvious. On the other hand, the FC has certain drawbacks. The most common types of FC use the reaction of water formation in order to generate the energy (the hydrogen contained in electrochemical cell reacts with oxygen contained in the air). However, hydrogen is explosive gas requiring the application of special storage and transportation methods, as well as the availability of airborne concentration transducers and certain approvals. Special metal hydride containers, see Fig. 5, used instead of regular hydrogen balloons, substantially increase the cost of the plant which is already several times more expensive than the diesel-generator set of the same power.

If the FCs and hydrogen balloons are installed outside the building, the protection against unauthorized access, acts of terrorism and property abuse, should be ensured in order to prevent the cataclysmic plant explosion.

Fig. 5. 5 kW fuel cell and hydrogen storage metal hydride containers

Also, the FC contains a lot of electronic transducers, microprocessors and other microprocessor-based devices controlling its operation and preventing emergency modes. Typical 5 kW FC generates low DC voltage (about 40 V). Then, it should be converted into standard 230VAC using the electronic inverter, or into standard 250VDC using the converter. Due to the numerous complex electronic systems, the FC is highly vulnerable to electromagnetic impacts — both to single HEMP and remote impacts of independent directed sources of high frequency energy. Altogether, it is necessary to install FCs and balloons outside the building in a special thick-walled steel box, ensuring explosion protection of the FCs upon different intentional destructive mechanical and electromagnetic impacts, see Fig. 6.

Fig. 6. The FCs with balloons, inverter, and batteries enclosed in special steel box of 2m x 3m x 2m: 1 – set of standard hydrogen balloons 150 atm; 2 – electrochemical cell; 3 – inverter and batteries.

Furthermore, an electrochemical cell of 5 kW FC contains more than 20 liters of electrolyte, which is usually characterized by high reactivity and chemical hazard (such as concentrated KOH solution). During the long periods of electrochemical cell inoperability, such a chemical reagent must be stored separately and poured into the cell just before its activation. Moreover, before the FC activation, its electronic systems should be started using the battery with a constant functioning charger.

All these features, or rather problems, make the FC hardly suitable to be used as a substation DCAPS redundant power supply.

In contrast to the FC, a regular 5 – 7 kW diesel generator is a compact, cheap, low-maintenance and thus a perfect choice to be used as DCAPS redundant power supply, see Fig. 7.

Fig. 7. Compact diesel-generator sets of 5 – 7 kW.

Such diesel generators are equipped with manual starters and do not require a battery. They can be easily mounted inside the substation building, requiring only an exhaust stack going through the building wall, see Fig. 8.

Fig. 8. Installation of compact diesel generator inside the substation building

Compact 5 – 7 kW diesel generators do not contain electronic control and monitoring systems, therefore they are much less vulnerable to HEMP compared to the FC. However, considering the fact that HEMP generates the electric-field strength up to 50 kV/m near the ground surface, such diesel generators must be protected against coil and wire insulation failure. A light metal container with a tight cover (door) made of 5 – 6 mm thick aluminum is the perfect choice to ensure the protection of a standby diesel generator stored at the substation. During the storage period, all external cables and the external exhaust stack must be disconnected from the diesel generator.

A 5 kW diesel generator consumes only about 1 liter of fuel per hour. Therefore, one plastic container with 200 liters of fuel, see Fig. 9, ensures a week of uninterrupted operation, while a 1000 liters' container – ensure a month of uninterrupted operation.

Fig. 9. Plastic containers used for storing diesel fuel.

In order to improve the availability, redundant power supply based on a diesel generator can also be equipped with a standby BC (to replace the main BC upon failure). Compact low power BCs with high frequency intermediate link are manufactured by numerous companies. For example, two compact BCs Series ADC7480 manufactured by the Finnish company Powernet, see Fig. 10, connected in parallel and equipped with all sorts of systems for stabilization, adjustment, protection and load sharing between devices, and energized by 5 – 7 kW diesel generator, can supply enough power to the medium-size substation, or ensure operation of critical equipment and keep the battery bank operable on the large substation.

Fig. 10. Battery charger Series ADC7480 with output voltage of 0V – 300V and output current up to 14A

Such a BC should be stored in a disconnected state in diesel generator container. The cost of the redundant power supply based on 5 kW diesel generator and equipped with a double BC with the total current up to 25 A costs approximately 10,000USD, which is near10 times less than the cost of the FC-based power supply of the same output power. Moreover, if you use diesel generators, you do not need any special hydrogen storage facilities or installation and operation approvals. The cost of one choke and one block varistor is approximately 30 - 50 USD each.

IV. CONCLUSION

The method proposed to improve the substation DCAPS survivability includes special varistors and choke-based facilities to protect the operating equipment, as well as redundant diesel generator power supplies and compact DC power sources installed in the enclosures. The cost of the proposed method is affordable and it can be easily implemented at the most critical substations using the commercially available components.

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