Preventing Impact of Geomagnetically Induced Current at High Altitude Nuclear Explosion on High-Power Transformers

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doi: https://doi.org/10.21467/abstracts.93.85

ABSTRACT

Protection of a power system's electrical equipment from a high-altitude (more than 30 km) nuclear explosion (HEMP) impact is a challenging issue, which until recently has not received proper attention. The fact is that HEMP does not affect people directly, while the electromagnetic pulse resulting from this explosion is a powerful devastating factor for the power grid's electronic and power supply equipment. Since the electrical power industry is the foundation of any country's infrastructure, such a feature of HEMP is very attractive for the military. HEMP is known to consist of three components: E1, E2 and E3. These are significantly different from each other in terms of their properties and specifications, due to a full set of complex physical effects occurring in the ionosphere upon nuclear explosion. For example, while the E1 component represents a short single pulse (2.5/25 ns) creating very high electrical field strength at the ground surface (50 kV/m), the E3 component is inversely a very slow oscillating process with a frequency of less than 0.1 Hz and low electrical field strength (up to 85 V/km) [3], which lasts several minutes. The E2 component is very similar to lightning in terms of its impact and thus protection of this equipment has been envisaged.

This abstract discusses protection of the electrical grid's power equipment from HEMP's E3 component.

It may seem that the issue of protection from slow electromagnetic oscillations with such low electrical field strength as 85 Volts per kilometer is exaggerated, nevertheless this is true at the first glance only. Indeed, these electromagnetic oscillations are induced in many kilometer-long *overhead power transmission lines* and closed through a very low impedance loop, e.g. a grounding system. As a result, geomagnetically-induced quasi-DC currents (GIC) with an amplitude of dozens and hundreds of Amps may pass through neutral conductors of power transformers. This leads to quick saturation of the transformer's core and consequently reduction of its impedance. Concurrently, operational current flowing through its windings will increase, resulting in the transformer's excessive heating. Such heating resulted in coils blowing of powerful power transformers that cost several million dollars. Apart from the high cost of such transformers, other problems would include long-term manufacturing of such equipment and complicated transportation of it to the point of use. That is why malfunction of such transformers represents an emergency situation for power systems requiring costly efforts to prevent them in the future. In addition, the power transformer with a saturated core acts as a powerful source of harmonics generated into the power system. These harmonics can negatively affect many types of electrical equipment in the power system, e.g. capacitor banks of *longitudinal and transverse* capacitive compensation, relay protection devices, etc. Another issue is a sharp loss of reactive power in the grid upon GIC impact onto power transformers and further sharp reduction of voltage. As a result, the power system's stability is compromised potentially leading to its collapse. The SolidGround™ device promoted by ABB company is meant for blocking GIC in neutral conductors of power transformers. This is a very expensive (~400,000 US Dollars) high-voltage unit, which requires ample space to be mounted at a substation site. Initially, this device was developed to block GIC during severe solar storms, which may

Published by AIJR Publisher in "Abstracts of The Second Eurasian RISK-2020 Conference and Symposium" April 12- 19, 2020, Tbilisi, Georgia. Jointly organized by AMIR Technical Services LLC, Georgian Technical University, Institute of Geography (Kazakhstan) and Russian Institute of Petroleum Geology and Geophysics.
DOI: 10.21467/abstracts.93

last for many hours. Later on, it was promoted as a main remedy to block the E3 component of HEMP, which lasts several minutes only. However, this difference has never been mentioned in technical literature. Alternatively, the developers (in order to promote this expensive piece of equipment) suggest that there is almost no difference between a solar storm's GIC and that induced by HEMP.

Our solution of the problem is based on the difference between GIC occurring during solar storms and GIC occurring during high-altitude nuclear explosion. The main idea behind it involves a short-term automatic disconnection of the power transformer (achieved by HEMP-protected relay upon sensing GIC in the neutral conductor) with further automatic return to operation after a several-minute pause (i.e. when the E3 impact is over). We developed an electronic relay for the transformer's protection, suitable for large-scale use and to be conveniently implemented in power systems. This protection relay includes the GIC sensor designed as a special portable current transformer to be put on the cable, grounding the transformer neutral and a special high reliable relay, which responds to a signal from the GIC sensor. The equipment also includes a tester for periodical testing of protection relay serviceability directly at the installation point by means of GIC simulation. This sensor provides 0V to 10V output voltage only in case 0 to 50A, 0 -1.5 Hz quasi-DC current of any direction occurs in that cable (i.e. it does not react to 50 Hz AC current). The sensor can sustain short-circuit current up to 8 kA in the cable without any damage. The sensor's tolerance is 0.5% of the full current rating (0.25 A for this design). The sensor is connected to the input of the improved reliability protection relay developed by author.

Under the normal mode of the power grid's operation it is only the alternating current that can pass through the cable grounding the neutral of the power transformer's coil "wye" connected. A high-altitude nuclear explosion will generate a direct current component (E3 component) in the cable, which produce voltage at sensor output proportionate to that current to the sensor's input. If the current value exceeds 20A, the output voltage from the sensor will be activate an electronic relay which controls the trip coil of the high-voltage circuit breaker through the substation's auxiliary relay (to disconnect the power transformer). Several minutes later (i.e. when the impact of the E3 component is over), the automatic reclosing system on the substation will return the transformer back to the operating mode. The same system performs short-term interruption of the power supply of GIC protective relay though an auxiliary timer. This short-term power supply interruption is enough for the GIC protective relay to return to the initial condition, i.e. into a stand-by mode.

In order to be sure that the GIC protection relay is serviceable, it needs to be periodically tested. A special portable tester has been developed and constructed by the author for periodically serviceability testing of the abovementioned protection relay placed on the grounding cable of the transformer's neutral. Two stages of output current can be use in the testing procedure. The lower stage serves to check failure of GIC protective relay actuation at current values slightly lower than its trip threshold, while the upper stage serves to check actuation of GIC protective relay at current values slightly higher than its trip threshold. The sensor mounting and testing procedure not needs any circuits interruption. The relay is placed into a sealed aluminium container, which ensures the circuit's protection from the E1 component of HEMP. The sensor is also placed into a similar shielding container. The circuit is then connected to external circuits by means of a shielded cable. The set of described devices developed by the author solves a problem of protecting power transformer (major element of an electrical power supply system) against HEMP and from consequences of its impact onto the power grid altogether. These device designs are very simple, inexpensive and are suitable for mass production. With this set of equipment, the issue of HEMP impact onto a power supply transformer can be deemed completely resolved.

DOI: 10.21467/abstracts.93