Proceeding Paper

Design and Analysis of Shielding for Denoising Sensitive Partial Discharge Measurements in a High Voltage Laboratory †

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Abstract: With today’s technological advancements, electromagnetic interference (EMI) in high voltage (HV) Laboratories is extremely important, especially for sensitive Partial Discharge (PD) measurements. To avoid electromagnetic interference during partial discharge studies, the laboratory must be shielded for accurate measurements and findings. There are number of techniques used for shielding to avoid noise during PD measurements, but all the techniques are very expensive and complex. In order to develop a low-cost, practical solution for denoising sensitive PD measurements, two portable prototype models of shielding enclosures based on the operating principle of Faraday Cages are fabricated and used in this research. A comparative analysis of both portable cages was undertaken and effect of the cage’s material on its denoising performance was observed. Practical experimentation yielded effective average noise reduction up to 0.5 pC for 1 kV by a thin aluminum foil cage, and ways to further improve the denoising capability are also suggested.

Keywords: partial discharge (PD); electromagnetic interference (EMI); shielding; high voltage

1. Introduction

The use of electronic devices has increased dramatically worldwide as a result of technological advancements. As the number of these gadgets grows day by day, so does their electromagnetic radiations [1]. Electromagnetic interference (EMI) is produced by these emissions, and it affects the performance of the devices in the vicinity. Noise from mobile towers, arc welding, and natural sources like lightning and solar flares are all common causes of EMI [2,3].

In a high-voltage laboratory, partial discharge (PD) is an important measure for measuring the performance of electrical insulation systems [4]. Significant background electrical noise can “drown out” the PD signal that is supposed to be detected in the particular environment [5]. Shielding lowers the impact of EMI to some level by erecting barriers made of metallic materials which have capability of conductivity [6]. Faraday Cages work on a similar working principle. When electromagnetic radiations, in the form of noise, reach the top layer of a metal, electric charges stimulate the metal’s surface to the point where the electric field at the cage’s surface cancels out, thus nullifying the electric field inside the cage. This phenomenon is used to keep electrical gadgets safe from the elements of EMI [7]. The purpose of a shielded laboratory is to attenuate incoming electromagnetic waves, inside the laboratory, and to reduce external electromagnetic noise to the point where it does not interfere with the signals being examined [8]. There are many other, additional, denoising techniques which are being used and however, these are usually very expensive and complex to implement [9]. Thus, a portable, low-cost shielding is the requirement of today’s sensitive PD measurements; it is both cheap and easy to develop.
Keeping in view of the above motivation in this research work, partial discharge tests on a test sample, using a test cell and PD setup, are performed to examine the denoising effect of two portable, low-cost shielding cages. Based on the experimental results and findings, recommendations were made for portable Faraday Cages at the end.

2. Configuration of Test Setup

The partial discharge test setup was constructed according to the IEC 60270 standard using a high voltage AC 440–100 kV Haefely step-up transformer, along with a Haefely quadripolar unit, coupling capacitor, and corona disc attached to it. A rectangular test cell was made using an acrylic sheet of thickness 5 mm for holding the test sample and conducting the partial discharge test on it, as shown in Figure 1a.

![Figure 1. (a) Acrylic Test Cell with Sample; (b) Needle-Plane Aluminum Electrodes.](image)

According to ASTM standard D2257, the needle-plane electrode configuration was used in this test setup, as shown in Figure 1b. The needle electrode was a rod made of aluminum and 6 mm in diameter, with a tip-end radius with a curvature of 1 mm, as per the dimensions given in [10]. While the plane electrode was made up of an aluminum rod of thickness 8 mm with a plane aluminum disc on one end having a diameter of 50 mm [11] and thickness of 12 mm. The separation gap between needle plane electrodes was maintained at 0.2 mm, as used in [12]. A test sample made up of neat epoxy with a diameter of 75 mm and 3 mm thickness [13] was used to perform the PD test.

3. Experimental Work

In the experimental work, a partial discharge test on the test sample was conducted by using two portable prototype Faraday Cages. Noise in picocoulombs (pC) was recorded and a comparative analysis was undertaken on the noise reduction capabilities of both cages.

3.1. Partial Discharge Test without Any Shielding Cage

In the first experiment, partial discharge test setup was used without covering the test cell with any of the shielding cages, as shown in the Figure 2. Calibration was undertaken at 10 picocoulomb (pC) to avoid any error by using Haefely charge injector before applying the high voltage. After calibrating the system, a high voltage was then applied and increased gradually, and respective noise in pC was recorded while the hall lights were on and all other capacitive and inductive loads were off.
3.2. Partial Discharge Test using Portable Mesh Prototype Cage

In the second experiment, the test cell, along with Haefely quadripolar unit and coupling capacitor, was completely covered by a shielding cage of dimensions 2.5 ft × 2.5 ft × 4 ft (L × W × H) made up of a hard iron mesh with a hole size of 0.5 cm, as shown in Figure 3. Calibration was undertaken again at 10 picocoulomb by using a Haefely charge injector, before applying a high voltage. After calibration, a high voltage was then applied and increased gradually, and respective noise in pC was recorded while hall lights were on and all other capacitive and inductive loads were off.

3.3. Partial Discharge Test using Portable Aluminum Foil Prototype Cage

In the third experiment, a shielding cage of dimensions 2.5 ft × 2.5 ft × 4 ft (L × W × H) was constructed by a general-purpose thin film of aluminum foil wrapped over a paper box, as shown in Figure 4. The test cell, along with Haefely coupling capacitor and quadripolar unit, was covered completely by this cage before performing the test. Calibration was undertaken at 10 Pico coulomb by using a Haefely charge injector before applying a high voltage. After calibrating the system, a high voltage was applied and increased gradually, and respective noise in picocoulomb (pC) was recorded while the hall lights were ON and all other capacitive and inductive loads were OFF.

Figure 2. Partial Discharge Test Setup without any Shielding Cage.

Figure 3. Partial Discharge Test Using Iron Mesh Shielding Cage.

Figure 4. Partial Discharge Test Using Aluminum Foil Prototype Cage.
4. Results and Discussions

The following results were recorded from all the above experiments, and a comparison was made in order to develop conclusions and recommendations.

4.1. Results of Mesh Shielding Cage Prototype

During experimentation, a high voltage was applied and gradually increased to record different noise readings with respect to applied voltage. For the first reading, the voltage was raised up to the level of 1 kV, and 1.33 pC of noise was recorded which was same as it was recorded without the cage. Subsequently, the voltage was further increased up to a level of 1.5 kV, and second reading of 1.35 pC of noise was recorded without any noise reduction. For the third reading, the voltage was increased up to the level of 7.60 kV, and as a result, a noise overshoot of 4.92 pC was recorded. The voltage was further increased up to the level of 14.87 kV in order to verify the overshooting, and instead of noise reduction, a further noise overshoot of 28 pC was recorded, as given in Table 1.

Table 1. Noise Readings Using Mesh Shielding Cage.

| Applied Voltage (kV) | Noise without Mesh Cage (pC) | Noise with Mesh Cage (pC) |
|----------------------|-----------------------------|--------------------------|
| 1.07                 | 1.33                        | 1.33                     |
| 1.50                 | 1.35                        | 1.35                     |
| 7.60                 | 1.39                        | 4.92                     |
| 14.87                | 2.0                         | 28.0                     |

4.2. Results of Aluminum Shielding Cage Prototype

During experimentation, a high voltage was applied and increased gradually in small steps, and the first reading was recorded at 1 kV. It was observed that a thin aluminum foil cage effectively reduces the original noise up to 0.5 pC from its original value of 1.57 pC at 1 kV. Subsequently, the voltage was further increased up to a level of 1.1 kV, and a second reading was recorded in which effective shielding of 0.61 pC was recorded at 1.1 kV. For the third reading, the voltage was increased up to the level of 1.57 kV, on which a noise overshoot of 10.2 pC was recorded, as given in Table 2.

Table 2. Noise Readings Using Aluminum Foil Shielding Cage.

| Applied Voltage (kV) | Noise without Aluminum Cage (pC) | Noise with Aluminum Cage (pC) |
|----------------------|---------------------------------|-------------------------------|
| 1.06                 | 1.57                            | 0.50                          |
| 1.1                  | 1.5                             | 0.61                          |
| 1.57                 | 2.0                             | 10.2                          |
Table 2. Noise Readings Using Aluminum Foil Shielding Cage.

| Applied Voltage (kV) | Noise without Aluminum Cage (pC) | Noise with Aluminum Cage (pC) |
|---------------------|----------------------------------|-------------------------------|
| 1.06                | 1.57                             | 0.50                          |
| 1.10                | 1.59                             | 0.61                          |
| 1.57                | 1.58                             | 10.2                          |

The reason for that noise overshooting in both cages was the close proximity of the cage walls to the high voltage electrode. As the clearance distance between the walls of the cage and high voltage electrode was very small and of the order of 130 mm, as shown in Figure 5a, the electric field becomes strong, and as a result, according to Gauss’s law, the electric charges start accumulating on the surface of the metallic cage, which causes overshooting in noise readings at a voltage level higher than 1 kV. For voltages up to 1 kV, the minimum proximity distance of 130 mm is sufficient to reduce noise up to the level of 0.5 pC, while at higher voltages, up to level of 10 kV, a minimum proximity clearance of 1300 mm (1.3 m) will be required, as shown in Figure 5b, to design the shielding cage. A separate isolation transformer should be used for a high voltage kit in order to avoid interference caused by other loads in the high voltage laboratory during sensitive PD measurements.

![Shielding Cage for 1 kV](image1)

![Shielding Cage for 10 kV](image2)

Figure 5. (a) Minimum Proximity Clearance for 1 kV; (b) Minimum Proximity Clearance for 10 kV.

4.3. Recommendations

- A thin-film Aluminum foil cage with a minimum proximity clearance of 130 mm is required for noise reduction up to the level of 0.5 pC at 1 kV.
- For higher voltages, up to the level of 10 kV, a minimum wall clearance of 1300 mm (1.3 m) is required between the walls of the aluminum foil cage and HV electrode.
- An iron mesh cage with hole size of 0.5 cm does not provide any denoising properties; hence, it is not recommended to use for shielding with these specifications.
- A separate isolation transformer is recommended for a high voltage kit to avoid interference during sensitive PD measurements.
- Further, detailed investigation is required and in progress.

5. Conclusions

PD is a challenging effect, and a lot of solutions are available. However, all those solutions are very expensive and complex. In this research work, a portable and cost-effective solution has been recommended. PD test setup was constructed using a Haefely ac step up transformer, and a quadripolar unit. An acrylic test cell for holding the test
sample and two aluminum electrodes were fabricated in a workshop. Experimentation was undertaken by fabricating two portable, low-cost Faraday Cages for conducting the PD test. A comparative analysis was undertaken, and the noise reduction capabilities of both cages were observed. It was concluded, after results and discussion, that the thin aluminum foil cage with a minimum wall proximity clearance of 130 mm can effectively reduce the external noise interference up to the level of 0.5 Pico at 1 kV, while the mesh cage with a 0.5 cm hole size does not reduce any noise at all. At higher voltages i.e., beyond 1 kV, the noise overshoots up to several picocoulombs in both cases due to the close proximity of the cage walls and the high voltage electrode. For the higher voltage of 10 kV, the thin aluminum foil cage with a minimum proximity clearance of 1300 mm (1.3 m) can be used for denoising.

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