Parametric Evaluation of 11kV Zinc Oxide Surge Arrester using Finite Element Analysis Model

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Abstract. A surge arrester on transmission line is used to deflect lightning surge to ground, avoiding power systems from destruction. During normal condition, there is a leakage current flow through surge arrester where it is one of the main causes of surge arrester humiliating. Thus, monitoring the surge arrester condition is very significant. In this work, the effect of several parameters in a 11kV zinc oxide surge arrester design based on leakage current distribution has been studied. A comparison is made between measurements and modelling in order to validate the model that has been developed using finite element analysis. This work found that the benefit of using FEA-based model where the design parameters that affect the leakage current can be identified. Through this study, a well knowledge of leakage current can be achieved and also help in zinc oxide surge arrester design.

1. Introduction

Electrical power system continuously has an obstacle with transmission lines which is lightning surge problem. This problem can be reduced by guarding the overhead lines using counter-poise wires, grounding rods and protective devices [1]. Many kinds of protective devices can be used on overhead transmission. Explosion gaps and protector tubes are used on the line itself while surge arresters are used at line terminations, junction of lines and substations.

The most efficient protective devices to defend transmission lines from lightning is surge arrester where it be able to limit the peak voltages to an acceptable value that will avoid the electrical apparatus from damage. There are two types of well-known surge arrester which produces since 1965 which are silicon carbide and zinc oxide surge arrester (ZnOSA) [2]. The housing of surge arrester also can be intended in many forms and materials which provide a contribution towards the defense of the environment. Nowadays, silicone rubber is used as housing and shed material due to its excellent chemical and physical properties.

To inhibit the continuous flow of leakage currents, the surge arrester design required spark gaps but this gap is not essential for ZnOSA. This is because ZnOSA have low leakage current elements. Nevertheless, due to the normal condition, leakage current still flows through ZnOSA and affected by some conditions [3].

The increasing leakage current may direct to humiliation of ZnOSA and can cause failures in electrical power system [4]. This failures will effect in high maintenance cost and time consuming.
where is some cases, the electrical equipment is compulsory to be changed [5]. Therefore, it is very substantial and important to avoid this breakdown [6]. This can be accomplished by examining the source of increasing leakage current [7]. In addition, the ZnOSA design also can be enhanced [8].

Modern enhancements correlated to the ZnO blocks have brought in impressive design improvements of ZnOSA. On the other hand, the design still can be improve on reducing the leakage current across the ZnOSA. Enhancement using finite element analysis (FEA) permits design engineers researchers to assemble a ZnOSA model based on real physical dimensions. Hence, the developed FEA model can be used to assess various design parameters affecting leakage current.

In this work, laboratory experiment and FEA simulation were performed to measure the leakage current across the 11kV ZnOSA. A three-dimensional (3D) surge arrester model was developed using FEA method to study the effect of surge arrester parameters on behaviour of leakage current. At first, the leakage current measurement results were compared to simulation results to validate the design. Then, the developed model was used to find the design parameters that affect the value of leakage current. The main advantage of parametric study is the most suitable affected parameter can be obtained within shorter time. Furthermore, the conducted study using the FEA model could be beneficial among surge arrester designers in designing suitable protection device. Therefore, performance of transmission lines can be improved mainly in reducing the leakage current on surge arresters.

2. Methodology
This segment explains the methodology used in this study. The leakage current measurement setup and design of the surge arrester using finite element analysis (FEA) software and its simulation are shown. The ZnOSA used in this study is 11kV with silicone housing produced by ABB as shown in Figure 1 which consists of two ZnOs blocks, a glassfibre between insulator and ZnO blocks, four silicone sheds and aluminum caps at both ends. The height of the ZnOSA is 227mm with 344mm creepage distance and maximum continuous operating voltage (MCOV) of 10kVrms.

![Figure 1. 11kV zinc oxide surge arrester](image)

2.1. Modelling of zinc oxide surge arrester
Finite element analysis (FEA) is a method for numerical solution of field problems and used in this study as a replacement of equivalent circuit model. By using FEA, the exact parameters of ZnOSA can be created. The ZnOSA was modelled in three-dimensional (3D) and physic used in this under ‘AC/DC Module’ is ‘electric current’. It is used to generate the current density on the ZnOSA model. The ZnOSA consist of of two zinc oxide blocks with diameter and height of 47mm respectively, a glassfibre of 10mm and the entire ZnOSA model geometry was surrounded by a layer of air with permittivity $\varepsilon_r$ equals to 1 to allow the electric potential and leakage current distribution along the surface of surge arrester to be calculated. The complexity of the ZnOSA model was diminished by eliminating the small scale elements such as drilled holes and disc string since these elements do not
influence the simulation outcomes. The 3D model is shown in Figure 2 and the electrical conductivity \( \sigma \), relative permittivity \( \varepsilon_r \) were assigned as in Table 1.

![ZnOSA geometry](image)

**Figure 2.** ZnOSA geometry (a) complete structure and (b) 3D model

The boundary conditions of the ZnO model were set with relevant interface settings and the model was meshed with solution of domain, boundary, edge and point of the model by using some elementary shape functions, which include tetrahedral, triangular, edge and vertex elements as in Figure 3 and Table 2. The simulation processes were then repeated for different parameters of surge arresters.

| Material   | Relative Permittivity, \( \varepsilon_r \) | Electrical Conductivity, \( \sigma \) (Sm\(^{-1}\)) |
|------------|----------------------------------------|-----------------------------------------------|
| Air        | 1                                      | 0                                             |
| Silicone   | 11.7                                   | \( 1 \times 10^{-12} \)                        |
| ZnO blocks | 2250                                   | From VI characteristics                       |
| Glassfibre | 4.2                                    | \( 1 \times 10^{-14} \)                        |
| Aluminum   | 1                                      | 3.77\( \times 10^7 \)                         |

**Table 1.** Material properties

![Meshing elements](image)

**Figure 3.** Meshing elements
Table 2. Mesh elements statistic

| Geometric entity level | Type of element | Number of element |
|------------------------|-----------------|------------------|
| Domain                 | Tetrahedral     | 106194           |
| Boundary               | Triangular      | 14943            |
| Edge                   | Edge            | 2792             |
| Point                  | Vertex          | 245              |

2.2. Leakage current measurement setup
This subdivision emphases on leakage current measurement setup as shown in Figure 4 used in the laboratory. It consists of a sinusoidal voltage source, a step-up transformer of 0.22/100kV, a protective resistor of 2.4MW to prevent short circuit, a measuring capacitor of 1nF to observe the applied voltage, a measuring circuit, a shunt resistor of 20kW to measure the leakage currents (measure the voltage drop from the current built across the resistance) and a digital storage oscilloscope.

![Leakage current measurement setup](image)

Figure 4. Leakage current measurement setup

3. Results
The feasibility of the ZnOSA FEA model has been successfully validated by having a good agreement between measurement and simulation as shown in Figure 5. Parametric assessments were performed on the effect of different design modifications related of the ZnOSA. The parameters that have been changed are ZnO width, glassfibre, thickness of silicone rubber and dielectric constant of the insulation layer.
3.1. Effect of ZnO width

The width of ZnO block was altered to study the influence on leakage current where initial value of ZnO width is 47mm and was reformed to 35mm, 40mm, 50mm and 55mm. Referring to Figure 6, the leakage current is decreases when the width of ZnO block increases which is due to larger ZnO radius yields larger cross sectional area. Its contains of ZnO grains that perform as electronic switch.

![Figure 6. Leakage current for different ZnO width](image)

3.2. Effect of glassfibre width

The current stress can be controlled by adding axial position of glassfibre outside the ZnO blocks. It also lessen possible sagging towards the wall of the silicone housing. Therefore, the glassfibre width was assessed with 5mm, 7mm, 10mm (initial size), 12mm and 15mm. There is a big decline on the leakage current with increasing width of the glassfibre as in Figure 7. This is because there is more size for ZnO heat to disperse into the glassfibre width and thus decreases the leakage current value.

![Figure 5. Comparison on ZnOSA leakage current of FEA model and measurement](image)
3.3. Effect of silicone housing thickness

Different thickness of silicone housing was simulated where initial thickness is 3mm and the thickness were changed to 1mm, 2mm, 5mm and 7mm. In Figure 8, it shows that there is a small difference in leakage currents. Yet, a small decrement is able to increase the lifetime of the ZnOSA and can decreases the electric field intensity of the ZnOSA housing [9].

![Figure 8. Leakage current for different silicone thickness](image)

3.4. Effect of the insulation layer relative permittivity

In this work, the influence of relative permittivity of silicone rubber and glassfibre on leakage current was examined since it is important in controlling the withstand capability of ZnO blocks due to surface flashover. Figure 9 displays the results for different relative permittivity value of glassfibre and silicone rubber. The initial relative permittivity value for glassfibre and silicone rubber were 4.2 and 11.7 respectively. The results obtained show that leakage current is influenced by the housing materials where when increasing the relative permittivity of insulation layers, the leakage current decreases.

![Figure 9. Leakage current for different glassfibre width](image)
4. Conclusions

In this work, an attempt is made to examine the condition of ZnOSA by means of leakage current measurement. The ZnOSA model is developed by using finite element analysis with actual dimensions. The FEA model showed an efficient accuracy compared to measurement. Hence, parametric study has been done to study the effect of leakage current under different size of design parameters. The results show that the most influenced parameter on the leakage current is zinc oxide. Therefore, the future study will related to dimension and grains structure of zinc oxide blocks. From this parametric assessment, it can assist engineers to consider the design of ZnOSA that affect the leakage current value.

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