The numerical analysis of partial discharge activities of silicone rubber composites

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Abstract. This paper discussed on the partial discharge phenomenon occurs in insulating materials-based silicone rubber. In general, the partial discharges occur due to the presence of additional substances or void in the material. The methods that are used to study partial discharge are offline monitoring, online monitoring, and numerical analysis. The numerical analysis was performed on this silicone rubber compound with the introduction of three identical void with the radius of 1.15 mm. The simulation results show that the pure silicone rubber material experiences the high impact of partial discharge activities compared to the second material; microvaristor filled with silicone rubber.

1. Introduction
Silicone rubber is form of polymer consist of oxygen, hydrogen, carbon, and silicon are commonly used as insulating material electrical power system due to its excellent performance such as has high hydrophobic properties and high chemical resistance to water, oil, and types of solvent. It has a stable element and non-flammable compound which allow it to withstand under high temperature for a long period. However, silicone rubber also has a poor tear strength and to overcome this problem, other ingredients or element can be added such as titanium dioxide to improve the strength of the compound [1][2].

Because these advantages, it is mainly used in the insulating devices compared to glass or ceramic material. However, silicone rubber still experiences an insulation failure in the material. Studies have reported many types of factors that could lead to insulation failure, as an example the location where the defects occur, a variation of the voltage and temperature, the moisture contents in the system, level of the aging and degeneration of the insulation system [3]. Partial discharge activities are one of the major issues that affect the long-term performance of silicone rubber due to the presence of impurities which allow unstable temperature profile, ageing and leading to the flashover. [3].

Partial discharge study is a diagnostic analysis to understand the quality of material particularly in insulation system during the manufacturing or service stage [1]. Partial discharge can be measured via online, offline, and numerical analysis. The online monitoring system is run under live recording of partial discharge activities which directly give the information of vulnerable areas that leading to catastrophic failure [3] for example, the assessment of medium voltage power cable. In this system, an efficient monitoring system was developed by focusing on three aspects, the usage of Rogowski coil (RC) for the sensor detection, Alterra board for the processing unit and an integrated GUI partial discharge monitoring system for the underground cable using LabView. [2].
On contrary, the offline monitoring system has no connection to the equipment set up, thus the variable voltages can be applied to measure the different electrical stresses levels. Therefore, the analysis of fault can be done safely without any harm to the equipment and personnel. Numerical analysis is a computation method that involving several simulation stages such as design, analysing, and implementation of specific algorithm which has been used in engineering, medicine, business and etc [3]. There are two general numerical analyses in high voltage system; Boundary Element Method (BEM) and Finite Element Method (FEM). The BEM analysis requires the located boundaries of the domain with two different approaches by having a closed boundary for the physical variables, considering on one side of the surface exterior or interior while the second option is open surface [4]. In this research, the FEM will be applied as it shows several advantages with vast of design flexibility, higher accuracy, visualization friendly compared to the latter techniques.

The phenomenon of partial discharges on silicone rubber is analysed via COMSOL Multiphysics software. The characteristics of pure silicone rubber during partial discharges will assessed before it will be compared with silicone rubber added microvaristor. The introduction of microvaristor is to control the occurrence of partial discharge due to its non-linear properties V-I characteristics. Microvaristor consist of small particles of electro ceramic with a highly nonlinear and it has the property of controlling voltage in electrical transport properties. For each one microvaristor a particle is shown to have an I-V characteristic close to a quantity of ceramics. The only difference is the scaling down of the switching voltage. The material of the formulation can be controlled to meet a certain specification. The particles and morphology and the sintering situations can change the characteristic of the switching voltage. Microvaristor can resist high current loading hence it has been used for issues electrical field control [3]. Figure 1 shows the electrical field conductivity of zinc microvaristor material. As it reaches 10kV/cm, the material acts as conductor with high current flow in the material drastically. The experimental work has been done by thinly coated a layer of microvaristor on a composite insulator modelled and the result of the electric field distribution on the surface of the insulator are promising [4].

![Figure 1. The electrical field conductivity of the zinc oxide microvaristors.](image)

2. Methodology

The partial differential equation (PDE) via finite element method will be resolved the distribution of the electric field in an insulation model [5]. Before partial discharge occurs, an ionization process is initiated from a voltage magnitude that rises to an equal value or higher than the inception voltage. In starting the electron avalanche, a free moving electron is needed [6].

The 2D model is drawn as shown in Figure 2 that involved two cylindrical electrodes, a rectangle representing the silicone rubber and a circle representing the cavity void of the model. The cylindrical electrode has a width of 30 mm and a height of 13 mm. The cylindrical electrode is using an aluminum
material. The insulating material is represented by rectangle shape has a width of 50 mm and height of 5 mm meanwhile the cavity or void has radius of 1.15 mm filled with air.

![Model illustration](image)

**Figure 2.** Model illustration.

The material properties are applied based on Table 1.

| Components                | Relative permittivity $\varepsilon_r$ | Conductivity $\sigma$ ($\Omega^{-1} \cdot m^{-1}$) |
|---------------------------|---------------------------------------|---------------------------------------------------|
| Aluminium electrode       | 1.00                                  | $3.774 \times 10^7$                                |
| Silicone rubber           | 2.50                                  | $1.210 \times 10^{-5}$                             |
| Microvaristor compound    | 56                                    | $\sigma(E) = \sigma_0 \exp(\alpha E)$            |

Meanwhile, the mathematical model representing the cavity inception field is referred [7]:

$$E_{inc} = (E/p)_{cr} p \left(1 + \frac{B}{(pl)^{n}}\right).$$

The mathematical model above is $(E/p)_{cr}$, B and n are gas parameters. For air the values assigned are $24.2 \text{ V Pa}^{-1} \cdot \text{m}^{-1}$, $8.6 \text{ Pa}^{0.5} \text{ m}^{0.5}$ and 0.5 accordingly. The pressure of the air is a constant denoted as $p$. The mathematical model determines the electric potential applied on each of the cavity. The properties of microvaristor are assigned as $E = 6.5 \text{ kV/cm}$, $\sigma_0 = 1 \times 10^{-7}$ and $\alpha = 2.4 \times 10^{-6}$. 
Three voids are introduced as shown in Figure 3 with the cut line defined for measurement taken for the electric potential and electric field analysis.

3. Result and Discussion

The observation is done when the partial discharges occur at three voids at the starting distance of 13 mm with applied voltage of 11 kV. Figure 4 shows the potential voltage is stepped to increase nearly 1 kV compared to pure silicone rubber when the microvaristor acts as conductor. Due to this condition, the partial discharge occurrence is delayed
Figure 5 shows the electric field for both materials, the high electrical field on the silicone rubber with microvaristor due it becomes conductive and homogenizes the electric fields of the series connection. This leads to the occurrence partial discharge is reduced.

4. Conclusion

The findings in this project are observing two situations of potential voltage and electrical field studies. Both results are encouraging as the microvaristor successfully minimised the potential of partial discharge to occur, hence it will provide the protection to the insulating material under high voltage operation. Therefore, it benefits the power provider to select the suitable material for their high voltage equipment for better reliability and durability.

5. References

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