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Partial Discharge Measurement Using Transient Earth Voltage Sensors with Different Dimensions in Metal Shrouded Equipment

Dedi Tri Laksono[a], Deni Tri Laksono[b], Monika Faswia Fahmi[b], Umar Khayam[c], Firman Maolana[d]

[a]*Politeknik Negeri Padang, Padang, Indonesia*
[b]*Universitas Trunojoyo Madura, Bangkalan, Indonesia*
[c]*Bandung Institute of Technology, Bandung, Indonesia*
[d]*Department of Mechatronics Engineering, University of Trunojoyo Madura, Bangkalan, Indonesia*

ABSTRACT

Partial discharge (PD) generally occurs in electrical equipment that is encased in metal. The metal box is a form of high voltage equipment such as Gas Insulated Switchgear (GIS), power switchgear. Indications of high-voltage electrical insulation failure can be detected by the appearance of partial discharge. One of the sensors to detect partial discharge is the Transient Earth Voltage (TEV) sensor. This study is to find the difference in detecting partial discharges in 3x3 cm handmade TEV sensors and 4x4 cm handmade TEV. The TEV sensor is positioned at the midpoint of the bushing area. A bushing is an area on high-voltage equipment where there is a small gap. The TEV sensor was placed at a distance of 15 cm, 30 cm, and 45 cm from the bushing. Some partial discharge measurements are in the form of partial discharge waveforms, partial discharge Inception Voltage, and phase patterns. Then the calculation is carried out on the frequency range of the TEV sensor. The source of partial discharge in the air insulation medium is a needle plate electrode. Based on the measurement results, both handmade TEV sensors can detect partial discharge in the ultrawide band frequency range. The result is that the 4x4 cm TEV sensor is better than the 3x3 cm TEV. This can be seen from the acquisition of PDIV, partial discharge waves, or capacitance values. Although the range of values is not large.

Keywords: Gas insulated switch gear, Metal shrouded equipment, Partial discharge,TEV sensor.

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1. INTRODUCTION

High voltage electrical equipment has a variety of problems. Ranging from manufacturing defects, insulation problems, or incompatibility with the voltage/power level used. Testing transformers or other electrical equipment is necessary to ensure equipment reliability and equipment life. [Partial Discharge (PD) can occur in gas, liquid, or insulation systems, due to imperfections or defects of an insulation material, such as voids in solid insulation materials, substances/particles trapped in insulation materials or damaged contact surfaces between conductors and insulation materials. [3].

These problems can interfere with insulation on system reliability so that supervision of the quality of electrical equipment insulation is needed. Taking measurements is one way to determine the quality of an insulation system item. [2]

Partial discharge produces electrical energy, electromagnetic waves, acoustic, optical, and heat. Partial discharge measurements can be made by detecting and measuring the presence of energy from the PD. The presence of partial discharge is a sign of insulation damage. PD detection is important so that engineers can check the condition and diagnose problems with the insulation. [6]

Previous research has been developed by Hikmah. In previous research, the frequency range of the TEV sensor was not measured. Another study by Lee Wai Meng found the results of the frequency range of 1 - 70 Mhz. The TEV HVPD as one of the TEV manufacturers, has a frequency range between 1 - 100 MHz. Another TEV manufacturer, TEV China has a frequency range of 1 - 120 MHz. In this study, it will be equipped with frequency range specifications. [7]

In addition, several other studies on detecting partial discharges with TEV sensors have been conducted. Previous researcher Yuuki Fujii, conducted research on the sensitive level of TEV sensors in noise conditions. The sensors used are two in number and are circular with a diameter of 4 cm. Wenbo Fan, conducted PD detection research using TEV sensors with 4 kinds of PD sources. This research was conducted in voltage levels of 3kV, 4kV, and 5kV. [Tao Han conducted PD research with TEV sensors under the same voltage, namely 10kV. With 3 types of partial discharge sources (corona, surface, internal). [9] Hikmah Prasetia, PD research using TEV sensors with varying voltage levels and 3 types of PD sources. [7]

* *Corresponding author.*
E-mail address: deditrilaksono@pnp.ac.id

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The difference discussed is the use of partial discharge sources in the form of corona with voltage levels of 6kV, 7kV, and 8kV. In addition, the frequency range of the TEV sensor was also measured.

II. MATERIALS AND METHODS

2.1 TEV Principle

When PD occurs, it produces several forms, such as heat, sound, light and chemical reactions [5]. When it occurs inside metal-encased equipment, high-frequency electromagnetic waves travel and spread far from the point of location of the PD source [6]. Then it spreads on the surface of the inner metal wall and generates surface currents. The current from the wave flows on the metal plane that has impedance and generates a voltage.

The occurrence of currents in high frequency makes the skin effect on the metal wall. Therefore, the transient voltage on the inside of the metal wall cannot be directly detected by the TEV sensor outside the equipment. The existence of gaps / holes in the equipment, such as bushings, gaskets, insulators, spacers, air vents, and flanges has a positive effect on the flow of transient voltages. [7]. solid

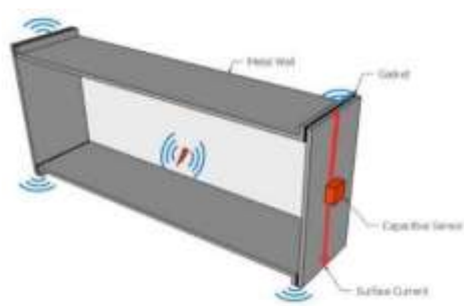

Figure 1. Transient earth voltage on a metal shrouded box [4]

2.2 TEV Sensor Design

In this research, the TEV sensor made is the same shape, which is square. To make a TEV sensor, we start by calculating the capacitance of the TEV sensor. Further calculations regarding sensor capacitance will be discussed below.

$$C = \varepsilon_0 \frac{A}{d} \qquad (1)$$

Where is it:
C = capacitor capacity
ε_0= air permittivity
A = cross-sectional area of each chip (m^2)
d = distance between pieces

Sensor TEV 3x3 cm:

$C = \varepsilon_0 \frac{A}{d}$
= $8,85.10^{-12}.0,2509\ m^2/1$ mm
= 2,220nF = 2.220pF

Sensor TEV 4x4 cm:
$C = \varepsilon_0 \frac{A}{d}$
= $8,85.10^{-12}.\ 0,2516m^2/1$ mm
= $8,85.10^{-12}.\ 0,2516m^2/1.10^{-3}$
= 2,226nF = 2.226 pF

(a) (b)

Figure 2. TEV Sensor; (a) TEV *Handmade* 3x3 cm, (b) TEV *Handmade* 4x4 cm

Table 1. Calculation of Capacitance Value

TEV Sensor	Capacitance Value
2x2 cm	2.216 pF
3x3 cm	2.220 pF
4x4 cm	2.226 pF
5x5 cm	2.234 pF
6x6 cm	2.244 pF
7x7 cm	2.252 pF
8x8 cm	2.273 pF
9x9 cm	2.284 pF
10x10 cm	2.301 pF

Based on the average size of the manufacturer's TEV sensor, which is China's TEV measuring 65mm x 58mm, and HVPD's TEV measuring 64mm x 60mm. If you look at the size of the manufacturer's TEV, it can be concluded that the sensor size is >60mm. The size of 3x3 cm and 4x4 cm was chosen for the TEV sensor plate size.

2.3 Experiment Method

Figure 3 below shows the partial discharge test set-up. The test high voltage comes from a 200V/100kV transformer supplied from a 220 V power supply. After that the transformer is installed with a 6.1k resistor. The transient voltage resulting from electromagnetic waves from the PD is detected by TEV sensors placed outside the surface of the metal box at a distance of 15 cm, 30 cm, 45 cm from the bushing. The partial discharge signal data will be displayed in the form of Vpp partial discharge waveform and phase pattern (φ, Vpp, n). Partial discharge measurements were performed at voltage levels of 6 kV and 7 kV, and 8 kV.

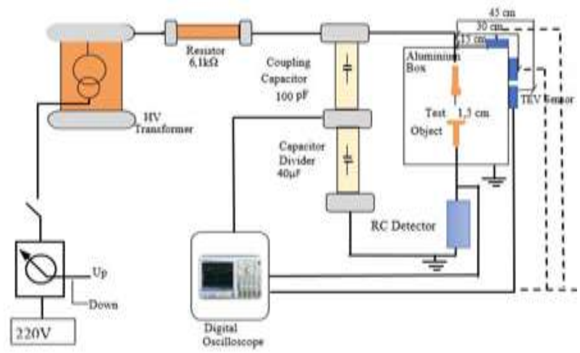

Figure 3. Experiment Circuit

III. RESULT AND DISCUSSION

Measurements in three experiments, namely measurements with TEV sensors with a distance of 15 cm from the bushing, a distance of 30 cm, and 45 cm from the bushing. Each distance measurement is given a voltage variation of 6kV, 7kV, 8kV. The measurements taken are:

1. PDIV (Partial Discharge Inception Voltage)
2. PD waveform
3. Vpp (Vpeak-peak)
4. Phase pattern and number of PDs.

3.1 Partial Discharge Inception Voltage (PDIV)

Figure 5. shows the PDIV waveform detected by the TEV HM 4x4 cm sensor placed 15 cm away from the bushing.

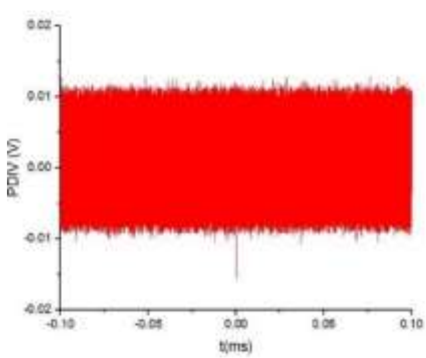

Figure 4. PDIV Sensor TEV HM 4x4 cm

Table 2. PDIV of each sensor at a distance of 15 cm

Sensor	Vpp(mV)	PDIV (kV)
TEV *hm* 3x3 cm	23,4	4,49
TEV *hm* 4x4 cm	26,4	4,24

The table above shows that the 4x4 cm handmade TEV has the largest value or can be said to have the highest level of sensitivity compared to other sensors.

Table 3. PDIV of each sensor at a distance of 30 cm

Sensor	Vpp (mV)	PDIV (kV)
TEV 3x3	21,56	4,51
TEV 4x4	23,24	4,51

Table 4. PDIV of each sensor at a distance of 45 cm

Sensor		Vpp (mV)	PDIV (kV)
TEV 3x3		35,84	3,96
TEV 4x4		34,72	4,02

In the measurement of the sensor distance of 30 cm from the bushing, it was found that the RC detector detected the first time the PD occurred at a voltage of 3.97kV. Even so, the largest Vpp value is on the 4x4 cm HM Sensor of 23.24 mV. In measuring the sensor distance of 45 cm from the bushing, it is found that the RC detector detects the first time the PD occurs at a voltage of 3.97kV. Even so, the largest Vpp value is on the 4x4 cm HM Sensor of 23.24 mV.

3.2 Partial Discharge Waveform

There are two waveforms, negative PD and positive PD. Negative PD occurs in negative cycles and positive PD occurs in positive cycles. PD waveforms are taken at voltages above the negative PDIV and positive PDIV voltage values. In this study, waveform data collection was carried out at sensor points at a distance of 15 cm, 30 cm, 45 cm with voltages at the level of 6 kV, 7 kV, and 8 kV.

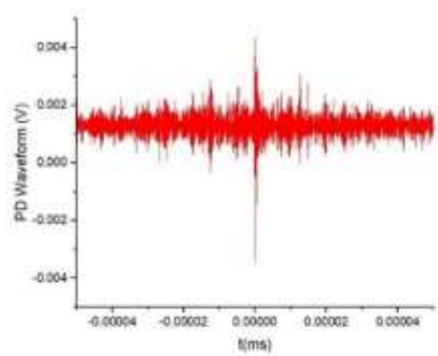

Figure 5. PD Waveform – TEV HM 4x4 cm

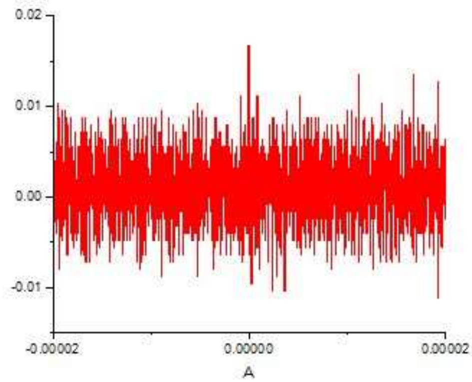

Figure 6. PD Waveform + TEV HM 4x4 cm

Table 5. Vpp PD measurement of sensor distance 15 cm

Sensor	6 kV	7 kV	8 kV
TEV *HM* 3x3 cm	27,24	27,96	30,4
TEV *HM* 4x4 cm	29,08	32,04	35,88

Data for each sensor was taken 40 times. Based on the table above, TEV HM 4x4 cm obtained the highest result of Vpp per level.

Table 6. Vpp PD measurement of sensor distance 30 cm

Sensor	6 kV	7 kV	8 kV
TEV HM 3x3 cm	25,68	26,84	29,40
TEV HM 4x4 cm	27,68	32,40	33,84

Data for each sensor was taken 40 times. Based on the table above, TEV HM 4x4 cm obtained the highest result of Vpp per level.

Table 7. Vpp PD measurement of sensor distance 45 cm

Sensor	6 kV	7 kV	8 kV
TEV HM 3x3 cm	26,64	26,72	26,92
TEV HM 4x4 cm	29,64	29,84	32,72

data for each sensor is taken 40 times. Based on the table above, TEV HM 4x4 obtained the highest result of Vpp PD phase pattern. The phase pattern of partial discharge (Vpp,n) in air (corona discharge) was measured at sensor distances of 15cm, 30cm, 45cm and at voltage levels of 6 kV, 7 kV, and 8 kV. The phase pattern measurement of the TEV HM 4x4cm PD at a distance of 15 cm at a voltage level of 6 kV is shown in Figure 7.

The results above are the form of data that has been plotted into Origin pro. For the number of PDs at a distance of 15 cm, it is shown in Figure 8.

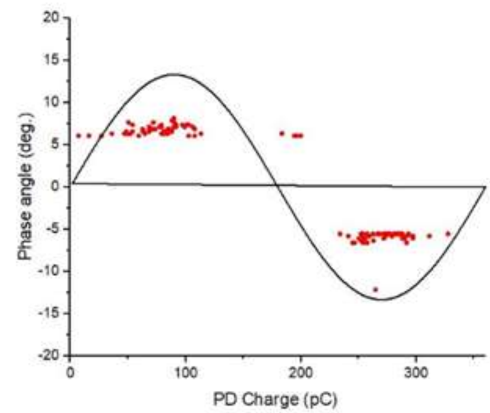

Figure 7. 4x4 cm TEV HM PD phase pattern

Table 8. Number of PDs at a sensor distance of 15 cm

Sensor	6 kV	7 kV	8 kV
TEV 3x3 cm	92	102	111
TEV 4x4 cm	96	100	152

The table above is a representation of the measurement results of the previous PD Pattern. Processed with the help of Ms. Excel, the results of TEV HM 4x4 cm at 6 kV voltage level were 96 pieces and 8 kV level was 152 pieces. For level 7 kV TEV HM 3x3 cm is the highest with 102 pieces.

3.2 Comparison of the amount of partial discharge detected by the sensor

Based on the sensitivity level of the sensor, when viewed from the number of PDs detected, the average of each sensor has a similar pattern of measurement result values. However, TEV HM 4x4 cm is more sensitive than TEV HM 3x3 cm.

Figure 8. Graph of the number of PDs at 6kV level

Based on the graph data above, the placement of the sensor when measuring plays an important role in the measurement results. The further away the sensor is from the bushing, the smaller the measured value.

Figure 9. Graph of the number of PDs at 7kV level

Figure 10. Graph of the number of PDs at 8kV level

The figure above shows the number of PD occurrences that can be detected on each sensor. The number of PD occurrences is compared with different sensor distances at voltage levels of 6 kV, 7 kV, 8 kV. The number of PDs detected on each sensor for sensor experiments with a distance of 15 cm from the bushing is more than the distance of 30 cm or 45 cm. This result is due to the influence of holes in the metal box, namely in the bushing area. This resulted in an increase in the sensitivity of the PD measurement by the TEV sensor, especially by the sensor located at the closest distance (15 cm).

The presence of gaps/holes (bushings) reduces the nature of the metal box as a resonance cavity. Therefore, the number of PDs that appear at a distance of 15 cm from the bushing is more than the number of PDs at a distance of 30 cm and 45 cm. This is due to the influence of the placement of the TEV sensor. If the further the TEV sensor is placed from the largest gap in the metal box, the less sensitive the TEV sensor is in detecting PD waves. Thus causing the small amount of PD read by the TEV sensor.

TEV sensors have difficulty detecting noise that can affect measurement results. When the amount of noise is less than the measured background noise, the noise is also detected. The sensitivity level of the TEV sensor is correlated with the area of the sensor plate. The wider the field of the sensor plate, the greater the charge storage. Here is the equation.

$Q = C.V$ (2)

For TEV HM 3x3 (2,220pF), has the amount of charge stored when measuring a distance of 15cm with a voltage of 23.40 mV. the amount of charge is 51.94 pC. As for TEV HM 4x4 cm (2,226pF) with a voltage of 26.40 mV. Then the total charge is 58.76pC. When compared to the charge value, the 4x4 cm TEV HM is better and more sensitive.

3.3 Measurement effects inside and outside the metal case

To know the attenuation of electromagnetic waves can be known based on the following equation:

$$I_t = I_0 e^{-\mu x} \qquad (3)$$

Calculation of electromagnetic wave attenuation on a metal box, if known μ (Al) = 0.293 mm-1, with aluminum material thickness x (Al) = 10 mm, then:

$$I_t = I_0 e^{-\mu x}$$
$$\frac{I_t}{I_0} = e^{-\mu x}$$
$$\frac{I_t}{I_0} = e^{-0.293x10}$$
$$\frac{I_t}{I_0} = 0{,}053397 = 5{,}34\ \%$$

This indicates that with an aluminum plate thickness of 10 mm, the electromagnetic wave that can be forwarded is only up to 5.34% only, so that the percentage of electromagnetic wave suppression is 94.26%, this is the reason why measurements outside the metal box have decreased partial discharge measurement results.

V. CONCLUSION

This research discusses the effect of the location of the TEV sensor on the metal box for partial discharge measurements. The following can be concluded from the research results:

The difference in the location of the TEV sensor position to the bushing gap / hole, affects the detection of the PD signal. The peak voltage (Vpp) tends to decrease along with the distance away from the position of the TEV sensor from the bushing. The metal box acts as a resonant cavity, reducing the sensitivity of the PD measurement by the TEV sensor. This results in the measured peak-peak voltage (Vpp) value decreasing when away from the metal box gap / hole.

Measurements of each sensor obtained results which based on the overall results, the majority of the 4x4 cm Homemade TEV sensors have better values than the 3x3 cm homemade TEV.

TEV with a wider sensor field area (4x4 cm) has a greater level of sensitivity to PD signals compared to the size of 3x3 cm. This is because TEVs that have a wider sensor cross-sectional area, which makes TEV sensors have the ability to store more electric charge capacity than smaller ones.

In general, the PD frequency occurs when the frequency is below 150 MHz. Increasing the voltage level from 6 kV, 7 kV, 8 kV or the position of the TEV sensor does not have much effect. The frequency range of frequent PD occurrence is found between 1 MHz - 120 MHz.

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