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ONLINE PARTIAL DISCHARGE MEASUREMENT AS A PREDICTIVE MAINTENANCE TOOL OF MOTOR AND GENERATOR STATOR WINDINGS

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ABSTRACT

Partial discharge data collected from more than hundred-unit machines with rated voltages from 6.3 kV to 28 kV with air and gas hydrogen cooling systems machines. Analysis of partial discharge data was carried out for several machines that were failed in services or on machines where evidence of damages to the stator insulation were found due to partial discharge during a visual inspection or offline test results. This analysis suggests that the increasing trend of partial discharge within a certain period is a very important parameter to know that there is an insulation failure process that is happening to the motor and generator stator. It was found that the ϑ angle of increasing partial discharge values from 86° - 90° is a critical increase in partial discharges and needs to be followed up immediately. The ϑ angle of increasing trend is obtained from arctan (Y/X) where X is the time of increasing trend usually in month period and Y is partial discharge's value that increased in the X period in mV. It was also found that each failure mechanism that occurring have different pulse distribution characteristics.

KEYWORDS Partial discharge, trend, coil, bar, stator, motor, generator

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INTRODUCTION

Generators and motors are the main electrical equipment in electric power generation systems and industries. Any generator failures in a power company will result in the interruption of electric energy production and reduce the revenue (Handoyo & Mulyandari, 2021). Statistically, the causes of generator failure can be divided into three, namely 50% by mechanical or vibration problems, 40% due to stator problems and 10% caused by problems with the rotor [1]. In terms of electrical problems, it can be said that the stator problem is the top contributor to generator failure. Stator failure, especially in high-voltage generators or motors, mainly stems from the problem of stator winding insulation. Problems with generator and high-voltage motors stator insulation are usually characterized by partial discharge activity on the stator insulation.

The partial discharge phenomenon is a symptom and at the same time a cause of deterioration in the strength of the stator insulation. To determine the quality of the stator insulation of generators and high-voltage motors, one of the methods commonly used is partial discharge measurement. Measurement of partial discharge can be done in two ways, namely offline, when the motor and generator are out of service and online, namely when the motor and generator are operating [2]**.** Online partial discharge measurement on motors and generators is a predictive maintenance tool for motors and generators, because the partial discharge data can be used as a warning if there is a problem within the stator and allows planning in terms of time and preparation of materials needed for maintenance whenever necessary.

RESEARCH METHOD

The definition of partial discharge according to the IEEE and IEC standards is an incomplete or partial electric discharge that occurs between insulations or between insulation and conductors or the ground. The cause of partial discharge is an excessive electric field pressure in an area of insulation, which exceeds the dielectric strength of the insulation in that area. Excess electric field stress in this isolation area usually occurs due to air pockets or voids and pollutants that have a lower dielectric constant than the main insulation in the area. Sensors used for partial discharge measurements on motors and generators vary, ranging from high frequency current transformers (HFCT), resistance temperature detector (RTD) sensors that have been installed on motors and generators to measure temperature, and those with coupling capacitors.

This study discusses partial discharge measurements using a 80 pF capacitor coupling sensor with high-frequency technology that have bandwidth 50 – 350 MHz, thus enabling online partial discharge measurements when the motor and generator are operating. Below is a line diagram of the sensor installation on the motor and generator shown in Figure 1.

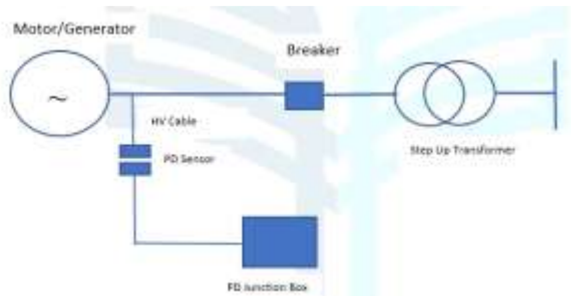

Figure 1. Line diagram of partial discharge sensors in motors and generators.

Researchers collected partial discharge data from 116 machines with a voltage level of 6.3 kV to 28 kV with an air cooling system and a hydrogen cooling system. The data is reviewed for feasibility, such as the appropriate range, the amount of noise that enters the measurement and the detected partial discharge pattern. Machines that have been visually inspected or repaired were selected because of high partial discharge or an anomaly from the average partial discharge of existing machines. Research was also conducted on the value of partial discharge, trend data and the correlation between the distribution of partial discharge pulses and the findings of current or existing stator isolation failures. The flow of this research is summarized in the flow chart in Figure 2 below.

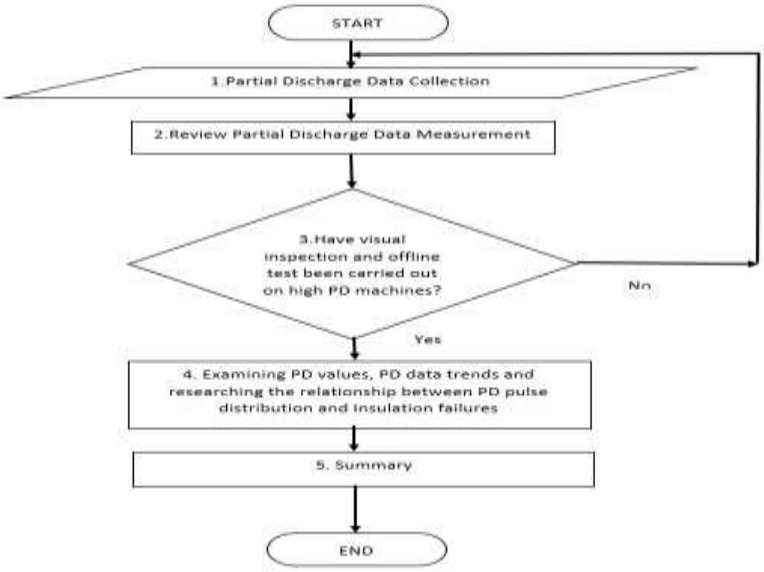

Figure 2. Research Flowchart

RESULT AND DISCUSSION

The following is a summary of the partial discharge data from the engine for the study given in table 1.

Because each partial discharge sensor is independent for each phase of the motor and generator, the actual data studied are 348 partial discharge data from 348 capacitor coupling sensors. The average partial discharge values based on voltage and cooling system categories are shown in table 2 and table 3 below.

This paper presents 3 out of 10 cases of partial discharge activity in the motor and generator. This analysis looks at the trend of partial discharges that occur, the distribution of partial discharge pulses or partial discharge patterns and their relationship to the results of visual inspection and or offline testing.

CASE STUDY

Case 1 – Contamination

Generator A (Machine A) has a voltage of 14 kV with a capacity of 90 MW and is air cooled, installed since 2003 and equipped with a partial discharge sensor for online measurements.

The trend of partial discharge generators has been stable for 8 years from the start of its operation in 2010 until 2018. However, phase B partial discharge began to rise in April 2019 and continues to increase as shown in the trend graph in Figure 4

The three phases exhibit partial discharge characteristics centered at 15°, 75°, 195° and 255° angles, which usually occurs due to the phase voltages at the ends of the stator winding (End winding) as shown in Figure 3 below. The highest measured partial discharge phase C values are Qm+ of 735 mV and Qm- of 711 mV, which is much greater than the average value of Qm in table 2 for the 13-16 kV engine category, which is 184 mV, or four times greater than the average value:

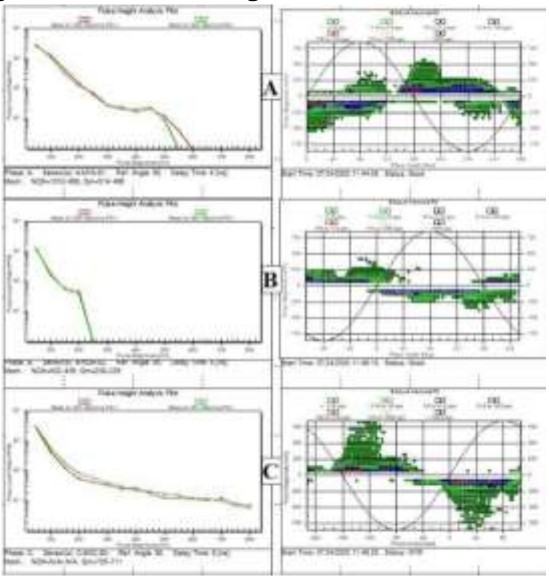

Figure 3. Distribution of Partial Discharge Pulses for phases A, B and C

Table 1. Machine for partial discharge research object

No	Rated Voltage	Cooling System	Number of Machines	Number of Sensors
1	6 kV	Air	33	99
2	10 – 12 kV	Air	42	126
3	13 - 16 kV	Air	13	39
4	10 – 11 kV	Hydrogen	8	24
5	20 – 23 kV	Hydrogen	20	60

Table 2. Average Qm value of air cooled engine

Rated Voltage	Number of Data (sensor)	Average Qm (mV)	Observation
6.3 – 6.6 kV	99	168	83% of machines have a Qm value below the average and 17% above average

10 – 11.8 kV	126	182	79% of machines have a Qm value below the average and 21% above average
13 – 16 kV	39	184	59% of machines have a Qm value below the average and 41% above average

Table 3. Average Qm value of Hydrogen cooled engine

Rated Voltage	Number of Data (sensor)	Average Qm (mV)	Observation
10 – 16 kV	33	39	61% of machines have a Qm value below the average and 39 % above average
19 – 23 kV	60	32	67% of machines have a Qm value below the average and 33% above average

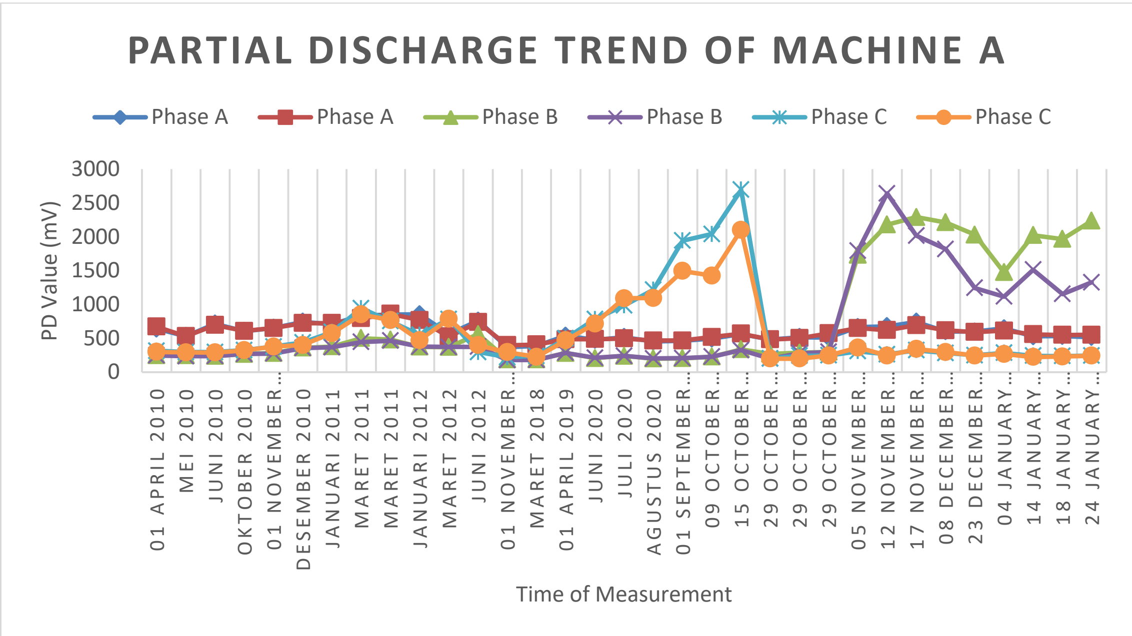

Figure 4. Graph of Partial Discharge Trend of Machine A

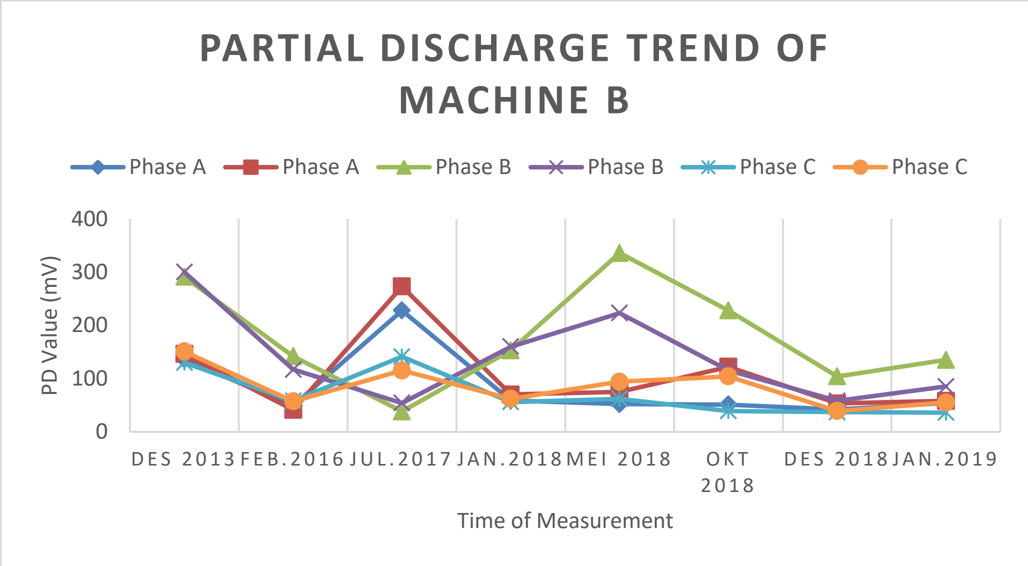

Figure 5. Partial Discharge Trend of Machine B

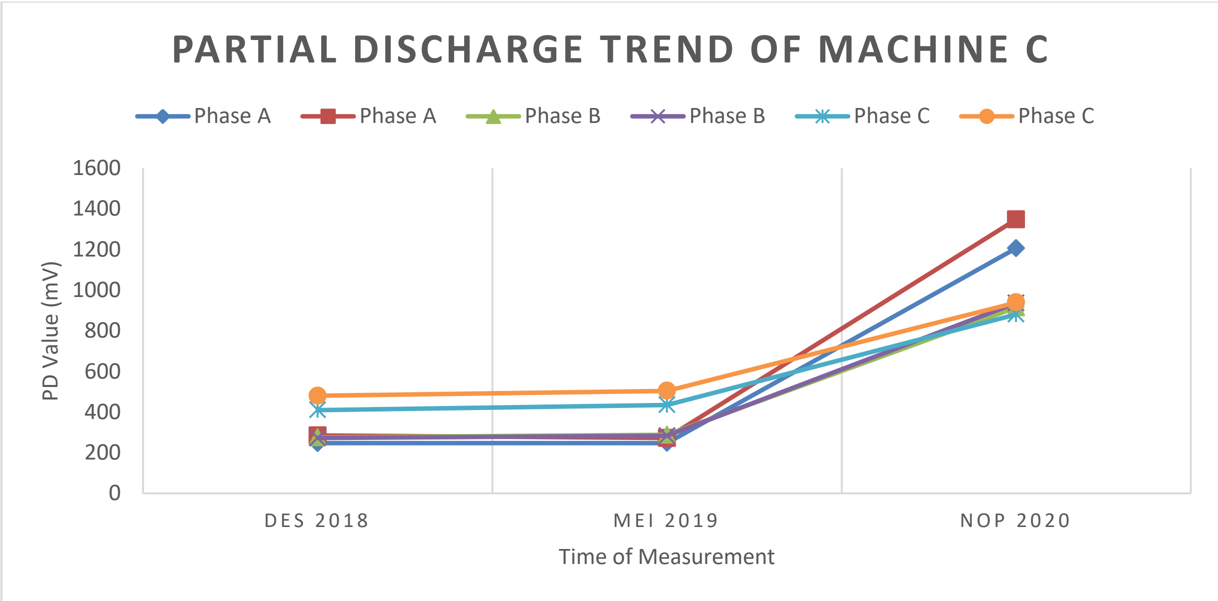

Figure 6. Partial discharge Trend of Machine C

For clarity, the distribution of pulses in phase C can be seen in the partial discharge pattern in Figure 7 with a lower range and a sinusoidal reference for phase C starting at an angle of 0°.

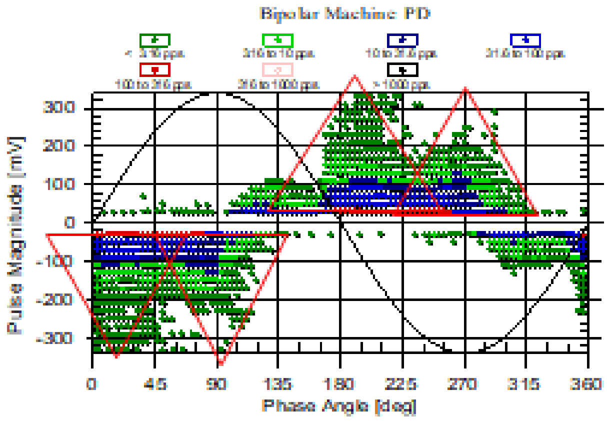

Figure 7. Distribution of Partial Discharge Pulses for phase C

The shape of the pulses centered at 15°, 75°, 195° and 255° angles is very similar to a partial discharge due to contamination problems [3].
The inspection results found oil contamination in the generator end winding section, especially in phase C, due to leakage. After cleaning, it is seen that the partial discharge pulse in phase C has decreased to its initial condition, but after the partial discharge in phase C can be overcome, a partial discharge in phase B appears again, which is similar to phase C.

Case 2 – Partial Discharge of Phases.

Generator B (Machine B) has a voltage of 11.5 kV and a capacity of 100 MW, is Hydrogen cooled and installed since 1993 and is equipped with a partial discharge sensor for online measurements.

The partial discharge measurement on Machine B shows an increase in partial discharge for phase B Qm+ from 153 mV at 41 psig hydrogen pressure in January 2018 to 228 mV at 42.64 psig hydrogen pressure as shown in the trend in Figure 6. This partial discharge value is almost six times the average value shown in table 3. The increase in the partial discharge value in May 2018 of 336 mV at a hydrogen pressure of 38.72 psig cannot be used as a reference, because the hydrogen pressure which decreased by around 3.92 psig resulted in increase of partial discharge activity.

The partial discharge pattern in Figure 8 shows the highest partial discharge activity in phase B and is centered at the angles of 15° and 195°, which is shifted 30° from the angles of 45° and 225°, thus indicating that the partial discharge occurs in the generator end winding area and occurs between phases. B and phase C, because phase C has the same partial discharge pattern as phase B but with reversed polarity [3].

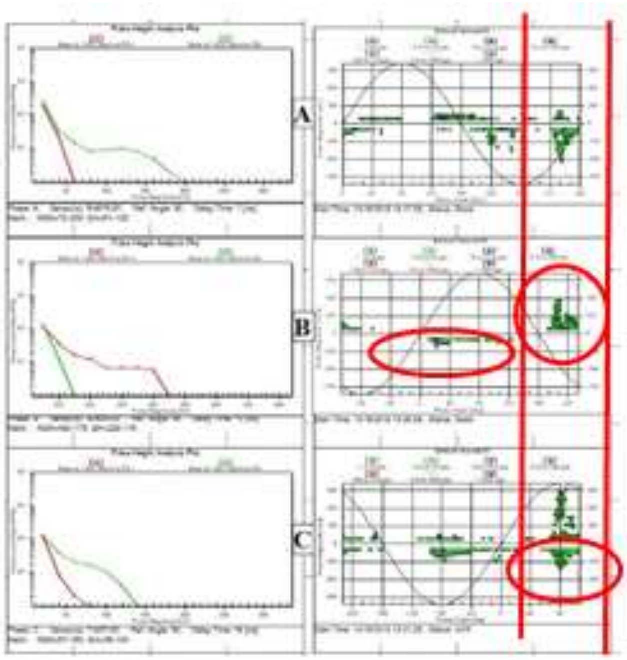

Figure 8. PD Pulse Distribution of Machine B

Visual inspection found evidence of partial discharge between phases B and C in the generator end winding area and in the generator winding connection area which was indeed detected in partial discharge at 0° and 180° angles.

Case 3 – Groundwall

Motor C (Machine C) has a voltage of 13 kV with a capacity of 8 MW, air cooled and installed in 1998.

On this motor, a very high partial discharge was measured in November 2020, which increased about five times from the previous measurement in May 2019, but for operational reasons the machine must continue to operate until it experiences a short circuit fault in phase A with a fault current measured in the relay during the disturbance as shown in table 4 below.

Table 4. Short circuit current in Motor Protection Relay

Phase	Fault Current (Amperes)
A	1120 *(shorted)*
B	230
C	225

The measurement results of the measured insulation resistance for phase A are only 1.5 kΩ, while phases B and C are measured above 1.5 GΩ. This can be said to be consistent with the partial discharge findings, namely that phase A was measured with the highest partial discharge level. The visual findings after the repair process was carried out in the workshop were also consistent with the partial discharge findings in the field, namely in phase A there was a hole in the insulation and melted copper as a result of a short circuit because there was already a weak point in the motor insulation.

The partial discharge pattern in Figure 9 also shows a correlation which is in accordance with the findings in the field, namely that the three phases exhibit very high partial discharge characteristics centered at 45° and 225° angles, which are usually caused by phase-ground voltages and that occur in the stator winding slot. The partial discharge pattern that occurs with an even distribution of positive and negative pulses is an indication of partial discharge in the stator main insulation or groundwall insulation [4].

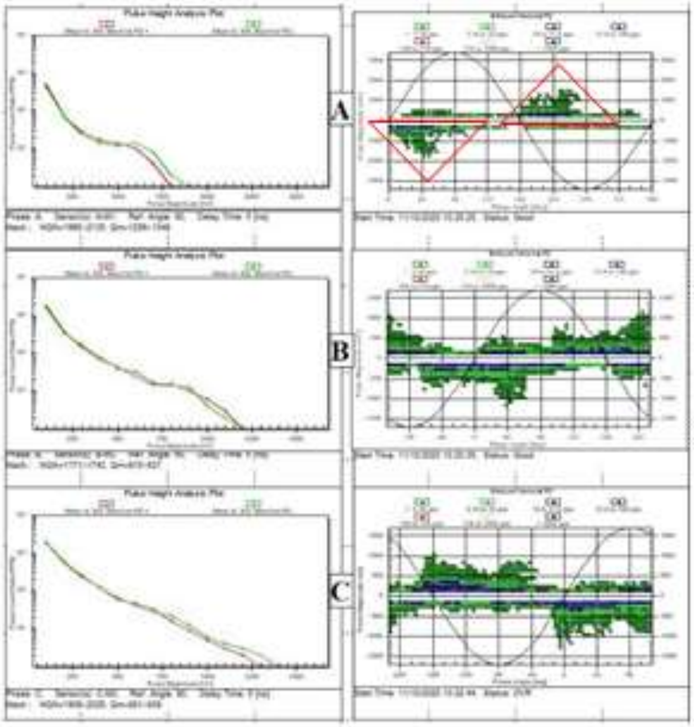

Figure 9. Partial Discharge Pattern of Machine C

From case studies and from other cases not discussed here, it appears that if there is a change in partial discharge that occurs, especially the trend of increasing partial discharge over a certain period of time, it is an indication of an ongoing process of insulation failure.

To observe the trend of increasing partial discharge, the following data is required:

- Initial value of partial discharge (Qm) before an increase
- The value of partial discharge (Qm) when the increase occurs
- The length of time for an increase from the initial value to an increase in partial discharge.

Since the period for increasing the value of partial discharge is different for each machine or case, it is difficult to make a guideline for the trend of increasing partial discharge, so the trend model for the increase in the value of partial discharge and the period of increase should be attempted using a trigonometric model as shown in Figure 10 below:

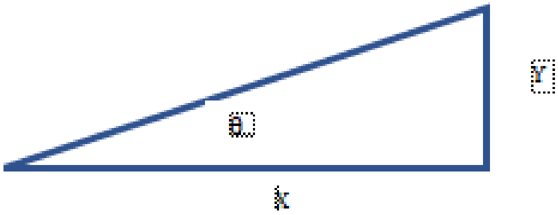

Figure 10. Trigonometric Model of Partial Discharge Rate of Increase
In which:
Y = The value of partial discharge Qm at the time the increase occurs minus the initial value of the partial discharge before the increase occurs.
X= The length of time for an increase from the initial value to an increase in partial discharge.
From the trigonometric formula

$$Tangent\ \theta = \sqrt{\frac{Y}{X}} \qquad (1.1)$$

$$\theta = tan^{-1}\frac{Y}{X} \qquad (1.2)$$

From formula 1.2 above, the angle (°) is obtained as the rate of increase in the partial discharge value.

Table 5 below is a summary of the rate of increase in partial discharge associated with partial discharge conditions based on the inspection results on the engine.

Table 5. Data Summary of Partial Discharge Rate Increase

No	Name of Machine	Initial PD value (mV)	PD value starts increasing (mV)	X- Time (Months)	Y	Tanθ	θ (°)	Generator Condition
1	Machine A Phase A (13,8 kV)	496	550	7	54	7.71	82.613957	No significant PD
2	Machine A Phase C (13.8 kV)	715	1090	1	375	375.00	89.85	Visual PD exists
3	Machine A Phase B (13.8 kV)	297	1729	1	1432	1432.00	89.96	Visual PD exists
4	Machine B Phase A (6.3	149	180	12	31	2.58	68.84	No significant

	kV)							PD
5	Machine B Phase B (6.3 kV)	234	423	12	189	15.75	86.37	PD Exists on the surface
6	Machine B Phase C (6.3 kV)	204	322	4	118	29.50	88.06	Machine Failed HIPOT Test on phase C
7	Machine C Phase A (11.8 kV)	53	58	13	5	0.38	21.04	No PD
8	Machine C Phase B (11.8 kV)	153	336	5	183	36.60	88.43	Visual PD exists
9	Machine C Phase C (11.8 kV)	39	55	13	16	1.23	50.91	No significant PD
10	Machine D Phase A (13.8 kV)	272	1348	16	1076	67.25	89.15	Machine operation failure (short circuit)
11	Machine D Phase B (13.8 kV)	272	937	16	665	41.56	88.62	Visual PD exists
12	Machine D Phase C (13.8 kV)	480	939	16	459	28.69	88.00	Visual PD exists
13	Machine E Phase A (13.8 kV)	188	300	5	112	22.40	87.44	Visual PD exists
14	Machine E Phase B (13.8 kV)	180	170	12	-10	-0.83	-39.81	No significant PD
15	Machine E Phase C (13.8 kV)	122	123	12	1	0.08	4.76	No significant PD

16	Machine F Phase C (13.8 kV)	400	1210	16	810	50.63	88.87	The operation failed and then the bar was replaced
17	Machine G Phase B (18 kV)	170	345	12	175	14.58	86.08	Visual PD exists
18	Machine H Phase B (13.8 kV)	80	325	1	245	245.00	89.77	PD exists due to contamina tion
16	Machine I Phase A (13.8 kV)	513	593	12	80	6.67	81.47	No significant PD
17	Machine I Phase B (13.8 kV)	429	456	12	27	2.25	66.04	No significant PD
18	Machine I Phase C (13.8 kV)	357	426	12	69	5.75	80.13	No significant PD
19	Machine G Phase A (13.8 kV)	74	80	12	6	0.50	26.57	No PD
20	Machine G Phase B (13.8 kV)	138	152	12	14	1.17	49.40	No PD
21	Machine G Phase C (13.8 kV)	180	135	12	-45	-3.75	-75.07	No PD
22	Machine H Phase A (6.3 kV)	175	167	12	-8	-0.67	-33.69	No PD
23	Machine H Phase B (6.3 kV)	165	179	12	14	1.17	49.398705	No PD
24	Machine H Phase C (6.3 kV)	56	53	12	-3	-0.25	-14.03624	No PD

CONCLUSION

Based on the results of this study, it can be concluded that:

1. A machine with a partial discharge value Qm above the average value and an increase in the rate of partial discharge with θ angle of increase between 86° - 90° means that the condition of the stator needs attention and an immediate visual inspection must be carried out.
2. A machine with a partial discharge value Qm above the average value and an increase in the rate of partial discharge with θ angle of increase between 80° - 85° means that the condition of the stator needs attention and more frequent partial discharge measurements must be carried out.
3. Machines with a partial discharge Qm value above the average value but the rate of increase in partial discharge with θ angle of increment < 80° only needs to be measured periodically for partial discharge.
4. The characteristics of the partial discharge pulses that occur due to contamination in the stator are triangular / gaussian and centered at angles of 15°, 75°, 195° and 255°
5. The characteristics of the partial discharge pulses that occur in the main isolation or internal discharge are triangular in shape and centered at an angle of 45° for partial discharges with negative polarity and 225° for partial discharges with positive polarity and no partial discharge polarity was dominant.
6. The characteristics of the partial discharge pulse due to the discharge slot are triangular in shape and centered at an angle of 0° for partial discharges with negative polarity and 180° or 225° for partial discharges with positive polarity with dominant positive partial discharge polarity.
7. The characteristics of the partial discharge pulses that occur in the grading coating area are triangular in shape and centered at an angle of 0° for partial discharges with negative polarity and 180° for discharges with positive polarity and no dominant polarity.
8. The characteristic of the partial discharge pulse that occurs due to the phase-to-phase partial discharge is triangular in shape and centered at the angles of 15° and 195° and is detected in the other phase with reversed polarity.

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