

Study of Partial Discharge Propagation Impact on Stator Dissipation Factor in High Voltage Turbine Generator

Ismayil Ismayilov
Azerbaijan State Oil and Industry
University
CBM Engineering LLC Examination
Baku, Azerbaijan
0009-0003-8470-1794

Abstract—High voltage rotating equipment, such as power generators, relies on robust stator insulation. Partial discharge and dissipation factor measurements are widely used for insulation diagnostics, yet their effectiveness in detecting early-stage deterioration remains a topic of debate. This study evaluates the correlation between partial discharges and dissipation factor in a turbine generator by analyzing field measurement data over two consecutive years (2023–2024). While dissipation factor values exhibited only a minor increase, partial discharges activity showed a significant rise, indicating substantial insulation degradation. The results highlight the limitations of dissipation factor as a sole diagnostic parameter and emphasize the necessity of integrating partial discharges assessments for a comprehensive evaluation of insulation health. Findings suggest that relying exclusively on dissipation factor may overlook critical defects, potentially leading to unexpected failures. This study reinforces the importance of combining partial discharges and dissipation factor measurements to enhance the accuracy of insulation condition monitoring in HV rotating machinery.

Keywords—High-voltage, partial discharge, PD calibration, dissipation factor, stator insulation, power generators, predictive maintenance, high frequency current transformers.

I. INTRODUCTION

High-voltage (HV) rotating equipment, such as power generators and motors, are critical components in industrial and power generation facilities. The reliability of these machines vastly depends on the condition of their stator insulation systems. The insulation degradation can lead to tragical failures, resulting in unplanned downtime and considerable financial losses. The insulation system of high voltage rotating machine is being affected during the operation to combined thermal, mechanical, electrical and environmental stresses which may alter dielectric properties [1]. The electrical stress can cause partial discharges (PD) in defects, which deteriorate insulating materials and can lead to electrical treeing, as the most important degradation in solid insulation [5].

PD and dissipation factor (DF) are broadly recognized as key indicatives of insulation health. The PD-measuring was established as one of the most important diagnostic techniques, and promises a very detailed assessment into the physical processes, which a premature ageing of the insulating materials [2]. The DF, also referred to as the loss tangent ($\tan \delta$), measures dielectric losses in insulation and provides data for assessment the overall efficiency of the insulation system.

Several authors have published that the DF and capacitance tip-up are functions of both the intensity and phase of discharge pulses [3]. Recent researches carried out in [1] has highlighted the relationship between thermal ageing

process of the insulation, PD, DF and Recovery Voltage measurements (RV). However, other research signified that the PD and DF testing methods could be used simultaneously reducing the time spent on measurements by 50% as stated in [4], despite that the PD measurement technique used in [4] has too many limitations and without adjustments cannot be recommended for use [4]. In practice, a lot of testing methods have been developed and applied for nondestructive diagnosis of high voltage rotating machines such as visual inspection, PD measurement, tip-up DF, insulation resistance and dielectric spectroscopy [5].

This study aims to identify and evaluate the impact of continuous PD propagation on changes in DF values by examining the interplay between PD and DF in a practical setting.

II. PROBLEM STATEMENT

Presently the measurement of the DF in rotating equipment is regulated by IEC 60034-27-3 which suggests the maximum values of tangent Delta and tip-up for motors and generators. The establishment of these values for DF was controversial. The most end-users took that the limits are easy to meet. However, machine manufacturers took the proposed limits as too strict, signifying that some well-made coils and bars would fail the test [8]. Moreover, due to continuous PD accumulation over the long period it is incorrect to assess the insulation condition via DF only, since the changes in insulation conditions can be unnoticeable for DF, while emerging PD pulses are progressing without proper understanding their types and nature. In light of this, it is vital to use the PD and DF measurements in parallel, to get more accurate and confident results for future corrective actions. This study focuses on analyzing both DF and PD measurement results over the two operating years of the same test object.

III. DESCRIPTION OF THE MEASUREMENT PRINCIPLES

A: Measurement Techniques for Partial Discharge in Rotating Equipment.

Partial discharge measurements can be conducted using online or offline methods:

1. **Online PD Measurement:** Online PD monitoring has been used as an effective way to assess the condition of the stator winding [6]. This method is used while the equipment is in operation and allows continuous monitoring without interruption of the operation [11]. During the nominal operation of the machine the PD pulses are being measured by High-Frequency Current Transformers (HFCTs) (Fig. 1) and Rogowski Coils (RC) that are connected to the oscilloscope-based PD

monitoring equipment. HFCT and RC are commonly used in this setup along with the coupling capacitors. Online measurements provide real-time data on PD activity with consideration of the mechanical and thermal stress machine experiencing during the operation, enabling early detection of insulation issues.

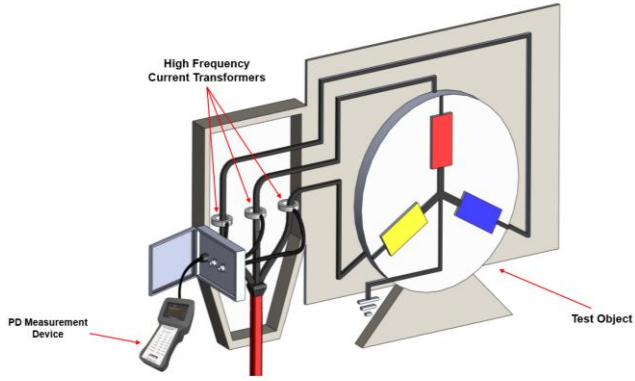


Fig. 1. Online PD measurement system with high frequency current transformers

2. Offline PD Measurement: This measurement technique is carried out under controlled conditions with the equipment de-energized. In this method, the test voltage is injected from the HV test source to the stator winding of the machine and at the same time emerged PD pulses are being measured by oscilloscope-based PD monitoring equipment using RC, HFCT or coupling capacitors. Moreover, this method necessitates to perform PD calibration prior to test voltage injection for accurate PD magnitude measurement in picocoulombs (pC) [9-10]. In this study, Omicron CPC 100 (control unit) + CP TD 1 (HV source and DF measuring tool) + CP CR 600 (compensating reactors) were used as HV test source (Fig. 2). Along with the mentioned equipment, HVPD Longshot was used as PD monitoring system in conjunction with HFCT sensors and PD calibrators (manufactured by Power Diagnostix Systems gmbh) CAL1A (1...100 pC) and CAL1E (0.5...50 nC). The calibration process involves injecting a known PD signal into the system and adjusting the equipment to match the specified reference values.

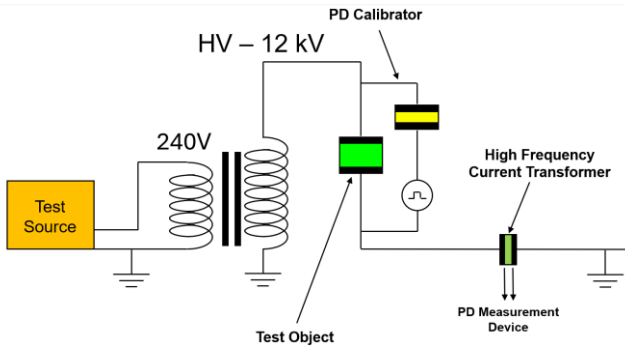


Fig. 2. Offline PD measurement system with high frequency current transformers

B: Dissipation Factor Measurement

The dielectric dissipation factor is a measure of the dielectric losses in the stator winding insulation. Measurement of DF stands for assessing the quality of new and aged stator winding insulation [7]. In this study, the Omicron CPC100 + CP TD1 + CP CR 600 test set was used for DF measuring on the test voltages up to 12 kV (Fig. 3). The testing procedure involves applying test voltage specified in IEC 60034-27-3 to the stator winding and measuring the dielectric losses in the insulation. The results assessment is also based on the requirements represented in IEC 60034-27-3.

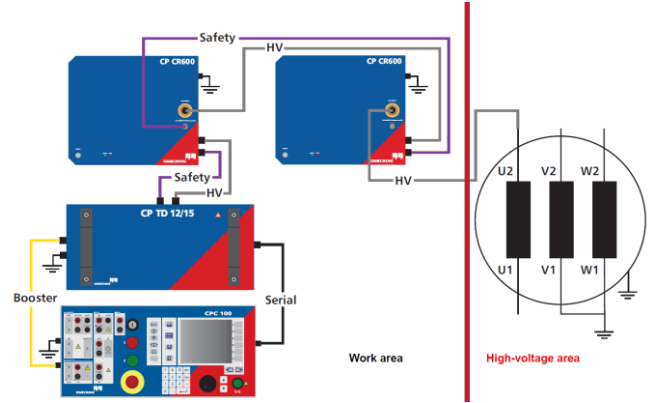


Fig. 3. Connection of the dissipation factor measurement system [12]

IV. MEASUREMENTS ON FIELD

Over the course of two years, annual tests were carried out (once a year) on the same turbine generator under similar ambient conditions (table 3). The turbine generator's nameplate data represented below (table 1):

TABLE I. GENERATOR NAMEPLATE INFORMATION

#	Generator Nameplate Data	
	Parameter	Value
1	Manufacturer	Siemens
2	Model	SGEN 5 – 100A – 4P
3	Rated Voltage L-L (V)	15000
4	Rated Current (A)	2117
5	Rated Power (MVA)	55
6	Rated Speed (rpm)	1500
7	Rated Power Factor	0.8
8	Rated Thermal Class	F

A: Dissipation Factor Testing on field

The first DF measurements were captured on October 2, 2023. Upon completion of the testing process and thorough analysis of the results obtained, the generator was restored back to normal operation. After one year of uninterrupted operation, the generator was retested on October 14, 2024. The test involved applying test voltages on industrial frequency incrementally to the stator winding and recording the corresponding DF values (table 2).

TABLE II. DISSIPATION FACTOR MEASUREMENT RESULTS FOR 2023 AND 2024

Dissipation Factor Measurements				
Test Date:	02 – October – 2023		14 – October – 2024	
Phase U: Capacitance – 332.901 nF				
Test Voltage L-G (kV) @ 50 Hz	Dissipation Factor (%)	Tip-up Dissipation Factor (%)	Dissipation Factor (%)	Tip-up Dissipation Factor (%)
1.73	1.5631	-	1.7743	-
3.46	1.6216	0.0586	1.8419	0.0676
5.20	1.6799	0.0583	1.9187	0.0768
6.93	1.7371	0.0572	2.0119	0.0933
8.66	1.7946	0.0574	2.1240	0.1121
6.93	1.7421	-0.0524	2.0156	-0.1084
5.20	1.6867	-0.0555	1.9211	-0.0945
3.46	1.6293	-0.0574	1.8433	-0.0778
1.73	1.5684	-0.0608	1.7760	-0.0673
Phase V: Capacitance – 332.986 nF				
Test Voltage L-G (kV) @ 50 Hz	Dissipation Factor (%)	Tip-up Dissipation Factor (%)	Dissipation Factor (%)	Tip-up Dissipation Factor (%)
1.73	1.5854	-	1.7596	-
3.46	1.6415	0.0561	1.8257	0.0661
5.20	1.6965	0.0550	1.8989	0.0732
6.93	1.7488	0.0523	1.9834	0.0845
8.66	1.8013	0.0525	2.0987	0.1153
6.93	1.7517	-0.0496	1.9984	-0.1003
5.20	1.6995	-0.0522	1.9054	-0.0930
3.46	1.6455	-0.0540	1.8303	-0.0751
1.73	1.5887	-0.0568	1.7649	-0.0654
Phase W: Capacitance – 334.161 nF				
Test Voltage L-G (kV) @ 50 Hz	Dissipation Factor (%)	Tip-up Dissipation Factor (%)	Dissipation Factor (%)	Tip-up Dissipation Factor (%)
1.73	1.5992	-	1.7596	-
3.46	1.6578	0.0586	1.8257	0.0661
5.20	1.7168	0.0590	1.8989	0.0732
6.93	1.7724	0.0556	1.9834	0.0845
8.66	1.8286	0.0543	2.0987	0.1153
6.93	1.7745	-0.0522	1.9984	-0.1003
5.20	1.7202	-0.0543	1.9054	-0.0930
3.46	1.6624	-0.0578	1.8303	-0.0751
1.73	1.6028	-0.0596	1.7649	-0.0654

TABLE III. TEST CONDITIONS FOR DISSIPATION FACTOR AND PARTIAL DISCHARGE MEASUREMENTS

Ambient Conditions		
Parameter	02 – October – 2023	14 – October – 2024
Ambient Temperature (C)	22	18
Relative Humidity (%)	69.12	60.81
Atmospheric Pressure (hPa)	1011.32 hPa	1017.48 hPa

It was observed that the DF increased proportionally with the applied voltage on both 2023 and 2024 test results. This behavior can be attributed to:

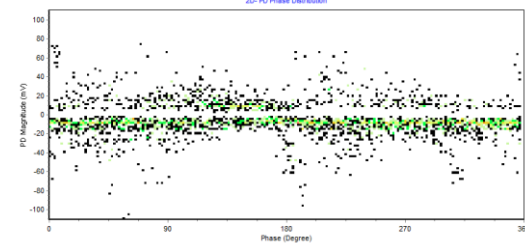
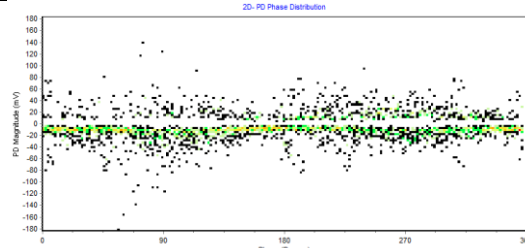
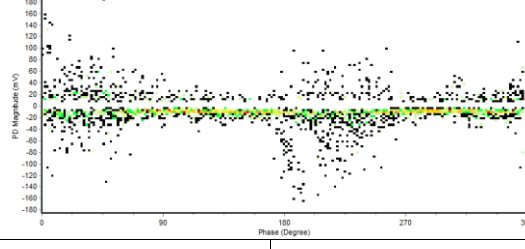
- Increased dielectric losses at higher electric field strengths.
- The initiation of PD within insulation voids or defects.

Comparison between 2023 and 2024 results demonstrate that the DF values obtained this year indicate a gradual deterioration in insulation, which is not critical if the fact that DF values are initially close to the IEC 60034-27-3 threshold (2%) and, in some cases, exceed them is neglected. Nevertheless, to acquire a more precise conclusion regarding the stator winding insulation condition, it is imperative to carry out the comparative analysis of PD measurements during the same period to obtain more information regarding the deterioration state of the insulation.

B: Offline Partial Discharge Measurements on field

Following the DF measurements, offline PD testing was conducted using the HVPD Longshot as PD monitoring system with HFCT sensors and the Omicron test equipment used for DF measurements as HV test source. The monitoring system was calibrated via the CAL1E calibrator on 0.5, 1, 2 and 5 nC. Once calibration was completed, a test voltage of 8.66 kV phase-to-ground was applied to the generator. The test results represented in Table 4:

TABLE IV. PARTIAL DISCHARGE MEASUREMENT RESULTS FOR 2023

Partial Discharge Measurements: 02 – October – 2023	
Phase	2D Partial Discharges Patterns
U	
	Peak PD activity 0.642 nC
V	
	Peak PD activity 0.766 nC
W	
	Peak PD activity 0.479 nC

The PD patterns captured in 2023 correspond to the PD signals caused by early staged surface discharges and slot end PD according to IEC 60034-27-1 "Rotating Electrical Machines - Part 27-1: Off-line partial discharge measurements on the winding insulation". The example of surface discharges and slot end discharges represented in the mentioned standard (Fig. 4-5).

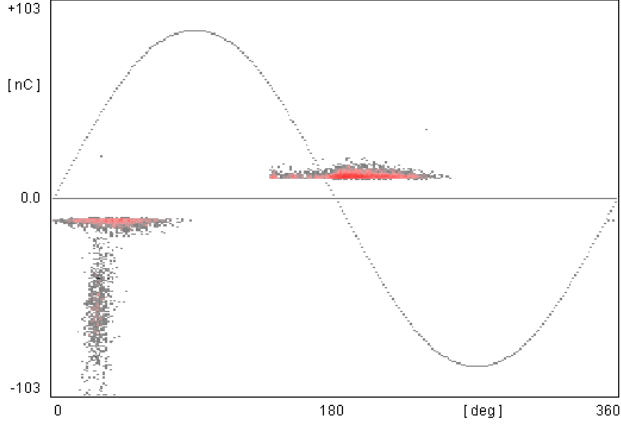


Fig. 4. Surface discharges pattern over the winding caused by contamination [10]

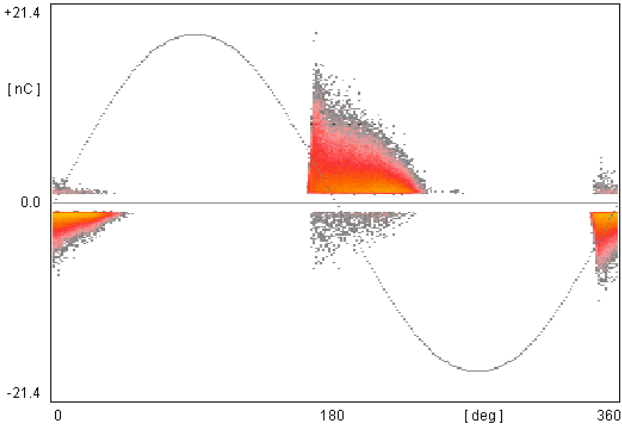
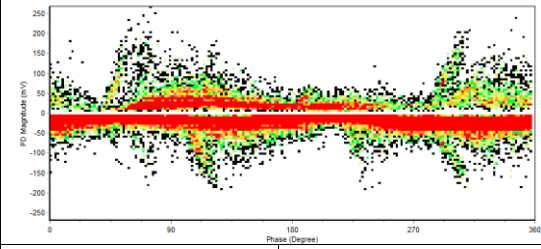
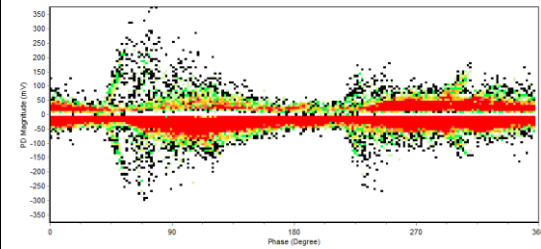
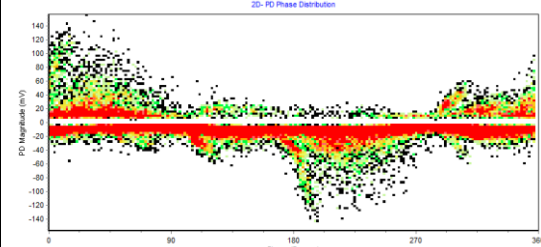


Fig. 5. Slot discharges pattern in the gap between the stator core and the side of the stator [10]

Although the discharges measured in 2023 have a clear correlation with the patterns of slot discharges and surface discharges, the peak PD amplitude represented in table 4 is not so critical and does not reflect the presence of strong discharges. For a more detailed comparison, the same tests were carried out, but already in 2024 under test conditions represented in table 3. These measurement results are presented in Table 5:

TABLE V. PARTIAL DISCHARGE MEASUREMENT RESULTS FOR 2024

Partial Discharge Measurements: 14 – October – 2024	
Phase	2D Partial Discharges Patterns
U	
	Peak PD activity 2.02 nC
V	
	Peak PD activity 2.82 nC
W	
	Peak PD activity 1.42 nC

A comparison of the values obtained in 2023 and 2024 indicates that the nature of the discharges has remained consistent. Nonetheless, the substantial changes in pattern density and the approximately 300% increase in discharge magnitude are significant and warrant careful consideration.

V. CONCLUSION

The results of partial discharge and dissipation factor measurements determined in 2023 and 2024 provide valuable outcomes into the reliability of DF and PD as an indicator of stator insulation condition. A comparison of PD values over the two years reveals a substantial increase of approximately 300% in 2024 compared to 2023. This indicates a significant deterioration of the insulation within the generator. Nevertheless, the DF measurements showed only a minor change, increasing from 1.8% in 2023 to 2% in 2024 – an increment of just approximate 0.2% (more detailed information represented in table 2). This marginal variation in DF does not correspond to the drastic increase observed in PD values. Such findings strongly suggest that DF measurement alone is not a reliable parameter for detecting significant changes in the insulation condition. While DF is commonly used as an indicator of insulation aging, its insensitivity to substantial variations in PD magnitude highlights its limitations in identifying early-stage insulation degradation.

These results emphasize the necessity of incorporating PD measurements alongside DF assessments for a more comprehensive evaluation of generator insulation health. Relying solely on DF may overlook critical insulation defects,

potentially leading to unexpected failures. Therefore, this study reinforces the importance of PD diagnostics as an essential tool for condition monitoring in electrical machines.

REFERENCES

- [1] M. Farahani, H. Borsi, and E. Gockenbach. "Experience with partial discharge, dissipation factor, and recovery voltage measurements for the evaluation of insulation systems of high voltage rotating machines". 2002 Annual Report Conference on Electrical Insulation and Dielectric Phenomena, IEEE 2002, pp 454-457.
- [2] M. Farahani, H. Borsi, E. Gockenbach, A. Bethge, M. Kaufhold and J. Jong, "Investigation on Characteristic Parameter to Determine the Actual Status of Insulation System for High Voltage Rotating Machines", The 9th International Electrical Insulation Conference, INSUCON 2002, Berlin.
- [3] S. Jiancheng, Y. Bo, X. Hengkun, "New estimating techniques for multi-stress ageing test of large generator stator winding insulation". ICPADM 2000, Session p. pp 951-956.
- [4] P. Mraz, P. Treyer, S. Gonzales, S. Azer. " Simultaneous Dissipation Factor and Partial Discharge Measurement on Rotating Machines – Limitations, Challenges, Solutions". International Conference on Condition Monitoring and Diagnosis, Jeju, South Korea, 2014, CMD 2014.
- [5] M. Farahani, H. Borsi, and E. Gockenbach, M. Kaufhold. "Partial Discharge and Dielectric Response Behaviour of Insulation Systems for High Voltage Rotating Machines under Electrical Stress". 2004 Annual Report Conference on Electrical Insulation and Dielectric Phenomena, IEEE 2004, pp 271-274.
- [6] Yuanlin Luo, Zhaohui Li, Hong Wang, "A Review of Online Partial Discharge Measurement of Large Generators", MDPI Energies, October 2017.
- [7] IEC 60034-27-3, "Rotating Electrical Machines - Part 27-3: Dielectric Dissipation Factor Measurement On Stator Winding Insulation Of Rotating Electrical Machines", 2015, Geneva, Switzerland.
- [8] H. Sedding, "Dissipation Factor Acceptance Criteria for Stator Winding Insulation", 19th Annual Iris Power Conference, June 2016, Scottsdale, Arizona.
- [9] IEC 60270: "High-voltage test techniques – Partial discharge measurements" 2015, Geneva, Switzerland.
- [10] IEC 60034-27-1, "Rotating Electrical Machines - Part 27-1: Off-line partial discharge measurements on the winding insulation", 2017, Geneva, Switzerland
- [11] IEC 60034-27-2, "Rotating Electrical Machines - Part 27-2: On-line partial discharge measurements on the stator winding insulation of rotating electrical machines", 2012, Geneva, Switzerland
- [12] OMICRON electronics GmbH "Omicron CP CR600 User Manual" 2019. Klaus, Austria.