Efficacy Study of a Pilot Installation of an On-Line Partial Discharge Measurement Sensor at KHP Unit 2 Generator

Thinley Dorji[1*], Deepen Sharma[2]

Centre of Excellence for Automation, Control & Protection, Hydropower Research & Development Centre, Druk Green Power Corporation,
E-mail: t.dorji3345@drukgreen.bt[1*] , d.sharma2099@drukgreen.bt[2]

Received: 14 April 2025; Revised: 9 June 2025; Acceptance: 10 July 2025; Published: 17 August 2025

Abstracts

Partial Discharge (PD) is a slow-progressing phenomenon in electrical equipment which deteriorates the insulation system over time. Monitoring the PD activities has become a vital method to prevent major failures of the electrical equipment (Yue et al., 2006). This paper presents a comprehensive study of the installation & efficacy of an on-line PD coupling capacitors on the unit 2 generator of the Kurichhu Hydropower Plant (KHP), which had been in operation since August 15, 2001, without any form of monitoring or measurement system to assess the insulation system of the stators. A comprehensive site assessment identified the necessity of three PD coupling capacitors (CCs) and associated accessories suitable for real-time monitoring of the generator stator, under electrical, thermal, ambient, and mechanical stresses. Following installation, a commissioning test was conducted, and initial PD measurements were recorded as baseline data. To evaluate the system's effectiveness, a trend analysis was performed on four sets of measurements taken from 2022 to 2024, also covering seasonal variations in 2024. Key parameters such as PD magnitude, NQS values, and level counts were analyzed along with Phase-Resolved Partial Discharge (PRPD) patterns to assess PD activity and severity. This study has done originally for the installed PD measurement system, which can be used for the similar study for the same measurement system on the generators. The results demonstrated that the online PD monitoring system effectively detected the integrity of the insulation system, with insulation resistance tests serving as a complementary validation method. The corresponding recommendations were made to KHP based on the findings.

Key Words: *Partial Discharge, Coupling Capacitors, PRPD, Online Monitoring, Generating Insulation*

1. INTRODUCTION

KHP has four units of hydropower generators commissioned since 2001 with a total installed capacity of 60 MW. Despite the two decades of its commissioning, there are no measuring systems installed on its units to monitor or assess the insulation system of the stator windings. Therefore, it was felt inevitable to have some sort of on-line measuring system to monitor the condition of the stator winding's insulation, given the age of the generators. In 2022, Centre of Excellence for Automation, Control & Protection (CoEACaP), Hydropower Research & Development Centre (HRDC), took the initiative to install the PD CC on unit 2 generator of KHP, as a pilot installation.

Right after the pilot installation, the commissioning test was also conducted, and the initial measurements were recorded as baseline data for future reference. Subsequently, the effectiveness study on this particular online measurement system was essential to further authenticate that the correct measurement is given by this particular system. In consequence, a trend analysis was conducted to validate the effectiveness of the measurement system. Four sets of measurements were taken for the trend analysis. Following the commissioning measurement in 2022, another measurement was done in 2023, and two sets of measurements were conducted in 2024, specifically pre-monsoon and peak-monsoon. The parameters such as PD magnitude, NQS value and level counts were considered to trend the results. The PRPD patterns captured during different times were also analyzed. The trend analysis indicated the online PD measurement system was found to be effective, revealing the type of PD activities and their severity. Additionally, the insulation resistance tests on the stator windings were also used as a complementary diagnostic test to further validate the stator insulation status. The corresponding recommendations based on this study were also provided to KHP.

2. PROBLEM DESCRIPTION

DGPC contributes most of the national revenue through the earnings from hydropower generation. The downtime of any hydropower plant can impact the country's economy. KHP's generators have been generating power since 2001 & despite their two decades of commissioning, no online monitoring system of the insulation condition of the generators has been installed. In response to this, the online PD monitoring system was installed on the unit 2 generator as a pilot installation for monitoring the condition of the stator's insulation system. Online PD measurement has been proven to be an effective tool in monitoring the condition of the insulation of the stator windings of large generators (Luo et al., 2017)

3. SITE ASSESSMENT

The comprehensive study on site assessment was conducted prior to initiation of the PD sensors installation, stressing the inevitable need of three numbers of PD CC, along with other mounting accessories, actually suitable for online PD measurement under actual operating stresses. Considering the suitability of KHP site & feasibility to install such a system, the availability of various standard sensor installation options were explored, amongst which the most suited option as per the site assessment was considered. The selected PD CCs were then installed as per the site assessment on the unit 2 generator.

***Fig. 1:** PD CC Installed at KHP*

The PD CCs and other associated connection accessories employed for the pilot installation at KHP have the technical specifications, matching KHP's generator rating and the available installation provision at the KHP site. The CCs and the accessories are from ohv diagnostics GmbH, Germany. The installed PD CCs shown in Fig. 1 come with the general technical specifications given in Table 1.

***Table 1:** Technical Specifications of PD CC*

Particulars	Technical Specifications
Product Name	HV CC (3 Nos.)
Model	CD-17
Rated Voltage (phase-phase rms)	17.5 kV
Ratio of Upper to Lower Voltage Capacitor	2 nF
PD Decoupling Signal	Confirming to IEC 60270
Signal Transmission Bandwidth	20 MHz at 50 Ω
Signal Output	BNC Female
Weight	1.8 kg

The mounting kit and other accessories such as HV cable connection leads, coaxial cables, ground leads and three-phase coupler termination box have the specifications suitable for the intended mounting of the couplers at the KHP site.

3.1. PD CC Installation

Several PD coupler's mounting options available were thoroughly studied in detail by CoEACaP and based on the site feasibility at KHP, the schematic shown in Fig. 2 was chosen as most appropriate & this represents the actual installation considered at the site for the pilot installation made in unit 2 generator.

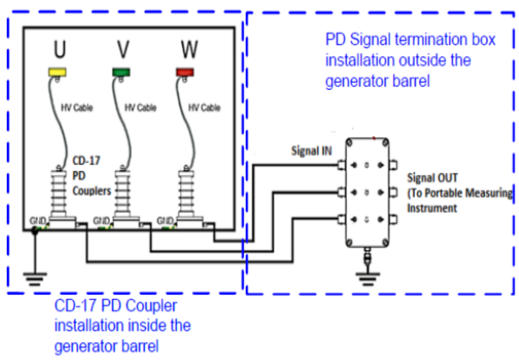

***Fig. 2:** PD CC and Termination Box Installation Schematic*

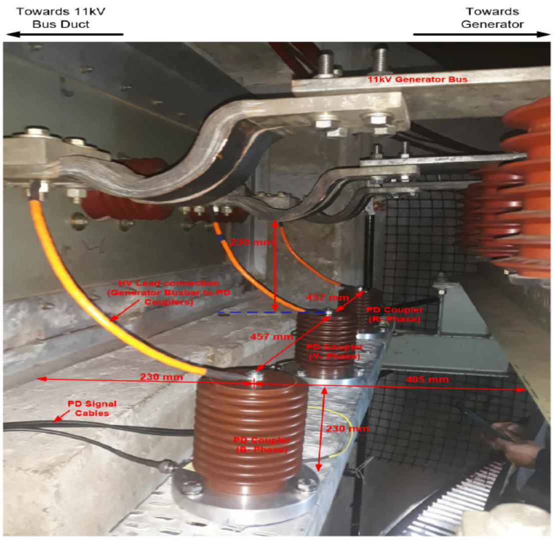

Fig. 3: *PD CC Installed inside Generator Barrel*

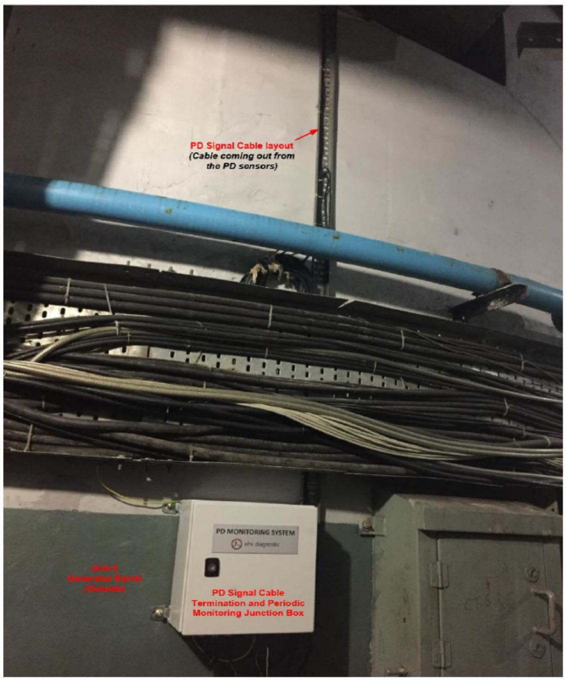

Fig. 4: *PD Signal Layout & Termination Box Mounted*

Three PD couplers, one for each phase, are rigidly mounted on a suitably fabricated steel platform inside the generator barrel, below the generator line terminal bus bars that emanate into the adjoining bus ducts. The three couplers are individually connected to each of the generator phases with HV jumper connections. The PD signals from the coupler are brought out using 10m long TNC to BNC cables, and terminated onto a 3-phase termination box that is mounted outside the generator barrel. The termination box additionally has three numbers of output BNC terminals for easy hooking-up of portable PD measurement instruments, whenever desired, for periodic acquisition of the PD signals. Fig 3 is an image from the KHP site for the actual installation of three PD couplers made inside the unit 2 generator barrel. It also shows various clearances maintained during the installation.

The signal cable layout and their termination to the signal termination junction box mounted outside the generator barrel are shown in Fig 4. The periodic online measurement or acquisition of the generator PD signals can be easily made from this junction box as and when required, with any compatible PD measurement instrument.

4. EQUIPMENT USED

Fig. 5 shows the portable PD measurement equipment named ICMcompact from Power Diagnostix, Megger family, utilized in capturing the PD patterns and inferring the corresponding results. This particular kit is designed for the condition evaluation of medium and high voltage insulation.

Fig. 5: *ICMcompact, PDIX Make, Megger*

Fig. 6: *Insulation Resistance Tester, MIT525*

In addition to this equipment, an IR tester, MIT525, also from Megger family, is also used to measure the insulation resistance of all the phases of the unit 2 generators. Fig. 6 shows the IR tester used to measure the insulation resistance.

5. PD MEASUREMENT

The definite PD quantification in the case of online measurement, with other generators and power system equipment working in unison, however is not generally possible. It is also generally true that not all PD may be equally harmful to insulation systems. Also, the abundance of noise and disturbance and the possible coexistence of multiple PD sources of various types within operational generators make fast and accurate PD measurement a highly complex task (High-Voltage Test Techniques-Partial Discharge Measurements, 2000) For this particular study, the PD measurement is done at different times but at the same generator loading of 16 MW to qualify the trend of PD activities over different times.

The PD measurements are acquired from the installed 2nF coupling outputs at their BNC connection junction box installed outside the generator barrel.

5.1. Commissioning Measurement in 2022

Following the installation of the PD CCs, the first measurement was taken. The PRPD patterns captured for all the phases are shown below.

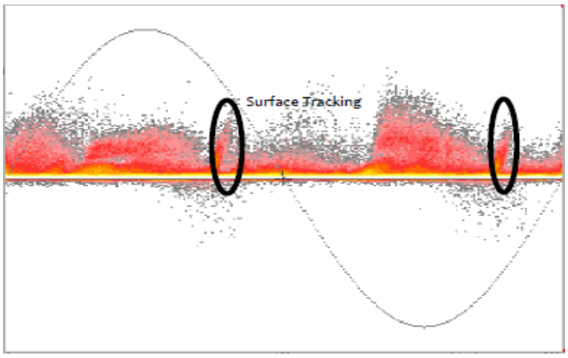

Fig. 7: *PRPD Pattern of R Phase in 2022*

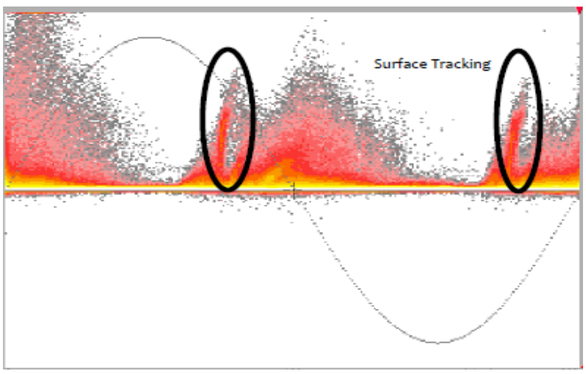

Fig. 8: *PRPD Pattern of Y Phase in 2022*

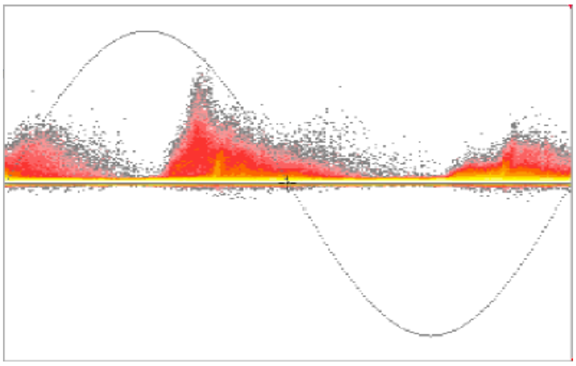

Fig. 9: *PRPD Pattern of B Phase in 2022*

A preliminary analysis of the PD signals acquired indicated the R and Y phases depicted the predominant presence of surface tracking as compared to B phase. All the generators have surface tracking, which is a common phenomenon in high-voltage generators. Y phase measured the highest amplitude of PD discharges in the range of 785.70 pC, when acquired.

5.2. Measurement in 2023

After the installation & commissioning measurements in 2022, the first PD measurement thereafter was taken on 5th September 2023. The analysis of PD patterns acquired is represented below.

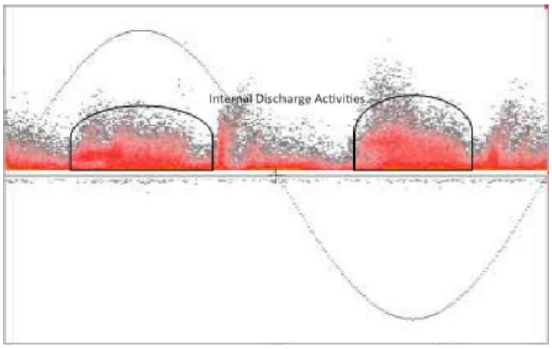

Fig. 10: *PRPD Pattern of R Phase in 2023*

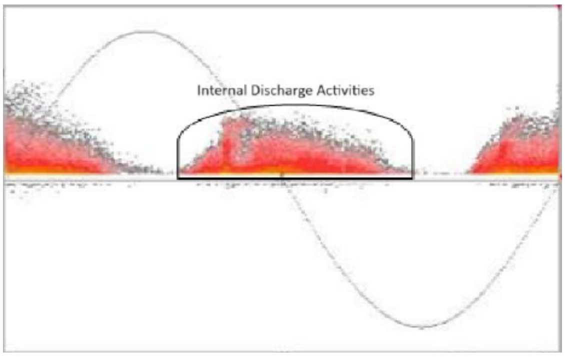

Fig. 11: *PRPD Pattern of Y Phase in 2023*

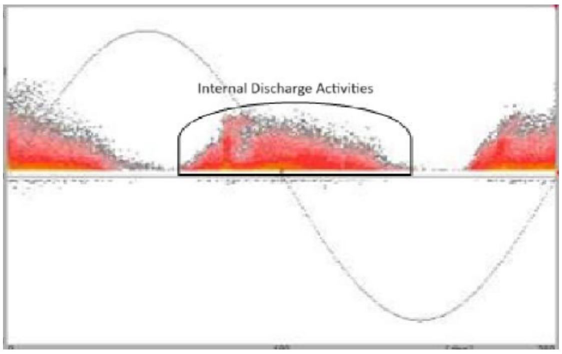

***Fig. 12:** PRPD Pattern of B Phase in 2023*

An analysis of the PD signals acquired indicated that all phases depicted the predominant presence of internal discharge activities, similar to the observation made during the commissioning measurement. The maximum amplitude of the PD pulse of 519.70 pC was again recorded for the Y phase.

5.3. Pre-Monsoon Measurement in 2024

These measurements were taken on 9th April 2024.

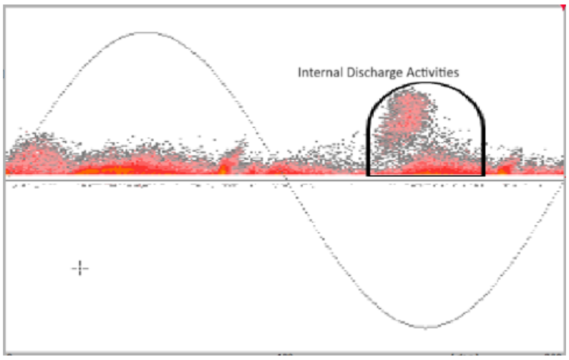

***Fig. 13**: PRPD Pattern of R Phase in Pre-Monsoon 2024*

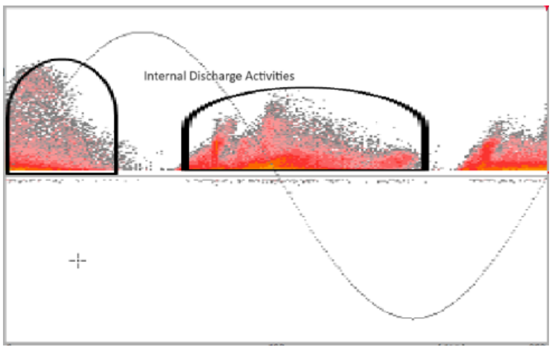

***Fig. 14**: PRPD Pattern of Y Phase in Pre-Monsoon 2024*

An analysis of the PD signals acquired again indicated that all phases depicted the predominant presence of internal discharge activities. The maximum amplitude of the PD pulse of 915.60 pC still was recorded for the Y phase.

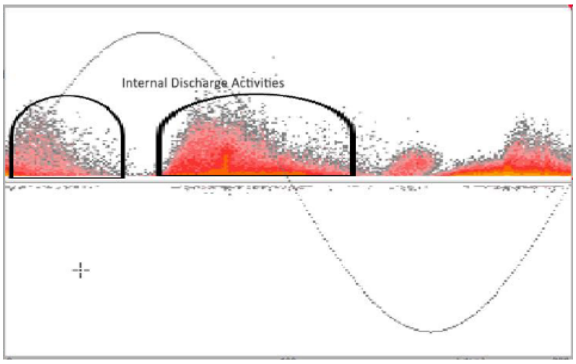

***Fig. 15**: PRPD Pattern of B Phase in Pre-Monsoon 2024*

5.4. Peak-Monsoon Measurement in 2024

PD measurements were taken on 1st August 2024 at 16 MW loading of the generator.

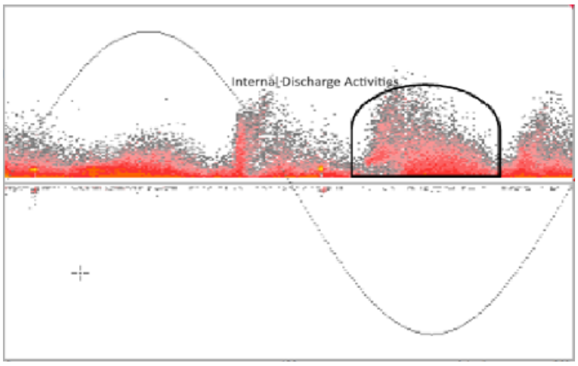

***Fig. 16:** PRPD Pattern of R Phase in Peak-Monsoon 2024*

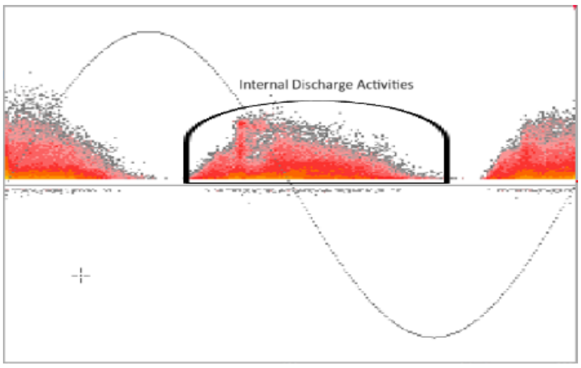

***Fig. 17:** PRPD Pattern of Y Phase in Peak-Monsoon 2024*

All phases depicted the predominant presence of internal discharge activities, with the consistent maximum amplitude of the PD pulse of 581.50 pC recorded for the Y phase.

For the reproducibility of the measurements, the PD measurements were taken on same loading of 16 MW. The maximum load of the generators of KHP is 16 MW. However, the measurements were taken during different seasons, which may be affecting the amplitude of the PD parameters, however, the PRPD patterns were found to be similar.

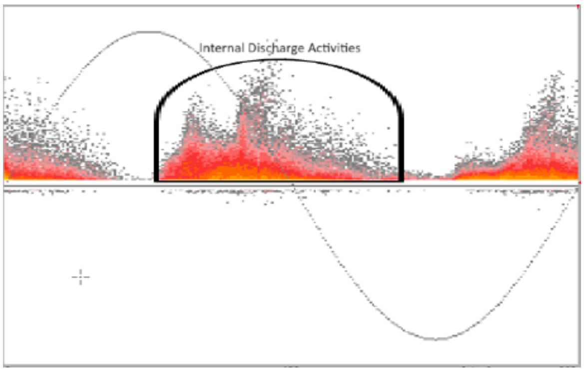

Fig. 18: *PRPD Pattern of B Phase in Peak-Monsoon 2024*

The measurements conducted during the peak-monsoon season is subjected to more external noise, given the more inflow of the rivers allowing all the generators to be in full load generation.

6. RESULT ANALYSIS

6.1. Trend Analysis

The PRPD patterns of all the phases acquired over the years are found to be consistently identical or comparable. The PRPD patterns show the presence of internal discharge activities in the insulation system of the stator which is very common in the generator. The measurements captured at different instances also consistently indicated maximum PD pulse amplitude for the Y-phase and near similar values every time on the other 2 phases. This indicated that the pilot installation of PD couplers on this particular generator was accomplished appropriately, with its capability to consistently capture similar PD occurrences. The periodic measurement, however, is essential for better insight and meaningful comparison that can result in early detection of any severe faults in the insulation system.

***Table 2**: PD Magnitude Over Time*

Phase	2022	2023	Pre-Monsoon 2024	Peak-Monsoon 2024
R	297.00	297.00	340.30	327.90
Y	785.70	519.70	448.50	581.50
B	210.30	265.00	266.00	482.60

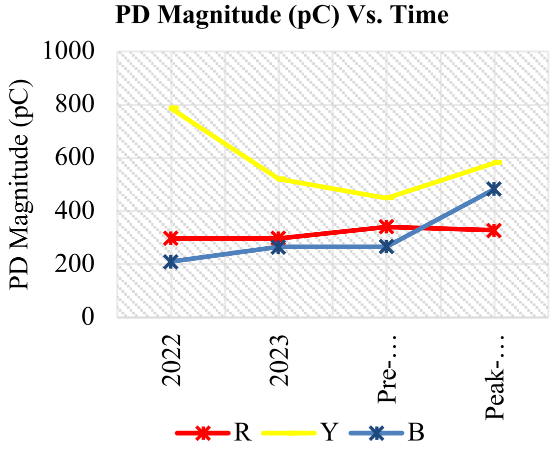

Fig. 19: *PD Magnitude Over Time*

Nevertheless, the parameters such as PD magnitude, NQS value, and level counts are analyzed and monitored during the measurement, where these parameters were also comparable indicating healthy insulation of the stator windings. The values of the various significant PD parameters measured over different time are as summarized in the following tables which were all done at 16 MW generator loading.

Table 3: *NQS Level Over Time*

Phase	2022	2023	Pre-Monsoon 2024	Peak-Monsoon 2024
R	123.19	113.51	11.64	87.42
Y	137.06	232.70	34.98	266.14
B	131.01	114.98	85.22	114.05

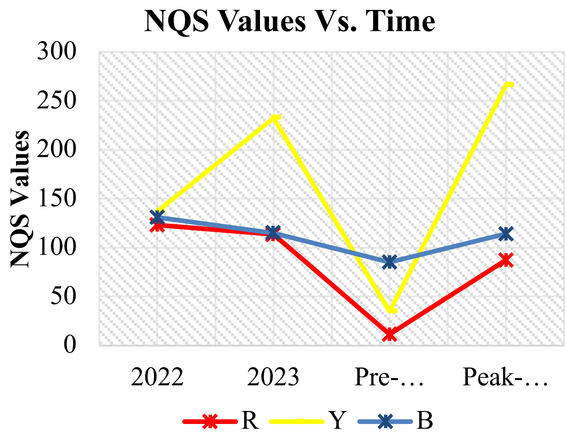

***Fig. 20**: NQS Values Over Time*

Table 4: *Level Counts Over Time*

Phase	2022	2023	Pre-Monsoon 2024	Peak-Monsoon 2024
R	916216	85520	4062	73397
Y	990722	97815	14571	107100
B	1048933	106443	77505	103701

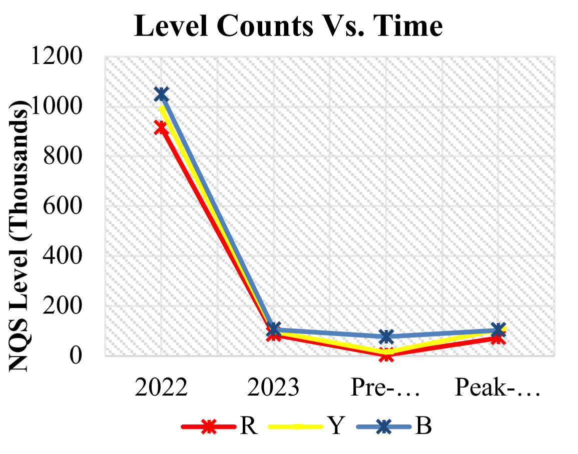

Fig. 21: *Level Counts Over Time*

To further examine the values, graphical representations were used. The graphs below show the parameters measured over time, plotted against the individual phases of the generator. Monitoring PD magnitude and level counts over time is crucial for assessing the true condition of the insulation system in the generator (Hudon & Belec´, 2005).

6.2. IR Measurement and Analysis

The Insulation Resistance (IR) values, Dielectric and Polarization Index (PI) values are used for the assessment of the different kinds of insulation system used in the large rotating machine. The values of the PI indicating the healthy insulation system in the rotating machines can be varying based on the size of the machines (Brown et al., 2011). For the hydro-generators at KHP, the PI values indicating the values above 2 is considered as healthy, as practiced by the KHP.

As a supporting test, an insulation resistance values conducted from 2022 to 2024 were analyzed to support the result reproduced by the online PD measuring system, further validating the effectiveness of installed PD measuring system. Table 5 shows the values of PI measured on unit 2 generator from 2019 to 2023. To further examine the PI values, the values are plotted on the graph shown in Fig. 22

Table 5*: PI Measured Over Time*

Year	Polarization Index (IR_{600s}/IR_{60s})		
	R-Y	Y-B	B-R
2019	4.04	2.75	3.39
2020	4.22	3.66	3.72
2021	5.75	5.75	3.65
2022	3.68	3.23	3.17
2023	4.89	4.80	4.75

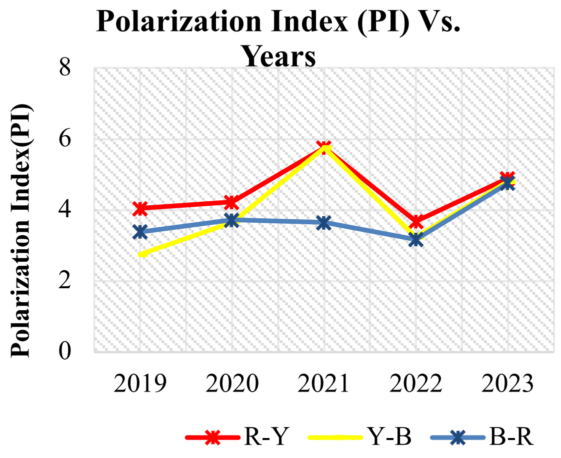

Fig. 22: *Polarization Index Over Time*

7. FINDINGS & RECOMMENDATIONS

PD Magnitude refers to the strength of the discharge, usually measured in pico-coulombs (pC). It indicates the amount of charge involved in a partial discharge event. Table 2 shows the PD magnitude in pC measured over time for all three phases of the generator. The PD magnitude of the Y phase is comparatively higher than the other two phases. Nevertheless, the maximum PD magnitude of the Y phase recorded during the commissioning period is 785.70 PC which is not in the range of nC. Additionally, the magnitude of the Y phase is seen to decrease and has been around 400 pC to 500 pC range afterwards. For the R and B phases, the PD magnitude has been around 200 pC to 500 pC and no drastic increase is observed over time. To sum up the findings from PD measurement, it showed that the insulation of the stator windings of unit 2 generator is in a healthy condition.

For further commendation on results obtained by PD measurement and analysis, the PI values from 2019 to 2023 were also analyzed and trended. The PI values were all above 2 from every year, indicating the healthy insulation of the stator windings. It therefore fairly validates that the PD measurement from the pilot installation system is producing reliable measurements to ascertain the insulation condition of KHP's U2 generator.

Based on the findings of the study, regular measurement to monitor the PD activities was recommended. Further, additional focus should be given to Y phase given its higher PD magnitude during annual maintenance. Given the effectiveness shown by this pilot installation, it is therefore recommended to install the same or similar online PD measurement system for other remaining units.

8. CONCLUSION

The study validates the effectiveness and the usefulness of the online pilot partial discharge measurement system, by way of sample measurements captured and analyzed for KHP's unit 2 generator It offers accurate and reliable PD monitoring capabilities monitoring capabilities, facilitates early detection of insulation faults, and enhances the overall life of the generator. This kind of measurement system can also help to reduce the downtime of the generators, ultimately aiding in the revenue generation.

The study fairly establishes the effectiveness and reliability of the pilot PD measurement setup at unit 2 generator, based on its measurements and analyses highlighted.

As a way forward to this study, the same measuring system can be integrated with the SCADA system for the real-time monitoring of the generator insulation system. The PRPD patterns acquired from this particular system be also analyzed using AI and Machine Learning based algorithms to enhance the predictive maintenance of the generators.

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