



REPORT

PD Survey of 66kV Oil Circuit Breakers



Private and Confidential

Prepared for: Client

Date: 8 March 2024

Version History

| Date | Version | Author(s) | Notes |
|------------|---------|-------------|-------|
| 08/03/2024 | 1.0 | Neil Davies | |

Final Approval

| Approval Type | Date | Version | EA Technology Issue Authority |
|---------------|------------|---------|-------------------------------|
| Technical | 11/03/2024 | 1.0 | B Monaghan |

CONFIDENTIAL - This document may not be disclosed to any person other than the addressee or any duly authorised person within the addressee's company or organisation and may only be disclosed so far as is strictly necessary for the proper purposes of the addressee which may be limited by contract. Any person to whom the document or any part of it is disclosed must comply with this notice. A failure to comply with it may result in loss or damage to EA Technology Ltd or to others with whom it may have contracted and the addressee will be held fully liable therefor.

Care has been taken in the preparation of this Report, but all advice, analysis, calculations, information, forecasts and recommendations are supplied for the assistance of the relevant client and are not to be relied on as authoritative or as in substitution for the exercise of judgement by that client or any other reader. EA Technology Ltd. nor any of its personnel engaged in the preparation of this Report shall have any liability whatsoever for any direct or consequential loss arising from use of this Report or its contents and give no warranty or representation (express or implied) as to the quality or fitness for the purpose of any process, material, product or system referred to in the report.

All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means electronic, mechanical, photocopied, recorded or otherwise, or stored in any retrieval system of any nature without the written permission of the copyright holder.

© EA Technology Ltd March 2024

EA Technology Pty Limited, 381 MacArthur Avenue, Hamilton, QLD 4007, Australia;

Tel: +61 (0) 7 3256 0534

<http://www.eatechnology.com.au>

ACN 134 783 887

Executive Summary

Background to the Project

EA Technology was engaged by the client to carry out an online partial discharge survey of the 66kV oil circuit breakers at one of their Terminal Stations.

A previous failure of one of the same type of 66kV circuit breakers at another Terminal Station had resulted in an exclusion zone being imposed on similar OCBs, requiring PD testing to be conducted before temporary removal of the exclusion. With works scheduled at this terminal station, EA Technology attended site on Thursday 07 March 2024 to undertake a non-intrusive PD inspection of the 7 in-service OCBs in the 66kV yard and to provide hands on instruction to local staff to allow consistent ongoing screening testing as required.

EA Technology performed the testing using the UltraTEV Plus² and UltraTEV Plus² UHF instruments. The test methods used for the PD survey were the Transient Earth Voltage (TEV), Ultrasonic and Ultra High Frequency (UHF). Each of the testing methodologies have the capability to find different defect types.

This report covers detailed analysis of all tests performed and discusses the captured results.

Scope and Objectives

The scope of the project is to:

- Execute a targeted non-intrusive partial discharge (PD) survey specifically on circuit breakers at this Terminal Station.
- Detect and document any instances of PD within these circuit breakers and determine the necessity for subsequent investigative actions.
- Provide on-site practical training in the use of the PD instrumentation to local Technicians.

The objective is to:

- Provide the client with a detailed assessment of the PD condition of the circuit breakers at the specified terminal stations.
- Offer analysis regarding the origins of any PD activities identified and recommend practical measures for remediation.
- Enable routine ongoing screening testing to be carried out in a consistent manner.

Conclusions

- C1. A significant source of PD activity was detected to the 66kV oil circuit breaker No. 6 FDR CB at the Terminal Station.
 - C1.1 Constant high level TEV activity was recorded with a maximum amplitude of 44dB on the white phase CB tank.
 - C1.2 The UHF antenna detected the same source of activity and helped to localise the source to this circuit breaker.
 - C1.3 The PRPD patterns recorded using both techniques were consistent and showed elements of contact / floating metalwork type activity and activity within oil.
- C2. Comparison of the PD detected on No. 6 FDR CB with the testing carried out in December 2023 indicates that the source has significantly increased in severity and progressed over the intervening 3-month period.

- C3. No other sources of partial discharge activity were identified on the other six oil circuit breakers within the 66kV switchyard.

Recommendation

- R1. Based on the findings of this report, and the increase in severity since the previous testing in December 2023, the PD source identified in No. 6 FDR CB has progressed to the point where further investigation in the short term is recommended.
- R2. An outage and inspection / maintenance of the circuit breaker is recommended to remove the source of PD from the network and reduce the level of risk.
- R2.1 DGA testing of the oil may help confirm the presence and location of the PD source.
- R2.2 Particular attention should be paid to the contacts and any components where gap type discharge could occur.
- R2.3 The highest level of activity was on the white phase and this would be the most obvious phase to closely look at first. It should be noted that due to the construction of switchgear and nature of the high frequency electromagnetic pulses and their propagation, the highest amplitude may not always be associated with the source of activity.
- R3. Should an outage and inspection / maintenance of this circuit breaker be difficult to arrange, regular testing can be undertaken to look for continued increase and progression of the source of PD and any potential runaway situation.
- R3.1 Regular handheld testing using the TEV and UHF techniques could achieve this.
- R3.2 Consideration could also be given to the installation of a temporary monitor utilising TEV probes. This would be a way of limiting personnel being in proximity to the discharging circuit breaker and quickly establish if the PD is indeed progressing or intermittent in nature based on other factors.

Contents

| | | |
|-----|----------------------------------|----|
| 1. | Background and Introduction..... | 1 |
| 2. | Results..... | 1 |
| 2.1 | Summary..... | 1 |
| 2.2 | TEV Measurements..... | 2 |
| 2.3 | UHF Measurements..... | 5 |
| 2.4 | Ultrasonic Measurements..... | 7 |
| 3. | Discussion..... | 7 |
| 4. | Conclusions..... | 10 |
| 5. | Recommendations..... | 10 |

Figures

| | | |
|-----------|--|---|
| Figure 1 | TEV PRPD Plot Blue phase of No. 1 FDR CB..... | 2 |
| Figure 2 | TEV PRPD Plot Blue Phase of No. 2 FDR CB..... | 2 |
| Figure 3 | TEV PRPD Plot Blue Phase of No. 3 FDR CB..... | 3 |
| Figure 4 | TEV PRPD Plot Blue Phase of No. 4 FDR CB..... | 3 |
| Figure 5 | TEV PRPD Plot Blue Phase of No. 5 FDR CB..... | 4 |
| Figure 6 | TEV PRPD Plot Blue Phase of No. 6 FDR CB..... | 4 |
| Figure 7 | TEV PRPD Plot Blue Phase of No. 7 FDR CB..... | 5 |
| Figure 8 | Background vs CB frequency sweep No. 3 FDR CB..... | 6 |
| Figure 9 | Background vs CB frequency sweep No. 4 FDR CB..... | 6 |
| Figure 10 | Background vs CB frequency sweep No. 6 FDR CB (Gain 25dB)..... | 6 |
| Figure 11 | Background vs CB frequency sweep No. 6 FDR CB (Gain 10dB)..... | 6 |
| Figure 12 | UHF PRPD Plot of No. 6 FDR CB..... | 7 |
| Figure 13 | TEV PRPD Plot Red Phase of No. 6 FDR CB..... | 8 |
| Figure 14 | TEV PRPD Plot White Phase of No. 6 FDR CB..... | 8 |
| Figure 15 | TEV PRPD Plot Blue Phase of No. 6 FDR CB..... | 8 |
| Figure 16 | No. 6 FDR CB, UHF Phase Plot, Test 2..... | 9 |

Tables

| | | |
|---------|-------------------------|---|
| Table 1 | Summary of Results..... | 1 |
|---------|-------------------------|---|

Appendices

| | |
|------------|----------------|
| Appendix I | Test Equipment |
|------------|----------------|

1. Background and Introduction

The seven in-service oil circuit breakers (OCBs) at this Terminal Station were non-intrusively tested for partial discharge (PD) using the UltraTEV Plus² and UHF Directional Antenna. The following procedure was used:

- TEV test on each of the three OCB tanks capturing phase resolved PD (PRPD) trace
- Background UHF frequency sweep compared to UHF frequency sweep of each OCB
- Where differences in frequency sweep were noted, UHF PRPD recording captured
- Ultrasonic survey undertaken using parabolic dish

2. Results

2.1 Summary

Table 1 provides a summary and comments of the assets surveyed.

Table 1 Summary of Results

| Asset Name | Result Sheet | | Comments |
|--------------|--------------|---|----------|
| No.1 FDR CB | UHF | All clear at time of test | |
| | TEV | | |
| | Ultrasonic | | |
| No.2 FDR CB | UHF | All clear at time of test | |
| | TEV | | |
| | Ultrasonic | | |
| No. 3 FDR CB | UHF | All clear at time of test | |
| | TEV | | |
| | Ultrasonic | | |
| No. 4 FDR CB | UHF | All clear at time of test | |
| | TEV | | |
| | Ultrasonic | | |
| No. 5 FDR CB | UHF | All clear at time of test | |
| | TEV | | |
| | Ultrasonic | | |
| No. 6 FDR CB | UHF | Internal Partial Discharge activity detected using TEV and UHF techniques | |
| | TEV | | |
| | Ultrasonic | | |
| No. 7 FDR CB | UHF | All clear at time of test | |
| | TEV | | |
| | Ultrasonic | | |

2.2 TEV Measurements

TEV measurements were taken on the three individual phase tanks in turn (red, white and blue). A noise source that was not phase-resolved was seen on all tests and presented as a flat line at around the 10dB mark. This low level of interference provides comfort that any significant level of PD would be easily identifiable within the 66kV yard. A representative example of this is shown in Figure 1, taken on the Blue-phase tank of No. 1 FDR CB.

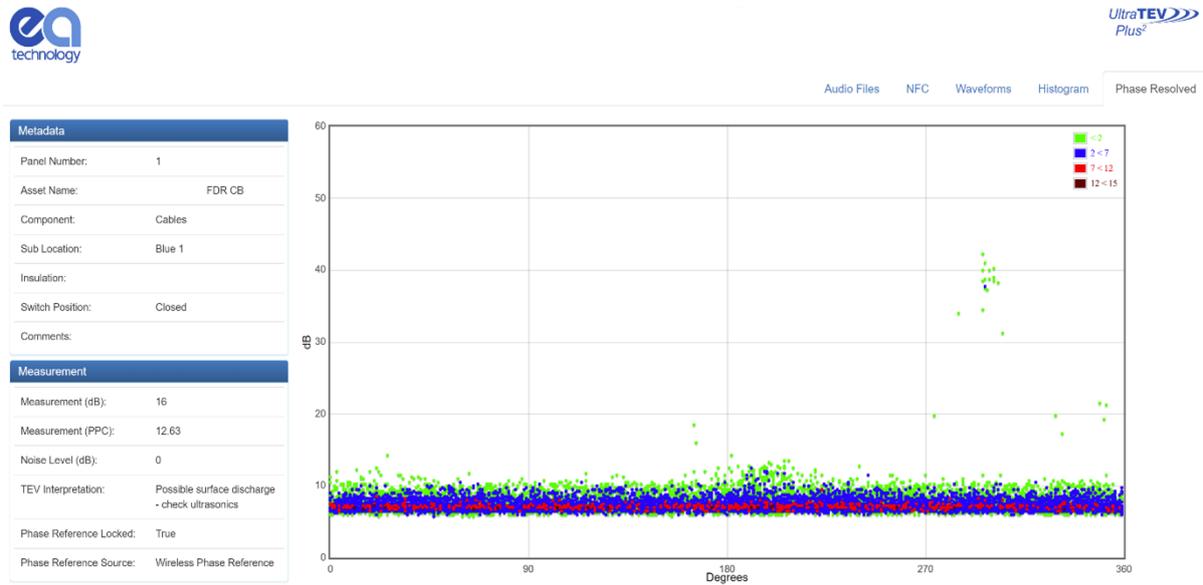


Figure 1 TEV PRPD Plot Blue phase of No. 1 FDR CB

Moving progressively down the yard from OCB No. 1 FDR CB towards the second from end No. 6 FDR CB, TEV signals were seen to get progressively higher and were displaying a distinctive phase resolved pattern. Continuing to use the Blue-Phase as a representative sample, the plots in Figure 2 to Figure 6 show activity across the next 6 OCBs.

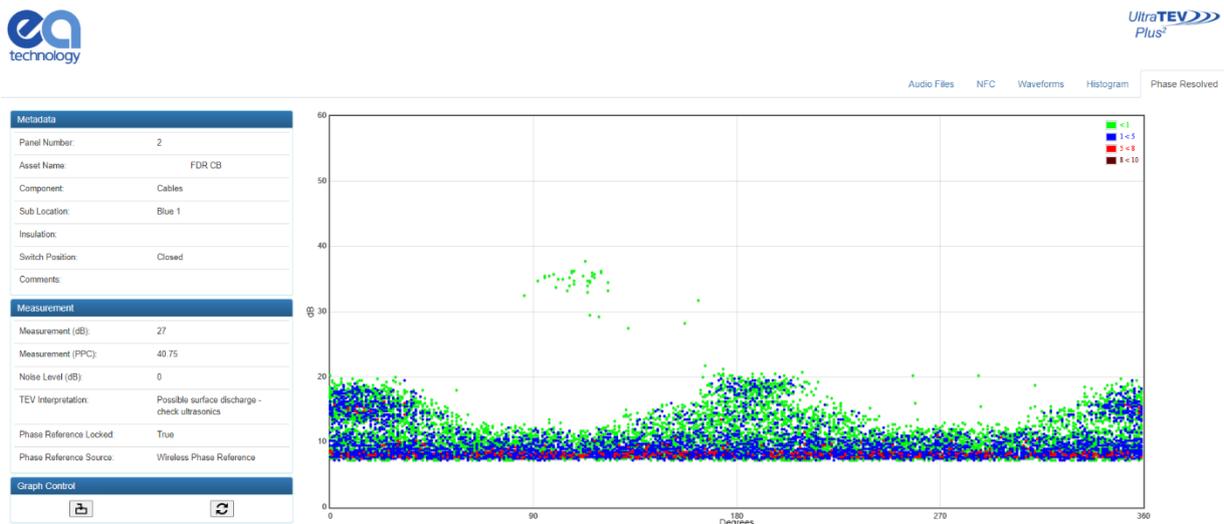


Figure 2 TEV PRPD Plot Blue Phase of No. 2 FDR CB

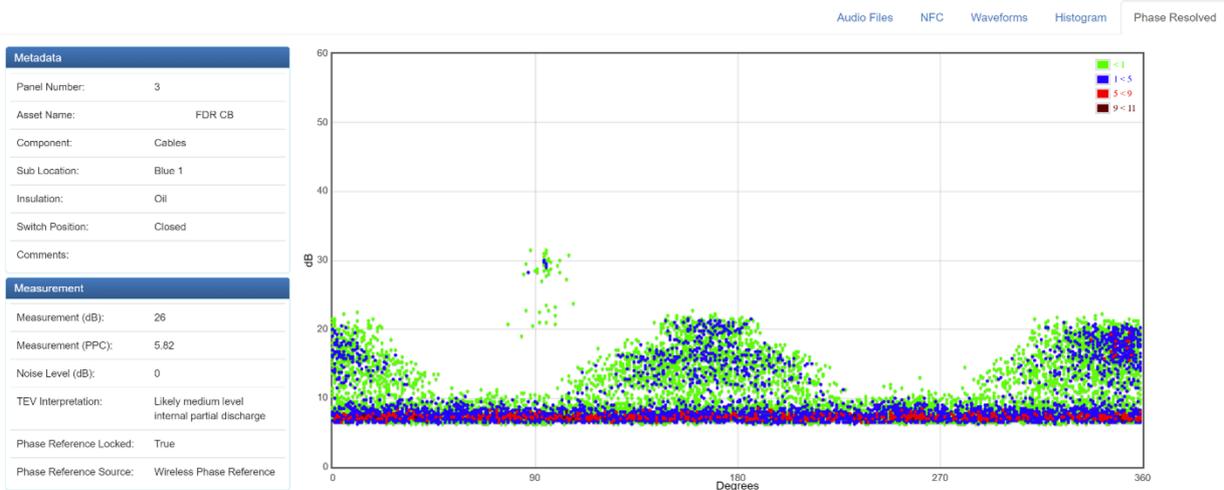


Figure 3 TEV PRPD Plot Blue Phase of No. 3 FDR CB

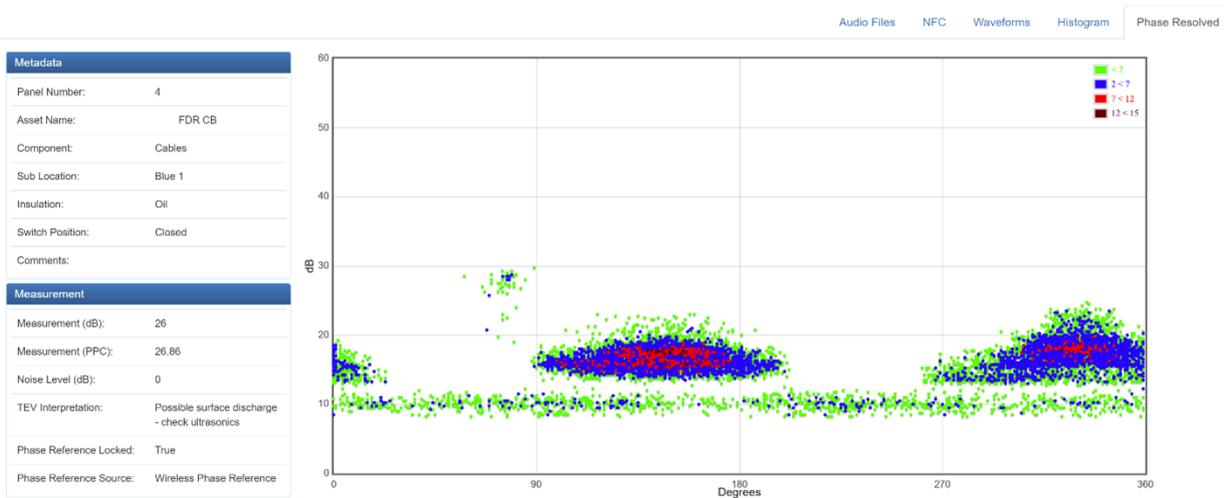


Figure 4 TEV PRPD Plot Blue Phase of No. 4 FDR CB

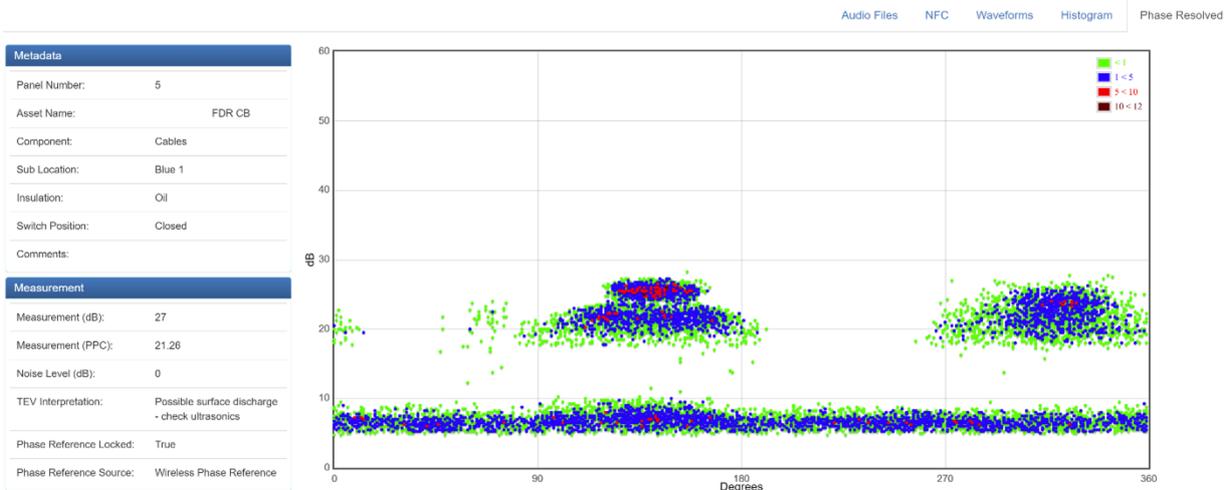


Figure 5 TEV PRPD Plot Blue Phase of No. 5 FDR CB

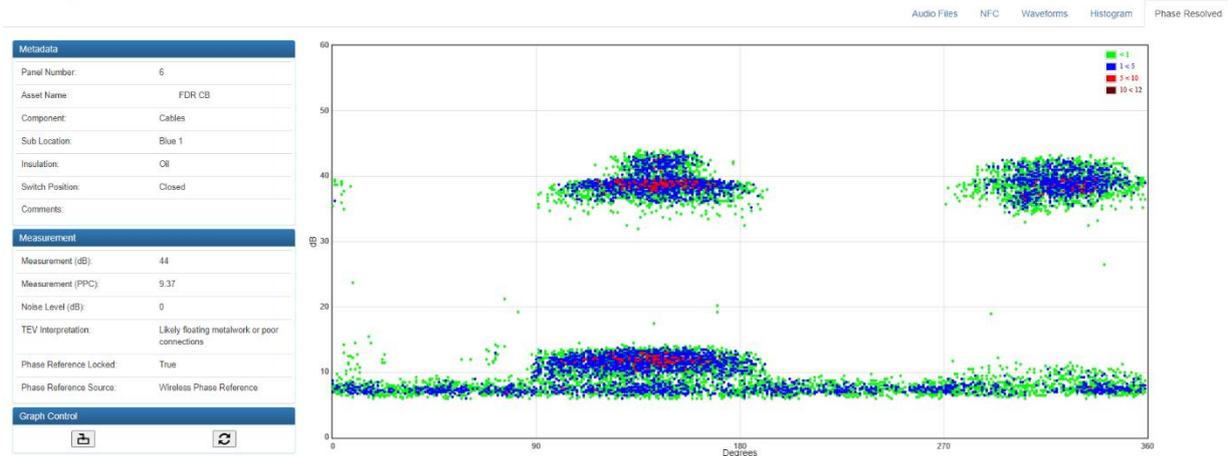


Figure 6 TEV PRPD Plot Blue Phase of No. 6 FDR CB

All the plots show single phase activity with similar characteristics and amplitudes getting progressively higher as it moves to DSH FDR CB.

Now looking at the PRPD plot on the Blue phase of the final OCB in Figure 7, again a similar pattern is seen but this time with lower amplitude. This all points towards a source of activity associated with No.6 FDR CB.

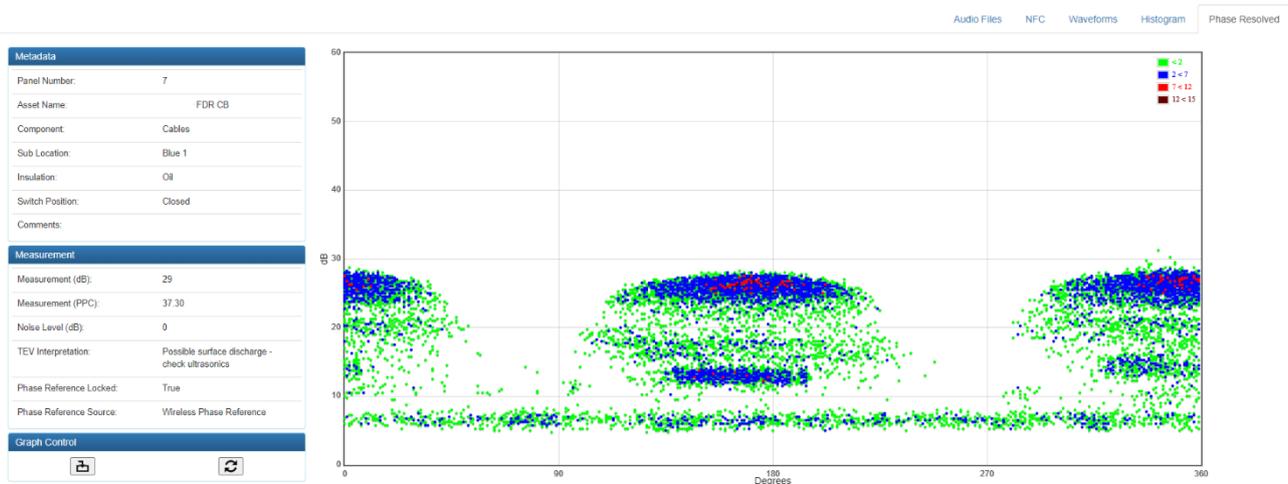


Figure 7 TEV PRPD Plot Blue Phase of No. 7 FDR CB

2.3 UHF Measurements

All seven of the circuit breakers were scanned using the scan frequency function where the instrument measures a sweep of electromagnetic activity detected from 53MHz to 999MHz. In each instance, a sweep pointing towards the OCB was compared to a background sweep pointing away from all assets. As the background noise level within the switchyard was relatively low, a gain setting of 25dB was used on the antenna. This provided very good sensitivity, particularly with the asset scans taken from only approximately 2 – 3m from the circuit breakers.

For the following circuit breakers no deviation of any note was seen between the background and asset sweeps:

- No. 1 FDR CB
- No. 2 FDR CB
- No. 3 FDR CB
- No. 4 FDR CB
- No. 5 FDR CB
- No. 7 FDR CB

Representative traces for two of the circuit breakers are shown in Figure 8 and Figure 9. In both traces, the background sweep is the grey line and the asset sweep the red line.

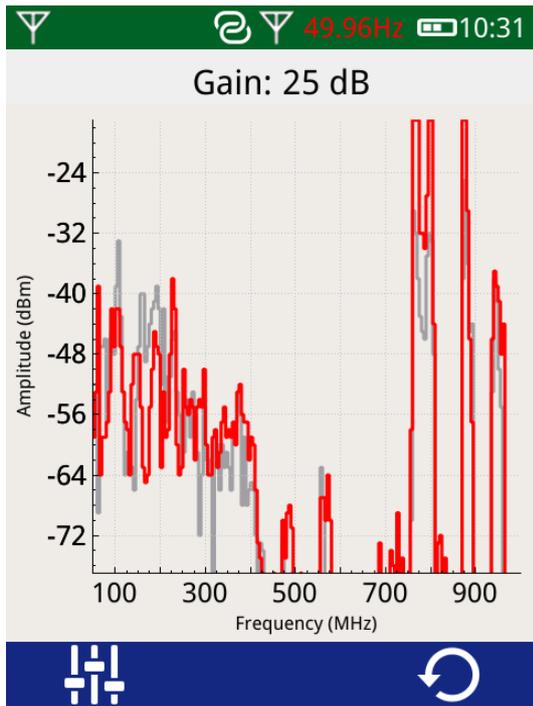


Figure 8 Background vs CB frequency sweep No. 3
FDR CB

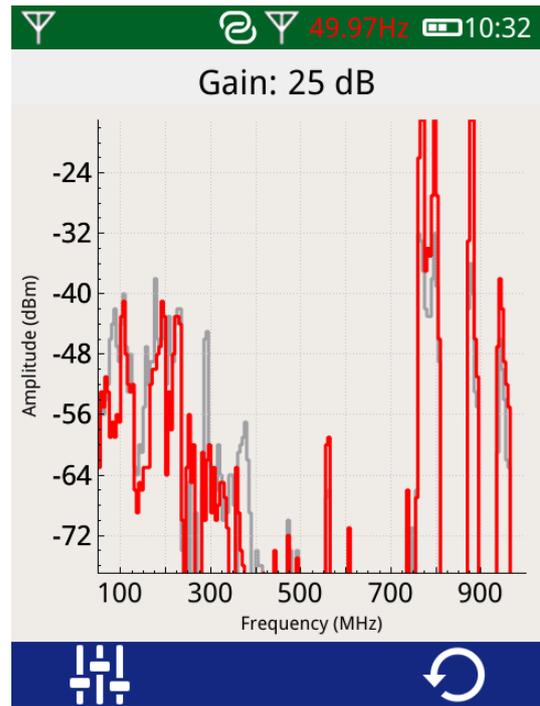


Figure 9 Background vs CB frequency sweep No. 4
FDR CB

When surveying the circuit breaker No.6 FDR CB however, a marked and noticeable difference was apparent. The overall amplitude was also significantly higher (particularly around the VHF / TEV frequencies), so much so that a second sweep with the gain reduced to 10dB was also taken. These traces are shown in Figure 10 and Error! Reference source not found. where once again the grey trace denotes background and the red the asset sweep.

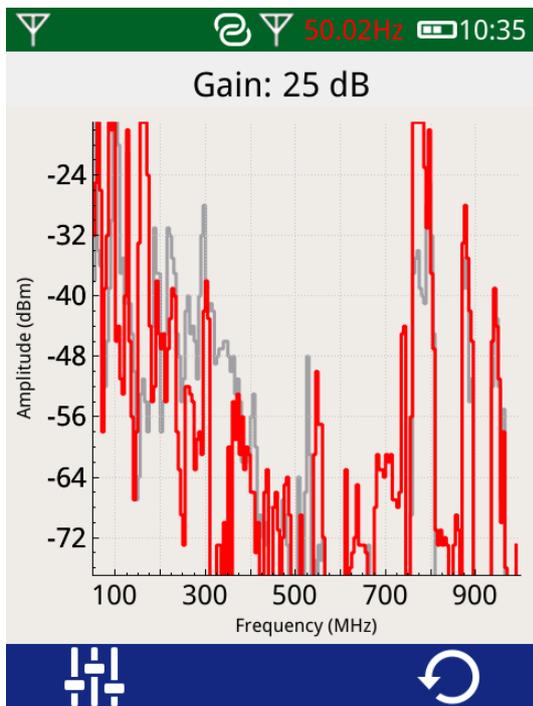


Figure 10 Background vs CB frequency sweep No. 6
FDR CB (Gain 25dB)

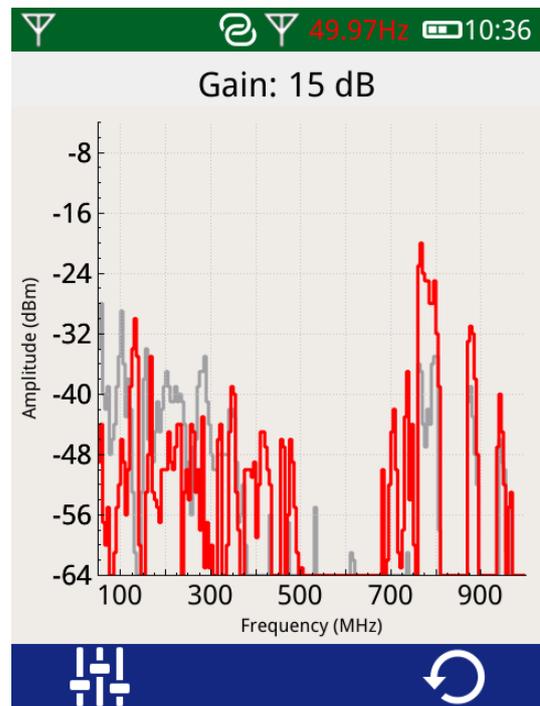


Figure 11 Background vs CB frequency sweep No. 6
FDR CB (Gain 10dB)

Looking at these traces, a very noticeable difference could be seen at the 700MHz frequency and this was also a very quiet part of the background spectrum. The antenna was therefore tuned to 700MHz and a PRPD trace captured when pointing toward No. 6 FDR CB which is shown in Figure 12.

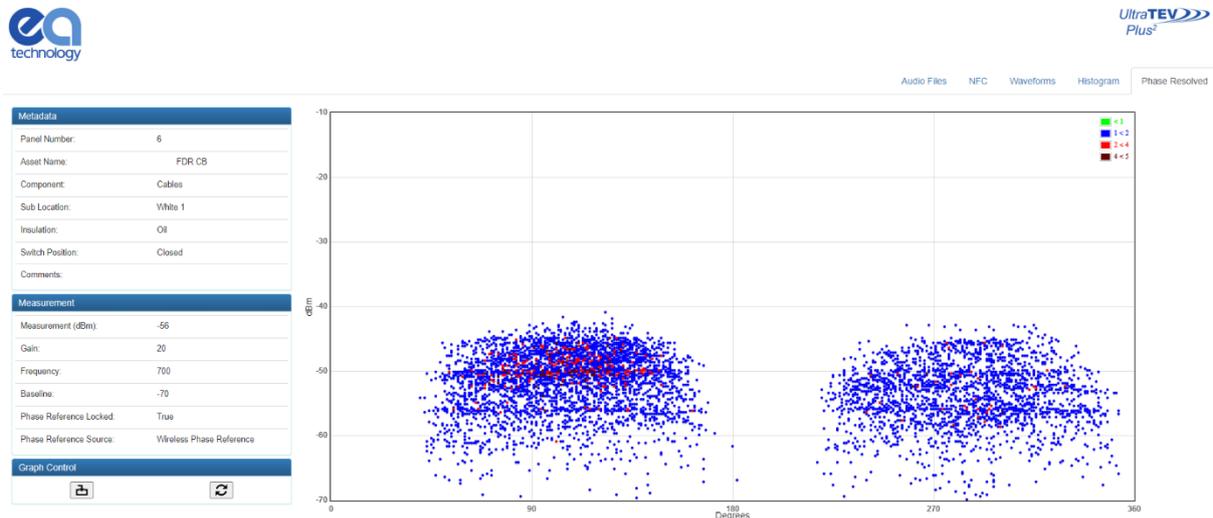


Figure 12 UHF PRPD Plot of No. 6 FDR CB

The UHF PRPD trace was consistent with the TEV traces in showing a single-phase partial discharge pattern associated with No. 6 FDR CB. The use of the UHF technique localised the signals and provided additional confirmation that this was indeed the source of the PD activity seen in the 66kV switchyard.

2.4 Ultrasonic Measurements

No ultrasonic sources of concern were found with only corona PD and small levels of surface PD across some porcelain insulators present.

3. Discussion

The circuit breaker No. 6 FDR CB was found to be exhibiting PD activity. The dual probe location technique was applied using the UltraTEV Locator accessory and whilst this also helped further confirm the source of the activity to this asset, it was not possible to conclusively indicate to which phase the issue was associated. Comparing the traces on each tank shown in Figure 13 to Figure 15, the White phase trace has a higher amplitude (44dB) and higher pulse per cycle reading and this would be the most likely suspect and place to start with any investigation. However, it is also true that that any inspection or remedial work would involve the complete circuit breaker so identification of exact phase non-intrusively is probably not the most important issue. The main aim is to identify PD and suspect circuit breakers which has been achieved.

The TEV trace of Figure 14 and the UHF trace of Figure 12 show patterns with characteristics of both PD across a gap and PD within oil. Therefore, one potential cause could be with a contact issue in one of the oil tanks with White phase being most suspect.

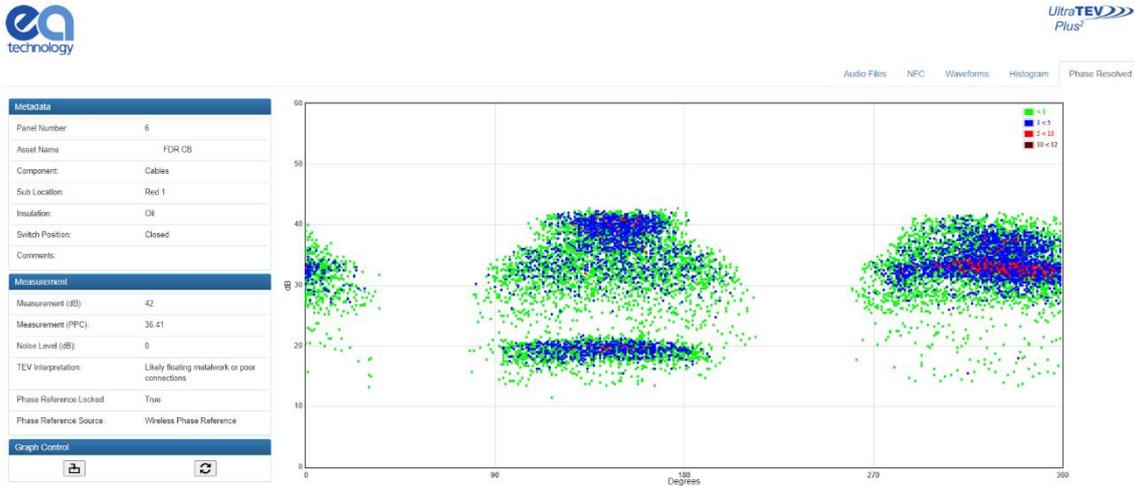


Figure 13 TEV PRPD Plot Red Phase of No. 6 FDR CB

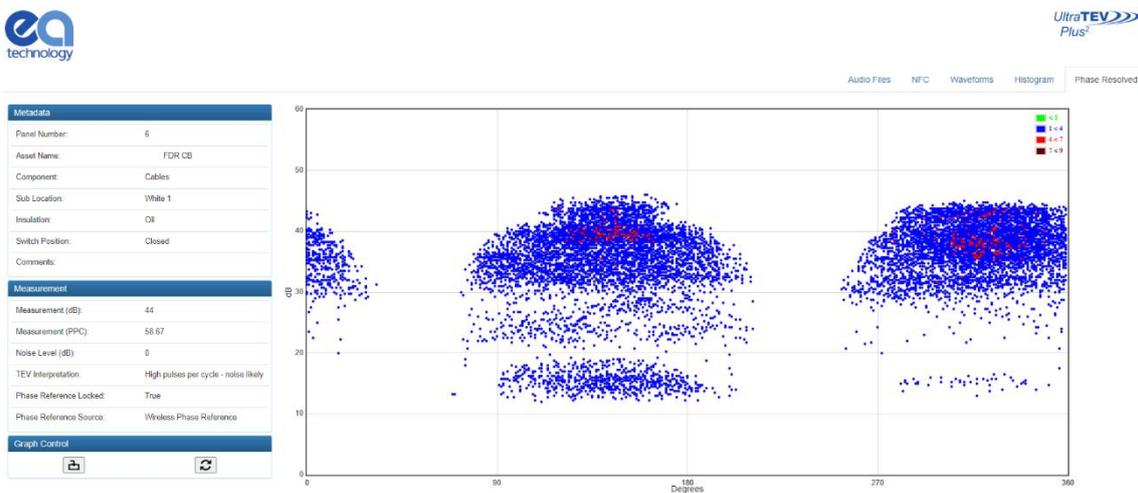


Figure 14 TEV PRPD Plot White Phase of No. 6 FDR CB

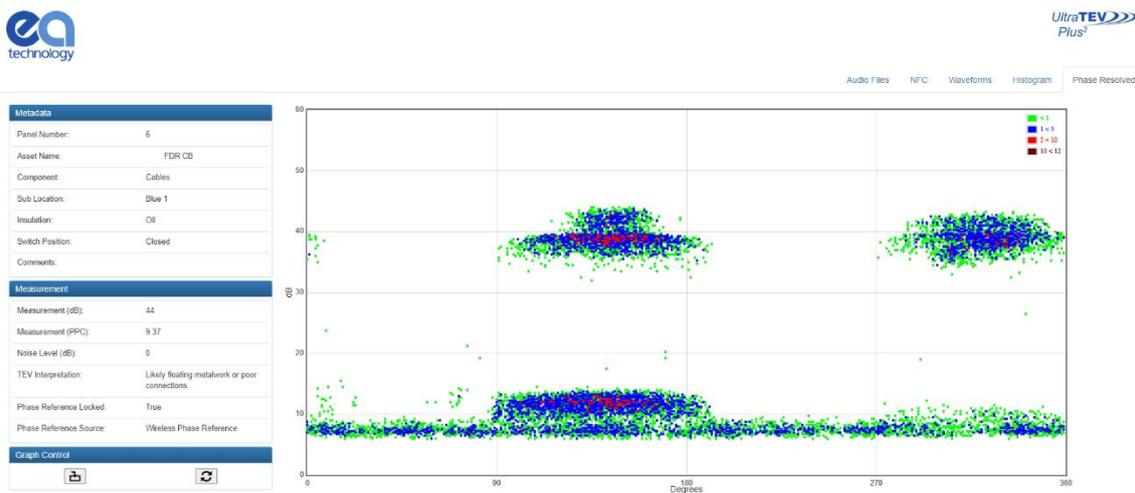


Figure 15 TEV PRPD Plot Blue Phase of No. 6 FDR CB

With respect to the severity of the PD, a TEV amplitude of 44dB is a high level large source of PD and warrants further investigation in the short term. This is particularly true when we compare the results to a previous series of tests undertaken by EA Technology at the same Terminal Station on 7th December 2023.

In that report, an intermittent source of PD activity was detected and noted on this circuit breaker. At the time, the activity was found to be active for only very short periods of time, making the testing difficult. In December, PD was only detected using the UHF method, but this may well have been due to the PD being inactive at the time of the TEV testing. Figure 16 taken from that report shows a much less conclusive trace of UHF activity and comparing this with Figure 12 we can see that the amplitude and rate of PD has substantially increased between these two measurements taken only 3 months apart.



Figure 16 No. 6 FDR CB, UHF Phase Plot, Test 2

Admittedly this is only based on only two samples of data, however, the PD source in the OCB appears to have substantially increased in severity over the intervening 3-month period.

In March the TEV and UHF measurements were very constant and the source was active for the whole period of testing and at a much higher amplitude and discharge rate.

4. Conclusions

- C1. A significant source of PD activity was detected to the 66kV oil circuit breaker No. 6 FDR CB at the Terminal Station.
 - C1.1 Constant high level TEV activity was recorded with a maximum amplitude of 44dB on the white phase CB tank.
 - C1.2 The UHF antenna detected the same source of activity and helped to localise the source to this circuit breaker.
 - C1.3 The PRPD patterns recorded using both techniques were consistent and showed elements of contact / floating metalwork type activity and activity within oil.
- C2. Comparison of the PD detected on No. 6 FDR CB with the testing carried out in December 2023 indicates that the source has significantly increased in severity and progressed over the intervening 3-month period.
- C3. No other sources of partial discharge activity were identified on the other six oil circuit breakers within the 66kV switchyard.

5. Recommendations

- R1. Based on the findings of this report, and the increase in severity since the previous testing in December 2023, the PD source identified in No. 6 FDR CB has progressed to the point where further investigation in the short term is recommended.
- R2. An outage and inspection / maintenance of the circuit breaker is recommended to remove the source of PD from the network and reduce the level of risk.
 - R2.1 DGA testing of the oil may help confirm the presence and location of the PD source.
 - R2.2 Particular attention should be paid to the contacts and any components where gap type discharge could occur.
 - R2.3 The highest level of activity was on the white phase and this would be the most obvious phase to closely look at first. It should be noted that due to the construction of switchgear and nature of the high frequency electromagnetic pulses and their propagation, the highest amplitude may not always be associated with the source of activity.
- R3. Should an outage and inspection / maintenance of this circuit breaker be difficult to arrange, regular testing can be undertaken to look for continued increase and progression of the source of PD and any potential runaway situation.
 - R3.1 Regular handheld testing using the TEV and UHF techniques could achieve this.
 - R3.2 Consideration could also be given to the installation of a temporary monitor utilising TEV probes. This would be a way of limiting personnel being in proximity to the discharging circuit breaker and quickly establish if the PD is indeed progressing or intermittent in nature based on other factors.

Appendix I Test Equipment

The following calibrated test equipment was used during this project.

| Manufacturer | Type | Model | Serial No. | Calibration Due |
|---------------|-------------------------------|------------------|------------|-----------------|
| EA Technology | UltraTEV Plus ² | UTP ² | 0000301 | 05/03/2025 |
| EA Technology | UltraTEV UHF | UHFR1 | 0000035 | 30/10/2024 |
| EA Technology | UltraTEV UHF | UHFDA1 | 005 | 30/05/2024 |
| EA Technology | UltraTEV Locator ² | UTL ² | 0017 | 14/07/2024 |



Safer, Stronger, Smarter Networks

EA Technology Limited
381 MacArthur Avenue
Hamilton, QLD 4007, Australia

t +61 (0) 7 3256 0534
e au.sales@eatechnology.com
www.eatechnology.com.au