ASSESSMENT OF ON-LINE DIAGNOSTIC USING PARTIAL DISCHARGE MAPPING SYSTEMS IN MVUG CABLE

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ABSTRACT

An extensive effort made to understand how to use effectively the various online partial discharge technologies to establish the condition of medium voltage underground cable circuits. Cable circuits often contain multiple branches with different cable designs and range of insulation materials. In addition, each insulation material ages differently as a function of time, temperature and operating environment. There is a wide variety of online partial discharge technologies available for assessing the condition of cable circuits with a diversity of claims about the effectiveness of each approach.
This assessment was undertaken to help address these issues especially on Malaysia underground medium voltage cable. All together three (3) manufacturers participated in this project. There are two (2) main parts in this project i.e. Desktop Assessment and Actual Testing Assessment.

INTRODUCTION

TNBD has embarked on off-line OWTS PD mapping as one of the main diagnostic tools in Condition Based Maintenance (CBM) activities for MVUG. Additional diagnostics equipment are being planned to complement OWTS for example DS, tan delta hence TNBD seek proven on-line PD mapping technique to be endorsed and applied into the system.

Main advantage of on-line diagnostic tools is there is no need to disconnect the cable under test. Furthermore, depending on the network configuration, switching is not always possible without loss of power to some customers. The PD measurement can also be continuous because the cable remains in normal operation. The measurement equipment is installed on the cable under test for longer periods of time or even permanently. This brings a few huge advantages in terms of monitoring the trend in PD activity gives important information on the severity of a defect. For example, a fast rising PD level is more dangerous than a sustained PD level of the same magnitude; and depending on the type of defect and the environmental conditions, such as loading, the PD activity is not always constant. There can be periods during which there is no PD activity. An offline test conducted in that period will fail to detect the defect. Most defects in the joints in cross-linked polyethylene (XLPE) cables lead to a rapid breakdown within a few days or weeks of PD activity [2, 3]. The chance of detecting such a defect with a periodic offline measurement is small. Continuous online PD monitoring detects every period of PD activity [1].

The goal of PD location is to determine the physical location of a defect, allowing the utility to replace the defective component. The PD location accuracy must be sufficient to be able to easily locate the physical location of the defect. A PD detection system locates the defect as a percentage of the total cable length. In order to convert this location to a physical location the exact cable length and cable route needs to be known. Depending on the utility, the accuracy of this information can vary from 5–10m to being completely unknown for a few cases. A PD detection system should have at least the accuracy of the lower limit to make sure that it is not the limiting factor in locating the physical defect. Due to the attenuation and dispersion this accuracy is not achievable for cables longer than approximately 1km and due to the frequency-dependent attenuation it is more convenient to specify the location accuracy relative to the cable length. A relative PD location accuracy is generally valid for a large range of cable lengths. Practical experience shows that a location accuracy of 1% of the cable length is both achievable during field measurements and acceptable for locating the physical defect location [4, 5].

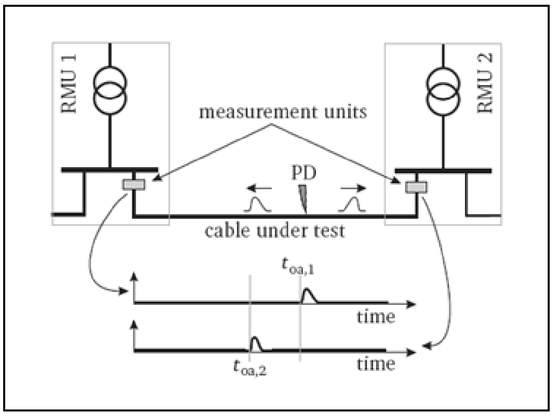

Figure 1: Schematic drawing of online PD detection and location in an MV cable between two RMU's [1]

EVALUATION METHODOLOGY

There are two (2) main tasks in this project i.e. Desktop Assessment and Actual Onsite Testing Assessment. In the desktop assessment, information from desktop survey, assessment results and bench marking were compiled and analysed. A set of comprehensive desktop assessment criteria that covered compliance to standard, suitability to MVUG cable system, operability, effectiveness of measurement and support was proposed and applied in assessing different dielectric response diagnostic technologies offered.

Selection of the online partial discharge technique

Based on the discussion with TNBD Asset Management, it was decided only a maximum of six (6) online partial discharge measurement techniques shall be selected for this feasibility study assignment. It is vital to have various online partial discharge techniques to be included in this exercise for better comparison / analysis of test results. This will ensure the most suitable dielectric response measurement technology that can be applied within TNB Distribution system for field testing of the selected MVUG cables. It was agreed and decided during the project proposal for TNBR to engage an independent expert collaborator to jointly perform this evaluation project. This was to ensure the integrity of the findings from this evaluation project.

In this evaluation exercises, three (3) dielectric response measurement systems were selected to participate. In general online techniques typically employ high frequency current transformers (HFCTs) or capacitively coupled voltage sensors to detect transient signals from discharges. Offline techniques most often employ voltage dividers at the voltage source or at the opposite end of the circuit.

When measuring PD, three prerequisites must be satisfied:

- The voids must be in a state that allows them to discharge,
- The PD signal must reach the detector in a suitably un-attenuated, undispersed state to be recognizable as PD signals with respect to the background noise, and
- The PD detection system must be properly calibrated to optimally account for the length and type of cable under test.

A high voltage is applied to the cable system. If conditions are right at the void location, a partial discharge, i.e. a discharge across the void occurs. The PD equipment detects transient microvolt or microampere level signals generated at the discharge site that travel through the cable to the detection equipment. The exact shape and bandwidth of these pulses depends on the discharge source, frequency response of the cable system, and frequency response of the measurement equipment. Each of these elements alters the shape of the original PD pulse. The PD pulses themselves must then be separated from ambient noise signals. The available PD instruments are classified by bandwidth as they can have bandwidths of hundreds of kilohertz (narrow band) up to 100 MHz (ultra-wide bandwidth (UWB)).

Figure 2 shows the commonly used equivalent circuit to describe PD measurements. The capacitances (C) are identified by the subscripts a, b and c. Ca represents the capacitance of an element of power cable that does not contain a defect. Cb and Cc represent an element of cable that contains a void defect, where Cc is the capacitance of the void and Cb represents the remnant cable element capacitance. Sg is the spark gap that represents the discharging defect/void.

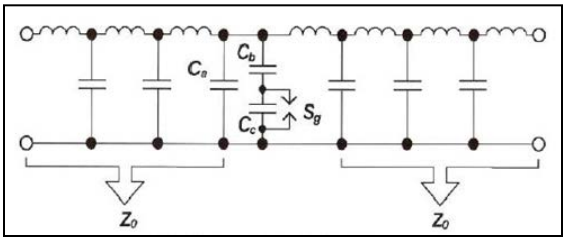

Figure 2: Equivalent circuit for power cable PD [6]

The online approach uses PD signals captured under operating conditions of voltage and temperature. The ability to test without disconnecting the system is often cited as an advantage. However, no less effort is required as some form of sensor needs to be attached at multiple locations of the cable system. This may be much easier for conduit systems tan for direct buried systems. This entails risks, including safety risks for line crews. In one form of this approach, the technique cannot pinpoint discharge locations between sensors. Discharges that are active only above operating voltage go undetected. The inability to locate discharges distant from the sensor may not be a serious handicap as many utilities replace cable sections or accessories rather than repair a specific location. In these cases, the ability to locate PD within a few feet is insignificant. Providers' different approaches make it very difficult to compare quantitative measurements [6]

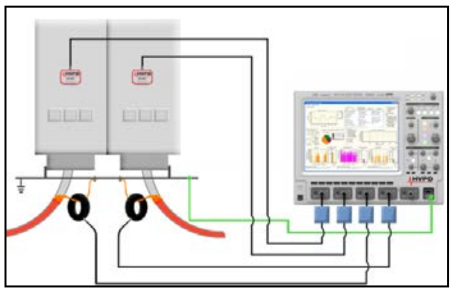

Figure 3: PD Online connection at substations

Selection of Test Sample

Actual testing evaluation was performed through onsite testing on actual cable circuits TNBD underground network. Actual onsite was performed to identify the capabilities of such online partial discharge system. Test circuits were selected based on the cable selection criteria. These criteria were selected based on the cables characteristics which are as follows:

- Accessibility of the grounding
- XLPE / MIX & PILC
- Severity index 3, 4 & 5
- Good condition & accessible link boxes

For onsite testing, six (6) cable samples from medium voltage underground distribution cable network as listed in table 2 were selected. Actual testing results from the field were compiled and compared with the OWTS measurement results.

Table 2: List of cable circuits of TNBD underground network

No.	Area	System	Near End	S/Gear	Far End	S/Gear	Cable Type	Length	Link Box	Estimated Joint No
1	Beranang	33kV	PMU Beranang (1L5)	VCB Tamco	PPU Beranang (B72)	VCB Tamco	XLPE/1C/630mm2	1617m	2	5
2	UNITEN	33kV	PPU Ikatan Bangi (H1)	VCB Tamco	SSU PRI (H50)	VCB Tamco	XLPE/1C/630mm2	1011m	1	2
3	Cheras	11kV	PE Jln Temenggong 10/7 BMC	Felcon Beta	PE Commercial Area No.2	Felcon Beta	XLPE/3C/240mm2	336m	n/a	1
4	Cheras	11kV	PE Jln Bendehara 12/7 BMC	Felcon Beta	PE Jln Putra 13/1 BMC	Felcon Beta	XLPE/3C/240mm2	1110m	n/a	7
5	Cheras	11kV	PE Pejabat Hutan Cheras	Felcon Beta	PE Tmn Cheras Zen	Felcon Beta	XLPE/3C/240mm2 + PILC/3C/185mm2	488m	n/a	4
6	Cheras	11kV	PE Pejabat Hutan Cheras	Felcon Beta	PE FRU	VCB Toprank	XLPE/3C/240mm2 + PILC/3C/185mm2	976m	n/a	6

FIELD TEST EVALUATION

Field study evaluation has been performed using several assessment criteria that are grouped in to three Categories e.g. Field Suitability, Test Management, Data Analysis and Report Preparation. Each Category consists of a few assessment criteria relevant to the category title. The assessment criteria are listed in Table 3.

Table 3: Onsite assessment criteria

Field Suitability	• Compactness – integrated or multiple pieces • Equipment Portability • Equipment handling and manpower requirement at site • Safety features
Test Management	• Test procedure • Test equipment setup (ease and expediency) • Test Protocol preparation • Test Object Library • Test duration
Data Analysis and Report Preparation	• Data and Results Retrieval procedure • Result Presentation • Data analysis and Interpretation • Report preparation • Data security

Scoring and Weighting Criteria

Category Score

The field and laboratory assessment has been performed based on three categories as listed in Table 4. Each Category has a few assessment criteria. The evaluation result for each assessment criterion is expressed in numerical term called "Criterion Score".

Category Weighting Factor

Weighting factors used in the field and laboratory assessment methodology recognize that some group assessment criteria affect to a greater or lesser degree than other group assessment criteria.

Total Score

The Group Scores are then weighted and summed to determine the "Total Score". This "Total Score" will be used to determine the "Overall Ranking" of all the dielectric response system in the order of merits.

Summary of Field Testing

Key observations and findings of onsite field are summarized in the following Table 4

Table 4: Summary of field testing

Circuit	Key Findings	Conclusion
C1-33kV	PD1 and PD2 shows no pd activities, PD3 however high pd level was detected at red phase.	OWTS shows high pd activity at the cable joint. Only PD3 shows similar result as OWTS
C2-33kV	PD1 detect internal pd and corona, PD2 detect cable pd and was located at the substation however no cable pd was detected using PD3.	OWTS shows high pd activity at the cable and small pd activity at the termination. PD1 and PD2 shows similar result as OWTS
C3-11kV	PD1 and PD2 shows no pd activities, PD3 however high pd level was detected.	OWTS shows high pd activity at the cable and small pd activity at Yellow and Blue phase Only PD3 shows similar result as OWTS
C4-11kV	No cable pd was detected using PD1 , Intermittent cable pd activity was detected from another circuit (crosstalk) using PD2 and PD3 detect pd activity from the transfomer	OWTS measurements shows no significant cable pd at on this circuit. All online system shows similar result as OWTS
C5-11kV	PD1, PD2 and PD3 detected local pd activity at the termination.	OWTS measurements show pd activity at the termination and at joint no 1. All online system shows similar result as OWTS
C6-11kV	PD1 detected external disturbances, corona and internal pd at the substation , PD2, PD3 shows no pd activity	OWTS shows high pd activity at the cable and small pd activity at Red and Yellow phase. None online system shows similar result as OWTS

SUMMARY OF ANALYSIS/FINDINGS FOR FIELD ASSESSMENT

Key points of findings are as follows:-

Field Suitability Assessment:
PD1 and PD3 have scored the highest as the Units are more compact and easy to handle at site compared to PD2. It is worth mentioning here that from the safety features point of view all of them are good.

Test Management Assessment:
PD1 and PD2 are at the top of the list. PD1 and PD2 have detailed Test Procedures and Test Protocol Preparation. PD3 has scored slightly better than the PD1 because of the "Test Protocol Preparation" criterion. It is worth mentioning here that from the Test Duration point of view PD2 "Test Duration" is the best compared to others.

Data Analysis and Report Preparation Assessment:

PD2 is at the top of the list. PD2 is strong in the areas of "Result Presentation", "Data Analysis and Interpretation", "Report Preparation" and "Data Security". In "Report Preparation" criterion PD2 and PD3 are equally strong. Based on these criteria it is found that PD2 is better than others.

CONCLUSION

The PD on-line measurement system has to be assessed as suitable for application to MVUG cable system in question based on criteria encompassing full compliance to standards in every respect along with explicitly expressed test procedures and protocol to ensure consistency in application and outcome. In terms of functional capabilities, it must be able to demonstrate effectiveness in consistently detecting and locating the source of PD, if there is PD, at the time of scanning. The measurement system has to be sufficiently sensitive and reliable in generating sets of information and analysis to specialist users in diagnosing presence of PD sources and locations. The set of assessment criteria, assigned weightages and rationales are developed to provide an objective assessment methodology or approach. As it turned out, each measurement system has its own strengths and weaknesses though the difference is perhaps marginal. However, based on established criteria for both desktop and field assessments, PD2 edged past PD1 and PD3 as the highest ranked measurement system.

PD2 PD on-line measurement system demonstrated design and application capabilities to offer an effective on-line PD diagnostic tool and subsequently assessed to be effective for field application to MVUG cables. On possible application of PD on-line measurement system, it has to be driven by well-developed driving asset strategy for MVUG cables life cycle management that balances cost, performance, values and risks in deploying set of diagnostic tools including PD on-line. However, the need for an experienced expert user is yet another critical consideration in its deployment.

Based on the benchmarking exercise it was found that not many utilities use Online PD detection / location for underground cable maintenance purposes. This may be due to it being less accurate when compared to the off line PD mapping technique. Since not many utilities have been adopting the Online PD monitoring technique, the technology is most probably NOT MATURE yet and needs many field experiences and testing data for references.

All the online technologies evaluated used HFCT for PD detection. It is worth mentioning, that using HFCT for PD detection on long length cable circuit especially for single core cable is an advantage where direct coupling technique via off line PD mapping has the limitation. The HFTC sensor can be installed at any assessable link boxes along the cable route for sectionalizing PD location.

In addition, maintenance strategy need to be clearly defined as how to utilize the online PD testing technology; to be used for scanning or locating purposes which shall require severity indicators to facilitate maintenance action after test. Based on this clear strategy, online PD testing can be assigned to appropriate maintenance level of either Tier 1: if it is to be used as a preliminary scanning for PD or Tier 2: if it is to be used for localization.

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