PARTIAL DISCHARGE MAPPING OF MEDIUM VOLTAGE CABLES
– TNB’S EXPERIENCE

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SUMMARY

The ability to proactively diagnose the
dielectric integrity of cables in service could
greatly assist utility in formulating a cost
effective maintenance program and at the same
time ensuring good quality supply to its
customers. For this purpose, TNB has
embarked on some intensive exercises to
evaluate the effectiveness of those diagnostic
techniques that are commercially available in
the market. Partial discharge mapping is one
of the techniques that had undergone extensive
field trial in TNB.

A brief insight on the details that is discussed
in this paper is as presented below.

i. TNB had begun on the measurements of
partial discharge activities on medium
voltage cables in June 1998. Hitherto, a
total of 209 feeder circuits had been
tested, which includes XLPE, PILC and
a combination of XLPE/PILC cables,
operating at 11kV and 22kV. About 20%
of those cables that had demonstrated
extremely high partial discharge values
were re-tested after a period of 6 months.

ii. Similar tests were conducted in
conjunction with Very Low Frequency
(VLF) testing technique on 27 cable
circuits that were prone to failures.
During these exercises, partial discharge
mappings were performed before and
after the VLF tests to detect any change
in the partial discharge activities within
the cable insulation. The VLF tests were
conducted based on test method as
recommended in the European
Harmonization Documentation HD 620
S1.

iii. A detailed analysis on the correlation
between the magnitude of partial
discharges versus the probability of time
to failure, based on the actual fault statistic.

This study indicates that though partial
discharge is both the symptom and cause of
deterioration, it does not necessarily represent
the probability of time to failure of these
cables. There are other attributes that could
cause the cable to fail earlier than anticipated,
such as ingress of water. Defect of this nature
generally does not generate any partial
discharge activity and hence would not be
detected by this testing technique.
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ABSTRACT

The ability to proactively diagnose the dielectric integrity of cables in service could greatly assist utility in formulating a cost effective maintenance program and at the same time ensuring good quality supply to its customers. In line with this objective, TNB has embarked on some intensive exercises to evaluate the effectiveness of those diagnostic techniques that are commercially available in the market. Partial discharge mapping is one of the techniques that had undergone extensive field trial in TNB.

The paper discusses in details the utility’s experience on this study which includes,

• Measuring the partial discharge activities in 209 medium voltage cables.

• Conducted conjuncture tests of partial discharge mapping and Very Low Frequency testing on 27 feeder circuits that were prone to frequent failures.

• Examined the correlation between the magnitude of partial discharge activities and probability of time to failures.

1. INTRODUCTION

Tenaga Nasional Berhad (TNB) is the largest electricity utility in Malaysia serving over 5 million customers throughout Peninsular and Sabah, with a peak maximum demand of approximately 9800 MW. The HV distribution systems are operating at 33kV, 22kV and 11kV and about 80% of the networks are underground cables. At this present moment, there are approximately 180,000 kilometers of medium voltage cables in service in its distribution networks.

By tradition, TNB had been relying solely on DC pressure testing to validate the overall dielectric integrity of the cables after installation at sites. The same practice is retained when XLPE cables were introduced into the system about 20 years ago. However recent study on cable failures in Europe and North America had revealed the fact that this traditional method of cable testing, which is relatively reliable on PILC cables, is ineffective in detecting potential defects in XLPE insulation. It has also been established that DC voltage testing could induce trapped space charges in the polymeric material, which are detrimental to the dielectric strength of the cables (1). It was reported that many breakdowns had occurred in polymeric cables when they were re-energized, shortly after they had been successfully tested with DC voltage (2).

Similar problems had surfaced in the underground distribution networks in TNB. Medium voltage cable failures had accounted for about 53% of the total HV faults occurred in the system. The nature of failures is 72% on joints, 22% on cable insulation and 6% on terminations. Three major processes were instituted to prevent similar failures from recurring in future.

i. Upgrade and maintain the quality of workmanship by creating a group of specialist jointers to provide personal coaching to other jointers at work sites, which includes joint analysis of faults.

ii. Institute a Product Acceptance Certification Program to ensure that only materials of approved design and quality are accepted for use in the system.

iii. To identify and adopt new diagnostic testing technique that could effectively detect potential defects in cables. Preemptive actions could then be instituted timely to remove these defects from the system prior to actual failures.

Program (i) and (ii) were instituted in early 1998 and had produced very positive results. They had effectively arrested the problems of premature failures of cable joints/terminations due to materials of inferior quality as well as poor workmanship at sites. In Metro Region where all new installations works were closely monitored, a total of 7446 joints/terminations were installed over
a period of 12 months and only 7 jointed had faulted till now. Postmortems conducted on these faulted joints also revealed that these failures were attributed to external factors, which were beyond the control of the cable jointers.

Henceforth, the challenge at hand for the utility is to identify a new diagnostic testing technique that could effectively detect potential defects in the cables in service. This will assist in enhancing the quality of supply to the customers as well as lowering operational and maintenance costs.

2. PARTIAL DISCHARGE MAPPING OF CABLES

Partial discharges are small discharges in the insulating materials. They are both symptoms and causes of deterioration. Partial discharges are recognized as the major reason for aging and eventual failure of electrical insulation, though it is rather difficult to establish a direct relationship between these two parameters. A partial discharge occurs when the voltage across the void or defect exceeds a critical threshold. When this occurs, the voltage across the defect will be largely neutralized. The neutralization process is accompanied by a redistribution of charges in the metal shields and the interface surrounding the insulating materials. For this reason, a small voltage pulse of nanosecond range and milivolt in amplitude will be generated during each of these discharges.

In line with international standards, partial discharge measurement is stipulated as one of the test requirements in TNB’s technical specification for polymeric cables, joints and terminations. They shall have a partial discharge value of less than 10 pC in when tested in the factory. The ability to monitor the variation in the magnitude of the partial discharges of the cables in service would hence provide a clear indication on the condition of the dielectric insulation within these cables.

2.1 Partial Discharge Mapping Equipment

The equipment uses a test frequency of between 0.05 Hz to 0.5 Hz to energize the cable up to a voltage level of 1.3U0. This voltage will help to generate the partial discharge activities in the cable without causing unnecessary high electric stresses on the dielectric materials. The discharges are then captured and measured by high speed transient recorders or oscilloscopes. The difference in the travelling time between the first incoming pulse and its reflection via the remote end of the cable is used to compute the locations of partial discharge along the cable.

The equipment used by TNB could measure partial discharges in cable from 4 meters to 2500 meters in length. The upper limit is normally dictated by the attenuation of the discharge pulses commonly associated with paper insulated cables (3).

The equipment consists of 3 major components as described below.

i. HV Supply Source

The HV supply source is powered by a 240 volts AC supply. It operates at frequency of between 0.05 Hz to 0.5Hz with a maximum output voltage of 40kV peak.

ii. Detection Circuits

The magnitude of partial discharges are measured via a high voltage blocking capacitor, which is connected parallel to the cable at the test end. A filter and buffer amplifier are used as the detection impedance and the signal is channeled to the measurement system via a 50 ohms coaxial cable.

iii. Computer Controlled Data Analyzer

The discharge activities are recorded in a digital oscilloscope and subsequently transferred to the disc storage under the control of the computer software. The recorded data is then processed to measure the magnitude of these discharges and their respective locations along the cable. The results would be generated in the form of a partial discharge map, which showed the discharge activities as a function of cable length. The measurements for all the 3 phases could be plotted together for ease of comparison and analysis.

2.2 Results On Partial Discharge Mapping

The measurements of partial discharge activities in medium voltage cables began in June 1998. Hitherto, a total of 209 feeder circuits had been tested. Similar tests were repeated on about 20% of these feeders after a period of 6months. A summary on the types of cable tested and results obtained are as tabulated below.

<table>
<thead>
<tr>
<th>Type of Cable</th>
<th>Voltage Rating</th>
<th>No. of Feeder tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>XLPE</td>
<td>11kV</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>22kV</td>
<td>13</td>
</tr>
<tr>
<td>PILC</td>
<td>11kV</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>22kV</td>
<td>36</td>
</tr>
<tr>
<td>XLPE/PILC</td>
<td>11kV</td>
<td>14</td>
</tr>
</tbody>
</table>
### TABLE 2: Results on PD Measurements

<table>
<thead>
<tr>
<th>Type of Cable</th>
<th>Voltage Rating</th>
<th>Feeders with PD</th>
<th>Average value of PD</th>
</tr>
</thead>
<tbody>
<tr>
<td>XLPE</td>
<td>11kV</td>
<td>8%</td>
<td>5,949pC</td>
</tr>
<tr>
<td></td>
<td>22kV</td>
<td>57%</td>
<td>3,648pC</td>
</tr>
<tr>
<td>PILC</td>
<td>11kV</td>
<td>98%</td>
<td>15,589pC</td>
</tr>
<tr>
<td></td>
<td>22kV</td>
<td>61%</td>
<td>1,980pC</td>
</tr>
<tr>
<td>XLPE/PILC</td>
<td>11kV</td>
<td>100%</td>
<td>23,362pC</td>
</tr>
</tbody>
</table>

#### 2.3 Additional Observations and Remarks

The following pertinent features were also noted during the data collection.

i. Eleven (11) feeders developed permanent faults during the partial discharge measurement. These cables faulted during the application of test voltage. In all cases, there was hardly any indication of partial discharge activity in the cable prior to the breakdown at the point of defect.

ii. About 20% of these feeders were re-tested after a period of 6 months. It was observed that the magnitude of partial discharge activities of most cables changes from the results of the first test. Some feeders indicated an increase while others a decrease in the partial discharge activities. The results also shown that some partial discharge activities detected earlier had disappeared while new discharges emerged at different locations.

iii. A few of the feeders tested had faulted later. It was however observed that the probability and locations of the failures do not generally coincide with severity of partial discharge activities captured earlier.

### 3. FIELD TRIAL ON VERY LOW FREQUENCY TESTING

This field trial was organized in March 2000 for TNB to acquire some hands-on experience on the application and performance of this new technique for on site testing of cables. Both XLPE & PILC cables that were prone to failures were identified and selected for this exercise. In addition, partial discharge measurements were carried out before and after the VLF test to detect any changes in the dielectric property of the insulating material during VLF testing.

The magnitude and duration adopted for VLF test were $3U_0$ for 60 minutes. This is in line with the test method as recommended in the European Harmonization Documentation HD 620 S1.

#### 3.1 Results of VLF Field Trial

Twenty-seven (27) circuits of medium voltage cables were tested and 4 feeders failed the VLF test during the field trial. A total of 8 potential joint faults were detected and located during these tests. Further details on the result of this field trial are as described below.

i. There were no significant changes on the magnitude of partial discharge activities after the VLF test as compared with the measurement taken earlier.

ii. For the 8 joints that had faulted, diagnosis conducted revealed the fact that the failures were all attributed to ingress of water. The jointing materials were badly oxidized and corroded due the prolong presence of water. Heavy tracking was also detected in some of the insulation tubing.

iii. It was noted that most of the actual point of failures did not coincide with the locations with severe partial discharge activities. Result on these measurements are as tabulated below.

#### TABLE 3: PD Mapping verses Fault Position

<table>
<thead>
<tr>
<th>No.</th>
<th>PD Measurement</th>
<th>VLF Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>All 3 phases shown PD of 7000pC @ 1750 m.</td>
<td>Both R &amp; Y phase failed the test after 1 min &amp; 48 mins. respectively.</td>
</tr>
<tr>
<td></td>
<td>1st joint fault @ 1400m.</td>
<td>2nd joint fault @ CT bushing</td>
</tr>
<tr>
<td>2</td>
<td>R phase, 1600pC @ 600m</td>
<td>Y phase failed the test after 4 mins.</td>
</tr>
<tr>
<td></td>
<td>Y phase, 1330 pC @ 230m</td>
<td>Joint fault @ 300m.</td>
</tr>
<tr>
<td></td>
<td>B phase, 480pC @ 600m</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>All 3 phases shown partial discharge activities of less 100pC.</td>
<td>B phase failed the test after 30 secs.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Joint fault @ 250m.</td>
</tr>
<tr>
<td>4</td>
<td>Heavy partial discharge activities were detected at the following locations.</td>
<td>All 3 phases failed the first test after 4 mins. Five (5) potential joint faults were subsequently located at the following locations.</td>
</tr>
<tr>
<td></td>
<td>Y phase @ 700m</td>
<td>1st joint fault @ 2600m</td>
</tr>
<tr>
<td></td>
<td>R phase @ 1000m</td>
<td>2nd joint fault @ 3200m</td>
</tr>
<tr>
<td></td>
<td>R phase @ 1800m</td>
<td>3rd joint fault @ 3400m</td>
</tr>
<tr>
<td></td>
<td>Y phase @ 3100m</td>
<td>4th joint fault @ 5150m</td>
</tr>
<tr>
<td></td>
<td>B phase @ 3300m</td>
<td>5th joint fault @ 5390m</td>
</tr>
</tbody>
</table>
4. SUMMARY OF FINDINGS

A summary of the findings is as presented below.

i. Almost all the areas of high partial discharge activities were located at the joints. The magnitudes of these discharges were very high as compared with the requirement of the factory test, which shall be less than 10pC. For the 11kV cables in particular, it was also noted that about 98% of the PILC cables tested exhibited heavy partial discharges, with an average magnitude about 3 times higher than that of XLPE cables. This was most probably attributed to aging of insulating media as these cables are already in service for more than 10 years.

ii. Some of the feeders tested had developed fault in service later. It was however noted that the locations of these failures generally did not correspond to the positions of high partial discharge activities. Tests conducted after repaired also revealed that the partial discharge activities still prevailed at the same locations.

iii. The inconsistency between actual failures and magnitude of partial discharge activities were again noted during the field trial on VLF test. Eight (8) potential joint faults were detected during the field trial and most of these faults did not occur in areas of high partial discharge activities.

iv. Postmortems conducted on the 8 faulted joints indicated that the root causes of their failures were attributed to prolonged ingress of water. This finding explained the inconsistency as highlighted earlier, i.e. most of cable failures in TNB were attributed to ingress of water in the joints which would not support the generation of partial discharges.

5. CONCLUSION

TNB has conducted an extensive study on partial discharge mapping of cables in its effort to identify the right diagnostic tool to monitor the condition of its medium voltage cables in service. Partial discharge mappings were carried out on 209 medium voltage cables within a period of about 2 years. In addition, conjuncture tests were also performed together with VLF testing on 27 problematic feeders. The results of this study revealed the following.

i. The partial discharge mapping technique could quite accurately measure the magnitude and locations of partial discharge activities within the cables. It helps to provide some information on the degree of deterioration of the insulating materials.

ii. On the other hand, though partial discharge is both the symptom and cause of deterioration, it does not necessary represent the probability of time to failure of this cable. There are factors that could lead to the early failure of cables, such as ingress of water. Defect of such nature would not generate any partial discharge activity and hence could not be detected by this testing technique. This problem would have to be resolved first before the testing technique could be effectively employed to predict the probability of cable failures.

iii. In the meantime, it is the author’s opinion that this equipment would serve best as a quality control tool, i.e. for validating the integrity of the cables after installation at sites as well as before the expiry of the warranty period.

6. REFERENCES


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