IMPLEMENTATION OF CONDITION BASED MAINTENANCE FOR MEDIUM VOLTAGE UNDERGROUND SYSTEM FOR TNB DISTRIBUTION

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ABSTRACT

As an effort to improve reliability, Tenaga Nasional Berhad (TNB) Distribution Division embarked on Condition Based Maintenance (CBM) program for medium voltage underground cables after early application of Very Low Frequency (VLF) technologies proven to cause "side-effects" on the insulation integrity of in-service cables. This paper discusses the approach, experiences and way forward in developing and implementing condition-based maintenance program, in particular partial discharge mapping, for medium voltage underground cables ranging from diagnostic technologies, supportive systems and tools for reporting and analysis to set of corrective actions. Overall impact of CBM program and case studies are cited and discussed as learning lessons.

In conclusion, this paper will highlight the key implementation strategies, challenges and issues of condition based maintenance for medium voltage underground system for TNB Distribution.

1.0 INTRODUCTION

Most of the power system equipment requires regular and effective maintenance to operate correctly and meet their design specifications. The consequences of ineffective equipment maintenance can be huge in terms of system reliability indices, revenue loss and organizational image. The traditional time-based maintenance is expensive and not efficient, compared to the conditioned-based maintenance Therefore, the importance of effective maintenance through condition monitoring of electrical equipment in the system is gaining importance to reduce the occurrence of such incidents. Assessing the condition and thereby reducing failures of equipment is a key to improving reliability and also effectively extending the life of equipment. Hence, utilities are continuously in search of best maintenance practices other than traditional methods/techniques to assess the condition of equipment in service so that remedial measures can be taken in advance to avoid disastrous consequences thereby saving lot of valuable resources.

Medium Voltage (MV) underground system represents a large asset base of TNB Distribution and contributed significantly to overall system performance. Causes of failures are predominantly due to issues related to "old cable joint technologies" used since early 80's until early 2000. TNB Distribution introduced new cable joint technologies but large population of joints of older technologies still represents substantial reliability risk to system performance.

2.0 MAINTENANCE REGIME

TNB Distribution Division has migrated from time based maintenance to CBM regime since September 2007. Failure modes, effects, and criticality analysis (FMECA) is being practiced to identify condition monitoring techniques appropriate for different failure modes of equipment to assess their condition. FMECA is a methodology designed to identify potential failure modes for a product or process, to assess the risk associated with those failure modes, to rank the issues in terms of importance and to identify and carry out corrective actions to address the most serious concerns.

Some of the advanced methodologies are developed in-house and incorporated into CBM-Distribution Maintenance Management System (DMMS). The severity and health indices based on sets of diagnostic tests conducted for the equipment are computed in CBM-DMMS.

Condition index may be used as an input to the risk-and-economic analysis computer model where it adjusts the equipment life expectancy curves. The output of the economic analysis is a set of alternative scenarios, including costs and benefits, intended for management decisions on replacement or rehabilitation. Following are the Tier 1 and Tier 2 tests conducted for MV underground power cable.

Tier 1

Maintenance Tests/Condition
Thermography
Tan δ
Insulation resistance
Operation and maintenance performance
Age

Tier 2

Maintenance Test
Dielectric spectroscopy
Partial discharge

Table 1: Cable Condition Indicators

Figure 1 below outlines the methodology for the computation of condition health index for assessing MV underground power cable condition. Each test in Tier 1 is assigned an indicator score, based on test results, and a weighting factor based on significance of test in ascertaining the actual condition of the MV underground cable. Tier 2 test results will further accordingly adjust overall condition health index of MV underground cable system. The condition index score at Tier 1 after incorporating Tier 2 test to give the total condition index value determines the course of intervention or asset management solutions.

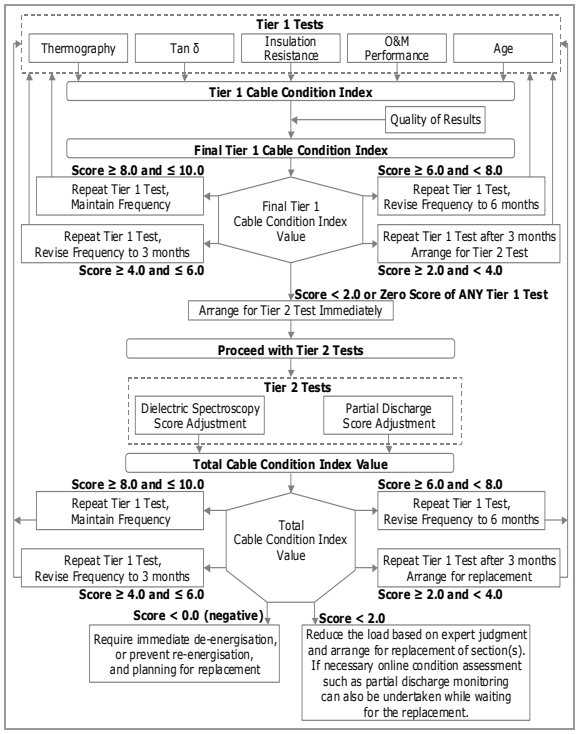

Figure 1: Flowchart for Calculating Cable Condition Index

Following table shows the total cable condition index score and its recommended action:

Total Cable Condition Index Value	Suggested Course of Action
≥ 8.0 and ≤ 10.0	Continue O&M without restriction. Maintain the normal frequency of Tier 1 tests.
≥ 6.0 and ≤ 8.0	Repeat Tier 1 test after 6 months. Conduct Tier 2 tests as needed.
≥ 4.0 and ≤ 6.0	Conduct Tier 2 test. Repeat Tier 2 tests as needed.
≥ 2.0 and < 4.0	Conduct both Tier 1 & Tier 2 tests after 3 months from this condition assessment activity.
≥ 0.0 and < 2.0	Reduce the load based on expert judgment and arrange for replacement of the unit.

Table 2: Cable Condition Based Alternatives

3.0 DIAGNOSTICS TESTING TECHNIQUES

The cables used in TNB Distribution are either solid dielectric or oil-filled. Cables are tested in accordance with manufacturer's recommendations and industry standards. TNB Distribution has introduced the Pre-moulded MV underground cable joints as a replacement for the heat shrink joints as TNB moves away from heat shrink technology. TNB has embarked to CBM strategy for its MV underground cable maintenance.

In year 2000, VLF testing was introduced in TNB extensively and it was used as withstand test for commissioning, after repair work, and reliability testing. Initially, the main goal of using VLF was to flush out the weak points in the system. Then, on April 2006, Partial Discharge (PD) mapping was introduced as one of the diagnostic testing methodology for MV underground cables in TNB Distribution Division network and it was used as the baseline reference. From 2006, VLF test was used only as withstand test for commissioning and after repair work. PD mapping was introduced as the replacement for withstand testing to test the reliability of the MV underground cables.

It is well known that Diagnostic Techniques able to reveal the presence of localized defects in insulation systems and it is very important to improve the reliability of the electrical network. PD measurement is the most important and reliable, non-destructive measurement to ensure performance and lifetime of HV equipments. Partial discharges occur in the power cable insulation system and it is normally caused by the presence of voids or cavities within the insulation system. When a particular void experiences potential gradient greater than its breakdown strength, discharge bridging will take place between the two affected surfaces of the void. The effect is localized burning of the insulation. As the process continues, the void will grow on to form electrical trees that finally cause insulation failure.

TNB Distribution currently performs all tests in Tier 1 except Tan δ and Partial Discharge Mapping as the advanced testing for Tier 2 for the MV underground power cables.

4.0 ON LINE VERSUS OFF LINE PD MAPPING

TNB Distribution Division evaluated both off- line and on-line PD Mapping system prior to deciding on off-line PD Mapping as the advanced diagnostic testing.

Partial Discharge Monitoring: On-line Technology

Following were the observations based on the field testing for on-line PD mapping test conducted at TNB network system:

- Physical accessibility to cable termination and the possibility for a suitable sensor location was a deterrent in this technique.
- Only about 20% of all cable terminations selected were accessible in this exercise because most of them are installed in switchgear cable box, which can only be opened and worked on after shutting down the system.
- The on-line partial discharge measurements are strongly influenced by the actual high frequency noise disturbance signals originating from the network. Filtering may help but with doubtful efficiency.
- It is known that changes in the cable operating conditions influence both the partial discharge inception voltage and amplitude. However, this important information cannot be obtained from the test.
- Analysis of partial discharge activity at different voltages such as inception voltage (PDIV), extinction voltage (PDEV) and phase voltage is very important. This system is not able to provide that information.
- The partial discharge location cannot be detected precisely by this system. It could only indicate which cable section has partial discharge activity.

Partial Discharge Mapping: Off-line Technology

Following were the observations based on the field testing for off-line PD mapping test using (Oscillating Wave Testing System) OWTS and VLF test systems conducted at TNB network system:

- The test can be carried out for all type of switchgears. Shutdown is needed as this is off-line technology.
- Measurement can be concentrated to a particular cable segment. The termination should be opened to avoid any confusion on the discharges from the other equipment. It will also detect if there are any discharges at the termination.
- It is possible to measure the absolute value of the discharges in pC or nC and also in µV or mV because the measurement can be calibrated.
- The information on partial discharge inception voltage, extinction voltage, discharge location, discharge magnitude and discharge density are very important to make decision for the course of action to be taken. OWTS system can provide this information, while VLF system could not provide the information on actual inception voltage and extinction voltage.
- Analysis of partial discharge activity at different voltages such as phase voltage and peak voltage is very important. The OWTS system is able to provide that information, while the VLF system offers only step voltage facility.

Based on observation and experience related to the field testing conducted, it could be concluded that on-line partial discharge detection is a relatively new technology. There are many site limitations, which need to be considered before applying at site. The most critical constraint for an on-line technology is accessibility to the cable termination. Minimal information obtained cannot really provide enough guidance on decision making for further action to be taken. Since so many utilities and academicians are still doing research on the partial discharge detection technology, the progress should be monitored and due consideration should be given in the future.

Our experiences with off-line partial discharge testing as a cable diagnostic system have produced very convincing results. Comparing the two technologies that have been tested on site, the OWTS seems to offer more information and better guideline on the next course of action to be taken after acquiring the results from the testing. A study by CESI [1] has also recommended the OWTS system for the cable diagnostic program not only in terms of technical aspects but also commercially.

5.0 FINDINGS FROM PD MAPPING TESTS

Many PD tests have been conducted in TNB. The occurrence of PD could be due to various reasons. Some of them are as listed as below:

i. Poor workmanship during jointing.

ii. Electrical tracking which lead to electrical tree growth was observed.

iii. Presence of voids.

iv. Presence of defects linked with the penetration of water or contaminants in the accessory.

v. Carbonised paper.

vi. Improper cable preparation/wrong assembly of joints; etc.

Cable circuits which had very low total cable condition index after the PD diagnostic testing were identified and the joints/cables were replaced. Following are some of the observations after conducting the post mortem:

Figure 2: MV Cable Joints Defects Observed during Post Mortem after conducting PD Mapping Test

6.0 CHALLENGES IN CBM PROGRAM IMPLEMENTATION

The CBM program that is implemented in TNB, had faced numerous challenges. The main challenge is the paradigm shift of the management and operational people, from the time-based maintenance to the conditioned-based maintenance.

Following were the major challenges faced during the implementation of the CBM program in TNB Distribution Division:

- People skill.
- Financial constraint.
- Training.
- New knowledge on the maintenance regime.
- Interpretation of the results, condition health index and the weightages based o the test data.
- Using the new diagnostic tools and equipment.
- To update the asset registry ERMS-PM (SAP application) to successfully implement CBM-DMMS system.

Continuous training and feedback from the staff is crucial in ensuring the successful implementation of the CBM-DMMS system for MV underground cable system. The management and staff have to work closely in ensuring the asset management initiatives and objectives are achieved in TNB.

Knowledge and competencies of Transmission and Distribution utility personnel at various levels will have to be assessed and comprehensive training program have to be developed to bridge any possible gaps. Of course, organization structure and manning level will have to be resolved for any human capacity development program to have the desired long-term impact. Workforce development will cover equipment technologies, maintenance and diagnostic methods, failure investigation and root cause analysis as well as related processes and procedures.

The CBM program implemented in TNB is constantly being reviewed. Since its implementation, many data have been acquired & analyzed; hence better understanding of the severity of the condition or health of the equipment has been established. The tests weightages, severity index and health index is constantly being adjusted, when new finding is established.

Until 2009, CBM program have shown that it is able to reduce significantly the number of unwanted failures or breakdown of the power equipments. The average SAIDI for the TNB Distribution network for the last financial year was 68.5.

7.0 CONCLUSION

The CBM program introduced and implemented in TNB had shown positive results, in bringing down the number of unplanned outages and interruptions to customers in the distribution system. It has also enabled the engineers to embark on a proper structured asset maintenance plan towards achieving a good asset management work culture.

In conclusion, the development of industry standard asset management capabilities in Transmission and Distribution utilities will have to be driven by top management as it requires leaders to embrace new risk-taking mindset, knowledge-based awareness, renewed focus to drive and institute wholesale changes in many critical areas such as organization structure, competencies and information system and other relevant areas within the organizational environment.

REFERENCES

[1] G. Rizzi, M. Nigris, A. Fara, V. Colloca, *Comparisan Among Different Diagnostc Systems for MV Cable Lines.*

[2] G. Rizzi, 2005, *Modern Approach to Condition Assessment of MV Power Cables*. CIRED.

[3] TNB, 2007, *CBM Manual for, MV Underground Cables,* Malaysia.

[4] TNB, 2009, *Application Manual of Distribution Asset Risk Assessment Tool (DARAT),* Malaysia.