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An Approach to Determine Health Index of Power Cable System

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Abstract

Power Cable System is a vital asset in Electrical Power System. Now a days power cables are used in transmission and distribution of electric power at MV, HV and EHV levels. Reliability and availability of power supply depends greatly on insulation condition of the power cable system. Therefore, power cable asset management is vital for taking decision on future course of action to minimize capital expenditure, maximize reliability and avoid forced outages. In this paper, how to deploy power cable asset management is discussed using Health Index based on diagnostic test data.

Keywords: Asset Management, Condition Assessment, Diagnostic Testing, Health Index

1. Introduction

Field testing of power cable systems can be used as a cable system asset management strategy. Data generated can be used for condition assessment and ranking. It can provide utility planners and other users with condition based information necessary to minimize capital expenditures and maximize reliability. At present due to decentralization of power sector and involvement of multiple stake holders, the asset owners or asset managers of generation, transmission and distribution utilities are encountered with the challenge to obtain the overview of the health and risk of large amount of assets in terms of maintenance action required, the remaining life expected, and the risk if no action is taken. The solution is an approach and system that works on the available data and provides a dashboard with best possible prediction. Power cable systems play a vital role in electrical power system. Therefore, condition of its insulation system needs to be assured as accurately as possible.

Health Indices is a practical technique to quantify O & M History, Visual Inspection and observations, laboratory and field diagnostic test data for arriving at overall condition of the asset. Asset Health Index is a useful tool for asset management and identifying investment needs and prioritizing investments in to new assets and maintaining old assets.

Several studies discuss diagnosis and condition assessment of power cables by offline diagnostic testing or online monitoring of parameters such as Insulation Resistance, Tan Delta Capacitance, and Partial Discharge etc. Very few papers are published in the area of statistical analysis diagnostic test data, health indexing and asset management of power cable system. In this paper an attempt is made to determine health index of power cable system in the same line for that of power transformers.

2. Diagnostic Test Data

According to IEEE Std 400-2012[1] the following test methods are proved effective for diagnosis and condition assessment of power cable system.

- Dielectric Response Methods
- Dissipation Factor (tan delta)[2]
- Leakage Current
- Recovery Voltage
- Polarization/Depolarization Current
- Dielectric Spectroscopy
- Partial Discharge Methods[3,4]
- Online
- Offline

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2.1 Dielectric Response Method

Dissipation Factor (tan delta), DC Leakage Current, Recovery Voltage, Polarization/Depolarization Current and Dielectric Spectroscopy methods provide an overall condition assessment of the complete cable system by offline testing. VLF Tangent Delta (TD), Differential Tangent Delta (DTD) and Tangent Delta Stability (TDTS) are considered for this work as Health Indices. The TD at 0.5 U_0, U_0, 1.5 U_0 are measured and DTD = TD (1.5 U_0 - 0.5 U_0) is calculated. The variation of tangent delta with at a particular voltage (TDTS) is measured and from which the mean standard deviation of the readings are calculated. $STDEV = \sqrt{\left\{\sum\left[(TD-\overline{TD})\div(n-1)\right\}\right]}$ where TD is tangent delta and TD is the mean or average value.

Table 1. Historical figure of merit for condition assessment of service-aged pe-based insulations

Condition Assessment	Tangent Delta Stability at U0 [10^{-3}]		Tip Up (1.5U0–0.5 U0) [10^{-3}]		Tangent Delta at U0 [10^{-3}]
No Action Required	<0.1	and	<5	and	<4
Further Study Advised	0.1 to 0.5	or	5 to 80	or	4 to 50
Action Required	>0.5	or	>80	or	>50

Table 2. Cable system rating based on Dielectric Response Factor (DRF)

Rating Code	Condition	Description
A	Good	DRF<1.2
B	Acceptable and Need Caution	1.2≤DRF<2
C	Poor and Need Action	2≤DRF<3

Table 3. Scoring and weight factors for dielectric frequency response data

#	Parameter	Score (Si)			Wi
		1	2	3	
1	VLF TD	<4	4 to 50	>50	3
2	VLF DTD	<5	5 to 80	>80	3
3	VLF TDTS	<0.1	0.1 to <0.5	>0.5	3
4	PI (Polarization Index)	>1.1	1to 1.1	<1	1

Table 1 gives historical figure of merit recommended in IEEE Std 4000.2-2013 for condition assessment of service-aged PE-baed insulations (e.g., PE, XLPE, and TRXLPE) using 0.1 Hz. Considering the IEEE recommendations, Table 2 and Table 3 introduce a ranking method developed using the Dielectric Response (VLF TD, VLF DTD and VLF TDTS). The Dielectric Response Factor (DRF) is described in Equation (1).

$$DRF = \frac{\left\{\sum_{i=1}^{4} SiXWi\right\}}{\sum_{i=1}^{4} Wi} \qquad (1)$$

2.2 Partial Discharge Method

Partial Discharge testing can indicate discharge locations (e.g. voids, sharp points/edges, floating parts, electrical treeing and tracking) as possible weak spots in cable system. Partial discharges are initiated in the localized areas of the cable insulation, joints, or terminations under electrical stress during overvoltage, steady state conditions in service, or by external test voltage. Partial discharges can be described by many important parameters such as PD inception and extinction voltages, PD pulse magnitude, PD patterns, and PD site location in power cable circuit. PD field measurements can be performed either online at U0 or offline at higher than Uo. Based on the field experience of the author[5–8] on PD diagnosis scoring and weighting factor for PD data has been decided. This does not have any standard recommendation. Similar scoring method as used for dielectric response is also used for PD data.

Table 4. Scoring and weight factors for partial discharge data

#	Parameter	Score (Si)			Wi
		1	2	3	
1	PDIV/PDEV	>1.5 U0	1 U0 to 1.5 U0	<1 U0	3
2	Insulation PD	<10 pC	10 pC to 20 pC	>20 pC	2
3	Joint PD	<500 pC	500 pC to 1000 pC	>1000 pC	3
4	Termination PD	<150 pC	150 pC to 250 pC	>250 pC	2

3. Health Index Formulation

Health indexing can quantify the power cable system condition based on numerous condition criteria or step by step logical sequence that are related to long term degradation factors that together lead to end-of life. Health indexing differs from maintenance testing which gives importance on finding the defective cable system component that need corrective or remediation to keep the cable system operating reliably during some time period. The objectives of formulation of a composite Health Index are:

- The health index should be indicative of the suitability of the cable system for continued service and representative of the overall cable network asset health.
- The index should contain objective and verifiable measures of cable asset condition, as opposed to subjective observations.
- The index should be understandable and readily interpreted.

Considering all the discussed parameters, the total HI for a power cable system is proposed in Equation (2).

$$HI \quad = 50\% \frac{x\left\{\sum_{j=1}^{j=1} KjXHIFj\right\}}{\sum_{j=1} 3Kj + 50\% \frac{x\left\{\sum_{j=2}^{j=2} KjHIFj\right\}}{\sum_{j=2} 3Kj}} \qquad (2)$$

Table 5. Health index scoring

#	Cable System Condition Criteria	K	Condition Rating	HIF
1	Dielectric Response	5	A,B,C	3,2,1
2	Partial Discharge	5	A,B,C	3,2,1

4. Health Index Rating

By multi-criteria analysis approach, the various factors can be combined in to a condition-based Health Index.

This involves grouping together various factors, crafting the mathematical and/or logical formulations, and establishing important weightings of all the factors to allow combining them in to a single Health Index.

Finally, Table 6 provides categories of Health Index results and correlates expected life time and action required.

A sample output results for power cables of heavy industry in India involved in Steel and Power is provided in Figure 1. In this case 86.11 % of power cables have a HI of more than 75% (Good). This classification gives a general idea to the utility about the overall health condition of the power cable asset.

Table 6. Health index and cable system expected life

HI	Condition	Expected Lifetime	Requirements
75-100	Good	More than 20 years	Normal maintenance
50-75	Acceptable	More than 15 years	Increased diagnostic testing and possible remedial work.
0-50	Poor	Near end of life	Immediately assess the risk: replace or repair based on assessment

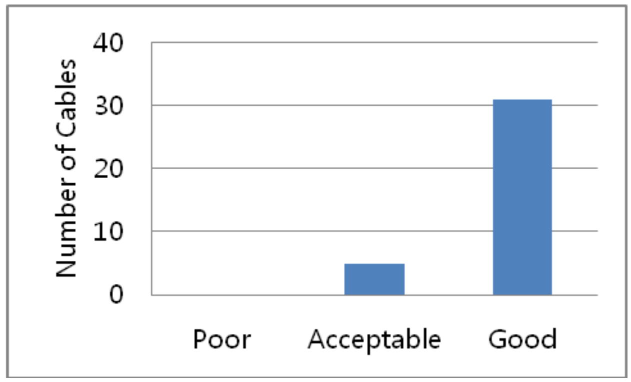

Figure 1. Result of HI analysis for a group of power cables

5. Conclusion

Dielectric Response and Partial discharge test data represent degradation of cable insulation system which in turn leads to end of life of a power cable system are considered to determine Health index. This paper illustrated application of health index method for power cable system using available data, field diagnostic experience of the authors and the recommendation of IEEE guidelines.

Some of the Dielectric Response parameters (like VLF Tangent Delta (TD), Differential Tangent Delta (DTD), Tangent Delta Stability (TDTS) and Polarization Index) and Partial Discharge Parameters (like PD Inception and Extinction Voltages, PD magnitude in Cable Insulation and accessories are considered for this work as Health Indices. Other parameter like load history, service conditions, maintenance record and failure rate parameters will be considered in the future work.

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