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HV SOLUTIONS

CONDITION BASED MAINTENANCE

Recommendation for condition assessment of service aged fluid-filled transmission power cables

Background

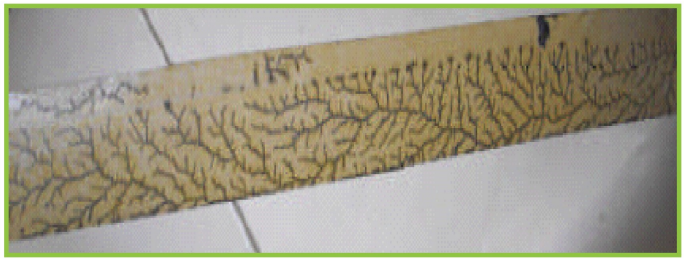
Remaining Life Management of high-pressure fluid filled (HPFF) and high-pressure gas filled (HPGF) transmission power cables (69 kV up to 345 kV) deals with a complex issue, consisting of a combination of technical, strategic and economic factors.

The process of natural ageing strongly depends on the operating mode of the cable system (nominal load or partial load, continuous or short time operation, overloads, number of starts, standstill periods) and on the local environment; the so-called TEAM-factors (Temperature, Electrical stress, Ambient conditions, Mechanical stress).

As the IEC standards are not giving any hand on the topic of power cable systems aging, based on international it can be considered that, see References [1-13]:

- A transmission power cable failure may refer to the situation where one or more of the cable system components e.g., cable insulation, cable joint or cable termination fails, because it cannot withstand operational conditions.
- The effect of a lower dielectric voltage breakdown strength makes that a failure can happen.
- Lower dielectric voltage breakdown strength is related to the deterioration of the dielectric material condition in cable system components.
- Such deterioration processes and externally introduced defects can result in enhanced electric field strength that can result in a breakdown. Insulation defects due to aging are natural effects of the deterioration of the cable system under service conditions.

To reduce the Operational Expenditures (OpEx) and to improve the Capital Expenditures (CapEx) of service aged HPFF and HPGF power cables with voltage ratings 69kV, 115 kV, 138 kV, 230 kV and 345 kV for the maintenance the following approach in the table has to be considered, see References [1-13].



Tracking traces on paper insulation of a 150 kV cable

Type test / diagnosis	Reasons why to use	Expected results	Applicability of the results for Asset Management decisions
Insulation weak spots detection by **damped AC Partial Discharge (PD) diagnosis**	To check for the presence of local insulation degradations that could be harmful in for safe operation in the future.	Using PD diagnosis detection, localization and interpretation of the harmfulness of discharging defects in all cable system components.	Yes, the outcome will provide information about insulation weak-spots. Information about weak-spots harmfulness is important for maintenance planning and future failure probability versus cable system future life estimation.
Insulation integral condition by **damped AC Dissipation Factor (tan δ) diagnosis**	To check for the presence of total insulation degradations that could be harmful in for safe operation in the future.	Using DF (tan δ) diagnosis detection and interpretation of the harmfulness of TEAM insulation degradation.	Yes, the outcome will provide information about insulation degradation. Information about actual condition is important for maintenance planning and future degradation probability versus cable system future load profiles and life estimation.

Damped AC Insulation Condition Evaluation

Damped AC (DAC) technology has the advantage of non-destructive testing and the method provides deterministic values of partial discharge (PD) activities in the cable system as well as the Dissipation Factor (tan δ) of the overall cable system.

The overall cable condition evaluation is performed by:

- **Condition Based Maintenance (CBM)**: DAC HV tests and diagnosis and the evaluation of diagnostic parameters
- **Cable condition index**: Partial discharge values and the PD evaluation together with the Dissipation Factor (tan δ) values are evaluated according to knowledge rules and statistical evaluation to obtain an overall condition index.
- **Future Life Estimation (FLE)**: Diagnosing the life consumption and future life estimation of Paper-oil insulated cable is based on thermal ageing and the diagnostic parameters (DF and PD).

Cable Condition Index

The measured Dissipation Factor (tan δ) and PD analysis are used as input for statistical analysis to obtain DF boundary values for a particular type of cable insulation.
These boundary values can be used for cable condition indexing. To obtain these values the fitted statistical distribution of tan delta values from measurements on comparable cable types are evaluated . The boundary values are used to provide a condition index that is indicated with number and color:

Index 9; very good (green)
Index 8; good (light green)
Index 6: moderate (yellow)
Index 3: poor (orange)
Index 1: very poor (red)

	Phase		
Condition parameter	**L1**	**L2**	**L3**
PD evaluation	3	6	9
Tan δ at 0.5 Uo	9	6	9
Tan δ at 1.0 Uo	8	6	8
Tan δ at 1.4 Uo	6	6	9
Δ Tan δ	1	3	3
Overall cable rating	**6**	**6**	8

Example of statistically obtained condition indices for the PD evaluation and the tan delta values at 0.5 Uo, Uo and 1.4 Uo with the condition indexing levels for an oil-filled 230 kV cable

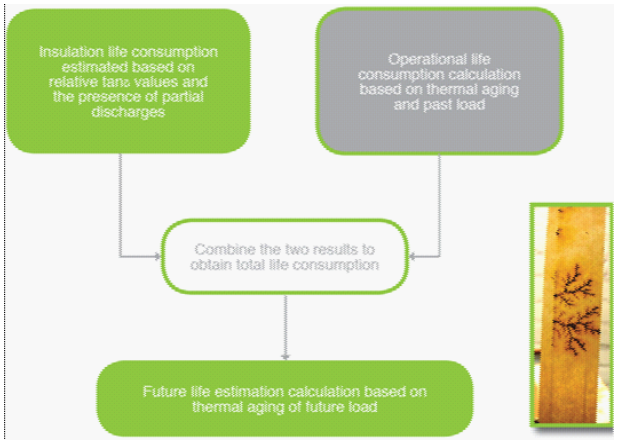
For each phase of a cable circuit at the different voltage levels the condition indexing can be obtained for the measured values. Eventually these values are combined to obtain an overall condition index per phase.

Future Life Estimation

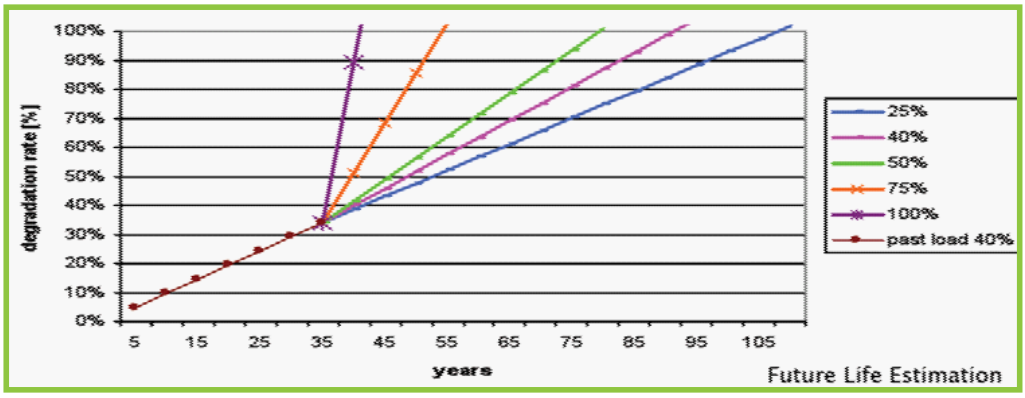
Diagnosing the life consumption and future life estimation of oil-impregnated paper insulated cable can be performed with a special ageing model. The FLE is obtained by combining:

- Insulation Life Consumption ILC), based on the actual measured tan delta values
- Operational Life Consumption OLC), based on thermal aging

Together with the future load, the life estimation can be estimated.



Flow chart of life consumption and future life estimation calculations



Future life estimation example of bad condition cable based on 40% average loading in the past

Conclusions

- The application of damped AC technology with on-site diagnosis of transmission power cables provides the essential information to evaluate your cable condition.
- PD detection is an adequate method to get insight into discharging insulation defects in both XLPE and paper-oil insulated cable insulation.
- The measurement of Dissipation Factor (tan δ) at various voltage levels provides valuable information regarding the overall paper-oil insulated cable insulation ageing.
- The diagnostic information as obtained using onsite DAC testing contributes in the overall cable condition assessment.
- The obtained experiences in the past years provided the information to develop our own specific knowledge rules to support maintenance and replacement activities of transmission power cables.

References

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