The study on diagnostics for aging trend of cable termination

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***Abstract*--The commercial diagnostics of insulation materials of cable system are the measurements of insulation resistance, dielectric power factor, and partial discharge. However, there is no standard stating permissible levels for these measurements. Besides, because the material breakdown may result from material aging or defect aging, the aging trends of different causes may be different. Therefore, two types of defects in cable terminations are made to comparing with good cable terminations. And two accelerating aging tests of cable system are set up in this paper. One is a synergistic experiment of temperature and moisture. Another environment is in a constant ac voltage of 15 kV$_{rms}$ with a 300 A$_{rms}$ current switching regularly. The measurements of partial discharge, insulation resistance, and dielectric power factor are all made periodically. The results show that dielectric dissipate factor has the ability to assess the aging degree of insulation of cable termination, and partial discharge measurement has the ability to detect defects in cable system but can't assess the aging degree of insulation system. The insulation resistance measurement is improper to assess the aging degree of insulation system.**

***Index Terms*—partial discharge, insulation testing, dielectric loss.**

I. Introduction

The Cable system is an important part in power system, and the high reliability is the basic requirement. One way to maintain high reliability is to replace old cables with new ones, while the cable lifetime elapses or the insulation condition is too bad. The lifetime estimation usually supposes cable system is used at predefined environment, and modify it by the load current and ambient temperature. However, the real situation affecting aging is somewhat different with the predefined situation, such as frequent load cycle. Therefore, insulation condition assessment becomes more effective to maintain high reliability of cable system to prevent cable system failure in time.

Insulation resistance measurement, dielectric power factor measurement, and partial discharge measurement are conventional diagnosis of insulation condition assessment. There are certain acceptance value to quality cable and its accessory, and less experiment deal with the acceptance value for in-service cable system. Because the cable won't be changed its structure during installation and the qualification test in factory is strict, the failure rate of cable is quite low in authors' experience. Cable accessory have more complex structure and is handmade assemblage in field. Due to this reason, authors set up a series artifactitious defects in cable termination to simulate the possible workmanship problems. Besides, two accelerating aging test environment also set up for simulating field environment, one is a synergistic experiment of temperature and moisture as severe environment, another is in a constant voltage of 15 kV$_{rms}$ with a 300 A$_{rms}$ current switching regularly to simulate frequent load cycle impaction.

The experiment lasts one year, and no electric breakdown happens yes. One set with synergistic environment show an obviously increasing trend of dielectric power factor. Another test set with frequent load cycle indicted divergent trend with time elapsing. In both test sets, insulation resistance shows incompetent ability to assess insulation condition. partial discharge measurement shows good ability to detect defects, but incompetent ability to assess the aging degree.

II. Ageing Mechanism

According to statistics in literature [3], cable termination and cable joint have highest failure rate among cable system as shown in figure 1. In authors' experience, more than 95 % cable system events are caused by cable termination and cable joint in distribution system and are usually caused by improper workmanship. Because there are many reach deal with cable, such as lifetime estimation, aging effect, insulation condition assessment, authors don't address cable in this paper. Therefore, this paper focuses on the issue of cable termination.

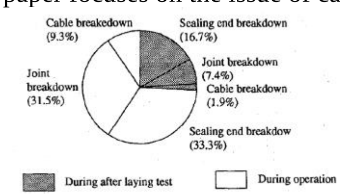
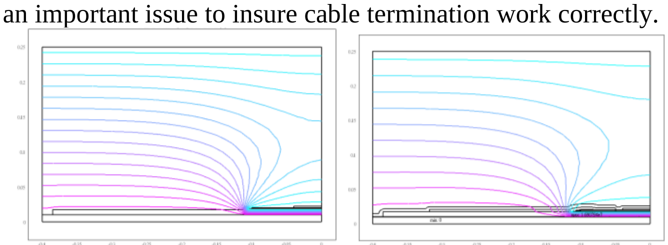


Figure 1 statistics of cable system failures[3]

The main cause resulting in cable termination is the high electric field intensity around the end of out-semiconductor. The stress cone is used to ease electric field intensity shown in figure 2. Hence, the installation of cable termination becomes an important issue to insure cable termination work correctly.



(a) without cable termination (b) with cable termination
Figure 2 potential gradient distribution

Figure 3 shows the structure of cable termination. As shown in figure 3, the cable termination has complex structure and has a delicate installation. Therefore, it is easy to left defects in cable termination reducing its lifetime. Figure 4 shows how these defects affect electric field intensity inside cable termination. Comparing figure 4a with figure 4b and figure 4c, defects will increase the electric field intensity up to 1.27~1.75 times than good one.

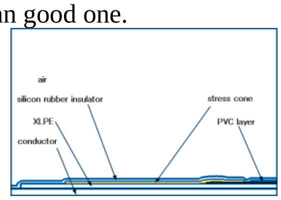
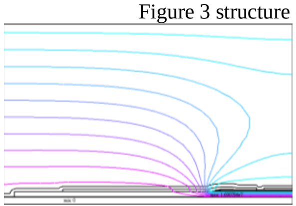
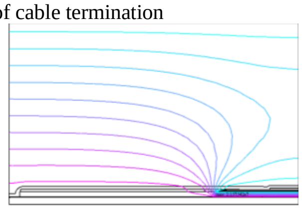


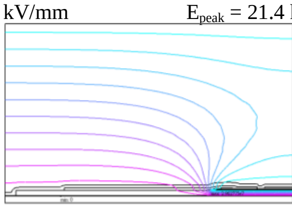
Figure 3 structure of cable termination



(a)Standard installation
E_{peak}=16.9 kV/mm



(b) Stress cone in improper position
E_{peak} = 21.4 kV/mm



(c) void left around the end of out-semiconductor E_{peak}=29.6 kV/mm

Figure 4 electric field intensity resulting from defect

Based on authors' experience, common defects caused by workmanship can be roughly classified as two types: one is contaminants left in insulation including water, dust, and the other is improper position of stress cone not attaching out-semiconductor. Therefore, this paper makes two kind of defects within cable termination separately. Cable termination with contaminant is made by an water-immersed cable without clear during cable termination installation. Cable termination with improper stress cone position is done by stress cone parted from out-semiconductor within 1 cm. A correctly assembled cable termination is taken as reference.

This paper mainly deals with the aging trend of cable termination with different defects. In order to find the aging trend, an accelerating life test take place with two different considerations. One is a synergistic experiment of temperature and moisture, and the other is a constant ac voltage of 15 kV_{rms} with a 300 A_{rms} current switching regularly. The accelerating life time lasts one year, and regularly measures the following index: insulation resistance, dielectric dissipate factor, and partial discharge.

III. Measure Results

the cable and cable termination used herein are 1C*38 mm^2 25 kV XLPE cable and 3M QT-II cable termination. There are twelve cables classified as 3 sets with different defects in cable termination. Table 1 shows the detail of defects in cable terminations. Each cable has two cable terminations, one is with predefined defect and one is correctly assembled. There are two accelerating life tests with different conditions as shown in Table 2. The mentioned monitoring indexes are measured at 0 hour, 312 hours, 696 hours, 1478 hours, 1862 hours, 2486 hours, and 3325 hours.

Table 1

Sample No.	Defect	Description
A1～A4	GOOD	Standard installation procedure
B1～B4	improper position of stress cone	Stress cone is apart from out-semiconductor by 1 cm.
C1～C4	Water	One side of cable is immersed in water for a week before cable termination assembling, and cable termination installation is without clearing.

Table 2

Test Group	Condition	Sample No.
A	Temperature:85 ℃, relative humidity: 90 %	A1～A2, B1～B2 , C1～C2
B	A constant ac voltage of 15 kV_{rms} with a 300 A_{rms} current switching regularly every 30 minutes.	A3～A4, B3～B4 , C3～C4

A. Insulation Resistance

After 3326 hours elapses, insulation resistances of all cables are larger than 250 GOhm no matter what defects they have or what test conditions they are under. This implies that insulation resistance can't be an good index used to monitor the insulation condition.

B. Dielectric Dissipate Factor

During the test period, the dielectric disspat factor shows different properties in two test groups. Table 3 and figure 5 show the measured results and trend chart of group 1. Under the environment of high temperature and moisture, dielectric disspat factor increases as test time elapses. Hence, the relationship between dielectric disspat factor and aging time is positive under the condition of group 1. Table 4 and figure 6 show the measured results and trend chart of group 2. Under the environment of frequent load cycle, dielectric dissipate factor shows no relation to test time, and oscillates with test time. This implies that the operating temperature and moisture affects cable aging more than load cycle does.

Table 3 dielectric dissipate factor under group A

Aging Time	A1	A2	B1	B2	C1	C2
0	.00231	.00189	.00130	.00170	.00256	.00220
312	.00257	.00313	.00161	.00157	.00290	.00330
696	.00327	.00384	.00229	.00184	.00304	.00296
1478	.00551	.00674	.00490	.00318	.00545	.00607
1862	.00858	.01180	.00536	.00485	.00794	.00796
2486	.00708	.00878	.00564	.00424	.00759	.00689
3326	.00906	.01330	.00401	.00680	.00958	.00915

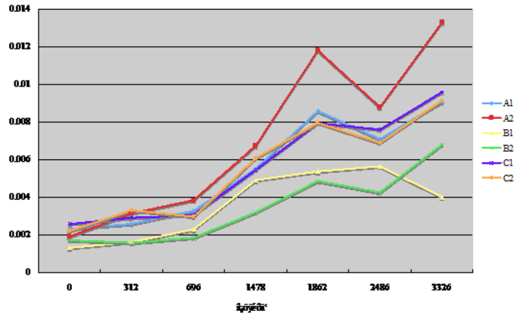


Figure 5 the trend of dielectric dissipate factor under group A

Table 4 dielectric dissipate factor under group B

Aging time	A3	A4	B3	B4	C3	C4
0	.00450	.00303	.00401	.00232	.00257	.00700
312	.00087	.00079	.00063	.00054	.00630	.00810
696	.00127	.00110	.00125	.00097	.00112	.00116
1478	.00771	.00410	.00524	.00361	.00393	.00358
1862	.00093	.00101	.00056	.00067	.00108	.00108
2486	.00697	.00423	.00438	.00397	.00369	.00408
3326	.00252	.00147	.00127	.00145	.00173	.00215

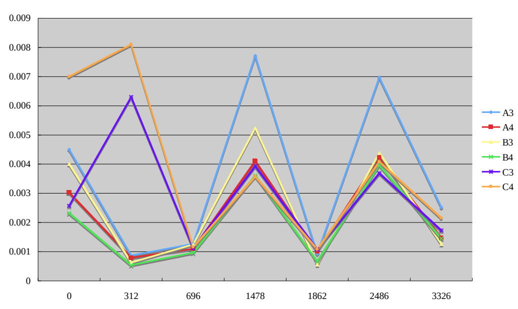


Figure 6 The trend of dielectric dissipate factor under group B

C. Partial Discharge

In order to find the index of aging trend, authors use tip-up method to measure partial discharge activity. The voltage is applied at a 5 kV step from 0 V to 25 kV, and each step lasts for 1 minute.

Figure 8 shows the trend of maximum apparent charge at 20 kV and 25 kV. The trends oscillate as time goes by, and it implies that there is no relationship between partial discharge activity and aging time unlike dielectric dissipate factor does.

Figure 9 is the collection of tip-up partial discharge measurement at every measurement time point. It also shows that no obvious relationship between accelerating life test conditions and tip-up partial discharge trend.

According to the measurement in this section, partial discharge measurement can be used to check if a defect is inside the cable termination, and there is still no sufficient evidence indicting that partial discharge measurement can assess the degree of aging.

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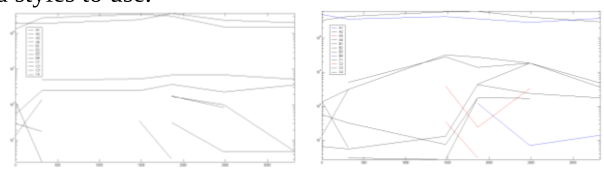
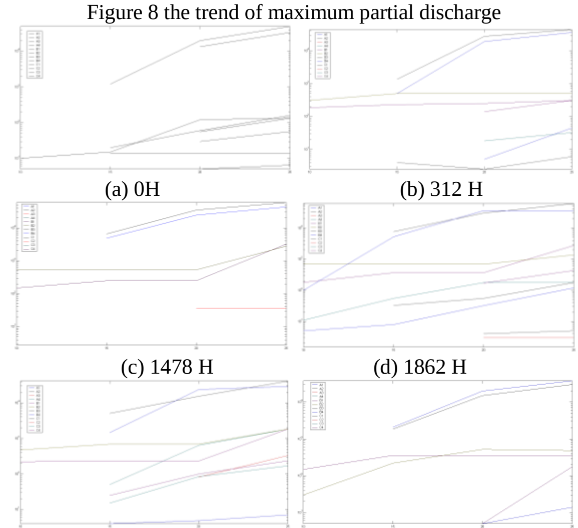


(a)20 kV (b)25 kV

Figure 8 the trend of maximum partial discharge



(a) 0H (b) 312 H

(c) 1478 H (d) 1862 H

(e) 2486 H (f) 3326 H

Figure 9 tip-up in different aging time

IV. Conclusion

According to the measurements, dielectric dissipate factor and partial discharge can both detect defects inside cable termination. Insulation resistance has no ability to distinguish whether a defect is inside the cable termination.

Comparing Table 1 ~ Table 4, dielectric dissipate factors do not have enough difference among all samples, implying that dielectric dissipate factors don't have sufficient ability to assess insulation condition with or without defects. Figure 8 and figure 9 show that cable terminations with defects have larger apparent charge reading relative to good ones.

As observing figure 5, the trends of dielectric dissipate factor under group A increases with aging time increasing. This phenomena indicts that the monitoring of dielectric dissipate factor can be helpful assessing the aging degree of insulation system. However, the trends of dielectric dissipate factor under group B does not show this tendency. The difference implies the influence of temperature and moisture on cable termination aging is more than load cycle.

Rather than the trend of dielectric dissipate factor, partial discharge measurements do not have the tendency increasing with aging time elapsing. Especially for cable terminations with water immersed, them show a decreasing trend as time going by. This may be caused by the formation of water tree, and it can't be verified before dissection.

Briefly speaking, the monitoring of dielectric dissipate factor is a good method to assess the aging degree of cable termination, but not a good diagnostic to detect defects inside cable terminations. Partial discharge measurement shows the opposite property that it is good diagnostic detecting defects, and worse approach assessing the aging degree up to now. And the worst diagnostic assessing insulation condition is insulation resistance; it shows no ability for detecting defects and assessing aging degree.

V. References

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