Engineering and Technology Journal e-ISSN: 2456-3358
Volume 09 Issue 01 January-2024, Page No.- 3313-3318
DOI: 10.47191/etj/v9i01.09, I.F. – 7.136
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Evaluation of the Medium Voltage Cable Line (SKTM) 20 kV Using Tan Delta and Partial Discharge Methods

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ABSTRACT*:* Distribution network with cable system requires maintenance to maintain the level of reliability. Many factors affect the reliability of this cable system, one of which is environmental factors that can cause deformation of the cable so that it is likely to affect the dielectric condition of the cable. Therefore, to determine and ensure the reliability of the cable system so that it can be known whether a cable is reliable or not, a cable condition diagnostic system is needed that can access the existing cable conditions in the field. Tan Delta (Dissipation Factor) and Partial Discharge are tests that can diagnose the condition of cable insulation in the field based of IEEE standard 400.2 and IEEE standard 400.5.

KEYWORDS: Distribution network, SKTM 20 KV, Tan delta, Partial Discharge, IEEE standard

I. INTRODUCTION

Under ideal conditions without deformation an insulation has an angle of 90° in the voltage and current relationship, this can mean that the ideal insulation is capacitive and when the insulation of the cable is poor it will cause an increase in resistive current through the insulation. The use of cables when in use will experience variable operating temperatures, besides that, environmental and human handling factors, namely the implementation of cable jointing can cause deformation of the cable so that it is likely to affect the insulation condition of the cable. Therefore, in order for new cables or those that have been operating for a long time to have high reliability, periodic maintenance is necessary.

These conditions will affect the reliability of the distribution of the electric power system, therefore it is necessary to periodically maintain with some diagnostic equipment that has been developed to be able to determine the condition of the cable. The Tangen Delta (TD) test method is a diagnostic test that can show the level of insulation degradation of a cable and the Partial Discharge test method by applying a Damped Alternating Current (DAC) voltage to the cable system on a TDM45 device that can record partial discharge activities on the cable.

II. RESEARCH METHODS

A. Tangen Delta Test

Tangent Delta or often referred to as angular shift or dissipation factor, is a parameter of a dielectric material that shows the nature of the electromagnetic energy dissipation of a dielectric material. This term refers to the complex number angle between the resistive (lossy) component of the electromagnetic field and the reactive (lossless) component. Apart from that, the Tangen Delta test on a cable system is a method to test the insulation quality of the cable, it aims to estimate the remaining life of the cable and determine the priority of replacing the cable. Suppose the cable is a capacitor that has a voltage and current phase difference of 90° . The current through the cable insulation is a capacitive current. If there is dirt on the insulation or the condition of the cable insulation deteriorates, the insulation resistance will decrease which will cause an increase in resistive current through the insulation. The extent to which the phase shift is less than 90° is an indication of the level of insulation contamination and the condition of the cable insulation itself. If the angle value of the phase shift increases, there will be an increase in pollution or a decrease in the insulation quality of the cable itself.

The three evaluation criteria in measuring Tangen Delta using the TDM45 tool are as follows:

1. Mean Tangen Delta, is the average test result of different test voltage levels, with the formula:

$$\overline{TD} = \frac{\sum_{i=1}^{i=N} Tan\ \delta_i}{N}$$

2. Differential Tangen Delta, is the difference or change from the highest test stress level to the lowest test stress level, with the formula:

$$\Delta\ \mathrm{Tan}\delta = \overline{TD}_{1,5\ U0} - \overline{TD}_{0,5\ U0}$$

3. Stability Tangen Delta, is the deviation that occurs to the standard, with the formula:

$$\text{ST Dev} = \sqrt{\frac{\sum_{i=1}^{i=N}(Tan\ \delta_i - \overline{TD})^2}{N-1}}$$

A. *Partial Discharge Test*

Partial Discharge detection can be done in two ways, namely on-line and off-line

1. On-line PD measurements are carried out temporarily with the cable system still in operation or in a voltage state. PD is in operation in all phases detected, but to distinguish between each phase will be difficult
2. In off-line PD detection, the cable system is free of tension. The cable is subjected to an external voltage from the test equipment to cause a discharge in the cable. The location of the PD is determined using Time Domain Reflectromery (TDR)

Based on the IEC 60270:2001 standard, partial discharge is the discharge of a local electric charge (a certain point) which only bridges an insulating part between the conductors in the part that can or cannot discharge the charge adjacent to the conductor. This discharge can occur in the insulation between the phase conductor and the ground or the phase conductor with a different phase potential. Partial discharge occurs due to contamination, voids, or fluid in the cable insulation, in this study XLPE. For example, a void has a different permissivity with XLPE insulation, where the relative permissivity of the void is 1 or the value is lower than that of XLPE which has a permissivity value of 2,3. In this situation, the intensity of the electric field in the voids is higher than the intensity of the electric field in the XLPE insulation. Under conditions of applying the same voltage, this will cause the voids to experience dielectric failure first than the insulation, this event can be called partial discharge. By using a simple analysis, namely:

$$Q = C \times V$$

C = Capacitanci Dielectric ($\boldsymbol{\mu}$F)
Q = Charge of Dielectric (C)
V = Voltage of Dielectric (V)

Then the charge that flows, namely partial discharge will occur due to the influence of capacitance and applied voltage. The amount of capacitance is the total capacitance of the insulation, where the magnitude of the influence of voids and other contamination in the insulation. In this study, partial discharge testing and measurement was carried out using a Damped Alternating Current (DAC) voltage source which was applied to the TDM45 cable diagnosis technology.

In the research "Assessment Study of 20 kV Cable Condition" conducted by PUSLITBANG by Buyung Sofiarto Munir, M.Sc, Elpis Sinamble, M.Sc, Satyagraha Abdul Kadir, S.T. , Nurul Fauziah, S.T. which in this study focuses on the initial emergence voltage of partial discharge (PDIV) and partial discharge loss voltage (PDEV) in the cable system.

If the PDIV is lower than the nominal voltage (U0), then during normal operation the PD will be active in the cable. Further PD analysis for the cable system should be carried out to analyze the location of the PD.

If the PDIV is above the nominal voltage (U0) and the PDEV is below the nominal voltage (U0), then if there is an overvoltage in the cable system it will trigger PD and PD will remain active in the cable system even though the voltage returns to normal, so that PD will accelerate the degradation process of the cable system. at the location where PD occurs. Further PD analysis for the cable system should be carried out to analyze the location of the PD.

If the PDIV and PDEV are greater than the nominal voltage (U0), then PD will only appear when there is an overvoltage in the cable system and PD will disappear when the voltage returns to normal.

III. EQUATION AND RESULTS

Based on the results of the Cable Assessment that was carried out at the Diskusi and Munas feeder in the GH166 segment towards the Dukuh Atas GI, the test results were obtained from the condition of the cable and the basis for maintenance that would be carried out next.

In the Cable Assessment process, namely the Tangen Delta and Partial Discharge testing, each test has a system standard to determine the status of the cable. The recommended decisions are the results of calculations and readings from the TDM45 tool. This standard has become a policy used by PT. Haleyora Power to deliver results from maintenance of 20 kV SKTM cables.

Table 1. Comparison of Tangen Delta Results on Both Feeders

Parameter	Diskusi Feeder			Munas Feeder		
	Phase L1(R)	Phase L2(S)	Phase L3(T)	Phase L1(R)	Phase L2(S)	Phase L3(T)
Average TD at U_0 [10e-3]	1,73	1,8	1,7	1	1	1
Difference TD among $0{,}5U_0$ [10e-3] & 1,5 U_0[10e-3]	1,2	1,4	1,2	0	0	0
TD Deviasi at U_0[10e-3]	0,05	0,04	0,04	0,00	0,00	0,00

Based on table 1. the results of the Tangen Delta test above, it can be seen that the magnitude of the parameter criteria of the test results at the Diskusi and Munas feeders is different. In the Diskusi feeder the average value of TD when the working voltage in the L1(R) phase is $1,73 \times 10^{-3}$, the L2(S) phase is $1,8\times 10^{-3}$ and the L3(T) phase is $1,7\times 10^{-3}$. While in the Munas feeder the average value of TD when the working voltage is in the L1(R) 1×10^{-3} phase, the L2(S) phase 1×10^{-3} and the L3(T) phase 1×10^{-3}. The value of the measured TD change in the Diskusi feeder when the working voltage in the L1(R) phase is $1,2\times 10^{-3}$, the L2(S) phase is $1,4\times 10^{-3}$ and the L3(T) phase is $1,2\times 10^{-3}$. While the change in TD value in the Munas feeder when the working voltage is in phase L1(R) 0×10^{-3}, phase L2(S) 0×10^{-3} and phase L3(T) 0×10^{-3}. For the TD deviation value in the Diskusi feeder when the working voltage in the L1(R) phase is $0,05\times 10^{-3}$, the L2(S) phase is $0,04\times 10^{-3}$ and the L3(T) phase is $0,04\times 10^{-3}$. While the deviation value of TD on the Munas feeder is when the working voltage is in the L1(R) phase 0×10^{-3}, the L2(S) phase 0×10^{-3} and the L3(T) phase 0×10^{-3}. The following is a graph of the test results from the feeders of the Diskusi and Munas:

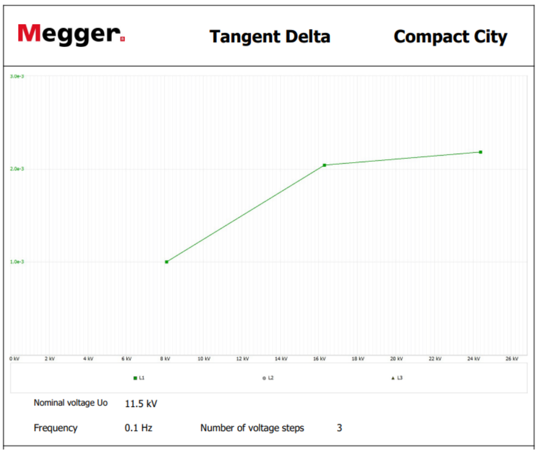


Figure 1. TD test result graph of Diskusi feeder L1(R)

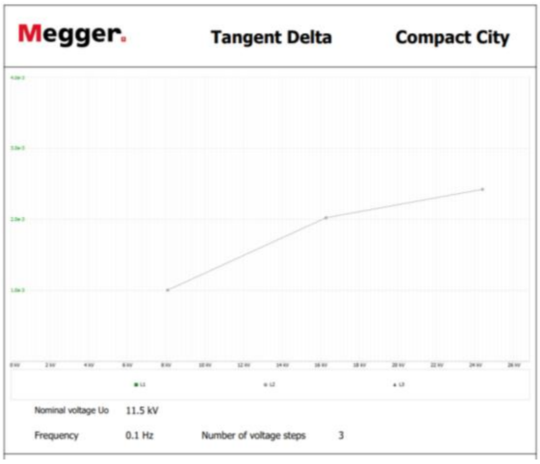


Figure 2. TD test result graph of Diskusi feeder L2(S)

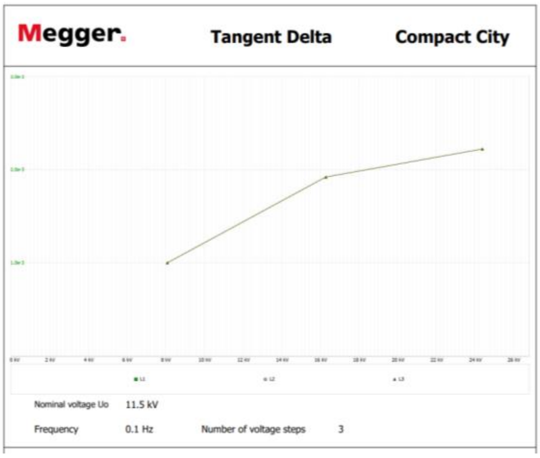


Figure 3. TD test result graph of Diskusi feeder L3(T)

Based on the standard test results according to IEEE 400.2, the overall cable condition in the Diskusi feeder is at "No Action Needed". This is because the value of the mean TD is < 4, the value of the change in TD is < 5 and the deviation value of TD is <0.1 is in the first category, namely No Action Needed. The next stage of testing is carried out in the next 5 years.

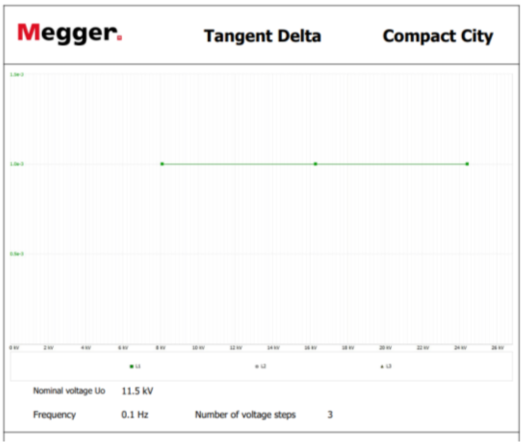


Figure 4. TD test result graph of Munas feeder L1(R)

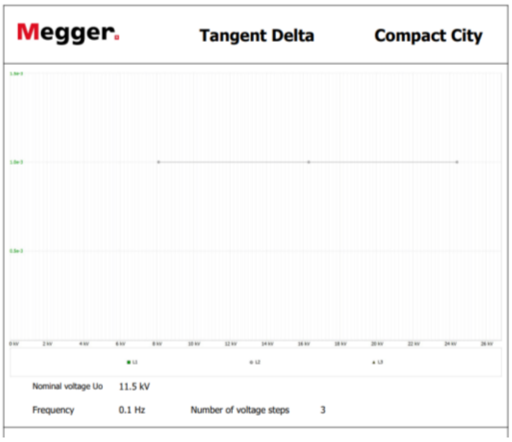
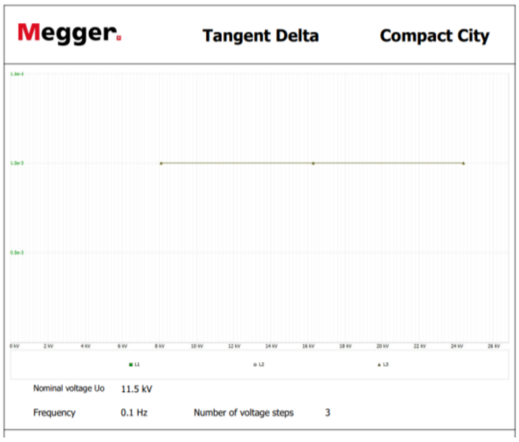


Figure 5. TD test result graph of Munas feeder L2(S)



Nominal voltage Uo 11.5 kV

Frequency 0.1 Hz Number of voltage steps 3

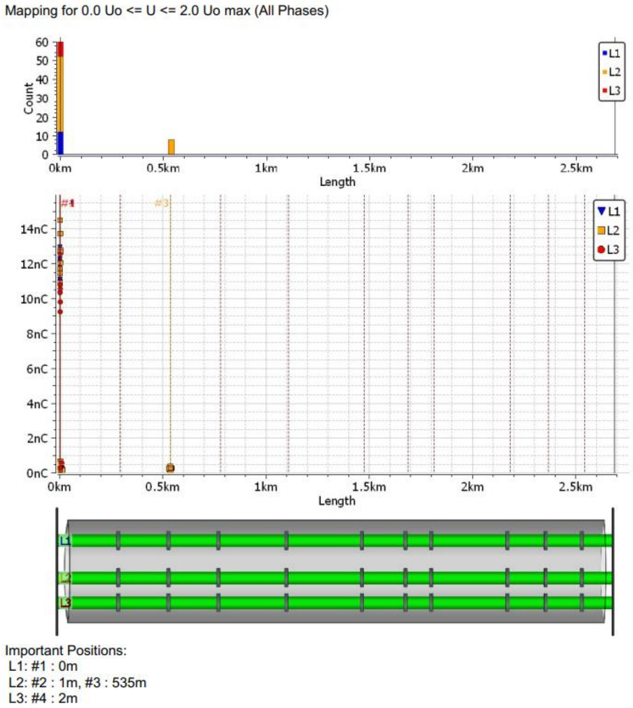
Figure 6. TD test result graph of Munas feeder L3(T)

Based on the standard test results according to IEEE 400.2, the overall cable condition for the Munas feeder is in "No Action Required". This is because the value of the mean TD is < 4, the difference TD is < 5 and the deviation value of TD is <0.1 is in the first category, namely No Action Needed. The next stage of testing is carried out in the next 5 years.

Table 2. Table of comparison of PD test results on both feeders with discharge parameters

Parameter	Penyulang Diskusi			Penyulang Munas		
	Pelepasan (pC)			Pelepasan (pC)		
	L1(R)	L2(S)	L3(T)	L1(R)	L2(S)	L3(T)
PDmax [pC] (PDIV)	13440	14450	10210	13720	42110	42020
PDmax [pC] (1 U_0)	639,8	198,9	10850	43240	47550	41340
PDlevel [pC] (1 U_0)	372,8	190,3	156,2	34870	45480	40040
PDmax [pC] (1,7 U_0)	13350	13150	12930	30290	35470	46600
PDlevel [pC] (1,7 U_0)	12570	12540	54680	27180	35120	41340

Based on table 2. the results of the Partial Discharge Test on the two feeders with the discharge parameters on the feeder Diskusi and Munas differences. In the partial discharge test there are several criteria that are seen. In the Diskusi feeder the results of the calculation of the discharge PDmax [pC] (PDIV) L1(R) 13440 pC, L2(S) 14450 pC and L3(T) 10210 pC. While in the Munas feeder, the calculation results of the working voltage PDmax [pC] (PDIV) L1(R) 13720 pC, L2(S) 42110 pC and L3(T) 42020 pC. For the Diskusi feeder of the calculation results of PDlevel [pC] (1.7 U0) L1(R) 12570 pC, L2(S) 12540 pC and L3(T) 54680 pC. While in the Munas feeder, the calculation results of the load discharge are PDlevel [pC] (1.7 U0) L1(R) 27180 pC, L2(S) 35120 pC and L3(T) 41340 pC.



Important Positions:
L1: #1 : 0m
L2: #2 : 1m, #3 : 535m
L3: #4 : 2m

Figure 7. PDmapping graph of partial discharge test at diskusi feeder

The PDmapping graph of the Partial Discharge test results in Figure 7. above on the Diskusi feeder informs that there are points of gaps/damage from the cable insulation with the released load. For the L1(R) phase, it is considered that there is no insulation damage gap, because the point at 0 meters can be indicated that the coupling of the injector cable from the tool is not perfectly attached. For the L2(S) phase, the insulation damage gap is at the point of 1 meter and 535 meters from the total cable length. For the L3(T) phase, the insulation damage gap is at a point 2 meters from the total cable length.

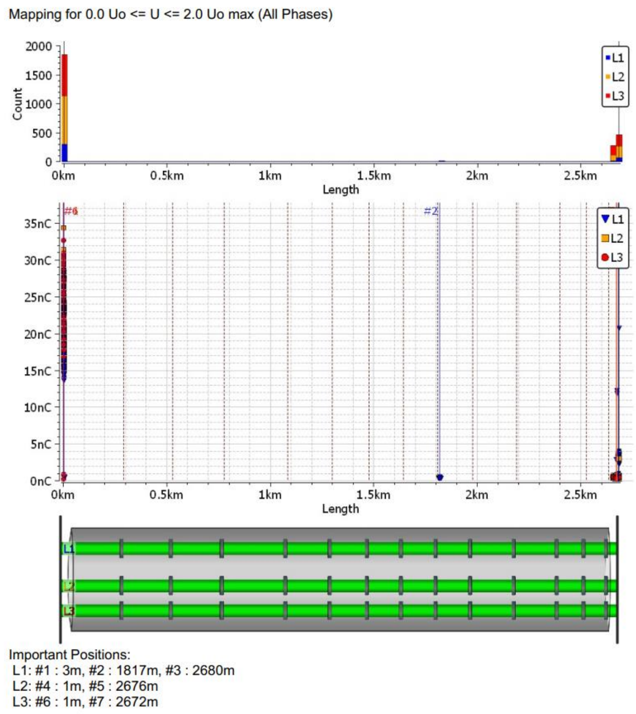


Figure 8. PDmapping graph of partial discharge test at munas feeder

The PDmapping graph of the results of the Partial Discharge test in Figure 8. above on the National Conference feeder informs that there are points of gaps/damages from the cable insulation with the load it releases. For the L1(R) phase, the insulation damage gap is at the point of 3 meters, 1817 meters and 2680 meters of the total cable length. For the L2(S) phase, the insulation damage gap is at a point of 1 meter, 2676 meters of the total cable length. For the L3(T) phase, the insulation damage gap is at a point of 1 meter, 2672 meters of the total cable length.

B. *Analysis*

Based on the results of the Tangen Delta and Partial Discharge tests on the Diskusi and Munas feeders and the calculation results obtained from the tests of the two feeders. The next stage is to analyze the condition of the cable based on the results of the tests and calculations above with reference to the applicable standards and used by PT. PLN (Persero) is standar IEEE 400.2 for Tangen Delta and standar IEEE 400.5 for Partial Discharge.

1. Cable Conditions at Diskusi Feeder
   a. Tangen Delta Test

      Based on the test results and calculations presented in table 1. in the Diskusi feeder, we can analyze that the average value of tangen delta in the L1(R) 1,73× 10^{-3}, L2(S) 1,8× 10^{-3} and L3(T) 1,7× 10^{-3} is less than 4× 10^{-3}. For the value of the change in tangent delta in the phase L1(R) 1.2× 10^{-3}, L2(S) 1.4× 10^{-3} and L3(T) 1.2× $10^{-3}$is less than 5× 10^{-3}. For the tangent delta deviation value in the L1(R) 0.05× 10^{-3} phase, L2(S) 0.04× $10^{-3}$and L3(T) 0.04× $10^{-3}$is less than 0.1× 10^{-3}. It can be concluded that the condition of the cable in the Diskusi feeder according to the tangen delta value with reference to the standards IEEE 400.2 is "No Action Needed" with an estimated return test after 5 years

   b. Partial Discharge Test

      Based on the test results and calculations presented in table 2. in the Diskusi feeder, we can analyze that the value of PDIV in the L1(R) phase is 17.2 kV, L2(S) 17.2 kV and L3(T) 19.5 kV. The value of PDEV in the L1(R) phase is 0.4 kV, L2(S) 17.9 kV and L3(T) 17.6 kV. In accordance with standar IEEE 400.5, if the PDIV and PDEV values are greater than the nominal voltage (U0), then PD will only appear when there is an overvoltage in the cable system and PD will disappear when the voltage returns to normal, according to the recommendation table to get point 1 for the X axis.

      The value of the discharge in phase L1(R) 13323 pC, L2(S) 13191 pC, L3(T) 12988 pC, according to the recommendation table if the discharge value is more than 1000 pC (Y > 1000 pC) get point 3 for the axis Y. The calculation is in accordance with the recommendation table IEEE 400.5 that this diskusi feeder gets points 1 + 3 = 4 with the status of the Alert cable, the estimation of retesting after 1 year.

2. Cable Conditions at Munas Feeder
   a. Tangen Delta Test

      Based on the results of the tests and calculations presented in table 1. at the Munas feeder, we can analyze that the average value of the tangen delta in the L1(R), L2(S) and L3(T) 1× 10^{-3}phases is less than 4× 10^{-3}. For the value of the change in tangent delta in the L1(R), L2(S) and L3(T) 0× 10^{-3} phases, it is less than 5× 10^{-3}. For the tangent delta deviation value in the L1(R), L2(S) and L3(T) 0.00× 10^{-3} phases is less than 0.1× 10^{-3}. It can be concluded that the cable condition in the diskusi feeder according to the tangen delta value with reference to the standards IEEE 400.2 is "No Action Needed" with an estimated return test after 5 years.

   b. Partial Discharge Test

      Based on the test results and calculations presented in table 2 in the Munas feeder, we can analyze that the value of PDIV in the L1(R) phase is 5.7 kV, L2(S) 5.7 kV and L3(T) 5.7 kV. The value of PDEV in the L1(R) phase is 5.3 kV, L2(S) is 6.3 kV and L3(T) 19 kV. According to standar IEEE 400.5 if the PDIV value is lower than the nominal voltage (U0), then during normal operation the PD will be active in the cable. Further PD analysis for the cable system must be carried out to analyze the location of the PD, according to the recommendation table IEEE 400.5 to get point 3 for the X axis.

The value of the discharge in phase L1(R) 30293 pC, L2(S) 35485 pC, L3(T) 46627 pC, according to the recommendation table if the discharge value is more than 1000 pC (Y > 1000 pC) get point 3 for the axis Y.

The calculation is in accordance with the recommendation table IEEE 400.5 that this Munas feeder gets points 3 + 3 = 6 with Very Bad cable status, the estimation of re-testing after 3 months.

IV. CONCLUSIONS

The condition of the cable in the feeder. Discussion after the Tangen Delta test is carried out, there is no need for action with an estimated re-test after 5 years. For Partial Discharge testing, it gets point 4, namely the status of the Alert cable with an estimated re-test after 1 year.

The condition of the cable at the National Conference feeder after the Tangen Delta test is No Action Needed with an estimated re-test after 5 years. For the Partial Discharge test, you get point 6, namely the status of the cable is very bad with an estimated test return after 3 months.

After the Cable Assessment was carried out, the comparison of the cable conditions at the Discussion feeder was Alert, while the cable condition at the National Conference feeder was Very bad.

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