The New Technique for Reliability Assurance of In-Service XLPE Power Cables

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ABSTRACT

This paper presents the application of a new on-site off-line non-destructive technique, Polarisation / Depolarisation Current (PDC) Analysis, for the reliability assurance of three in-service 33 kV single-core XLPE submarine cables. The insulation system between the conductor and the inner screen as well as between the inner screen and the outer armour was measured. The insulation properties evaluated from the measurement results included frequency scan of dissipation factor and capacitance in addition to the insulation resistance. The PDC results of the first tests and the second tests seven months later are discussed. The conclusion outlines how the reliability of the submarine cables can be assured by this technique.

1. INTRODUCTION

The Kissing Point Submarine Cable in the Hatea River forms a part of Onerahi – Kioreroa 33 kV sub-transmission circuit. The remainder of the circuit is an overhead line. The old submarine 3/c Paper-Insulated Lead Cable was damaged by a boat keel and was replaced by 3-1/c XLPE power cables in 1994. The details of the XLPE cables starting from the core are:

- 400 mm^2 Compacted Al core conductor.
- 8.0 mm XLPE insulation (with semiconductive screen).
- 95 mm^2 Cu wire screen
- Extruded bedding.
- 2.5 mm Al wire armouring
- 2.8/2.8 mm LDPE/HDPE outer sheath. The dual LDPE/HDPE sheath was designed to resist abrasion, moisture ingress, cold temperature and marine borer (e.g. Toredos, Pholads).

Each cable is a single run of about 560-590 m. Fig. 1 shows the Onerahi end of these submarine cables where all the tests were carried out. Access to the other end was difficult.

Three transient faults, all in phase R, on the 33 kV sub-transmission circuit during April-May 2003 prompted the investigation of these submarine cables. A new on-site off-line non-destructive diagnostic tool based on the Dielectric Spectroscopy in Time Domain or Polarisation / Depolarisation Current (PDC) Analyser [1] – [4], which was designed for dielectric response measurement of electrical power apparatus especially power transformers, was utilised to assure the future reliability of these single-core XLPE cables.

The test arrangement is shown in fig. 2 [1], [2], [4]. The time domain measurement of polarisation (or charging) current and depolarisation (or discharging) current is not new and the application to assess water trees in service aged XLPE cables was reported in 1999 [5]. It was shown in that paper that the high water tree density in one cable sample led to the high dielectric loss factor deduced from measured depolarisation current. The longest trees with low water tree density that were found in another cable sample had low depolarisation current / loss factor, but that polarisation current was much higher (up to 1,000 times) than the depolarisation current. Reference [6] reveals the electric breakdown is closer related to the length of the longest water tree than the density of water trees. Both references led to the conclusion that the PDC technique is an informative method to assess water trees in XLPE cable.

What is new in this latest technique is the ability to measure very small current with high accuracy and repeatability. This allows the insulation test to be carried out with much lower voltage which means non-destructive. In addition, the whole in-service cable can be assessed on-site, instead of testing on cable samples in the laboratory as in [5]. Some results of the new technique on XLPE cables were presented in [4].

Fig. 1. The 3 -1/c XLPE submarine cables at Onerahi end

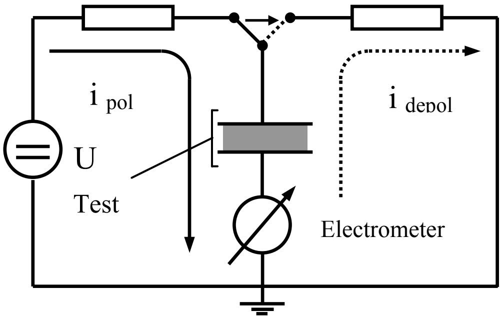

Fig. 2. Principle of test arrangement for PDC measuring technique [1], [2], [4].

2. PDC MEASUREMENT OF THE MAIN INSULATION SYSTEM BETWEEN THE CONDUCTOR AND THE INNER SCREEN

2.1 Test Connection and the initial assessment of remaining current

As can be seen in fig. 1, the inner screen (Cu wire) and the outer screen (Al wire armour) of the XLPE submarine cables are connected together and grounded in service. Before the PDC measurement, both inner screen and outer screen were floated from earth at both ends.

The first assessment of the submarine cables started with phase R. The Al conductor was connected to the V-probe of the PDC Analyser. The inner screen, which was still connected to the outer screen, was connected to the I-probe of the instrument. All other terminals of the other phases, which were not tested, were connected to earth.

The first procedure for PDC measurement is to ensure that the remaining current (or background current) of the insulation under test is as low as possible. In this initial measurement, the charging time is set to zero. Without polarisation (or no charging voltage), the depolarisation (or discharging) current is measured. This refers to the charges remaining in the insulation system. The time during this initial measurement depends on the level of remaining charges in the insulation and its decay rate. For the test on phase R, the remaining current before the PDC measurement was 28 pA.

When the same test was applied to both phase Y and phase B, a much larger constant remaining positive current of 19 µA and 17 µA respectively, was detected during the initial current measurement. Similar results were obtained on these two phases when the current was sensed from the outer screen with the inner screen floated. **This means the outer screen of cable phase Y and phase B had high conduction to earth**. Therefore, the main insulation system between the conductor and the inner screen of phase Y and phase B was then assessed with the outer screen floated. The remaining current of phase Y and phase B in this latter connection was only 3.3 and 22.9 pA respectively. In the second assessment of these two cables in Dec-03, the outer screen was connected to earth but the currents were very close to the first measurement, as shown in figure 3. The results confirmed that the inner screen of phase Y and B still had low conduction to earth.

2.2 PDC Measurement Results of the insulation between conductor and inner screen

Fig. 3 shows the PDC measurement results of the insulation system between the conductor and the inner screen of all three single-core submarine cables. The test voltage was 300V d.c. The results from the first test in May-03 are shown on the left. On the right, the PDC results from the second test of the same phase are added for comparison. The last two charts are the current results of all three phases from each assessment. It’s clearly seen that the results of phase Y and phase B are very close in both first and second measurement. The current in the first 10 seconds in phase R was lower than the other two phases in May-03, but it increased closer to the other phases on the second PDC test in Dec-03. Though the average ambient temperature during the first test was 13°C and during the second test was 21°C, the temperature of the insulation during the off-line testing would not have a significant difference or influence on the PDC measurement results, particularly as the cables were energized at no load before switching off for both tests.

For each cable and each measurement result, the polarisation current and the depolarisation current were very close, especially in the first 30 seconds. This means the conduction current was very small. In another words, the internal insulation system between the conductor and the inner screen of all three cables was dry.

To access the influence of external surface leakage current, one test on phase R was undertaken during a shower of rain. The results are shown in fig. 4. In this case, the polarisation current measured at the time of the shower was much higher than in dry conditions, but of course the rain did not influence the depolarisation current

2.3 Evaluation of PDC Measurement Results

2.3.1 Dielectric Dissipation Factor (DDF) and Capacitance of insulation between conductor and inner screen

With the continuous measurement of Polarisation / Depolarisation Current e.g. from 1 to 100 seconds, the standard software of the PDC Analyser evaluated the DDF and Capacitance from 0.01 Hz to 1 Hz. The evaluation results of the first test and the second test are shown in Fig. 5 and Table 1. The DDF results in both tests for phase Y and phase B are very close, so the test dates for these two cables were not mentioned in the figure. Regarding to the DDF results of phase R, the second test (Dec-03) was obviously higher than the first test (May-03). Nevertheless, the DDF curve of phase R in the second test was still lower than the other two phases. Considering the low DDF values of all results, the three cables are acceptable at this stage.

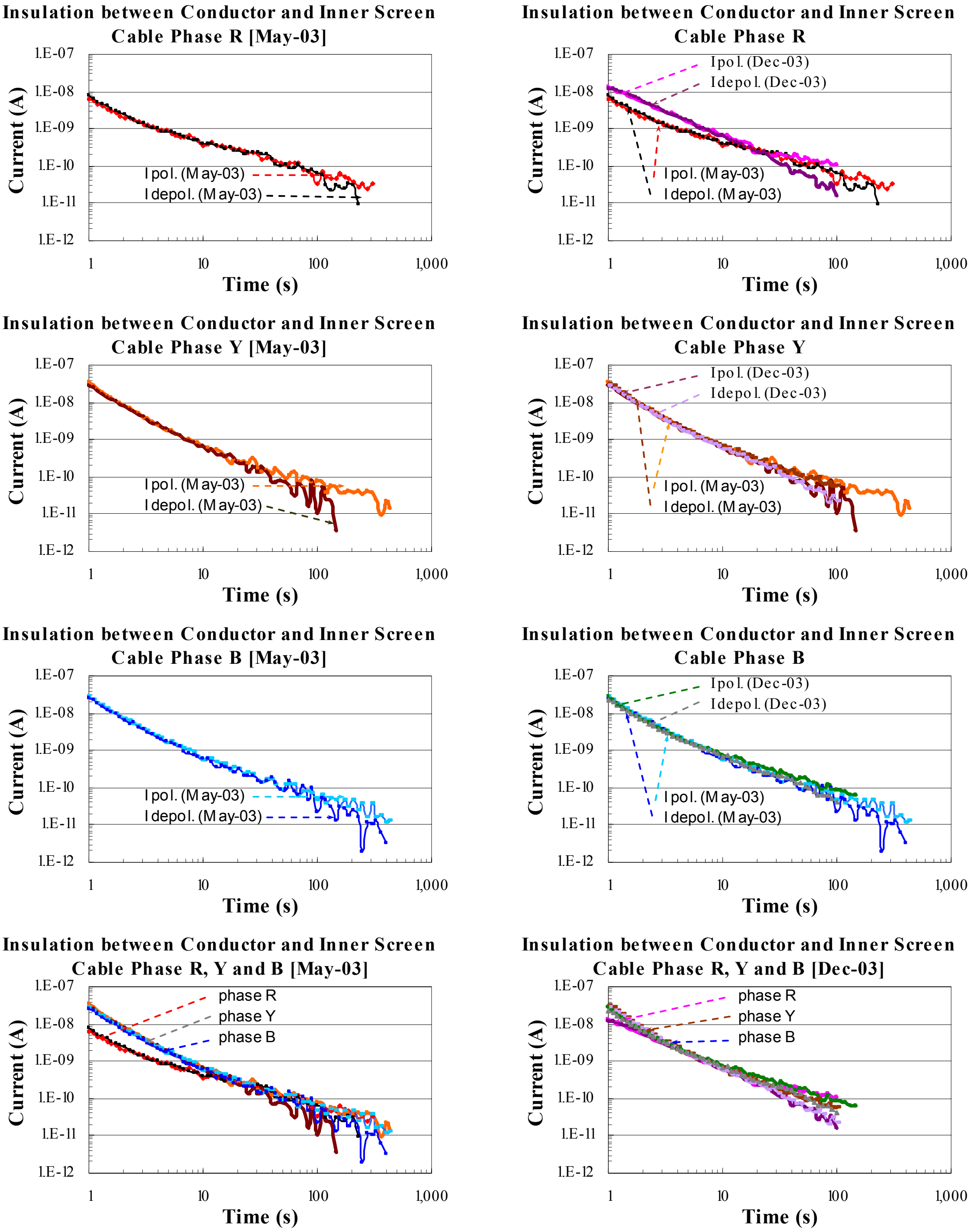

Fig. 3. PDC Measurement Results of Insulation between the Conductor and the Inner screen for all three single-core submarine cables form the first test in May-03 and the second test in Dec-03.

Table I also presents the capacitance values measured by the PDC Analyser. For this test connection, the capacitance of the insulation between conductor and inner screen was quite constant from 0.001 Hz to 50 Hz. Since the exact length of the cable is not known and it is likely that the capacitance of 0.270 µF/km mentioned in the manufacturer's data is the designed value rather than the factory test value, the results from the PDC Analyser are therefore kept for future reference. Although the capacitance of phase R shows the deviation between the first test and the second test, the value in the second test was quite comparable. The other two phases had no change between the two tests.

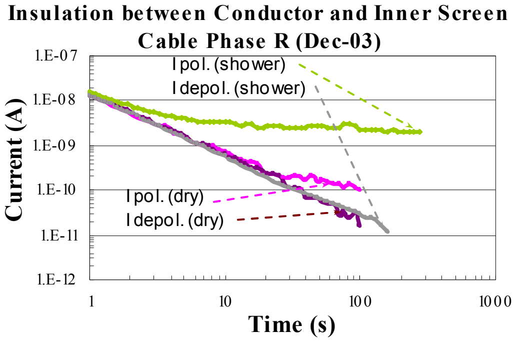

Fig. 4. PDC Measurement Results of phase R, carried -out in wet and dry condition.

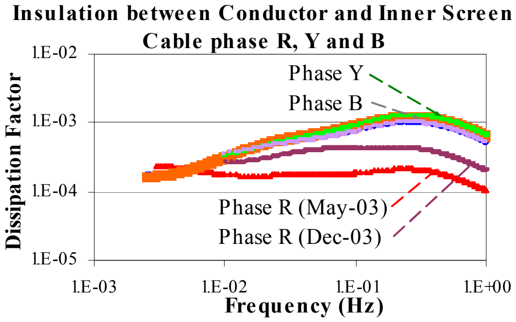

Fig. 5. Frequency scan of DDF evaluated from PDC measurement results

Table I

Evaluation Results from PDC measurement of 33 kV Submarine Cables

Insulation Analysed	**Between Conductor and Inner screen**						**Inner and Outer Screen**
Description	**phase R**		**phase Y**		**phase B**		**phase R**
Test Date	Dec-03	May-03	Dec-03	May-03	Dec-03	May-03	Dec-03
Test Voltage (V)	300	300	300	300	300	300	30
Ambient temperature (°C)	21	13	24	13	21	13	23
Capacitance at 50 Hz (µF)	0.129	0.135	0.125	0.125	0.128	0.128	0.591
DDF at 0.001 Hz (polarisation)	-	-	-	-	-	-	4.91×10^{-2}
DDF at 0.01 Hz (polarisation)	2.64×10^{-4}	1.77×10^{-4}	3.27×10^{-4}	3.32×10^{-4}	3.52×10^{-4}	3.07×10^{-4}	9.88×10^{-2}
DDF at 0.1 Hz (polarisation)	4.31×10^{-4}	1.86×10^{-4}	9.15×10^{-4}	9.49×10^{-4}	7.53×10^{-4}	7.93×10^{-4}	6.95×10^{-2}
DDF at 1 Hz (polarisation)	1.99×10^{-4}	1.04×10^{-4}	6.57×10^{-4}	6.56×10^{-4}	5.17×10^{-4}	5.31×10^{-4}	8.41×10^{-3}
DC Resistance at 15 s (GΩ)	863	950	751	784	649	786	0.32
DC Resistance at 60 s (GΩ)	2,010	2,580	3,080	3,200	2,050	3,000	2.14

2.3.2 Insulation Resistance of insulation between conductor and inner screen

Fig. 6 shows the PDC evaluation results of insulation resistance between conductor and inner screen. The values at 15 seconds and 60 seconds of all three cables from the first test and the second test are included in Table I.

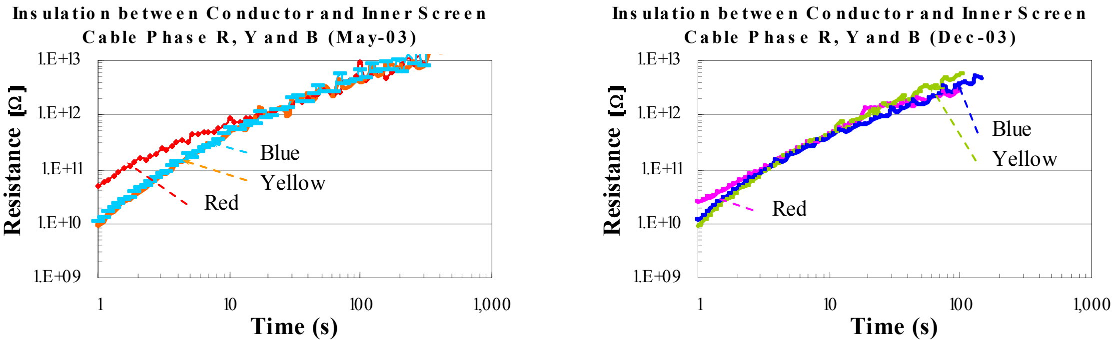

Fig. 6. PDC Evaluation Results of Insulation Resistance between Conductor and Inner Screen

3. PDC MEASUREMENT OF THE INSULATION SYSTEM BETWEEN THE INNER SCREEN AND THE OUTER SCREEN

Without a “Phantom”, an accessory of PDC Analyser for measuring earthed equipment, the insulation between the inner screen and the outer screen of only phase R could be assessed (since the outer screen of the other two cables had very high conduction to earth). This part of insulation was measured in the second assessment (Dec-03). The test voltage in this case was 30 V. The PDC measurement results and evaluation results are shown in Fig. 7 and also included in Table I. The very similar results of the polarisation current and the depolarisation current within 100 seconds. (one-tenth of the charging time) indicated very small conduction current. This confirmed that the insulation between the two screens of cable phase R was dry.

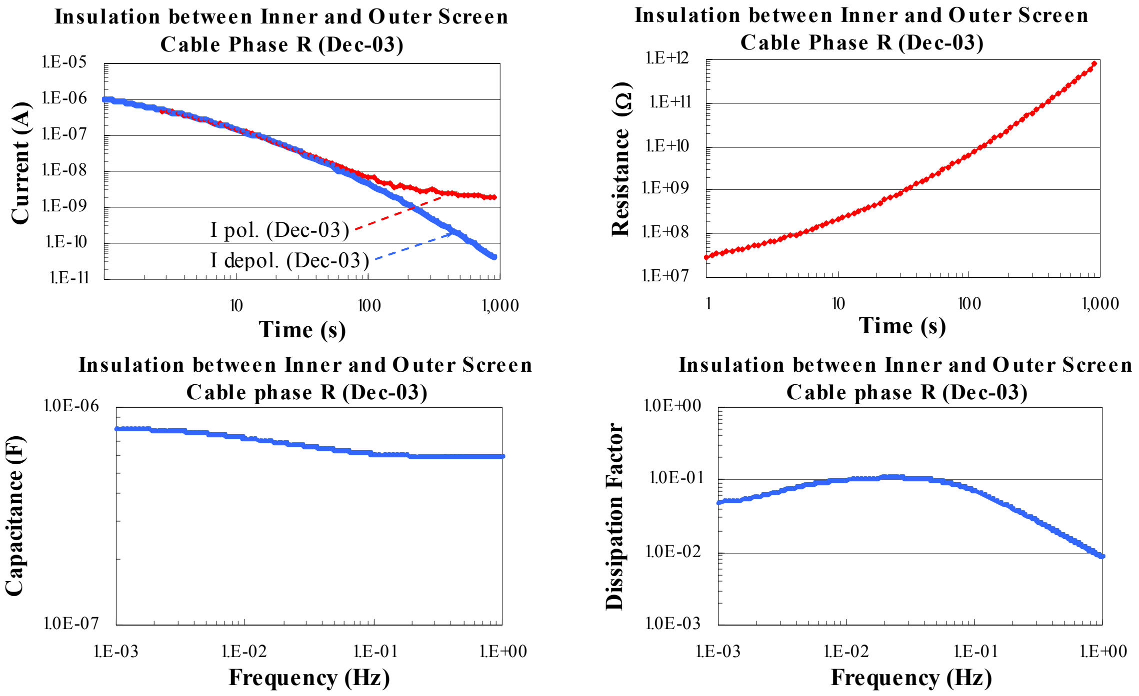

Fig. 7. PDC Measurement Results and Evaluation Results (Resistance, capacitance and DDF) of Insulation between Inner Screen and Outer Screen.

4. CONCLUSION

Three transient faults on the 33 kV sub-transmission circuit prompted the investigation of the XLPE submarine cables. The recorder revealed all three faults occurred in phase R while the first results of PDC Analysis on the insulation between conductor and inner screen confirmed the healthy state of this phase but there was some aging of the other two (which led to larger initial currents). It is likely that the fault in phase R caused the temporary overvoltage of the other two phases which then increased their relaxation currents and dielectric losses. Retesting after seven months with no faults showed very similar results in phase Y and phase B but an increase of initial current in phase R, though this was still within acceptable limits. This second test assured the cable reliability and at the same time, proved the repeatability of the PDC technique over two tests.

PDC Analysis is a non-destructive test. Without any voltage applied to the insulation, the remaining current of the outer screen can be measured. In this case, PDC detected the high positive remaining current at the outer screen of phase Y and phase B which meant the outer screen of these two cables had high conduction to earth. An accessory of the PDC Analyser for measuring earthed equipment called "Phantom" will be required, in order to confirm the insulation condition between the inner screen and the outer screen. By comparing the difference of polarisation current and depolarisation current within about one-tenth of the charging time, and comparing the evaluation results with phase R, the presence of water in the insulation between the two screens of the two cables can be assessed. Hopefully, the damage of the outer screen can be localized by this non-destructive technique and the reliability of all three submarine cables can be doubly assured.

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