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Insulation Condition Assessment of Transformer Bushings by means of Polarisation / Depolarisation Current Analysis

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***Abstract*: This paper presents some practical experience of Polarisation / Depolarisation Current (PDC) Analysis on a number of condenser bushings having three different insulation designs – Oil Impregnated Paper (OIP), Synthetic Resin Bonded Paper (SRBP) and Resin Impregnated Paper (RIP). It suggests methods for performing successful on-site measurement. The document contains PDC measurement results and evaluation results of main insulation C1 for each type of bushing. It proves that the sensitivity in detecting insulation aging of the PDC technique is better than the conventional 50 Hz test.**

INTRODUCTION

A failure of transformer accessories such as condenser bushings sometimes leads to a transformer failure and long-term outage. Often, moisture is a cause of explosion for service-aged bushings. On-line monitoring of insulation dryness in bushings through oil analysis is a difficult task and may not represent the moisture in the paper. In recent years a new on-site off-line technique, Polarisation / Depolarisation Current (PDC) Analysis was designed for insulation condition assessment of electrical power apparatus especially for oil-paper insulation systems e.g. power transformers [1-4]. The successful application of this Dielectric Spectroscopy in Time Domain Method to monitor moisture in 275 kV condenser bushings installed in test stands was reported in 2001 [5], although the attempts in doing PDC measurement on the bushings installed in transformers had not yet been achieved.

With the great support from power companies in Australia and New Zealand, opportunities have been given since 2001 in applying the PDC technique to assess the insulation condition of 39 condenser bushings having three different insulation designs: oil impregnated paper (OIP), synthetic resin bonded paper (SRBP) and resin impregnated paper (RIP). Among these units, there were 37 installed in transformers and 2 installed in test stands. Some results of PDC Analysis on main insulation C1 of these bushings will be presented in this paper.

PDC MEASUREMENT & CONNECTION

In this technique, the main insulation C1 is charged by a constant dc voltage over a period of time. The current during this period is called "polarization current". At the end of polarization, the insulation is disconnected from the power supply and immediately replaced by a short-circuit for about similar time period. The current during this discharging is called "depolarization current". Although it is recommended to polarize the insulation for at least 3,000 seconds and depolarize for at least another 3,000 seconds, the time period can be much less in case of a new bushing with very good and dry insulation as shown in a later section.

To carry out the PDC measurement on bushings installed in a transformer, all bushing terminals (including Neutral in case of star-connected) of the same winding shall be connected together. The dc voltage is then applied to the head of the condenser bushing under test and the current is sensed from its test tap. All other bushing terminals of the other winding(s), which are not tested, shall be connected to the grounded transformer tank. To avoid nonsensical results and to obtain healthy and successful measurement, some suggestions are:

1. Ensure that the Ground Reference of PDC Analyser has the same potential as the bushing flange or the transformer tank in case of bushings installed in transformers. The best practice is bonding the ground point of the PDC Analyser to the ground terminal of the transformer and isolating the power source of PDC Analyser from earth.
2. The voltage cable of PDC Analyser is connected directly to the head of the bushing under test, not through the other connected wires which are not coaxial type.
3. To eliminate or decrease any interference during on-site measurement, a Faraday cage or a metal screen having the same ground reference as the PDC Analyser is sometimes required in order to prevent any foreign charges which may introduce to the bushing head. Fig. 1 shows one case where a metal bin was used as a screen. The metal bin was insulated from the energised bushing head by means of a clean plastic bin.

   In another case a scaffold was temporarily built to facilitate the test connection. The scaffold could act as a perfect screen by bonding the steel structure to the ground reference of the measuring circuit

Figure 1- A set-up on a bushing head for interference suppression

PDC MEASUREMENT RESULTS

OIP Bushings

The polarization current and the depolarization current of a new bushing with very good insulation are very similar and fit the inverse power equation with n very close to 1, as in the case of OIP-01 in figure 2 (top). The time taken for each test was only a few minutes. The measurement was carried out at 200V, 500V and 1,000 V in order to prove the linearity upon voltage. At higher voltage e.g. at 500 V and 1,000 V, the final depolarization current was found to be slightly higher than the final polarization current. This behaviour did not appear at 200V. The tests on 6 new bushings installed in transformers confirmed this behaviour.

Figure 2 (middle) shows the PDC measurement results of three identical bushings OIP-02A, OIP-02B and OIP-02C after nearly 40 years in service. The measured currents of OIP-02A and OIP-02C were about ten times higher than OIP-02B, in spite of having the same environment and quite similar stresses in operation. The moisture in paper evaluated by the software of PDC Analyser was 3.0-3.5%, 1.0-1.5% and 3.5% for OIP-02A, OIP-02B and OIP-02C respectively.

In some cases such as OIP-03 in figure 2 (bottom) and OIP-04 in figure 3, the PDC measurement results show very high initial currents. It is likely that the conductivity of the oil in parallel to the condenser paper was very high. Figure 3 also shows the result of moisture in paper evaluated by the PDC software. The evaluation is done by fitting the measured currents (especially the final currents) with the simulated currents of different values of moisture in paper.

The bushing OIP-05 in figure 2 (bottom) was one of the two cases among 39 units where the initial polarization and depolarization currents were much different. It is suspicious that the dry bands (caused by chemical pollution) on the porcelain surface might be the cause. The other unit in the same transformer had clean surface and the PDC pattern was very similar to OIP-01. The case was under investigation.

SRBP Bushings

Figure 4 shows the PDC measurement results of SRBP Bushings SRBP-01, SRBP-02 (top) and SRBP-03 (bottom).

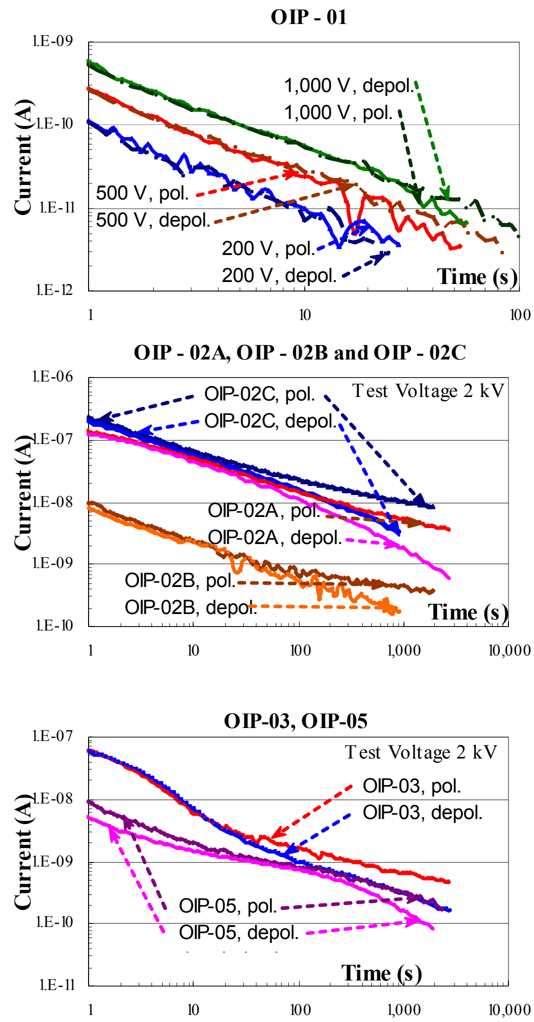

Figure 2 – Some PDC measurement results of OIP Bushings

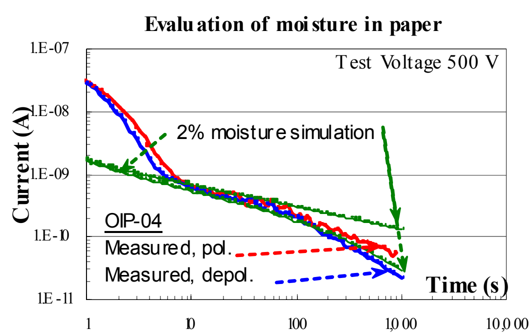

Figure 3 – PDC measurement result of OIP-04 and the evaluation of moisture in pressboard by the software of PDC Analvser

The SRBP-01 and SRBP-02 are identical 220 kV units from the late 1960's and have been kept in stands as spare bushings. During storage, the lower part of SRBP-01 was covered but the lower part of SRBP-02 was not. The similar results of the depolarization currents but different results of the polarization currents of both units revealed moisture ingress of SRBP-02.

The 275 kV bushing, SRBP-03 was tested in poor weather condition. Though the bins similar to the ones in figure 1 were used during the test, the dispersion of PDC results remained. The smooth lines in figure 4 (bottom) are the fitting curves generated by PDC Analyser for the evaluation of dielectric responses.

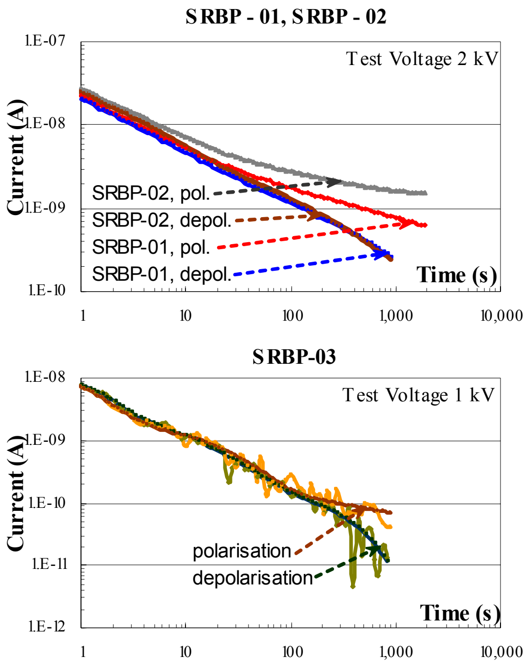

Figure 4 – PDC Measurement Results of SRBP-01, 02 and 03

RIP Bushings

The measurement was performed on new RIP bushings after some months in service. The PDC results of three identical bushings installed in the same transformers had quite similar shapes but different magnitude of the currents. The results of two bushings are shown in figure 5 (RIP-02 had the highest currents and RIP-01 had the lowest). Apparently, the new identical units can have different insulation quality.

PDC EVALUATION RESULTS

From the measurement results of polarization / depolarization current, the software of the PDC Analyser evaluates the following dielectric responses:

- Capacitance (C) and Dielectric Dissipation Factor (DDF)
- Insulation Resistance and Polarisation Index (P.I.)
- Recovery Voltage Polarisation Spectrum

For OIP bushings, the evaluation of moisture in pressboard is included. An example was previously shown in figure 3 and described under item 3.1.

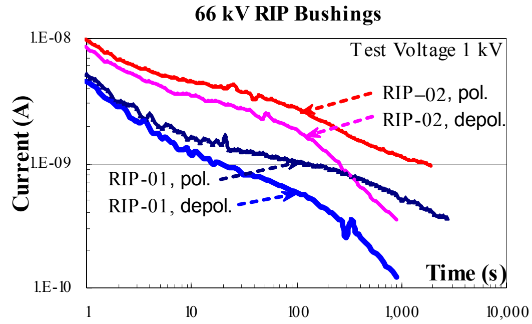

Figure 5 – PDC Measurement Results of RIP-01 and RIP-02

Table I shows PDC evaluation results of 8 bushings. Some results from conventional 50 Hz C & DDF tests are included. As can be seen from the results of OIP-02C, OIP-03 and SRBP-01 that the DDF at 1 Hz from PDC evaluation is more sensitive in detecting insulation aging than the 50 Hz test.

Figure 6 shows some PDC results of C & DDF. For bushings having good insulation such as OIP-01 and OIP-02B, C will be quite constant from 1 Hz towards lower frequencies. When moisture in paper is very high such as in the case of OIP-02A and OIP-02C, the ratio of C at 0.001 Hz to 1 Hz can be higher than 10. Considering other bushings having identical design such as SRBP-01 and SRBP-02 or RIP-01 and RIP-02, the difference in C and DDF of each pair is more obvious at very low frequencies than at 1 Hz. Finally OIP-04 which had low moisture in paper but likely that the oil had high conductivity, the DDF shape is different from the others e.g. the value at 0.1 Hz is higher than at 0.01 Hz.

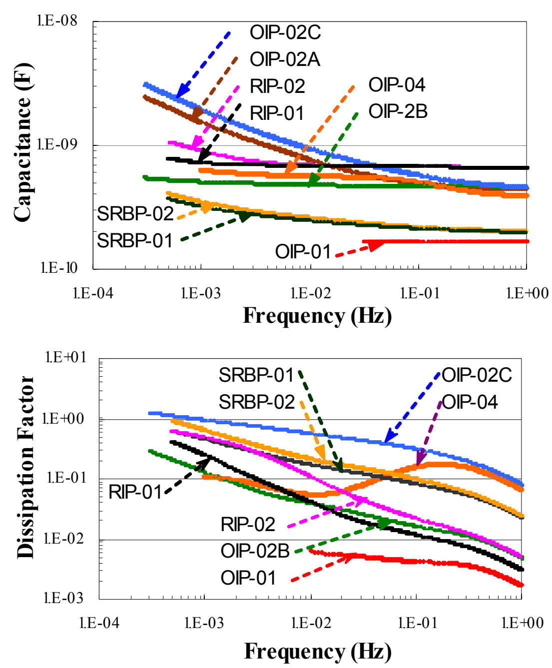

Figure 6 – Capacitance and Dissipation Factor from PDC

Table I
PDC Evaluation Results of some OIP, SRBP and RIP Bushings

Description		OIP-01	OIP-02B	OIP-02C	OIP-03	SRBP-01	SRBP-03	RIP-01	RIP-02
Year of Manufacturer		2003	1963	1963	1963	1960's	1977	2003	2003
Rated Voltage	(kV)	110	330	330	132	220	275	66	66
Test Voltage	(V)	500	2,000	2,000	2,000	2,000	1,000	1,000	1,000
Average ambient (oil in case of OIP) temperature	(°C)	13	27	30	18	20	10	17	19
Polarisation test duration	(s)	55	3,000	3,000	3,000	2,000	1,000	3,000	2,000
Depolarisation Test duration	(s)	91	3,000	3,000	3,000	1,000	890	1,000	1,000
Moisture content in paper	(% wt.)	0.5	1.0-1.5	3.5	2.5-3.0	N/A	N/A	N/A	N/A
Capacitance at 50 Hz	(pF)	176	455	459	329	196	183	655	654
Capacitance from conventional 50 Hz test	(pF)	-	459	451	340	203	-	504	504
tg δ or DDF at 0.001 Hz		-	0.125	0.919	0.254	0.441	0.113	0.241	0.479
tg δ or DDF at 0.01 Hz		-	0.038	0.548	0.114	0.167	0.093	0.040	0.108
tg δ or DDF at 0.1 Hz		0.004	0.016	0.305	0.128	0.080	0.050	0.011	0.022
tg δ or DDF at 1 Hz		0.002	0.005	0.078	0.028	0.022	0.014	0.003	0.005
tg δ at 1 Hz (multiply the previous line with 100)	(%)	0.16	0.47	7.76	2.80	2.21	1.40	0.30	0.50
DDF at 50 Hz from conventional on-site test	(%)	-	0.38	0.51	0.63	0.80	-	0.46	0.53
Insulation Resistance at 15 s.	(GΩ)	31,600	1,080	37.4	484	481	1,060	659	238
Insulation Resistance at 1min.	(GΩ)	-	2,230	70.7	1,010	943	3,540	882	314
Insulation Resistance at 10 min.	(GΩ)	-	4,120	169	2,580	2,170	13,000	1,520	763
P.I. (between 1 and 10 min. of pol.)		-	1.85	2.39	2.54	2.30	3.67	1.72	2.43
Charging time at 1st peak of polarisation spectrum	(s)	-	1,600	120	2.8	960	340	700	280
Maximum Recovery Voltage at 1st peak	(V)	-	172	263	166	254	67	69	112
Initial Slope at the Maximum Recovery Voltage	(V/s)	-	0.33	20.80	81.88	1.62	0.37	0.30	1.34

Note: The conventional 50 Hz C & DDF on-site test results are included for reference.

Figure 7 shows the PDC evaluation results of recovery voltage polarization spectrum (top) and the chart in which initial slope is plotted against maximum recovery voltage (bottom).

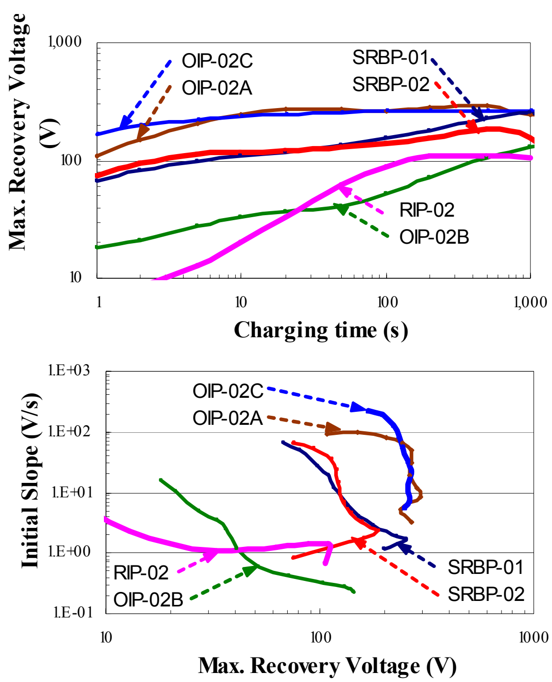

Figure 7 – Recovery Voltage Polarisation Spectrum from PDC

CONCLUSION

Ground reference, right connection and good screen are the keys to avoid the problem of polarity reversal during PDC measurement of bushings installed in transformers. The PDC shape of a bushing depends on the design and its insulation condition. No matter what type of insulation is, the quality of bushing main insulation C1 can be judged from the PDC evaluation results especially DDF at various frequencies and the capacitance at very low frequencies. Finally, the PDC collection in this paper confirms that the insulation aging of in-service bushings can be assessed on site by the PDC technique and the sensitivity is better than the conventional 50 Hz test.

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