ON-SITE PARTIAL DISCHARGE MEASUREMENTS ON POWER TRANSFORMERS

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ABSTRACT

Typical mechanisms of insulation degradation in power transformers and corresponding sources of partial discharges are characterized. Field experience with the Universal Partial Discharge Analyzer application is described, and in-field history cases are presented.

Key words: Transformer- Partial Discharges- Insulation- Field assessment of insulation.

INTRODUCTION

During recent years the technical policy of power utilities is changing under the pressure of economical considerations. There is a common tendency of moving from the time-based to the condition-based maintenance to reduce maintenance costs, and, at the same time, to prevent sudden failures, particularly catastrophic ones that typically follow main insulation faults. A vital problem is also how to continue the operation of a questionable transformer, especially if it reveals the symptoms of partial discharge (PD) activity. Then, one may emphasize a clear tendency to perform maintenance procedures in-field condition, especially without de-energizing the equipment. Question arises how to verify quality of such works?

An incipient failure of insulation attributes always to PD activity. PD measurements [1-4] were recognized as the main and most reliable method of the insulation condition evaluation at factories. Can it be duplicated in field, particularly to verify repair quality or to ensure that incipient fault suggested e.g. by DGA test will not progress to affect the insulation system? There have been several technical obstacles, especially a high external noise and need in special expensive facilities. Therefore, only a system of acoustical PD detection has been practically used, in some instances very effectively [5, 6].

The recent progress in PD measuring technologies has opened really new opportunities in an effective rejection of external interference and on-site diagnosis of the condition of transformer insulation, quite similarly to well established tests at the transformer factories. The successful implementation of PD electrical field tests has been reported in several papers [7-11]. This paper discusses problems associated with PD activity and PD identification in power transformers, and the effectiveness of diagnostic methods available. The case histories with problem identification using PD Universal Analyzer are presented.

HISTORY OF FIELD PD MEASUREMENTS

ZTZ-Service Co has utilized PD measurement technology since early 70s. At first, it was an attempt to duplicate in the field factory PD measurements. Large electrostatic shields placed on the bushings and separate energizing source have been used to minimize the external noise. However, feasible PD signals could be recorded above the level of 5,000-10,000 pC only [12]. Then special balancing (bridge) circuits has allowed reducing the recorded level of PD signal to 600-900 pC during the tests of shunt reactors [13], and even to 50-100 pC using separate diesel-generator as a source of energizing [14]. But due to restrictive costs such tests have been performed only occasionally, as a part of life extension program.

After that mainly an acoustic monitoring technique with piezoelectric transducers have been utilized, basically on units exhibiting PD or arcing activity through DGA test. But since 1998, ZTZ – Service has implemented the Universal Partial Discharge Analyzer of Cutler-Hammer recording electric signals directly [15]. The practical experience has confirmed that this test technique provides high sensitivity to PD in field conditions, about 20-50 pC, and may be used as an effective diagnostic instrument [11].

The following transformers have been considered as candidates for PD monitoring:

- Exhibiting PD or arcing activity through DGA test
- After in-field repair and refurbishment
- At ranking the units requiring in repair
- Assessment of maintenance (processing) program
- Assessment of the conditions of critical transformers (nuclear units, equipment of 750 kV transmission system, etc.)

PD PROBLEMS IN POWER TRANSFORMERS AS VIEWED FROM PRACTICAL EXPERIENCE

Table 1 shows a classification of PD generation sources in operating transformers that has been defined on the basis of many years of experience. There are three main potential sources of PD generation in power transformers: Core and Coils assemblies, Bushings, and LTCs. On the other hand, the sources of PD can be associated with the operating voltage, with the voltage induced by the main magnetic flux, or with the voltage induced by a stray flux.

If bushings and LTC are excluded the problems associated with sparking and arcing within a transformer could be roughly distributed as follows:

PD associated with the main magnetic flux	31 %
PD associated with the stray flux	41 %
PD associated with the operating voltage:	
conductor under floating potential, bad contacts	14 %
creeping discharge	14 %

The Creeping discharge in major insulation is the most dangerous defect, and the unit with it must be taken from operation immediately. But this defect appears less than in 15% of cases. On the other hand, failure analysis has shown [11] that about 15-20 % of annual sudden failures and most of catastrophic events are caused by an impairment of the conditions of the main and minor insulation due to a particle contamination or the ingress of moisture that reduces the impulse withstand strength. These events definitely attributed to PD activity frequently remained undetected.

TABLE 1
Sources of PD generation

Components	Source of PD	Typical faults
Core and Coils Assembly *oil-barrier-paper structure and oil* *Electrostatic Shields* *Leads*	*Operating voltage* PD attributed to reversible changes in insulation condition PD attributed to an irreversible degradation of insulating material:	Oil/surface contamination with particles, bubbles, static electrification, bad impregnation, high moisture, partial breakdown in oil; surface discharges; creeping discharge Sparking and arcing in bad connections "Conductor under floating potential" discharges Tracking in wooden blocks.
	Voltage induced by the main magnetic flux Voltage induced by the stray magnetic flux	Closed loops between adjacent members linked by the main flux (insulated bolts of core, pressing bolts, pressing metal rings, etc.); Sparking due to floating potential. Closed loops between adjacent members linked by the stray flux; floating potential (e.g. ungrounded magnetic shunts)
Bushings	*Operating voltage*	Localized defect within the core: bad impregnation, high moisture, short-circuits between layers, sparking across the core surface Breakdown in oil; surface discharges along the lower porcelain
LTC	*Operating voltage* PD associated with operating voltage at the fix tap position: PD associated with switching processes	Partial breakdown in the selector and in the diverter switch compartment Poor or worn out contacts

MECHANISMS OF INSULATION DEGRADATION

Defect-free transformer insulation is characterized with possible apparent PD charges of 10-50 pC or lower. Increasing in the PD level up to 100-300 pC is associated typically with the presence of particles and (especially just after filling the transformer with oil) with trapped small air bubbles [17]. The ionization level of 25-500 pC in an oil-barrier insulation does not affect its dielectric withstand strength and may be considered as typical for normal deterioration [18-20].

A reversible change in insulation condition due to the defect appearance is usually associated with PD levels above 1000 pC, and may be caused by different degradation mechanisms:

- Conductive particles that bridge oil gaps and result in discharges with magnitudes from 100 to 10,000 pC [18].
- Increase in the moisture content in the paper up to 3-4 % and relevant increase in the concentration of moisture in oil, which causes reduction of PD inception voltage by 20 % and occurrence of PDs with the level up to 2000-4000 pC [21].
- Poor impregnation originating discharges of about 1,000-2,000 pC [17].
- Large (3-5 mm in diameter) air/gas bubbles in oil resulting in discharges ranging in magnitude from 1,000 to 10,000pC [17].

In general, PD level over 2500pC (in paper) and over 10,000 pC (in oil) may be considered as a destructive ionization in a long-term action [1, 20].

Mechanism of the incipient irreversible failure in oil-barrier insulation:

- Is initiated by the breakdown of oil gap which is registered as an apparent charge in excess of 10,000 pC that rises rapidly to 100,000-1,000,000 pC [21, 22].
- Progresses in surface discharge in oil across the barrier with PD magnitude over 100,000 pC.
- “White marks”appear on the surface due to forcing oil and water out of the pressboard pores followed with carbonized “black marks” on the barrier.
- PDs of 10,000-100,000 pC may cause an irreversible damage during dozens of hours.
- Minimum energy required to cause incipient carbonizing in the cellulose (heating over 300^0C) is estimated as 0.1 J, which corresponds to several charge pulses of 100,000-1,000,000 pC [1],
- Stable discharge in oil associated with PD power is $P>0.4$ W.
- An average rate of gas generation under the effect of stable PDs in oil is 50µl/J[23, 24].
- Further steps progress either in the breakdown of the insulation space or in the occurrence of creeping discharge.

Creeping discharge:

This is, likely, the most dangerous failure mode that typically results in catastrophic failures at normal operating conditions. The phenomenon occurs in the composite oil-barrier insulation and progresses in several steps:

- Partial breakdown of oil gap.
- Surface discharge in oil across a barrier (an appearance of black carbonized marks on the barrier).
- Microscopic sparking within the pressboard. The presence of some excessive moisture stimulates this process.
- Splitting oil molecules under the effect of sparking. The formation of hydrocarbons followed with the formation of carbonized traces in the pressboard. This process is resulted in lowering magnitudes of PD apparent charges to 1,000-5,000 pC. Creeping process can continue from minutes to months or even years, until the treeing conductive

path causes shunting of an essential part of transformer insulation resulting in a powerful arc.

The cellulose destruction (creeping discharge) while progressing within the pressboard is associated with PD intensity $q \geq 1000$ pC; PD power P=0.1-1 W, average rate of gas generation of 40-50 μl/Joule [24].

Failure of turn-to turn insulation:

- Occurrence of sporadic PD pulses with the magnitude over 400 –1000 pC during several hours [25].
- Rapid rise in PD activity up to above 100,000 pC (duration-up to tens of minutes).
- Paper puncture, turn-to-turn short-circuit (duration- several seconds).

DIAGNOSTIC CHARACTERISTICS OF A FAULTY TRANSFORMER INSULATION

Faulty conditions can be characterized in terms of PD activity, fault gas generation, and changes in the conductance, capacitance and dielectric loss factor of a defective area. Typical scenario of initially defect-free insulation failure is the following:
Contamination (particles, water, bubbles) ⇒ *Occurrence of moderate PD* ⇒ *Occurrence of destructive PD* ⇒ *Gas generation* ⇒ *Progressing PD accompanied with gas generation* ⇒ *Tracking/treeing accompanied with gassing and changing dielectric characteristics, critical pre-failure PD* ⇒ *Breakdown*

The relevant diagnostic characteristics are:

- PD parameters: apparent charge magnitude, Pulse repetition rate, Discharge Power, PD Signature.
- Faulty gas content.
- Gas generation rate as a rate of degradation of insulating materials that is a function of discharge power.
- Change of Power Factor, Conductivity and Capacitance of the defective insulation space [26].

Diagnostic technique shall advise how to distinguish between really dangerous problems (e.g. destructive PD in the oil-barrier structure), and problems that does not affect the functionality of a transformer to a danger extent, and an equipment could be kept in service at least for some time. Apparently, the consideration about a possible critical transformer condition must be supported by the design review, especially to assess “the sensitive points” of the equipment.

METHODS OF PD REGISTRATION

Three of the most frequently used types of PD sensing are electrical, acoustic and electromagnetic. Cons and Pros of the methods are presented in Table 2.

TABLE 2
Comparison of PD registration methods

TYPE OF SENSORS	ADVANTAGES	DISADVANTAGES
ELECTRICAL Direct connection to the test tap or through high-frequency CT on the grounding wire, "Rogovski" coils Additional sensors in bus ducts, on electrostatic shields, neutrals, etc.	High sensitivity. Can be calibrated in terms of apparent charge. Detects an approximate location of PD source. All capabilities to trend data. Permits to use PD- pattern-recognition technology. Sensors configuration can match for better noise rejection.	Needs de-energizing for sensors installation.
ELECTROMAGNETIC Antenna	Easy to use. Possible assessing of external PD problems including PD in the bushings. Serving as a noise (corona) channel.	High disturbances. Only discharges of extremely high level can be detected. Difficult to distinguish an equipment having problems from surrounding equipment.
ACOUSTIC Piezo-accelerometer placed on transformer tank	Easy to install. Capability to detect acoustic emission magnitude and trend, pulse repetition rate and trend. Localizing a source of PD using signal time of arrival to different locations.	Low sensitivity. Minimum detecting apparent charge >10,000 pC. Responds to rain, sleet, electrical disturbances in the substation. The level of signal depends on coupling between the sensor and surface. Effect of design (variables inside the tank) on the propagation of sound waves.

Ideally, the combination of all three methods can be a powerful diagnostic tool:

- Rough detection of the problem externally using an electromagnetic sensor,
- Identification of insulation condition with electric method,
- Location of the PD source by an acoustic device.

However, the electrical method only can detect and identify defective conditions that associated with PD activity ranged below 1,000 pC. Our experience has confirmed that the acoustic detection of PD is a very effective complementary tool to localize a source of gassing caused by very strong arcing in oil. The diagnostic method in this case can be: DGA as an alarm trigger and an acoustic sensor as a locating tool.

However, the successful identification of arcing problems through "DGA + acoustic" technique is possible in cases of the dissipation of high energies (typically, over 500-1000 kJ). This technology, consequently, shows very strong degradation processes only. Acoustic PD monitoring has not been effective in identifying of progressing creeping discharges. Minimum PD signal effectively detecting by an acoustic sensor in full-scale transformer model was limited to the level of approximately 10,000 pC and above.

EXPERIENCE IN FIELD PD IDENTIFICATION USING UNIVERSAL PD ANALYZER

PD Technology

The portable Cutler-Hammer Universal PD Analyzer *UPDA* has been used for different in-field applications to detect PD activity in power and instrumental transformers. The UPDA monitors the wave forms for several power frequency cycles from several (up to 8) sensors simultaneously, and then identifies the PD pulses in the acquired information using up to 5 independent noise deletion systems [15].

Radio frequency pulses are measured at the output of the capacitance taps of the bushings (typically six sensors), and on neutral and tank/active part grounding wires. Some of measuring inputs can be used to connect acoustic sensors and an electromagnetic sensor (antenna).

The reduction of noise is provided by the following measures:

- Selection of the frequency band. As a rule, the frequency band from 1 MHz to 20 MHz is selected. UPDA also has the option to choose full frequency band or to use an external filter.
- Filtering (sometimes, when a radio transmission interference is very high).
- Electronic processing of signals: phase and frequency selection, time delay selection, signal comparison, etc.
- Time window method (provided with the gate, which can be opened and closed at pre-selected moments).
- Comparison of signals from different sensors (to reduce corona disturbances, in CT's especially).
- Balanced circuit- in the shunt reactors and CT's.

The high frequency band used in measurements can sometimes create a problem associated with the attenuation of PD signals while they travel in the transformer to the sensor. Therefore, a calibration is important to evaluate the sensitivity and to determine possible attenuation impact on the data collected. High frequency band may also exert an effect of screening PD impulses in the range of 100-1,000 kHz that typically accompany powerful PDs of 100,000-1,000,000 pC. In such cases the test procedure can be specifically adjusted for the particular transformer design.

The calibration is an important process typically provided immediately after the monitoring system commissioning. Calibration allows:

- To recalculate pulse magnitude into an apparent charge.

- To evaluate the sensitivity in the each measuring channel.
- To compose calibrating cross-matrix that serves as an important diagnostic tool permitting to distinguish between PD sources in the core, in the bushings or in winding insulation, and to determine an approximate PD location.

The test protocol includes cross-matrix, detected noise level, residual (white) noise level, maximum pulse magnitude, Pulse repetition rate, and PD Power. Three-dimensional phase-resolved analysis is also available for PD pattern recognition.

The diagnostic method consists of several steps:

- Evaluating PD characteristics.
- Considering voltage/load/temperature effects on PD activity.
- Considering accompanied factors (DGA, oil tests, and dielectric characteristics).
- Design review.

Comparative tests in the factory

The effectiveness of noise deletion by UPDA was evaluated by comparative tests in the factory. The tests using an accepted factory technique and UPDA were performed on the transformer 500/220 kV, 100 MVA (Table 3) and on the 330 kV current transformer (Table 4). Factory test setup used all known noise reduction means including screened room and diesel-generator as a power source. The tests have shown a good agreement between factory Lab's and UPDA technique. It was found that UPDA Analyzer achieved satisfactory signal-to-noise ratio, even without special procedures that were critical for factory setup.

TABLE 3
Comparative PD tests provided on a 100 MVA, 500/220 transformer

Place of sensor Applied voltage	Factory test technique		UPDA Analyzer	
	Special shield on 500 kV bushing	Without shield	Special shield on 500 kV bushing	Without shield
HV, neutral, grounding 476 kV (1.64 Ur)	24 pC	2800 pC	30.7 pC	68.7 pC

TABLE 4
PD test on the 330 kV current transformer

Place of sensor Applied voltage	Factory test technique Balanced circuit	UPDA Analyzer Direct test
Measuring tap, Grounding tap («0»–electrode) 275 кV (1.3 Ur.)	26 pC	11 pC

IN-FIELD EXPERIENCE: HISTORY CASES

Case 1. Verification of the quality of in-field repair of a 200 MVA auto-transformer

An auto-transformer 200 MVA, 330/110 kV has failed after 13 years in operation due to the explosion of 330 kV bushing. The failure was accompanied with the tank rupture, damage to HV winding insulation and severe contamination of the core and coils assembly with carbon, pieces of porcelain, etc. ZTZ-Service has performed remedy repair on the substation in field conditions. The insulation conditions after repair were evaluated as satisfactory (water content in the pressboard 0.7 %, PF =0.2% at 45^0C, low content of particles in oil, etc.). However, some doubt remained especially referring to a possible localized contamination in HV winding.

PD measurement has been performed with UPDA at rated voltage U_r and at $1.05U_r$. (the unit was energized from 110 kV side). The results obtained have confirmed a good condition of the insulation integrity (Table 5).

TABLE 5
PD Test Report for the auto-transformer 200 MVA, 330/110 kV after in-field repair

Sensor	Deleted Noise, nC	Max PD Magnitude		Repetition Rate, ppc	PD Power, mW
		V	*pC*		
Bush_A_S	0,989	0,0266	53.2	1,11	0,531
Bush_B_S	3,42	0,0376	75.2	1,88	0,904
Bush_C_S	0,547	0,0298	59.7	2,07	0,838
Bush_Am_S	4,63	0,0266	47.9	1,01	0,294
Bush_Bm_S	4,68	0,178	320	12,3	16,7
Bush_Cm_S	0,66	0,075	135	11,1	9,06
Neutr_S	0,169	0,0133	40	10,4	1,11

Case 2. Assessing the condition of a 220 kV auto-transformer after long service

The PD tests have been incorporated in the program of life assessment of a 240 MVA, 220/110 kV, core-form auto-transformer with the goal to make a decision if an urgent necessity of insulation reconditioning after 28 years of service exists.

Water Heat Run Test (WHRT, see [11]) has revealed symptoms of significant insulation aging. At heating the transformer up to 65^0C and holding for 24 hours the water-in-oil content doubled. The reduction in dielectric breakdown voltage was about 20%, and its variation coefficient increased to 15% that was a symptom of large particles presence. Particles in-oil count has shown the level of contamination denominated as “High”(NAS class 7). Water content in cellulose estimated through PF test and WHRT was about 2%.

The results of DGA for this transformer are presented in Table 6, of PD tests- in tables 7 and 8. These results have shown a moderate deterioration of the insulation integrity. Maximum PD magnitude in the insulating spaces with a minimum safety margin, that is the insulation of the series winding 220 kV, was below 400 pC. Correspondingly, it was advised to postpone the repair of the unit and to prolong its operation without oil and insulation processing.

TABLE 6
Dissolved Gas Analysis results for the auto-transformer 240 MVA (in ppm)

H2	CH4	C2H2	C2H4	C2H6	CO	CO2	Σ C3	1-C4H8	O2	N2
4.7	none.	none.	52	none.	162	1388	67	2039	0.60	2.21

TABLE 7
Calibrating cross-matrix for the auto-transformer 240 MVA

Calibrating pulse applied to…	Sensors outputs							
⇓	A_220	B_220	C_220	Am_110	Bm-110	Cm_110	Neutral	Ground
A_220 -Tank	1.000	0.054	0.076	0.120	0.033	0.065	0.022	0.022
B_220 – Tank	0.231	1.000	0.212	0.077	0.269	0.096	0.038	0.038
C_220 – Tank	0.081	0.135	1.000	0.054	0.095	0.135	0.027	0.027
Am_110 – Tank	0.054	0.076	0.043	1.000	0.207	0.065	0.022	0.022
Bm_110 – Tank	0.022	0.044	0.061	0.050	1.000	0.033	0.011	0.011
Cm_110 – Tank	0.073	0.164	0.145	0.145	0.255	1.000	0.036	0.036
Neutral – Tank	0.058	0.050	0.058	0.033	0.075	0.067	1.000	0.017
Tank - Ground	0.143	0.143	0.214	0.071	0.107	0.143	0.393	1.000
A_220 –Tap	1.000	0.069	0.069	0.139	0.056	0.069	0.028	0.028
B_220 – Tap	0.290	1.000	0.290	0.161	0.516	0.194	0.065	0.065
C_220 – Tap	0.091	0.109	1.000	0.073	0.127	0.164	0.036	0.036
Am_110 – Tap	0.046	0.062	0.031	1.000	0.115	0.069	0.015	0.015
Bm_110 – Tap	0.022	0.033	0.033	0.050	1.000	0.044	0.011	0.011
Cm_110 - Tap	0.105	0.063	0.053	0.074	0.126	1.000	0.021	0.021

TABLE 8
PD Test Report for the auto-transformer 240 MVA

Sensor position	PD Power mW	Residual noise nC	Max. PD pulse magnitude nC	Repetition rate, ppc
A_220_S	84.5	0.074	0.298	150.0
B_220_S	53.1	0.128	0.355	128.0
C_220_S	88.3	0.078	0.389	132.0
Am_110_S	20.5	0.068	0.127	95.1
Bm_110_S	9.39	0.036	0.160	31.7
Cm_110_S	1.38	0.115	0.066	7.35
Neutral_S	20.1	0.057	0.303	32.4
Ground_S	0.14	0.031	0.0426	0.466

Case 3. Assessment of the seriousness of gas generation in an auto-transformer 300 MVA

One of two sister–type shell-form auto-transformers, 300 MVA, 500/220 kV, revealed the clear signs of faulty gases generation, likely associated with a combination of PD activity, localized oil heating and cellulose decomposition (Table 9). To continue the operation of both units was very critical. The problem was formulated: how serious is the symptom of this abnormality? Will it progress to affect the insulation system in a short time? To answer these questions PD measurements were provided on the auto-transformer (Table 10).

TABLE 9
DGA data for the auto-transformer 300 MVA (in ppm)

Data	H2	CH4	C2H6	C2H4	C2H2	CO	CO2
27.09.97	1	1	4	1	1	4	49
17.10.97	53	2	1	1	2	46	235
12.11.97	154	6	2	3	2	105	684
14.05.98	447	32	11	23	1	580	1920
30.06.98	563	151	50	148	1	605	1757
23.07.98	557	155	45	156	<1	588	1720
02.09.98	674	204	70	217	<1	722	2174

TABLE 10
PD test report for the auto-transformer 300 MVA

Sensor location	Noise, pC	Maximum pulse magnitude, pC	Repetition rate ppc	PD power mW
Bush U	127	1,270	100	10.7
Bush V	127	225	1000	47.1
Bush W	142	252	1800	80.6
Neutral	37.8	0	0.759	0.00046

The analysis of PD characteristics has pointed out at a defective condition of the auto-transformer. Particularly, the presence of a source of PD generation on the phase U close to its HV terminal has been admitted. However, the level of ionization could not cause the destruction of insulating material and explain the observed rate of gas generation. It was suggested that the main problem is not attributed to PDs in the major insulation and the unit may be left in operation for a certain time (at least for one year). Unfortunately, it was not possible to perform PD test on the fully loaded transformer in order to check a possible relation between PD level and the stray flux.

Case 4. Verifying insulation health of transformers 500 kV at a hydro power plant early in their service life

PD test has been carried out on 20 sister GSU units 172.5 MVA, 500 kV at a hydro power plant to verify their condition after 2-4 years of service and, specifically, to assess the condition of their SF6 500 kV bushings. PD test results are presented in the Figures 1 and 2. The tests showed:

- The residual noise was suppressed to a level less than 20 pC.
- The PD parameters measured on HV side confirmed a defect-free condition (average value of PD magnitude was 28 pC, average PD Power- 0.14 mW).

Only in the neutral of one unit the PD level of 670 pC and PD Power of 7.2 mW have been observed. This not dangerous ionization was, likely, attributed to the insulation of the no-load tap changer. Several significant PD sources were observed in bus ducts on 13.8 kV side of a GSU transformers. An additional investigation was not done since bus ducts were out of the goal of these tests.

Case 5. Identification of a critical PD source in the 750 kV auto-transformer

The bank of three single-phase auto-transformers rated 333 MVA, 750/330 kV was energized after storing during 9 months. A sporadic crackling sound has appeared from the tank of the phase “A.” Urgent PD tests were advised to identify the problem. The tests have been performed at three voltage steps: 0.5Ur, 1.0Ur and 1.05Ur using the unit of phase “B” as a power supply transformer. The residual noise level was 50 pC.

An intensive ionization was observed when the voltage was increased to 1.05Ur (Table 11). Destructive PDs with an apparent charge over 12,000 pC had demonstrated that a serious destructive problem exists on the 750 kV side. Further visual inspection has found the traces of progressing creeping discharge across the 750 kV bushing insulation (Figure 3). The problem was associated with a free water penetration through the loosened top sealing of the 750 kV lead.

TABLE 11
PD Test Report for the auto-transformer 333 MVA, 750/330 kV

Sensor location	Voltage on HV side, kV	Maximum apparent charge, pC	Comments
A750 S	230	72	No symptoms of abnormality
A330 S		100	
A 750 S	750	72	No symptoms of abnormality
A 330 S		100	
A 750 S	787	11400	Occurrence of intensive ionization
A 330 S		2000	

CONCLUSIONS

1. The practical experience has confirmed that the modern PD electrical measuring devices can provide a high sensitivity to PDs in field conditions, quite comparable to one achieved in laboratory tests at the transformer factories. Such a technique may be effectively used as an on-line diagnostic instrument for on-line monitoring power transformers, shunt reactors and current and potential transformers.

2. Our experience showed that the modern PD measuring technology can be effectively used in field conditions for:

- monitoring the units suspected in PD or arcing activity by DGA test,
- the assessment of transformer condition after repair and refurbishment made in field,
- ranking units requiring repair,
- the assessment of maintenance (processing) programs,
- the assessment of the conditions of critically important transformers.

3. Only 15% of insulation problems associated with arcing or sparking inside the transformer tank are related to discharges in major insulation and provide an imminent danger for further transformer operation. PD technique should advise how to distinguish between dangerous discharges (e.g. destructive PDs in the oil-barrier structure), and the problems that do not affect equipment functionality to a critical extent.

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BIOGRAPHIES

Dr. Victor V. Sokolov, a CIGRE Member and the Convenor of CIGRE WG 12-18 “Transformer Life Management”, obtained his MSEE in 1962 from the Kharkov Polytechnic University, and Ph. D. in High Voltage Technology in 1982 from the Kiev Polytechic University. Dr. Sokolov possess a world level expertise in all questions of designing, manufacturing, testing and maintaining power transformers. He is an author of numerous publications. Now he is the Technical Director of the Scientific-Engineering Center “ZTZ-Service” (Ukraine).

Vladimir P. Mayakov, a member of CIGRE, is the head of the Field Test Laboratory of the “ZTZ-Service” Co. In 1968 he got his MSEE from the Technical University in Zaporozhye. Prior to “ZTZ-Service” he worked for Zaporozhye High Voltage Apparatus Plant as the head of the PD Test Laboratory providing quality control for high voltage current transformers, then- for Zaporozhye Transformer Plant ZTZ. His field of activity includes in-field methods for evaluating conditions of transformer equipment. He has 12 publications.

Prof. George S. Kuchinsky got his MSEE (major- High Voltage Technology) and then Ph.D. from the Leningrad Polytechnic Institute (now St. Petersburg Technical University), Russia. Since 1947 he is lecturing and providing R&D activity in his alma mater being state certified as a Professor and Doctor of Technical Sciences. He is a Member of the International Power Academy, Honorary Academician of the Russian Academy of Electrotechnical Sciences, Distinguished Scientist of Russian Federation, Member of the Russian Association of Electrical Engineers. His professional interests concentrate on electrical-physics processes in high voltage equipment insulation, electrical discharges and permissible operating voltage gradients in transformer, cable and capacitor insulation. He is an author of 14 books and 200+ papers.

Dr. Alexander Golubev got his MS in Experimental Physics and Ph.D. in Physics and Mathematics from the Moscow Physical Technical Institute (Russia) in 1978 and 1985, respectively. He has an extensive experience in research and design in Laser and Electron Beam Generation, Plasma Coatings, High Frequency Measurements. Since 1995 he is a Manager of R&D of the Predictive Diagnostics Division of Cutler-Hammer Engineering Services. He develops new technologies for on-line monitoring and diagnostics of high voltage electrical equipment, produces monitoring equipment and provides on-site expert evaluations of equipment conditions for electric utilities and industrial customers.

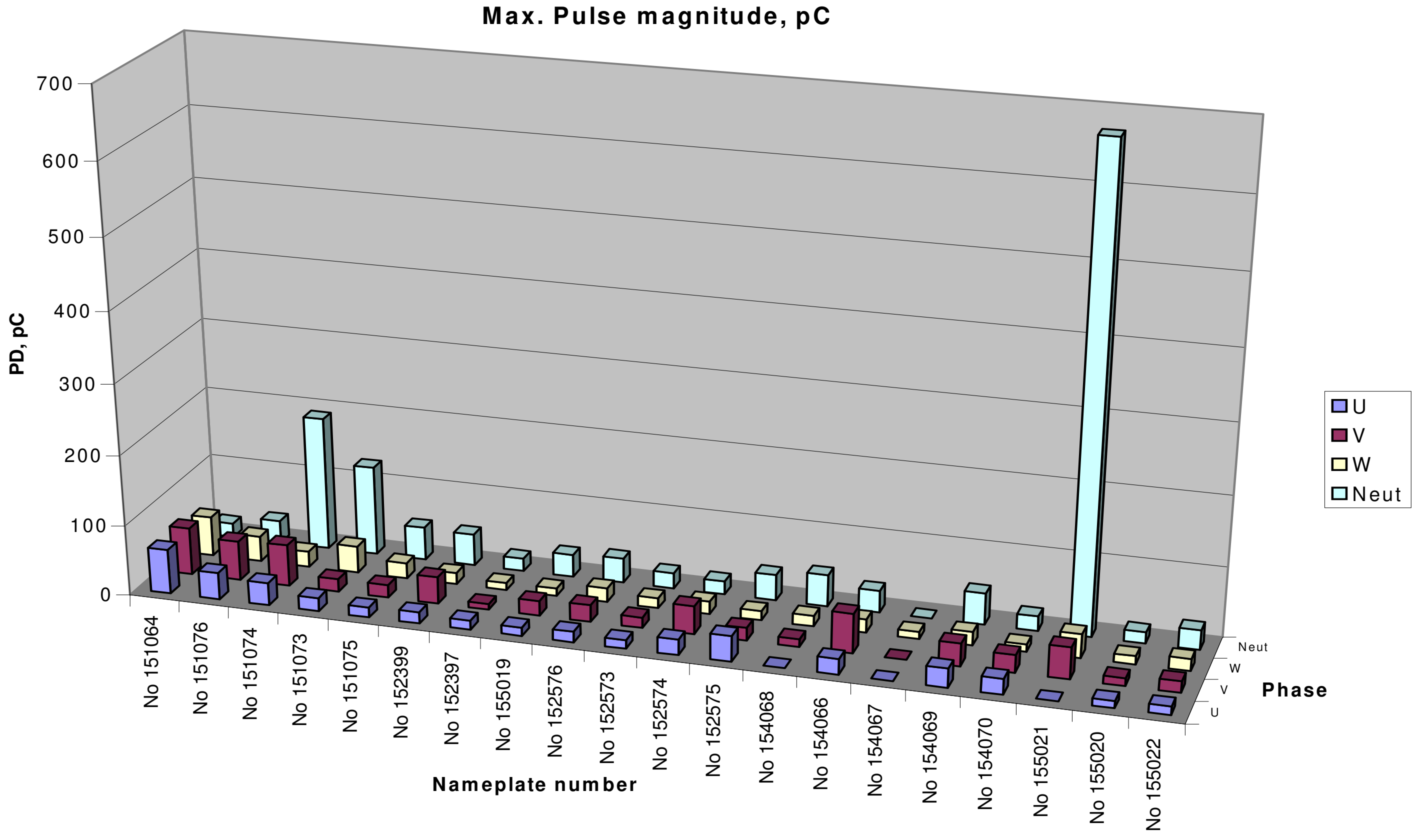

FIGURE 1.
Distribution of PD magnitudes in twenty GSU transformers tested

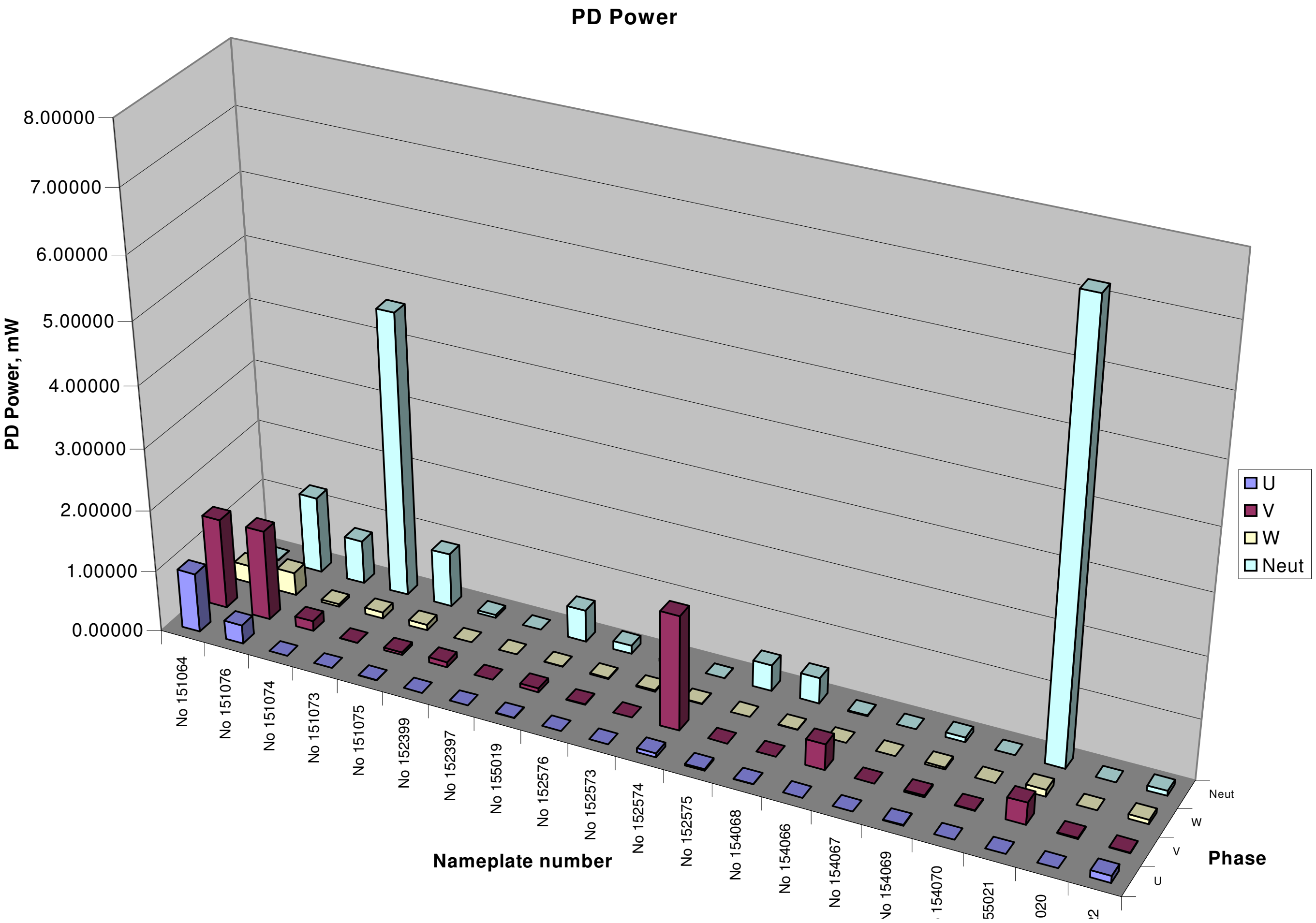

FIGURE 2.
Distribution of PD power in twenty GSU transformers tested

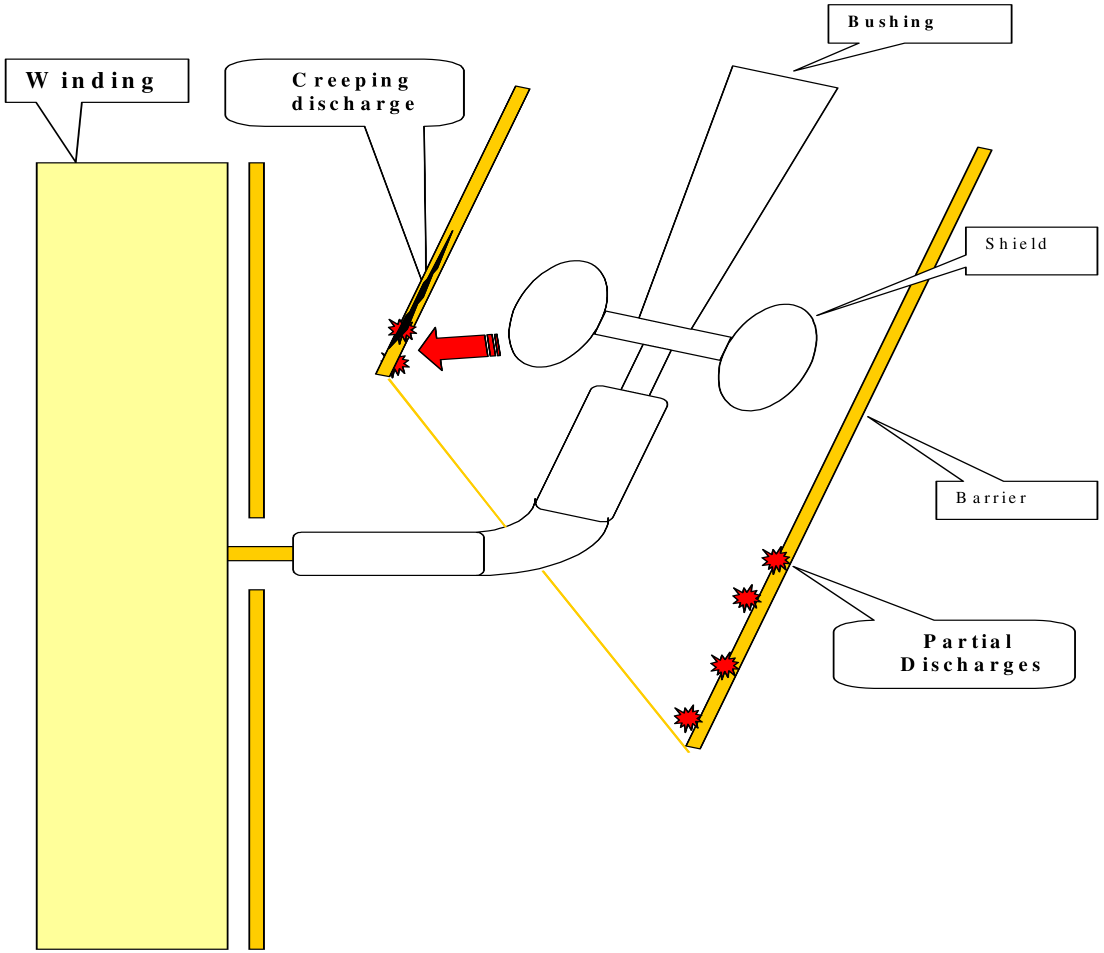

FIGURE 3.
Sketch of the defects associated with the 750-kV transformer bushing and detected by PD measurements

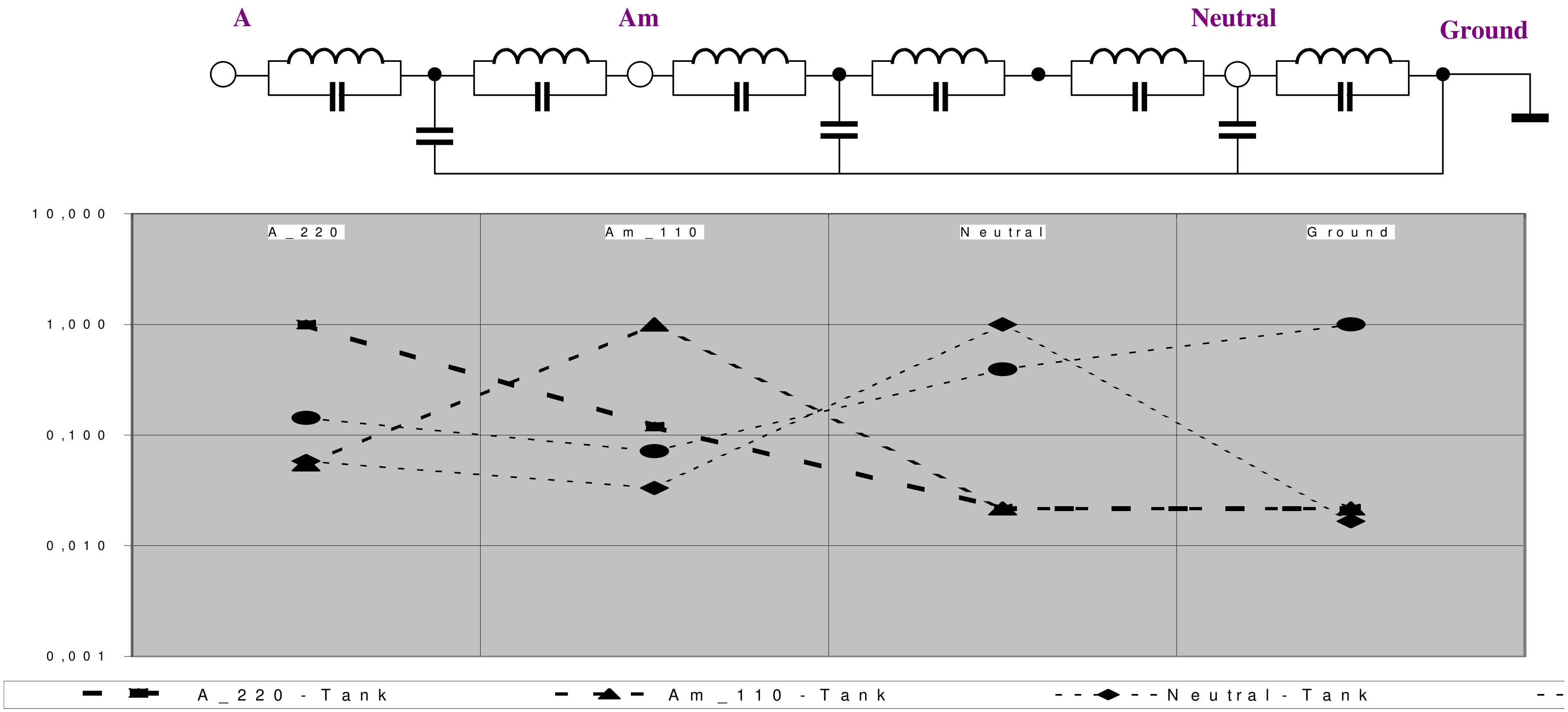

FIGURE 4.
Graphic presentation of calibrating cross-matrix for 240 MVA autotransformer, phase “A”.