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Experience with On-Line Insulation Diagnostics of Surge Arresters By Partial Discharges Measurement in the Field

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SUMMARY

Although surge arresters are relatively cheap equipment, they play an extremely important role on high voltage power stations. Because of their direct connections to high voltage, any fault can have serious consequences to the system. The evaluation of these equipments is therefore an important task to maintenance engineering. However, due to their high number, removing all equipments from the system to perform proper laboratorial tests is not feasible, and an evaluation in the field is often necessary.

The evaluation of integrity of surge arresters is traditionally performed by the measurement of the leakage current and/or Radio Interference Voltage (RIV). Another effective tool is the measurement of Partial Discharges (PD). PD measurement can be used to evaluate the health condition of those equipments during their normal operation, without necessity of their disconnection from the electrical system.

This paper describes the experience applying a simple methodology to evaluate surge arresters in the field, measuring PD through a high frequency current transformer (HFCT) connected on the grounding cable using a modular digital oscilloscope and a laptop PC.

The initial development of this methodology was performed in the lab. The frequency responses of several available HFCTs were evaluated, and the best sensible band was determined. Moreover, the digital measurement system characteristics were considered, and the required parameters of the digitizers such as bandwidth, sample rate and vertical resolution were also determined.

Once defined the suitable instrumentation, several tests were performed in the field using two different PD measurement techniques: the pulse recording in the time domain and the well known Phase Resolved Partial Discharge (PRPD) measurement. Due to the simplicity of the proposed methodology, more than 500 surge arrester units in operation in several Brazilian power substations were evaluated in a considerably short time.

Finally, this paper presents a case study of a surge arrester tested in the field, then taken out from a Brazilian power substation to be tested in the lab and after dissected for analysis.

KEYWORDS

Partial discharge (PD), surge arrester, high frequency current transformer (HFCT), predictive diagnostic, maintenance engineering, substation.

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1. INTRODUCTION

The equipments installed in a substation are subject to severe stress conditions caused by voltage surges from occurrences in the electrical system and/or lightning (impulses). In order to prevent damaging of these equipments by voltage transients, it is necessary to install appropriate devices to limit the maximum levels of voltage surge. The surge arresters are the most appropriate equipments to perform this function. They act to limiting the level of voltage at the terminals of the substation equipments, preventing voltage surges to achieve the equipment for which is provided protection.

The surge arresters play an important role in the electrical system because they make a real contribution to its operational capability, security, economy and reliability. These equipments usually have no indication of their operating condition, and little is known about its operating state after its energizing. The evaluation of surge arresters is still hampered by the large number of units installed in substations of the system.

The failure in a surge arrester, in addition to its loss, can cause oscillations in the system, damage to peripheral equipment and also put at risk the physical integrity of people who are working in the vicinity at the instant of the failure.

The development of this new technique for detection of partial discharge (PD) using high frequency current transformers (HFCT) [1][2][3] in conjunction with the tests already consolidated, like thermo vision and measurement of leakage current, will give the largest subsidies for maintenance engineering of companies can better manage the replacement of surge arresters having any operational fault indication, thereby increasing the reliability of the whole electric power system [4][5].

2. USE OF HFCT FOR PARTIAL DISCHARGE MEASUREMENT

When a HFCT is used for measuring partial discharges, the use of impedance measurement, also known as quadrupole, can be eliminated. Moreover, the use of HFCT provides Galvanic isolation between the PD meter and high voltage circuit, increasing the levels of safety of persons and the instruments used in the test. However, the big advantage of use of HFCT is the low impact on electrical system, because there is no need for interruptions in the flow of energy.

The HFCT used in test are of type bipartite (Clamp) – Figure 1. This allows the installation of HFCT, for the most part, to take place in normal conditions of operation, embracing the conductor that connects the surge arresters to the ground.

Figure 1 – Clamp HFCT on the grounding cable of a surge arrester

2.1. Assessment of sensitivity of several HFCT in the detection of the partial discharges

The main goal for this stage of the research was to evaluate the different types of HFCT which the CEPEL (Electric Energy Research Center) possesses. They were evaluated by their sensibilities in detection of partial discharge signals using the equipment's grounding conductor. In total 5 HFCT have been assessed, as shown in Figure 2.

Figura 2 – Several HFCT assessed

The conventional methodology for measurement of partial discharges using a coupling capacitor and a measurement impedance (coupling device) was used as a reference when assessing the sensitivity of HFCT. CEPEL adopted the following procedures for this evaluation, always measuring by two methods, the conventional (electromagnetic) and the non-conventional (HFCT):

1 – Applying a known calibration pulse and registering it through the HFCT grounding cable connected to the object under test. The amplitude values and the time base of the registered signals shall be observed and recorded.

2 – Apply increasing values of voltage to the object under test until the nominal value, registering partial discharge signals detected by HFCT by an oscilloscope. In this case the object under test should be grounded and the HFCT must be connected to the grounding cable, as shown in Figure 3:

Figura 3 – Lab test circuit to evaluate the sensitivity of HFCT

The HFCT number 3 presented the best performance among all HFCT in comparisons with the results achieved by the conventional method for measurement of DP. The results are shown in Figures 4 to 6.

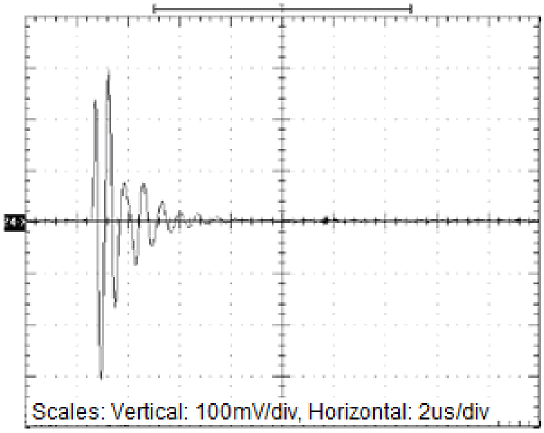

Figure 4a – 1 V calibration signal detected by the conventional method

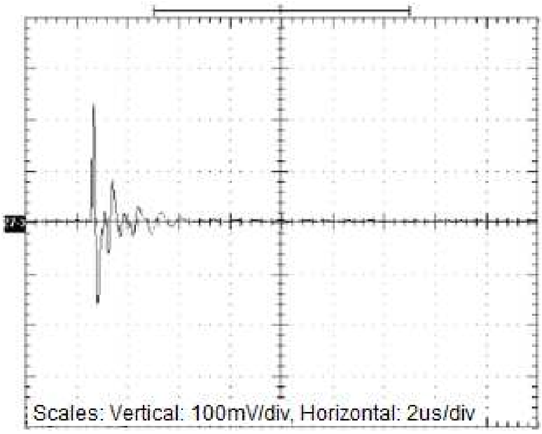

Figure 4b – 1 V calibration signal detected by the HFCT number 3

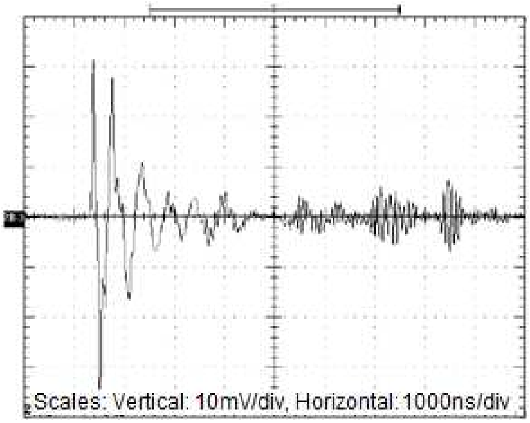

Figure 5a – 50 pC calibration signal detected by the conventional method

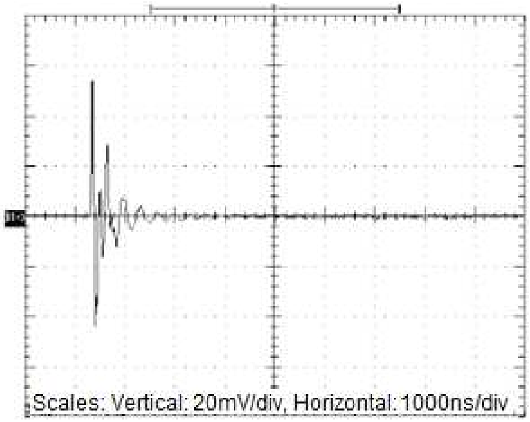

Figure 5b – 50 pC calibration signal detected by the HFCT number 3

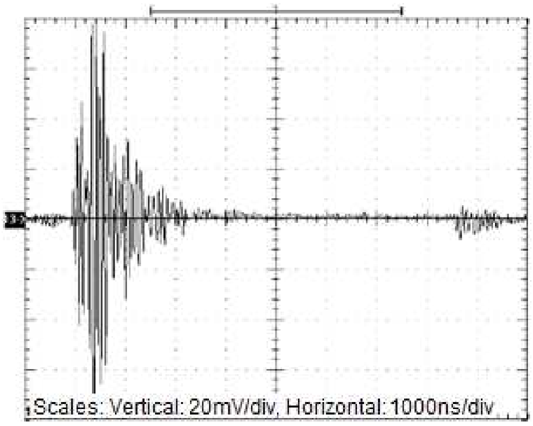

Figure 6a – PD signal detected by the conventional method

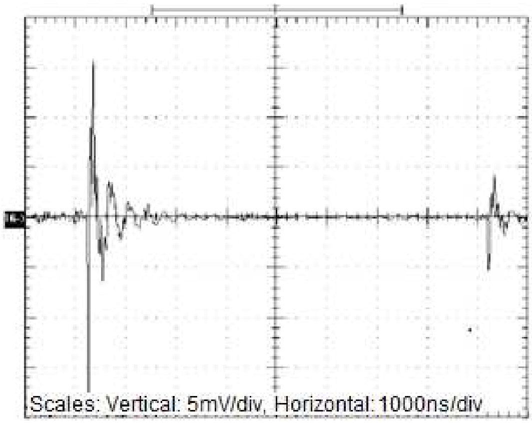

Figure 6b – PD signal detected by the HFCT number 3

The results obtained in the laboratory have shown that the measurement with HFCT can be performed satisfactorily on the evaluation of surge arresters operating condition, without significant loss of information or sensitivity in quantifying the phenomenon. In addition, the non-intervention in the supply of electrical energy is a significant factor.

3. TESTS IN THE FIELD

In September 2014 there were conducted field tests in a substation of the Brazilian electrical system for PD detection in surge arresters using HFCT as transducer. Tests were performed in surge arresters of 138 and 230 kV class. For the detection and recording of high frequency current pulses produced by PD it was used one 4-channel oscilloscope, an acquisition board, a notebook, a software to record the signals, a HFCT and the IMA-DP system (Instrumentation for Monitoring and Analysis of Partial Discharge) developed by CEPEL [6].

The results of the tests performed on the surge arresters of 230 kV class (phase-to- phase or 133 kV phase to earth voltage), are presented in Table 1.

Table 1 – Results of tests on surge arresters of 230 kV

Localization	Phase A (mV_{max})	Phase B (mV_{max})	Phase C (mV_{max})
Line 1	180	270	220
Line 2	80	100	**88**
Line 3	80	160	110
Line 4	-700	1100	420
Line 5	150	230	130
Line 6	1600	**-39000**	1200
Reactor 1	10	95	120
Reactor 2	70	100	125
Reactor 3	350	130	130
Reactor 4	300	340	140
Transformer 1	112	240	120
Transformer 2	120	230	170
Capacitive bank 1	1500	820	330

The amplitude of the signals recorded by the oscilloscope is compared between phases of the same circuit. In the case of the results shown in Table 1, the surge arrester installed in phase B of line 6 showed higher amplitude in relation to the adjacent phases, and was suspected of internal partial discharges in the preliminary assessment.

The same signal was analyzed in the time domain and the frequency domain, in order to assist in the characterization of PD (whereas the HFCT responds to high frequency, the recorded signals must have higher frequency components, of a few MHz order). The records of the 3 phases of the line 6 were performed and these are shown in Figures 7 to 9.

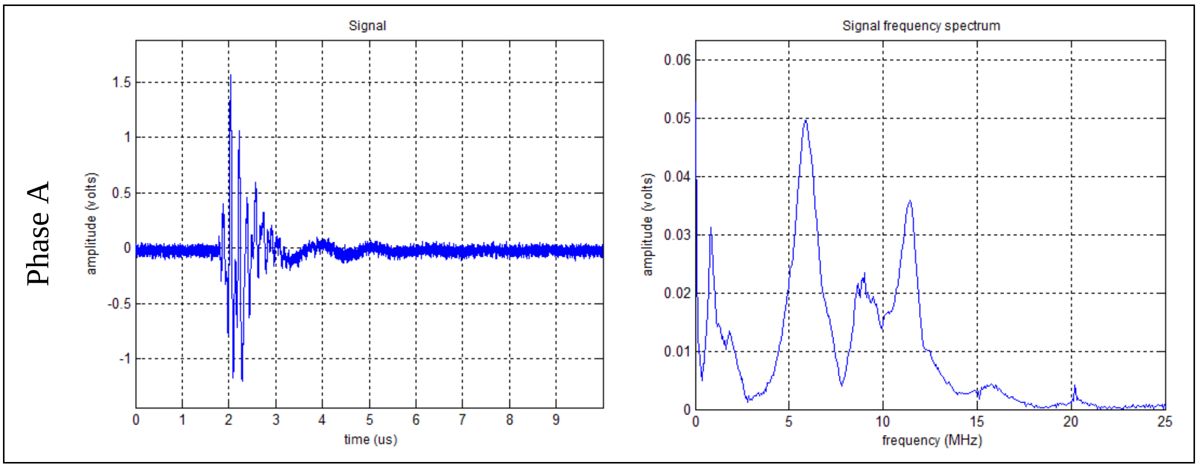

Figure 7 – Signal and the frequency spectrum in phase A of line 6

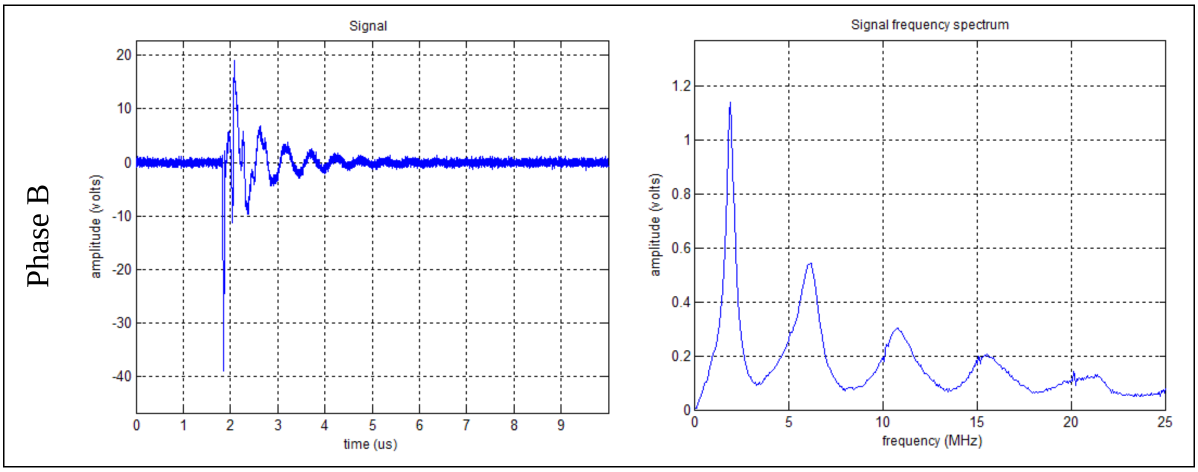

Figure 8 – Signal and the frequency spectrum in phase B of line 6

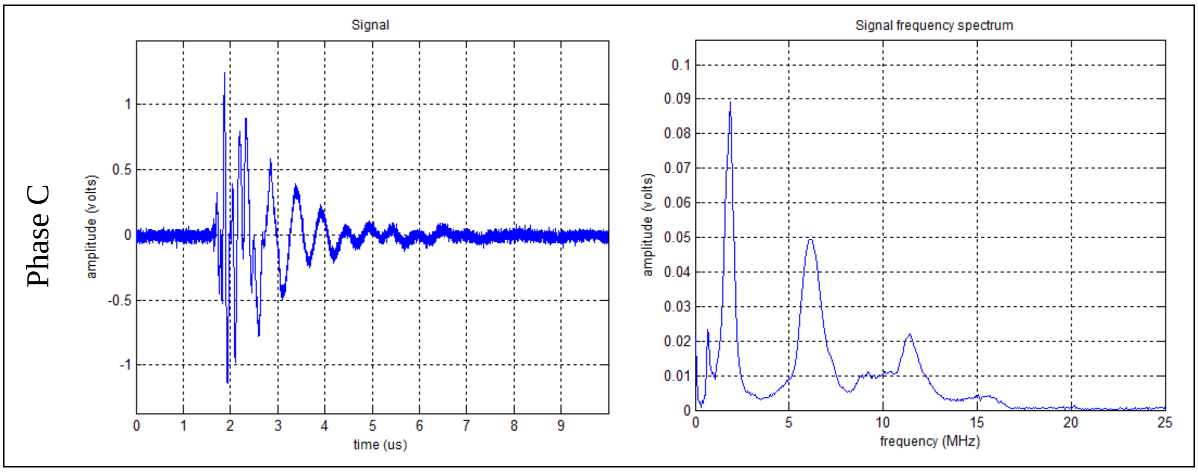

Figure 9 – Signal and the frequency spectrum in phase C of line 6

The test records shown in Figures 7 to 9 indicate that the signal detected in phase B shows a rapid wave front, almost instantaneous decay and high frequency components. These indicators are derived from internal PD signals and put this equipment as an anomaly suspect. This signal can also be compared with Figure 6b, obtained in laboratory, and similarities can be noted.

4. TESTS IN LABORATORY

The next step was the removal of this equipment for tests in the laboratory. It was an important step for technical validation, paving the way for the consolidation of this new methodology, simple enough to be performed in the field. Figure 10 shows the equipment properly mounted within the CEPEL laboratory tests.

The surge arrester in question has two modules that have been tested separately. One of the modules presented PD signals in order 200pc, well above the tolerable (10pc). Figure 11 shows the time signal measured by the module in question in the laboratory using the HFCT. In the Figure 12 presents a PD map registration of the module in question, acquired through the IMA-DP system developed by CEPEL [6]. These signals resemble internal signals of PD. However, it was not possible to say what are the sources of discharges, because there is no information in the literature correlating such anomaly. This step should be reached at the time of the physical opening of the device, which is scheduled for the first half of 2016.

Figure 10 – Arrangement in the laboratory for PD measurement on the surge arrester module

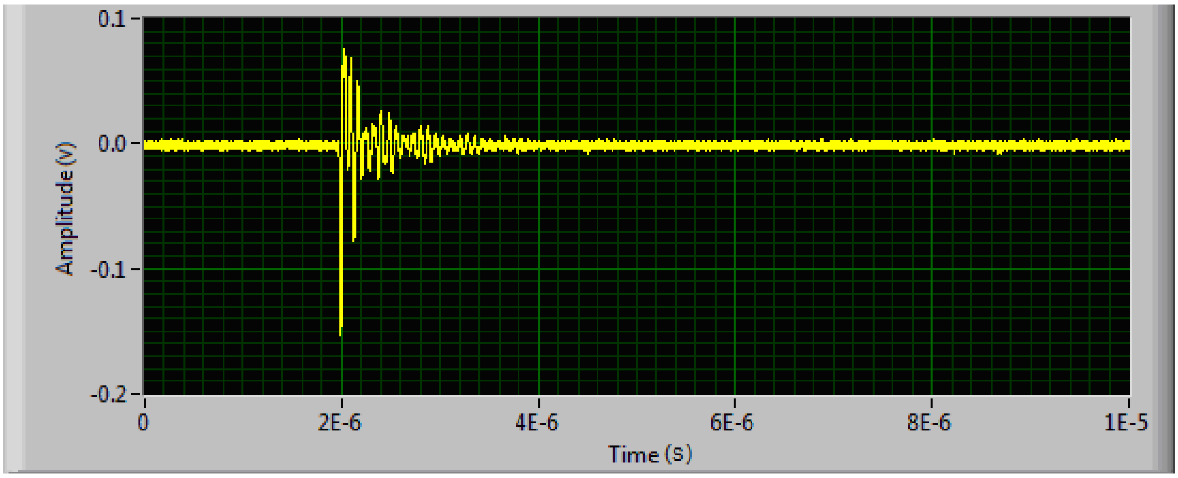

Figure 11 – PD Signal acquired in time with HFCT
via ground cable on the surge arrester module

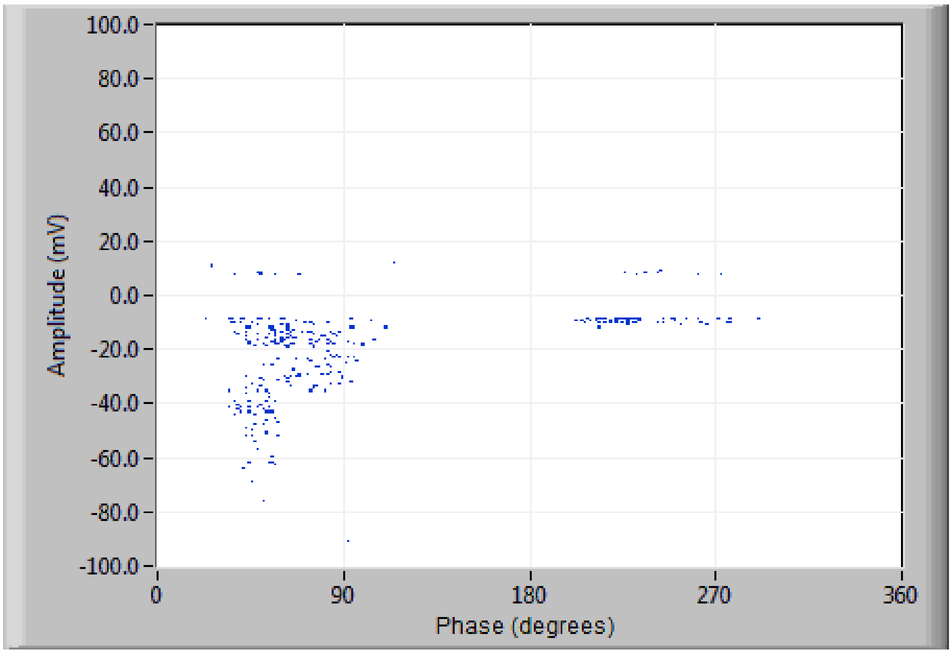

Figure 12 – PD signal recorded by the IMA-DP system

5. CONCLUSION

Comparing the waveform of the signal recorded in one of the columns of the suspect surge arrester removed from the field and the signal recorded in lab, which admittedly contained internal PD, it's possible see that there are significant similarities between the signals, which may serve as another useful information in diagnosing the surge arrester. In the case of an experimental study where there are few reports and actual findings, a representative event or even a small detail, can be crucial to indicate new ideas that help to identify the problem.

Therefore, it is possible to establish, even in a preliminary manner, mechanisms that allow the recognition of signals indicative of PD, as in the case of the aforementioned surge arrester. The signals that have a slow wave front and a damped decay with multiple oscillations can be interpreted as an external corona signals, which are not a risk to the equipment. The signals that have quick wave front and almost instantaneous decay are due to internal PD signals, as was observed in the measurement and evaluation in the field and also in the laboratory.

The implantation of this type of testing in the field as part of preventive maintenance will allow regular inspections can be made at defined periods of time and taking measurements after failure events on the network caused by temporary surges of high amplitude and / or long term.

The main advantages of this technique include:

1) The speed of execution of tests and evaluation of surge arrester in operation, thus allowing their withdrawal before a possible explosion;
2) Conducting the test with energized equipment and in normal operation without the need for intervention in the equipment nor the electric power system;
3) Possibility to prevent costs caused by failures of surge arresters;
4) Provides security to maintenance crews.

In addition, the development of methods for evaluating the operating state of surge arrester, promotes interaction and the transfer of knowledge between the companies of the Eletrobras System.

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