ON-LINE PARTIAL DISCHARGE DETECTION IN TRANSFORMERS

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This article describes an on-line partial discharge (PD) detection technique applicable to distribution transformers.

This technique uses a spectrum analyzer with a high-frequency preamplifier and high-frequency current probes.

The PD measurements normally are made on each of the primary and secondary windings with a high-frequency current transformer clamped around the cables below the bushing of each winding. This technique is capable of detecting PD activity in the range of l00kHz to 200 MHz.

The on-line PD detection technique was used alongside the Dissolved Gas Analysis (DGA) technique to check the insulation integrity of several transformers. This article describes the results of these test methods applied on seven 300kVA transformers. These transformers show different levels of deterioration with the DGA concentrations in the range of 44 to 5,042 ppm and PD activity ranging from 15 to 1,800 pC.

INTRODUCTION

PD pulses generate electromagnetic waves, acoustic waves, local heating and chemical reactions. Detecting these phenomena possibly would indicate a PD defect. Chemical reactions produce dissolved gases in a transformer's insulating oil. For many years, DGA helped indicate the presence of serious defects in the insulating system.

Normally, DGA does not provide information about the present conditions of the transformer since gas formation is a cumulative process. DGA data collected over a period of time is required to assess transformer conditions.

Since the early 1960s, acoustical detection frequently was used to detect PD sources in power transformers [l-3]. The main problem with locating PD defects is the ability of acoustic waves to propagate equally in all directions [2]. Onsite PD detection was achieved by installing fixed acoustic sensors at different positions inside the transformer tank [3].

Most PD electrical detection in power transformers is performed with a classical discharge detector according to IEC Publication 270. Location methods are based on the analysis of the measured time resolved signals at the transformer terminals [4-61. Electrical PD detection and location normally are conducted on new or newly refurbished transformers at the manufacturer's facility. Performing these measurements onsite requires the removal of the transformer from service. It also requires, besides the PD detector, additional high-voltage components like a test-voltage supply and a coupling capacitor, which are heavy, expensive and not very suitable for on-site tests. On-line electrical PD detection is reported in reference [4]. This was accomplished by equipping the transformer with PD sensors (high-frequency current transformers) at different bushings (high voltage, low voltage and neutral terminations). This article describes an on-site PD measurement technique. The on-line technique can detect PD in distribution and sub-transmission transformers.

MEASUREMENT TECHNIQUES

In power transformer insulation, partial discharges generate high-frequency electromagnetic pulses that travel along the windings, bushings and

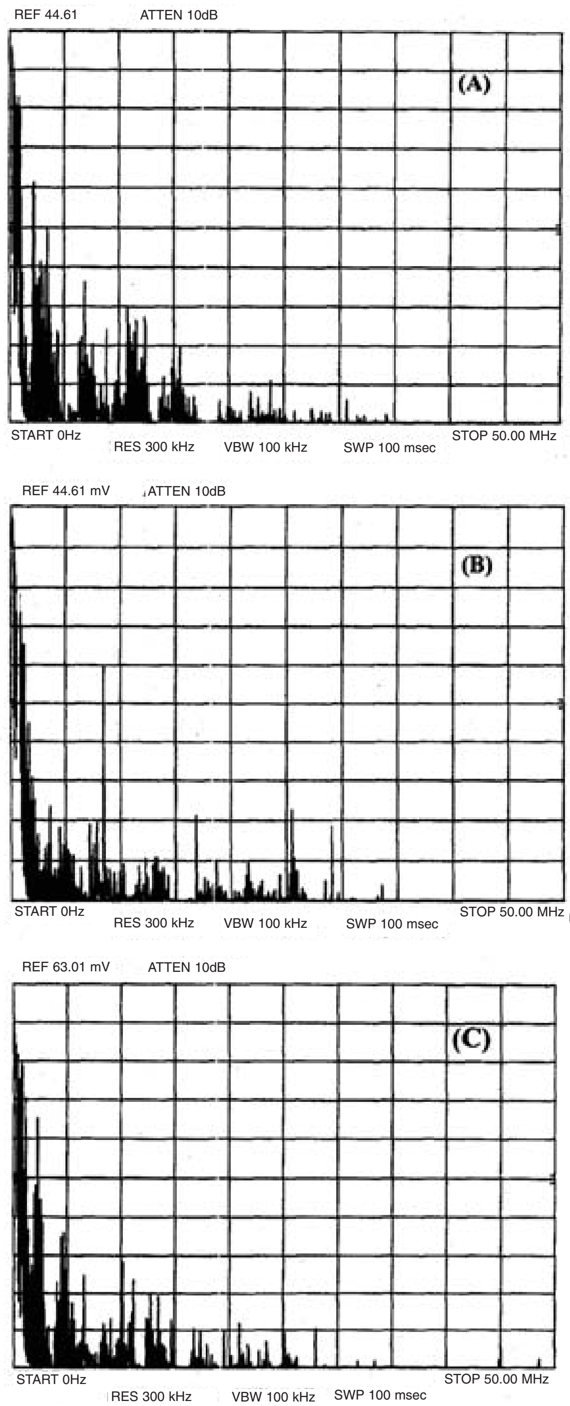

Figure 1: Signal detected from the primary windings of transformer #l. (A) X-phase (B) Y-phase (C) Z-phase.

the cable feeding the transformers.

During testing, these pulses are collected via a clamp-type high-frequency current transformer attached to the cables below the bushing of each winding. The high-frequency current probes used in this technique are made in two equal halves. One end of each of the halves is hinged and the other end butts together when clamped. The mating faces at both ends are machined flush to reduce air gaps to an insignificant amount. This ensures that the permeability of the toroid, and not the air gap, is the limiting factor in concentrating the magnetic field and reducing the overall path reluctance. It should be noted that the size, number, and deployment of the coupling turns of wire around the toroid determine both the circuit inductance and parasitic capacitance. The maximum usable frequency is limited to a value below self-resonance.

Thus, it is evident that any current probe can be designed to cover only a limited range in the frequency spectrum. Five current probes were used in the present investigation. Each consisted of a ferrite core with eight-coupling turns. These probes are sensitive to a frequency range of l0kHz to 200MHz.

Transformer Number	Dissolved Gas Concentration (ppm)						Possible Defects
	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO	
1	3,784	422	9	69	1	757	Corona
2	300	1,066	1,886	280	65	507	Arcing
3	14	254	558	1,776	145	37	Arcing
4	593	62	17	11	1	419	Corona
5	178	62	139	12	162	263	Arcing
6	0	0	17	5	0	130	-
7	11	0	4	0	0	28	-

Table 1 DGA data of 300 kVA transformers.

The detected signals are coupled to a spectrum analyzer by a preamplifier. The characteristics of the spectrum analyzer used in this investigation are: frequency range from 100 Hz to 1,500 MHz; amplitude range from -135 dBm to 30 dBm; frequency span of 100 Hz to 1,500 MHz plus zero span; resolution bandwidth of 10 Hz to 3 MHz; video bandwidth of 1 Hz to 3 MHz; and sweep time of 20 ms to 1,500 s. A dual-channel preamplifier was used. The frequency range of the first channel was 0.1 to 1,300 MHz with a gain of 25 dB, while the frequency of the second channel ranged from 0.001 to 50 MHz with a gain of 28 dB.

It should be noted that the high-frequency components of the partial discharge spectrum are attenuated more rapidly than the low-frequency components. This behavior is used to locate the PD source.

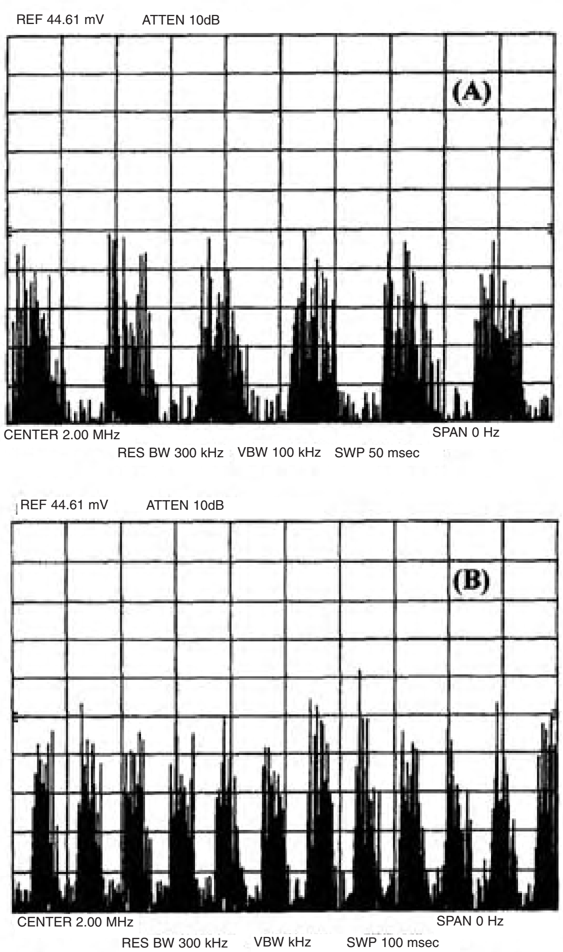

Figure 2: Zero-span spectrum of 2-phase, transformer #1. (A) 3-cycles (B) 6-cycles.

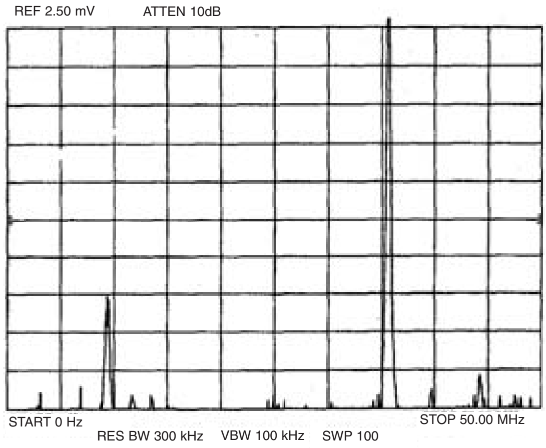

Figure 3: Signal detected from the secondary winding of transformer #1.

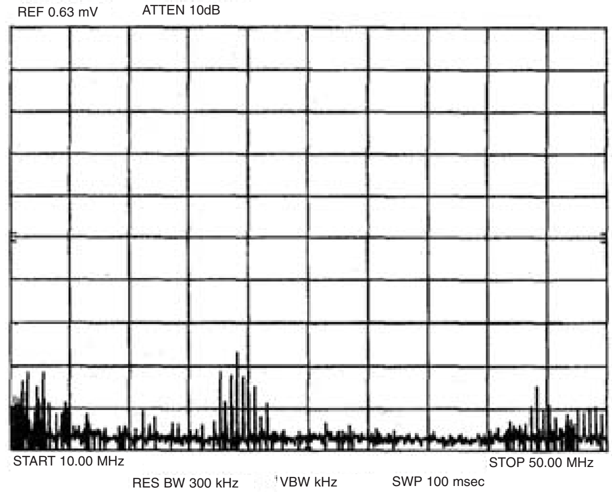

Figure 4: Signal detected from the primary winding of transformer #7, Y-phase.

RESULTS

On-line partial discharge measurements and DGA were made on seven 300 kVA, 13.2kV/480V/227V transformers feeding a busy shopping center in Metropolitan Detroit.

DISSOLVED GAS ANALYSIS

The DGA data are given in Table 1. The quantity of primary combustible gases of transformer #1 is about 5,042 ppm. The hydrogen concentration is elevated (about 15 times higher than normal) indicating possible corona problems.

Transformer #2 also shows a high concentration of combustible gases (4,105 ppm). The elevated concentration of acetylene (five times higher than normal) indicates arcing is occurring inside the transformer. As in transformer #2, elevated concentration of acetylene also was found in transformer #3 indicating possible arcing. The hydrogen level of transformer #4 is about twice the normal value pointing indicating possible corona. All combustible gases, except acetylene, are below the normal values of transformer #5.

Acetylene concentration is about 15 times the normal level.

This elevated value of acetylene might be because of electrical arcing in the transformer. Gas concentrations found in transformers #6 and #7 are either undetectable or well below the normal values.

ON-LINE PD MEASUREMENTS

In each transformer, PD measurements were made on all primary and secondary windings. The PD highest level is detected in transformer #l. A significant amount of PD activity was observed in all three primary windings. (see Figure 1.) Pulses in the frequency range of 2 to 30 Mhz were detected. The PD level of Z-phase was the highest, more than 1,800 pC. These PDs occur at both the negative and positive cycles of the operating voltage. Figures 2a and 2b show the 2-MHz PD-component occurred during three and six cycles of the operating voltage, respectively. This was obtained by running the spectrum analyzer in the zero span mode. The center frequency is tuned to the frequency where the PD level was the highest (2 MHz). Zero-span examinations also were made at center frequencies of 4.8, 7.5, 12.4, 20.3 and 28 MHz. The zero-span spectrums at these frequencies were similar to those conducted at 2 MHz. No PD was observed in the secondary windings. (see Figure 3.)

This is true for all the transformers.

Partial discharges on the order of 1,200 pC were detected from transformer #2 with X-phase showing the highest readings. Moderate PD activity ranging from 300 to 600 pC was observed in transformers #3, #4 and #5. Partial-discharge pulses with magnitude below 30 pC were detected from transformers #6 and #7. The frequency of these pulses ranged from 22 to 26 MHz compared with a range of 2 to 30 MHz in transformers #1 through #5. (see Figure 4.)

PD normally produces pulses with

Transformer #	DGA (ppm)	PD (pC)
1	5,042	1,800
2	4,105	1,250
3	2,784	600
4	1,102	300
5	816	500
6	152	30
7	44	20

Table 2 The quantity of the combustible gases and the maximum PD signals detected in 300 Kva transformers.

frequencies ranging from few hundreds kHz to few hundreds MHz. The attenuation of these pulses is a function of frequency. The higher frequency components will be rabidly attenuated as they travel alongside the windings of the transformer. This behavior can be utilized as a means of locating the source of PD. For instance, the detection of high frequency components (up to 200 MHz) indicates that the PD likely originates in the winding turns next to the transformer bushing.

ON-LINE PD TESTING VERSUS DGA

The results of both the DGA and PD measurements have been summarized in Table 2. In cases of severe insulation deterioration, PD results fully agree with the DGA data.

However, when small to moderate defects are present such as those found in transformers #5, #6 and #7, electrical PD detection is more accurate than DGA in identifying the extent of the deterioration.

CONCLUSION

On-line PD detection techniques using a spectrum analyzer capable of detecting PD activities in distribution and sub-transmission power transformers are presented in this article.

The technique is very attractive to utility engineers in assessing integrity insulation of power transformers since it is not a destructive technique and it does not require the system to be de-energized. It also is inexpensive when compared with other detection methods since no heavy equipment is needed.

The suitability of this technique was checked against DGA.

In severe insulation deterioration, PD results fully agree with DGA data. However, the PD measurement technique was more effective in detecting small defects. DGA does not provide information about the present condition of the transformer since gas formation is a cumulative process.

DGA data obtained over a period of time is required to assess the transformer's condition. On the other hand, PD technique provides information about present conditions and does not interfere with the operation of the transformers. It also provides information about the location of defect.

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