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Development and Testing of an On-Line AE (Acoustic Emission)/Vibration Instrument

1012344

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Technical Update, December 2006

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ABSTRACT

In 2001 EPRI research started with the objective of exploring and further develop the existing test procedures and diagnosing capabilities of the Acoustic Emission (AE) technique when applied for both power transformers and Load Tap changers. The goal was to expand the use of AE Technology for all types of Power Transformer faults. The development of an online instrument has evolved from above program – and the development and field verification are reported on in this document. The objective was to simplify electronics and software so that trending of key power transformer health factors could be coordinated with other power transformer evaluation methods and monitors. The objectives were met – and the report presents the results and thoughts on future research.

The research performed in 2006 also developed a powerful new signal processing feature called TAFI (Time Arrival Feature Index). The new processing allows for robust confirmations of signals in synchronization with the power frequency – even in the presence of large amounts of background noise.

CONTENTS

1
AE SENSOR HIGHWAY II

Introduction

In 2001 an EPRI research project was started with the following objectives:

1. To develop a new acoustic emission technique to detect and locate sources of gassing in power transformers.
2. To test the techniques in the laboratory and on operating transformers.
3. To develop a test method and evaluation algorithm(s) to enable development of problem criteria.
4. To construct a database of different sources and degrees of gassing severity.

The project consisted of two phases and involved several utility partners. Phase 1A was laboratory testing to demonstrate the effectiveness of AE in detecting gassing sources. The project team conducted this preliminary work on the cooling loop test facility at Rensselaer Polytechnic Institute. This facility can reproduce nitrogen blanketed, free breathing, and conservator systems over the full range of transformer temperatures and flow rates. Fault conditions were simulated to reproduce gas evolution generated by conductor overheating.

In Phase 1B, the team collected data using field instrumentation at 61 gassing and non-gassing sister transformers to build an initial test database. They provided an experienced two-man crew with a consistent set of equipment to run a minimum 24-hour test/data collection on each transformer. Existing AE instrumentation were modified to allow online correlation of acoustic energy with other parametric data. The data were evaluated using graphical and statistical analyses and neural network techniques to identify and discard background noise and signal distortions.

Phase 2 covered three major tasks. The first was to continue growing the existing database to include 102 total tests (includes Phase 1 tests) on gassing and non-gassing units. Low frequency acoustics were introduced using accelerometers to enhance the LTC evaluation.

The second task was to modify hardware and software to accommodate the use of accelerometers while simultaneously taking AE measurements. Software was developed to improve the post-test analysis data filtering process and to document the database for rapid review of past test results as a function of equipment type and DGA history. Improvements were made to the 3D source location software algorithm and event periodicity became a new feature for identifying events from electrical faults.

As part of the Phase II goals, a technology package was further refined and assembled for release to the cosponsors and eligible EPRI members. This package, called PowerPAC™, included all of the necessary equipment, software and procedure for reproducing the AE technology developed over the course of Phase 1 and Phase 2.

Finally, all the knowledge acquired during these earlier Phases were considered to develop a new simplified on-line monitoring system to provide early warning on developing problems in power transformers.

This report details the development of this new on-line system:

System Description

The sensor highway system is a combined Acoustic Emission (AE) and Vibration monitoring system with up to 16 high speed (for AE, Vibration) monitoring channels and 4 additional parametric input channels. The Sensor Highway II has been developed for un-attended use in "Asset Integrity Monitoring" management and condition monitoring applications. The system consists of a 16-channel unit (node) in a rugged outdoor case (figure 1-1), capable of operating in extreme weather and factory conditions.

The key feature of the sensor highway system is its highly flexible sensor fusion interface for input and processing of any and most different sensors. The system is able to accept AE sensors (using the standard "phantom power" coaxial connection for powering external preamplifiers), ICP (Amplified) Accelerometers, and various sensors with current and voltage outputs. This interface is accomplished through the use of standard industrial, DIN Rail mounted signal conditioning modules, with options for proximity probes, tachometers, pressure transducers, load cells, thermocouples, environmental sensors, strain gages, etc.

Figure 1-1
Internal view of Sensor Highway II

The Sensor Highway II has several communication interfaces available for data communication and remote control. The principal interface is its Ethernet 10/100 (and optionally, wireless

Ethernet). Other available interfaces include: Telephone modem, RS-232/485, USB host and device, 4 – 20ma and digital I/O, and relay outputs for alarm and control purposes.

The "Data Collection" (SH-II DC) system, figure 1-2, (the most basic and low cost system), is capable of remote acquisition and storage of (short term) sensor data, with some basic signal processing and alarm screening capabilities. Data download can be accomplished by a walk-up attachment (plug in a notebook computer via its standard Ethernet port, see figure 1-3) or through an automated remote interface, either via Ethernet, or optional wireless Ethernet, Internet, or Telephone Modem, to a remote control and data processing station. The remote system with the aid of a trained user, performs the data analysis and asset integrity assessment. This SH-II DC system is the lowest cost solution and is for situations where remote analysis is desired, and is usually associated with a monitoring contract. Optionally, an Internet web access site can be made available for customer status, activity, trend monitoring and customer data visualization.

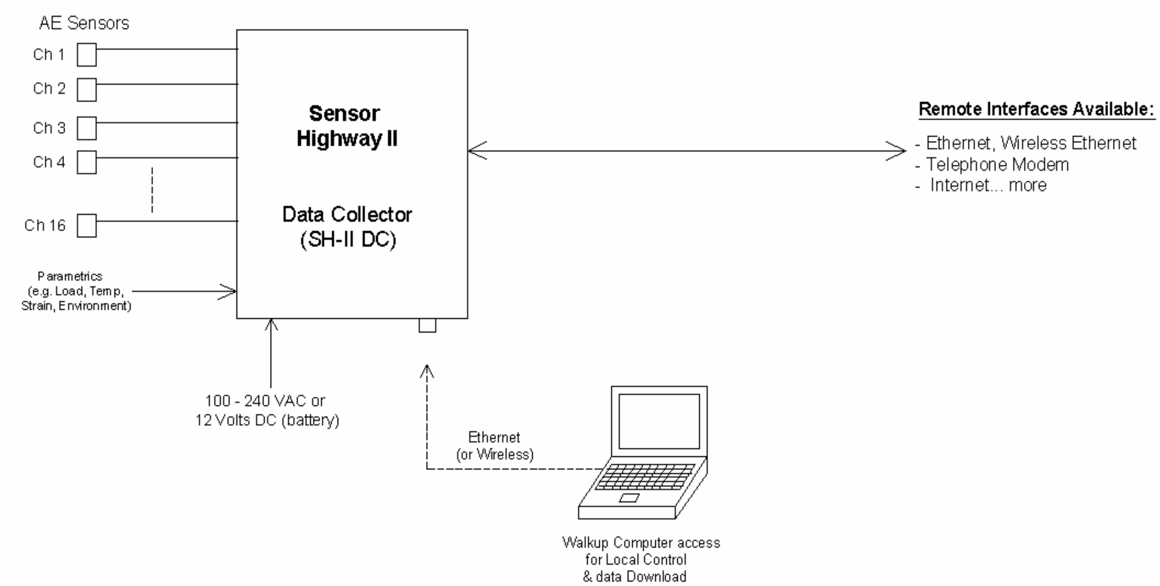

Figure 1-2
Sensor Highway II data collector system

Figure 1-3
Plug in laptop computer

The case size is approximately 20” x 16” x 6” deep. The AE Sensor Highway is scalable for large factory use, allowing for multiple units to be placed near the machinery or structures that are being monitored. There is no theoretical limit to the number of overall channels (based on 16 channel separate units) that can be connected in one location (plant).

The system is designed for outdoor environments, with a minimum power dissipation and a temperature range of (-35° - 70° C) without the need for heaters or air conditioners.

System features and specification

Physical Features:

- NEMA 4 Enclosure ~ 20” x 16” x 6” with removable bottom panel.
- Expandable to 16 channels (4 non-multiplexed, full time, independent 4-channel modules) or 32 channels (4 Multiplexed 8-channel modules), in a single NEMA enclosure.
- Scalable system comprised of one Main Board, one CPU Board and up to four 4-channel signal-processing modules.
- Easily accessible and changeable DIN signal conditioning modules.
- SMA input connections for AE Ch. and Terminal Block connections for Vibration Ch.
- Direct On-Board Terminal Block connections for parametric inputs.

Electrical Features

- Wide range AC or DC power supply with DIN mounted connections and power switch.
- Main Power input voltage/current consumption and enclosure temperature monitoring.
- Phantom Power for AE Sensors and ICP Power for Accelerometers.
- Selectable sensor power voltages.
- Transducer bias monitoring.
- Hit LED connections.
- Scope monitor output for connecting up data collectors in the field.
- Time synchronization between remote units.
- DIN rail modules able to measure pressure, temperature, tachometer speed, RMS values, etc.
- Ethernet (or optional wireless Ethernet) Communication is the main communication channel.
- Upgradeable to handle control system interface (Profibus, Modbus TCP, ControlNet)

Sensor Highway II Standard Built-in Software Features:

- **Basic, Built-in Features common to all Sensor Highway systems include**;
  - Data Acquisition: Full AE Feature and waveform data acquisition to a data file, with ability to be downloaded either locally via walk up Ethernet plug-in port or remotely via Ethernet/Internet connection or optional wireless Ethernet (WiFi) or telephone modem.
  - Status and Trending Capabilities: Ability to generate timed STA files for system status and trending. STA files are generated on a user set periodic basis (per hour, per day, etc.) reporting the following system parameters in an *.STA file at the end of each monitoring interval: Parametric value for each parametric, latest ASL value for each channel, average ASL over monitoring interval for each channel, total AE Events, AE counts, Energy and Waveforms over the monitoring interval, Number of AE Hits on each channel during the monitoring interval, Number of Events and Cumulative Energy on first hit channel for each Event Group over the monitoring interval, each alarm generated during the monitoring interval, and disk space remaining at the end of the monitoring interval.
  - AE system setup & control: Utility program to remotely setup the Sensor Highway II system, generating a layout file that can be uploaded to the Sensor Highway. In addition, the setup and control program has the ability to control the AE system with commands to start, stop or pause a test.
  - Data file upload and download; are available through an FTP server with a Windows Explorer interface for transferring files between the remote (or walk-up and plug-in) computer and the Sensor Highway.
  - Alarm capability: The basic Sensor Highway II embedded has built-in alarms, based on Hit/Event activity or feature based (not location or cluster based, this is available on the SH-II-SRM). Some customization can be provided for special combinatorial features, but not complex signal processing based alarms.
  - Communications: Ethernet networking built-in for walk-up, plug-in operation and remote Ethernet/Internet communications. In addition, other communications options include; Telephone Modem interface, Serial Port (RS-232/485) or cellular modem.
  - AE Software Analysis Compatibility: The Sensor Highway *.DTA", AE data files are fully compatible with AEwin for Sensor Highway II (AEwinSH). The remote user needs to have AEwinSH installed on his analysis workstation where he/she could analyze AE data files downloaded from the Sensor Highway system. On walk-up and plug-in situations, AEwinSH has been developed so that the user can replay the existing AE test and continue to operate in semi-real time, as data collection continues.

Main Board Specifications

Power Requirements:	85-260 VAC or 9-28 VDC
Power Consumption:	12W + sensor requirements
Digital Signal Processing:	Xilinx Spartan 3, 4 million gate FPGAs
Digital I/O:	8 Digital, & 8 Outputs

Parametrics

On-Board Single-Ended inputs:	10kSPS, 16 bit, +/-10V input, qty: 12
On Board Differential inputs:	10kSPS, 16 bit, +/-10V input, programmable gain, offset and excitation voltage, qty: 4
External Parametric:	2 SPI Interfaces for 16 additional parametric inputs

4-Channel Module Specifications

Number of Channels:	4
High Pass Filters: Analog	1Hz, 10Hz, 10kHz, 100kHz
Low Pass Filter: Analog	1MHz, 6th order
Low Pass Filters: Digital	100Hz, 1kHz, 10kHz, 100kHz, 300kHz, 400kHz
Bandwidth:	1Hz- 1MHz
ADC:	20MSPS, 18-bit
Accelerometer Power:	ICP, 24V
AE Sensor Power:	Phantom Power, Selectable 5V, 12V, 28V

CPU Board Specifications

Network:	Ethernet 10/100 BT
USB:	2 Full speed USB Host, 1 Full Speed USB Device
Serial:	One RS-232, One RS-485
IDE:	Full size 40-pin connector
Processor:	200 MHz, ARM920T Core
Memory:	Flash: 64 Mbytes SDRAM: 128 Mbytes Compact Flash Interface

System Physical Specifications

Standard Enclosure:	Steel, NEMA 4, IP-66 (Indoor/Outdoor)
Weight:	< 25 lbs. w/enclosure
Size:	20” x 16” x 6”
Operating Temperature:	-31° - 158° F (-35° - 70° C)
Storage Temperature:	-40° - 167° F (-40° - 75° C)

2

COMPARISON TEST - SENSOR HIGHWAY II VS STANDARD AE INSTRUMENTATION

A comparison test was arranged once the prototype Sensor Highway II system was ready. The purpose of this test was to verify on the field that the new design was able to handle high hit rates without loosing any critical information.

The transformer under test was manufactured in 1947, 3 phase, 100 MVA, 69/13 kV, FOA-T Class, this unit was selected due to a sudden increase in gases in August 2006, particularly methane and ethylene, see Figure 2-1.

Date	Temp C	Hydrogen	Methane	Ethane	Ethylene	Acetylene	CO	CO2	Remarks
10/12/2006	40	131	467	158	1053	2	125	2921	No Thermo or Acoustics.
10/11/2006	55	104	413	141	940	2	106	2614	Thermo showed coolers were clogged.
09/26/2006	39	127	414	130	889	1	121	2546	Ran duplicate DGA by HS.
09/21/2006	43	115	392	131	869	2	116	2474	
09/13/2006	45	141	456	151	1022	2	127	2934	
09/07/2006	45	128	420	135	919	2	127	2713	
08/28/2006	40	143	474	101	840	0	124	2869	Thermography and Acoustic Ok.
08/27/2006	42	176	469	100	802	1	150	2690	Thermography and Acoustic Ok. MVA:18. All fans were on.
08/26/2006	43	170	473	105	826	1	149	2728	Thermography Ok Acoustic Ok.MVA:20.1000 Amps? Fans were on.
08/24/2006	50	184	496	108	857	1	160	2890	Thermography Ok Acoustic Ok.Not enough sample to run duplicate DGA.
08/22/2006	50	173	468	99	799	1	155	2689	Not enough sample to run duplicate DGA.
08/07/2006	50	112	375	112	786	2	127	2583	Not enough sample to run a second DGA.
06/26/2006	54	87	310	94	657	0	133	2379	Ran duplicate DGA by VE.
04/05/2006	42	56	231	52	412	0	138	2072	Ran duplicate DGA by HS.
01/06/2006	40	38	161	54	344	0	149	2112	
11/30/2005	50	72	200	44	337	0	204	2215	Priority #10 per S. McCann.
11/04/2005	41	76	209	44	349	0	203	2490	
10/31/2005	53	74	191	42	330	0	185	2204	Thermography Survey OK.
10/25/2005	39	66	196	44	345	0	170	2393	
10/25/2005	38	43	168	36	295	0	168	2238	
10/24/2005	47	72	204	41	323	0	205	2199	Sample taken at 0800 Hours. 7 MVA output. No change in Thermography Survey.
10/24/2005	39	71	211	42	327	0	197	2198	51 MVA output. Thermography Survey OK. Sample taken at 1400 Hours.
10/23/2005	50	85	207	44	341	0	222	2297	Sample taken at 0800 Hours. 32 MVA output. Thermography Survey: 6636 A & phase same 10 degree celsius. #9 Disc OK. #1 XFRM Disc OK. Weather Windy.
10/23/2005	56	82	198	42	330	0	214	2240	Sample taken at 1400 Hours. 38 MVA output. No change in Thermography Survey.
10/22/2005	55	85	212	45	351	0	224	2359	Sample taken at 1400 Hours. 43 MVA output. No change in Thermography Survey. Still Raining.

Figure 2-1
DGA History of this transformer

Two instruments were installed on this unit, a standard AE, 24 channels, instrument and a Sensor Highway II system, 18 channels were installed on the standard AE system whereas the SHII unit only has capability for 16 channels. Figures 2-2 – 2-5 show the location of the sensors used on each system.

Also, one parametric channel was used to monitor the oil temperature on the transformer.

RED = DISP
BLUE = SENSOR HIGHWAY II

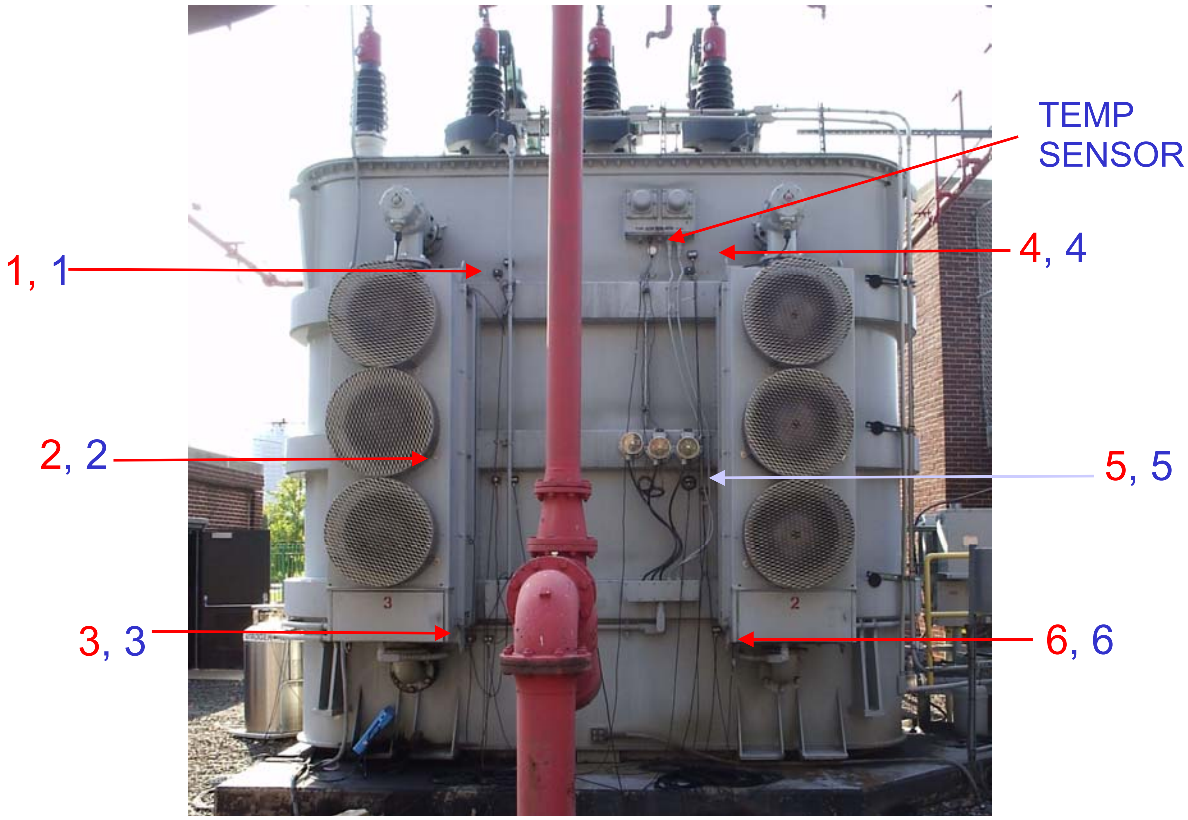

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Figure 2-2
High Voltage Side

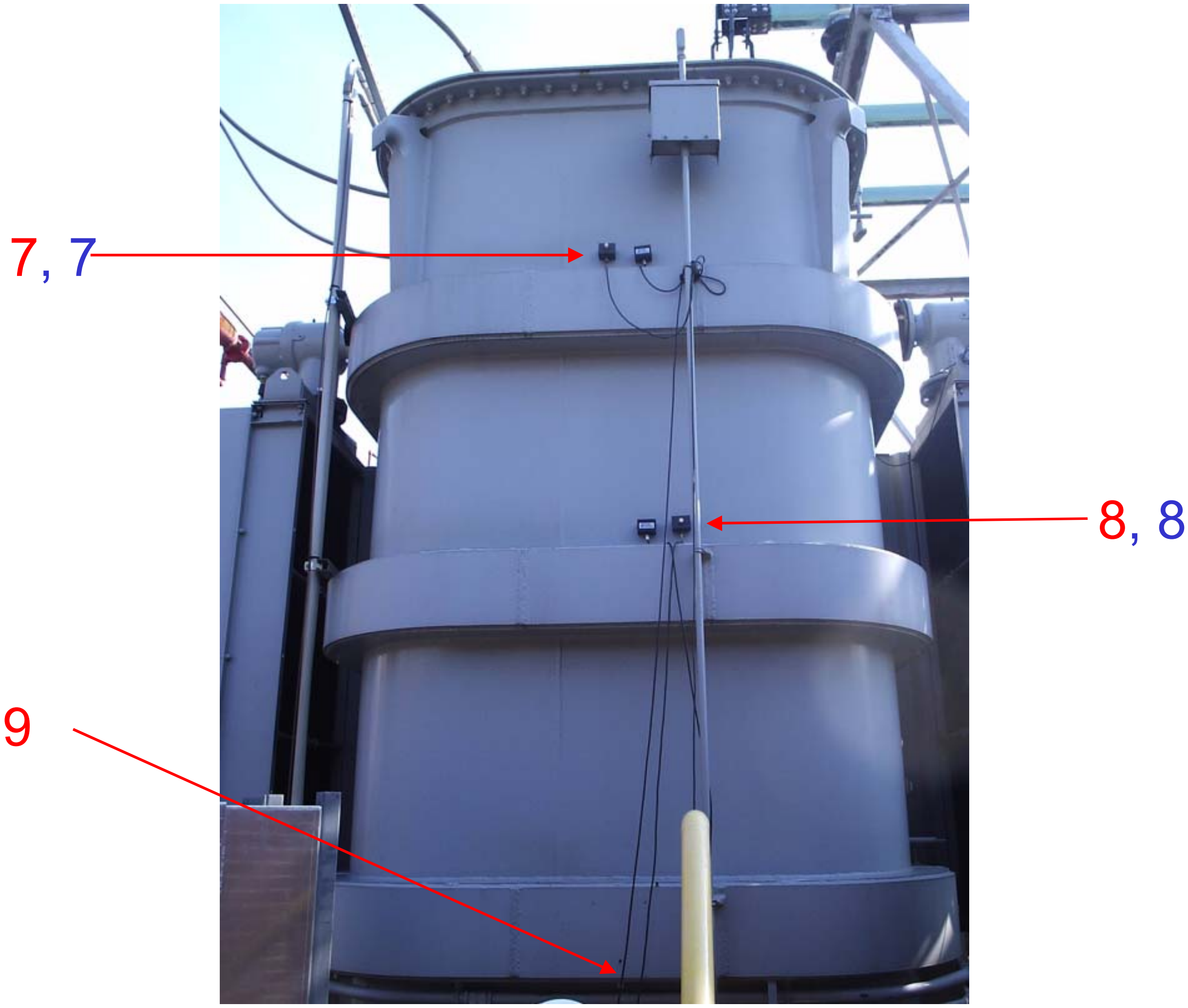

Figure 2-3
Right side

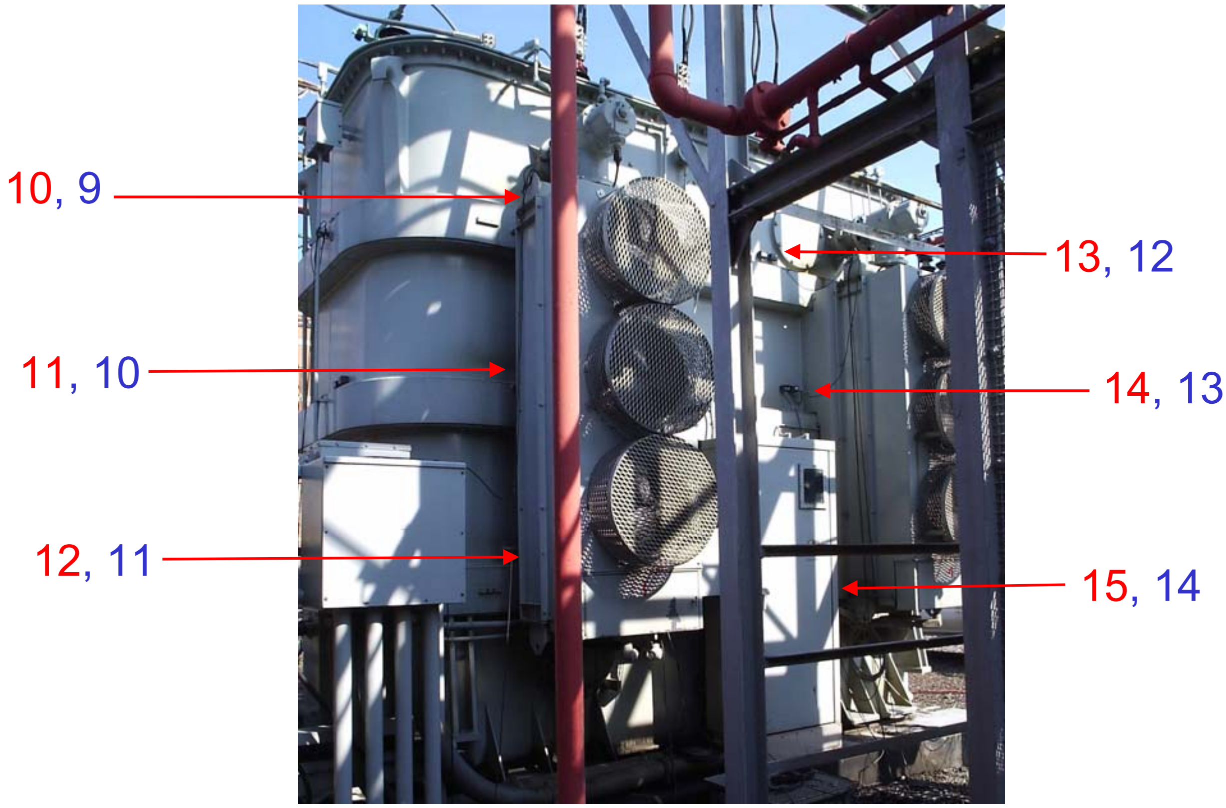

Figure 2-4
Low Voltage side

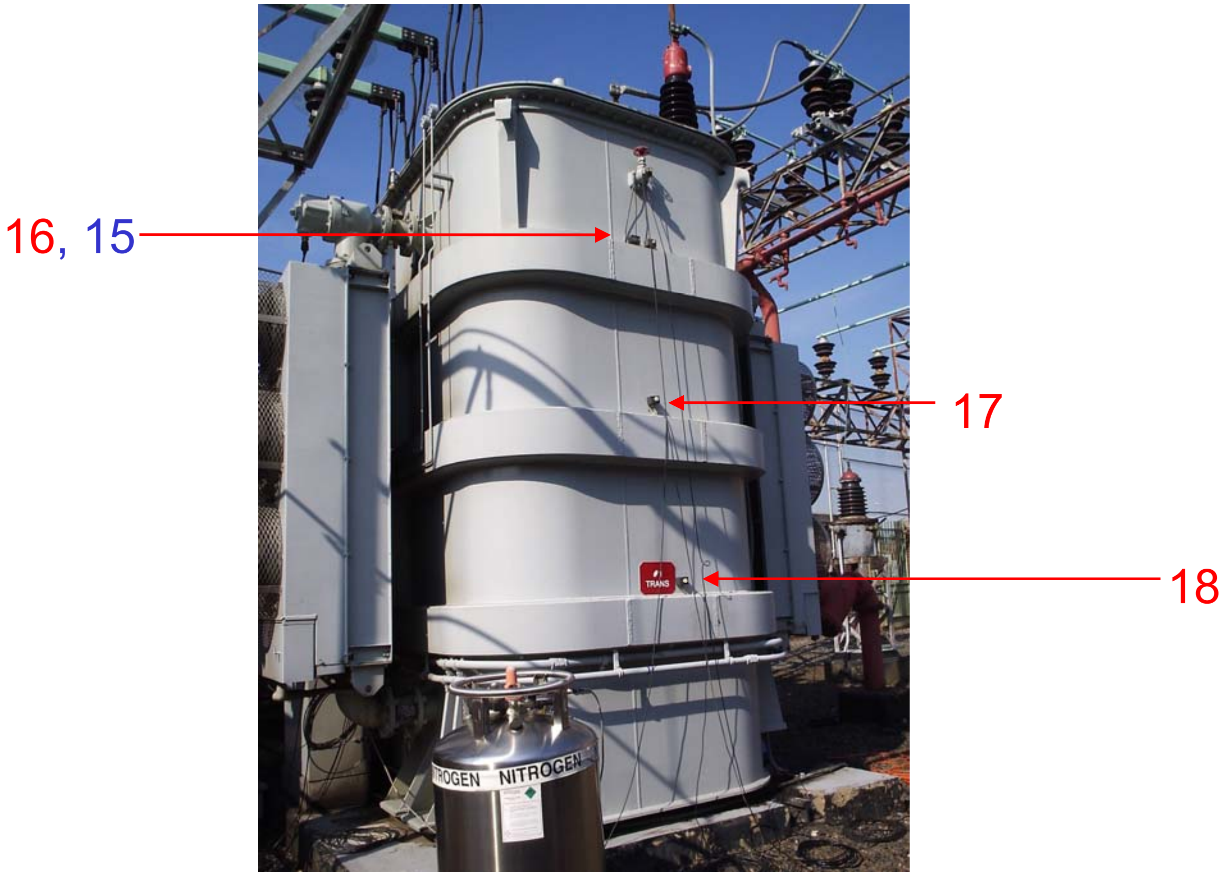

Figure 2-5
Left side

Figure 2-6
Installation on-site of the acoustic sensors and parametric channel

As can be seen on the photographs, this transformer has 4 oil pumps on the upper part of the transformer (two on the High Voltage side and 2 on the LV side). This unit being a FOA-T class indicates that at least 2 pumps need to be running at all the time.

At the time of the test, all pumps were operating and continuous acoustic activity was detected on sensors close to the pumps (1, 4, 7, 10, 13, 16 for the DiSP [standard 24 channel instrument] & 1, 4, 7, 9, 12, 15 for the Sensor Highway II).

Very similar responses were obtained for both systems as can be observed on figure 2-7.

Most of the data detected by both systems corresponds to pump operating noise, however, an increase in acoustic activity can be observed on sensors 2 & 3 as well as continuous activity on sensors 4, 5, 6, 7 & 8 (same numbers on both systems).

In order to verify that the acoustic activity detected was produced by pump operation noise, several pumps were turned off at different times and a significant decreased on the acoustic activity was observed, see figure 2-8.

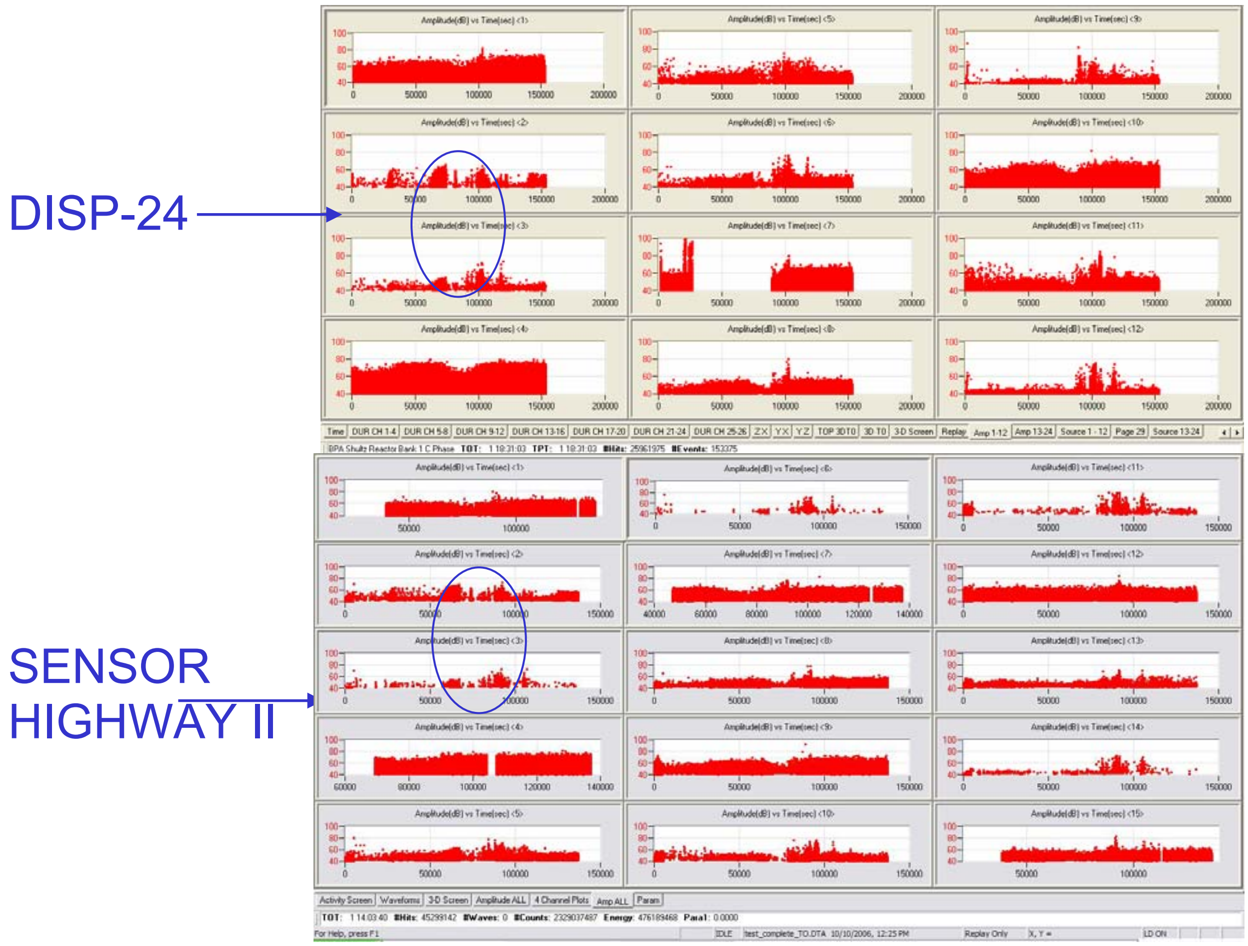

Figure 2-7
Comparison of data collected by Sensor Highway II and Standard instrumentation

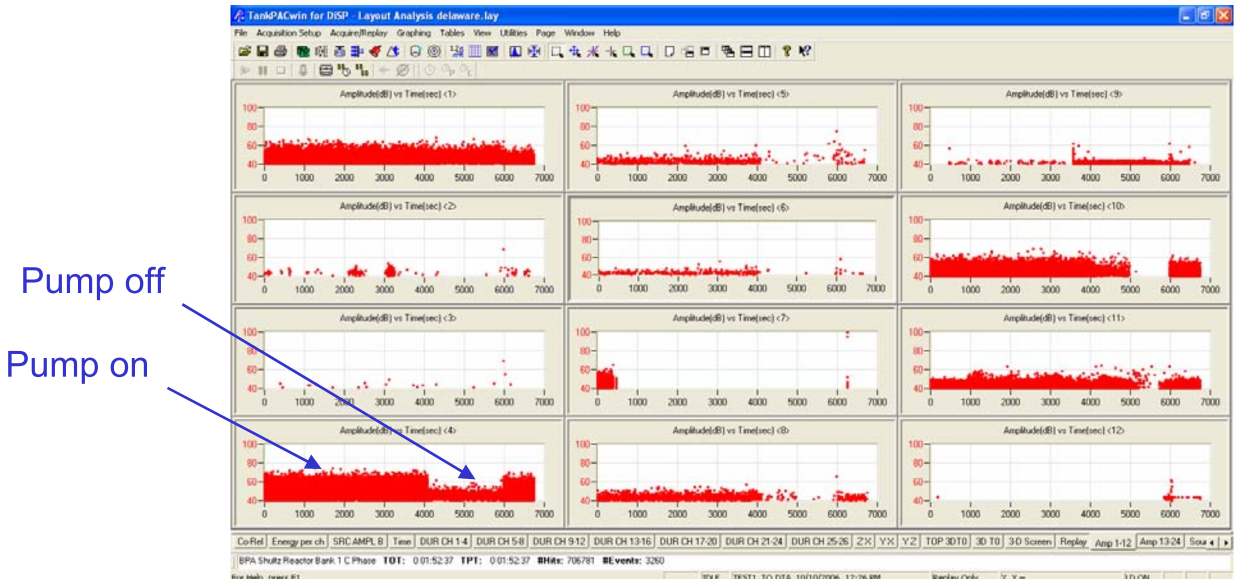

Figure 2-8
Change in acoustic activity when pumps were turned off

After data analysis, two areas were identified as having activity different that pump operation noise. One is on the lower part of the phase C coil and the other on the middle section of the Phase A coil.

The on-line monitoring system installed compared satisfactorily to the standard instrumentation, figure 2-9 presents a comparison of statistics obtained per system. More data was detected by the on-line monitoring system because front end filters were used on the DiSP system and not used on the on-line monitoring system (this was done unintentionally).

```
Total AEHits    :   45299143
Total TDDs      :     142779
Total Waveforms:           0
Total Resumes   :          1
Total Pauses    :          1
Total TimeMarks:           0

Channel          AEHits
   1            3608675
   2             106807
   3               7646
   4           24381775
   5              74795
   6               1594
   7            6407156
   8              81948
   9            1104168
  10             778413
  11              56215
  12             686056
  13             449874
  14              42644
  15            7489541
  16              21836
```

```
Total AEHits    :   25961977
Total TDDs      :     153001
Total Waveforms:           0
Total Resumes   :          2
Total Pauses    :          1
Total TimeMarks:           0

Channel          AEHits
   1            4894130
   2              70485
   3              20517
   4            4850275
   5              98234
   6              55361
   7            3054400
   8             268650
   9              11659
  10            2733154
  11            3178571
  12            1089430
  13              82325
  14             226201
  15             215046
  16            5047164
  17              21895
  18               5127
  19              39345
  21                  8
```

Figure 2-9
Comparison of statistics obtained per system, left for SHII and right for DiSP

An internal inspection was performed and revealed that the core appeared to be intentionally grounded at the bottom to the tank.

3
INSTALLATIONS ON CRITICAL TRANSFORMERS

In order to evaluate the on-line monitoring system (Sensor Highway) under real field testing conditions, two transformers were selected at two separate utility sites to install these monitors.

3 phase, 336 MVA, 230/138/13.8 kV Transformer

This transformer was built in 1966, 3 phase, 336 MVA, 230/138/13.8 kV, FOA Class with LTC compartment and preventive autotransformer compartment.

This unit has been tested acoustically in three occasions previous to the installation of the on-line monitoring system: 2001, 2004 and February 2006. The reason for the test was a steady increase in arcing related gasses (hydrogen and acetylene) as can be seen in table 3-1 and figure 3-1. The purpose of the test was to try to determine the location where those gases were produced.

Table 3-1
Dissolved gas analysis values on transformer

DATE	H2	CO	CO2	CH4	C2H6	C2H4	C2H2	TDCG
3/3/04	261	515	2306	63	37	27	32	935
2/16/2006	204	128	1051	47	23	37	43	482

For comparison purposes, a standard AE 24 channel instrument was installed at the same time that the on-line system. Figures 3-2 to 3-5 show the location of the acoustic sensors on each wall of the transformer, red numbers indicate the sensors for the standard AE system (DiSP) and blue numbers indicate the sensors for the on-line monitoring system (SHII).

Tank	Date	Lab Date	Temp C	Std	E	Hydrogen	Methane	Ethane	Ethylene	Acetylene	CO	CO2	Oxygen	Nitrogen	Tot Gas	Water
MAIN	11/15/2005	11/23/2005	29	PEC01	4	212	49	23	38	44	138	1215	941	5275	.8	6
MAIN	08/15/2005	08/25/2005	45	PEC01	4	160	36	16	24	30	131	1377	580	4027	.6	7
MAIN	05/16/2005	05/27/2005	42	PEC01	4	89	26	12	19	25	115	1229	3236	8169	1.3	4
MAIN	03/02/2005	03/03/2005	26	PEC01	1	91	22	7	13	15	100	836	1629	6418	.9	3
MAIN	02/09/2005	02/16/2005	40	PEC01	4	110	24	11	19	28	102	1029	313	1483	.3	5
MAIN	11/16/2004	11/18/2004	46	PEC01	1	74	13	5	8	11	58	512	1223	6475	.8	4
MAIN	08/18/2004	08/26/2004	43	PEC01	1	53	7	2	4	9	38	316	941	3372	.5	8
MAIN	07/20/2004	07/22/2004	46	PEC01	1	80	12	3	6	14	60	549	616	3716	.5	8
MAIN	07/06/2004	07/07/2004	43	PEC01	4	76	11	3	6	15	53	503	1154	5039	.7	11
MAIN	06/18/2004	06/21/2004	43	PEC01	4	57	7	2	4	7	39	397	1074	2767	.4	17
MAIN	05/20/2004	06/07/2004	40	PEC01	4	6	2	1	1	3	30	301	822	3355	.5	10
MAIN	05/05/2004	05/07/2004	21	PEC01	4	3	1	0	1	2	13	161	945	2360	.3	9
MAIN	04/27/2004	04/27/2004	42	PEC01	1	1	0	0	0	0	4	50	818	1884	.3	7
MAIN	04/26/2004	04/26/2004	30	PEC01	1	1	0	0	0	0	3	45	1036	1921	.3	5
MAIN	04/23/2004	04/23/2004	17	PEC01	1	0	0	0	0	0	3	32	2427	5992	.8	10
MAIN	04/05/2004	04/12/2004	25	PEC01	4	332	87	53	47	42	658	2996	1047	26169	3.1	4
MAIN	04/02/2004	04/05/2004	26	PEC01	4	283	70	40	37	33	524	2426	2378	33735	4	2
MAIN	03/25/2004	03/26/2004	26	PEC01	3	200	60	41	36	32	479	2043	1145	40380	4.4	7
MAIN	03/17/2004	03/18/2004	24	PEC01	4	268	66	38	30	34	517	2081	558	39015	4.3	2
MAIN	03/11/2004	03/12/2004	13	PEC01	4	400	53	29	20	23	410	2076	7855	103278	11.4	9
MAIN	03/03/2004	03/04/2004	37	PEC01	4	261	63	37	27	32	515	2306	449	37740	4.1	5
MAIN	02/26/2004	02/26/2004	30	PEC01	4	250	62	35	25	27	525	2152	406	40248	4.4	3
MAIN	02/17/2004	02/25/2004	18	PEC01	4	215	58	33	23	27	500	2097	862	38568	4.2	3
MAIN	11/17/2003	11/19/2003	39	PEC01	1	89	48	34	19	10	504	2345	546	38509	4.2	8
MAIN	09/24/2003	09/30/2003	37	PEC01	1	88	47	39	22	12	491	2413	243	36719	4	6
MAIN	08/18/2003	08/28/2003	40	PEC01	1	97	46	33	18	11	496	2487	251	36830	4	10
MAIN	07/24/2003	08/04/2003	45	PEC01	4	101	47	36	20	14	506	2465	398	38769	4.2	13
MAIN	06/23/2003	07/01/2003	46	PEC01	1	118	42	29	16	13	449	2214	380	35099	3.8	8
MAIN	06/16/2003	06/16/2003	43	PEC01	4	125	45	31	17	14	479	2322	472	38680	4.2	9
MAIN	05/22/2003	05/30/2003	38	PEC01	4	110	33	30	15	13	401	1880	948	34932	3.8	9
MAIN	02/25/2003	03/04/2003	21	PEC01	1	41	31	25	11	4	381	1631	723	32868	3.6	5
MAIN	11/14/2002	11/27/2002	20	PEC01	1	31	30	28	11	4	305	1978	4112	45061	5.2	6
MAIN	09/17/2002	09/27/2002	38	PEC01	1	50	43	27	11	4	403	2208	515	35596	3.9	7
MAIN	08/15/2002	11/01/2002	50	PEC01	1	49	29	22	10	4	394	2042	558	31957	3.5	
MAIN	06/13/2002	07/02/2002	54	PEC01	4	44	30	25	10	4	398	2142	542	33949	3.7	12

Figure 3-1
DGA values from 2002 to 2005

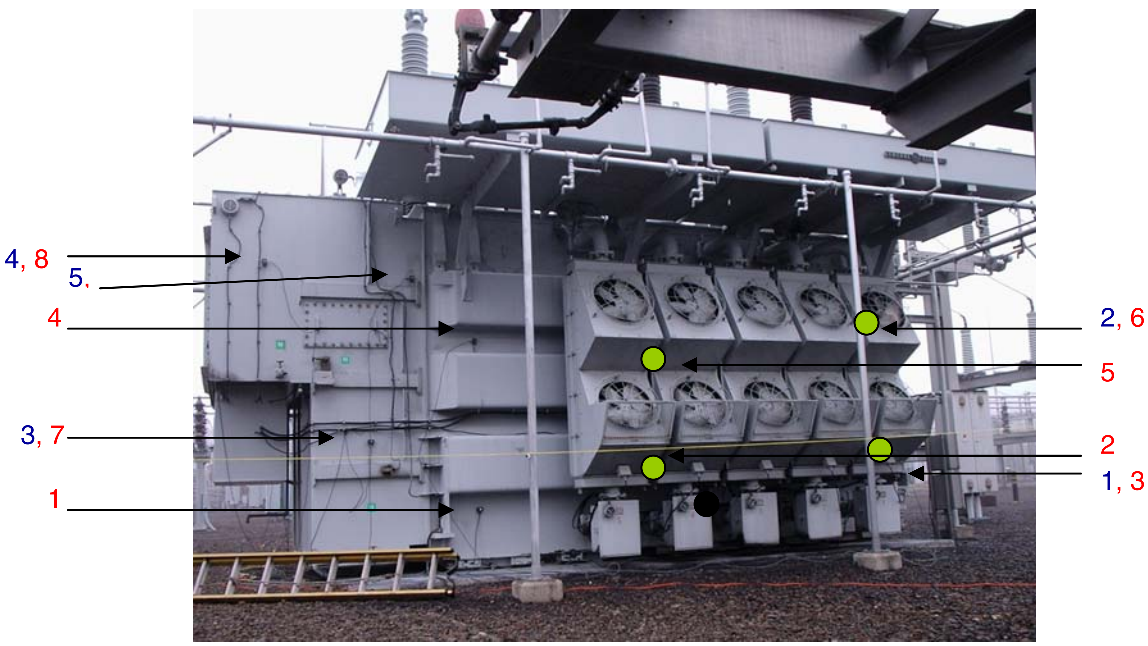

Figure 3-2
Location of acoustic sensors on HV side

Figure 3-3
Location of acoustic sensors on "right" side

Figure 3-4
Location of acoustic sensors on LV side

Figure 3-5
Location of acoustic sensors on Load Tap Changer compartment side

During the 2001 test, part of the Phase I of this Research project, 2 sources were identified, one inside the main tank (behind the control cabinet of the transformer in the lower part of the Phase A coil) [cluster 1] and another inside the LTC compartment [cluster 2]. Figure 3-6 presents the 3D plot obtained using the oldest software version (DOS based).

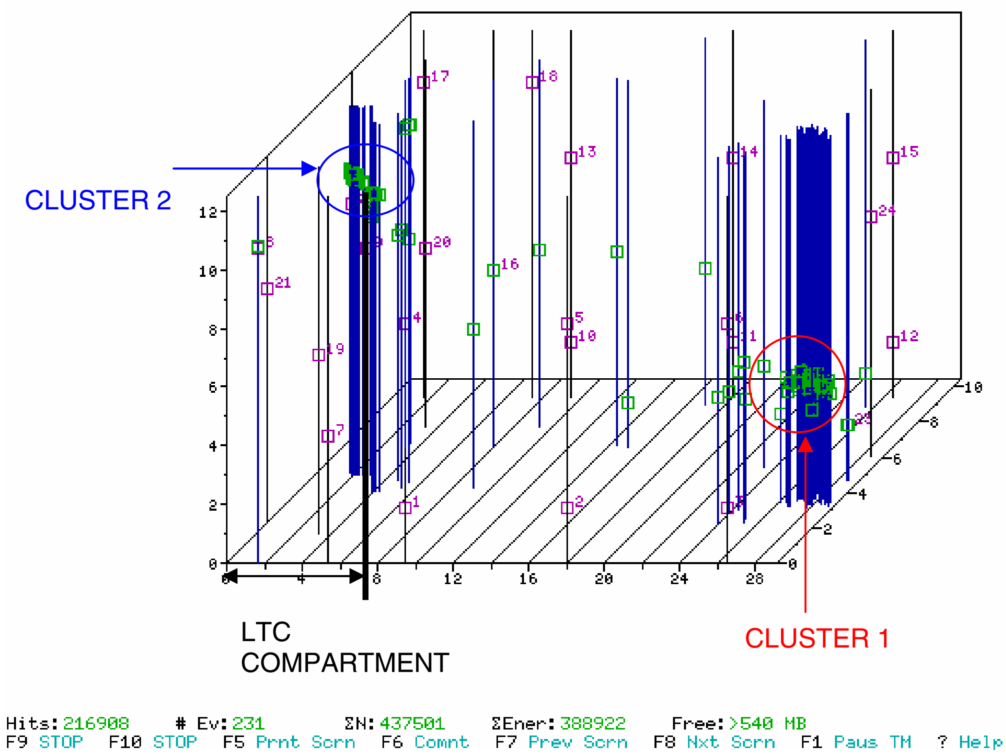

Figure 3-6
Three dimensional plot obtained after the test performed in October 2001

It is important to mention that at the time of the test, this transformer had the LTC on the automatic operation mode however, no LTC operation occurred during the monitoring period. At that time, it was believed that the source detected on the main tank was LTC-position related.

Three years later an increase in acetylene was registered and a new AE test was performed to compare with the test done in 2001. As can be observed in figure 3-7, the two sources were detected again, however, the source in the LTC compartment was also detected on the preventive autotransformer compartment and much more activity was registered. At the time of this test, the LTC was also in automatic operation mode.

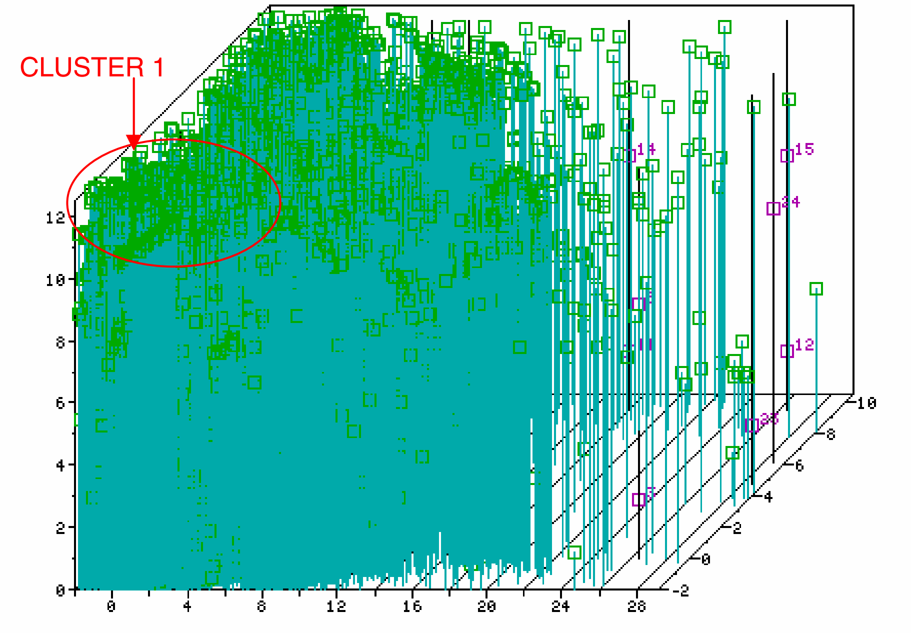

Figure 3-7
Three dimensional plot obtained after the test performed in March 2004

The oil was degassed and the unit was kept in service, the gases increased slowly back to the same levels observed in previous tests and a new test was performed in February 2006, figure 3-8 shows the 3D location plot obtained at that time. As can be seen, the source inside the main tank is still detected but no events were obtained on the LTC compartment.

At the time of the test the LTC was being operated on the automatic mode, at the beginning of the test the LTC was in position 23R and no acoustic activity was detected. It was decided to perform a LTC operation from 23R to 24R to see if this trigger the acoustic activity, however no acoustic activity was detected, therefore, it was concluded that this source was no related to a specific LTC position.

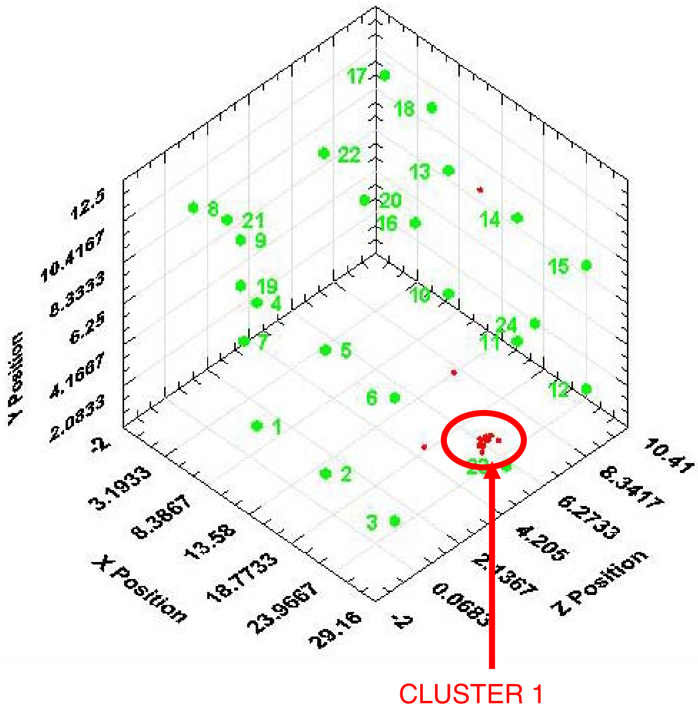

Figure 3-8
Three dimensional plot obtained after the test performed in February 2006

The electrical utility decided to operate the transformer on a fixed position of the LTC since February 2006 to see if the gases kept increasing. The gases kept increasing and that is why this transformer was selected for on-line monitoring.

Due to the availability of only 15 acoustic sensors (plus 1 for ambient noise) on the on-line monitoring system, their location had to be planned to cover both areas (lower part of main tank) and LTC & preventive autotransformer compartments.

Monitoring this unit simultaneously for 24 hours with standard instrumentation and the on-line monitoring system, the same activity was detected on both system: cluster of events on the lower part of Phase A and continuous activity (no events) on sensors installed on the LTC and preventive autotransformer compartments, see figure 3-9.

This system has been working since October, the second week of November 2006 the power supply for the system was not working properly and the system stop acquiring, fortunately, no data was lost because at the same time the unit was taken out of service for maintenance work.

No changes have been detected on the characteristics of the acoustic activity, however, it has been seen that most of the data is obtained from 06:00 hrs until 00:45 hrs of the next day, see figure 3-10**.** The customer has review the load and voltage profiles and seems to be voltage related activity.

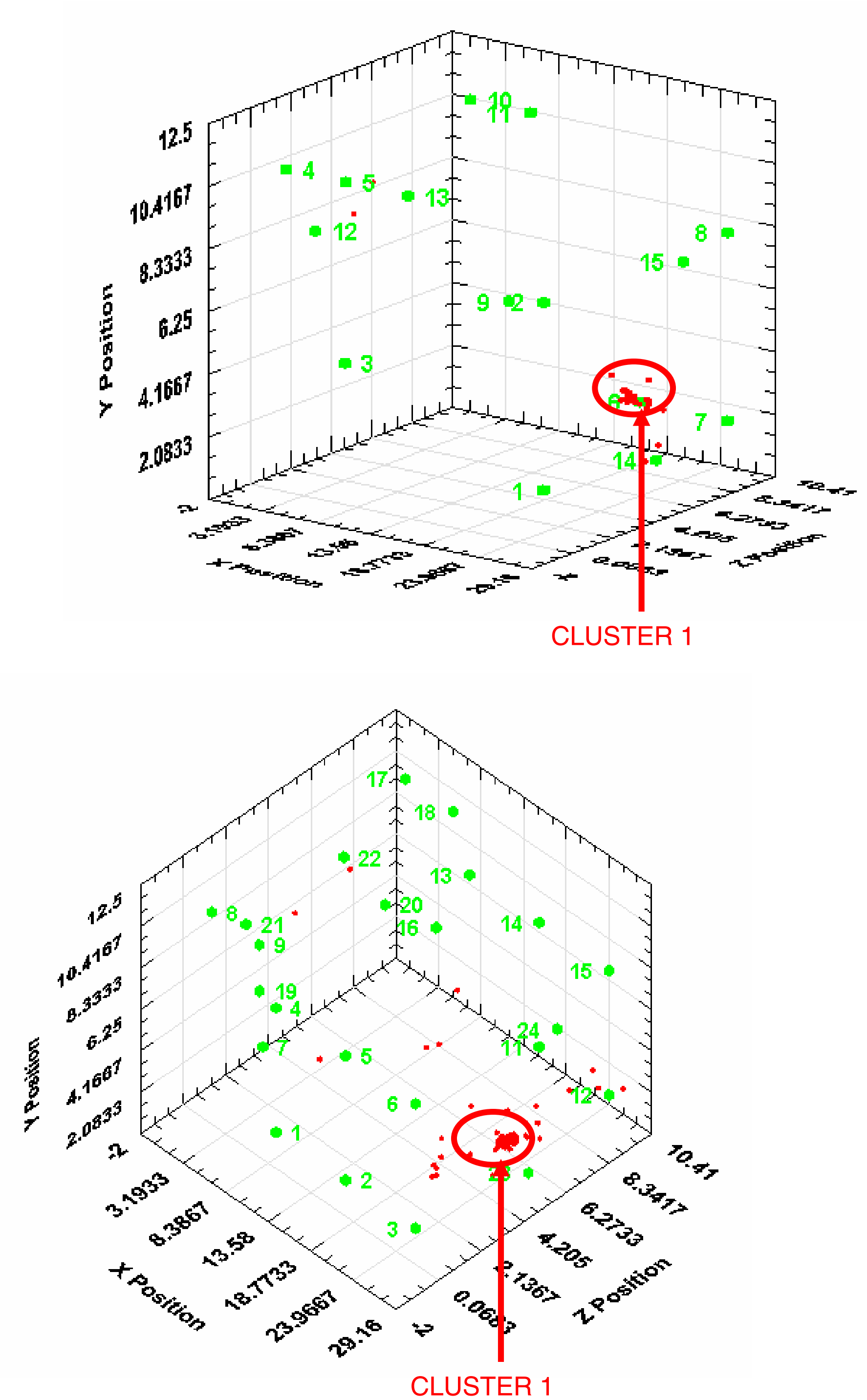

Figure 3-9
Three dimensional plots obtained after the test performed in October 2006, top for SHII and bottom for standard instrumentation.

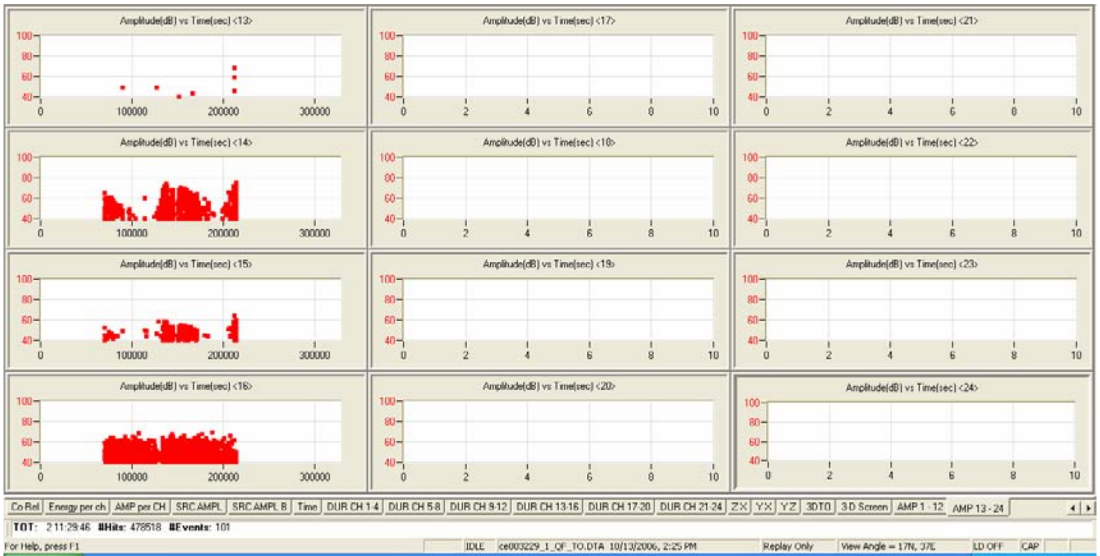

Figure 3-10
Acoustic activity detected in this transformer between 6 am and 00:45 hrs

300/336 MVA, 230/138/64.5 kV Transformer

Three phase transformer, 300/336 MVA, 230/138/64.5 kV, FOA Class. This transformer was tested acoustically in June 2006, at that time; the acoustic test was performed because this unit has a history of increases and decreases in the amount of combustible gases. At the time of the test, DGA values indicated a condition 3 based on the total amount of combustible gases according with the IEEE C57.104 standard. The main gas was ethylene which indicated a thermal fault, see Table 3-2.

Table 3-2
Dissolved gas analysis values on transformer

DATE	INST	H2	CO	CO2	CH4	C2H6	C2H4	C2H2	TDCG
6/7/06	PAC KELMAN	171	148	814	782	609	1423	11	3144
10/18/06	PAC KELMAN	2480	634	1636	5126	1782	6035	32	16089
10/19/06	Utility's KELMAN	2501	657	1671	5441	1702	6104	32	16437
10/18/06	Utility's LAB	1563	<25	1337	5867	2230	6815	37	16527
11/16/06	PAC KELMAN	2452	639	1633	5229	1730	5938	25	16013
11/16/06	Utility's KELMAN	1564	654	1647	5628	1435	6020	29	15330

During the June test, 23 acoustic sensors were used to monitor this unit, see figures 3-11 to 3-14 for sensor location. At the end of the test, two areas of acoustic activity were detected, one on the lower part of the Phase A coil and the other on the upper part of the Phase C coil, see figure 3-15

Figure 3-11
Sensor location HV side

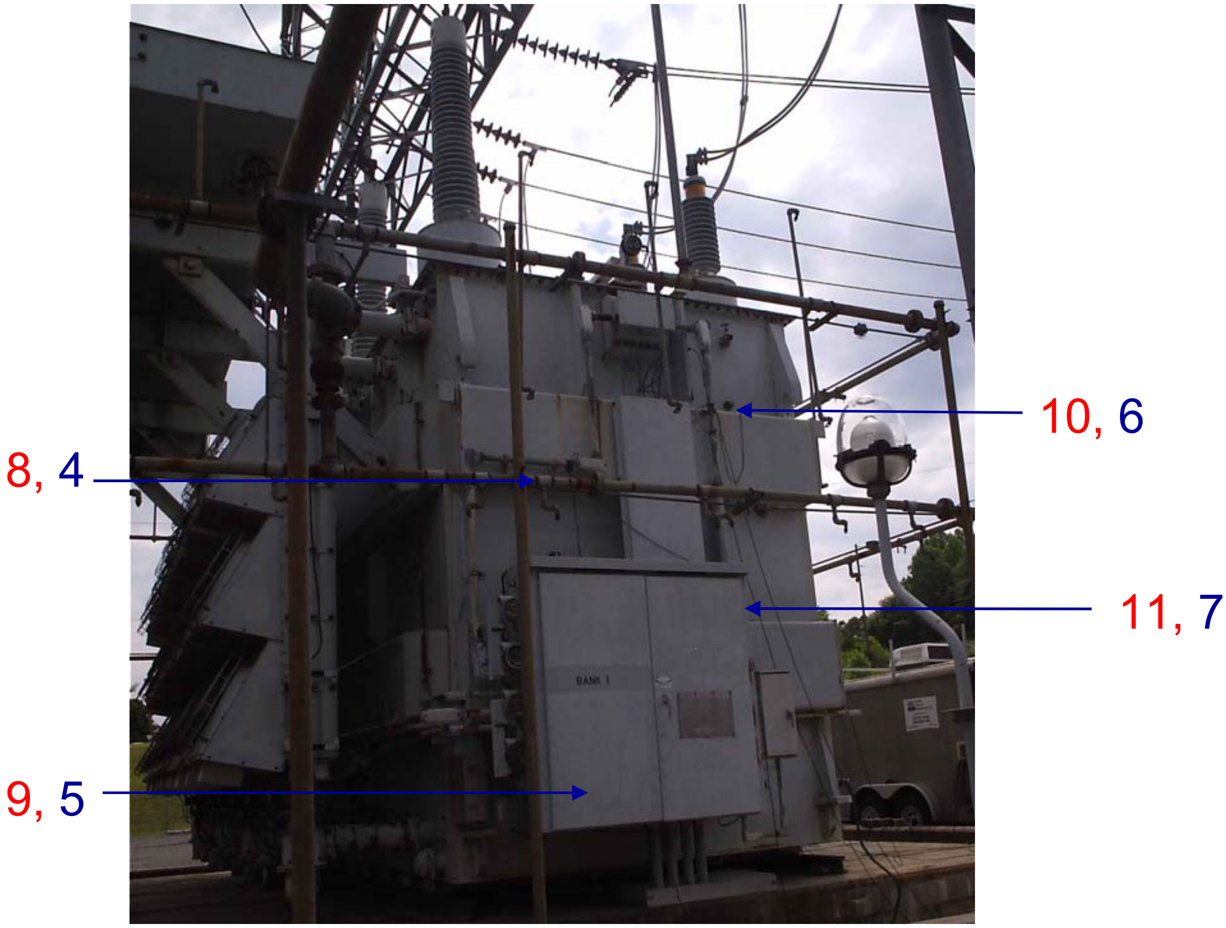

Figure 3-12
Sensor location on Right side

Figure 3-13
Sensor location Low Voltage Side

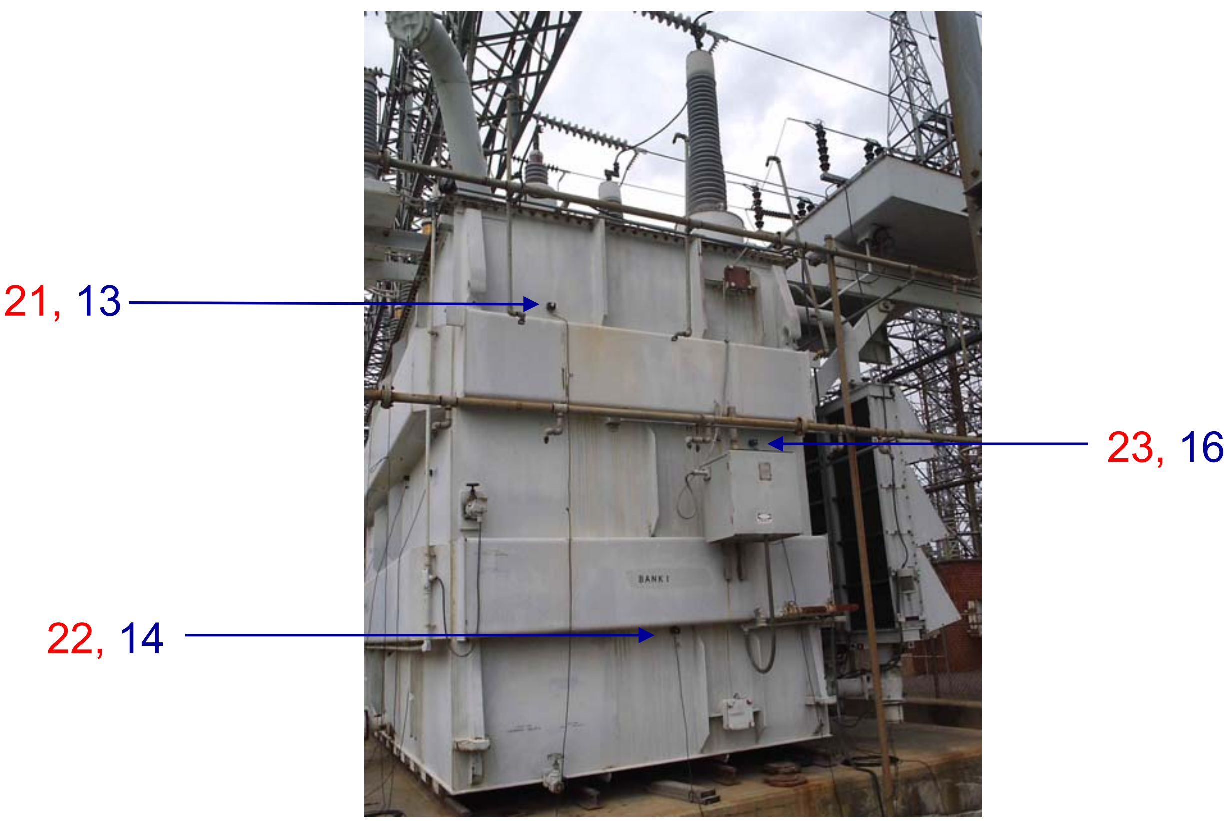

Figure 3-14
Sensor location left side

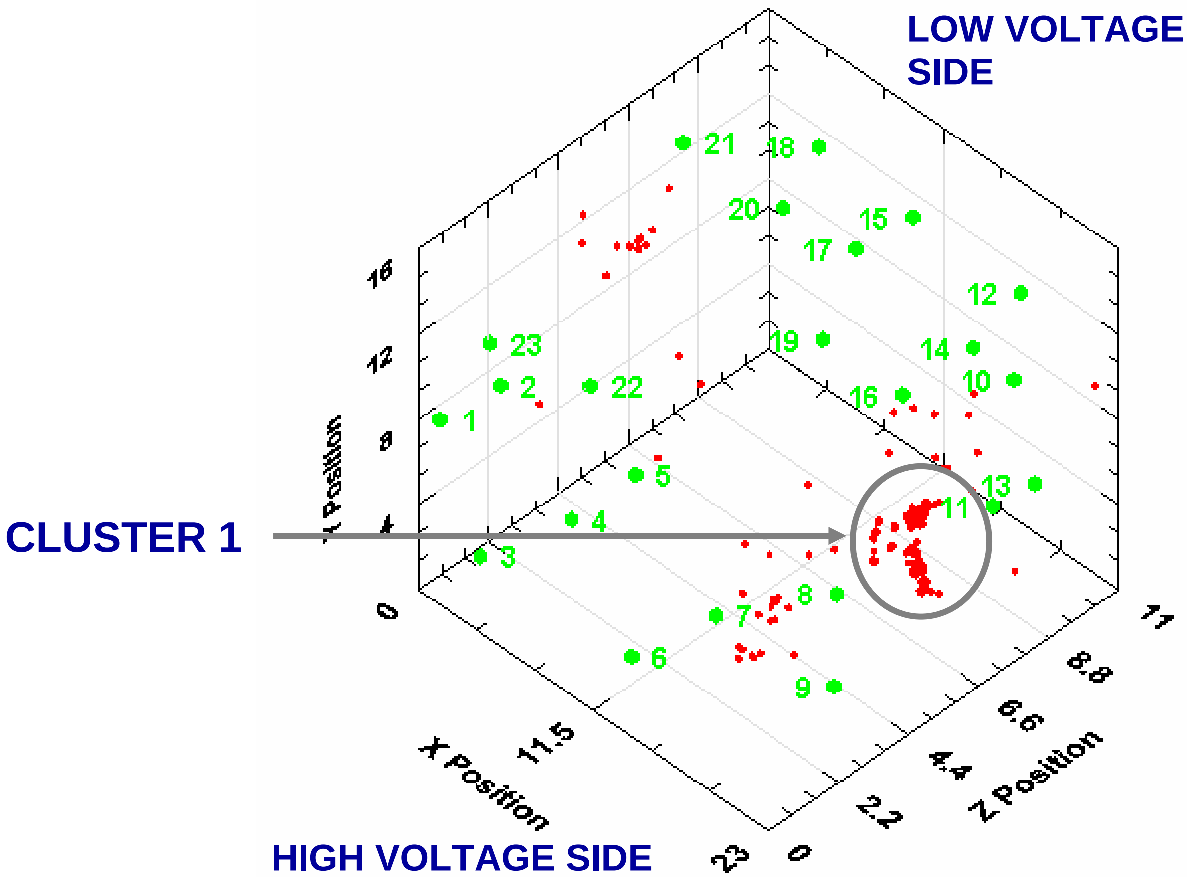

Figure 3-15
Three dimensional plot obtained after the June 2006 test

It was decided to install the on-line monitoring system on this unit due to the importance of this transformer and also based on its gassing history. This installation was performed in October 2006. The standard instrumentation was installed along with the on-line monitoring system for comparison purposes. Also, new DGA samples were taken on site with the surprising results of an increase from 3000 ppm to 16000 ppm on TDCG, see table 3-2. These results indicate a significant increase on the DGA values and indicate severe degradation on the transformer.

The same two areas detected in 2006 were detected in October 2006 plus an additional source located on the lower part of the HV side, see figure 3-16.

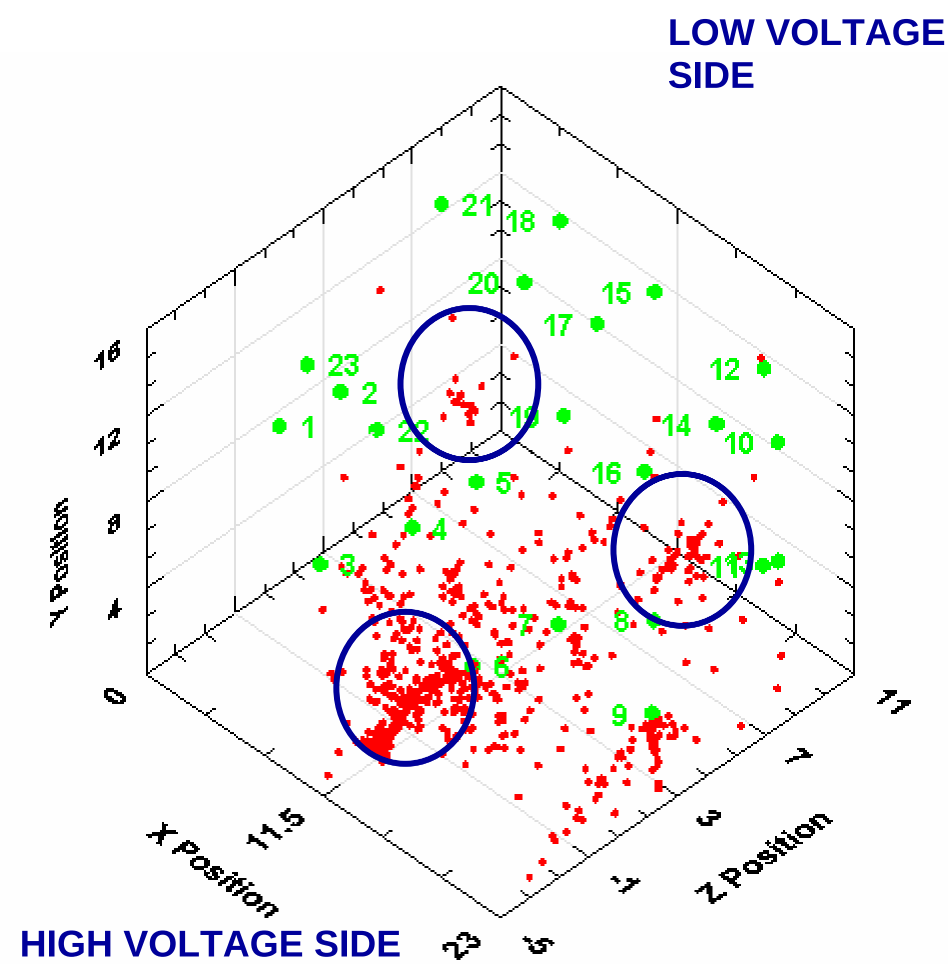

Figure 3-16
Three dimensional plot obtained after the October 2006 test

The on-line monitoring system failed due to a failure on the modem and no data was collected during the first 2 weeks of November. On November 16 the system was repaired, new DGA samples were taken and a small decrease on the TDCG values was observed. No changes on the AE detected have been observed as of November 21, 2006.

4
SOFTWARE DEVELOPMENTS

PARTIAL DISCHARGE DETECTION MATE (PDDMATE) SOFTWARE

During Phase I and Phase II of the research, software named TBFH (Time Between First Hits) was developed in order to help identify the origin of events obtained on a three-dimensional plot (thermal or electrical source). Although this software is very useful and has proven to be accurate, it has the limitation of requiring several hundreds of events to be obtained in order to be able to perform the analysis.

In the 2006 research, a new, more powerful algorithm was built to perform the same analysis on a per channel basis. It does not require synchronization with an external voltage signal and depends only on the acoustic emission data detected per each sensor.

The new feature called TAFI (Time Arrival Feature Index) is calculated per channel. A TAFI value of 1 means that the signal is being detected on both peaks of the voltage waveform (8.33/10 ms and 16.66/20 ms), a TAFI value of 2 indicates that the signal is being detected on one peak of the waveform whereas a higher TAFI value indicates that the signal is being detected every other cycle. These values can also be used to determine the intensity of the signal, a signal with a TAFI value of 1 is stronger that a TAFI 2 and so on.

Word of caution: The Test Engineer still has to use his expertise and criteria when interpreting these results, the software perform the same analysis on data acquired on every sensor regardless of its location on the transformer. This means that it would not consider if the activity detected is produced by magnetostriction (shell form units) or vibration of the structure, or a defective sensor/cable, etc.

Results from the PDDMATE software

Case 1: TAFI and TAFID with Clear PD Feature.

This is data collected from a transformer considered to have PD. As can be seen of figure 4-1, channels 11, 13, 14 and 15 are more active than other channels.

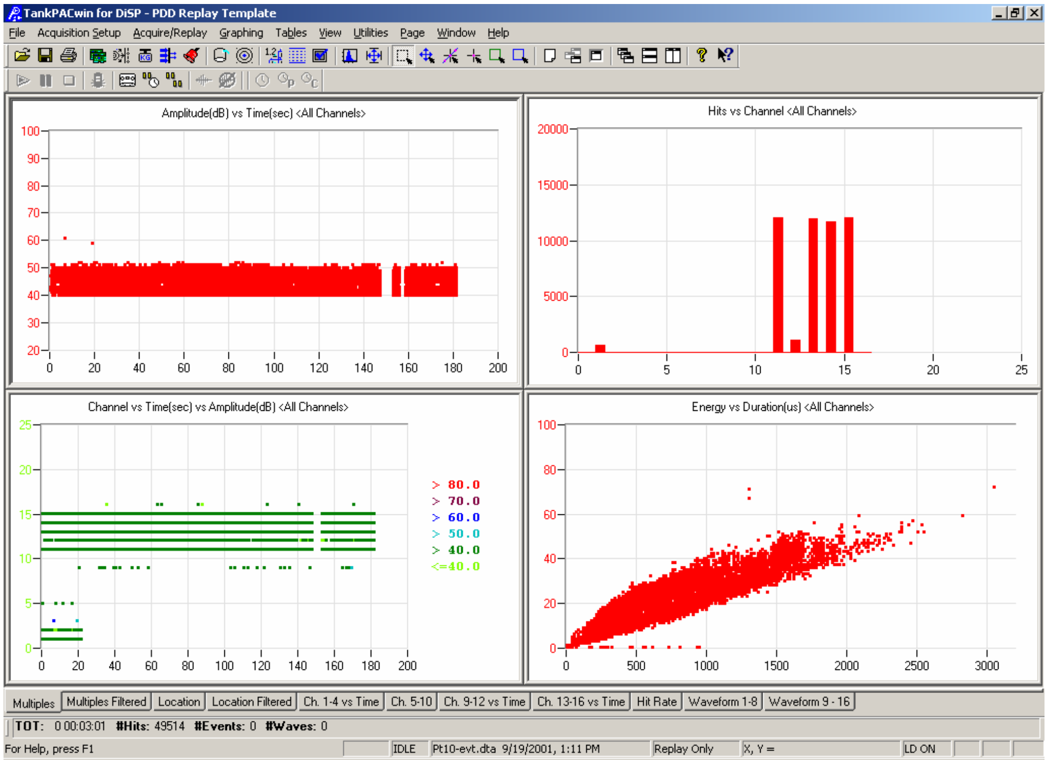

Figure 4-1
AE features

The TAFI and TAFID (TAFI distribution) are shown in figures 4-2 & 4-3 respectively. In figure 4-2, horizontal straight lines composed of scattered dots are clearly seen. They are located around the expected integer values. As indicated before, this indicates very high probability of partial discharge. Channels 11, 13, 14 and 15 show the most significant PD feature than other channels.

Figure 4-3 presents the total number of hits on each channel on top of each graph.

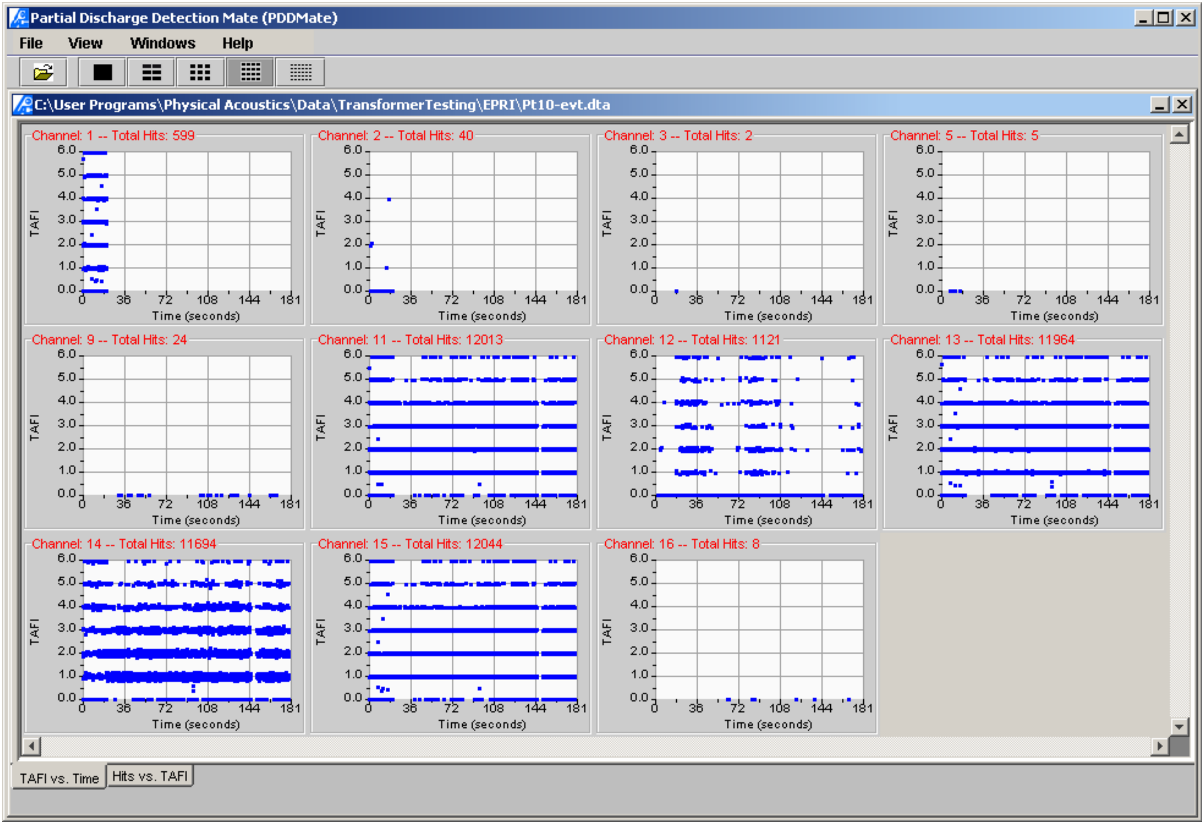

Figure 4-2
TAFI from a transformer with suspected PD

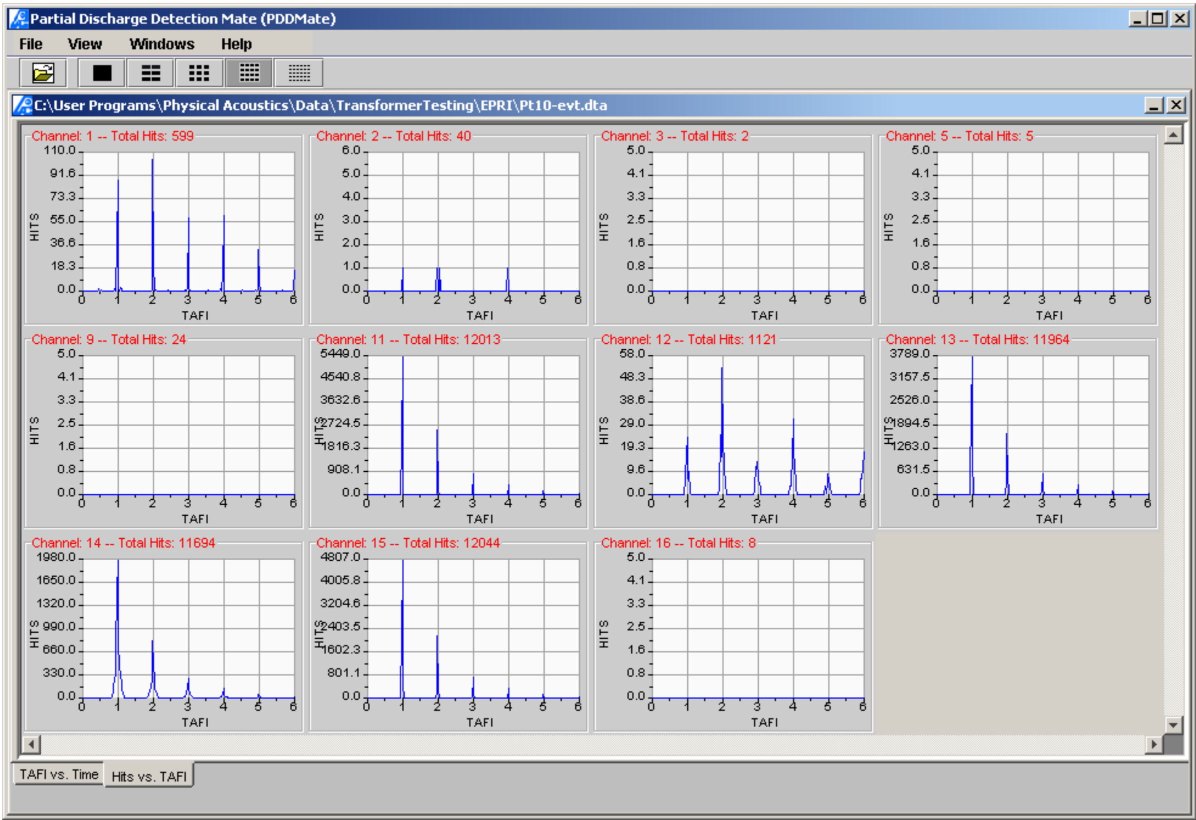

Figure 4-3
TAFID PLOTS FOR TRANSFORMER WITH PARTIAL DISCHARGE

Case 2: TAFI and TAFID of AE data produced by Rain.

It is known that rain affects the quality of an AE test as it usually generates a significant AE data. An example of AE features obtained during rain periods can be seen in figure 4-4. Not only many AE hits were detected in each channel, but also high amplitude hits were detected. If analyzed by inexperience persons or if the person who does the analysis does not know the data is contaminated with rain they could easily misinterpret this data as AE hits generated by a fault. However, calculating the TAFI and TAFID values, the data produced by rain can be easily identified as shown in figures 4-5 and 4-6 in comparison with the PD case presented above.

It is clear that no PD pattern is obtained on the TAFI plot of figure 4-5. The Indices are randomly distributed. Moreover, the TAFID graph of figure 4-6 does not show significant peaks on integer TAFI values. All these suggest that the rain data could be identified and removed in post-test analysis.

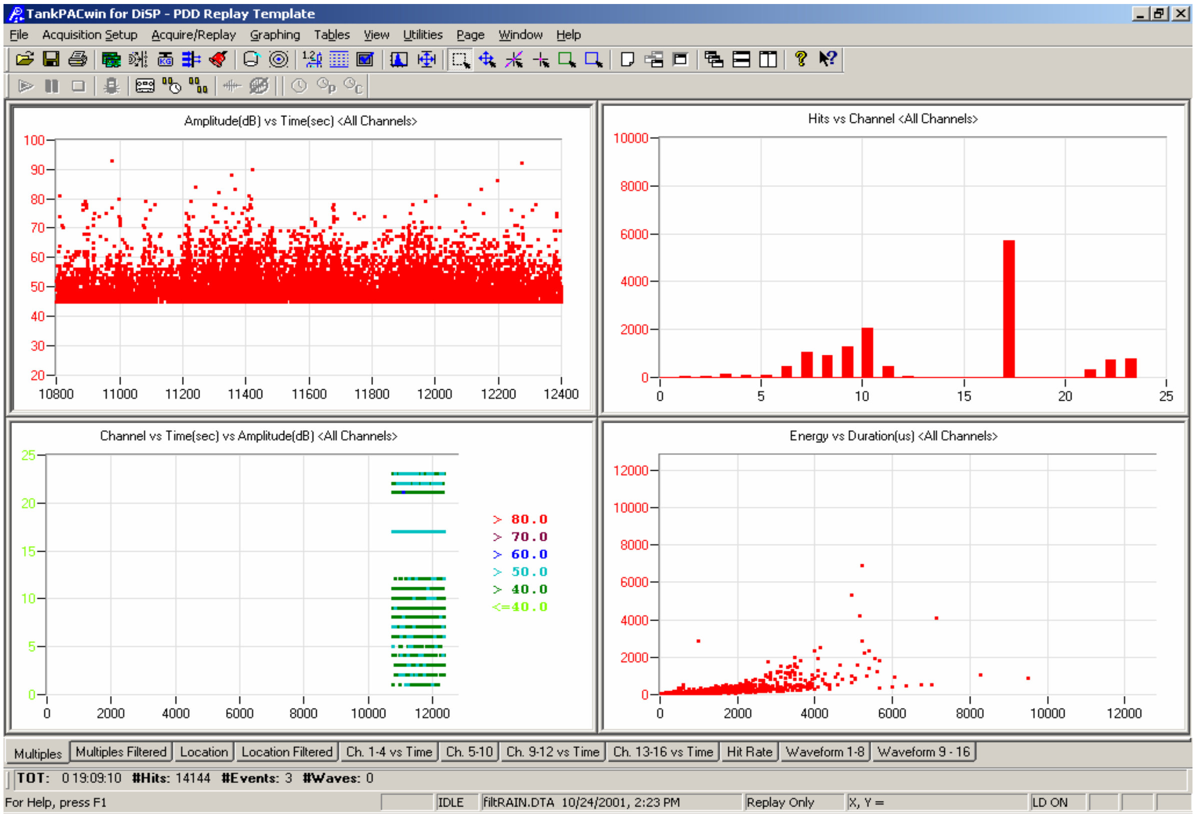

Figure 4-4
AE data obtained during rain

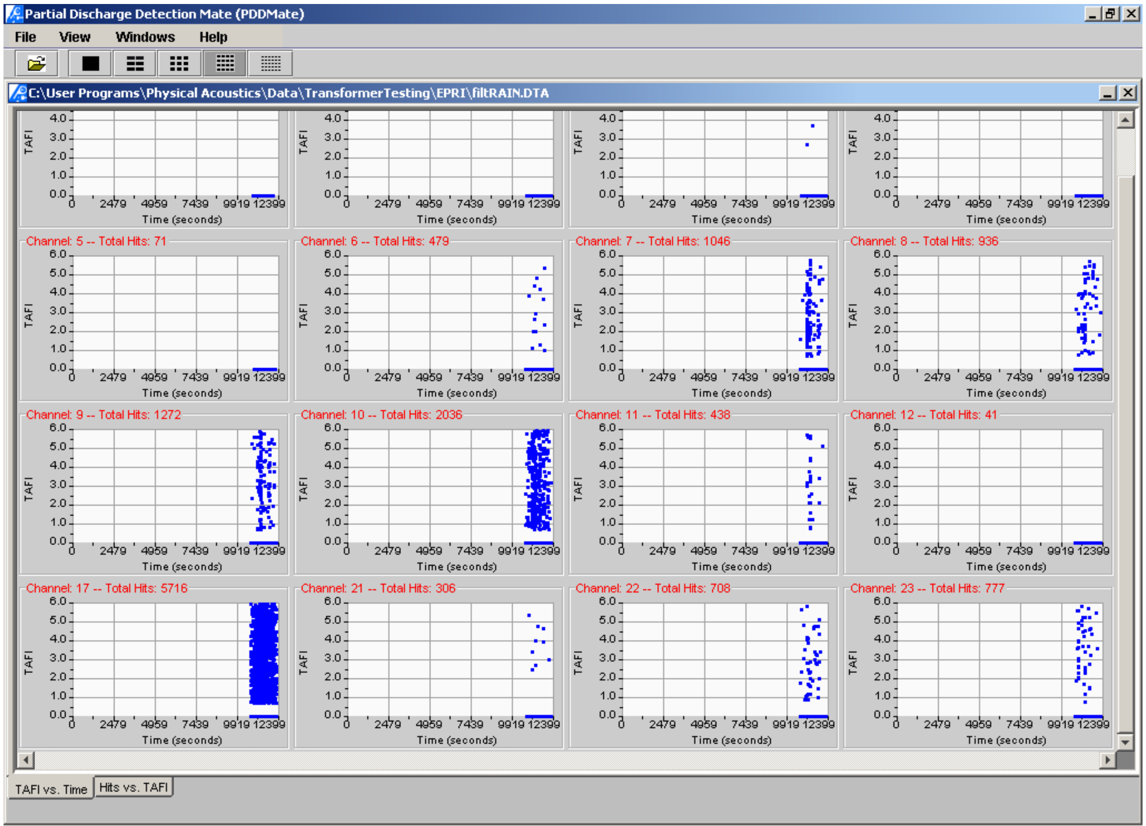

Figure 4-5
TAFI values calculated for rain data

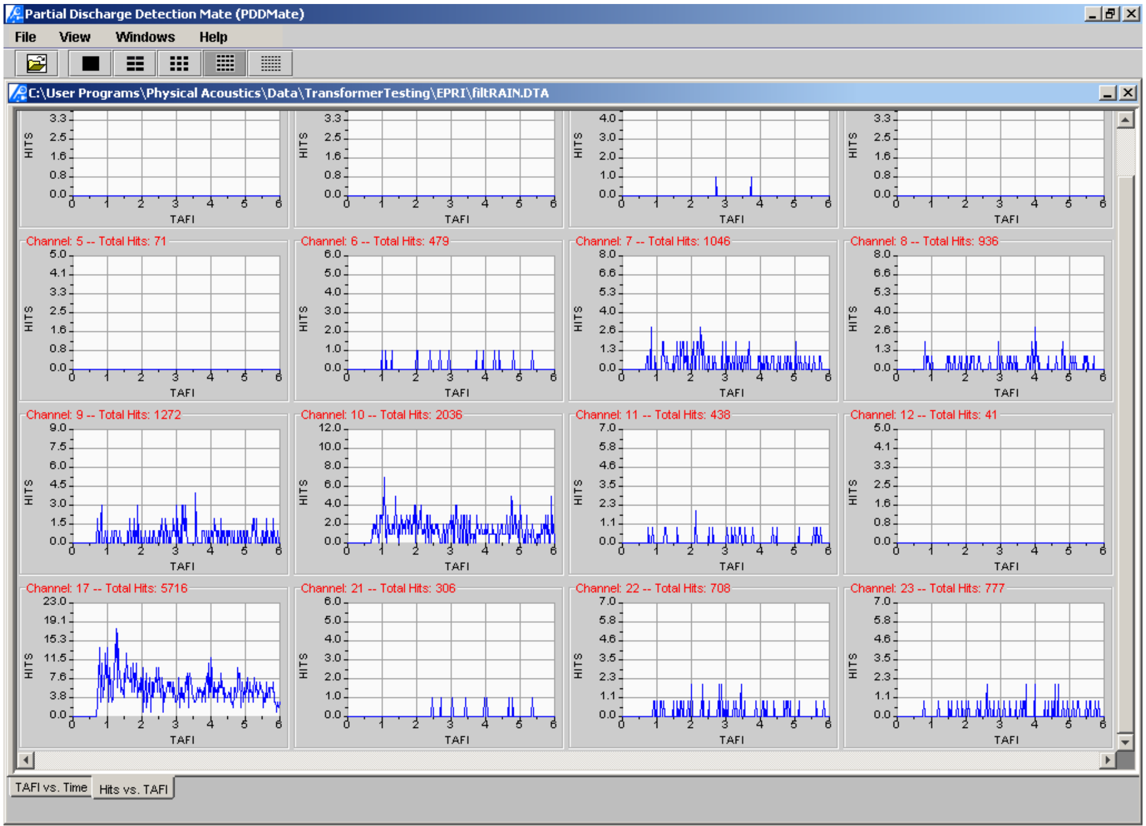

Figure 4-6
TAFID for rain data

Case 3: TAFI and TAFID of Mixed data from PD and Noise.

In some cases, such as testing of shell form transformers, FOA class units and some shunt reactors, background noise is significant. The AE data produced by the PD source might be masked by background noise as seen in figure 4-7. It is difficult to identify the PD signal from any of the conventional AE features. However, with the help of TAFI and TAFID graphs, the PD signal might be identified and separated from the overall noise. The effectiveness of the TAFI feature and graphs for separating the PD signal from noise can be further viewed from figure 4-8 and 4-9 where the PD and other noises are present at the same time in the same graph. Although much noise was involved, it is seen that TAFIs induced by noises are randomly scattered whereas a line around integer values of TAFI is still visible which separate themselves from noises as is seen in Channels 3, 4 and 6 of Figure 4-8. Actually, when both noise and PD exist, the TAFID (Figure 4-9) presents even better PD discrimination as the peaks at the integer TAFI values are superimposed on the noises and are very much higher (more hits) in comparison with the peaks induced by noise in Channels 2, 3, 4, 6, 8 and 9.

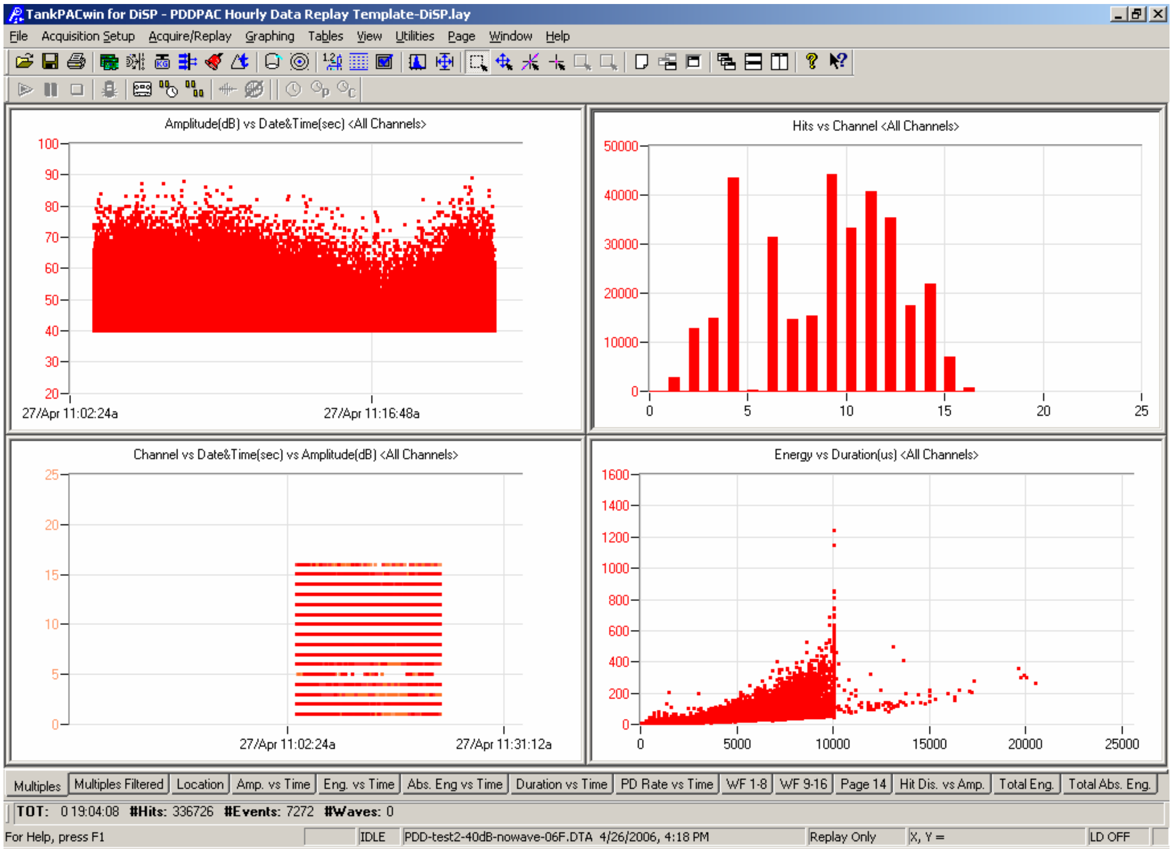

Figure 4-7
AE data, PD and background noise combined

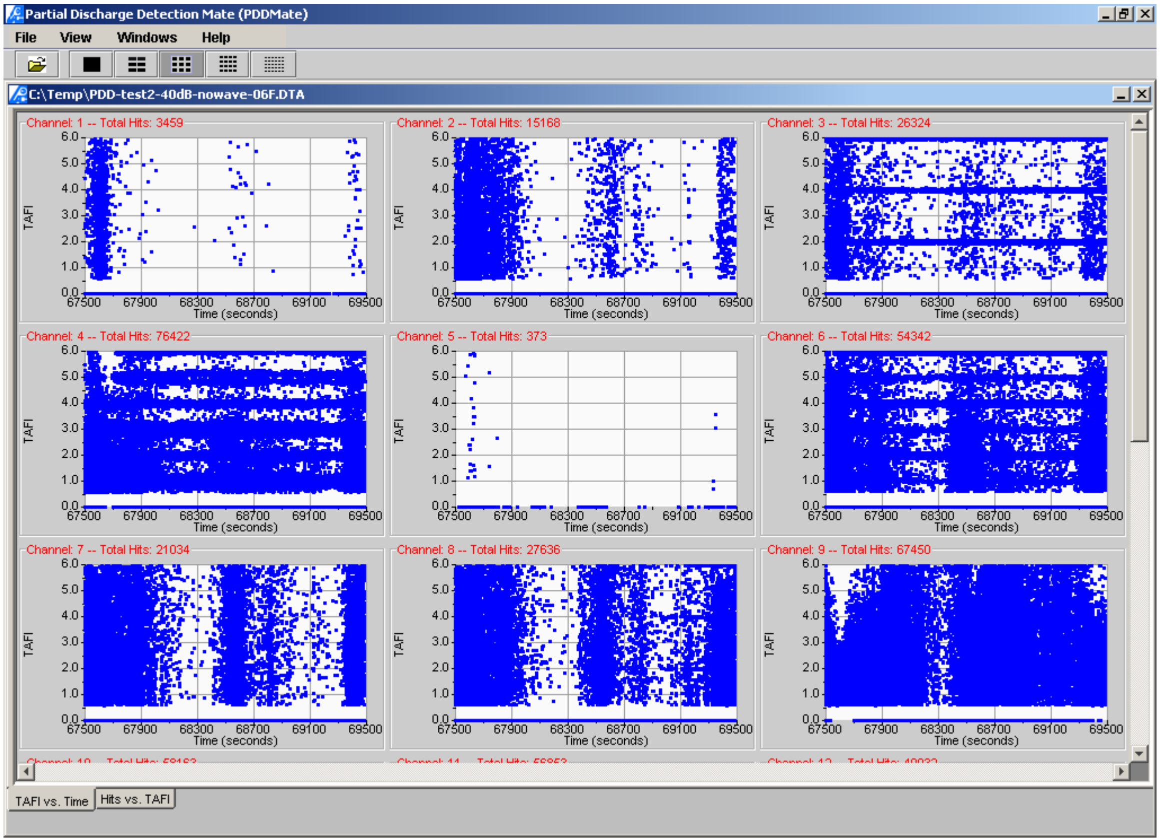

Figure 4-8
TAFI from data with PD & noise combined

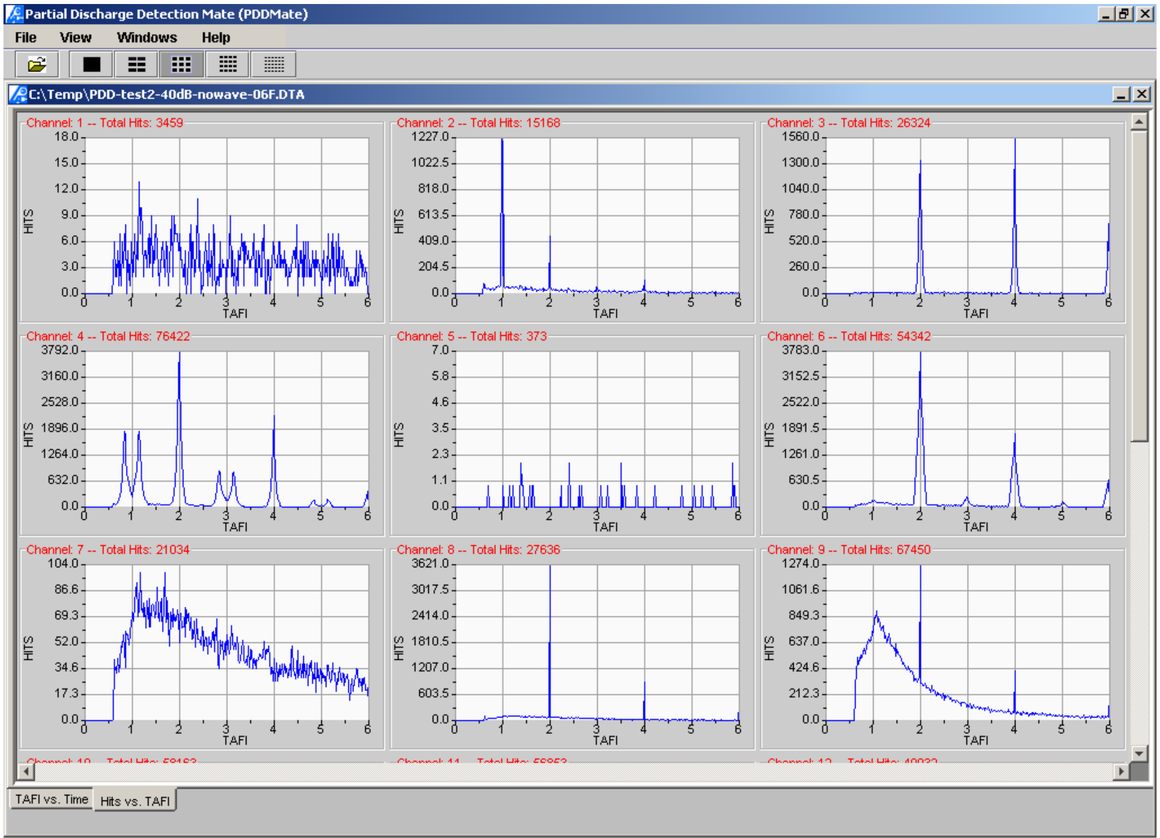

Figure 4-9
TAFID plots for PD & noise combined

5
FUTURE WORK

It is proposed that future research continue to build on these successes. Based on funding availability, the following topics are proposed for future work:

1. Further improvement of the online filtering and trending software.
2. Testing of techniques to include electrical partial discharge information into the AE signal processing. There are a number of options for coupling the electrical signals (e.g. RF CT schemes, UHF couplers) and the future research could examine the optimal pairing of the electrical and acoustic data.
3. Further research is proposed on improved field/communication interface techniques. Running communication lines to a transformer is a difficult and expensive task – and alternatives should be researched and trialed in the field.

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