ALTERIA AUTOMATION

Bright ideas!

PARTIAL DISCHARGE DETECTION

BUILDING A CONDITION BASED PREDICTIVE MAINTENANCE FOR TRANSFORMER SUBSTATIONS AND POWER GRIDS

APPENDIX: PROOF OF CONCEPT ROUGH PROPOSAL FOR ENEL

White Paper

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AUTHORS

JOSE R. VIGIL
JAVIER MUNOZ
MARIO ALFONSO

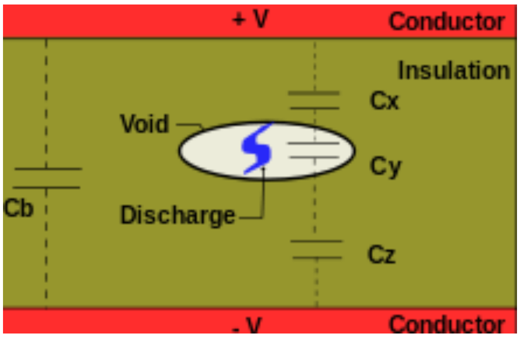
BACKGROUND

Partial discharges are in general a consequence of local electrical stress concentrations in the insulation or on the surface of the insulation.

During a partial discharge, an impulse conversion of some part of electric energy (about 1-5%) to mechanical energy happens, which produces an ultrasonic acoustic emission wave and a detectable RF burst in the UHF range.

The remaining part of that stray energy includes electric, thermal and chemical transformations.

Many defects of the oil/paper transformer insulation materials are created by partial discharges.



Partial Discharge may lead to damage of high-voltage devices in a short time, although some defects can develop for years before a major failure happens.

Partial discharge can also be a spotty event that depends on different factors.

Therefore, the assessment of dynamic changes of Partial Discharge intensity over time is essential to the bottom line of Medium and High Voltage asset maintenance.

Prediction of failure is possible with today's technology before it happens

Some technologies that are being recommended to monitor the development of partial discharges are:

- DGA - Dissolved Gas in oil Analysis,
- UHF - Ultra High Frequency emission
- AE - Acoustic Emission Detection

Each method is characterized by certain advantages and disadvantages, which were summarized in Table 1 on the next page.

ALTERIA has developed technology for both the UHF and the Acoustic Emission detection methods. However, the Acoustic Emission (AE) method is reported by many experts as the preferred and believed to be the easiest to implement.

The detection of Acoustic Energy as a predictive maintenance method is applied in electrical power engineering for detection and location of Partial Discharge (PD) sources in insulation system of large power transformers and GIS/GIL (Gas Insulated Substations/Gas Insulated Transmission Lines).

ACOUSTIC EMISSION

The Acoustic Emission (AE) is a group of phenomena involving generation of transient elastic (acoustic or vibro-acoustic) waves, resulting from the liberation of intermolecular bond energy (deformation, cracking, phase transitions). Acoustic emission technology is widely use among others in:

- Industrial predictive maintenance
- Machinery and civil structures condition assessment.
- Fatigue and fracture materials research.
- Detection of material defects.
- Chemical reactions and phase transitions research.

OUR MISSION IS TO BECOME A PREDICTIVE MAINTENANCE INDUSTRY LEADER FOLLOWING OUR TECHNOLOGICAL ADVANTAGE APPROACH
(JOSE R VIGIL C.T.O. ALTERIA AUTOMATION)

Possibilities	Method		
	DGA	UHF	AE
Detection	Yes	Yes	Yes
Detection sensitivity	High (~10pC, depending on time of PD activity)	High (~1-10pC, depending on distance and location of the PD source)	Moderate (> 300 pC, depending on location of the PD source)
Intensity measurement	No	Limited	Limited
Identification	No	Yes	Yes
Location	Limited	Limited	Yes
Installation difficulty	Moderate (transformer must be turned off)	Moderate (through oil valve, transformer under load / through dielectric window, transformer must be turned off and opened)	Low (transformer under load)
Sensors	1 (due to high costs)	limited by number of oil valves or dielectric windows	open structure, typically 1-16

Table 1. The comparison of the PD monitoring methods for large power transformers

The main advantages of the Acoustic Energy (AE) method are:

- Tests are taken when the transformer is online
- Installation is simple and can be performed online
- Susceptibility to external electrical disturbances is relatively low
- The possibility of partial discharge recognition, location, and on-line monitoring. See *(Institute of Electrical and Electronics Engineers [IEEE], 2007; Kuffel et al., 2000; Lundgaard, 1992a, 1992b; Markalous et al., 2003).*

<u>ALTERIA has developed over the last two years embedded edge pre-processing technology for Acoustic Energy analysis in the ultrasound range</u>.

Shown in figure 2 our technology features the following advantages:

- Adoption of optimal AE signal processing algorithms for <u>efficient detection and recognition under extreme environments</u> such as inside transformer substations where EMI/RFI levels are high enough to disturb most monitoring devices.
- All the <u>signal processing work is made right at the transducer edge</u>, the sensor forwards a simplified data structure following a proven, Patent Applied for method that saves 93% of data payload.
- Using our patented technology <u>Wireless Connectivity is now possible</u> using narrow band solutions.
- Today highly miniaturized electronics and the high power embedded processing of the new generation of IIoT devices allow <u>affordable, scalable solutions for Acoustic Energy monitoring</u>.
- AE Detection is proven, reliable <u>and performed in real time and on-line</u> with a high S/N (Signal to Noise Ratio)

COST AND SPACE IS RADICALLY IMPROVED USING OUR SMART SENSOR EMBEDDED EDGE TECHNOLOGY

CURRENT TECHNOLOGY

ALTERIA’S TECHNOLOGY

1 piezoelectric AE sensors and preamplifiers
2 signal acquisition unit with expert system software for insulation faults (PD sources) detection and recognition
3 signal conditioning unit (filters, amplifiers)
4 climate (temperature, humidity) control unit

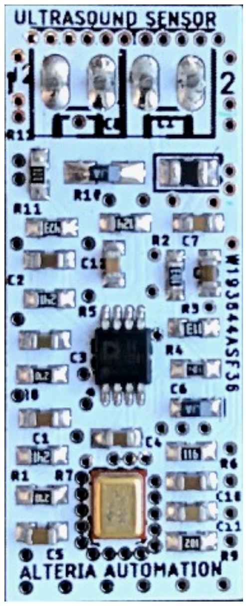
Real size is 100 mm!

What is inside

Fig 2. <u>On the top left the processing system used by Sikosky and Ziomek in March 2012 is shown</u>, a large 19” rack full of processing and acquisition equipment. An effective but <u>very expensive non scalable approach</u>.

<u>On the right ALTERIAS’s technology is shown</u>. The complete sensor is displayed at the top right measuring 100 mm wide for comparison.

Real size is 35 mm!



PCBs containing the low noise pre-amplifier, signal conditioning (bottom right) and the digital pre-processing that includes time to frequency domain algorithmics (bottom left) are 35 x 15 mm size each.

<u>Same effectivity at a reduced footprint and price!</u>

A. E. MEASUREMENT SYSTEM

A typical measurement system for partial discharge detection, based on acoustic emission method is composed of:

- Acoustic Emission Transducer
- Low noise Preamplifier
- Signal conditioning unit
- Signal acquisition unit (sampling)
- Specialized firmware for digital signal processing.
- A data transceiver that forwards the AE information over a communication network, either bus wired or wirelessly to a Gateway.

For more information about our solutions and a proposed layout, please check out our monitoring proposal starting on Page 10.

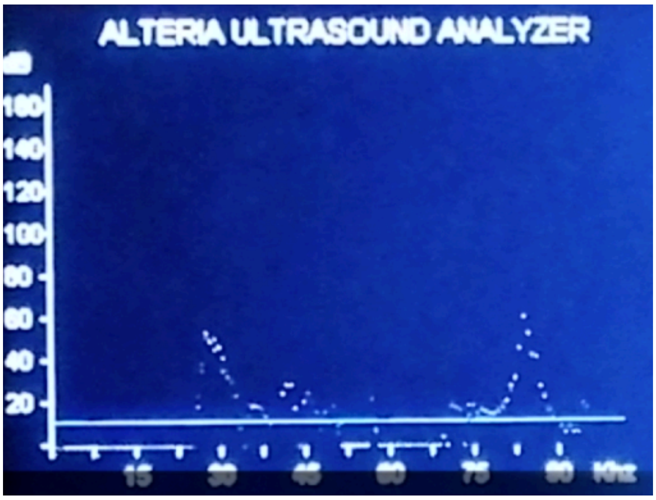


Fig. 3 AE Spectogram shot with ALTERIA UD 103, ultrasound AE sensor. (Watch our video)

LINK TO VIDEO HERE:
https://www.youtube.com/watch?v=Y9jp9hLKUuA

In addition, The AE sensors have to be designed to work in a harsh environment (high Temperature, corrosion, extreme EMI/RFI conditions…)

Our sensors provide high detection efficiency of surface discharges (generating acoustic emission signals with frequencies from 20 to 100 kHz), which generally have higher energy and can cause insulation accelerated degradation.

In turn, other experts suggest a choice of broadband transducers (up to 1 MHz) *(Boczar, 2001; Lundgaard, 1992a, 1992b; Markalous et al., 2003; Sakoda et al., 1999; Sikorski & Siodla, 2005; Varlow et al., 1999).*

Theoretically, they enable the detection of all types of partial discharges that may occur in transformers with oil/paper insulation.

The disadvantage of this wideband solution is the smaller sensitivity of surface discharge detection.

A fundamental importance in the detection of partial discharges in a power transformer is a proper acoustic coupling between the sensor and the surface of the tank (*American Society for Testing and Materials [ASTM], 2007)*.

The lack of direct contact of the acoustic sensor with the tank causes a strong attenuation of the AE amplitude signal, and thus a strong decrease in sensitivity of partial discharges detection.

For this purpose silicone grease or gel dedicated to ultrasonic applications can be used.

ALTERIA manufactures also sensors that are air coupled. A practical solution facilitating the mounting of the AE sensor to the tank wall is the use of strong neodymium magnets.

APPLICATION TO TRANSFORMERS

In the case of large power transformers, the main problem is an environmental heterogeneity between partial discharge source and AE sensor (Sikorski et al., 2007c).

The acoustic field inside the tank is very complex due to wave reflection and diffraction in different materials (pressboard, copper, pressboard, paper, oil).

The acoustic wave propagates in materials, from which the transformer is made, with different velocity: 1413 m/s in transformer oil, 1500 m/s in impregnated pressboard, 3570 m/s in copper and 5100 m/s in steel.

The velocity of the AE wave propagation in oil strongly depends on its temperature. When the oil temperature equals 20 C the velocity of wave propagation amounts to 1413 m/s.

For higher oil temperatures the velocity falls and equals: 1300 m/s by 50 C, 1200 m/s by 80 C and 1100 m/s by 110 C.

The velocity in metal is greater than in oil, therefore very often the wave, which most of its way travels in tank wall (structure-borne path), arrives at the sensor first.

The measuring set up in a power transformer tank and its influence on signal acquisition is presented in Fig. 4.

The correct interpretation of measurement results may be affected by disturbances during on-site PD detection.

The main sources of the interference are:

- Switching of on-load tap changer,
- Thermal faults of transformer's active part,
- High-voltage switchgear operations near the investigated transformer,

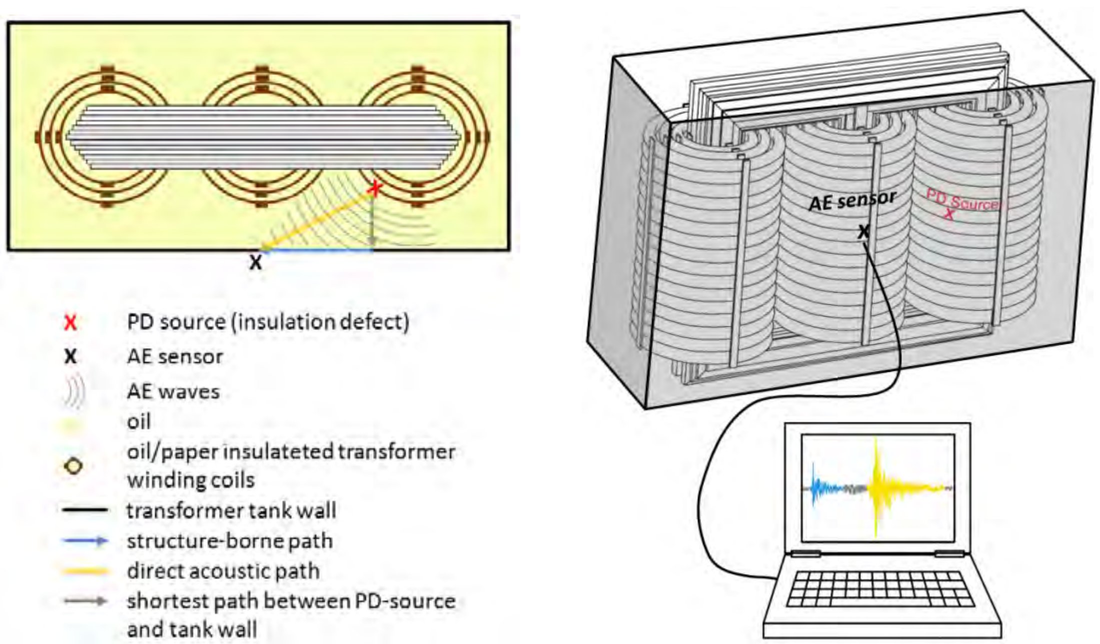


Fig. 4 Basic schematic Transformer sensor approach

With a certain time delay, the sensor registers a secondary wave, which propagated in the oil at a slower speed (direct acoustic path).

The problem of structure-borne waves may be minimized by placing the acoustic sensor inside the tank, but this solution comes with a price. The transformer has to be off-line for installation and service is a mess.

- Environmental noises (thunderstorms, rain, wind),
- Core magnetostriction noise (Barkhausen effect),
- Loose shielding connection in transformer tank.

METHODS OF AE PROCESSING

Our research included the selection of signal processing methods which would support both the detection and Partial Discharge improved recognition.

The criteria used for algorithm selection included immunity to disturbances both wideband and narrow-band noise, minimizing the computing payload, and overall efficiency.

Based on the results of numerous computer simulations and a widespread literature study, high-resolution spectral analysis (HRSA) and joint time-frequency analysis (JTFA) were chosen as the optimum methods for establishing the AE-based PD-patterns, *see (Antoniadis & Oppenheim, 1995; Holschneider, 1998; Kia et al., 2007; Lobos et al., 2000, 2001; Ma et al., 2002; Shim et al., 2000; Yang & Judd, 2003; Zhang et al., 2003).*

High-resolution spectral analysis methods, also known as subspace methods, generate the frequency component calculation for a signal based on eigenanalysis or eigendecomposition of the correlation matrix *(Hayes, 1996; Marple, 1987).*

HIGH RESOLUTION SPECTRAL

These methods exploit the noise subspace to estimate unknown frequency parameters of a random process and are very effective in the detection of sinewaves (a PD signal can be approximated as an exponentially attenuated sinusoidal oscillation) buried in noise, especially when the signal-to-noise ratio (S/N) is low.

This property makes that analysis method particularly attractive for efficient detection of PD signals recorded under conditions of strong external interference, such as the harsh environment of a power substation.

Following this technology the detection of internal discharges occurring in a power transformer in which the acoustic signal is damped by pressboard barriers is also possible.

It is worth mentioning that such efficient detection with the use of the classic and well known Fast Fourier Transform (FFT) is not possible.

Fast Fourier Transform allows detection of PD signals only in the absence of other common noise sources that are present in the transformer substation for sure.

Among available subspace algorithms, Multiple Signal Classification (known as MUSIC) was chosen. See *(Schmidt, 1986).*

The MUSIC algorithm very precisely identifies harmonic components (*Besson & Stoica, 1996; Hayes, 1996; Lobos et al., 2000, 2001; Marple, 1987).*

Therefore, in a case of measurements under industrial harsh conditions (e.g. in a power substation), it is advantageous to replace the classic FFT analysis with the MUSIC algorithm, or a similar high-resolution spectral method.

OIL-PAPER INSULATION MODELS

Investigations conducted on models are important sources of information on the electrical performance of the transformer parts, such as coil-to-coil insulation, clearance to core, space at the bushings etc.

Some basic rules for model creation are:

- The construction of models should have the same material structure, shape and proportional geometrical dimensions as the part of the insulation that is modelled; it should reproduce the same mechanism of initiation and development of partial discharges,
- The construction of models should reproduce real distribution of the electric field.
- The oil in the model should have similar composition as the real one such as content of water, dissolved gases and solid impurities.

PD1	Surface discharges in uniform electric field, where the normal component of field strength vector is insignificant
PD2	Surface discharges in moderate non-uniform electric field with small normal component of field strength vector
PD3	Surface discharges in non-uniform electric field with large normal component of field strength vector
PD4	Partial discharges in internal gas void
PD5	Partial discharges in gas bubbles in oil
PD6	Pressboard penetrating discharges (puncture)
PD7	Partial discharges from a needle in oil (point-to-plane electrode system)
PD8	Partial discharges from a needle on free potential in oil
PD9	Partial discharges in oil wedge at the oil-pressboard-electrode triple junction
PD10	Turn-to-turn insulation discharges (interturn)

TABLE 5. PD types: Characterization of Partial Discharge Models

The model investigations performed by some researchers allowed to register the waveforms of AE signals generated by partial discharges of a power transformer (*Bengtsson & Jönsson, 1997; Boczar, 2002; Lundgaard, 2000; Elborki et al., 2002; Harrold, 1975; Massingue et al., 2006)*

The influence of some factors on AE signals frequency parameters was investigated. The factors, among others, were:

- Moisture content
- Aging degree of pressboard/paper samples
- Test voltage polarity
- Electrode and insulation samples geometry
- Type of applied AE sensor (narrow/wideband)

As a result of this research, ten different types of Partial Discharge event categories were characterized. See Table 5.

The most common types of partial discharges recognized in power transformers are easy to detect with narrow band transducers (20Khz to 100 Khz, that are affordable and easy to install, while wideband sensors are better to detect oil discharge events

PARTIAL DISCHARGE PATTERNS

For all the AE pulses registered, a high-resolution spectrum was calculated an recorded on the cited research papers.

Their analysis shows that each investigated Partial Discharge type has different dominant frequency spectrum fingerprint.

This property allows the creation of a Partial Discharge pattern catalog, that will be useful to create a predictive maintenance model.

A database prepared with the PD-patterns in the form of spectrum data can then be analyzed in a computer server performing automatic detection and recognition of discharges occurring in oil-paper insulation *(As suggested by Sikorski et al., 2007a).*

Efficiency improvement of PDs' detection and identification process can be achieved by conducting additional analysis in the joint time-frequency domain.

LOCATION OF DISCHARGE

The location of partial discharges with the use of acoustic emission technology may be conducted by:

- Measurement of AE pulses amplitude in different distances from PD source (auscultatory method)
- AE Time of Arrival (TOA) at sensors placed in an array (triangulation method) (*Markalous et al., 2008).*

The auscultatory method is the easiest way to locate the PD sources *(IEEE, 2007).*

Despite the fact that its accuracy is lower than that of triangulation method's, it may be very efficient and useful in cases, when:

- The measurement time is limited by the time of voltage tests.
- During the voltage test, the phase with PD source has been detected, so there are clues of location.
- Acoustic measurement is conducted with one-channel-setup
- The detail of internal construction of the investigated transformer is known
- The investigated transformer is relatively small.

The triangulation method is gaining strengh as the price of transducers and pre-prpocessing embedded edge technology is becoming accesible.

Image 6 shows auscultatory method with ultrasound transducer located in the focus parabolic point.

Image 7 shows ultrasound transducer array being soldered in an PCB array.

Image 8 shows the principle of time-of-arrival method and the detection of location by precision time delay analysis using an array of transducers.

Images are self explanatory.

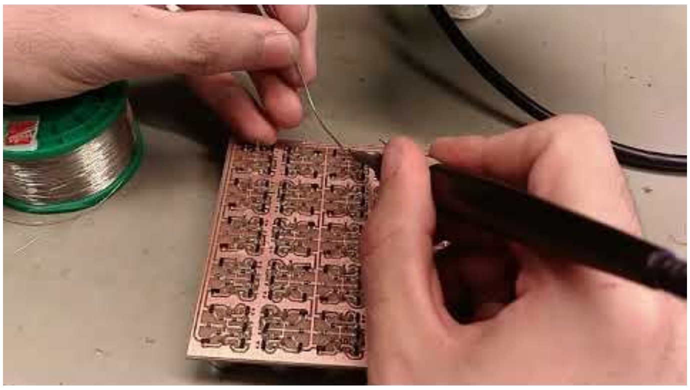


FIG 7 Soldering a PCB with an array of ultrasound AE transducers, location calculation is performed by Time Of Arrival a similar technology to SONAR

FIG 6 Parabolic ultrasound used in AE location

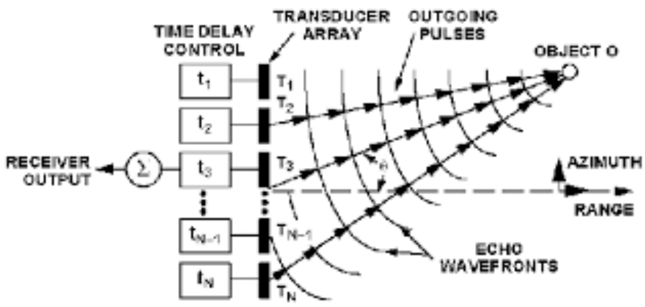


FIG 8 Ultrasound Time of arrival detection transducer array

APPENDIX: PROOF OF CONCEPT ROUGH PROPOSAL FOR ENEL

TRANSFORMER PREDICTIVE MAINTENANCE PRIMER: OUR APPROACH

This section was added to the original white paper on Dec 5th 2018, in order to place a provoking-though proposal to ENEL only.

We are describing here the possibility of a complete proof of Concept for remote monitoring with predictive maintenance primarly based upon Ultrasound, Acoustic Energy technology for Partial Discharge detection and thermal infrared NIR technology.

This is a low-cost approach that works and is scalable.

These two basic culprits (AE and NIR) are complemented with some other sensors in order to show other monitoring possibilities that might improve the experience of remote monitoring and condition based predictive maintenance.

EMBEDDED EDGE TECHNOLOGY

Alteria Automation specializes in the design and manufacture of smart sensors with Embedded Edge Pre-Processing technology.

With this hardware architecture (see Figure 2) the sensor pre-processes the data at the source with the following advantages:

- The bandwidth of the data transmission channel is minimized.
- Minimizes the space at the Database on the server side.
- Only relevant data is stored, eliminating the “noise/garbage" of the prediction models.
- The process of creating predictive maintenance models is streamlined.
- The effectiveness of the alarms created by the deviation of patterns is improved using neural networks for predictive maintenance.

The embedded edge technology of ALTERIA is based on a proven pre-process method with patent applied for #62684218 (June 2018).

SENSOR FUSION

ALTERIA is also developing prediction technology based on the Sensor FUSION concept.

Sensor fusion is not a new concept. Probably born in the aerospace industry where different sensor readings are used in inertial navigation systems (INS)

Sensor Fusion has been widely used lately in the development of the autonomous vehicle.

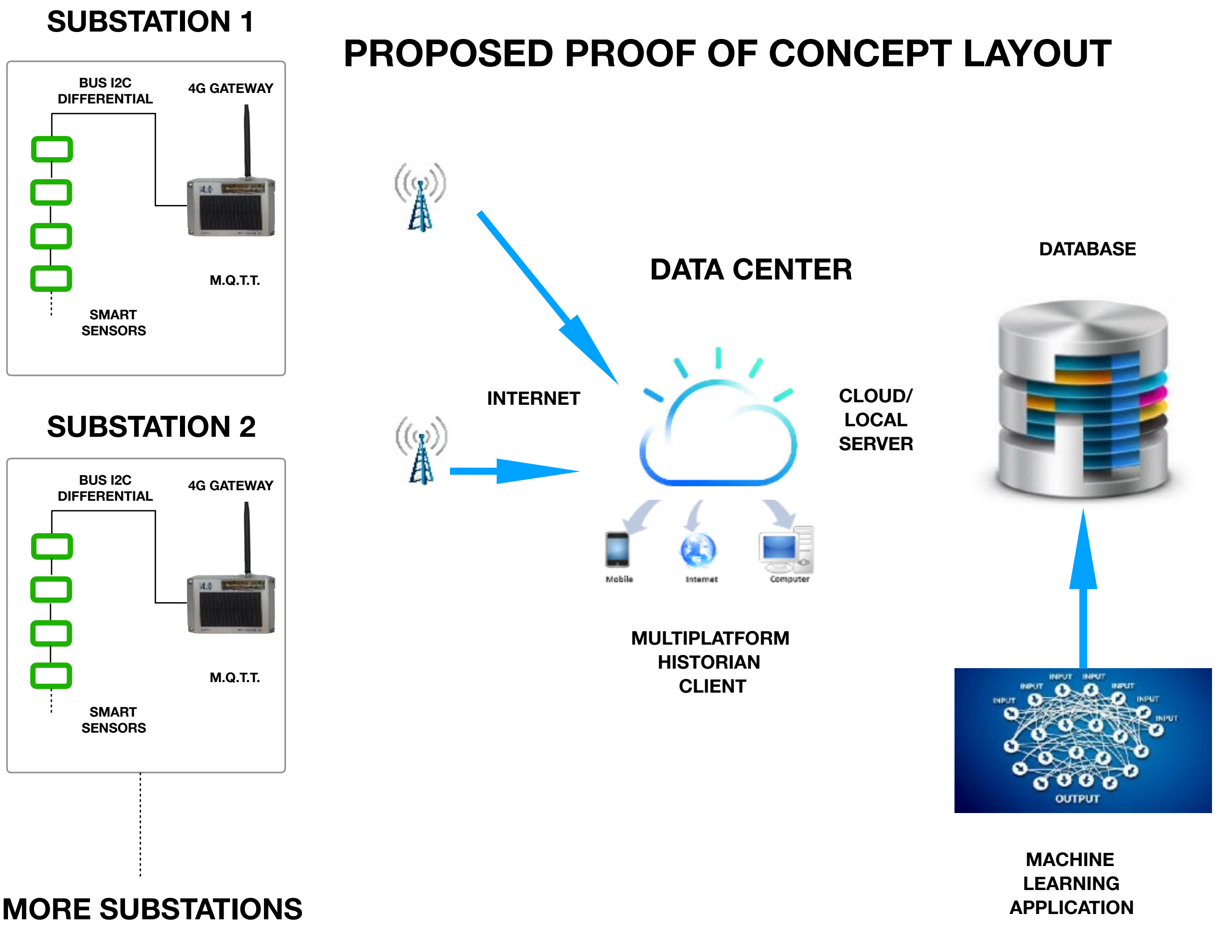
The concept makes a lot of sense when reading the definition of INDUSTRY 4.0: "create a virtual model of the factory from the point of view of its physical parameters. This virtual model, a digital twin, is a replica of what is happening in the factory "

Therefore, for this digital twin to be possible, multiple sensors must be installed in the asset to be monitored that read different physical variables and then the data from these sensors must be analyzed with a time synchronization method to detect common patterns of degradation of performance in the time and creation of alarms.

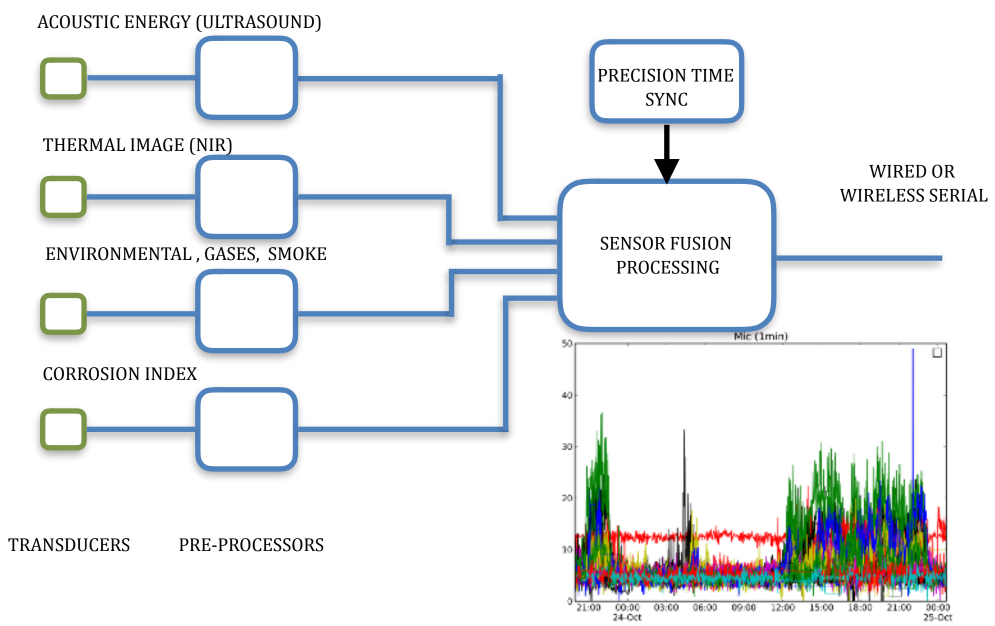
In a nutshell, the signals coming from the sensors must be pre-processed, minimizing the data payload, structured and organized as internal layers of a data transmission protocol and put into time synchronization with a precision time stamp.

Then, predictive models can be built based on data that has been properly organized, where unnecessary garbage/noise has been eliminated but maintaining underlying information of the environment that allows to helping the process of creating a predictive maintenance model that works.

PROPOSED PROOF OF CONCEPT LAYOUT



GENERAL SENSOR FUSION CONCEPT



SENSOR FUSION FEATURING TIME SYNCRONIZATION ALLOWS SUPERIOR FAILURE PREDICTION

PROPOSED SENSOR OPTIONS

This rough proposal is based on the installation of a set of ALTERIA smart sensors for the purpose of monitoring transformer substations.

FUNCTIONALITY OF THE PROPOSED SENSORS

1. PARTIAL DISCHARGE ULTRASOUND SENSOR UD 103

Measures the following variables

Acoustic energy

It is a broadband ultrasound acoustic energy sensor includes high-resolution spectrum pre-processing and a second Cartesian simplification algorithm patented by ALTERIA.

Measures the acoustic energy to detect the phenomena of partial discharge in the dielectric of the transformer.

It also measures the false contacts, the corona effect, and the ionization in the environment and the good condition of the electrical distribution boards.

Object of the sensor: This technology is considered the best predictive maintenance tool by real-time analysis of the condition of the equipment.

2. LOW-RESOLUTION THERMAL IMAGE SENSOR STM 108

Measures the following variable

Thermal image of objects with 768 Pixels
resolution and an opening of 60 °.

It is a NIR sensor (Near Infra Red) without contact, non-intrusive, last generation that measures the temperature of the objects (not the environment) is the same as shown (STM 102) but is multizonal, and therefore works as a thermal camera with a resolution of 32 x 24 pixels.

Its resolution is good enough to obtain a thermal image with a very precise indication of temperature in each pixel and in real time, with very low thermal inertia and without latency.

This transducer was developed for the military, its accuracy is one hundredth of a degree.It it low cost and ideal for predictive maintenance.

The purpose of this sensor is to obtain a thermal image of the transformers and it could also be used for the electrical panels of the center.

3. COMBINED ENVIRONMENTAL SENSOR MD 101

This is a multiple sensor that reads the following variables

Room temperature
Relative humidity RH%
Dew Point
Atmospheric pressure Hpa
VOC level: Compounds
volatile organic (solvents) PPM

The purpose of this sensor is to measure the most important environmental parameters both the interior and exterior substation in order to establish the environmental operating conditions to which the transformation center is subject.

4. FLOOD SENSOR FL 115

Measures the following variables

Waterflood

This is an electronic sensor that measures the presence of water by its conductivity. It has no moving parts, it does not get stuck or frozen, it does not rust, it does not contain mercury and it is completely watertight.

The purpose of this sensor is to prevent flooding of the transformation center

5. PRESENCE SENSOR / MOVEMENT / DOOR OPENING PI 116

Measures the following variables

Movement
Human presence

This is a sensor based on an infrared PIR transducer with a pre-process that avoids false triggering

The purpose of this sensor is to inform of human presence and movements in the interior.

6. CM 117 DIGITAL PHOTOGRAPHY CAMERA

Measures the following variables

Visual check of the interior substation condition with real resolution after compression > 1 Mpixel

CM 117 is a CMOS color camera and a pre-processing unit that digitizes and compresses the image, minimizing the data payload in the output and in a format compatible with MQTT.

Featuring a fisheye lens with an angle of 160º. The objective is interchangeable to obtain different viewing angles.

Includes a flash unit with high brightness LEDs in order to obtain proper exposure.

Triggers from the PIR PI 116 sensor.

5. GAS SENSOR SXG 15X

Measures the following variables

Specific gas X (such as Ozone) in PPM

This is a specific sensor for the measurement of a single gas of interest to be determined by ENEL.

The purpose of this sensor is to ensure the safety at work of the maintenance personnel of ENEL and its subcontractors.

8. CORROSION SENSOR SCR 109

Measures the following variables

Relative index of corrosion%

Measures a relative index of corrosion that occurs due to the following phenomena

Saline environment / corrosive gases, Continuous humidity, Leakage currents

The purpose of the sensor is to predict exposure to corrosion.

9. SUSPENDED PARTICLES SENSOR IN THE AIR (SMOKE)

Measure the following variable:

Relative index of particles in air%
Measures a relative index of air pollution by suspended particles.

This is more than a simple smoke or smoke detector. it works by the reflection index of a Laser diode beam over the air.

The object of the sensor is to measure the presence of solid particles produced by combustion (smoke, dust and ash)

10. CURRENT/ VOLTAGE SENSORS

This rough proposal assumes Voltage/current sensors are already in place at the substation.

However if that is not the case or they are not precise or fast enough to deliver good data, we can fit our own current/voltage sensors.

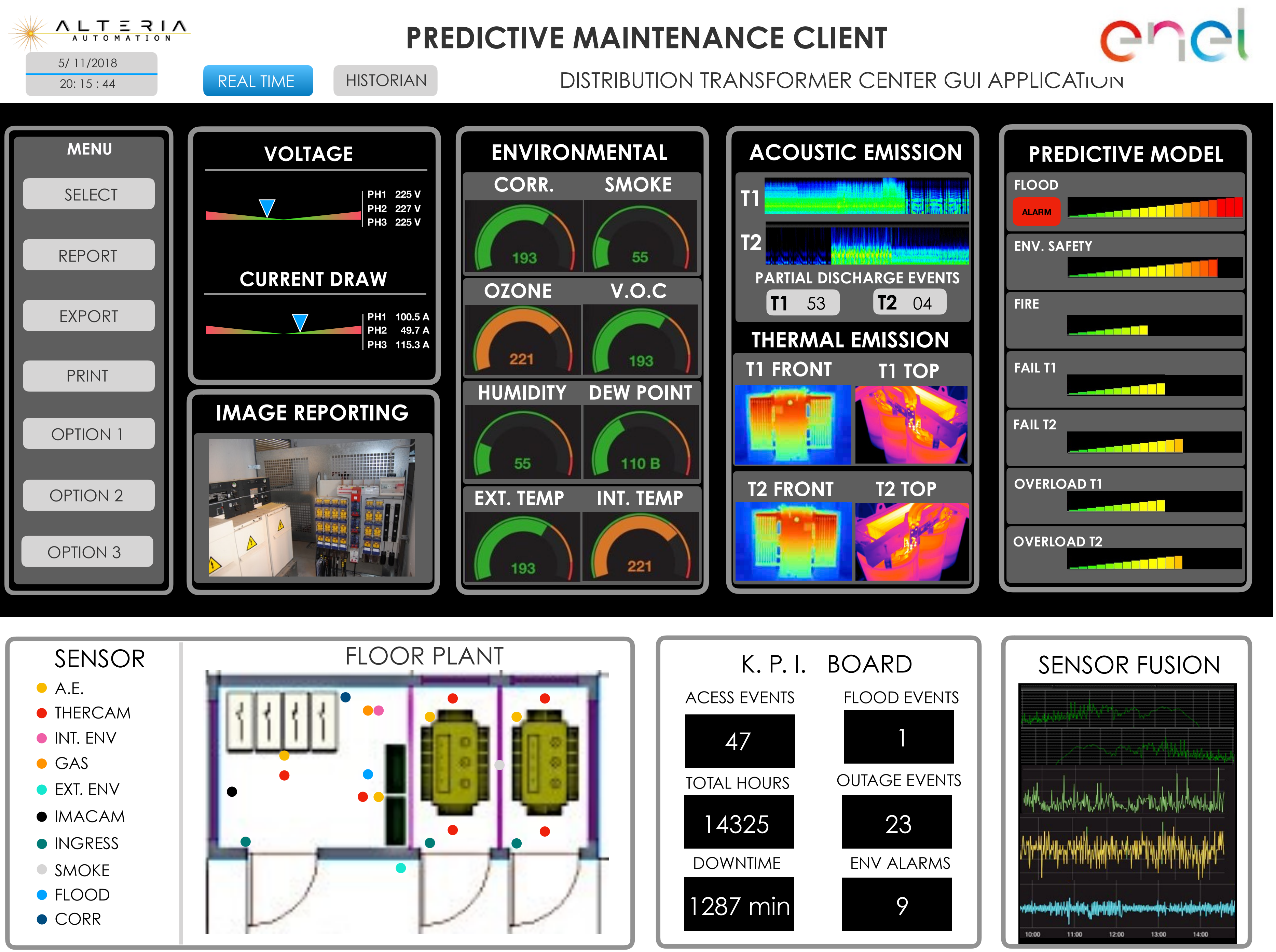
In the GUI proposed current and voltage is displayed on the upper left side of the screen and must be anlayzed in a sensor fusion mode with the other sensor reading in order to get as much information as possible to create prediction models.

SUMMARY SENSORS

Below is a summary table with all the physical variables measured and the units delivered.

These can be complemented with others for which one can leave several slots for future expansion in the communication protocol between the sensors and the Gateway.

	MEASURED VARIABLE	**UNIT**
1	Acoustic Energy (ultrasound)	VAR
2	Thermal image 768 Pixels resolution 60º aperture	º C/Px
3	Indoor Temperature	º C
4	Exterior Temperature	º C
5	Relative humidity	RH%
6	Dew Point	º C
7	Atmosferic Pressure	Hpa
8	VOC: Volatile Organic Compounds (Solvents)	PPM
9	Ozone Gas	PPM
10	Water Flood	ALARM
11	Movement and human presence	ALARM
12	Indoor Visual check	JPG
13	Suspended Particles in air (smoke)	%
14	Corrosion relative index	%
15	Current/Voltage	V/Amp


ALTERIA AUTOMATION
5/ 11/2018
20: 15 : 44
REAL TIME
HISTORIAN
PREDICTIVE MAINTENANCE CLIENT
DISTRIBUTION TRANSFORMER CENTER GUI APPLICATION
enel
MENU
SELECT
REPORT
EXPORT
PRINT
OPTION 1
OPTION 2
OPTION 3
VOLTAGE
PH1 225 V
PH2 227 V
PH3 225 V
CURRENT DRAW
PH1 100.5 A
PH2 49.7 A
PH3 115.3 A
IMAGE REPORTING
ENVIRONMENTAL
CORR.
193
SMOKE
55
OZONE
221
V.O.C
193
HUMIDITY
55
DEW POINT
110 B
EXT. TEMP
193
INT. TEMP
221
ACOUSTIC EMISSION
T1
T2
PARTIAL DISCHARGE EVENTS
T1 53
T2 04
THERMAL EMISSION
T1 FRONT
T1 TOP
T2 FRONT
T2 TOP
PREDICTIVE MODEL
FLOOD
ALARM
ENV. SAFETY
FIRE
FAIL T1
FAIL T2
OVERLOAD T1
OVERLOAD T2
SENSOR
A.E.
THERCAM
INT. ENV
GAS
EXT. ENV
IMACAM
INGRESS
SMOKE
FLOOD
CORR
FLOOR PLANT
K. P. I. BOARD
ACESS EVENTS
47
FLOOD EVENTS
1
TOTAL HOURS
14325
OUTAGE EVENTS
23
DOWNTIME
1287 min
ENV ALARMS
9
SENSOR FUSION
10:00
11:00
12:00
13:00
14:00

GRAPHIC USER INTERFACE PROPOSAL CONCEPT

The system is designed to be multiplatform in both hardware and operating system and can be viewed from any device connected to the internet, accessing the database. A GUI rough proposal is offered in the image on page 16 before.

It serves as a study and reference for future discussion with ENEL only. The actual GUI may not be the same and may be modified by ALTERIA during development. This GUI facilitates at a glance monitoring of the substations in real time, the data will be stored in the database and then be used for further studies.

Stored data is then analyzed with a data application with a Machine Learning plug-in in order to train a prediction model.

This part of the project is not described at this time, but ALTERIA might cooperate with its expertise in the creation of an advanced Predictive Maintenance model.

WIRELESS OPTIONS: CURRENT TECHNOLOGY DISCUSSION

ALTERIA has a vast experience in the use of wireless transceivers. There is such a thing like a best wireless solution for Industrail IoT. There are many options with broadband and narrow technologies using different types of modulation. Each one has a better application according to the project.

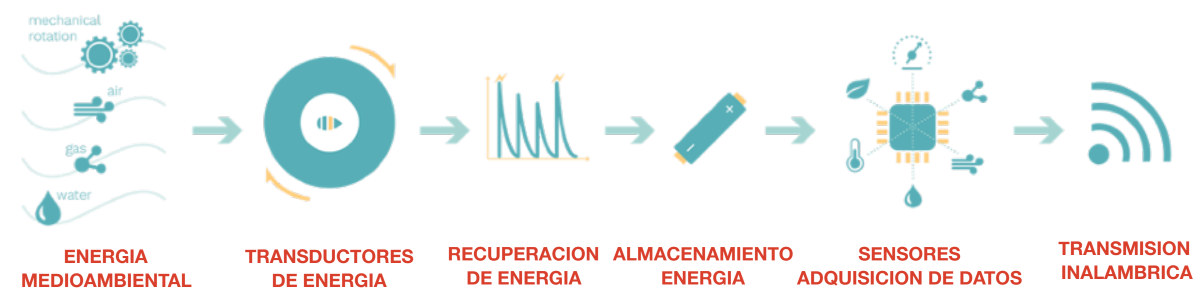
To interconnect these sensors there is a new technology that seems appropiate launched in September 2018 called Bluetooth Mesh 5.0

This system is very different of the original Bluetooth and is specifically designed for industrial IoT. This technology is still in a testing phase.

Bluetooth Mesh 5.0 It is a good compromise between medium bandwidth and medium range that can be very interesting for this application. We do not recommend the use of WIFi or Bluetooth 4.2 due to its lack of reliability in industrial environments.

The problem to include the project with wireless sensors is the power supply. In our wired system the power is provided by two cables at the data bus. We use 5 Volts DC in our system. Energy harvesting is being presented as an option to replace battey operated sensors lately.

MODELO DE SENSORES SIN ALIMENTACION



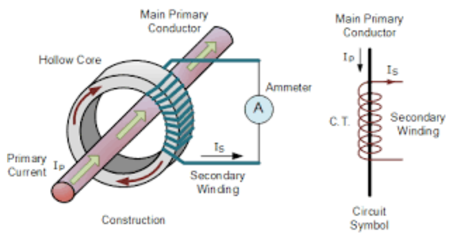
We discourage the option of using industrial sensor systems with a low power battery (such as button batteries) These sensors don’t work in real time.

In these systems to extend the life of the battery the sensor processor wakes up the circuits, a measurement sample of the transducer is acquired and after transmitting the data the processor puts the circuits in a state of hibernation or "deep sleep" to avoid consuming the battery.

This type of systems does not provide useful information to make predictive models and also the battery life announced by many manufacturers (up to ten years) is extremely overrated.

Changing wasted batteries in substations doesn’t make any sense.

In the case of an indoor application, such as a transformer substation the best option seems to obtain energy with current transformers that can be installed on the cables in non-intrusive mode, without galvanic connection to the transformer wiring.



The alternating current (Primary of a wire) would induce a certain voltage on a secondary of about 3000 to 5000 turns that can be managed with an energy harvesting electronic unit. This approach is non-intrusive and might work for wireless option sensors with the scope of this project.

During the development of the project, new options may arise that improve this concept. Our proposal is to verify the proof of concept with a hard-wired equipment but study the possibilities of a wireless system inside the substation monitoring equipment.

External connectivity can be performed by either ethernet TCP/IP) wired Internet or 4G wireless data-only modems.

REAL TIME MONITORING

The offered system monitors in real time, does not perform samples in time intervals like other systems, reads and forwards the data 24/7.

The ALTERIA Patent applied for pre-process system is non-destructive and forwards data to make predictive models including the underlying information of the measurements.

This feature contrasts with many other systems in the market that perform only one sample, for example, every minute or every hour. For example, our Partial Discharge ultrasound system obtains 192.000 samples per second in real time.

SUMMARY

In the first part of this white paper, examples of efficient detection and recognition technologies for partial discharge (PD) sources using acoustic emission (AE) method with advanced ultrasound signal processing were presented.

Pre-processing frequency translation algorithm choice

High-resolution Multiple Signal Classification algorithm, our best choice for the frequency analysis, effectively detects in registered AE signal (usually sunk in noise) frequency components corresponding to partial discharges.

Partial Discharge Characterization

On the basis of selected digital signal processing methods and complex model research, a database with PD type classification with different Patterns was shown in order to prepare Predictive Maintenace models.

Partial Discharge Pattern Fingerprinting

An important conclusion of this characterization and modeling research is that each of the investigated insulation defects (PD sources) generates repeatable, characteristic and unique acoustic emission signals that can be analyzed as a fingerprint.

WideBand Vs. Narrowband transducer options.

The increase of different PD pattern detection and recognition efficiency can be improved by simultaneous application of narrow (20÷100 kHz) and wideband (100÷900 kHz) ultrasound sensors.

On the second part of this paper, a proposal for a proof of concept combines Acoustic emission sensors (ultrasound) for partial discharge analysis with NIR (Thermal image sensors) for thermal stress analysis, with other -more common-sensors in order to provide a Sensor Fusion analysis.

This Sensor Fusion approach features two benefits.

- On one side, sensors like thermal imaging provide a perfect complement to Acoustic Energy sensing.

- Other capabilities such as taking and forwarding an image, environmental monitoring etc provide a complete assessment of the substation condition in real time that might improve and lower the cost of substation maintenance.

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