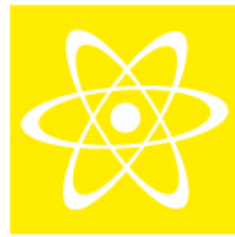
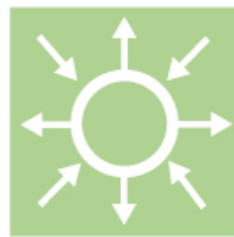


# Reliability study of monitoring systems for power transformers in the smart grid

Elforsk rapport 31181



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March 2014



**ELFORSK**

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## Preface

*The project is specifies appropriate methods to ensure the quality of measurement procedures and measuring equipment used for condition monitoring of power transformers. The study focuses on on-line monitoring systems for:*

- *Temperature*
- *Partial discharge (PD)*
- *Sound and vibration*

*The work has carried out within SP Swedish National Research Institute and financed jointly by Elforsk and SP.*

*This document is intended to be useful for scientists, system designers and engineers who develop new monitoring equipment, technical personnel responsible for selecting and buying the monitoring equipment and calibration authorities who are responsible for validation of this kind of measuring equipment.*

## Sammanfattning

Krafttransformatorer i allmänhet anses vara en av de viktigaste komponenterna i ett elkraftsystem. Detta beror på de stora investeringarna i krafttransformatorer och betydelsen av transformatorernas funktion för att uppnå en hög tillförlitlighet hos systemet som helhet. Avbrott på grund av oväntade fel i transformatorerna kan i vissa fall bli katastrofala. Tillståndsövervakning av krafttransformatorer har därför varit föremål för betydande forskning och utveckling under flera år. Även om det nu finns övervakningssystem på marknaden som framgångsrikt kan upptäcka och diagnostisera problem så kvarstår tyvärr grundproblemet. Sättet att kvalitetssäkra mätningar är visserligen standardiserat, bl a genom standarden ISO 10012: 2003 Ledningssystem för mätning - Krav på mätprocesser och mätutrustning men dessa krav tillämpas inte på övervakningssystem på krafttransformatorer. Cigré WG A2.27 konstaterar nämligen att övervakningssystemen har kortare livslängd och lägre tillförlitlighet än anläggningen som de är satta att övervaka. Incitamenten att installera ett övervakningssystem på en ny transformator saknas därmed eftersom dess mätningar sannolikt kommer att vara opålitliga eller ha slutat fungera när transformatorn blivit gammal nog för att behöva övervakas.

Projektet anger lämpliga metoder för att kvalitetssäkra mätprocesser och mätutrustning som används för tillståndsövervakning av krafttransformatorer, då specifikt ett urval av on-line övervakningssystem för:

- temperatur
- partiella urladdningar (PD)
- ljud och vibration

Metoderna som tas fram ska i efterföljande projekt kunna vidareutvecklas för att även täcka kvalitetssäkring av andra typer av mätprocesser och mätutrustning för underhållsplanering.

## Summary

Power transformers are generally considered as one of the most important components in a power system. This is due to the large investments in power transformers and importance of the transformer's functionality to achieve high reliability for the system as a whole. Interruptions due to unexpected failures in transformers can be disastrous. Condition monitoring of power transformers has been the subject of considerable research and development for several years. Although there are now monitoring systems on the market that can successfully detect and diagnose problems, there is a remaining fundamental problem. The way to assure the quality of measurements is indeed standardized, partly through ISO 10012: 2003 management system for measurement - *Requirements for measurement processes and measuring equipment*, but these requirements are not applied to monitoring systems for power transformers. Cigré WG A2.27 finds that monitoring systems have a shorter lifespan and lower reliability than the facility they are monitoring. The incentive to install a monitoring system on a new transformer is thus reduced because its measurements are likely to be unreliable or it has stopped working when the transformer becomes old and has a serious need for monitoring.

The project suggests appropriate methods for quality assurance of measurement processes and measuring equipment used for condition monitoring of power transformers, specifically for selection of on-line monitoring systems for:

- Temperature
- Partial discharge (PD)
- Sound and vibration

The developed methods can be developed further in subsequent projects to cover the quality of other types of measurement processes and measuring equipment as part of maintenance planning activities.

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# 1 Introduction

## 1.1 Importance of condition monitoring of transformers

Maintenance of a transformer can be performed based on one of the following choices:

- Repair after failure: **Corrective Maintenance**
- Replace on planned time: **Time based maintenance**
- Repair before failure based on condition assessment: **Condition based maintenance**

Corrective maintenance is not a wise selection. Repair or replacement in short time after the failure asks for high price of the material and expert man-hour even after having access to the right resources directly after the failure. In addition, lack of the power at an unplanned time is not accepted by consumers. Time based or periodic maintenance has disadvantages of longer outage time and higher cost of resources used for maintenance, because of the obligation of changing parts before reaching their real end of the life time. The most logical selection, therefore, is the maintenance based on condition assessment.

Figure 1 demonstrates how the high voltage system can benefit from protective relays or monitoring systems. Although protection relays are very important to prevent spreading out the damages on the system after detection of failure, monitoring systems can detect potential failure causes and support preventive actions to avoid that incipient failures develop further. Monitoring equipment helps to achieve a more reliable system.

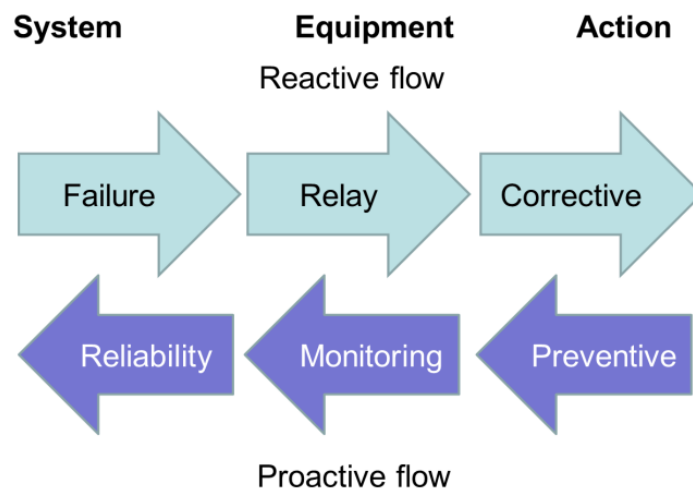


Figure 1. Selectable flow diagram for asset management strategy

The need for wider use of reliable condition monitoring systems is accentuated by:

- Recent technological progress in the field of condition monitoring of high voltage equipment,
- needs for being smarter with introduction of smart grids,
- higher reliability expectation from the generation and the supply networks,
- older transformers in the grid,
- more limits on financial supports for maintenance of electrical network elements
- and finally having more and more private sector role players in generation and transmission of electrical energy.

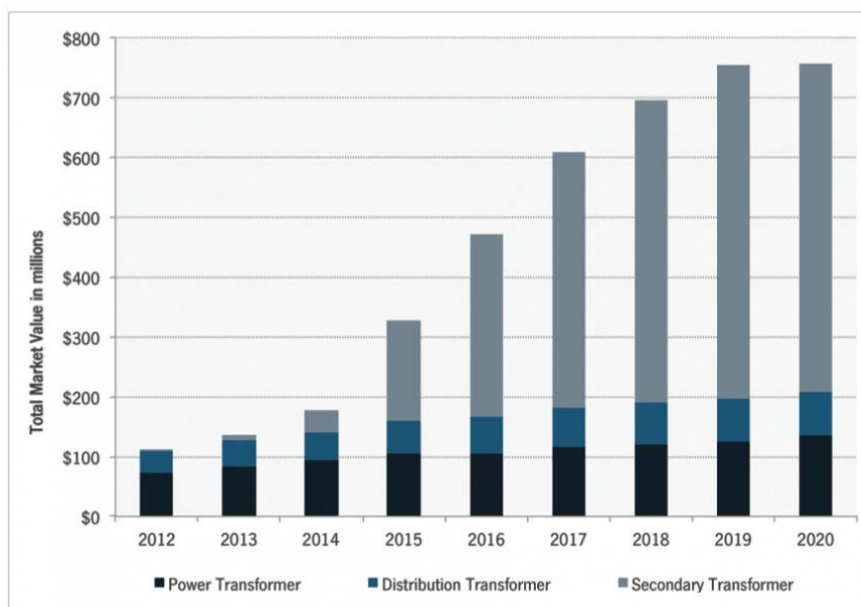
In addition many countries started to push the obligation for monitoring the condition of the electrical system. Network operator needed to demonstrate that the high voltage assets are in safe operating condition [18].

A 150 pages report entitled “Transformer Monitoring Markets, 2013-2020” forecasts the annual market for transformer monitoring hardware in the U.S. [2].

According to Figure 2 taken from the report [2], the market will grow considerably from \$113 million in 2012 to more than \$755 million in 2020.

The report [2] is the most considerable report of its kind and offers technology-specific analysis for transformer monitors and sensors, dissolved-gas analysis (DGA) monitors and bushing and Partial Discharge systems among the other hardware and software used for monitoring of transformers.

**Transformer Monitoring Market by Transformer Class**

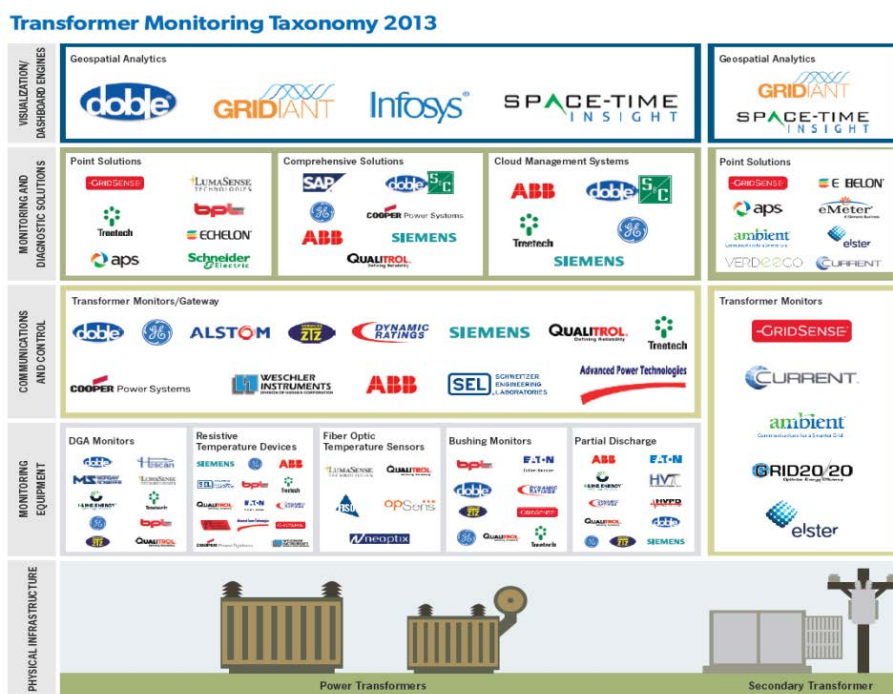


**Figure 2. Transformer monitoring equipment market growth from 2012 to 2020 [2]**

The report contains vendor analysis for many of the components of power, distribution and secondary transformers. Companies analyzed include:

- ABB
- Alstom Grid
- Ambient
- BPL Global
- Cooper Power Systems
- Doble Engineering
- Dynamic Ratings
- Echelon- Elster
- General Electric
- GRIDiant
- GridSense
- Grid 20/20
- Infosys
- LumaSense
- Morgan Schaffer
- Qualitrol
- S&C Electric
- Schneider Electric
- Schweitzer Engineering Laboratories
- Siemens
- Space-Time Insight
- Ventyx

Figure 3 demonstrates a summary of active producers of transformer monitoring equipment in USA categorized by monitored parameters.



SOURCE: GTM RESEARCH

Figure 3. Transformer monitoring taxonomy 2013 [2]

According to information published by Elforsk, as shown in Figure 4, the number of power transformers installed between 1967 and 1987 in Sweden was higher than 20 units per year which are now aged between 30 to 50 years [19]. This shows that the importance and the need for condition monitoring systems in Sweden will increase dramatically in the following years.

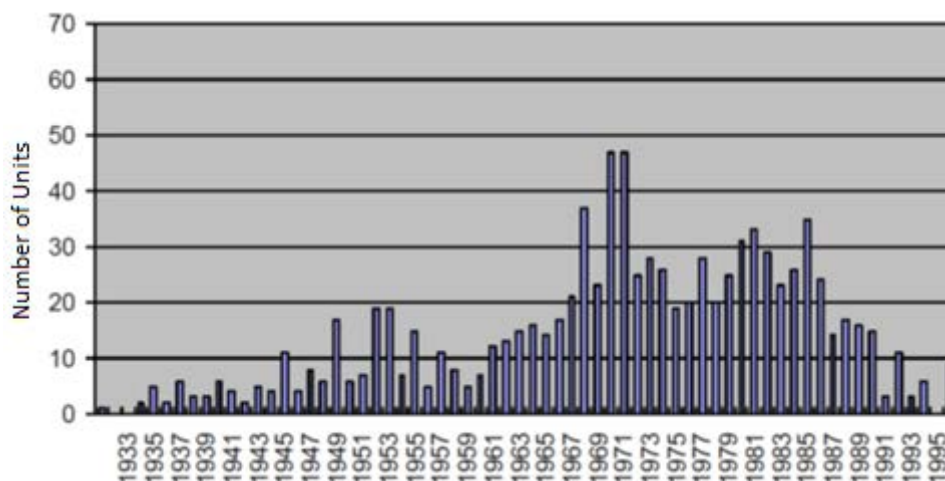


Figure 4. Power transformers installation rate for Sweden [19]

## 1.2 Reliability of Monitoring systems

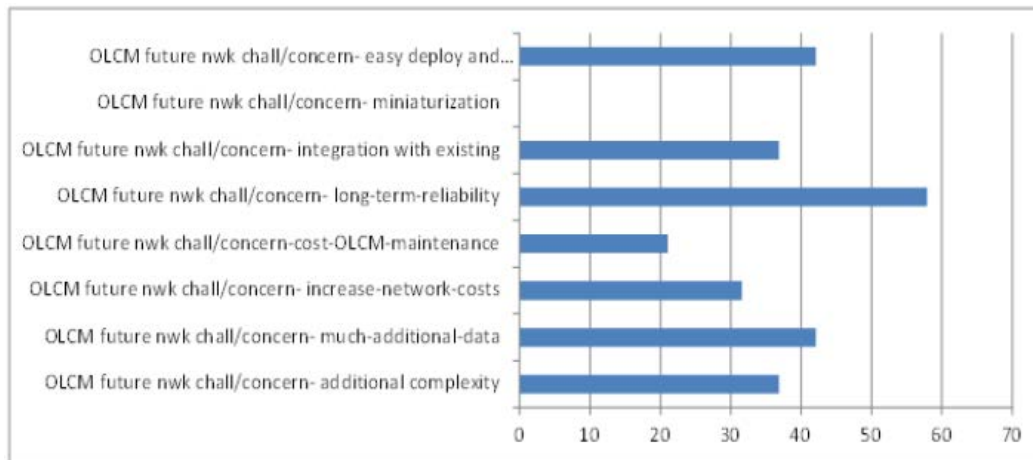
For the above mentioned interests, many players are going to step into the monitoring equipment market and that is the reason for many technical committees to be worried about the reliability and quality of the presented systems.

The number of working groups studying monitoring systems in Cigré was 2 before year 2000 and increased to 11 after year 2000 [15]. Cigré Working group A2.27 published the report 343:2008 titled *Recommendations for condition monitoring and condition assessment facilities for transformers* and the working group A2.44 established in 2010 works on *Transformer intelligent condition monitoring* and will release a report on standardization and reliability of transformer monitoring systems in 2014 [22].

Cigré Working group D1.17 published the report 420:2010 entitled *Generic Guidelines for life time condition assessment of HV assets and related knowledge results*. This guideline describes how to select suitable condition assessment tools and how to handle and qualify measurements, validate measured data and do statistical analysis and explains methods for interpretations of results and suitable data mining techniques.

IEEE Substations committee and Cigré SC B3 had two joint roundtables future developments, challenges and chances regarding high voltage equipment online monitoring systems [20].

The view of experts attended the meeting regarding challenges and concerns in the future of monitoring systems is presented in Figure 5 and shows that the highest concern is related to long term reliability of these devices [20].



**Figure 5. Future challenges or concerns regarding online condition monitoring systems [20]**

Reliability of transformer monitoring systems can be increased by attention to different technical aspects of the system:

- providing suitable and easily available interfaces on transformer for installation of different types of monitoring systems at different times of life of transformer, when the transformer is manufactured; This can be done based on information and guidance presented in Cigré Working group A2.27 published the report 343: 2008 - *Recommendations for condition monitoring and condition assessment facilities for transformers*,
- increasing reliability of data acquisition, data communication and data storage systems using standardized substations communication protocols; This can be done based on the in progress work of Cigré working group A2.44 in interaction with IEC groups, like the one preparing the IEC 61850 for condition monitoring diagnosis and analysis (IEC 61850-90-3), and also Cigré WG B3.12 – *Obtaining value from on-line substation Condition Monitoring*,
- increasing reliability of extracted analyzed monitoring data results using artificial intelligence technics and with correlating the results of several monitoring systems; for example based on information presented in Chapter 10, *Artificial-intelligence techniques for incipient fault diagnosis and condition assessment* [16] and generic guidelines introduced in reference [18],
- and finally increasing quality of measurement of measuring systems used in the monitoring equipment; This can be done by application of measurement quality assurance criteria presented in this report, which is based on ISO 10012, *Measurement management systems-Requirements for measurement processes and measuring equipment*.

According to European metrology road map shown in Figure 6, improved tools for grid monitoring and control are amongst the targets for the Technical Committee for Electricity and Magnetism [6].

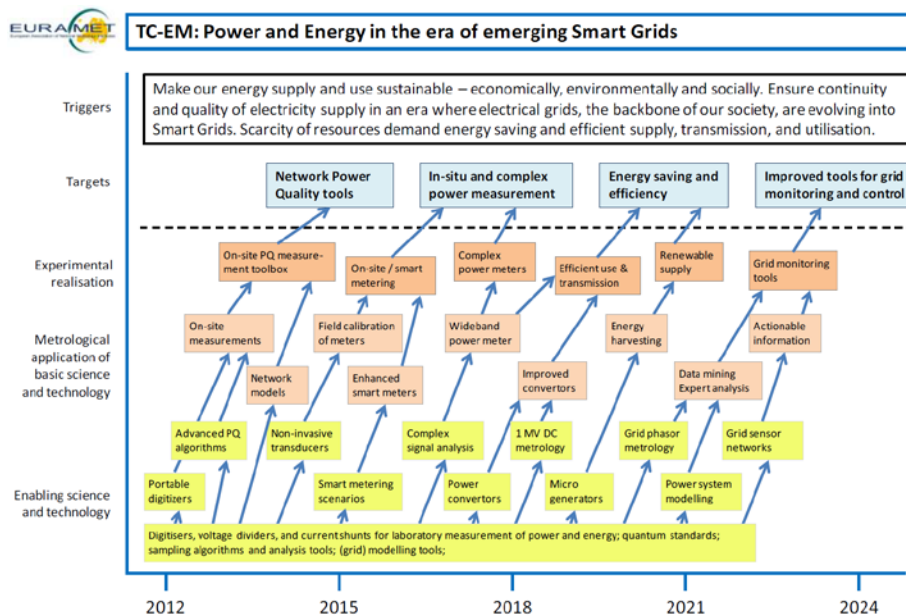


Figure 6. European metrology roadmap [6]

### 1.3 Project steps

The project consists of the following steps:

- Literature study and contacts with transformer manufacturers and representatives from Cigré WG A2.27
- Selection and study of specifications and data sheets for representative monitoring systems from leading manufacturers, three systems per temperature, three per PD and three per sound and vibration
- Evaluation of the extent to which selected surveillance systems described above can be expected to meet the relevant requirements of ISO 10012: 2003, including measures that might be taken by the transformer owner to maintain the monitoring system reliability over time (periodic inspection, maintenance, personnel training, etc.)
- Development of recommendations to improve the reliability of current monitoring systems
- Development of recommendations for possible future work

## 2 Literature study and selection of representative transformer monitoring systems

More than 100 technical documents have been reviewed with the aim to locate any standards that can apply to performance of a transformer monitoring equipment.

The result of study is the list of standards that can be introduced in manufacturer's specification sheets of the monitoring equipment and it is presented in Table 4 Appendix A.

Technical documents from Cigré that contain useful information regarding monitoring equipment are presented in Table 5 Appendix A.

67 products from several well-known producers, purposed to be a transformer monitoring system are studied, 20 products of which were related to the targeted temperature, PD and sound & vibration.

Table 6 Appendix A presents the list of transformer partial discharge, temperature and sound & vibration monitoring systems which are mostly known and in-use in the market.

From 20 selected products, 8 were for Temperature, 7 for PD and 5 for sound & vibration.

3 products for Temperature, 3 for PD and 3 for sound & vibration which had the most complete specification were selected. Manufacturer's technical specifications are presented in Appendix B.

Table 7 Appendix A presents the equipment selected for the study in this project. These equipment have the most complete specifications that can be used for evaluation of their measurement quality and reliability of the device.

In the following is a selection of the data presented in selected equipment specifications regarding their reliability and measurement quality. Some claims regarding their reliability and quality are supported with the claims of compatibility to international standards and some other have no support.

## 2.1 Temperature

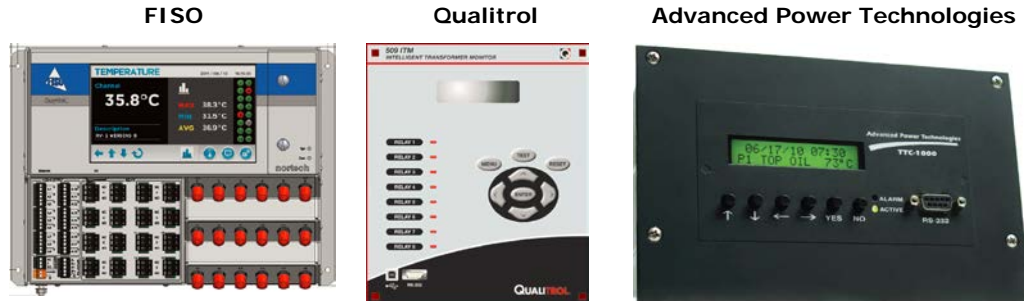


Table 1 Appendix A presents the summary of specifications of the selected temperature monitoring equipment.

The most complete technical specification is given by **Fiso** Company **Nortech EasyGrid** system. The system uses optical fibers to measure the temperature directly from any point inside the transformer tank. Using “temperature dependent band gap shift of the GaAs”, it claims that “the system will not drift nor require any recalibration for the life of the transformer.” Temperature measurement accuracy is  $\pm 1^\circ\text{C}$ . Its light source life length is equal to transformer’s. Environmental condition like temperature, humidity, shock and vibration are considered in its design. The system is completely immune to EMI/RFI having compatibility based on EN 61000-4 standard series.

The second in the row is **Qualitrol** Company **509 DW** system. This system also uses optical fibers to measure the temperature directly from any point inside transformer tank. It uses also drift-free GaAs technology with the accuracy of  $\pm 1^\circ\text{C}$ . It claims that its “light source has a MTBF of 300 years.” Like the first system, although the same environmental conditions are also mentioned here, no standard introduced here as a proof of compatibility with the claimed conditions. The system’s EMC immunity is certified based on IEC 61000-6-2 which defines EMC immunity requirements for industrial environments (including all related EN 61000-4 testing standard series).

The third is **Advanced power technologies** Company **TTC-1000** system. The system uses resistance temperature detectors (RTD) as temperature sensor for measuring top oil temperature. The system claims that no calibration required ever for it! It has the average error of  $\pm 1^\circ\text{C}$  over entire range and absolute error of  $\pm 1.5^\circ\text{C}$  at any temperature. The system’s EMI immunity is certified based on ANSI C37.90.2 which only demonstrates withstand capability of its relay systems to radiated electromagnetic interference from transceivers.

## 2.2 Partial discharge



Table 2 Appendix A presents the summary of specifications of the selected Partial discharge monitoring equipment.

The most complete Technical specification is given by **Qualitrol** Company **609 PDM**. It uses UHF technology for monitoring Partial discharge and claims that its sensitivity is higher than other types of PD activity monitoring systems like DGA (Dissolved Gas Analysis), acoustic or even conventional (direct electrical) measurement methods. The producer also claims that the system has excellent interference immunity in comparison with conventional or acoustic measuring systems. The system can use all types of UHF pick up antennas including

- Internal (installed during transformer manufacturing)
- Window (A dielectric window is installed on tank body during transformer manufacturing and lets UHF waves from inside the tank pass outside through it.)
- Drain valve (an antenna is projected inside the tank through one of the oil draining valves).

The system uses an optical converter unit to filter noise and extract and send UHF signal characteristics to the system analyzing unit. An additional optical fiber cable is installed to be used for self-test procedure of each channel. The converter unit is totally immune to high voltage transients.

The system claims compatibility with the standards introduced in Table 2 regarding enclosure rating, seismic, Temperature and humidity, vibration and EMC. In its specification no standard related to partial discharge measuring systems requirements is mentioned.

The second in the row is **Doble Lemke** Company **PD Smart electrical** system. Although the Doble Lemke PD-Guard/UHF system is solely designed for on-line monitoring of partial discharges, because of having more complete specification, here the PD Smart system is considered. This system can be used for periodic on-line and off-line PD testing for both on-site and in-house applications. In its specification only the standard related to partial discharge measuring systems requirements is mentioned and no standard related to any of environmental requirements. The minimum detectable apparent charge claimed to be  $<0.1\text{pC}$ . Operating temperature is 0 to  $40^{\circ}\text{C}$  which means that it needs extra housing equipment to make the operation of the system possible under temperatures below  $0^{\circ}\text{C}$ . No information regarding environmental conditions and immunity characteristics of LDM-6 PD measuring adaptors which are installed on transformer tank, is not presented in the related specifications.

The third is **Power Diagnostix Systems** Company **SPECmonitor** system. The system is based on narrow band measurements so it claims to have better signal to noise ratio. The device can be supplied with acoustic sensors (AS), UHF sensors or standard bushing test tap coupling units. Operation temperature for acquisition unit is 10 to  $40^{\circ}\text{C}$  non-condensing which means it should be operated inside an additional cabinet or inside the control room. In its specification no standard related to partial discharge measuring systems requirements and no standard related to any of environmental requirements is mentioned. Minimum detectable apparent charge is  $< 2\text{ pC}$  and its input sensitivity is  $<400\mu\text{V}$ .

## 2.3 Sound & Vibration



Table 3 Appendix A introduces the main suppliers of vibration measuring systems that are used by these transformer monitoring system providers. It seems that the proposed systems use general purpose, technically well-established, vibration measurement systems and do not see necessity for introduction of any international standards regarding measurement quality requirements, environmental conditions or immunity.

The most complete Technical specification is given by **Mistras** Company **Sensor Highway II**. The system is designed for unattended use. It claims to have a rugged outdoor case for extreme weather operation condition. The system can be supplied with different types of AE sensors, ICP accelerometers or with sensors having current or voltage outputs. Different types of data communication and remote control interfaces offers capability of remote data acquisition and analysis for the system. A typical sensor which is offered to be installed on transformer tank for monitoring purpose is PK15I Medium frequency integral preamplifier resonant sensor. It has the peak sensitivity of  $-36\text{dB}$  (Ref  $\text{V}/\mu\text{bar}$ ), and can operate in temperature range of  $-35$  to  $80^\circ\text{C}$  under a shock limit of  $500\text{g}$  and benefiting from completely enclosed crystal has RFI/EMI immunity. This sensor together with the cable will be the parts which have to operate under harsh environmental condition.

The second in the row is the system configured by **Vallen systeme** Company which can be used for partial discharge monitoring or for vibration monitoring of power transformers. This system includes a chassis, ASIP-2 AE signal processor boards, several sensors and an analysis software. Its sensors are mostly equipped with a calibration–pulse-through feature which increases reliability and by checking couplings, cables and preamplifier functions simultaneously, can be used for metrological confirmation purpose. Vallen claims that their extremely robust preamplifiers can ensure reliable operation under tough operation condition. Its dual channel AE signal processor, ASIP-2 has a high sensitivity and lowest possible system noise using “filtering the ADC data stream digitally”. Processors front panel BNC connectors are hardened for better on-site performance. AMSY-6 Chassis has a rugged design proper for field use.

The third is **Dimrus** Company **Vesta** system. The proposed system uses Vibro Center Company’s Diana-2M, ViAna-1 or Vibro Vision-2 as vibration measurement systems. The Vesta system can be used for monitoring of core and windings clamping systems and transformer cooling system oil pumps bearings and rotor and electric motor condition.

## 2.4 Selected systems summary

Table 8 Appendix A presents the summary of standards which is introduced in the specification of the selected monitoring equipment and is related to their measurement quality.

## 3 Principle of operation of transformer monitoring systems and quality of measurement

### 3.1 Temperature

Oil temperature is normally sensed from a thermometer pocket according to EN 50216-4. A temperature measuring sensor is placed inside a metal pocket installed on and welded to the transformer tank cover plate and filled with transformer oil. Temperature range used for oil temperature measurements is -40 to 120 °C. Oil temperature measurements can be affected by local environmental condition or by heating of tank body resulted from local eddy current. The temperature measured in thermometer pocket may be several degrees below the actual temperature of the oil under the tank cover [17].

Other points for sampling and measuring oil temperatures can be the cooler inlet and outlet temperatures to monitor the efficiency of cooler and a point at the top of the tap changer oil compartment. Cooling medium (air or water) temperature at input and the output to the transformer cooler can also be monitored [17].

Winding hot spot temperature monitoring can be performed by two different methods: a method based on top oil temperature and considering transformer electrical current data, or direct measurement using optical fiber technique. In the first method a heater warms up the oil inside the pocket on the top of the transformer with a heat produced by a resistive heater supplied with a current proportional to winding temperature. A temperature sensor measures the oil pocket temperature (heated up simultaneously and directly by oil and indirectly as a reflection of winding hot spot temperature by winding current).

Although optical sensors can provide useful information, the optical sensors should be fitted during transformer manufacturing process when the active part is accessible [17].

The calibration of the system which directly measures the temperature of a point on the winding is impossible using the conventional methods which are based on comparison with a reference measuring system or measurement of a known reference temperature.

BS EN 12830:1999, *Temperature recorders for the transport, storage and distribution of frozen food, Tests, performance and suitability* and BS EN 1434-1:2007, *Heat meters, General requirements* together with BS EN 1434-4:2007, *Heat meters, Pattern approval tests* are samples of standards which express requirements regarding temperature monitoring systems quality assurance.

In these standards items like general conditions for tests, effects of influencing environmental conditions on equipment, metrological characteristics, environmental classification, operation conditions and tests and measurements are presented.

Figure 7 presents a sample test program regarding quality assurance of a heat meter and its sub-assemblies.

Unfortunately there is no standard specially tailored for transformer temperature monitoring systems, but as it can be observed in Table 4 and Table 8, general environmental testing standards are applicable to representative monitoring equipment. The reason for having a

standard for each above mentioned temperature monitoring systems is that they are widely used by public during their daily life.

| Test   | Sub-clause | Exposure                                      | Temperature sensor pair | Flow sensor | Calculating device | Complete meter | Sample no. |
|--|------------|---|-------------------------|-------------|--------------------|----------------|------------|
|  |            | <b>INFLUENCE FACTORS</b>                      |                         |             |                    |                |            |
| MPE  | 6.4        | Performance test                              | X                       | X           | X                  | X              | 2          |
| MPE  | 6.5        | Dry heat                                      |                         | X(a)        | X                  | X              | 2          |
| MPE  | 6.6        | Cold  |                         | X(a)        | X                  | X              | 2          |
| MPE  | 6.7        | Static deviations in supply voltage           |                         | X(a)        | X                  | X              | 2          |
|  |            | <b>DISTURBANCES</b>                           |                         |             |                    |                |            |
| NSFa   | 6.8        | Durability                                    | X                       | X           |                    | X              | 4          |
| NSFd   | 6.9        | Damp heat, cyclic                             |                         | X(a)        | X                  | X              | 1          |
| NSFd   | 6.10       | Short time reduction in supply voltage        |                         | X(a)        | X                  | X              | 3          |
| NSFa   | 6.11       | Electrical transients                         |                         | X(a)(b)     | X(b)               | X              | 3          |
| NSFd   | 6.12       | Electromagnetic field                         |                         | X(a)(b)     | X(b)               | X              | 3          |
| NSFd   | 6.13       | Electromagnetic field - digital radio equipm. |                         | X(a)(b)     | X(b)               | X              | 3          |
| NSFd   | 6.14       | Radio frequency, amplitude modulated          |                         | X(a)(b)     | X(b)               | X              | 3          |
| NSFa   | 6.15       | Electrostatic discharge                       |                         | X(a)        | X                  | X              | 3          |
| NSFd   | 6.16       | Static magnetic field                         |                         | X           | X                  | X              | 3          |
| NSFd   | 6.17       | Electromagnetic field at mains frequency      |                         | X(a)        | X                  | X              | 3          |
| NSFa   | 6.18       | Internal pressure                             |                         | X           |                    | X              | 1          |
|  | 6.19       | Pressure loss                                 |                         | X           |                    | X              | 1          |
|  | 6.20       | Electromagnetic emission                      |                         | X(a)        | X(b)               | X              | 3          |
|  | 6.21       | 24 hrs interruption in supply voltage         |                         |             | X                  | X              | 3          |
| NSFd   | 6.22       | Flow disturbances                             |                         | X           |                    | X              | 1          |
| MPE - Maximum permissible error according to Clause 9 of EN 1434-1:2007<br>NSFd - No significant fault shall occur during the test<br>NSFa - No significant fault shall occur after the test<br>X - Test to be performed<br>a - Only for flow sensors with electronic devices<br>b - This test shall be done with connected cables |            |   |                         |             |                    |                |            |

Figure 7. Test program for heat meters and their sub-assemblies [4]

Use of optical fiber for direct monitoring of winding temperature becomes popular. They can replace older systems which simulate winding temperature based on measurement of winding current. Producers of direct winding temperature monitoring system claim that their system life time is longer than a power transformer life. This should be verified. There is a long way to convince transformer operators to replace the old system with this new one but they started to place the sensors in the windings when they order new transformers to manufacturers.

Reliability and quality of measurement of old and new systems should be evaluated separately and based on materials, operating concept and historical background of each of the product types.

## 3.2 Partial discharge

### 3.2.1 Partial discharge measurement in general

IEC 60270:2000 *High-voltage test techniques – Partial discharge measurements* deals with electrical methods for measurement and calibration of partial discharges in the transformers with alternating voltages up to 400 Hz. This standard explains all the terms and measured quantities during such measurement.

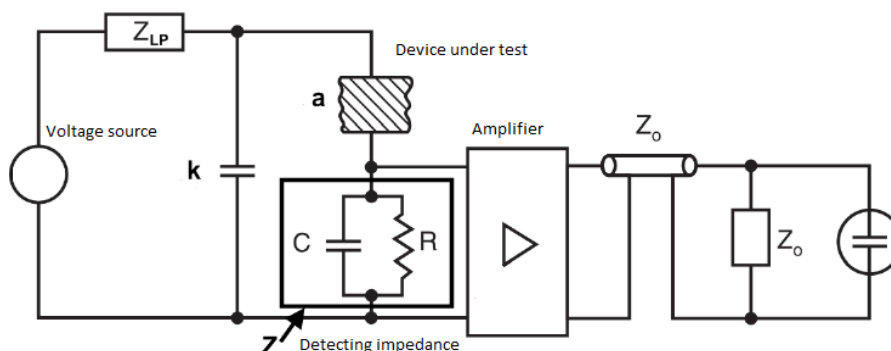
Digital and analogue measuring circuits and calibration requirements are explained. It explains also electrical measurements of impulsive discharges, but gives a reference to non-electrical methods used for localization of PD activities and processing of measured data [9].

Partial discharge can cause creation of light and sound, increase in dielectric losses, propagation of electromagnetic waves, chemical reactions, and creation of high gas pressure and generation of electrical pulses caused by charge transfer [12].

For detecting partial discharges electrical and non-electrical methods can be used. Although non-electrical methods can be used for detection purpose, it is not possible to measure partial discharge (PD) using the methods.

- Using electrical method, the partial discharge is monitored by a wide bandwidth connection to transformer bushing tap which is preferably designed according to ANSI C57.19.01. Care must be taken to prevent high voltages appearing on the tap under transformer normal operation and impulse condition to be transferred to the monitoring system [17].
- UHF measurements inside transformer tank using fed-in or dielectric window antennas operates based on measurement of electromagnetics signals created by high frequency discharge activities caused by partial discharges[17] [12].
- Vibration accelerometers can be fitted on tank cover or acoustic sensors can be fed into the tank body to act as detector of partial discharge activities inside the tank [17].
- Capacitive coupler which is fitted close to line terminal can also be used as a capacitive transducer for measurement of fast transient partial discharge pulses [17].
- Rogowsky coil fitted on grounded natural terminal can also be used for monitoring high speed current PD pulses.
- Dissolved Gas Analysis (DGA), measurement of propagated sound caused by PD, emitted light and heat detection are among the non-electrical methods for detection of PD activities in side transformer tank

The most important detection and measurement method is based on electric signals measurement. Partial discharge causes current pulses to pass through transformer high voltage electrodes [12]. There are many different arrangements for measurement of partial discharges but all of them can summarized as general circuit diagram in Figure 8 [12].



**Figure 8. Partial discharge electrical detection system [12]**

The circuit elements are [12]:

- Noise free voltage source
- Device under test (a)
- Detecting impedance which converts current pulses to measurable voltage signal
- Coupling capacitor (k) which facilitate passing high frequency discharge pulse currents
- Amplifier with suitable gain and frequency response range
- Recorder and display for received signals
- High voltage filter for elimination of high frequency noises from high voltage source

Partial discharge signals have a very broad frequency range (up to few GHz). Depending to type, gain and band-width of their amplifier systems, every measuring system can only amplify a limited range of the frequencies of their input signals [12].

Acoustical, UHF and Broad band electrical measurements are suitable for monitoring and detection purpose but only Broad band and Narrow band electrical can be used for PD measurement on a power transformer based on IEC 600270.

### 3.2.2 Online partial discharge measurement, handling noises

In case of a monitoring system operation in a high voltage substation, the system should be able to eliminate noises caused by discharge pulses created by corona outside the transformer tank and transmitted by high voltage supply line toward inside transformer tank.

To decrease effect of noise on the measuring signals, the signals are converted to light signals using a convertor as soon as they are taken out of transformer tank. Consequently, the signals transmitted to any distance using optical fibers. Use of fibers increases the safety of the monitoring system dramatically. Light signals are converted to electrical signals and supplied through a digitizer card to a PC for evaluation and display.

The voltage source which supplies the transformer under monitoring is not noise free. Normally it is not possible to add high voltage filters between the source and the transformer. The noise should be suppressed using differential measurement methods or by gating and windowing on measured data signals.

Increased number of conversion stages, by introduction of converters and digitizers, introduces more parameters to be considered during quality assurance activities of the whole system.

Because there are different stages of noise elimination every calibration activity should be repeated in case of any modification in system hardware (amplification or conversion stages) or software (windowing or gating features applied to signal delivered to PC).

### 3.3 Sound and vibration

Although BS 6955 or ISO 5347 series, *Calibration of vibration and shock pick-ups* give basic information regarding calibration of vibration measuring systems, the Brüel & Kjær Piezoelectric accelerometers and vibration preamplifiers handbook [7] gives useful summary of information regarding sound and vibration measurement theory and applications.

Guidelines for the proper use of the accelerometer sensors to obtain a high quality of measurement are described in chapter 4 of the handbook. In chapter 5 useful information regarding calibration and environmental and operational testing of the accelerometers is presented.

It should be noted that it is mostly the accelerometer or vibration pickup sensor and its connection cable to the preamplifier which are subjected to outdoor environmental condition (in case of monitoring an outdoor transformer).

There are two types of sources for vibration inside the transformer. Vibration monitoring can be used to detect faults like displacement of coils or core laminations by comparison with measured values under defined voltage or current condition.

The electromagnetic force caused by current carrying coil conductors subjected to leakage flux is proportional to square of the coil current. The frequency of vibration is twice the operation frequency.

Magnetic flux inside the core creates two types of forces. Electromagnetic force which tries to decrease air gaps between columns and yokes, and Magnetostriction force which tries to change the length of the magnetic material in the direction of the higher magnetic field. In the transformer the latter causes higher noise than the previous force type.

These forces cause vibrations at two main frequencies of 100 and 200Hz for a 50Hz operating frequency. At the higher voltages where the core flux is near the saturation region, 200 Hz vibrations will be dominant comparing with 100 Hz vibrations.

A new transformer has a low level of sound and vibration. Transportation problems, loose fasteners inside the tank for core and coil assembly or transformer or external short circuits (which can cause disposition of coils and loosening of fixtures) will result higher sound and vibration.

For online monitoring purpose, vibration sensors placed on the tank cover near the points which are mechanically coupled to the active part [12].

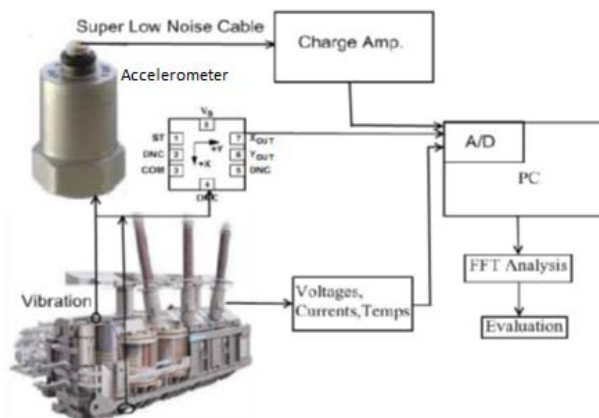


Figure 9. Vibration monitoring and analyzer system [12]

Most basic and commonly used vibration sensor is a piezoelectric sensor which converts mechanical vibration to electrical charge  $q$ . Very low charge is transferred to a charge amplifier using a super-low-noise cable. The amplifier converts delivered charge to voltage. The voltage is transferred to an analog to digital converter and analyzing processes in time or frequency domain is performed on received signal.

There is another kind of vibration sensor on the market which is based on measurement of deviations in capacitance because of vibration. The outputs are two voltage signals sensitive to vibrations up to 2.5 kHz in two perpendicular directions.

Capacitive sensor is much cheaper and suitable for pure vibration monitoring, but it has a limited frequency range (compared with 10 kHz for piezoelectric sensor) and it is not useful for sound measurements which can be part of partial discharge monitoring system.

In modern systems, integrated circuit piezoelectric sensors are used instead of simple piezoelectric sensors. The charge produced by an accelerometer is very small, implying that the output is very sensitive to noise. Integrated circuit piezoelectric (ICP) sensor or Integral Electronic Piezoelectric (IEPE) integrates the sensitive electronics with the transducer and improves the noise immunity. This type of accelerometer consists of an amplifier and a constant current source. The current source injects current into the accelerometer and the accelerometer returns a voltage signal proportional to the acceleration [14].

Regarding sound and vibration monitoring, all three suppliers use the main measurement setup consisting of set of general purpose, specially selected and tailored for transformer application of:

- Accelerometers,
- Charge amplifiers,
- and a Diagnostics Analyzing software

For each combination of accelerometer, preamplifier and analyzing software together with connecting cables and joints, a system calibration shall be performed by the system supplier.

Regarding quality of measurement of the monitoring system the rules can be divided to two groups: first regarding a vibration measuring system in general and second regarding the auxiliary connections and housings which makes it possible to use the system in harsh and long lasting transformer operational environment.

Effect of environmental conditions like temperature or vibration on electronic circuits should be investigated by performing proper quality assurance programs.

### 3.4 Data mining

The data collected by condition monitoring systems will not result in reliable information about condition of high voltage equipment unless it processed by modern analysis and data handling techniques or so called Data Mining. Here some precautionary measures that shall be considered in the stage of data analysis are presented [18].

- Data history should be considered to discover the trends
- Inaccurate results should be removed but none of accurate results should be ignored
- Operational changes in HV equipment condition should be considered in interpretation of the collected data
- Only information from populations of the components of the same type should be used in the statistical analysis of the results

## 4 Measurement Quality assurance of the monitoring systems

### 4.1 ISO 10012:2003

To manage the risk of production of incorrect results out of transformer monitoring systems a measurement management system should be established and implemented by transformer operator. ISO 10012 [11] expresses separately, the guidance and the requirements for implementation of this kind of management system. The management methods can range from simple equipment verification to using statistical techniques to control the measurement processes.

Following bodies may refer to international standard ISO 10012:

- Transformer manufacturer or operator when specifying required product
- Monitoring equipment supplier when specifying offered product
- Regulatory or legislative body
- Measurement management systems assessment and auditing bodies

The organizations should determine the level of required supervision and specify the management system requirements as part of their organizational management system.

The criteria and procedures should be defined to gain a set of measurable quality objectives like:

- No monitoring process to be out of control without detection for more than a predetermined period of time
- All calibration operations to be completed by agreed periods of time
- There are to be no illegible records of metrological confirmation
- All the technical training schedules be executed before the due date
- The non-availability of any of monitoring equipment to be reduced to a predetermined percentage

Metrological confirmation consists of measuring equipment verifications and calibrations activities. According to this international standard [11]:

- Procedures should be implemented to gain required competence for the personnel and their responsibilities should be defined. The procedures shall be documented, validated and properly and consistently implemented.
- All the monitoring equipment shall clearly and individually be identified and confirmed for a particular monitoring process use.
- Any software used for monitoring systems should be validated and approved before initial use and later be identified, documented and controlled to ensure its proper long term usage.
- The equipment shall be used in the specified environmental condition based on limitations dictated by their measurement accuracy limits. These types of environmental conditions should be recoded.
- The suppliers for any kind of services for monitoring equipment (like calibration services,) shall be evaluated based on documented requirements and all the related data should be recorded.
- Information regarding metrological confirmation intervals and status for all the monitoring equipment shall be available to the operator.

- Software or hardware adjusting means of the devices shall be safe guarded to prevent any changes out of the metrological confirmation process procedures.

The standard specifies the details of documents that shall be recorded regarding any metrological confirmation process.

According to ISO 10012 [11]:

- "Measurement processes which are part of the measurement management system shall be planned, validated, implemented, documented and controlled."
- "The complete specification of each measurement process shall include identification of all relevant equipment, measurement procedures, measurement software, conditions of use, operator abilities, and all other factors affecting the reliability of the measurement result."

Main purpose of specifying any measurement process for a monitoring system is to increase reliability of the system by preventing erroneous results, early detection of deficiencies and finally having more time for eventual corrective actions.

All in all, measurement quality of any monitoring equipment shall be monitored implementing documented procedures and at predefined intervals, by definition of measurement processes as part of controlled measurement management system and this prevents deviations from requirements and ensures production of transformer life-long referable and comparable high voltage equipment condition data.

## 4.2 Importance of manufactures specifications

Manufacture specifications provide very important information which is used for measurement quality assurance of a monitoring system. The information is used also for selection of new equipment or replacing an old system with a new one. Measurement uncertainty, tolerance limits used for calibration and testing and risk analysis for accepting faulty results can only be extracted from the equipment specification [13].

### 4.2.1 What is a specification?

Specifications describe tolerance limits that can affect the attributes of measuring equipment. For example, temperature or vibration parameters can affect sensitivity of a monitoring device.

Price of similar equipment can be compared using their specifications. The information can also be used for technical selection of measuring equipment. Uncertainties of measured values can be determined using data given in instruments specification sheet. Tolerances given in specification data sheets can be used to set maximum time between calibrations.

For complex instruments specifications, may include range and time dependent tolerances. Manufacturers give the information about operation condition limits to not loose market in the case of out of limit applications. The limits have to be reviewed completely in the stage of technical evaluation of an instrument.

### 4.2.2 Are specifications standardized?

For presentation of monitoring systems measuring specifications, even for well-known general monitoring systems of one type which is manufactured by different producers no standard method is established. The situation is even worse in the case of transformer monitoring

equipment which is new in the market and developed by the manufacturers originating from transformer industry rather than precision lab measuring equipment manufacturers.

Inconsistency of equipment specifications is evident if specifications for similar monitoring systems are studied. "Although measuring and test equipment specifications are an important element of measurement quality assurance, only a handful of articles and papers have been written about the difficulties encountered when interpreting their specifications. The measurement science community as a whole is only now beginning to formally address the issues regarding their development, interpretation and application." [13].

### 4.2.3 Transformer Monitoring Equipment (TME) specifications

Although the manufacturers tend to present additional information regarding qualifiers of the equipment for gaining the market, going through specification documents of TME targeted in this study shows that nearly all the specifications suffer from lack of crucial information needed to evaluate TME for their measurement quality purpose. There is no information about time dependent and range dependent characteristics.

They do not reveal probability distribution for the TME performance parameters and do not present confidence level related to specified parameters tolerance limits.

## 4.3 Elements of monitoring equipment

Generally each monitoring system can consist of the following elements:

- **Instrument:** Instrument is a device which is used to measure and/or provide a specified output.
- **Sensor & transducer:** Sensor is a device that detects a physical input and transducer converts one form of energy to another. Some sensors or transducers directly convert input data to an electrical output and some needs an external electrical source to complete the action.
- **Signal conditioner:** A device used for modifying the characteristics of a signal such as attenuator, filter or amplifier.
- **Data Acquisition device:** A device that acquires and store measured data.
- **Data Processor:** Method or equipment to perform required calculations like curve fitting, interpolation, unit conversion.
- **Output display:** Computer screen or digital displays like LED or LCD screens to present processed data.
- **Cables and connectors:** Auxilliary equipment required during measurement.

## 4.4 Performance characteristics of TME

### 4.4.1 Static characteristics

Static performance characteristics include:

- **Sensitivity:** Ratio of output signal to corresponding input signal. The difference between the actual ideal output responses is the sensitivity error.

- **Zero offset:** Non-zero output for Zero input.
- **Nonlinearity:** Change of actual sensitivity over the range of the device.
- **Hysteresis:** Dependency of the output to change of magnitude and direction of change of input.
- **Noise:** Random change of output for the same input during sequential observations.
- **Resolution:** Discrete output steps in response to continuous varying input.

#### 4.4.2 Dynamic characteristics

Dynamic characteristics include Response time, Frequency response, Damping ratio and Stability [13].

In case of transformer monitoring equipment under study for this project, dynamic performance characteristics can be ignored. It is expected that change of monitored temperature, vibration or Partial discharge will happen in hours or even days.

Dynamic response of protective devices is vital as the transformer should be disconnected from the network as soon as a short circuit happens in any connected part of electrical network.

#### 4.4.3 Other characteristics

The characteristics, not categorized as the static or the dynamic characteristics include:

- **Dead-band and Threshold:** Lower and upper detection limit of the device.
- **Environmental operating conditions:** Temperature, pressure, humidity, shock, electromagnetic and electrostatic effects and dust or spill water which can have a major effect on TME performance.
- **Excitation Voltage or Current:** Voltage or current required to generate the necessary output response.

### 4.5 Verifying Performance characteristics given in specification

For quality assurance of a TME the specification of it should be verified. This verification can be performed by following actions [13].

#### 4.5.1 Acceptance testing

Acceptance testing can be performed to show that the product is free from defect and to demonstrate that the defined operating and environmental condition meets performance specifications.

The test condition should be as close as possible similar to instrument usage extreme condition.

The tests can include evaluation of environmental performance characteristics or accelerated aging tests.

#### 4.5.2 Measurement quality assurance

Measurement quality assurance means series of actions to confirm that the measuring equipment is in conformance with related specification.

Continued quality assurance can be achieved by periodic calibration and by estimating measurement uncertainties accounting for all elements of uncertainty like environmental condition or display resolution.

Periodic calibration determines if the instrument operates within specified tolerance limits. Calibration data is not enough for accepting or rejecting equipment. The measurement uncertainty during calibration should also be considered as complementary information in this regard.

The calibration or test laboratories shall meet **ISO/IEC 17025:2005** to ensure that the produced test results are valid and that the calibration results are traceable to a national or international metrology institute.

Calibration period is determined by stability, demonstrated by monitoring system over previous calibration activities and eventual exposure of the equipment to unexpected stresses.

#### 4.5.3 Engineering analysis

Engineering analysis consists of technical assessments to check whether or not given specifications meet the requirements dictated by intended application.

Regarding tolerance limits, the accuracy requirement analysis should be performed at the lower side of rated operation range if the limits are given as a percentage of full scale.

#### 4.5.4 Modifying limits given in specification

To control the risks resulted from improper measurements, the limits can be modified based on actual calibration history.

### 4.6 Acquiring specifications

For selection or before use of TME the specification can be acquired from different sources like manufacturer's websites, marketing literature, technical catalogues or operating instructions in the form of data sheets, user manuals, application notes and technical articles [13].

### 4.7 TME transfer function

For proper judgment about performance of a TME it is important to understand and correctly interpret operating principles of the system.

The information from the theory and principle of application of a monitoring system should be converted to a transfer function. The transfer function equation is a basis to be used for judgment about quality of measurement of the measuring system.

Sample transfer function for a sensor is given like [13]:

$$LC_{out} = W \times S \times V_{Ex}$$

where

$$\begin{aligned} LC_{out} &= \text{Output voltage} \\ W &= \text{Applied load or weight} \\ S &= \text{Load cell sensitivity} \\ V_{Ex} &= \text{Excitation voltage} \end{aligned}$$

which can be improved and modified to account for a complete set of performance parameters and presented as [13]:

$$LC_{out} = [(W + TE_{out} \times TR_{\circ F}) \times S + NL + Hys + NS + ZO + TE_{zero} \times TR_{\circ F}] \times V_{Ex}$$

where

$$\begin{aligned} LC_{out} &= \text{Output voltage, mV} \\ W &= \text{Applied weight or load, lb}_f \\ TE_{out} &= \text{Temperature effect on output, lb}_f / \circ\text{F} \\ TR_{\circ F} &= \text{Temperature range, } \circ\text{F} \\ S &= \text{Load cell sensitivity, mV/V/lb}_f \\ NL &= \text{Nonlinearity, mV/V} \\ Hys &= \text{Hysteresis, mV/V} \\ NS &= \text{Noise and ripple, mV/V} \\ ZO &= \text{Zero offset, mV/V} \\ TE_{zero} &= \text{Temperature effect on zero, mV/V/} \circ\text{F} \\ V_{Ex} &= \text{Excitation voltage, V} \end{aligned}$$

As it can be seen the primary transfer function is adjusted to include the other important operation parameters which can be considered as error sources for the measured data.

## 4.8 Validation of conformity to Specification

To assure quality of measurement of any TME it should be validated that the performance parameters of it are in conformity with specified tolerance limits for the instrument [13].

**ISO/IEC 9001** specifies requirement for a quality management system of any company in meeting their customer requirements. Power grid system operator companies that maintain ISO/IEC 9001 should implement an effective calibration program to demonstrate conformity of their monitoring systems with the manufacturer's specifications.

**ISO 10012** explains quality assurance requirements for metrological confirmation of any measuring equipment. Metrological confirmation includes series of operations which ensures that all performance parameters, specified for measuring equipment are in conformance to the requirements of the equipment. Metrological confirmation is achieved by acceptance testing and performing periodic calibration. For some conditions the Bayesian analysis can also employed for evaluation of critical performance characteristics of monitoring equipment which is not easy to access.

The validation can be performed by following actions [13]:

- Acceptance testing
- Measurement quality assurance
- Engineering analysis

### 4.8.1 Acceptance testing

Acceptance tests are performed:

- to show that the product is free from defect,
- to demonstrate that the defined operating and environmental condition meets performance specifications,
- to confirm that the monitoring system functions effectively within its specified accuracy limits,
- and to confirm that the device fulfills the requirements regarding its intended duty under defined working environment.

The tests are performed at actual or simulated extreme operating condition.

The tests should be repeated if the instrument is modified to be implemented for a new application or decided to be exposed to a new measuring environment.

The tests regarding performance characteristics of a monitoring system can be classified as followings [13]:

- **Static Characteristics:** The tests performed according to procedures published by organizations like IEC, ASTM, ASME or ISA. A range of static inputs are applied and resulted outputs are recorded. Static performance parameters are examined as followings:

**Sensitivity:** An array of steady state increasing or decreasing inputs is applied and the ratio of measured output to input signals is calculated. The ratio should typically be constant throughout the input range.

**Zero offset:** The output is measured having no input signal.

**Linearity:** An array of steady state increasing or decreasing inputs is applied and the ratio of measured output to input signals is compared with the ideally calculated constant output to input ratio.

**Hysteresis:** An array of steady state increasing (or decreasing) inputs is applied and followed by a decreasing (or increasing) direction. The highest difference between the output values during increasing and decreasing stage is registered.

**Dead band:** The non-zero output is detected by gradually increasing of input signal from zero. The dead band value is the measured input signal when the nonzero output is detected.

**Full scale output:** The output is measured for a period of time when the full scale input signal is established.

**Repeatability:** Two similar cycles of measurements is performed by applying an array of rising or falling steady state input signals. Environmental condition, test equipment, procedures and even test persons should be the same for two cases. For a defined input range, the highest difference in the measured outputs is registered.

- **Environmental tests:** There are no industrial standards for environmental testing, but handbooks or standards like IEC 60068-1: Environmental testing can be named. The tests are conducted using an environmental chamber which can simulate one, two or several environmental conditions at the same time. A controlled condition is applied until an environmental equilibrium is reached. At least one test cycle should be performed for

each environmental condition range. The tests can include study of the effect of temperature, humidity and/or vibration on zero offset and the effect of temperature, pressure and/or vibration on sensitivity of the monitoring system.

- **Accelerated life tests:** For Accelerated life tests, there are no governmental or industrial standards. The tests can be performed for evaluation of reliability of instrument to check if the equipment fulfills constraints according to manufacturer's specifications in longer period of life time. The system is operated at higher stress, compared to normal operational condition. Analytical methods are used to calculate long term normal operational condition of the instrument.

#### 4.8.2 Measurement quality assurance

Measurement quality assurance means series of actions to confirm that the measuring equipment is in conformance with related specification.

Continued quality assurance can be achieved by periodic calibration and by estimating measurement uncertainties accounting for all elements of uncertainty like environmental condition or display resolution. Periodic calibration is performed to setup and preserve a proper (accurate and reliable) performance of the equipment over a long period of time. The calibration determines conformity of the instrument with its specification. Periodic calibration determines if the instrument operates within specified tolerance limits.

The calibration or test laboratories shall meet **ISO/IEC 17025:2005** to ensure that the produced test results are valid and that the calibration results are traceable to a national or international metrology institute [13].

Calibration period is determined by application and by stability, demonstrated by monitoring system over previous calibration activities and eventual exposure of the equipment to unexpected stresses.

Calibration can be done by one of the following methods [13]:

- A reference standard instrument and the TME both measure a common input value
- The TME measures a known reference standard value

Here are some references regarding calibration of measuring equipment:

- **ISO/IEC 17025: 2005**, General requirements for the competence of testing and calibration laboratories
- **ANSI/NCSL Z540.3: 2006**, Requirements for the calibration of measuring and test equipment
- **NCSLI RP-3: 2007**, Calibration procedures

Calibration data is not enough for accepting or rejecting equipment. The measurement uncertainty during calibration should also be considered as complementary information in this regard.

- **Uncertainty of calibration:** All kinds of measurements have errors which are resulted from accuracy of measuring equipment, measurement procedures and measurement site environmental condition. Assuming that the values of these errors are unknown, there is uncertainty in measurement results. Measurement uncertainty associated with any TME calibration or acceptance testing should be estimated and presented together with the measurement results. This will help to decrease number of incorrect rejection or acceptance of the equipment based on its conformance or non-conformance to the related specification.

- **Self-calibration:** Self-calibration feature may seem suitable replacement for periodic calibration especially in the case of equipment which is hard to access or to be dismantled for calibration. The equipment with this capability becomes common in recent years. A firmware has been inbuilt to discover and diagnose predefined faulty operation problems. This is done for example by using a built-in reference. The feature is only proper for basic performance checks, any built-in standard needs to be periodically calibrated using traceable references and the internal calibration procedures shall be regularly updated.
- **In place calibration:** This kind of calibration is preferable when possible disconnection of the monitoring equipment from the transformer is time consuming or takes a long time and involves the risk of not detecting faults in the period of time when there is no monitoring on transformer. Sometimes it is impossible to disconnect the sensors from the transformer or to simulate operation condition out of transformer tank. The required references should be transported to installation site and the reference should be able to operate in the same operational condition as TME sensor.

Having not stable or predefined environmental condition in installation site dictates corrections in the calibration results depending on the differences between the actual installation site and the ideal laboratory environment condition. If it is not practical to do a complete range calibration, at least three points in each direction of increasing or decreasing cycle should be applied. The benefits of in-place calibration can include, eliminating for need of mechanical and electrical disconnections, bringing the actual stresses on the TME into consideration, minimizing the instrument's downtime and decreasing the costs by not using the spare parts required eventually for replacement. In-place calibration is not described in ISO/IEC 17025.

- **Laboratory calibration:** A stable environmental condition similar to operational condition should be established. Related to operating range(s), sufficient number of calibration points in at least one increasing and decreasing cycle should be selected.
- **Calibration report:** The calibration report should be in accordance with ISO/IEC 17025 and at least provide the following information:
  - Information about equipment including serial Number, model and manufacturer's name
  - Operating parameters and ranges
  - Complete information about calibration equipment
  - Environmental conditions related to device under calibration and reference instrument
  - Calibration procedure
  - Measurement results and estimated uncertainties
  - Out of tolerance values
  - Data analysis summary

### 4.8.3 Engineering analysis

Engineering analysis consists of technical assessments to check whether or not given specifications meet the requirements dictated by intended application.

Regarding tolerance limits, the accuracy requirement analysis should be performed at the lower side of rated operation range if the limits are given as a percentage of full scale.

## 5 Conclusion and discussion

The study demonstrates that the transformer monitoring equipment and its reliability is becoming more and more important for the industry. International technical committees have started to think about the subject and to release documents in this regard. The equipment available in the market is far from a common standard in following the reliability aspects of the monitoring equipment and related data. Measurement quality assurance, which is an important part in a reliability management of monitoring systems, is discussed in this report.

The inconsistency of the monitoring equipment technical specifications in presenting equipment's compatibility with measurement quality criteria is obvious. Although the selected equipment is among the most well-known products from the antecessor companies, nearly none of them have proven to introduce a complete set of standards regarding the measurement quality aspects.

Normally, the information is extracted from the technical data presented for marketing purposes and it can, therefore, in many cases be far from reality. To prove all the claims of having strong points and to discover all the weakness points of the equipment, series of detailed laboratory testing and field operation history study of these monitoring equipment should be performed which are suggested for future work.

The selected method for the study cannot reveal if the metrology confirmation processes are established and executed by network operators as part of a whole quality management program. This should definitely be considered for continuation of this project.

It was not possible to borrow a system from a manufacturer or a network owner to be submitted to a simple evaluation at SP's laboratories. This can be done as part of an extended activity in continuation of this project.

The following can be performed in steps as future work:

- Extending the metrological reliability studies to the **other types of monitoring systems** installed on Power transformers specially Gas & humidity in oil , On load tap changer and Bushing monitoring systems,
- **Practical evaluation of reliability** of the monitoring systems by performing all the tests and calibrations regarding environmental and metrological requirements of the monitoring systems introduced in the equipment technical specifications or by related international standards,
- Reliability assessment of the **installed transformer monitoring systems** based on their technical specifications data, the environmental tests and the metrological calibrations results, and on-site study of the installed monitoring systems typical faults and the established metrological confirmation processes under the quality management programs.

## 6 References

- [1]1 ANSI webstore: <http://webstore.ansi.org/>
- [2]2 B. Kellison, Smart grid analyse report, Transformer monitoring markets, 2013-2020: Technologies, Forecasts and leading Vendors, , GTM Research, 2013
- [3]3 BS EN webstore: <http://shop.bsigroup.com/>
- [4]4 BS EN 1434-4:2007, Heat meters, Pattern approval tests
- [5]5 EN webstore: <http://www.cenelec.eu>
- [6]6 G.Rietveld, SC Power and Energy, EURAMET, TC-EM (Electricity & Magnetism Technical Committee), 5th meeting, 21 November 2012, Berlin, Germany
- [7]7 Handbook: Piezoelectric Accelerometers and Vibration Preamplifiers, Primers & Handbooks, Brüel & Kjær Sound & Vibration Measurement A/S, <http://www.bksv.com/library/primers>
- [8]8 IEC webstore: <http://webstore.iec.ch/>
- [9]9 IEC 60270, High-voltage test techniques – Partial discharge measurements, 2000
- [10]10 IEEE webstore: <http://standards.ieee.org/>
- [11]11 ISO 10012, Measurement management systems requirements for measurement processes and measuring equipment, 2003
- [12]12 M. Allahbakhshi, Ph.D Thesis, Insulation condition evaluation for power transformers using intelligent data fusion approaches, 2011
- [13]13 Nasa, Measurement quality assurance handbook, Annex2, Measuring and test equipment specifications, 2010
- [14]14 National Instruments, knowledge base support, What is IEPE  
<http://digital.ni.com/public.nsf/allkb/E96DCCBD929EF9E886256C93006D9EC5>
- [15]15 N.L.Fantana, ABB Corporate research Germany, On line condition monitoring importance and evaluation, Session 4, Condition assessment and test procedures, Nordic insulation symposium, 2011
- [16]16 R.E. James, Q. Su, "Condition Assessment of High Voltage Insulation in Power System Equipment", Book published by The Institution of Engineering and Technology, UK, 2008
- [17]17 Report 343 WG A2.27 Cigré, Recommendations for condition monitoring and condition assessment facilities for transformers, 2008
- [18]18 Report 420 WG D1.17 Cigre, Generic Guidelines for life time condition assessment of HV assets and related knowledge results, 2010
- [19]19 S. Gubanski, Prezentation, High voltage technology course, Chalmers university of technology, 2013
- [20]20 Summary report, 1<sup>st</sup> IEEE substations committee - Cigré SC B3 joint meeting on Online condition monitoring, 2011
- [21]21 VDE webstore: <http://www.vde-verlag.de/normen.html>
- [22]22 Working group form, WG A2.44 Cigre, Transformer intelligent condition monitoring, 2010

## 7 Appendices

## Appendix A Tables

Table 1. The comparison table of specifications of the selected temperature monitoring equipment

|                                     | Qualitrol509DW   | FisoEasyGrid                                 | APTechTTC1000   |
|-------------------------------------|--|--|---|
| <b>Temperature range</b>            | from -80 to 250°C  | from -40 to 225°C                            | from -35 to 180°C   |
| <b>Accuracy</b>                     | ±1°C   | ±1°C (For transformer life)                  | Avg error over entire range ± 1 °C (Absolute error at any temperature ± 1.5 °C) |
| <b>operating temperature range</b>  | from -40 to +70°C  | from -20 to +65°C                            | from -50 to +85°C   |
| <b>Surge Protection</b>             |  | 4000V (IEEE C37.90.1-2002)                   | ANSI C37.90.1   |
| <b>Light source MTBF</b>            |  | > life of the transformer                    | NA  |
| <b>Humidity</b>                     | 5% to 90% non-condensing                                 | 95% RH Non-Condensing                        | 95% RH Non-Condensing   |
| <b>Shock</b>                        | 10 G's half-sine, in three orthogonal planes             | MIL-STD-810F                                 |   |
| <b>Vibration</b>                    | 60/120 Hz @ .004 inch displacement; 10/150 Hz at 1G      | MIL-STD-810F                                 |   |
| <b>Dielectric isolation</b>         | 2500 VAC, 60 seconds to ground                           |  |   |
| <b>Certifications</b>               | IEEE C37.90.1, IEC 61000-6-1, IEC 61000-6-2, IEC 61010-1 | EN 61326 (EMC)                               |   |
|                                     | CE approved  | EN 55011 Class A (Industrial)                |   |
|                                     |  | EN 61000-4-2 EN 61000-4-5                    |   |
|                                     |  | EN 61000-4-3 EN 61000-4-6                    |   |
|                                     |  | EN 61000-4-4 EN 61000-4-11                   |   |
| <b>Environment Testing: General</b> |  | IEC 60068-2-1 Test A: Cold                   |   |
|                                     |  | IEC 60068-2-2 Test B: Dry Heat               |   |
|                                     |  | IEC 60068-2-14 Test N: Change of Temperature |   |
|                                     |  | IEC 60068-2-30 Test Db and Guidance: Damp    |   |
|                                     |  | IEC 60068-2-78 Test Cab: Damp Heat, Steady   |   |
| <b>EMI Withstand</b>                |  |  | ANSI C37.90.2   |
| <b>Electrostatic Discharge</b>      |  |  | IEC 801-2   |

**Table 2. The comparison table of specifications of the selected Partial discharge monitoring equipment**

|  | <b>Qualitrol 609PDM</b>   | <b>DobleSmart Elect</b>     | <b>PoDiag SPECMonitor</b>             |
|--|---|-----------------------------|---------------------------------------|
| <b>Ambient operating temperature</b>                         | -45° to +55° C  | 0° C to 40° C               | 10° C to 40° C                        |
| <b>Humidity</b>  | 5 - 95% non-condensing  | 5 % - 95%, non-condensing   | non-condensing                        |
| <b>Enclosure rating</b>                                      | IP66 (IEC 60529)  |                             |                                       |
| <b>Seismic</b>   | IEEE C37.98 ( seismic testing of relays )   |                             |                                       |
| <b>Environmental test compliance</b>                         | BS EN60068-2-2, BS EN60068-2-1, BS EN60068-2-78   |                             |                                       |
| <b>Vibration test compliance</b>                             | BS EN68-2-6, BS EN68-2-27, BS EN68-2-29   |                             |                                       |
| <b>EMC test compliance</b>                                   | BS EN55022 (:2006);<br>BS EN61000-3-2 to -3-3,<br>BS-EN61000-4-2 to -4-6,<br>(Conforms to relevant specifications for monitoring / control equipment in HV substations)<br>BS EN61000-4-8, BS EN61000-4-11, BS EN61000-4-18; IEC 60255-5, IEC 61180-1 |                             |                                       |
| <b>Others</b>  | EMI / RFI immunity  |                             |                                       |
| <b>Evaluation &amp; interpretation of Partial Discharges</b> |   | IEC 60270, VDE0434 and ANSI |                                       |
| <b>Minimum detectable apparent charge</b>                    |   | < 0.1 pC                    |                                       |
| <b>Single Pulse detection</b>                                |   | < 4 ns                      |                                       |
| <b>Max. double pulse resolution</b>                          |   | < 32 ns                     |                                       |
| <b>time range, super position error</b>                      |   | < 1 %                       |                                       |
| <b>Minimum detectable apparent charge</b>                    |   |                             | < 2 pC                                |
| <b>Input sensitivity</b>                                     |   |                             | < 400µV (standard version)            |
| <b>Ambient operating temperature (Coupling unit)</b>         |   |                             | from -20° C to 75° C (non-condensing) |

**Table 3. Main suppliers of vibro-acoustic measuring systems which are employed by transformer monitoring system providers**

| <b>Transformer monitoring system supplier</b> | <b>Vibration equipment manufacturers</b>   |
|---|--|
| <b>Mistras</b>                                | Vibra-Metrics (owned by Mistras group)<br>Phsycal Acoustics Corporation (owned by Mistras group) |
| <b>Vallen Systeme GmbH</b>                    | Vallen   |
| <b>Dimrus</b>                                 | Vibro-Center   |

Table 4. Standards related to transformers monitoring equipment [8][10][3][5][1][21]

| name                    | Latest revision | title  |
|-------------------------|-----------------|--|
| <b>IEC 60529</b>        | 2013            | Degrees of protection provided by enclosures (IP Code)   |
| <b>IEEE C37.98</b>      | 1987            | Standard seismic testing of relays   |
| <b>BS-EN 60068-2-1</b>  | 2007            | Environmental testing. Tests. Test A. Cold   |
| <b>BS-EN 60068-2-2</b>  | 2007            | Environmental testing. Tests. Test B. Dry heat   |
| <b>BS-EN 60068-2-6</b>  | 2008            | Environmental testing. Tests. Test Fc. Vibration (sinusoidal)  |
| <b>BS-EN 60068-2-27</b> | 2009            | Environmental testing. Tests. Test Ea and guidance. Shock  |
| <b>BS-EN 60068-2-78</b> | 2013            | Environmental testing. Tests. Test Cab: Damp heat, steady state  |
| <b>BS EN 55022</b>      | 2010            | Information technology equipment. Radio disturbance characteristics. Limits and methods of measurement   |
| <b>BS-EN 61000-3-2</b>  | 2009            | Electromagnetic compatibility (EMC) Limits. Limits for harmonic current emissions (equipment input current $\leq 16$ A per phase)  |
| <b>BS-EN 61000-3-3</b>  | 2013            | Electromagnetic compatibility (EMC) Limits. Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current $\leq 16$ A per phase and not subject to conditional connection |
| <b>BS-EN 61000-4-2</b>  | 2009            | Electromagnetic compatibility (EMC). Testing and measurement techniques. Electrostatic discharge immunity test   |
| <b>BS-EN 61000-4-6</b>  | 2009            | Electromagnetic compatibility (EMC). Testing and measurement techniques. Immunity to conducted disturbances, induced by radio-frequency fields   |
| <b>BS-EN 61000-4-8</b>  | 2010            | Electromagnetic compatibility (EMC). Testing and measurement techniques. Power frequency magnetic field immunity test  |
| <b>BS-EN 61000-4-11</b> | 2004            | Electromagnetic compatibility (EMC). Testing and measurement techniques. Voltage dips, short interruptions and voltage variations immunity tests   |
| <b>BS-EN 61000-4-18</b> | 2007+A1 :2010   | Electromagnetic compatibility (EMC). Testing and measurement techniques. Damped oscillatory wave immunity test   |
| <b>IEC 60255-5</b>      | 2000            | Electrical Relays - Part 5: Insulation coordination for measuring relays and protection equipment - Requirements and tests   |
| <b>IEC 61180-1</b>      | 1992            | High-voltage test techniques for low voltage equipment - Part 1: Definitions, test and procedure requirements  |
| <b>IEC 60270</b>        | 2000            | High-voltage test techniques -<br>Partial discharge measurements   |

| <b>name</b>              | <b>Latest revision</b>                            | <b>title</b>   |
|--------------------------|---|--|
| <b>VDE 0434</b>          | DIN EN<br>60270/A<br>1 VDE<br>0434/A1:<br>2011-01 | Hochspannungs-Prüftechnik<br>Teilentladungsmessungen   |
| <b>IEEE<br/>C37.90.1</b> | 2012  | IEEE Standard for Surge withstand capability (SWC) tests for relays and relay systems associated with electric power apparatus   |
| <b>EN 61326</b>          | EN<br>61326:1<br>997                              | Electrical equipment for measurement, control and laboratory use - EMC requirements  |
|                          | EN<br>61326-<br>1:2013                            | Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 1: General requirements   |
|                          | EN<br>61326-2-<br>1:2013                          | Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 2-1: Particular requirements - Test configurations, operational conditions and performance criteria for sensitive test and measurement equipment for EMC unprotected applications   |
|                          | EN<br>61326-2-<br>2:2013                          | Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 2-2: Particular requirements - Test configurations, operational conditions and performance criteria for portable test, measuring and monitoring equipment used in low-voltage distribution systems                                      |
|                          | EN<br>61326-2-<br>3:2013                          | Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 2-3: Particular requirements - Test configuration, operational conditions and performance criteria for transducers with integrated or remote signal conditioning  |
|                          | EN<br>61326-2-<br>4:2013                          | Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 2-4: Particular requirements - Test configurations, operational conditions and performance criteria for insulation monitoring devices according to IEC 61557-8 and for equipment for insulation fault location according to IEC 61557-9 |
|                          | EN<br>61326-2-<br>5:2013                          | Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 2-5: Particular requirements - Test configurations, operational conditions and performance criteria for devices with field bus interfaces according to IEC 61784-1  |
|                          | EN<br>61326-2-<br>6:2006                          | Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 2-6: Particular requirements - In vitro diagnostic (IVD) medical equipment  |
|                          | EN<br>61326-3-                                    | Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 3-1: Immunity requirements for safety-  |

| <b>name</b>   | <b>Latest revision</b> | <b>title</b>   |
|---|------------------------|--|
|   | 1:2008                 | related systems and for equipment intended to perform safety-related functions (functional safety) - General industrial applications   |
|   | EN 61326-3-2:2008      | Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 3-2: Immunity requirements for safety-related systems and for equipment intended to perform safety-related functions (functional safety) - Industrial applications with specified electromagnetic environment |
| <b>EN 55011</b>   | 2007                   | Industrial, scientific and medical (ISM) radio frequency equipment - Electromagnetic disturbance characteristics - Limits and methods of measurement   |
| <b>EN 61000-4-3</b>                                     | 2006                   | Electromagnetic compatibility (EMC) - Part 4-3: Testing and measurement techniques - Radiated, radio-frequency, electromagnetic field immunity test  |
| <b>EN 61000-4-4</b>                                     | 2012                   | Electromagnetic compatibility (EMC) - Part 4-4: Testing and measurement techniques - Electrical fast transient/burst immunity test   |
| <b>EN 61000-4-5</b>                                     | 2006                   | Electromagnetic compatibility (EMC) - Part 4-5: Testing and measurement techniques - Surge immunity test   |
| <b>IEC 60068-2-14</b>                                   | 2009                   | Environmental testing - Part 2-14: Tests - Test N: Change of temperature   |
| <b>IEC 60068-2-30</b>                                   | 2005                   | Environmental testing - Part 2-30: Tests - Test Db: Damp heat, cyclic (12 h + 12 h cycle)  |
| <b>IEC 61000-6-1</b>                                    | 2005                   | Electromagnetic compatibility (EMC) - Part 6-1: Generic standards - Immunity for residential, commercial and light-industrial environments   |
| <b>IEC 61000-6-2</b>                                    | 2005                   | Electromagnetic compatibility (EMC) - Part 6-2: Generic standards - Immunity for industrial environments   |
| <b>IEC 61010-1</b>                                      | 2010                   | Safety requirements for electrical equipment for measurement, control, and laboratory use - Part 1: General requirements   |
| <b>ANSI C37.90.2</b>                                    | 2004                   | IEEE Standard for Withstand Capability of Relay Systems to Radiated Electromagnetic Interference from Transceivers   |
| <b>BS-EN 61000-4-2</b>                                  | 2009                   | Electromagnetic compatibility (EMC) Testing and measurement techniques. Electrostatic discharge immunity test  |
| <b>BS 6955-0, ISO 5347-0 to BS 6955-22, ISO 5347-22</b> | 1987-1997              | Calibration of vibration and shock pick-ups  |
| <b>ISO 16063-1</b>                                      | 1998                   | Methods for the calibration of vibration and shock transducers -- Part 1: Basic concepts   |

**Table 5. Published papers from Cigré related to transformer condition monitoring systems**

| <b>technical Document</b>     | <b>Title</b>  | <b>Working group</b>             | <b>Release date</b> |
|-------------------------------|---|----------------------------------|---------------------|
| Brochure 227                  | Life management techniques for power transformer  | A2.18                            | June 2003           |
| Brochure 343                  | Recommendations for condition monitoring and condition assessment facilities for transformers   | A2.27                            | April 2008          |
| Brochure 445                  | Guide for Transformer Maintenance   | A2.34                            | February 2011       |
| Brochure 462                  | Obtaining value from on-line substation condition monitoring  | WG B3.12                         | June 2011           |
| Brochure 298                  | Transformer lifetime data management  | A2.23                            | August 2006         |
| Brochure 420                  | Generic guidelines for life time condition assessment of hv assets and related knowledge rules  | D1.17                            | June 2010           |
| Report ELT 227                | Transformer reliability surveys   | SC A2 Reliability Advisory Group | August 2006         |
| Report.A2-110_2006            | Electronic transformer control with monitoring and diagnostics  | SC A2                            | 2006                |
| Report A2-206_2010            | Experiences with wireless transformer monitoring system installed by the manufacturer and operated at strategically important locations of the Mexican grid | SC A2                            | 2010                |
| Report A2-202_2010            | Vibro-acoustic diagnostic: contributing to an optimized On-Load Tap Changer (OLTC) maintenance strategy   | SC A2                            | 2010                |
| CIGRÉ Canada Conference Paper | Extending the life of your transformers, GIS and bus bars via condition monitoring (Vibration)  |                                  | 2012                |

**Table 6. List of transformer partial discharge, temperature and sound & vibration monitoring systems which are mostly known and in use in the market**

| <b>Producer</b>                                 | <b>Country of origin</b> | <b>Product type designation</b>      | <b>Product description</b>   | <b>monitors</b>                 |
|---|--------------------------|--------------------------------------|--|---------------------------------|
| <b>Advanced Power Technologies</b>              | USA                      | TTC-1000                             | Intelligent Transformer Temperature Control                                | Temperature, LTC                |
| <b>bpl</b>                                      | USA                      | TM-TMS                               | Temperature monitoring system  | Temperature                     |
| <b>DESC</b>                                     | Germany                  | TMS (OPDM2012)                       | Transformer monitoring system  | PD & (LTC, Gas, Moisture)       |
| <b>Dimrus</b>                                   | Russia                   | Vesta                                | System for vibro-acoustic monitoring of core and winding clamping pressure | Vibration                       |
| <b>Doble Lemke</b>                              | Germany                  | PD smart/electrical & UHF            | on-line el PD Monitoring   | PD                              |
| <b>FISO</b>                                     | Canada                   | Nortech EasyGrid                     | Windigs hot spot temperature monitoring solution                           | Direct Temperature              |
| <b>HVPD</b>                                     | England                  | Multi-Permanent                      | Continious remote access PD monitoring                                     | PD                              |
| <b>IrisPower</b>                                | Canada                   | PD Trac II                           | Partial discharge monitoring   | PD                              |
| <b>LumaSense</b>                                | USA                      | LumaSmart                            | Fluoroptic Thermometry   | Direct Temperature              |
| <b>Masibus</b>                                  | India                    | Trafoguard                           | Online Vibration Monitoring System   | Vibration                       |
| <b>Mistras</b>                                  | USA                      | Sensor Highway II                    | Acoustic Emission (AE) Monitoring System                                   | Sound & vibration               |
| <b>Mistras (Phsyscal Acoustics Corporation)</b> | USA                      | PowerPAC™                            | Acoustic Emission & Thermal faults Monitoring System                       | Vibration, Temperature, Current |
| <b>Omicron</b>                                  | Austria                  | OMS Series? (MPD600, UHF620, PDL650) | Partial discharge monitoring   | PD                              |
| <b>OpSens</b>                                   | Canada                   | PowerSens & OTG-T & SoftSense        | Fiber optic transformer temperature solution                               | Direct temperature              |

| <b>Producer</b>                 | <b>Country of origin</b> | <b>Product type designation</b> | <b>Product description</b>  | <b>monitors</b>    |
|---------------------------------|--------------------------|---------------------------------|---|--------------------|
| <b>Power Diagnostix Systems</b> | Germany                  | SPECMonitor                     | Partial discharge monitoring  | PD                 |
| <b>Qualitrol</b>                | USA                      | 509 DW                          | Intelligent transformer monitor with direct winding                 | Direct Temperature |
| <b>Qualitrol</b>                | USA                      | 609 PDM                         | UHF Partial discharge monitoring for transformers                   | PD                 |
| <b>Qualitrol (NeOptix)</b>      | USA (Canada)             | T/Guard                         | Fiber Optic Power Transformer Winding Temperature Monitoring System | Direct Temperature |
| <b>Vallen</b>                   | Germany                  | AMSY-6                          | Acoustic Emission Measurement                                       | Sound & vibration  |
| <b>Weidmann</b>                 | Switzerland              | InsulogixT                      | Hot spot winding temperature monitoring and control                 | Direct temperature |

Table 7. The equipment selected for the study in this project

| Producer                           | Country of origin | Product type designation      | Product description  | monitors           | ELforsk project |
|------------------------------------|-------------------|-------------------------------|--|--------------------|-----------------|
| <b>FISO</b>                        | Canada            | Nortech EasyGrid              | Windigs hot spot temperature monitoring solution                           | Direct Temperature | Temp1           |
| <b>Qualitrol</b>                   | USA               | 509 DW                        | Intelligent transformer monitor with direct winding                        | Direct Temperature | Temp2           |
| <b>Advanced Power Technologies</b> | USA               | TTC-1000                      | Intelligent Transformer Temperature Control                                | Temperature, LTC   | Temp3           |
| <b>Qualitrol</b>                   | USA               | 609 PDM                       | UHF Partial discharge monitoring for transformers                          | PD                 | PD1             |
| <b>Doble Lemke</b>                 | Germany           | PD smart/electrical & UHF     | on-line el PD Monitoring   | PD                 | PD2             |
| <b>Power Diagnostix Systems</b>    | Germany           | ICMMonitor                    | Partial discharge monitoring   | PD                 | PD3             |
| <b>Mistras</b>                     | USA               | Sensor Highway II & PowerPAC™ | Acoustic Emission (AE) Monitoring System                                   | Sound & vibration  | Vib1            |
| <b>Vallen</b>                      | Germany           | AMSY-6                        | Acoustic Emission Measurement  | Sound & vibration  | Vib2            |
| <b>Dimrus</b>                      | Russia            | Vesta                         | System for vibro-acoustic monitoring of core and winding clamping pressure | vibration          | Vib3            |

**Table 8. Summary of standards which is introduced in the specification of the selected monitoring equipment and is related to their measurement quality**

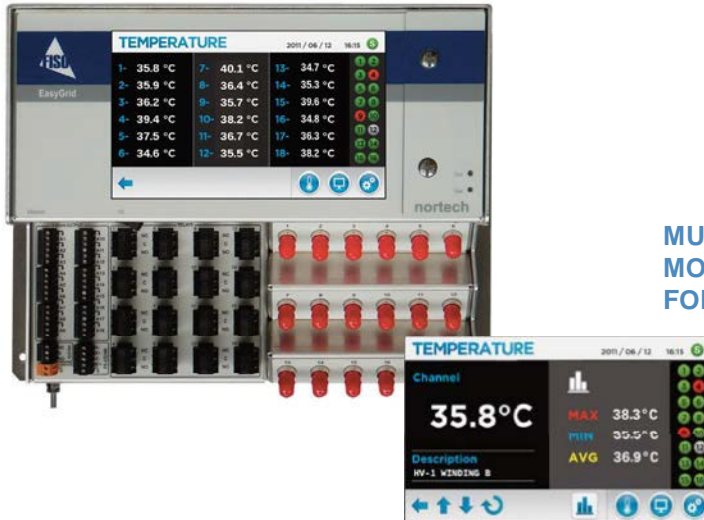
| <b>name</b>      | <b>Note</b>   | <b>Product used</b> |
|------------------|---|---------------------|
| IEC 60529        | Only IP number is given in specification              | PD1                 |
| IEEE C37.98      |   | PD1                 |
| BS-EN 60068-2-1  |   | PD1, Temp1          |
| BS-EN 60068-2-2  |   | PD1, Temp1          |
| BS-EN 60068-2-6  |   | PD1                 |
| BS-EN 60068-2-27 |   | PD1                 |
| BS-EN 60068-2-29 | 1987, Withdrawn & replaced by : BS EN 60068-2-27:2009 | PD1                 |
| BS-EN 60068-2-78 |   | PD1, Temp1          |
| BS-EN 55022      | Version 2006 introduced in spec.                      | PD1                 |
| BS-EN 61000-3-2  |   | PD1                 |
| BS-EN 61000-3-3  |   | PD1                 |
| BS-EN 61000-4-2  |   | PD1, Temp1          |
| BS-EN 61000-4-6  |   | PD1, Temp1          |
| BS-EN 61000-4-8  |   | PD1                 |
| BS-EN 61000-4-11 |   | PD1, Temp1          |
| BS-EN 61000-4-18 |   | PD1                 |
| IEC 60255-5      |   | PD1                 |
| IEC 61180-1      |   | PD1                 |
| IEC 60270        |   | PD2                 |
| VDE 0434         |   | PD2                 |
| IEEE C37.90.1    | Version 2006 introduced in spec.                      | Temp1,Temp2,Temp3   |
| EN 61326         |   | Temp1               |
| EN 55011         | Class A industrial                                    | Temp1               |
| EN 61000-4-3     |   | Temp1               |
| EN 61000-4-4     |   | Temp1               |
| EN 61000-4-5     |   | Temp1               |
| IEC 60068-2-14   |   | Temp1               |
| IEC 60068-2-30   |   | Temp1               |
| IEC 61000-6-1    |   | Temp2               |
| IEC 61000-6-2    |   | Temp2               |

---

| <b>name</b>                | <b>Note</b>  | <b>Product used</b> |
|----------------------------|--|---------------------|
| IEC 61010-1                |  | Temp2               |
| ANSI C37.90.2              |  | Temp3               |
| IEC 801-2                  | 1991, Withdrawn and replaced by BS-EN 61000-4-2:2009 | Temp3               |
|                            |  |                     |
| No standard is introduced. |  | Vib1                |
| No standard is introduced. |  | Vib2                |
| No standard is introduced. |  | Vib3                |

## Appendix B Products specifications

| Producer                           | Country of origin | Product type designation      | Product description  | monitors           | ELforsk project |
|------------------------------------|-------------------|-------------------------------|--|--------------------|-----------------|
| <b>FISO</b>                        | Canada            | Nortech EasyGrid              | Windigs hot spot temperature monitoring solution                           | Direct Temperature | Temp1           |
| <b>Qualitrol</b>                   | USA               | 509 DW                        | Intelligent transformer monitor with direct winding                        | Direct Temperature | Temp2           |
| <b>Advanced Power Technologies</b> | USA               | TTC-1000                      | Intelligent Transformer Temperature Control                                | Temperature, LTC   | Temp3           |
| <b>Qualitrol</b>                   | USA               | 609 PDM                       | UHF Partial discharge monitoring for transformers                          | PD                 | PD1             |
| <b>Doble Lemke</b>                 | Germany           | PD smart/electrical & UHF     | on-line el PD Monitoring   | PD                 | PD2             |
| <b>Power Diagnostix Systems</b>    | Germany           | ICMMonitor                    | Partial discharge monitoring   | PD                 | PD3             |
| <b>Mistras</b>                     | USA               | Sensor Highway II & PowerPAC™ | Acoustic Emission (AE) Monitoring System                                   | Sound & vibration  | Vib1            |
| <b>Vallen</b>                      | Germany           | AMSY-6                        | Acoustic Emission Measurement  | Sound & vibration  | Vib2            |
| <b>Dimrus</b>                      | Russia            | Vesta                         | System for vibro-acoustic monitoring of core and winding clamping pressure | vibration          | Vib3            |



## MULTI-CHANNEL FIBER-OPTIC MONITOR/CONTROLLER FOR ENERGY APPLICATIONS

### Accurate, Reliable & Cost-Effective Winding Hot Spot Temperature Monitoring Solution for Transformers and Reactors

#### Description

The Nortech EasyGrid is the perfect complement to your Smart Grid. The fiber optic signal conditioner is designed for direct, accurate and real-time temperature monitoring to manage and maximize your transformer performance.

The EasyGrid provides critical information about the level of thermal stress and the management of the life cycle of any transformer or reactor. From an EHV/UHV, HVDC to a distribution transformer the cost-effective EasyGrid will meet the highest requirements.



A large 7" (800 x 480) Color Touch Screen LCD Display allows you to monitor and configure up to 18 channels and 16 form-C programmable relays. The graphical user interface makes it easy to customize to your needs.

Through the USB communication port, the Nortech Client software allows full configuration and complete monitoring of your system. View all data logging information live on your PC without stopping the acquisition or downloading of any file.

For over 15 years, FISO has been the leader in the Fiber-Optic White-Light Technology. The EasyGrid is using the temperature dependent band gap shift of the GaAs crystal to provide a fast and accurate measurement. Inherent to the technology, the system will not drift nor require any recalibration for the life of the transformer.

\* Optional

#### Key Features

- Robust Design
- 6 to 18 Channels, 1 Analog Output / Channel
- Large 7" Color Touch Screen LCD (800x480)
- 0, 8 or 16 Form-C Programmable Relays
- Modbus, TCP/IP/Modbus\*, TCP/IP/Serial \* IEC 61850\*, IEC 61870-5-104\*, DNP3.0\*
- 4 GB Data Storage
- No Calibration Required, no Light Source Change for the Life of the Transformer
- Autodiagnostic Features
- 5 Year Warranty

#### Applications

- EHV/UHV/HVDC Transformers
- Power Transformers
- Distribution Transformers
- Reactors, Generators
- Load Tap Changers
- Switchgear
- Power Cables



## Specifications

|                           |                                      |
|---------------------------|--------------------------------------|
| Number of Channels        | 6, 8, 9, 10, 12, 14, 16 or 18        |
| Reading Temperature Range | -40 °C to 225 °C                     |
| Temperature Accuracy      | ±1°C                                 |
| Resolution                | 0.1°C                                |
| Sampling Rate             | 1 Hz                                 |
| Operating Temperature     | -20°C to 65°C                        |
| Storage Temperature       | -30°C to 85°C                        |
| Light Source              | Life of the Transformer              |
| EMI/RFI Susceptibility    | Completely Immune                    |
| Humidity                  | 95% RH Non-Condensing                |
| Display                   | Large 7" TFT Color Display (800x480) |
| System Configuration      | Touch Screen Panel or USB Remote     |
| Security                  | Password Protection                  |

|                         |  |
|-------------------------|--|
| Communication Port      | USB, RS-485 & Ethernet*  |
| Communication Protocol  | Modbus, Nortech IEC61850*, IEC60870-5-104*, DNP3.0* TCP/IP/Modbus*, TCP/IP/Serial*   |
| Analog Output           | 4-20 mA Configurable, 0-1 mA also Available 0.2-1.5mm <sup>2</sup> (IEC) / 28-14 AWG |
| Relays                  | 0, 8 or 16 User Configurable Form-C 0.2-2.5mm <sup>2</sup> (IEC) / 26-12 AWG         |
| System Fault Relay      | 1 Dedicated System Fault Relay   |
| System Status Indicator | LED  |
| Memory                  | 4 GB Memory Card > 30 Years at 1 measurement/minute                                  |
| Auto-Diagnostic         | Light Level, Signal Level  |
| Power Requirement       | 24 VDC   |
| Wattage                 | 40 Watts   |

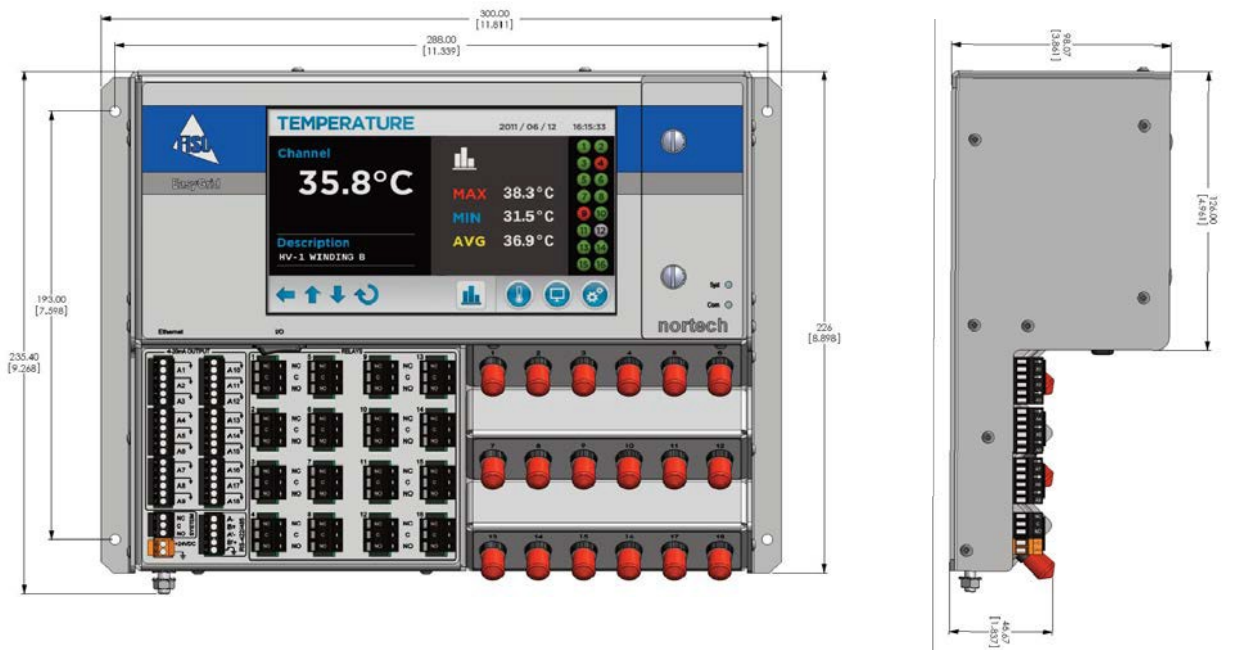
## Environmental standards

|                 |                               |
|-----------------|-------------------------------|
| IEC 600068-1    | Environment Testing: General  |
| IEC 600068-2-1  | Test A: Cold                  |
| IEC 600068-2-2  | Test B: Dry Heat              |
| IEC 600068-2-14 | Test N: Change of Temperature |
| IEC 600068-2-30 | Test Db and Guidance: Damp    |
| IEC 600068-2-78 | Test Cab: Damp Heat, Steady   |
| MIL-STD-810F    | Vibration and Shock           |

## Immunity standards

|   |                               |
|---|-------------------------------|
| IEEE C37.90.1-2002 (4000V) Surge Protection | EN 61326                      |
|   | EN 55011 Class A (Industrial) |
|   | EN 61000-4-2                  |
|   | EN 61000-4-3                  |
|   | EN 61000-4-4                  |
|   | EN 61000-4-5                  |
|   | EN 61000-4-6                  |
|   | EN 61000-4-11                 |

\*Optional



# QUALITROL® 509 DW

Intelligent transformer monitor with direct winding



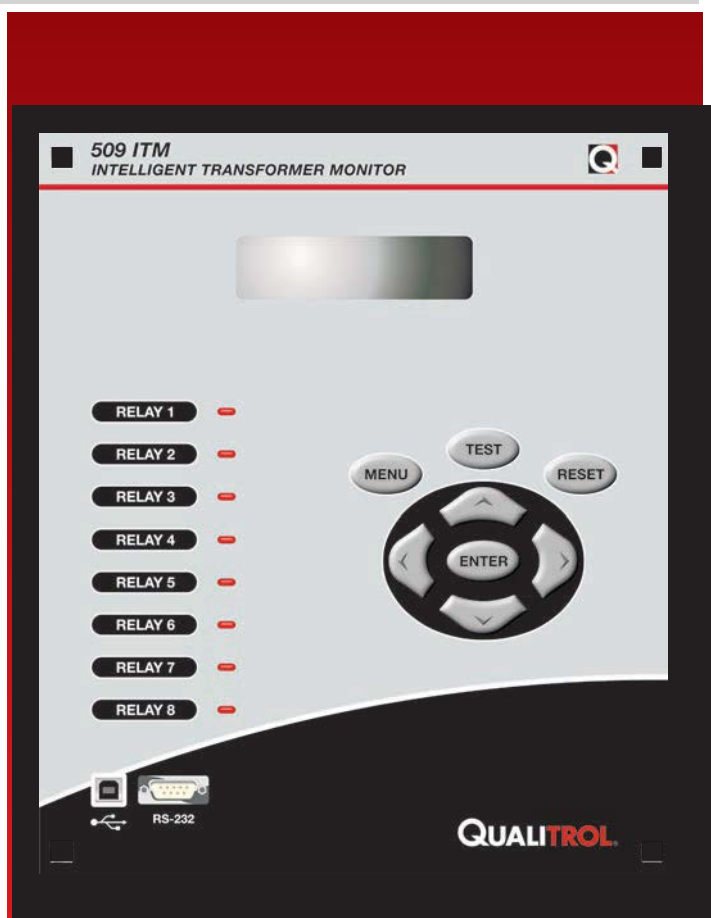
## Real time comparison of calculated and direct winding temperatures

- Maximize cooling efficiency with more accurate hot spot temperature measurement
- Safely optimize loading without compromising transformer life
- Avoid emergency shutdowns by monitoring long-term, gradual transformer deterioration

### Product Summary

**Description** Measures transformer temperatures (direct winding, calculated winding, main tank oil, load tap changer, ambient). Consolidates temperature information with alarm contacts and other information using customizable relays. Accepts most third party sensors for other parameters.

**Application** Remote and local monitoring of oil-filled transformer and load tap changer parameters, including alarming and advanced control of cooling systems.



**QUALITROL®**  
Defining Reliability

# QUALITROL® 509 DW intelligent transformer monitor with direct winding

## Real time comparison of calculated and direct winding temperatures

- Real time comparison of direct (what the temperature actual is) and calculated (what the temperature should be) winding temperatures insures that the transformer continues to operate within OEM specifications and sends an alarm if it is not
- QUALITROL advanced calculated winding temperature uses IEEE and IEC models to estimate the winding temperature based on information provided by the transformer OEM
- QUALITROL hot spot temperature measures the actual temperatures wherever the probe is installed directly

## Maximize cooling efficiency with more accurate hot spot temperature measurement

- Improved control of transformer cooling through fast and accurate measurements, keeping transformers from damaging peaks in winding temperature
- Automatic cooling bank switching normalizes fan and pump usage for maximum life
- Pre-cooling functionality can mitigate damaging high temperatures produced by high transient overloads by initiating the cooling system when load currents exceed configurable set points, rather than waiting for oil or winding temperatures to rise
- Low temperature lock out insures oil pumps remain off at cold temperatures to prevent static electrification and arcing
- Seasonal setback allows for customized cooling schemes depending on the time of the year, helping to optimize cooling system settings
- Adaptive setback improves cooling system efficiency by measuring ambient temperature and then adapting cooling and alarm set points based on temperature trends
- Cooling monitor series learns as it operates; automatically calculates maximum, minimum, and average values for determining set points

## Safely optimize loading without compromising transformer life

- Improved accuracy gained by use of direct winding temperature measurements permits less contingency for measurement error, enabling safe operation at higher loads. This can increase revenue and savings by deferring capacity upgrades

## Avoid emergency shutdowns by monitoring long-term, gradual transformer deterioration

- Continuous monitoring allows for the utilization of a predictive maintenance program, optimizing maintenance performance and costs
- Calculated life consumption based on IEEE or IEC standards aids predictive maintenance programs by providing a representation of the consumed life span of the transformer

## Insure proper load tap changer operation

- Load tap changer monitor series monitors tap position, mechanism and motor performance
- Can detect proper tap movement and contact wear, and logs tap position history
- Alarms for contact loading (instantaneous and cumulative), excessive tap counts over time, false tap movements, false or no motor movement, motor and mechanism problems (overloading, breakage, binding) and worn tap contacts or coking

## Real-time transformer status

- Utilizes digital protocols over Ethernet, RS-232, RS-485 or fiber optics to eliminate costly trips to the substation and integrate with today's communication systems

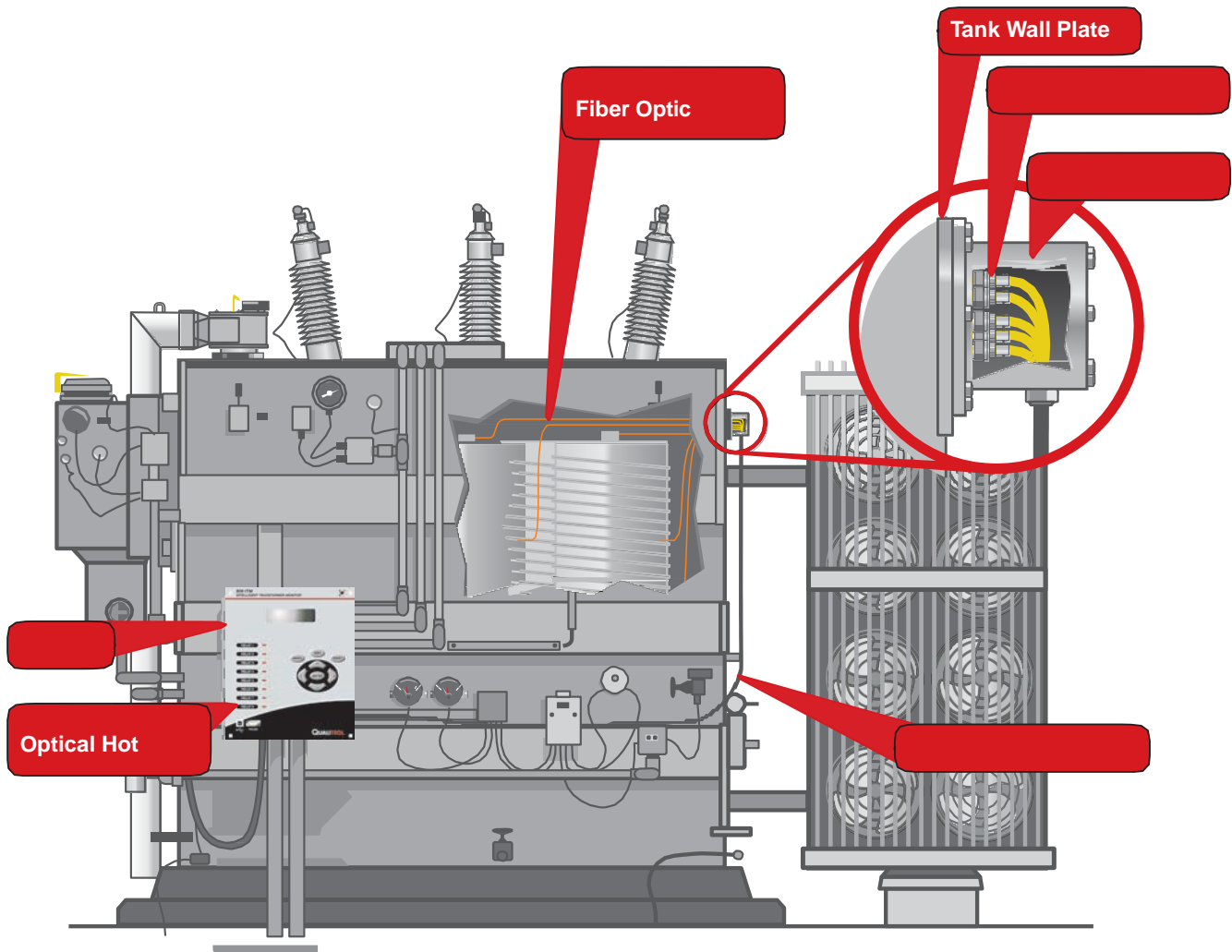
## Real-time automated control

- Flexible inputs (compatible with RTDs, CTs, voltages, current loops and switch contacts) enable all parameters of transformers to be monitored in one integrated device
- Configurable relays can be set to alarm based on customizable set points, a matrix of set points and difference calculations. Improves identification of transformer issues and reduces false trips

## System alarm diagnostics

- Self-diagnostic function continuously tests internal circuitry, processor and external sensors for proper function. If abnormal conditions detected, transformer will be placed in safe mode with fans and alarms on but without false tripping

## System overview



### Winding temperature uncertainty

Winding temperature is a prime concern for transformer operators, a variable that needs to be known under all loading conditions. It is particularly important in unusual conditions involving rapid dynamic load changes. Accurate measurement of the winding's hottest temperature is critical for calculating the insulation's rate of aging. The hot spot temperature is also important in assessing the risk of bubble evolution and in the short term forecasting of overload capability.

Use of fiber optic sensors for temperature measurement within the winding is the only method of directly measuring the hot spot within a transformer. QUALITROL 509 DW fiber optic sensors provide dependable information wherever they are placed, under any loading condition.

### Transformer life

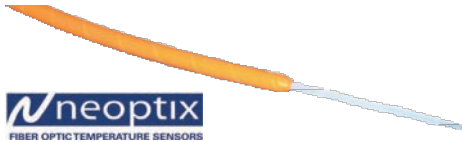
Several factors can reduce a transformer's life: Deteriorating paper insulation (due to elevated temperatures), inaccurate winding temperatures (negatively affecting cooling system efficiency) and fan/pump failure (due to inappropriate on/off switching), to name just a few.

The versatile QUALITROL 509 DW intelligent transformer monitor integrates direct winding measurement and cooling management technology to increase both insulation and cooling system life.



## Components and accessories

### Fiber optic temperature probe (CAB-699)



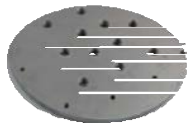
- Life-long accuracy with drift-free GaAs technology
- Surpass ASTM D2413 and D149 dielectric strength tests
- Successfully tested for transformer use by WEIDMANN
- Continuous slit jacket allows uniform oil impregnation
- Accuracy of  $\pm 1^{\circ}\text{C}$
- Solvent and chemical resistant

### Optical feedthrough (CON-159-1)



- Reliably withstands the most demanding conditions without leaking
- Optically bonded with no seals or epoxies
- Survives full vacuum and up to 16 Bar (200 PSI)
- Glass solder seals without gaskets or glue

### Tank wall plate (PLT-201 & PLT-202)



- Standard plate can hold up to 12 optical feedthrough connectors
- Machined holes are numbered and identify oil side
- Provides clear to read identifiers even if painted
- Available in bolted or welded versions
- Custom plates available upon request

### Junction box (COV-121-1)



- Robust neoprene gaskets
- Removable feedthrough access plate for access without disturbing conduit
- Designed to mate with tank wall plate
- 14 gage powder coated steel
- Flat side for easy, leak free, conduit connection

### QUALITROL 509 ITM (ITM509)



- Integrated calculated and direct winding measurement comparison
- Up to 8 flexible inputs: liquid temperature, calculated winding temperature, differential temperature and more
- Cooling system and load tap changer monitor versions available
- Matrix relays allow for maximum flexibility, control and alarming
- All the functionality of the QUALITROL 509 Series ITMs

### Optical hot spot module (MOD-638)



- Based on Neoptix field proven technology
- Up to 8 channels of fiber inputs
- Robust, machined aluminum enclosure
- Data logging capable with OptiLink™ software
- Compatible with any Neoptix probes (with no calibration)
- Light source has a MTBF of 300 years
- Up to 2 modules (16 channels) can connect to one 509 ITM

### Portable fiber optic thermometer (KIT-057-1)



- Perfect for probe verification during installation
- Up to 8 hours of battery operation
- Data logging with secure digital card
- Large LCD display with backlight
- RS-232 communications port for use with OptiLink™ software
- No calibration required
- Accuracy of  $\pm 0.5^{\circ}\text{C}$



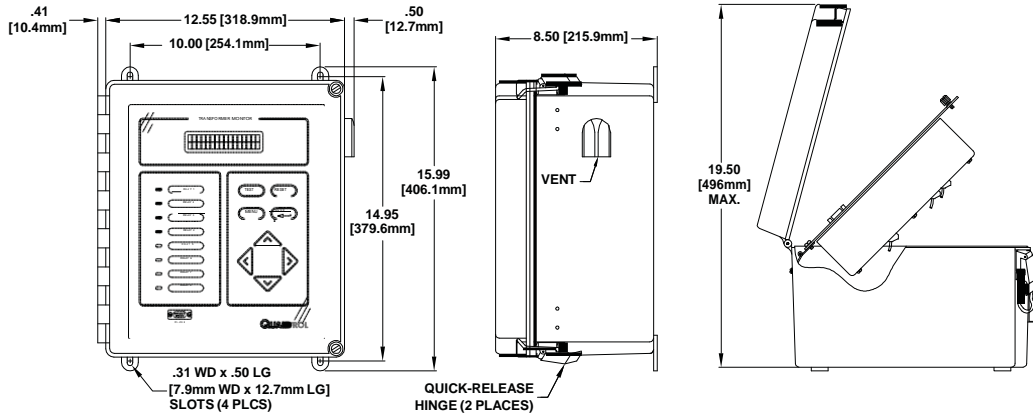
TECHNICAL SPECIFICATIONS

|                                |                             |   |
|--------------------------------|-----------------------------|---|
| <b>Power Supply</b>            | Type                        | Universal; 90 to 264 watts VAC; 47-63 Hz, 40-290 VDC  |
|                                | Consumption                 | <35 watts   |
| <b>Input module parameters</b> | Number of inputs            | Accepts up to 8 input modules of various, configurable types  |
|                                | Accuracy                    | ± 0.5% full-scale input range   |
|                                | RTD                         | 10 ohm copper & 100 ohm platinum (-40°F to 248°F/-40°C to 120°C range)  |
|                                | AC voltage                  | 0 to 140 and 0 to 360 VAC ranges  |
|                                | Potentiometer               | Accepts potentiometers from 5K to 15K   |
|                                | Dry switch contact          | Measures a dry switch contact as wither open or closed  |
|                                | Powered switch contact      | Optically isolated; detects AC or DC from 120 to 250 volts  |
|                                | Tap position                | Detects resistor bridges of 40 to 1 K; up to 32 resistors   |
| <b>Output relays</b>           | Number of relays            | 8 programmable, 1 system status, 1 for heater control   |
|                                | Type                        | Form C, 10 amps @ 120/240 VAC, 10 amps @ 30 VDC   |
| <b>Output current Loop</b>     | Number of loops             | 4 magnetically-isolated current loops   |
|                                | Type                        | Customer configurable in software to hoose between 0-1 mA (max load 450Ω) and 4-20 mA (max load 10,000Ω)                    |
| <b>Communications</b>          | RS232 port                  | 1 port for set-up communications located on the front panel; varying baud rates   |
|                                | RS485 port                  | 1 port, 4-wire optically isolated for digital protocols   |
|                                | Fiber optic port            | ST connectors, 820 nm wavelength, max distance 1500m  |
|                                | USB ports                   | 1 type B (slave) for local setup, 1 type A (master) for data logging download and configuration upload with USB flash drive |
|                                | Protocols                   | DNP 3.0 level 1 slave, Modbus RTU, ASCII, IEC 61850, IEC 60870  |
| <b>User Interface</b>          | Control                     | 8 pushdown buttons located on front panel   |
|                                | Local display               | 2 x 16 character backlit LCD  |
| <b>Environmental</b>           | Operating temperature       | -40°F to 161.6-40°F (-40°C to + 72°C)   |
|                                | Storage temperature         | -58°F to 185°F (-50°C to + 85°C)  |
|                                | Humidity                    | 5% to 90% non-condensing  |
|                                | Shock                       | 10 G's half-sine, in three orthogonal planes  |
|                                | Vibration                   | 60/120 Hz @ .004 inch displacement; 10/150 Hz at 1G   |
| <b>Immunity</b>                | Dielectric isolation        | 2500 VAC, 60 seconds to ground  |
|                                | Certifications              | IEEE C37.90.1, IEC 61000-6-1, IEC 61000-6-2, IEC 61010-1, CE approved   |
| <b>Data logging</b>            | Number of points            | Logs up to 20 parameters  |
|                                | Log rate                    | Selectable from one minute to 24 hours  |
|                                | Memory capacity             | Memory size capable of storing 8 parameters at one hour log rate for over 19 months. Shared 32MB non-volatile flash memory  |
| <b>Event Recording</b>         | Number of points            | Logs up to 8 events   |
|                                | Record types                | 2 record types: time and date or complete system snapshot   |
|                                | Memory capacity             | Memory size capable of storing 62,500 time and date events, shared 32 MB non-volatile flash memory                          |
| <b>Direct winding</b>          | Fiber optic probes          | Neoptix T2® fiber optic temperature probe   |
|                                |                             | Up to 16 channels via 2 optical hot spot modules  |
|                                | Fiber optic extension cable | Polyurethane sheath, Kevlar reinforcement and PVC liner   |

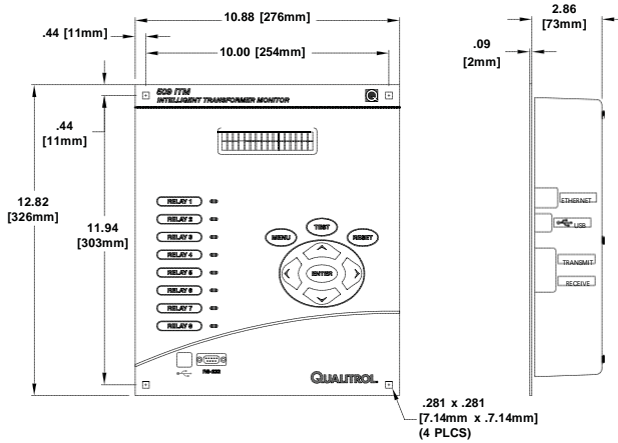
# QUALITROL® 509 DW intelligent transformer monitor with direct winding



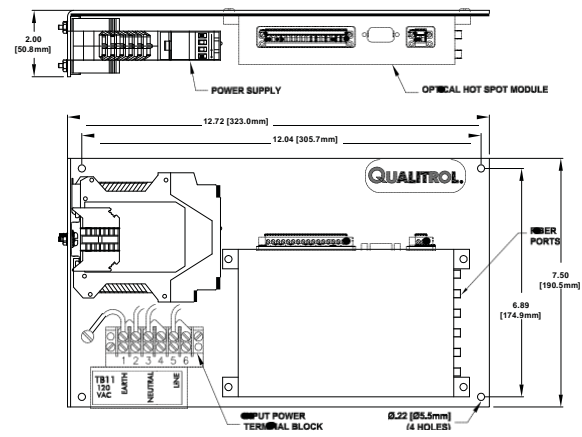
## Weatherproof enclosure



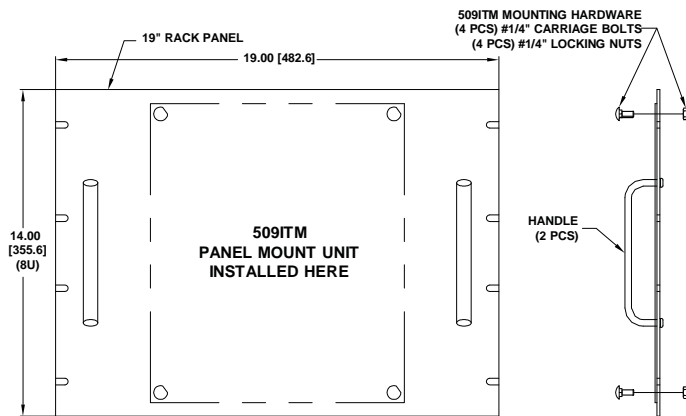
## Panel mount



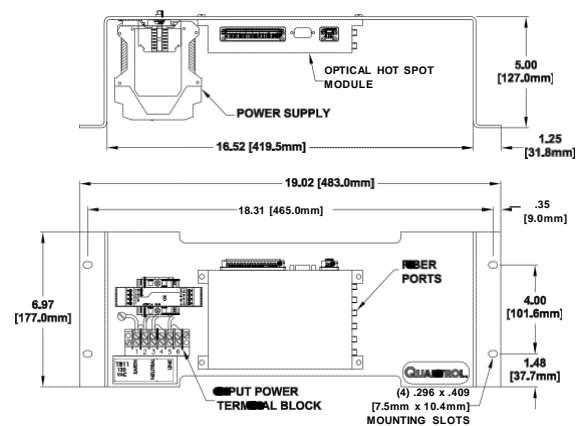
## DW component



## 19" rack mount



## DW component



## About QUALITROL®

QUALITROL Company LLC manufactures substation and transformer monitoring and protection devices used by electric utilities and manufacturing companies. It is the global leader in sales and installations of transformer asset protection equipment, fault recorders and fault locators. Established in 1945, QUALITROL Company produces thousands of different types of products on demand, each customized to customers' unique requirements.

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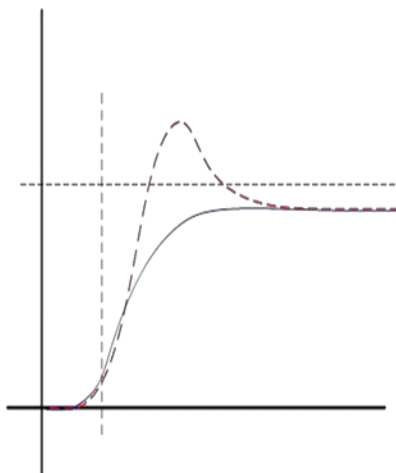
# TTC-1000

## Monitor With Confidence™

- Liquid Temperature
- Winding Hotspots
- LTC Differential
- Ambient Temperature
- Load Current
- High-Precision RTDs
- No Calibration Required, Ever.



### Complete Monitoring for Your Power Transformer



“Smart Grid” Ready

Load Based Pre-Cooling

Track LTC Position for Complete LTC Monitoring

SCADA Communications

Consolidate Alarms with Mini-RTU Capability

Simple to Configure

Highly Cost Effective & Easy to Install

Lifetime Warranty

TM

# TTC-1000

Intelligent Transformer Temperature Control

## Available in 2 Mounting Options

- Panel Mount - For mounting within the transformer control cabinet. (As shown on cover)  
7.2" W x 3.558" H x 6" D  
Aluminum Chassis
- NEMA 4X Enclosure - For mounting on the exterior of the transformer, typically used for retrofit applications.  
15.25" H x 7" W x 5.25" D  
304 Stainless Steel  
Heater option available.



NEMA 4X Enclosure

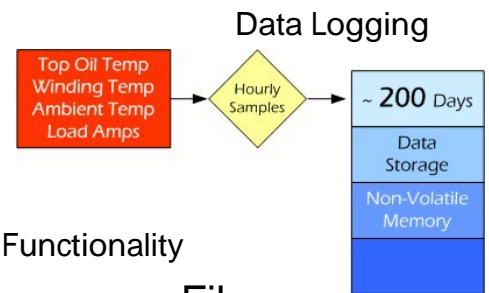


## Monitor **Critical** Temperatures

- Up to 3 Temperature Probes (-35 to 160 °C)
- Set Points for Alarms & Fan Control
- Up to 3 Calculated Winding Hotspot Temperatures
- Monitor Ambient Temperature to Calculate Loss-of-Life
- Up to 2 LTC Differential Temperatures Simultaneously  
- Mag-Mount Probes Available

## Collect Data & Communicate It

- Temperature, Load, and Min/Max Data Logging
- LTC Position & Differential Temp Data Logging
- Up to 4 Analog Outputs (0 to 1 OR 4 to 20 mA)
- Up to 14 Optically Isolated Digital Inputs for Mini-RTU Functionality
- DNP3.0 Level 1 or MODBUS RTU Communications via Multi-Mode Fiber



Advanced Power Technologies



## “On-Line” LTC Monitoring

LTCs are a critical **Point of Failure** on your transformer...

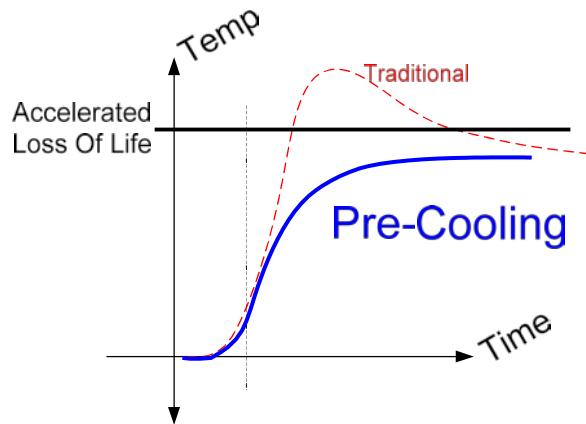
What is your LTC doing right NOW?

- Continuous LTC Differential Monitoring (-20 to +20 °C)
- Patented Dual-Algorithm LTC Condition Monitoring™
  - Protect Against Dangerous “Coking” Contacts
  - Alarm for Rapid LTC Heating Events
- Patented Sensorless LTC Position Monitoring™
  - Know with Certainty Which Taps are Getting Hot
  - Monitor Tap Change Operate Times and Alarm

## Cool Your Transformer

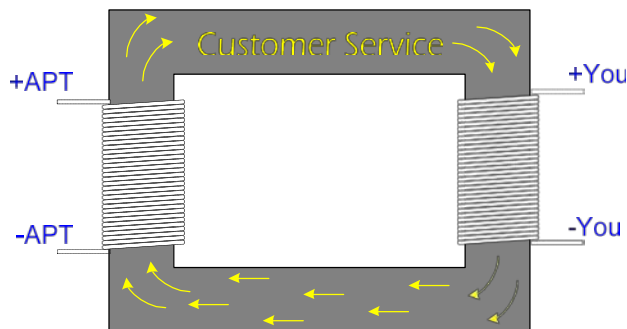
With Confidence...

- Patented Load Pickup Cooling™
  - Transformer **PRE-Cooling**
  - Extend Transformer Life
  - Longer Short-Term Overloads
  - Sustain Paper Insulation **DP** Levels
  - Ideal for Wind Farm Load Cycles
- Up to 8 Form C Relay Outputs
  - Control Fans and Pumps



## Additionally...

- Exceptional Customer Service
  - Periodic Fan Exercising.
  - Fan Bank Alternate Feature
    - Built In Self Check
- Dedicated Form B Device Alarm Relay
- Easy to use, Excel-Based Setting Templates



# TTC-1000 Model Option Table

Ordering Information

Select **One** Option from each Feature Matrix

TTC-1000 - **U** **V** **W** **X** **Y** **Z**

## Mounting

|                   |   |
|-------------------|---|
| Panel Mounting    | 0 |
| NEMA 4X Enclosure | 3 |
| NEMA 4X w/ Heater | 4 |

## Extra Auxiliary CTs

|       |  |
|-------|--|
| 0     | No Extra Auxiliary CTs                                       |
| 1 - 8 | 1 or More Extra Auxiliary CTs<br>(Enter Number of Extra CTs) |

## Analog Outputs, DNP & MODBUS

|                           | Communications | No DNP 3.0 | MODBUS RTU |
|---------------------------|----------------|------------|------------|
| No Analog Outputs         | 0              | 5          | 1          |
| 1 Analog Output           | 2              | 6          | 9          |
| 2 Analog Outputs          | 3              | 7          | A          |
| 3 Analog Outputs          | 4              | 8          | B          |
| 4 Analog Outputs          | G              | S          | T          |
| 1 Isolated Analog Output  | C              | H          | M          |
| 2 Isolated Analog Outputs | D              | J          | N          |
| 3 Isolated Analog Outputs | E              | K          | P          |
| 4 Isolated Analog Outputs | F              | L          | R          |

## Multi-Mode Fiber 12 Optically Isolated Digital Inputs Extra RS-232 Port

|   | No Digital Inputs<br>No RS-232 Port | 12 Digital Inputs | Extra RS-232 Port | 12 Digital Inputs &<br>Extra RS-232 Port    |  |
|---|-------------------------------------|-------------------|-------------------|---|--|
| 0 | 5                                   | 1                 | 7                 | No Fiber                                    |  |
| 3 | 6                                   | 4                 | 8                 | Multi-Mode Fiber for<br>DNP or MODBUS       |  |
| 9 | B                                   | A                 | C                 | V-Pin Multi-Mode Fiber for<br>DNP or MODBUS |  |

## Form C Relay Outputs 2 Optically Isolated Digital Inputs Sensorless Tap Position Monitoring (TPM)

|   | No Digital Inputs<br>No Tap Position Monitoring | 2 Digital Inputs | Tap Position Monitoring (TPM)          |  |
|---|---|------------------|--|--|
| 0 | 2   | ■                | 4 form C Outputs                       |  |
| 1 | 5   | 6*               | 6 form C Outputs (* 2 inputs with TPM) |  |
| 8 | ■   | 9                | 8 form C Outputs                       |  |

## Temperature Probe Channels & Auxiliary CT1

|                              | No Auxiliary CT | 1 Auxiliary CT |
|------------------------------|-----------------|----------------|
| 1 Temperature Probe Channel  | 1               | 3              |
| 2 Temperature Probe Channels | 2               | 4              |
| 3 Temperature Probe Channels | 6               | 7              |

## Additional Specifications:

- Operating Temperature Range: -50 °C to +85 °C, 95% Relative Humidity (non condensing)
- Universal Power Supply: 38 to 290 VDC or 120 VAC
- Winding Temp Measurement Range: -35 °C to +180 °C
- Temperature Measurement Accuracy: Avg error over entire range ± 1 °C. Absolute error at any temperature ± 1.5 °C.
- Output Contact Rating: 30 amps make for 250 msec, 10 amps continuous at 250VAC.
- Optically Isolated Inputs: Operates from 38 to 290 VDC or 24 VAC to 260 VAC. External wetting voltage required.
- Alarm Contact Rating: 0.4 amp continuous at 290 VDC (NEMA), 0.15 amp continuous at 290 VDC (Panel)
- Analog Output: Selectable, 0 to 1 mA or 4 to 20 mA. Maximum load 10,000 Ohms (0 to 1mA), 510 Ohms (4 to 20 mA).
- Communications Interfaces: Front Panel Mounted RS-232, DB-9 Null Modem Interface
- SCADA Interface: DNP3.0 Level 1 Protocol using half duplex RS-485 interface, Multi-Mode or V-Pin fiber optics.
- Current Measurement Range: 0 to 50 A
- Surge Withstand/Fast Transient: Relay outputs and station battery inputs: ANSI C37.90.1
- EMI Withstand: ANSI C37.90.2, IEC 801-2
- Electrostatic Discharge: IEC 801-2
- Timers: Output Pickup Timer, and Load Pickup Timer: 0 to 255 seconds

## TTC-PROBE - X Y - Z Z Z

Probes must be ordered separately from the main TTC-1000 unit

### Probe Type

|  |   |   |
|--|---|---|
| Ambient Temperature Probe (50 ft lead)               | 0 | 0 |
| Universal Well Probe w/ Snap Elbow                   | 0 | 1 |
| Magnetic Surface Mount Probe                         | 0 | 2 |
| ANSI C57 Well Probe w/ Snap Elbow                    | 0 | 5 |
| Universal Well Probe Liquid Tight Ready <sup>1</sup> | 1 | 1 |
| ANSI C57 Well Probe Liquid Tight Ready               | 1 | 2 |
| 5/16" Well Probe w/ Snap Elbow                       | 2 | 1 |
| 1/4" Well Probe w/ Snap Elbow                        | 3 | 1 |
| Ceramic Probe for Dry Types 160 <sup>1</sup>         | 5 | 1 |

NOTE: <sup>1</sup> Handles thermometer well diameters of:  
- 0.375 inches  
- 0.500 inches  
- 0.625 inches  
- 0.700 inches

### Additional Lead Length

ZZZ Probe lead length (10 to 250 feet). Enter 3 digit length. Example: 050

NOTE: A 10 ft. lead length is automatically included, with the exception of the Ambient probe which is 50 ft. Add additional lead length as needed.

Retrofit Mounting Bracket available for NEMA 4X enclosure option P/N 80001000167:

## Advanced Power Technologies

[www.AdvPowerTech.com](http://www.AdvPowerTech.com)

215 State Route 10, Building 2  
Randolph, NJ 07869  
Phone: (973) 328-3300  
Fax: (973) 328-0666

# QUALITROL® 609 PDM

Transformer partial discharge monitor



## Turn key condition monitoring solution to prevent costly failures and extend asset life of transformers

Accurate and early incipient fault detection ensures reliable operation and reduces supply outages

Creates highly accurate reports on asset condition hence reduces maintenance cost

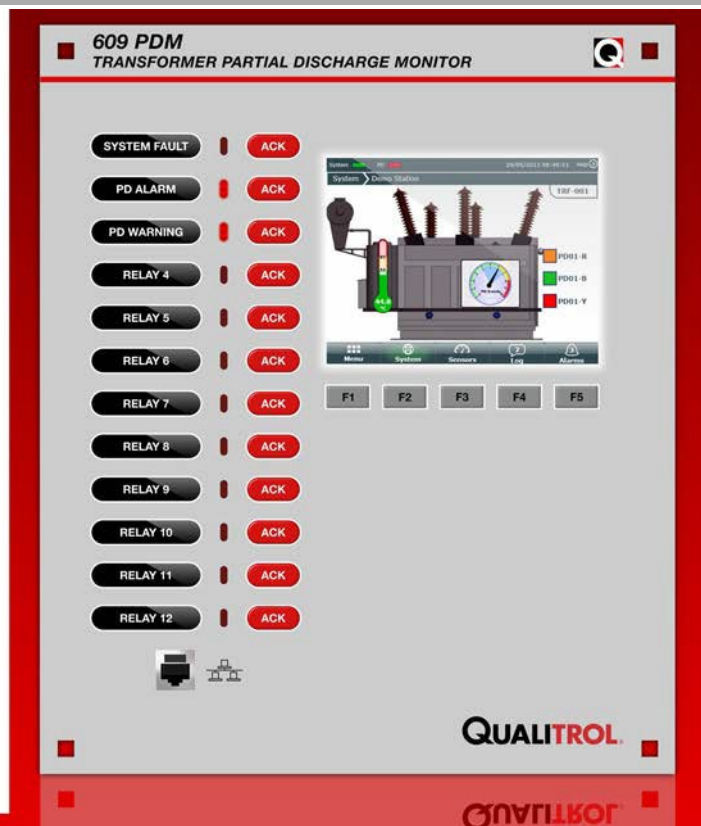
Monitors multiple transformers simultaneously resulting in higher return on investment

Robust design and excellent interference immunity for measurements under difficult environmental conditions

### Product Summary

**Description** The 609 PDM system is an on-line partial discharge (PD) monitoring system for power transformers, based on industry accepted UHF technology.

**Application** The 609 PDM is used to continuously assess the performance of insulation in a power transformers so that corrective actions can be taken before any failure occurs. The information gained from the system is used for condition based maintenance decisions to optimise maintenance expenditure.



**QUALITROL®**  
Defining Reliability

## QUALITROL 609 PDM Transformer partial discharge monitor

### Turn key condition monitoring solution to prevent costly failures and extend asset life of Transformers

The 609 PDM is a complete PD monitoring package that includes sensors, cables, data acquisition unit, processing unit (CPU) and software

- Commissioning, training and diagnostic services through our expert engineers and researchers
- Condition monitoring of insulation of power transformer whilst asset is still in service
- Calibration facility for sensors to verify proper operations

### Accurate and early fault detection ensures reliable operation and reduces supply outages

- Outstanding sensitivity and accuracy (-75 dBm) of UHF measurements
- Built-in sensitivity of -75 dBm enables better PD analysis
- Wide bandwidth of 300 to 1500 MHz
- Higher sample resolution (256 samples per cycle) improves definition of PD events
- Amplitude comparison helps in approximate localisation of PD fault
- Easy alarm setting configurable for each channel separately

### Creates highly accurate reports on asset condition hence reduces maintenance cost

- Integrated Reporting: Need based customizable reports created automatically in a single document
- Flexible PD event visualization, including PRPD (Phase Resolved Partial Discharge), PRPS (Phase Resolved Pulse Response), POW (Point on Wave) and STT (Short Term Trend)
- PRPD recording facility helps in analyzing historic data
- Fast and easy access of data in generating reports

### Monitors multiple transformers simultaneously resulting in higher return on investment

- Suitable for 1 to 24 channels depending on the transformer location and monitoring sensors per transformer
- External OCUs can be connected to the same 609 base unit
- No need for any additional cabinet, CPU and software

### Robust design and excellent interference immunity for measurements under difficult environmental conditions

- Rugged sensors and connectors with IP66 rating
- Built-in display and remote client enable safe operations in difficult environmental conditions
- Noise gating by external signal antenna (optional)
- Transient protection for each channel

### Advanced HMI provisions (intelligent data handling, display and interpretation)

- Built-in LCD screen with touch screen based interface
- Automatic self-check of PDM with faults logged and alarmed
- 2D and 3D display of PD signals in multiple formats (PRPD, PRPS, POW and STT)
- Trend analysis facility on stored PD data
- Self-test functionality for each channel saves time in diagnosing system fault
- Export functions for PD results / reports
- Remote client interface with integrated software to view, analyse and display PD events and trending

### Qualitrol Expert PD analysis services

- Highly experienced and industry known experts to analyse PD events
- PD analysis report (on demand) prepared by Qualitrol experts
- Support available on system installation, testing and PD analysis

*A complete condition monitoring package...*



**Flexible installation and configuration options to meet customer expectations**

Very rapid and easy deployment  
Sensors can be fitted to available inspection hatch, drain valve or manhole as retrofit  
Easy configuration of system (offline / online) using touch screen interface  
Required modules and features already installed into the system  
Support to multiple operating systems (Windows XP, Windows 7)

**Smart and quick real time alarming / alerting mechanism**

Easily programmable alarm criteria and rule engines  
Hardwired alarms for SCADA and local user interface  
Real-time monitoring of events with time accuracy of 1 millisecond  
Facility to alert through SMS, email, IEC 61850, substation RTU

**Remote monitoring and configuration**

Secure client interface provides functionality to monitor and archive alarms and event information  
Facility to configure system remotely  
Multiple communication methods (Ethernet, RS-485, RS-232)  
Built-in support for Modbus, DNP3.0 and IEC 61850 protocols

**Expandable and field upgradable without reconfiguration**

Designed for future expandability and ability to take inputs from sensors with 4 -20 mA output  
16 GB SLC SSD storage capable of being upgraded if required  
Supports addition of future client applications  
Easily changeable front panel alarm layout

**Other key benefits**

Designed to meet highest security standards, including NERC cyber-security standards  
Built-in time synchronization through NTP/SNTP

**Why UHF (Ultra High Frequency) technology?**

UHF technology is industry proven technology for online monitoring of partial discharge in insulations of HV apparatus  
The sensitivity is higher than any other kind of PD measurement e.g. DGA, Acoustic, or conventional measurement  
Immediate detection of partial discharge makes it ideal for online monitoring and detects PD earlier than DGA (Dissolved Gas Analysis)  
Excellent interference immunity compared to acoustic and conventional measurements

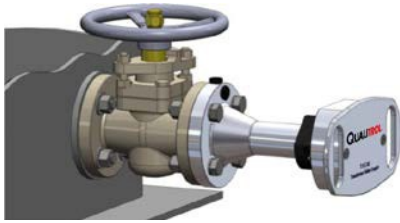
**Why Qualitrol DMS?**

Qualitrol DMS is the pioneer in UHF based PD measurement technology  
Qualitrol DMS has more than 20 years of experience in supplying UHF based PD monitoring systems to utilities across the world  
Proven and tested hardware and software systems for more than 20 years  
Industry known expert service in PD analysis and reporting  
Long term serviceability assurance and upgrade options to the 609 PDM system

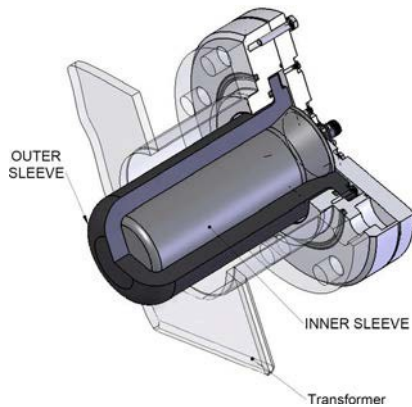
*...from the world leader in PDM*

# QUALITROL 609 PDM Transformer partial discharge monitor

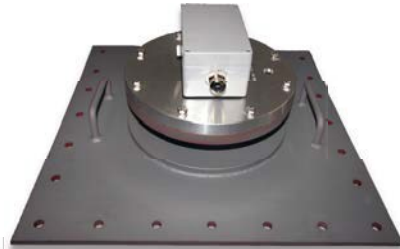
## System components



▲ Oil drain valve sensor



▲ Window sensor (patented)



▲ Sensor - retrofit to hatch cover



### UHF sensor (coupler)

UHF sensors are the key components of any PDM system. They capture the UHF signals induced from PD pulse and send to the data acquisition system for interpretation.

The 609 PDM can be connected with any available UHF sensor internal, window or drain valve sensor. The system can be scaled from one sensor to 24 sensors.

In new transformers the sensors are usually fitted internally, inside the tank wall (internal sensors). They act as antennas picking up UHF signals induced from PD. Complete protection for sensitive electronics of the 609 PDM is assured by fitting an external DMS protector which shunts dangerous voltages to earth.

For retrofitted systems, external sensors are fixed in either hatch covers or drain valve.

Qualitrol DMS can custom-design all types of UHF sensors for particular applications and calibrate them to ensure they meet the users specification for sensitivity and bandwidth.

### Optical Converter Unit (OCU)

Each OCU takes the signal from the UHF sensors and applies filtering to reject interference (noise) that can result from broadcast signals, discharges in nearby air-insulated equipment and other sources. The characteristic of the UHF pulse is then sent to the Equipment Cabinet.

Additional fibres within the cable are used for OCU control and to initiate an integrated self-test procedure that automatically checks and logs the condition of each channel.

The OCUs are totally protected against high-voltage transients and are suitable for use in harsh environments.

### Equipment Cabinet

The Equipment Cabinet consist of central processing unit (CPU), switch to connect OCU and inputs for 4 - 20 mA signal. It also has an option to include an OCU in the box

Embedded processors format the data and provides a real-time display of the partial discharge activity.

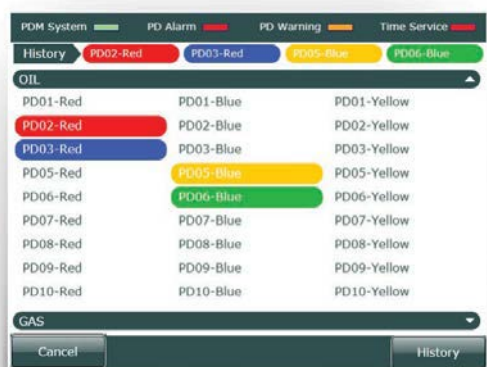
The CPU receives the optical data streams from the OCU's and transmits control signals back to the OCU (i.e. for the self test).



## System software



Touch interface (showing PD display)



Touch interface (showing PD plot)

High clarity PD analysis, easy configuration and operation of PD events and easy access to historical data

## Data handling, display and interpretation

All single-cycle event data gathered by the sensors is automatically analyzed by a range of sophisticated software and display logics to identify the PD. At the same time, sources of interference such as lights, radar, mobile phones, motors, etc, are rejected.

The 609-PDM system operates simultaneously in different modes and will capture isolated PD events even while displaying the current on-line data. The data can be viewed in a number of ways including POW, PRPD, PRPS, and STT format to give an instant impression of the PD characteristics.

For the remote operation of the system, a duplicate PC, modem and LAN interface can be installed off-site. This enables the 609 PDM family to be operated, controlled and data received in a similar way to being present at the substation.

### Key features

2D and 3D real time PoW, PRPD and PRPS data display and analysis

3D, real time single-cycle (PRPS) and PRPD display and analysis

True PRPD, STT real time displays

Periodic storage of point-on-wave displays for trend analysis

Event Mode captures single events

Data stored on hard disk for up to 10 years

Automatic self-check of PDM with faults logged and alarmed

Transfer of data to remote site by company LAN or Modem

Programmable alarm criteria

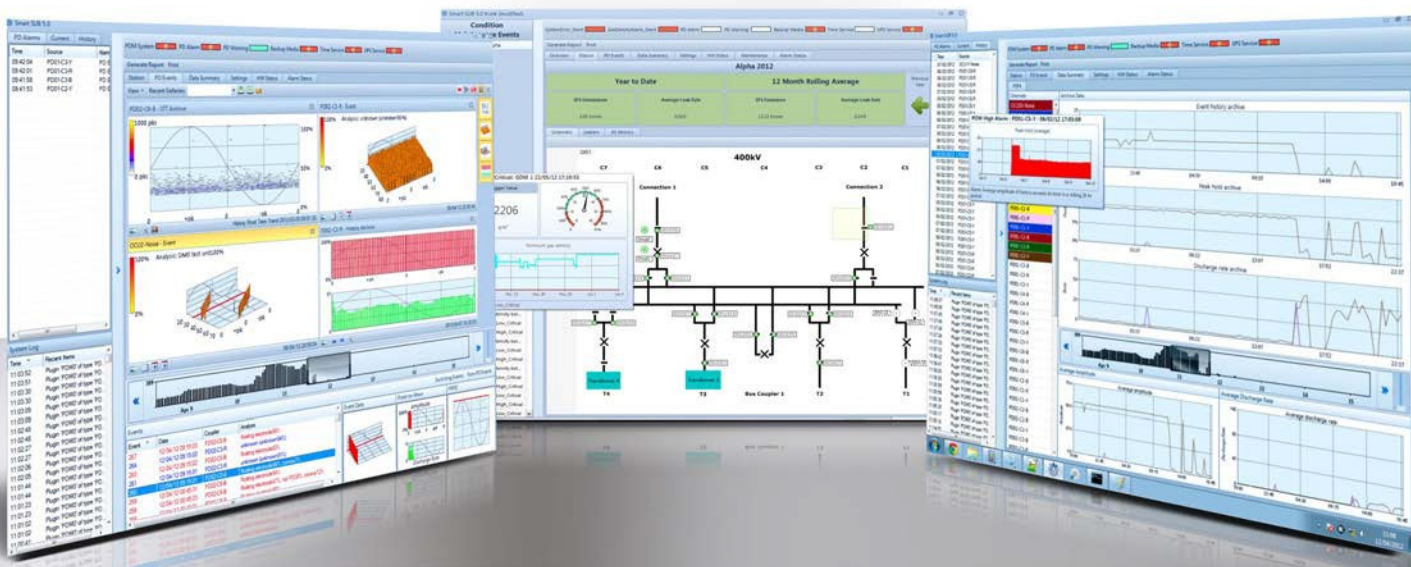
Warning of PD activity

Alarm of high or increased PD activity

Automatic communication of warning / alarm condition to headquarters PC

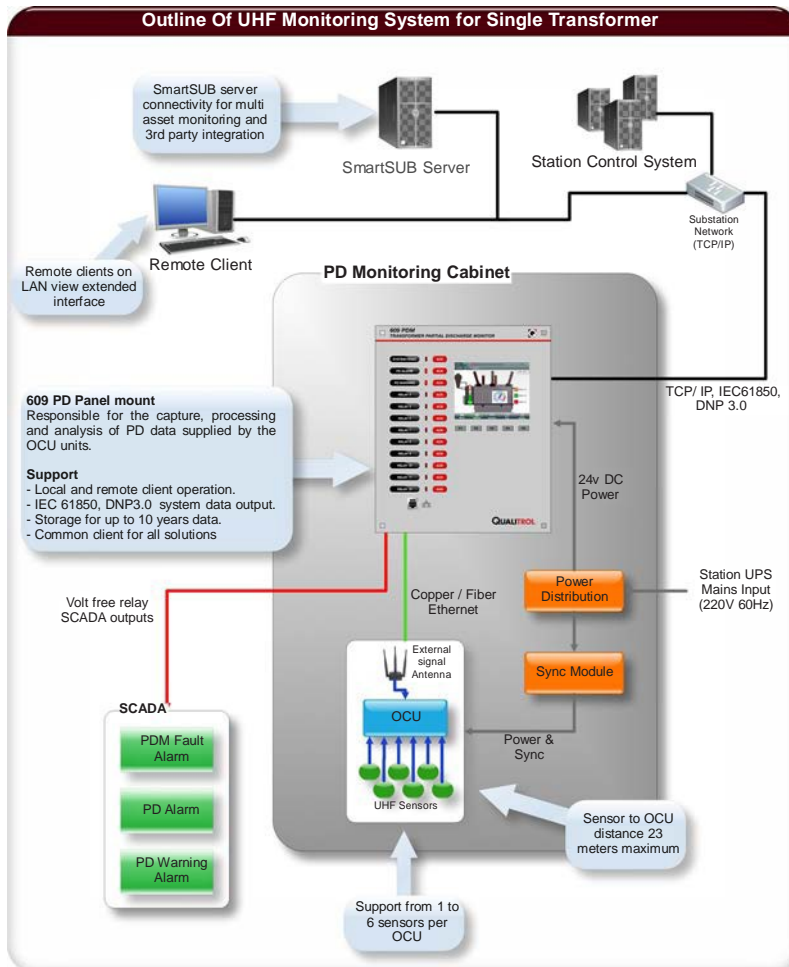
Alarm notification using IEC 61850

Automatic report generation (daily / weekly / monthly) as per customer needs



# QUALITROL 609 PDM Transformer partial discharge monitor

## 609 PDM architecture



### A typical 609 PDM system consists of:

- UHF sensors / couplers (internal, external, or drain valve sensors)
- 1 OCU that can support 1 to 6 sensors
- 609 main panel including central processing unit (PD monitor)
- PD analysis and reporting software

### Optional:

- External OCUs that can support 1 to 6 sensors each
- Independent system enclosure for 609 base unit and one OCU
- 1 Ethernet switch (fiber-optic or copper) for each external OCU

## 609 PDM - full after sale support

### Commissioning and calibration



- Qualitrol provides additional service and tools for calibrating sensors and commissioning the PD monitoring system
- Our staff can install, calibrate and verify proper operation of the system
- We also provide training to customer's staff on how to operate and maintain the system
- After installation, Qualitrol also provides assistance in setting up the configuration e.g. alarm limits, noise gating, drawing layout diagrams into the system etc

### Training and Expert service



- Qualitrol DMS provides a training course to customers on PD measurements, analysis and how to operate and maintain the 609 PDM system
- Additional training programs are also organised for all customers to make them aware about PD measurements and analysis using our products
- Qualitrol DMS also provides detailed PD analysis service by its highly experienced and industry known experts on UHF technology. PD analysis reports can be made available periodically (on demand) based on the PD event data received from the field

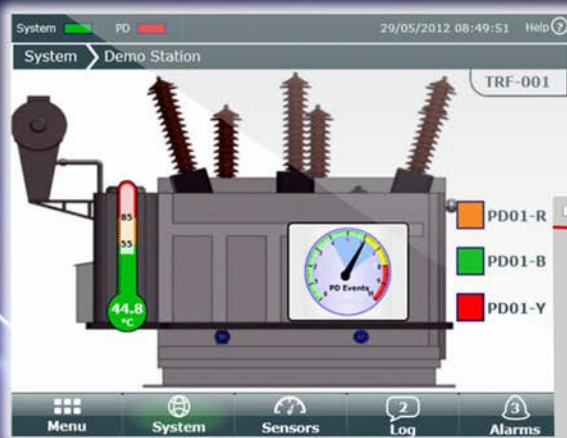
## TECHNICAL SPECIFICATIONS

|                                     |   |   |
|-------------------------------------|---|---|
| <b>Power supply</b>                 | Voltage range                           | 90 to 264 V AC; 47 to 63 Hz   |
|                                     | Supply power                            | 70 W  |
|                                     | Local MMI interface                     | 5.7" resistive touch  |
|                                     | Output                                  | Three SCADA/ SCS alarms contacts:<br>PD Warning<br>PD alarm<br>System Fault<br>Ethernet, IEC 61850<br>12 x LED status indicators (bi-colour)  |
| <b>MCU (Optical Converter Unit)</b> | Input (UHF)                             | Supports 1 to 6 UHF channels for UHF sensor inputs  |
|                                     | Input (noise)                           | 1 separate noise channel for external noise antenna   |
|                                     | Dynamic range                           | -75 to -35 dBm (logarithmic)  |
|                                     | Sample rate                             | 15360 samples/s per channel at 60 Hz  |
| <b>UHF sensors</b>                  | Mounting                                | Internal or External  |
|                                     | Output                                  | Coaxial Analog output (N-Type)  |
|                                     | Bandwidth                               | Wideband 200 - 1500 MHz   |
|                                     | Sensitivity                             | < 5pC   |
| <b>Noise sensor</b>                 | Gating antenna                          | 100 - 3000 MHz  |
| <b>609 Base Unit PC</b>             | Memory                                  | 2 GB. Upgradable (if required)  |
|                                     | Minimum size for installation           | 20 MB   |
|                                     | Data storage                            | 16 GB   |
|                                     | Clock                                   | 1.6 GHz   |
|                                     | Interference filtering                  | Gating, bandpass filtering, software filtering  |
|                                     | Reporting                               | Daily, weekly and monthly reports   |
| <b>Panel PC</b>                     | Ethernet ports - external               | RS-232, RJ45 (10/100 Mbps)<br>Optional RS-485 (full duplex and half duplex)   |
|                                     | USB                                     | One port to facilitate firmware upgrade, configuration upgrade and manual download of data  |
|                                     | Protocols                               | Ethernet / serial; Modbus (serial); IEC 61850   |
| <b>HV testing</b>                   | Compatible                              | Ability to monitor and record PD during testing   |
| <b>Environmental</b>                | Ambient operating temperature           | -45° to +55° C [-49° to +131° F]  |
|                                     | Storage temperature                     | -25° to +85° C [-13° to +185° F]  |
|                                     | Humidity                                | 5 - 95% non-condensing  |
|                                     | Enclosure rating                        | IP66  |
|                                     | Seismic                                 | IEEE C37.98 (seismic testing of relays)   |
|                                     | Environmental test compliance           | BS EN60068-2-2, BS EN60068-2-1, BS EN60068-2-78   |
| Vibration test compliance           | BS EN68-2-6, BS EN68-2-27, BS EN68-2-29 |   |
| <b>Immunity</b>                     | EMC test compliance                     | Conforms to relevant specifications for monitoring / control equipment in HV substations.<br>BS EN55022 (:2006); BS EN61000-3-2 to -3-3, BS-EN61000-4-2 to -4-6, BS EN61000-4-8, BS EN61000-4-11, BS EN61000-4-18; IEC 60255-5, IEC 61180-1 |
|                                     | Others                                  | EMI / RFI immunity  |



# 609 PDM

A complete CBM package



**H**ighly sensitive and most effective UHF PD detection

**S**upports IEC 61850

**E**xpandable to monitor PD up to 24\* power transformers simultaneously

**E**xcellent interference immunity for PD measurement under difficult conditions

**H**V record mode, versatile sync, superior data review method

**I**mplementation of efficient, condition-based maintenance strategies

**E**xpert PD analysis and reporting by Qualitrol Experts

**R**ugged and reliable design (IP66 rated)

**R**educes insurance premium of costly HV apparatus

**S**mart and Quick realtime alarming / alerting mechanism

\* Depending on the transformer location and monitoring sensors per transformer

### About QUALITROL®

Established in 1945, with continual improvement at the core of our business, QUALITROL® provides smart utility asset condition monitoring across the globe. We are the largest and most trusted global leader for partial discharge monitoring, asset protection equipment and information products across generation, transmission and distribution. At QUALITROL® we are redefining condition monitoring technology for Electric utilities assets.

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## PD-Smart electrical

### Applications

The digital, highly advanced and multi-purpose Partial Discharge and Diagnostics System PD-Smart is developed for periodic on-line and off-line PD testing on power apparatus and high voltage insulation systems, for both in-house and on-site applications. The compact and rugged PD-Smart allows you to test and analyze rotating machines, transformers, cables and insulating busbars while in service or offline by using an external power resource. It is fully compatible to DIN EN 60270, VDE 0434, ANSI and other IEEE-Standards.



Following application fields are possible:

- » Lab measurements on any type of insulating material and HV components during Research & Development (R&D) as well as for sciences measurements
- » Quality testing in regard to PD on HV apparatus and accessories during or after assembling/manufacturing
- » Partial Discharge testing and analysis whilst installation or commissioning of HV apparatus
- » Partial Discharge Measurements during the complete service life of the equipment (while in operation or during maintenance/revision)

### Benefits

- » Highest measurement accuracy and sample rate due to complete digital system. Furthermore the PD charge evaluation with the PD-Smart is fully compatible with IEC 60270, VDE 0434 and ANSI.
- » Advanced noise suppression tools. Nothing is more problematic than the interferences caused by on-site noise. The PD-Smart has a variety of noise suppression techniques:
  - » Noise Gating via integrated hardware gating channel
  - » PD Windowing with unlimited number of windows for an easy suppression of phase-locked noise signals
  - » Freely adjustable frequency and filter
- » Synchronous measurement. The system can be easily extended for truly synchronous multi-channel measurements. The Star-Diagram helps to differentiate various PD sources and noise from each other. While measuring three phases simultaneously, the combined results are displayed in the Star-Diagram.
- » Smart User Interface. The new smart user interface represents over 40 years of Lemke's knowledge in design of measurement equipment. Each user can now customize the layout of the dashboard to his personal needs. PD testing will therefore

## PD-Smart electrical

be easier, faster and a great experience.

» Well-known and advanced Lemke Noise Gating Technology. The PD-Smart provides one separate channel for real hardware gating. The elimination of external noises happens via a separate antenna (gating sensor L110). These features are already included in the standard PD-Smart delivery volume. No other units are needed and thus no extra charge will apply.

» Ruggedized and easily transportable. The PD-Smart is self-contained in a rugged polyurethane case and is especially designed for the day-to-day field use. The PD-Smart comes with an ABS Peli Suitcase, which makes the transport to different locations easy and uncomplicated.

» Superior safety in high voltage test set ups due to complete galvanic isolation between the PD-Smart and Laptop via fibre-optical cabling. This allows also a remarkable reduce of the background noise level.

### Specifications

Main electrical parameter - in general:

- » permanent detection of all PD events
- » Evaluation and interpretation of the Partial Discharges according to IEC 60270, VDE 0434 and ANSI
- » Digital, numerical real-time integration of the PD events
- » Minimum detectable apparent charge: < 0.1 pC
- » Measurement interval: unlimited
- » Single Pulse detection: < 4 ns
- » Max. double pulse resolution: < 32 ns (time range, super positionerror < 1 %)
- » Integration in time and frequency range:
  - » Time range: 140 ns ... 8 us
  - » Frequency range: 35 kHz ... 20 MHz
  - » Filter bandwidths free adjustable
- » Max. pulse frequency: > 2.1 MPulses / sec
- » Synchronization between units: < 800 ps
- » Voltage supply: 8.4 V DC with battery or external power supply

(100 - 240 V, 50 - 60 Hz)

» Outputs:

- » 1 x FOL-Output with E/O converter as Ethernet
- » 1 x FOL-Output Downlink
- » 1 x FOL-Output Uplink
- » 1 x TNC Trigger output
- » 1 x FOL Trigger output

» Inputs:

- » 2 x TNC (HF PD-Signal "PD" and LF-voltage signal "TV")
- » 1 x TNC HF Gating Signal

Main electrical parameter-Input "PD-Partial Discharge"

- » Input impedance: 50 Ohm
- » Input frequency range: DC to 20 MHz
- » Dynamic range: 16 bit, 100 dB
- » Max. Input voltage: 70 V rms
- » Input protection against over-voltage and short-circuit

## PD-Smart electrical

Main electrical parameter-Input "TV - Test Voltage"

- » Input impedance: 1 MOhm
- » Input frequency range: 15Hz to 10 kHz
- » Dynamic range: 16 bit, 80 dB
- » Max. Input voltage: 50 V rms

Environmental conditions:

- » Temperature range:
  - » 0° C to 40° C (operation)
  - » -10° C to 60° C (storage)
- » Humidity:
  - » 5 % - 95%, non-condensing

### Accessories

For all applications:

- » UHF-Unit for non-conventional PD measurements
- » LDC-5 - Calibrator(5, 20, 100, 500 pC)
- » LDM-5 or LDM-5/U-Measuring Impedance with voltage output 50 V, type BNC
- » LDB-5 - Bridge impedance
- » Notebook

For measurements on Rotating Machines:

- » PDDC-24 PD Coupler (with integrated measuring impedance and HV fuse) for decoupling PD pulses
- » PDDC-17 PD Coupler (with integrated measuring impedance) for decoupling PD pulses
- » LDJ-5- Charge Injector with higher pulse charges up to 10,000 pC

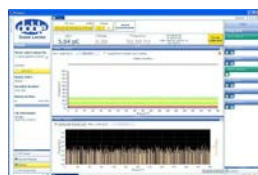
For measurements on Transformers:

- » LDM-6/U: bushing tap adapter, PD measuring impedance with voltage decoupling for power transformer bushings
- » LDM-5/U5: Measuring impedance with additional 2 switches for 4 Cu's

For measurements on Cables:

- » HFCT-Sensors (Rogowski-Coils)
- » Software Add-on: PD Fault Location ("PD Mapping") via Reflectometer Method

### Additional Pictures



# SPECmonitor



Instruments

SPECmonitor - PD Monitor with Selectable

The SPECmonitor is a partial discharge (PD) measurement device comprising a spectrum analyzer, an acoustic detector, and a conventional PD monitor in one instrument. This combination enables PD measurements even with high levels of background noise e.g. on power transformer within substations or power plants.

Observing the frequency spectrum of a harshly disturbed PD signal allows to select frequency bands with less disturbances. Using this center frequency for a PD acquisition, gives a largely improved signal-to-noise ratio resulting in a clear pattern acquisition. The combination of spectrum analyzer and PD detector within one instrument greatly expands the measurement possibilities when analyzing the insulation systems in a noisy environment.

In the standard version, the SPECmonitor comes with an eight or four channel multiplexer to directly select the input signal. The instrument provides five different display modes and several interfaces like e.g. TCP/IP or modern for remote control and diagnosis.

### *Measuring partial discharge within noisy environment*

#### **SPEC Mode**

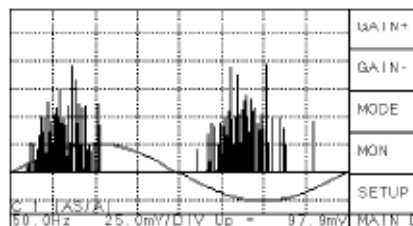
The SPEC mode shows the frequency spectrum of the input signal up to 10 MHz. Three traces for the current input channel allow storing, comparing and processing of this spectrum. The bandwidth

of the demodulated signal can be set to 9 kHz or 270 kHz, respectively.

#### **SCOPE Mode**

The SCOPE mode displays the PD pattern versus phase as known from the ICM series. Hereby, the selected center frequency and bandwidth of the SPEC

mode is used, in order to disregard frequency ranges occupied with disturbances. The SCOPE mode offers viewing an oscilloscopic display (below) as well as a pattern display.

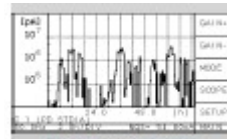




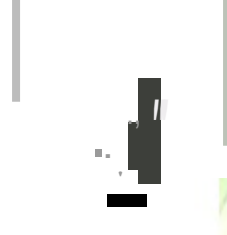
Motlltomg dJSpIay



Spectrum display



Trending information



Acous c msgneti::holder



Bushing adapter and coupling unit

coupling unit

### MON Mode

The monitoring display allows to set alarm levels of NQS or Qp that will trigger when those values are exceeded.

### TIME Mode

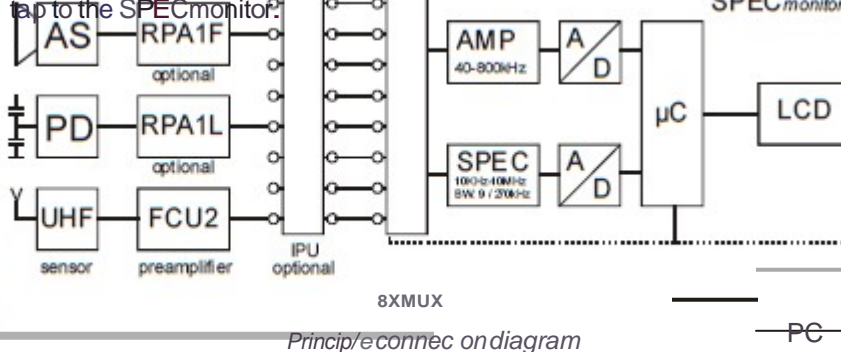
Additionally, the SPECmonitor collects and displays PD data over a specified time interval for easy trending and observations of changes in the Qp and NQS levels of the monitored system.

### Software

Besides this autonomous functions, the instrument can be connected to a computer via serial interface, modem, or TCP/IP. A special software allows the remote control of the instrument and the download of the stored data. An autoscan function takes the trending information as well as the phase-resolved pattern of one or multiple units.

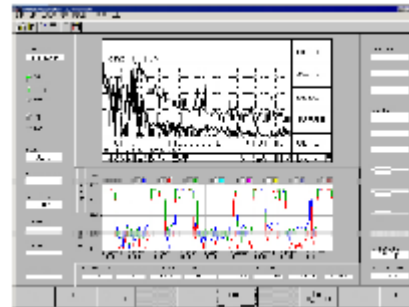
### Accessories

It is possible to connect acoustic sensors (AS), UHF sensors, or the standard coupling unit from the bushing test tap to the SPECmonitor.



Principle connection diagram

Combining a spectrum analyzer and the multifunctional SPECmonitor greatly expands the measurement possibilities of the SPECmonitor. This combination allows PD monitoring even with a large background noise and with different sensors connected.



SPECmonitor software

Different preamplifiers like RPA1F, RPA1L or FCU2 can be used in case of weak signals or to drive long cable lengths.



SPECmonitor in a hJ619\* rack

### 3 Technical Data

#### 3.1 Acquisition Unit

|                                |  |                                |
|--------------------------------|--|--------------------------------|
| Mains Supply:                  | 8S.264VJG, 47-440Hz  | (automatic)                    |
| <b>Line Fuse:</b>              | 1.6 A time-lag   | (SS.264VJG)                    |
|                                | 0.5A time-lag  | (200-264V...)                  |
| <b>Power Requirements:</b>     | approx. 20VA   |                                |
| Display:                       | backlight LCD  |                                |
| Display                        | <b>120mm x 64mm</b>  |                                |
| Size:                          | 128 x 240 Pixel B/W  |                                |
| Display Resolution:            |  |                                |
| Operation:                     | 5 menu supported pushbuttons                               |                                |
| <b>Input Impedance (PD):</b>   | 500hm/50pF   | (RPA2-Input, standard)         |
|                                | 10kOhm/50pF  | (RPA1-Input, optional)         |
| <b>Input Sensitivity:</b>      | <400 V   | (RPA2-Input, standard)         |
|                                | <200 V   | (RPA1-Input, optional)         |
| <b>Lower Cut.Off (&amp;B):</b> | 40, 80 or 100kHz   | (software controlled)          |
| <b>Upper Cut.Off (&amp;B):</b> | 250, 600 or 800kHz   | (software controlled)          |
| <b>Acquisition Bandwidth:</b>  | 2MHz - 20MHz   | (built-in RPA2, standard)      |
|                                | 40kHz - 800kHz   | (built-in RPA1, optional)      |
|                                | 300MHz - 2000MHz   | (external RPA6C, optional)     |
| <b>Synchronization:</b>        | <b>Coupler input, with automatic change to line signal</b> |                                |
|                                | 30Hz - 150Hz   | (automatic)                    |
| External Sync (Option):        | too_v_max into 1MOhm/200pF                                 |                                |
| Recorder Output (Option):      | 0-10V with R=1000hm  | (re-converted analog NQS)      |
| <b>Serial Interface:</b>       | RS232, 57.6 kBits/s  |                                |
| <b>Operation Temperature:</b>  | 10-40°C  | (non-condensing)               |
|                                | 0-55°C   | (optional)                     |
| Weight:                        | approx. 5-6kg  | (depends on installed options) |
| Overall Size:                  | <b>260 x 305 x 130mm<sup>3</sup></b>                       | (H x W x D)                    |

### 3.2 CC20B Coupling Unit(standard)

|                           |                      |             |
|---------------------------|----------------------|-------------|
| Capacance: Rate<          | t 45pF               | (t t0%)     |
| Vokage: <b>Voltage</b>    | 20kV...,             |             |
| <b>endurance: PD</b>      | 50kV''               | (1 min)     |
| <b>I</b> evel:            | <2pC                 | (>30kV c)   |
| <b>Temperature range:</b> | <b>-20°C - +15°C</b> |             |
| VWeight:                  | 1.9kg                |             |
| Overall Size:             | 300x 100x 130mm*     | (H x W x D) |

### 3.3 CC25B Coupling Unit(optiona)

|                           |                      |             |
|---------------------------|----------------------|-------------|
| Capacance:                | tnF                  | (t t0%)     |
| Rate< Vokage:             | 25kV...,             |             |
| <b>Voltage endurance:</b> | 50kV''               | (1 min)     |
| PD <b>I</b> evel:         | <2pC                 | (>30kV c)   |
| <b>Temperature mnge:</b>  | <b>-20°C - +15°C</b> |             |
| VWeight:                  | 3.2kg                |             |
| Overall Size:             | 300x 140x 170mm*     | (H x W x D) |

### 3.4 CTB1 Coupler Terminalen Box (standard)

|                           |                      |             |
|---------------------------|----------------------|-------------|
| Vokage (Gas Gap):         | <b>90V</b>           |             |
| <b>Temperature range:</b> | <b>-20°C - +75°C</b> |             |
| VWeight:                  | .4kg                 |             |
| Overall Size:             | 100 x 150x 35mm*     | (H x W x D) |

### 3.5 CSC1 Coupler SignalCombiner (optional)

|                          |                      |             |
|--------------------------|----------------------|-------------|
| Voltage (Gas Gap):       | <b>90V</b>           |             |
| <b>Temperature mnge:</b> | <b>-20°C - +75°C</b> |             |
| VWeight:                 | .5kg                 |             |
| Overall Size:            | 100 x 150x 35mm*     | (H x W x D) |

### 3.6 BCU1 Bushing Coupling Unit

|                             |                                     |           |
|-----------------------------|-------------------------------------|-----------|
| <b>Divider Capacitance:</b> | 0.33F – 4.5F                        | (± 5%)    |
| <b>PD coupling:</b>         | H'-CT                               |           |
| <b>Temperature range:</b>   | <del>-20°C</del> - <del>+75°C</del> |           |
| <b>Weight:</b>              | ~0.5kg                              |           |
| <b>Overall Size:</b>        | 140x 140x 170mm <sup>3</sup>        | (H xWx D) |

### 3.7 RPA6C UHF Processor

|                               |   |   |
|-------------------------------|---|---|
| <b>Frequency Range:</b>       | 300MHz – 2000MHz                                  |   |
| <b>Input Impedance:</b>       | 50ohm//40pF                                       |   |
| <b>Input Sensitivity:</b>     | <200V @ 500MHz                                    | (-61dBm @ 500MHz)                       |
| <b>Dynamic:</b>               | >3.5 Decades                                      | log scale                               |
| <b>Input Connector:</b>       | N-Plug  |   |
| <b>Output Connector:</b>      | BNC-Plug  | (optionally TNC)                        |
| <b>Operation Temperature:</b> | 0-55°C  | (non-condensing)                        |
| <b>Weight:</b>                | 75g<br>155g                                       | (standard version)<br>(IP65 protection) |
| <b>Overall Size:</b>          | H26 x W26 x L86mm <sup>3</sup><br>035mm x L 105mm | (standard version)<br>(IP65 protection) |

### 3.8 WS95 Window Sensor

|                           |                                     |           |
|---------------------------|-------------------------------------|-----------|
| <b>Frequency range:</b>   | 300MHz - 2000MHz                    |           |
| <b>Temperature range:</b> | <del>-20°C</del> - <del>+75°C</del> |           |
| <b>Weight:</b>            | ~180g                               |           |
| <b>Overall Size:</b>      | 115x 185x 115mm <sup>3</sup>        | (H xWx D) |

### 3.9 M57k6 Modem Unit

|                               |   |                  |
|-------------------------------|---|------------------|
| <b>Mains Supply:</b>          | 90-130V...; 47-65Hz<br>200-264V...; 47-65Hz |                  |
| <b>Line Fuse:</b>             | 0.5A time-lag                               | (90-264V...)     |
| <b>Power Requirements:</b>    | approx. 11VA                                |                  |
| <b>Data Rate:</b>             | 57.6kBits <sup>s</sup>                      |                  |
| <b>Operation Temperature:</b> | 10-40°C                                     | (non-condensing) |
| <b>Weight:</b>                | ~1.3kg                                      |                  |
| <b>Overall Size:</b>          | 160 x 140x 70mm <sup>3</sup>                | (H xWx D)        |

## 4 Listing of Connections and I/O Signals

### 4.1 ICMmonitor Acquisition Unit

|                           |  |
|---------------------------|--|
| Signal Input:             | 4 BNC connectors (500hm) to the 4-channel input multiplexer  |
| Gate Input:               | 1 BNC connector (500hm)  |
| Recorder Output:          | 1 BNC connector  |
| <b>Serial Interface:</b>  | <b>5 pin round connector</b>   |
| Alarm Relay (Contact A):  | Screw terminal 1 – NC<br>Screw terminal 2 – Common<br>Screw terminal 3 – NO<br><br>Screw terminal 4 – NC<br>Screw terminal 5 – Common<br>Screw terminal 6 – NO |
| (Contact B):              | Screw terminal 7 – Line<br>Screw terminal 8 – Neutral<br><br>Screw terminal 9 – Line<br>Screw terminal 10 – Neutral<br>4 Screw terminals (Green/Yellow)        |
| Power Supply:             |  |
| Modem Power Supply:       |  |
| <b>Protective Ground:</b> |  |

### 4.2 CC20B & CC25B Coupling Units

|                           |  |
|---------------------------|--|
| High Voltage Terminal:    | Mount screw terminal (CC20)<br>Mount screw terminal (CC25) |
| Signal Output:            | 1 BNC connector (500hm)                                    |
| <b>Protective Ground:</b> | <b>M5 screw terminal</b>                                   |

### 4.3 CTB1 Coupler Terminalien Box

|                           |                          |
|---------------------------|--------------------------|
| Signal Input:             | 3 BNC connectors (500hm) |
| Signal Output:            | 3 BNC connectors (500hm) |
| <b>Protective Ground:</b> | <b>M5 screw terminal</b> |

### 4.4 CSC1 Coupler Signal Combiner

|                           |                          |
|---------------------------|--------------------------|
| Signal Input:             | 4 BNC connectors (500hm) |
| Signal Output:            | 1 BNC connector (500hm)  |
| <b>Protective Ground:</b> | <b>M5 screw terminal</b> |

### 4.5 BCU1 Bushing Coupler Unit

|                |   |
|----------------|---|
| Signal Input:  | Custom connector to bushing tap   |
| Signal Output: | 2 TNC connector (500hm)<br>Optionally N-connector or watertight through |

### 5 Mechanical Dimensions

The enclosure of the *ICMmonitor* is made of cast-aluminum. The protection grade of the enclosure is IP65 with the Plexiglas cover duly dosed and protective caps attached to unused connectors. Figure 15 shows a front view of the acquisition unit, while a side view is shown with Figure 16 (next page). The coupler termination box CTB1 and the signal combiner box CSC1 have the same size of 150mm x 64mm x 35mm. Consider additional space for the BNC terminals and the coaxial cables in general.

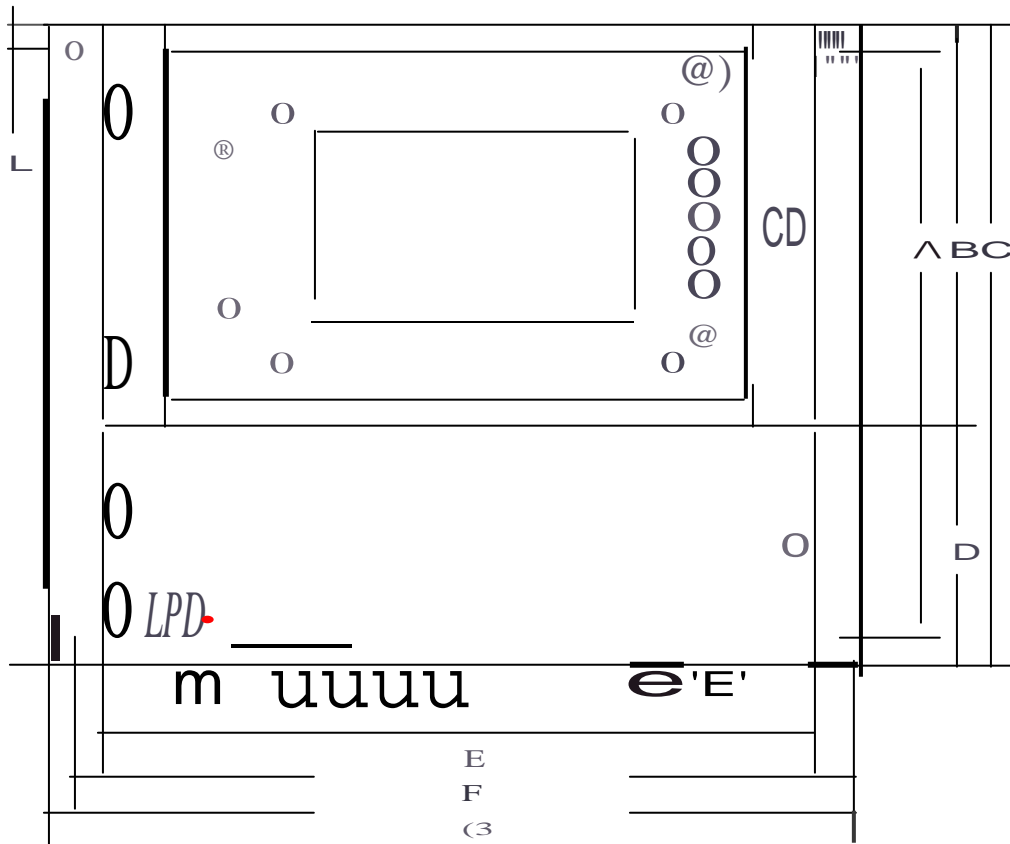


Fig. 15, Front view of the IOAmonitor acquisition unit

|           |       |       |       |       |       |        |
|-----------|-------|-------|-------|-------|-------|--------|
| Item      | A     | B     | C     | D     | E     | F      |
| Dimension | 220mm | 149mm | 241mm | 90mm  | 264mm | 305mm  |
| Item      | G     | H     | I     | J     | K     | L      |
| Dimension | 305mm | 10mm  | 100mm | 130mm | 6,5mm | 10,5mm |

Table 1, Dimensions of the ICMmonitor acquisition unit (refer to figures 15 & 16)

## Online Monitoring of Power Transformers with AE SENSOR HIGHWAY IPM

### Introduction and Overview

The Sensor Highway System™ is an Acoustic Emission (AE) Monitoring System with up to 16 high speed monitoring channels and 4 parametric input channels. The Sensor Highway II™ has been developed for unattended 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), capable of operating in extreme weather and factory conditions.

### Features

The key feature of the Sensor Highway System™ is its highly flexible sensor fusion interface for input and processing of 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.

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.

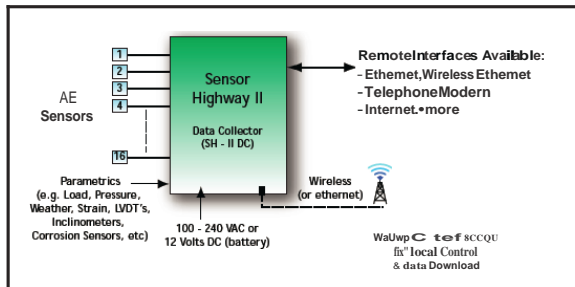


Figure 2. Sensor Highway II™ DC Data Collector System



Figure 1. Inside the Sensor Highway Cabinet

### Application solutions

The system is currently offered as a "Data Collection" (Sensor Highway II™ DC) System, (the most basic and low cost system). It is capable of remote acquisition and storage of (short term) sensor data with some basic signal processing and alarm screening capabilities.

This Sensor Highway II™ DC System is a solution 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, and trend monitoring and customer data visualization. A block diagram of the system is shown in Figure 2.

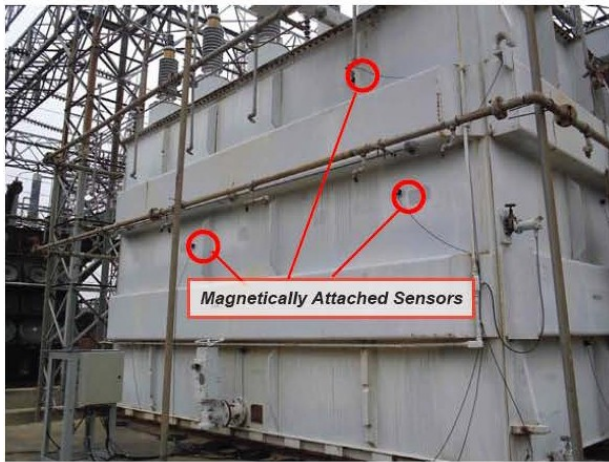


Figure 3. Typical Power Transformer of Sensor Highway I/ITM

This system is ideal for on-line monitoring of critical transformers. Figure 3. represents a typical power transformer of Sensor Highway II™ System installed on a 3 phase, 300/336 MVA, 230/138/64.5 kV, FOA Class Transformer in North Carolina.

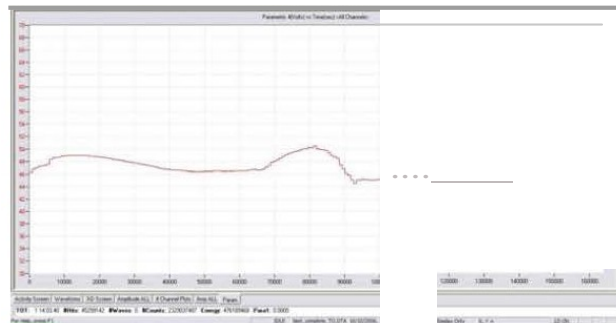
Data download can be accomplished by a walk-up attachment (plug in a notebook computer via its standard Ethernet port), see Figure 4; through an automated remote interface, either via Ethernet; optional wireless Ethernet; Internet; or Telephone Modem to a remote control and data processing station. The remote system with the aid of a trained user, performs the data analysis and asset integrity assessment.



Figure 4. Configuration of the Sensor Highway I/ITM System via a Laptop



Acoustic Activity in Decibels per Channel for a Transformer Test during a 24 Hour Monitoring Period



Oil Temperature Measured as a Parametric Input for a 24 Hour Test Period

For additional information on AE Sensor Highway II, please contact your local PAC Sales Representative or our headquarters at 609-716-4000.

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 Email: sales.systems@mistrasgroup.com • www.mistrasgroup.com

## PowerPAC™

### Technology Package for Acoustic Emission Testing Instrument and Procedure for Detecting, Locating and Assessing Electrical and Thermal Faults in Power Transformers during On-Line Monitoring

This Technology Package is being introduced for Acoustic Emission (AE) testing of Power Transformers. This package was developed under an ongoing EPRI sponsored Tailored Collaboration (Project I.D. No. 051481) and is designed to provide on-line monitoring of Power Transformers for detecting, locating and assessing electrical and thermal faults.

This monitoring follows a procedure that was introduced in the Tailored Collaboration and refined throughout two Phases of program development. Transformers are instrumented with AE sensors covering both the tank and the LTC compartment (if one is present). In addition, other sensors (used to monitor pump current, fan current, load current, tank wall temperature and LTC compartment wall temperature) are used to collect data for comparison with the AE data during post test data analysis.

Data is collected over a period of 24 hours in order to observe the effects of a complete load cycle. Results are presented showing the location (in three dimensions) and types of faults. A grading system is used to grade each fault and to provide an overall grading of the transformer to be used for maintenance or operations planning.

The system is based on the Physical Acoustics Corporation (PAC) model DiSP, digital AE instrument. It operates using application specific software designed for data acquisition during field testing and has several utilities for post test analysis. Some of the key features of this software is its ability to perform three dimensional source location and to grade each fault using a four-grade system (A – D).



The details of the different items offered in this technology package are described as follows:

- DiSP-24 Hardened, Portable Computer
- PCI/DSP-4 Data Acquisition Boards w/ up to 4 parametric inputs
- RISI-AST sensors with integral 40dB preamp
- Parametric breakout box and parametric sensors
- PowerPACIM Data Acquisition and Analysis Software w/ AEwin 2D & 3D Location Software Modnies
- AEwin Post Processing Analysis Software
- Database Skeleton Software
- Automated software in Post-processing software
- 3-Days Classroom Training (theory) and Stmt-up Assistance
- 10 Days on the job Training (Field Test)
- Consulting Time (Remote and On-site)

The details of the different items offered in this technology package are described as follows:

#### **Hardware:**

**DiSP-24** 24 channel, digital AE instnment. It includes PAC R151 integral preamp sensors with built-in self diagnostics capability (Auto Sensor Testing) and 30 meter cables. The system comes with a built-in high performance PC controller, RW-CD, keyboard, mouse and video monitor and is shipped in a mgged transport case. This system can be used from the smallest of transfonners (typically around 13.8 kV) up to the largest GSU transfonners (typically around 500 kV). 3 cunent transducers (CT) and 2 resistance thennal devices (RTD) needed for recording parametric signals are also included in this package.



DiSP-24

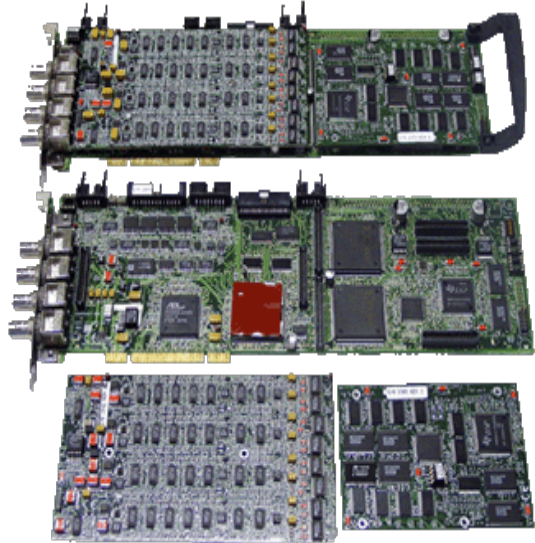
### PCI/DSP-4

The PCI/DSP-4 board is the heart of the DiSP System. Due to advances in surface mount technology and high density ASIC devices, we have been able to provide this single PCI card with 4 complete high-speed, channels of Digital Signal Processing (DSP) based AE data acquisition, up to 8 parametric input channels (on the first card) and optional waveform module. Through the high performance PCI bus, significant AE data transfer speeds (up to 132 Megabytes/second) can be attained. This assures a wide bandwidth bus for multi-channel AE data acquisition and waveform processing.

Since the 32-bit PCI bus has become the de-facto standard in all PC computers today, PCI/DSP-4 boards can be implemented inside your PC or inside one of PAC's rugged, multichannel DiSP workstations.

### Features:

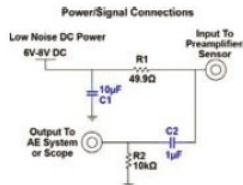
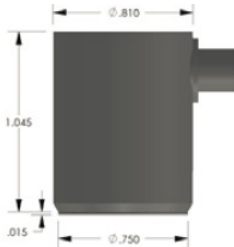
- Advanced parallel DSP acoustic emission technology with high-speed PCI cards
- Proven knowledge-based software and state-of-the-art LAN networking capabilities
- Four 16-bit, high-speed A/D converters (no gain changes)
- High-performance, multiple DSP technology on a single 4-channel PCI card



# PK151

## PK151 Sensor

### Medium Frequency Integral Pre-amplifier Resonant Sensor



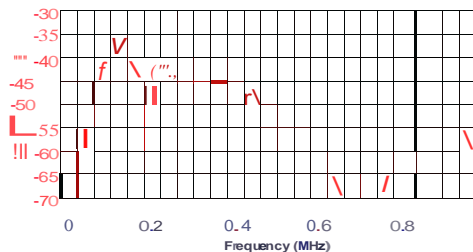
#### DESCRIPTION AND FEATURES

The PK151 sensor is a medium frequency, resonant, acoustic emission sensor with an integral, ultra low noise, low power, filtered, 26dB pre-amplifier, which can drive up to 200 meters of cable. This new sensor represents an improvement in both noise and low power consumption performance, with noise level below 3  $\mu$ V and power consumption of 25 mW. The PK151 features a strong stainless steel integrated body structure. The sensor is smaller size and the same frequency response as the R151 sensor.

The integrated Auto Sensor Test (AST\*) capability allows these sensors to pulse as well as receive. This feature lets you verify the sensor coupling and performance at any time before, during or after the test.

#### APPLICATIONS

The PK151 sensor has been designed to be used with the Pocket AE, a small handheld AE system, or with the Sensor Highway II, an outdoor rated, on-line monitoring system.



#### OPERATING SPECIFICATIONS

##### Dynornic

Peak Sensitivity, Ref V/ubar ..... -36 dB  
Operating Frequency Range ..... 101.450 kHz  
Resonant Frequency, Ref V/ubar ..... 150 kHz  
Directionality ..... +/- 1.5 dB

##### Environmental

Temperature Range ..... -35 to 80QC  
Shock Limit ..... 500g  
Completely enclosed crystal for RFI/EMI immunity

##### Physical

Dimensions ..... 0.812"00 X 1.06" H  
20.6 mm OD X 27 mm H  
Weight ..... 5.1 grams  
Case Material ..... stainless Steel  
Face  
Material ..... Ceramic  
Connector ..... SMA  
SMA Connector Locations ..... Side

##### Electrical

Gain ..... 26 dB  
Power Requirements ..... 4-7 VDC @ 5 mA  
Operating/Max Current ..... 5/35 mA  
Noise Level (RMS RTI) ..... < 3  $\mu$ V

#### ORDERING INFORMATION AND ACCESSORIES

PK151 ..... PK 51  
Cable (specify cable length) ..... 1234-SMA/BNC-X  
Magnetic Hold-Down ..... MIHPK 51  
Amplifier Subsystem ..... AE2A, AE5A  
Sensors include  
NIST Calibration Certificate & Warranty

AST — Auto Sensor Testing feature allows AE systems to control the sensor as a pulser and a receiver at the same time. It can therefore characterize its own condition as well as send out a simulated acoustic emission wave that other sensors can detect, so the condition of the nearby sensors also can be tested.



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# Acoustic Emission measurement for PD detection in transformers

AE-measurement is a suitable method to detect and locate partial discharge in transformers. It is a non-intrusive method and capable of monitoring the whole volume of a transformer. An AE test can be conducted while the transformer is in service.

Partial discharge, an electrical phenomenon, is a localized dielectric breakdown. Partial discharges cause a progressive deterioration of insulating materials, which eventually leads to electrical breakdown. Such an electrical breakdown may ultimately lead to complete failure of equipment. Especially for very expensive equipment such as transformers used in power generation or smart grids failure must be avoided. Electrical power supply reliability for consumers and industry depends critically on sustained operation of these transformers.

Integrity of insulation has to be monitored and confirmed during manufacturing stage and during operation in regular intervals. Regular inspections can trigger early warning signals for maintenance.

## Typical System Configuration:

|                                  |  |
|----------------------------------|--|
| <b>Chassis</b>                   | MB19 in single chassis or multi chassis configuration              |
| <b>AE-signal processor board</b> | ASIP-2/S   |
| <b>AE-sensors</b>                | VS150-RIC  |
| <b>Analysis software</b>         | VisualAE   |
| <b>Location modules</b>          | 3D location  |
| <b>Additional modules</b>        | ECP to program own analysis routines or license routines of others |

## AE Sensors

With more than 30 AE sensor models, Vallen offers a wide range covering many acoustic emission testing applications. The highly sensitive piezo sensors are available in all relevant frequency ranges and sizes. All sensors are optimized for greatest sensitivity and are subject to strict quality controls. Some of the most commonly used sensor models are:

- VS150-M 150 kHz resonant, multi-purpose sensor
- VS150-RIC 150 kHz resonant, with integrated preamplifier, for pressure/ integrity test
- VS375-RIC 375 kHz resonant, with integrated preamplifier, for crack detection in noisy environments
- VS30-SIC 25-80 kHz, low frequency, with integrated preamplifier, for tank bottom testing

Most sensors with integrated preamplifiers are equipped with a calibration-pulse-through feature. This shortens time for checking sensor coupling, cables and preamplifier function. To simplify mounting, sensor holders with heavy duty magnets are offered.



VS700-0 is a small, light sensor that can be easily coupled to a paper specimen by means of shown magnet



VS150-I with full metal case designed for composite testing



VS75-V with ceramic shoe is often used for partial discharge detection

## AE Preamplifiers

Vallen offers a number of extremely robust preamplifiers perfectly suited for use with the AMSY-6 system. Bandwidth and performance can be selected to match the test requirements. Their consequent design with 500 impedance matching and their low noise input stage make them unique on the market. To ensure reliable operation even under difficult operating conditions, only selected components and materials are used.

### AEP4, AEP4H

Multipurpose preamplifiers for the frequency range from 3 - 2000 kHz (AEP4H: 20 - 2000 kHz), are suitable for most applications. Each comes with a rugged case and a calibration bypass for the sensor coupling and wave velocity test.

### AEP3

The AEP3 amplification can be selected in the range from 34 to 49 dB via software. Exchangeable frequency filter modules allow the use without steep downstream frequency filters. AEP3 provides two inputs, one with the common single-ended BNC connector and the other with a differential BNC connector.



AEP4 preamplifier



VS375-RIC combines AE sensor and preamplifier for tank bottom testing.



AEP3 preamplifier



## «Vesta» - the System for Fast Estimation of the Transformer Winding and Coil Clamping Force



The force of the winding clamping of high voltage transformers specifies their protection against short circuit currents which could pass through the transformer under failure conditions.

The clamping force usually weakens with time that is why the clamping force monitoring is an important diagnostic task.

Most of the systems for clamping force diagnostics require, at least, the monitored transformer de-energizing and bus disconnection. The «Vesta» system allows evaluating the winding and core clamping condition on-line, using the surface transformer tank vibration as the diagnostic parameter.

The «Vesta» system operation is based on the mathematic model of the transformer, where only the active elements (core and windings) are considered to be the source of vibration. Following the transformer equivalent circuit, only the core vibrates at transformer running with no load, and the winding vibration adds when running on load. If the winding is well-pressed then it vibrates with the frequency of 100 Hz. If the winding clamping force is less than normal, then high harmonics multiple by 100 Hz (200, 300, ..., 1000 Hz) appear in the vibration spectrum.

For the expert system operation the vibration should be measured in the spectrum of up to 1000 Hz at 12 typical points on the transformer tank. The points are situated on the level of the top and bottom edges of the transformer phase windings of the HV and LV side of the transformer. The vibration should be measured in two operation modes: no load and on load close to the nominal load as much as possible.

The vibration measurements are carried out with the portable vibrometer (Diana-2M // ViAna-1 // Vibro Vision-2) included into the delivery set of the «Vesta» system. The vibration sensor is fixed on the transformer tank surface with a magnet. For the sensor installation the insulating rod is usually used.

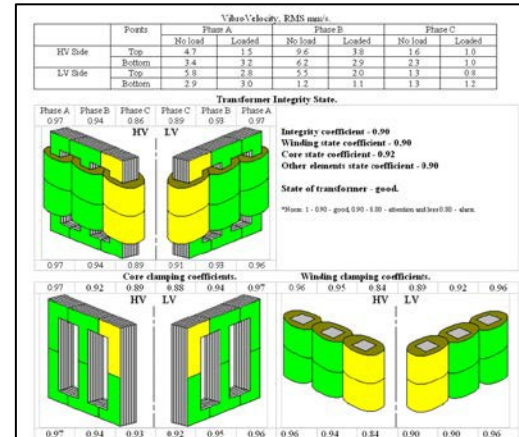


As the transformer tank vibration is measured the information is stored in the device memory. The memory volume is enough for storing the data of 40 transformers' inspections. Later the data is transferred to PC and is stored in the «Vesta» expert software database.

The estimation of the transformer winding and core clamping quality is done automatically by the «Vesta»

expert system. The user should only select the two measurements done at the two different operation modes from the database.

For quantitative evaluation of the winding clamping quality the calculated «condition coefficients» are used. This allows getting the unified diagnostic conclusions for almost all the transformer types used nowadays.



The condition thresholds of the monitored parameters are specified as follows:

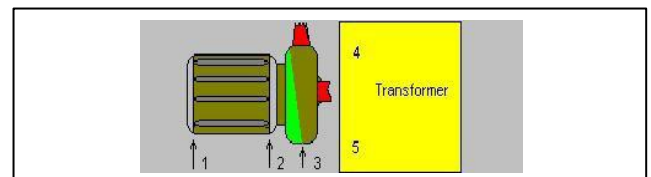
If the calculated condition coefficient (the transformer condition, the winding condition, the core condition) is more than 0,9, then the transformer condition is good.

If the calculated condition coefficient is less than 0,9 but more than 0,8 then the transformer warning condition.

If the calculated condition coefficient is less than 0,8 then the transformer condition is alarm. So the remedy measures should be taken or at least planned.

The «Vesta» software automatically makes the report on the clamping quality of the transformer active elements. The report includes the complete information and pictures, and can be printed.

The «Vesta» expert system includes the specialized function for transformer cooling system oil-pump



condition diagnostics on vibration parameters. The oil-pump vibration measurement is done with the portable vibrometer (Diana-2M // ViAna-1 // Vibro Vision-2) included into the delivery set. As the result the report on the oil-pump bearings' condition, electric-motor condition and the oil-pump rotor condition is made.

## Diana-2M - the two-channel analyzer of vibro-signals (vibroanalyzer)



The vibration double-channel analyzer (vibroanalyzer) Diana-2M is intended for diagnosis of a state and balancing of the rotated equipment. It is portable, small-size, effective and low-cost solution for diagnostic works most often meeting in practice. The device is simple and can be used by specialists of various level of vibrating preparation. It has small weight and keyboard protection.

The device is made on the modern processor for fast calculations. The memory size for a data storage (64 Mb) is enough for conducting of operative works and a information storage. Possibility of calculation of spectrum with high-resolution 51200 (!) lines, synchronous registration of waveforms on two channels allows to raise productivity of diagnosis works. Device can record vibration signals with duration up to 1 hour.

There are several additional algorithms of vibration analysis in device:

- Equipment balancing;
- Calculation of amplitude and phase of harmonic;
- Bump test;
- Measurements by route

Device Diana-2M is released in two modifications: industrial and explosion-proof modifications.

### Technical specifications

|   |   |
|---|---|
| Frequency range, Hz                               | 3 – 10000   |
| Frequency range of sensor VK-310A, Hz             | 3 – 5000  |
| Analog integration                                | single, double                                      |
| Measurement type                                  | peak, RMS, peak-to-peak, excess, waveform, spectrum |
| Measurement range: acceleration                   | 0,3 - 100 m/s <sup>2</sup> (peak)                   |
| Velocity  | 0,3 - 100 mm/s (RMS)                                |
| Displacement                                      | 5 - 500 $\mu$ m (peak-to-peak)                      |
| Maximum spectrum Frequency, kHz                   | up to 10  |
| Spectrum resolution, lines                        | up to 51200   |
| Measurement Window                                | Hamming   |
| LCD Screen  | 320*240 pixels                                      |
| Memory  | 64 Mb   |
| Connecting with PC                                | USB 1.1   |
| Power supply                                      | accumulators  |
| Time of operations work, without backlight, hours | 12  |
| Dimensions, mm                                    | 200*140*38  |

The delivery of device Diana-2M includes the software of vibrating diagnostics [Atlant](#) and [Aurora-2000](#). By means of this program storage of vibro-signals and spectrum in a computer is realized. Transfer of the information from the device in a computer is made by USB port. Time and frequency transformations of vibro-signals, wavelet-conversion of signals are realized in the program [Atlant](#).

The software [Atlant](#) included:

- Expert system of diagnostics and search of defects of rotating equipment;
- System of diagnostics of defects of rolling bearing on spectrum envelope of vibro-signals;
- Language of writing of diagnostic rules Pallada by means of which the user can formalize and use all the operating time in automated diagnostics

# **ELFORSK**

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