QUALITROL®
Defining Reliability

Regional Seminar, Russia, June 2014

Trends in Transformer Monitoring

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- Agenda:
  - Why to do Transformer Monitoring?
  - Technology
    - Current Trends
    - Future Options
    - Questions

Why Transformer Monitoring is Important?

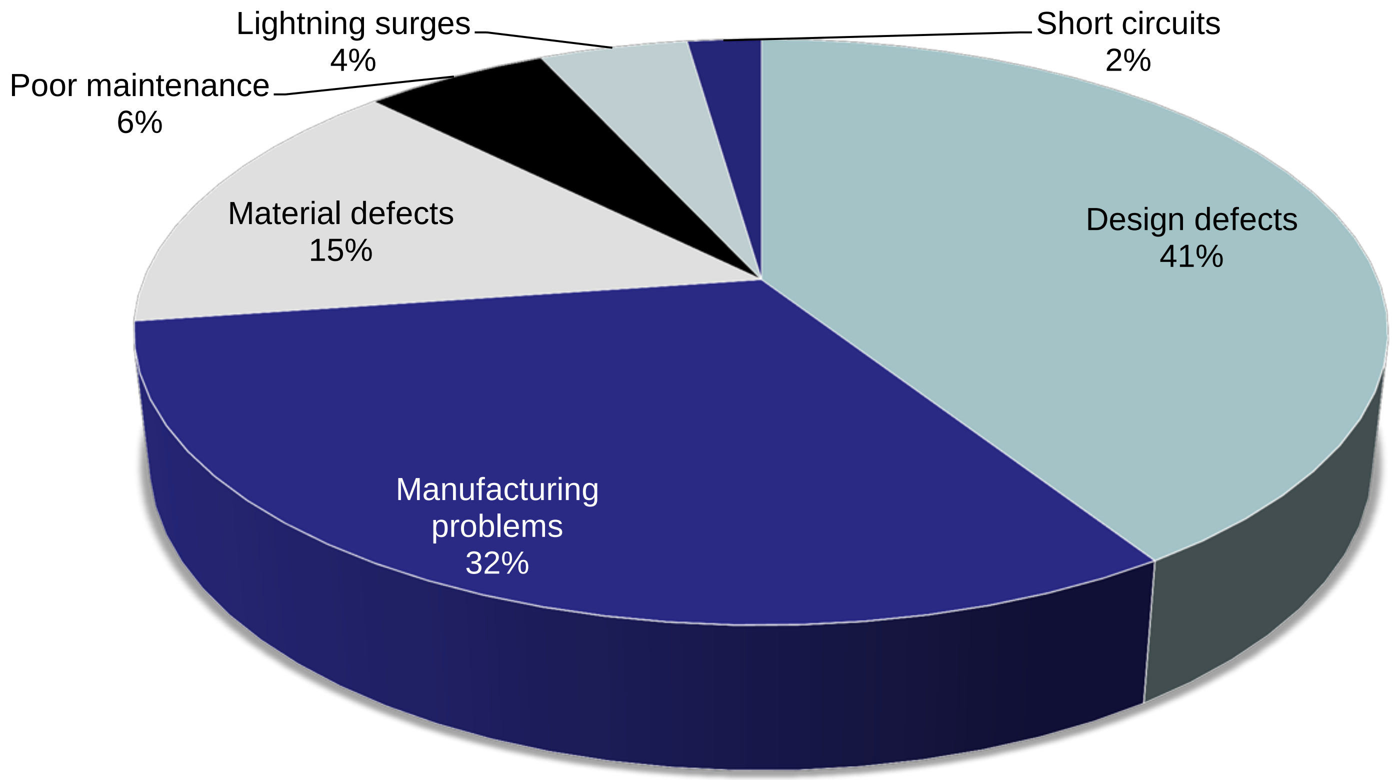
- Transformers are a critical part of an electrical utility’s asset base.
- Loss of a transformer in a utility, generation plant or process can cost many millions of dollars, depending on how long it is out-of-service.
- On-line monitoring and diagnostics is a useful tool to help operators to manage their assets and make decisions on continuing operation, maintenance or replacement

- What is the risk of transformer failure?

- UK typically 1% per annum for large units
- UK less than 0.5% for small distribution units

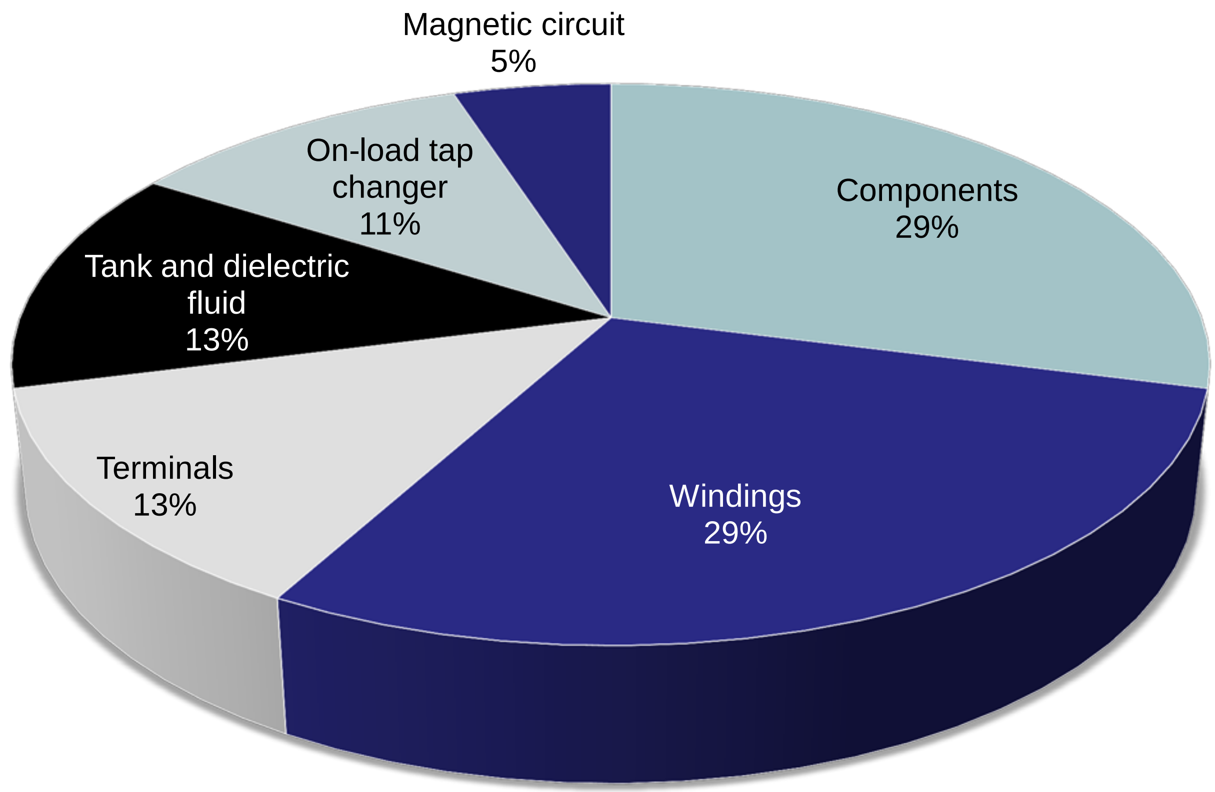
- Dependent on transformer type and duty
- Failure rates higher in industrial applications
- Furnace and rectifier transformers
- Generator transformers

Major causes of transformer failure



Source: Cigré WG 12.05 reliability study circa 1983

Major causes of transformer failure



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Source: Cigré WG 12.05 reliability study circa 1983

Failure can be grouped into three categories

- Due to weak specifications, poor design, poor manufacture quality or material defects
- Due to system disturbances, operational factors, interaction or with other components on the power system
- Due to maintenance or refurbishment operations that have or have not been undertaken

How do transformer faults show?

- Sudden Explosion
- Protection Trip
- Detected by condition monitoring

Transformer Faults and Failure

Catastrophic Failure

- Sudden explosion
- Perhaps a major fire event
- Tank rupture

Causes

- Bushing failure
- Tap changer failure
- HV line to ground fault in tank
- Three phase internal fault

Transformer Faults and Failure

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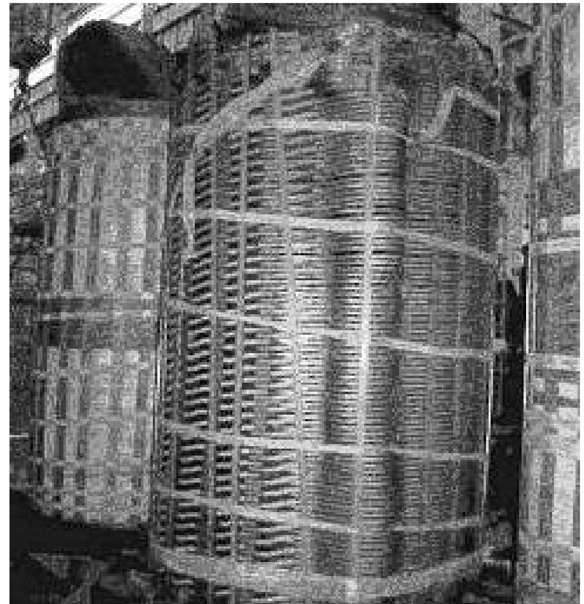
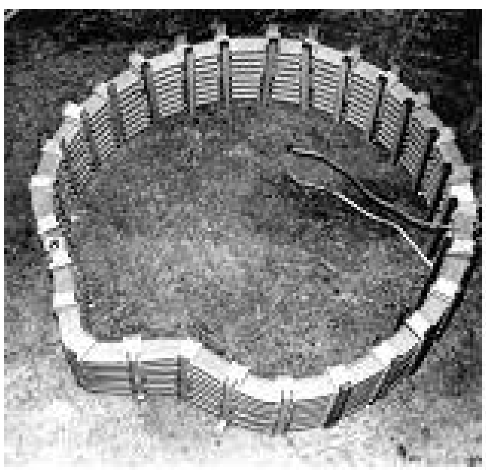
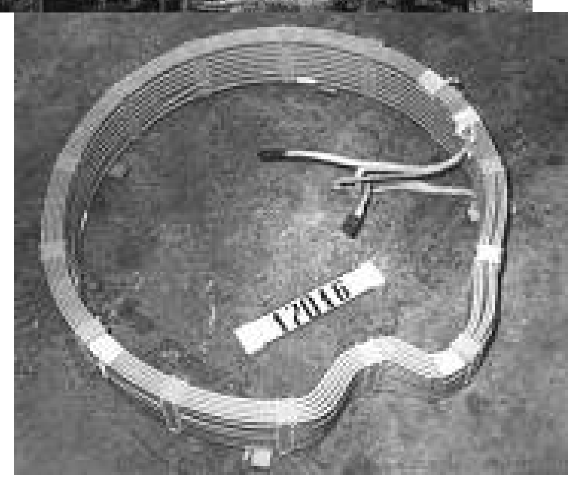
Transformer Faults and Failure

Transformer Faults and Failure



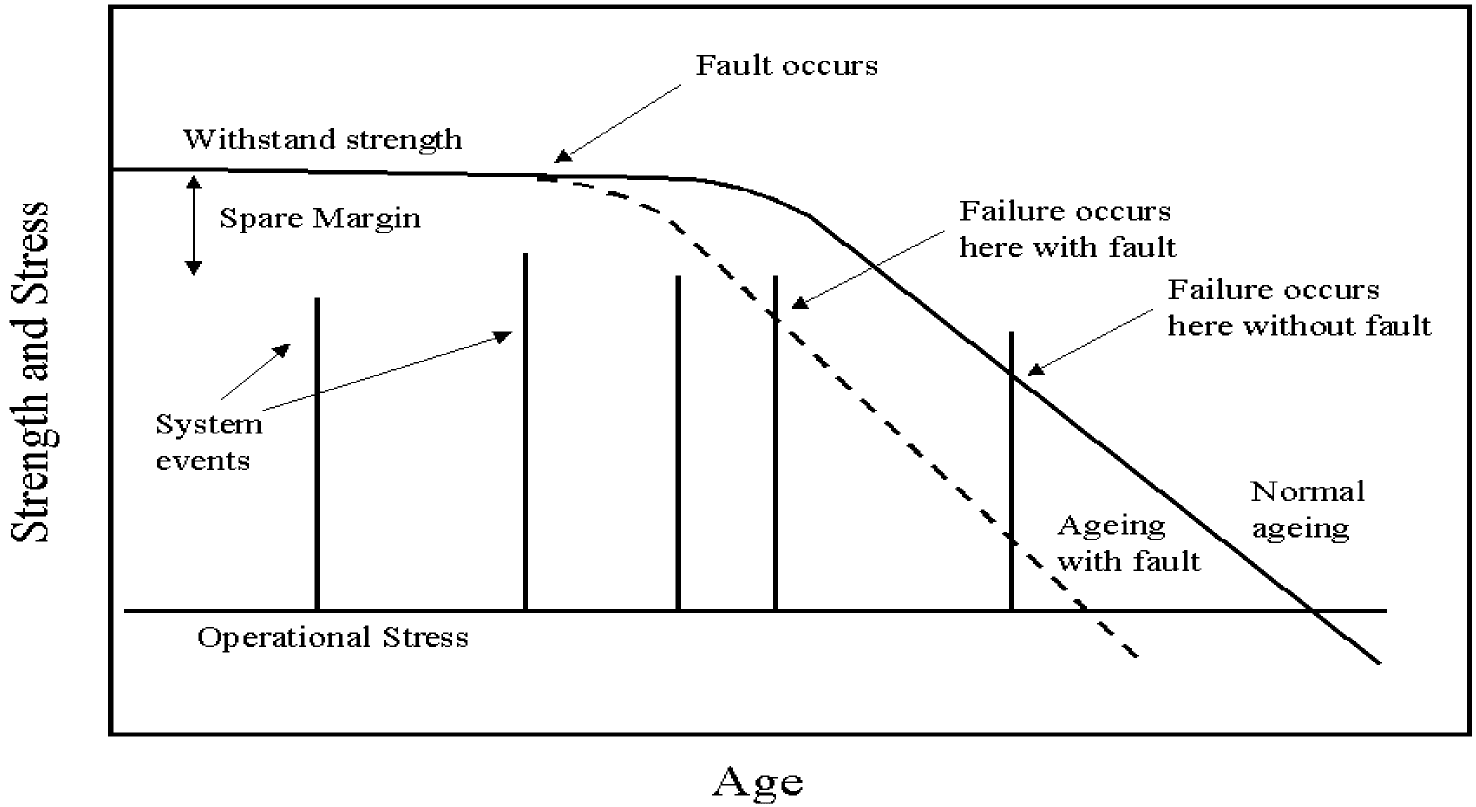




Transformer Faults and Failure

Transformer Faults and Failure

Transformer Withstand Strength v Time



What can be monitored?

Technology:

- What is available and is common practices?

Transformer Monitoring

- Temperature measurement
- Load and short circuit current
- System voltage
- Tap Changer
- Oil levels
- Dissolved Gas Analysis
- Bushing tap voltage/current
- Cooler operation
- Buchholz gas volume
- Bushing oil pressure

Temperature measurement

Temperatures are used by the majority of monitoring systems to indicate the instantaneous thermal rating of the transformer and to infer the health and efficiency of cooling systems and tap-changers. Measurements are taken from:

- Bottom and Top oil,
- Cooler inlet and outlet oil
- Tap-changer selector compartment(s) oil
  - for transformer with a separate oil compartment for the selector.
- Main tank adjacent to tap-changer
  - for transformer with bolt-on type tap-changers

Temperature measurement (continue)

- Winding hotspot temperature
  - Generally a winding temperature indication is required for each winding if a tap-changer is fitted or the transformer has more than two windings.
  - The winding hotspot temperature may be derived by a monitoring system using the oil temperature and load data.
  - Or by direct measurements of the winding hotspot temperature using a fiber optic technique.
  - Direct hotspot measurement is valuable for determining the thermal parameters of a transformer

Dissolved Gas Analysis

- There are a range of sensors available that require access to the transformer oil in order to give information on the condition of the transformer and the oil.
- Measuring dissolved gas-in-oil is a well established way of detecting faults in the transformer.

Dissolved Gas Analysis (continue)

- The devices available fall into two categories:
  - Single output systems, that provide a single output signal that is in some way proportional to one or several of the gasses present. These systems are useful for detecting problems and correlating gas production with particular operating conditions, giving clues as to the origin of the fault.
  - Multiple gas analyzers, that provide information on the level of several diagnostic gasses. These systems are particularly useful for helping to determine the type of fault and its development.

Dissolved Gas Analysis (continue)

- The available dissolved gas-in-oil sensors have one of two types of fitting:
  - Direct, mounted on a valve on the side of the tank or in a pipe with direct access to the oil. Single output systems may be of this type.
  - Oil sample loop, where the instrument continuously or periodically takes an oil sample via small bore pipework, returning the oil to the same or a different point. Generally multiple gas analyzers are of this type.

DGA - What are we looking for?

- In general there are NO normal levels of gas in transformers
- Every family of transformers has its own typical operating gas levels
- Some of these transformers can run with high levels of gases quite happily
- Changes in gas levels – trends and rate of change
- Standard fault fingerprints

DGA – Problems

- Annual sampling leaves gaps where medium term faults can develop without detection
- Trends analysis can be badly affected by outside influence
  - Oil treatment
  - Oil Changes
- Deciding what is an important problem and when to act on it

Moisture in Oil

- The monitoring of moisture in oil with a correlation to loading and temperature can give useful indications of the overall moisture status of the transformer.
- Transformers may be expected to be dry when new and so a moisture sensor is more likely to be justified on older units.
- Moisture sensors generally require a direct type of fitting.

Bushing tap voltage/current

- Partial discharge (PD), winding frequency response, fast transient monitoring and bushing monitoring can all be done with a high bandwidth connection to a bushing tap.
- Furthermore the loss factor and capacitance of a bushing could be monitored to see moisture and changes in the bushing insulation system.
- This connection can also be used to monitor system voltage. Precautions must be taken with connections to the bushing tap to prevent damaging voltages appearing on the tap under both working and impulse conditions.

Current Trends:

What is coming?

Partial discharge detection and location

- Partial discharge (PD) detection and location can be performed using electrical and acoustic techniques. These techniques involve the detection of electromagnetic or acoustic signals radiated by the PD.

- Ultra high frequency (UHF) PD location techniques require that the sensor is introduced into the tank through a valve, or mounted on a dielectric window or permanently installed inside the tank.

Partial discharge detection and location (continue)

- Acoustic sensors for PD monitoring can be fitted by means of magnetic clamps.
- Since PD detection and location techniques are still evolving it is recommended that DN50 valves are provided for the later fitting of probes as this provides the greatest flexibility for the future.
- Alternatively dielectric windows can be provided for UHF sensors.

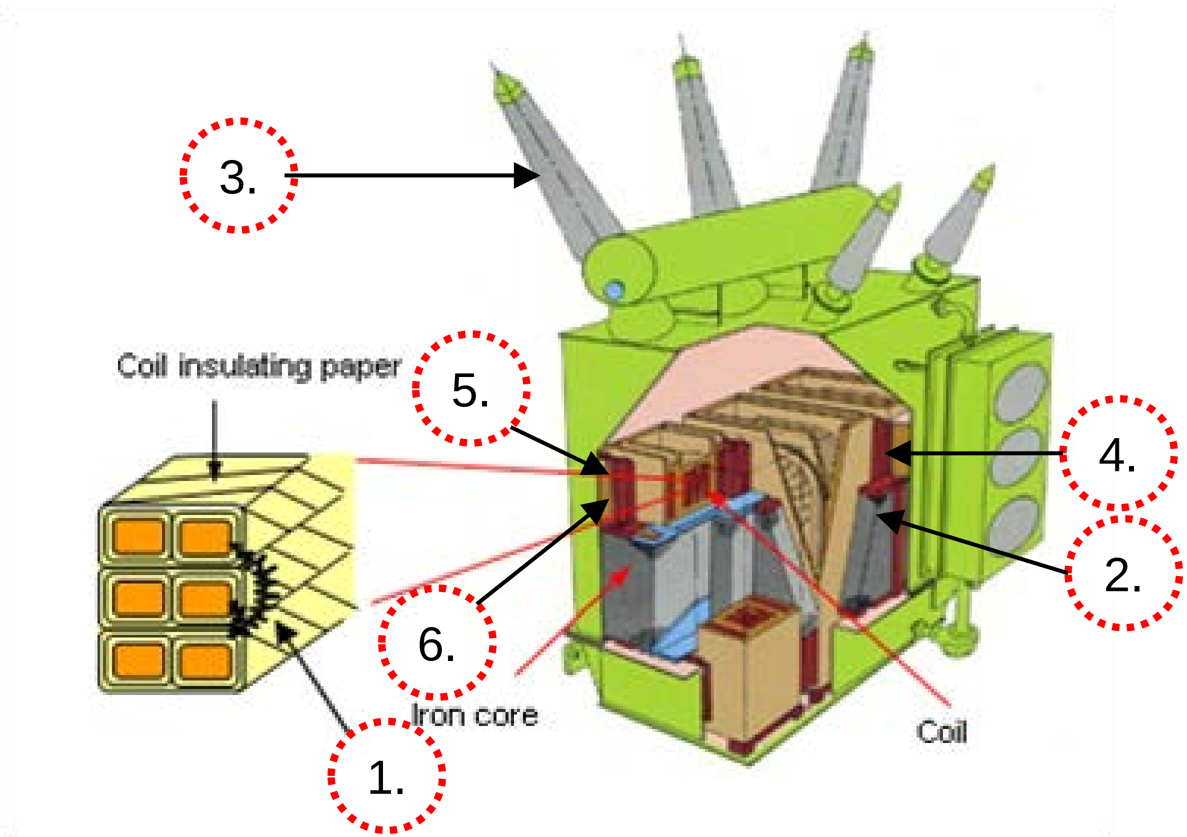
Partial discharge detection and location (continue)

- For PD location purposes, a total of four sensor locations in minimum are required, ideally each near a different corner of the tank and not all in the same plane.
- Valves for PD sensors must be located in position where a metallic protrusion of 50mm into the tank is permissible (a low power frequency electric field area).
- For PD detection only, one or two valves are required and these may be the same valves as used for oil filtering provided the above requirements regarding position are met.

Partial discharge detection and location (continue)

- Knowledge of the position of the windings, core, connections, leads and obstructions within the tank is very helpful for the interpretation of partial discharge location information. Consideration should be given to how this information can be made available over the lifetime of the transformer.

Type of Defects in transformers

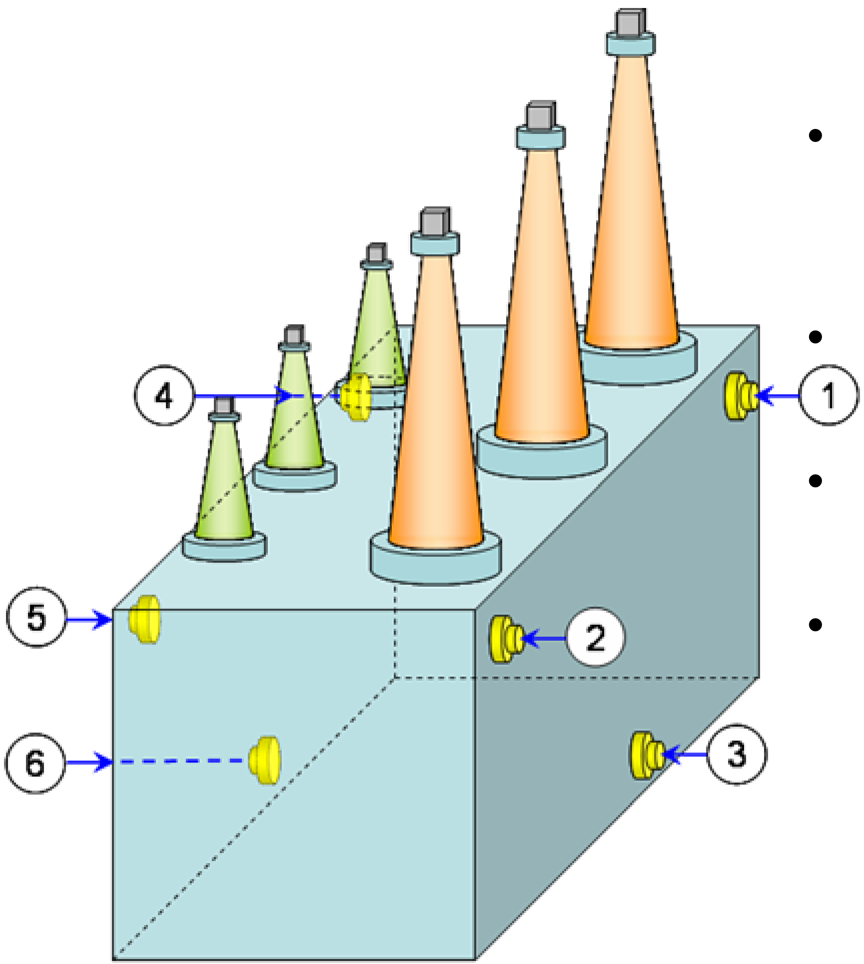


1. Discharge in Coil winding
2. Corona discharges on sharp edges (ground or HV)
3. Void discharges from bushings
4. Floating parts (not proper connected to HV or ground)
5. Void discharges in solid insulation material
6. Surface discharges (on insulating material)

UHF Sensors for Transformers

- In new transformers, Sensors can be fitted by the OEM at little extra cost or effort
- For in-service transformers, Sensors can be fitted to any available inspection hatch or manhole as a retrofit – this requires an outage and oil handling
- It is also possible to fit “probe” type Sensors through the oil drain/filter valve of “ball” or “gate” type valves – this does not require an outage
- The UHF Sensors are very simple and robust and contain no electrical parts to fail or age over the transformer lifetime – designed for 40++ years

UHF Sensors on Transformers



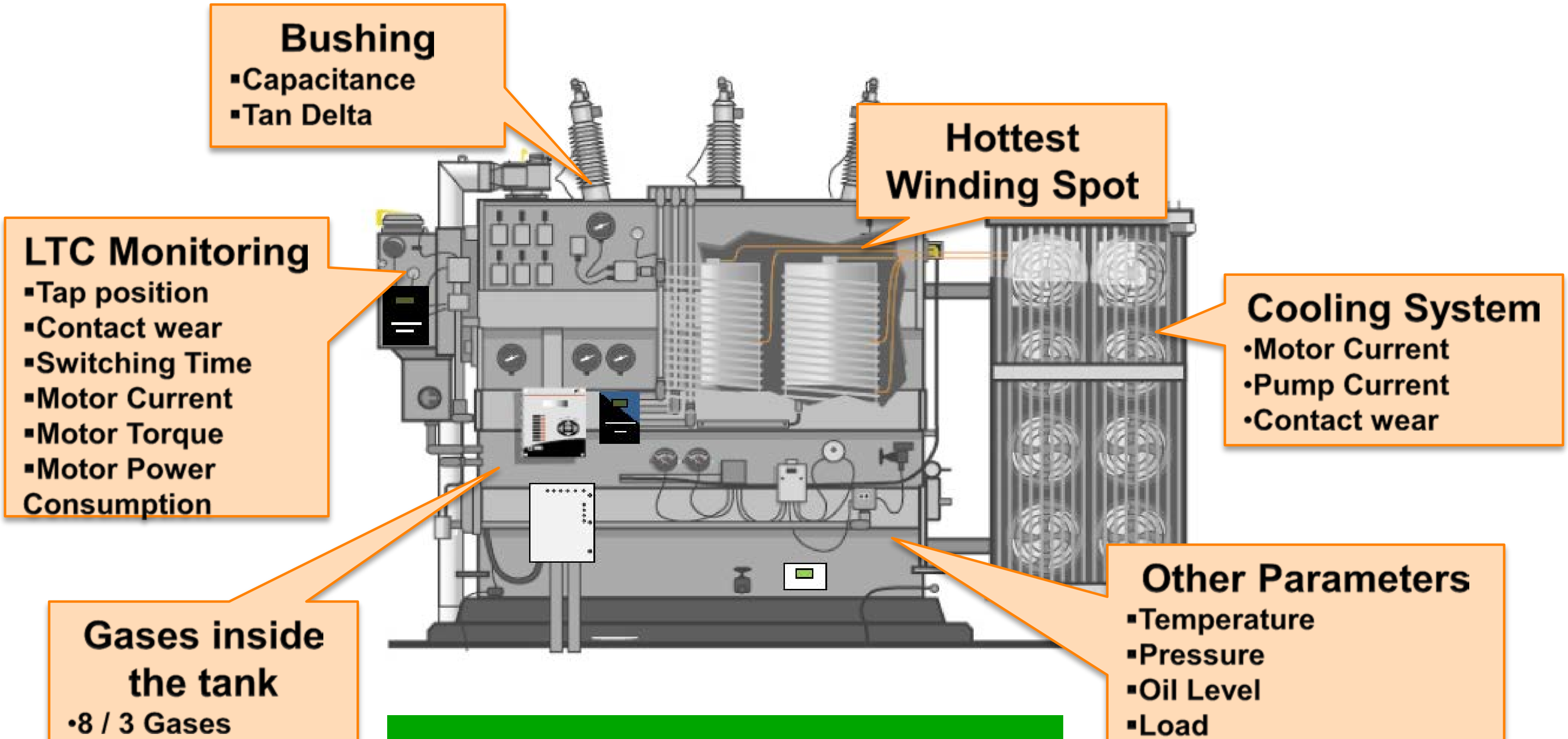
- Sensors are to be fitted with maximum possible spacing between them to allow better triangulation of signal
- Standard sensors must not intrude into high field areas – special sensors are available for such areas
- Sensors near top of tank are more sensitive to defects in bushing connection area
- Lower sensors can be installed using drain valves (this does not need oil to be drained)
- Number of sensors depends on size of transformer (minimum of 3 needed for location, 4 to 6 preferred depending on complexity of internal parts, separate tap changers etc.)

Pressure Measurement

- Pressure measurements can be useful for monitoring fault conditions and oil leaks on sealed systems such as Oil Impregnated Paper (OIP) bushings.
- It is recommended that either a pressure sensor with a 4-20mA output or a facility for fitting a sensor is provided on large oil filled bushings.

New trends in Transformer Monitoring

- **Investing in fault prevention by online monitoring**



Models

Insulation Ageing	Life time Consumption	Moisture in Insulation	Bubbling Temperature

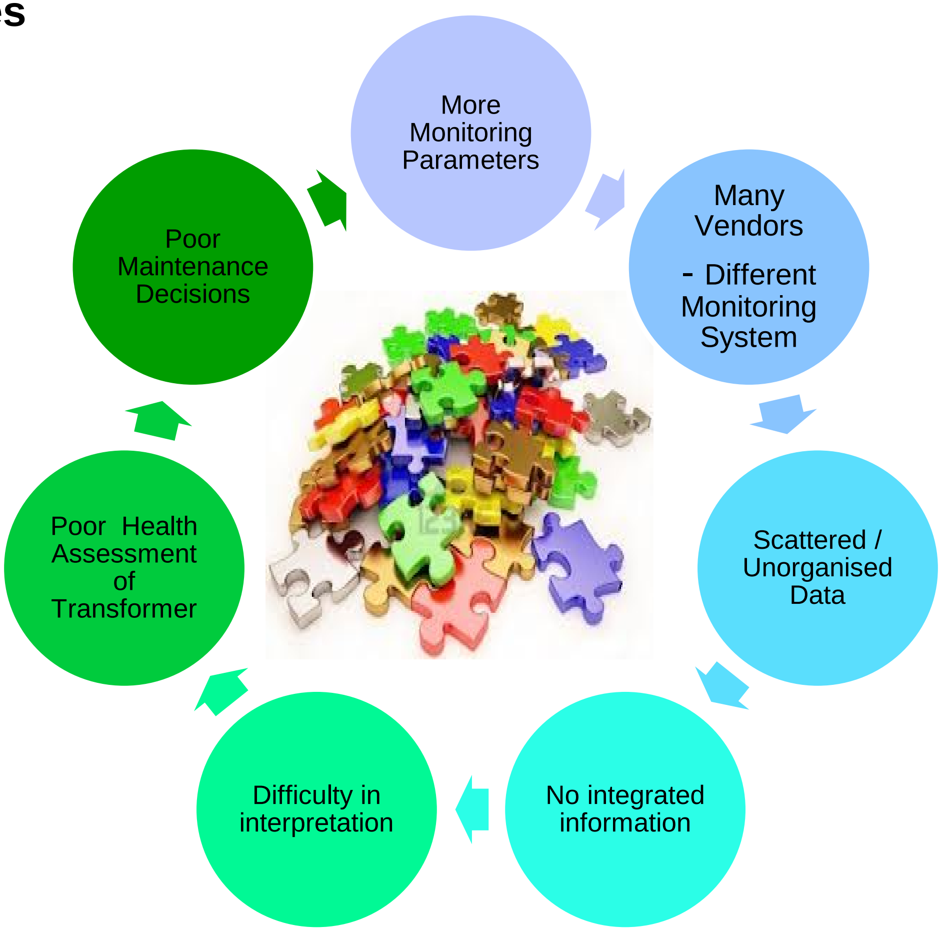
Expectations from Condition Monitoring

- **Prevent Major Failures and optimize maintenance**
  - **Reduce cost of sudden outages**
  - **Avoid unnecessary maintenance visits**
- **Achieve better utilization of Load Capacity**
  - **Put closer watch on the units that has higher risk levels**
  - **Expert Decision Support System**
- **Extend the remaining lifetime**
  - **Comparison with benchmark data**
  - **Failure pattern analysis**
- **Simulation tool for training new staff**
  - **Knowledge database with situation analysis capability**

Challenges associated with the Monitoring

- **Managing large amounts of monitoring data**
  - **Separating the important information**
  - **Correlate data from different sources**
  - **Maintaining data security**
  - **Easy-to-use human interface**

- **Overall health assessment**
  - **Co-relative analysis of parameters**
  - **Risk Index for Transformers**
  - **Building an accurate knowledge database**



Solution to the Challenges

Collect Accurate Data

- Fast
- Reliable
- Real-time

Combine Captured Data

- All information required to assess the condition of the Asset
- Prioritise, organise data
- Multi client concurrent access

Assess overall Asset Health

- State of the art analysis and interpretation
- Correlate analysed data -> SEVERITY ANALYSIS
- Substation automation using IEC 61850

Present information intelligently

- User friendly interface
- Combined input alarming
- Intelligent report generator
- Training Tool

QCM-TMS: Product Components

Sensors

- UHF PD Sensors
- DGA
- Temperature sensors
- Wining Temp (fiber)
- Oil Level Indicator
- Flow Indicator
- Pressure Gauges
- Bushing Sensors

Monitors

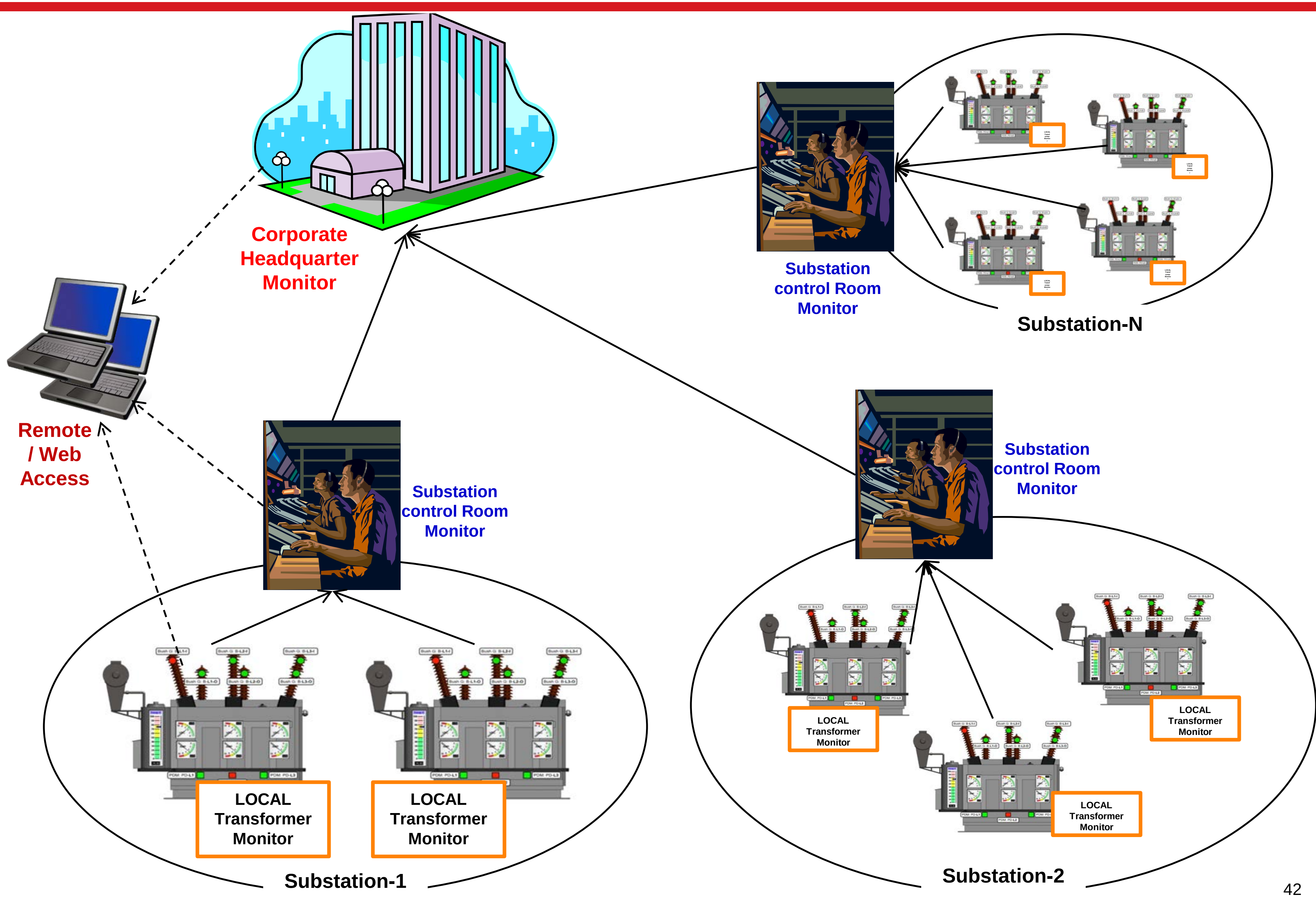
- **609 PDM**
- **Serveron TM8**
- **ITM 509 series**
- **Bushing Monitor**

Expert Analysis System

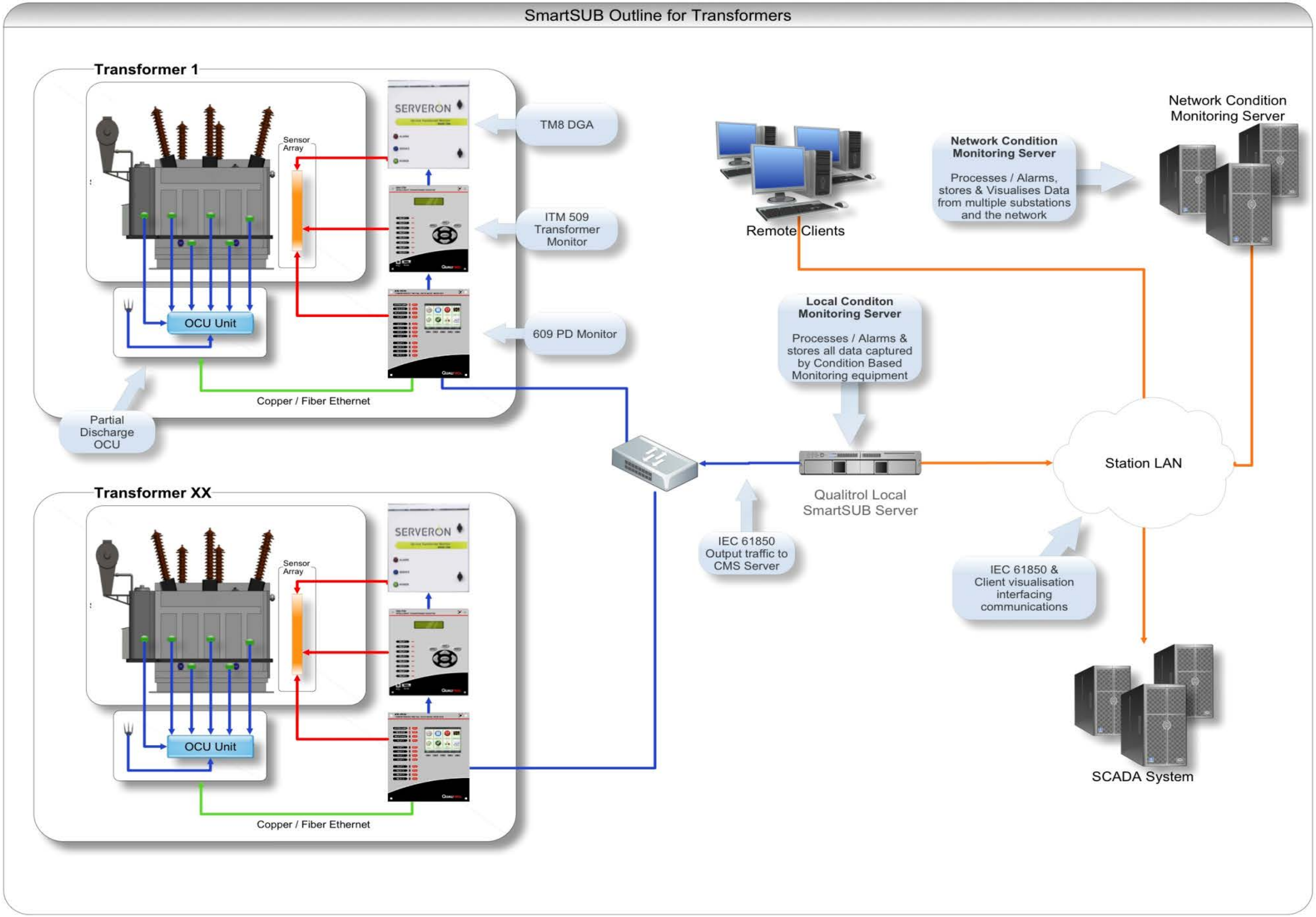
SmartSUB

- SmartPDM
- SmartDGA
- SmartBushing
- SmartITM

Monitoring Architecture



TMS System Architecture Example



TMS Sensor Examples

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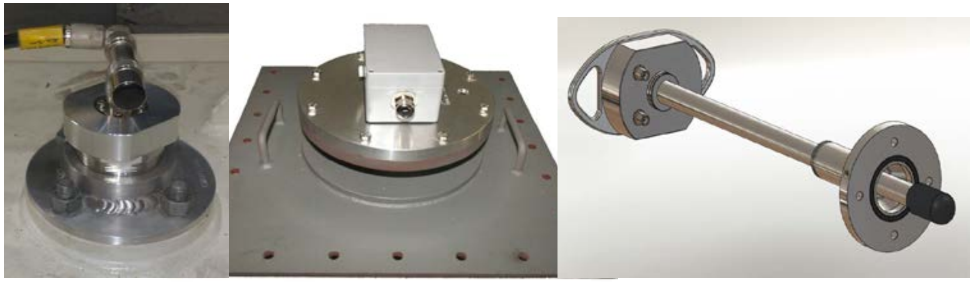
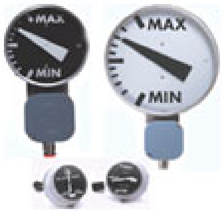
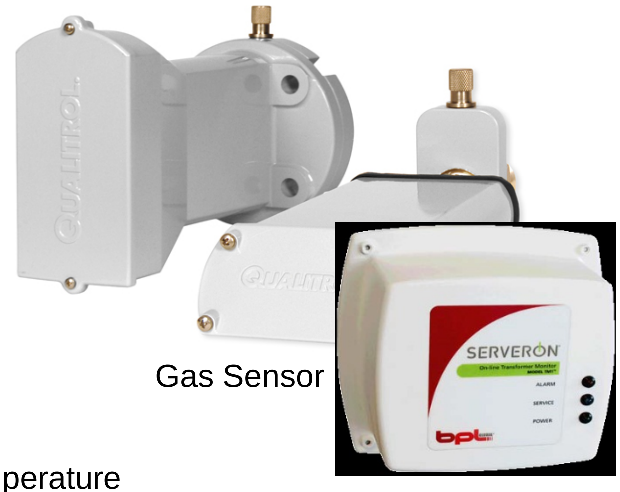
Temperature Measurement Devices


UHF PD Sensors


Pressure Controls, Gauges, & Relays

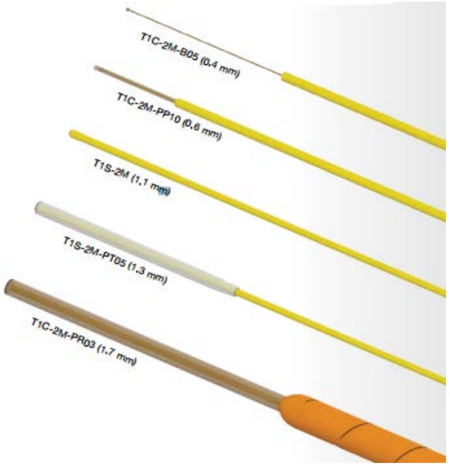


Flow Indicator



Gas Sensor

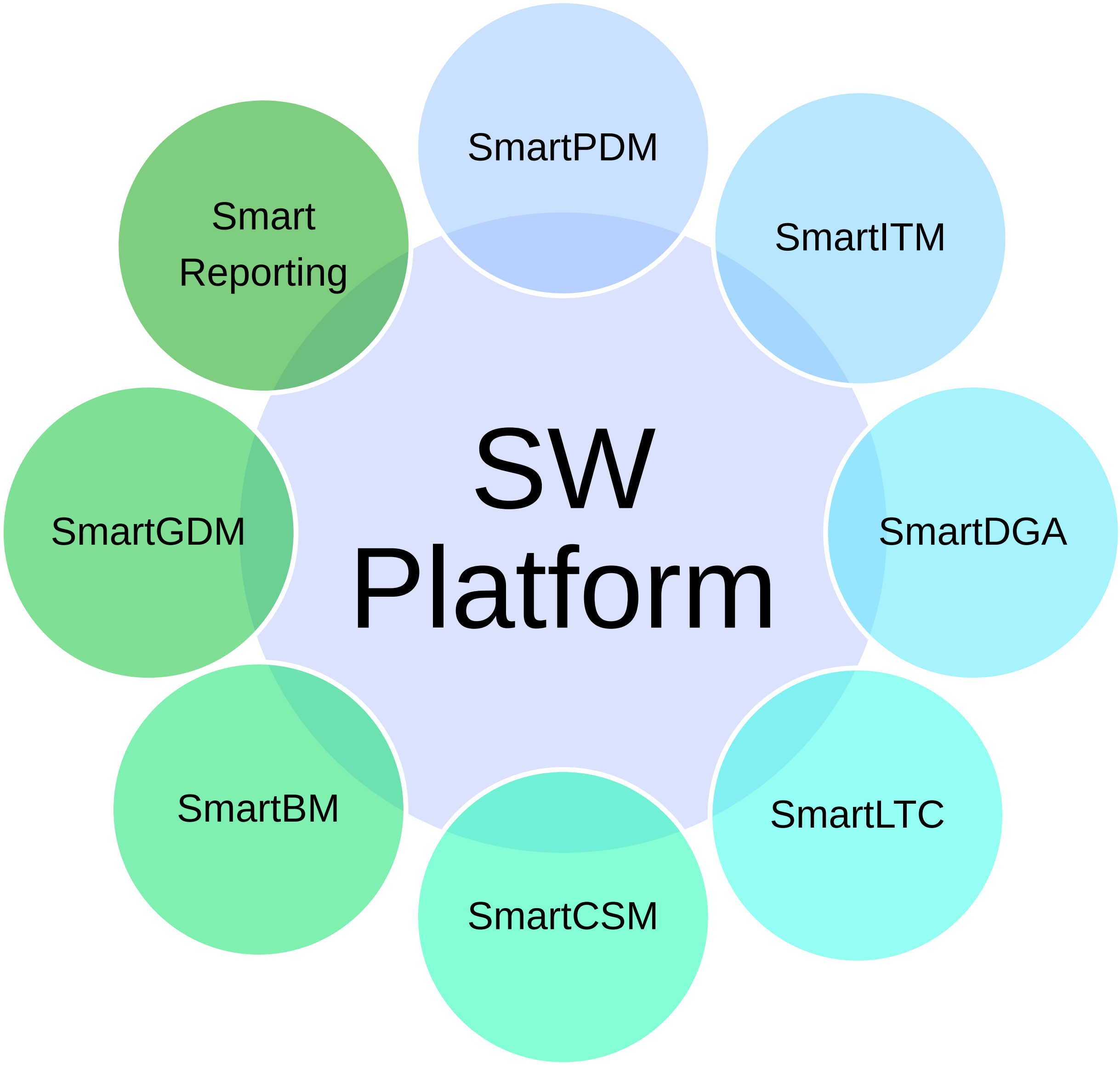

Liquid Level



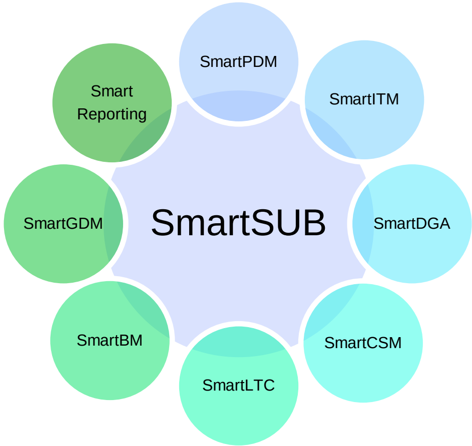
F5ber Optic Temperature Probe

Winding Temperature Simulation System

Example for Expert Analysis System



Example for Expert Analysis System

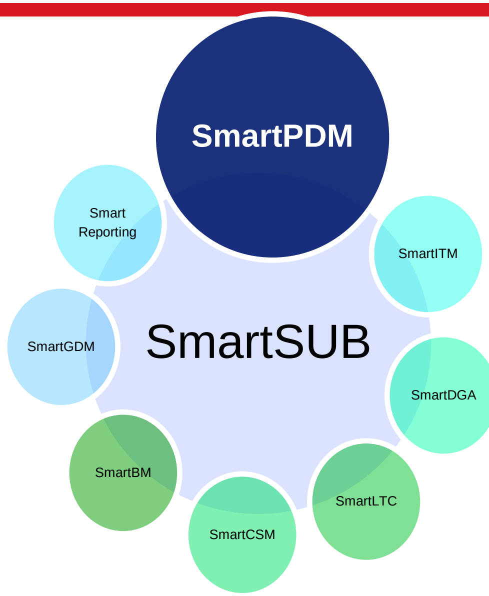


- Should provide common integration platform for all monitoring devices
- Single device to station wide to country wide monitoring
- Modular and scalable system architecture
  - Ease of device integration.
  - Plug-in device support modules to support each device / protocol
- Rules driven decision engine, configurable in field
- Windows Client interfaces built from linked components toolkit & IDL
- High level of security
  - NERC compliant
  - All client communications over proprietary protocol & SSL encrypted

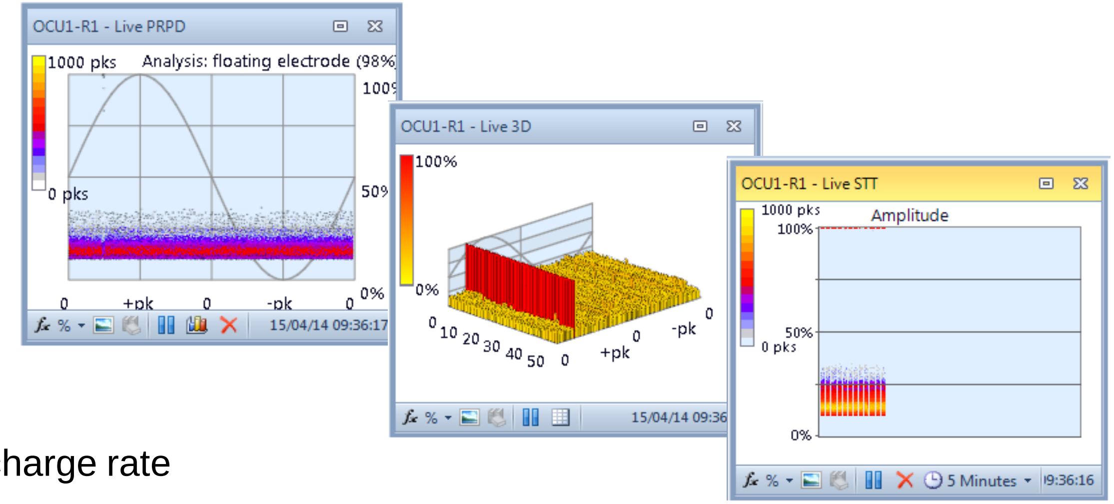
Partial Discharge Monitoring

- PD analysis on UHF signals
- Artificial intelligence and Neural Network based algorithms
  - Accurate PD alarms
  - Efficient noise elimination
- Simple analysis output

Event	Date	Coupler	Analysis
1541	15/04/14 05:50:03	OCU1-R1	floating electrode 99%
1539	15/04/14 05:45:07	OCU1-R1	floating electrode 98%



- PD analysis screens for experts
  - PRPD display
  - Single Cycle Display
  - STT display
  - History and Event Archive
  - Trend display for peak hold and discharge rate



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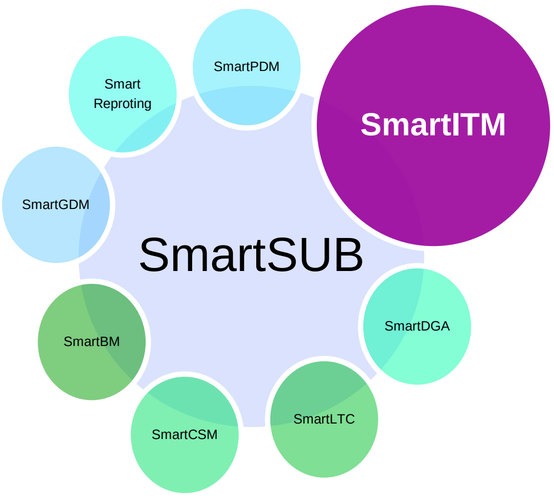
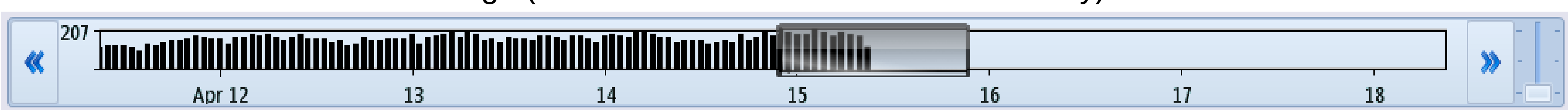
Intelligent Transformer Monitoring



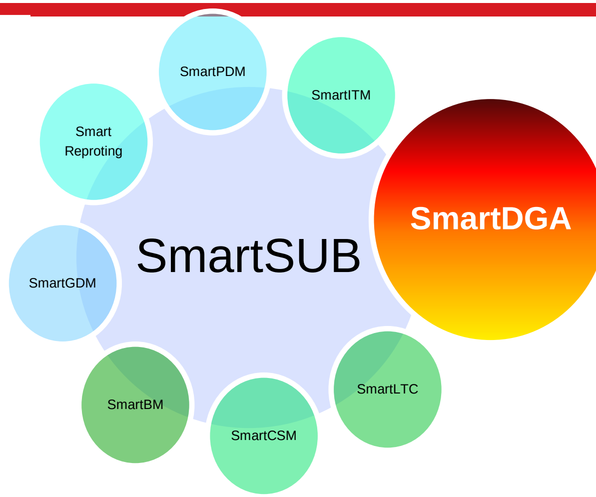
- Output from analog (RTD, 4-20 mA, CT, VT) and digital (Dry and Powered contact switch) sensors
- Current values for all the active components of Main Tank
  - Temperature (Ambient, Oil, Winding)
  - Pressure (Main tank, conservator)
  - Oil Level (Main tank, conservator)
  - Load Current and Voltage
  - Digital Status – PRD, Breather, RPRR, any other monitor
- Historic trend value for all active components
  - User selectable date range (with zoom in and zoom out functionality)

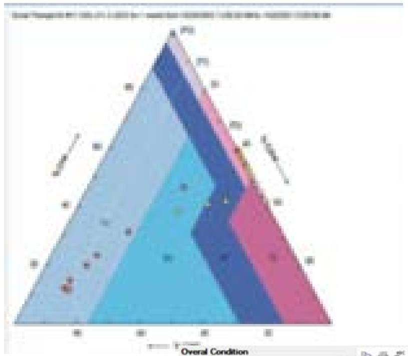


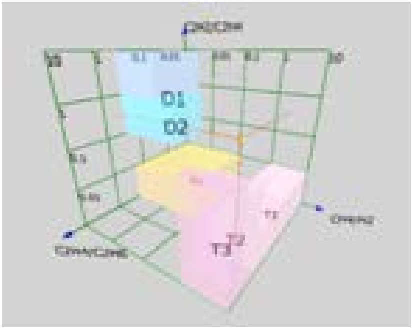
  - Stacked trend chart for similar kind of parameters – Easy for comparison of trends

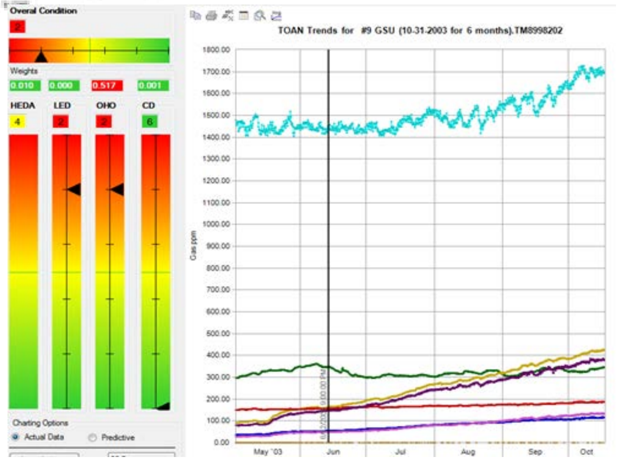
Dissolved Gas Analysis

- Gas chromatography (GC) technology based
- Optional measurement capabilities including oil temperature and moisture-in-oil readings
- Analysis models
  - Current ppm value and trend for historic values
  - Rate of Change (RoC) graphs
  - 3 x Duval Triangles
  - Rogers Ratio
  - Dornenberg Ratio
  - IEC - ratios
- TOAN (Transformer Oil analysis and Notification)
  - Artificial Intelligence and Neural Network based algorithms, developed with Arizona Public Services
  - Indicate criticality of the gases generated inside the tank

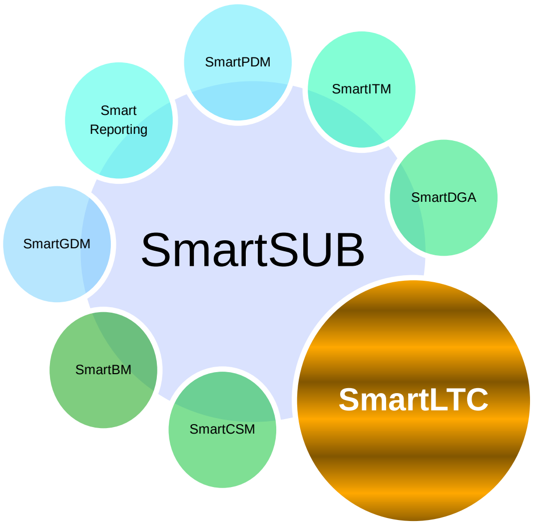








Load Tap Changer Monitoring



- Output from analog (Register Bridge, RTD, CT, VT) and digital (Dry or Powered contact switch) sensors
- Current and historic trend values for
  - LTC tap position
  - Switching Time for tap movements
  - Power consumed in tap movements
  - In-rush and Steady state motor current value for tap movements
  - Temperature Difference between Main tank and LTC tank
- Alarms for any deviations on the monitored value from the fingerprints
- Calculates contact wear of the bushing tap and life estimation

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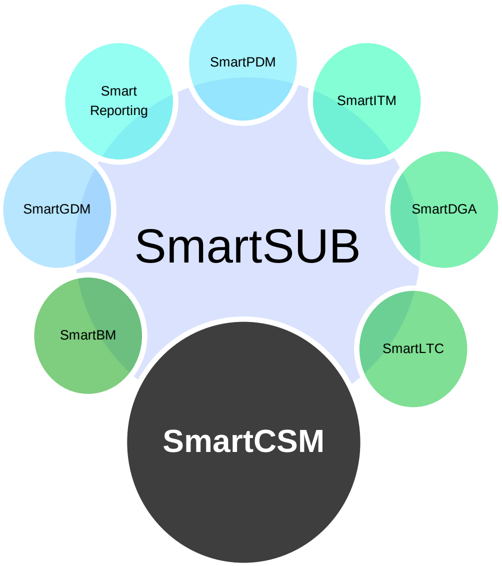
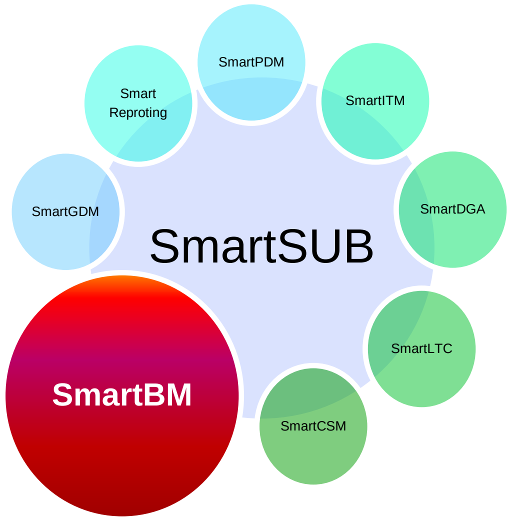
Cooling System Monitoring



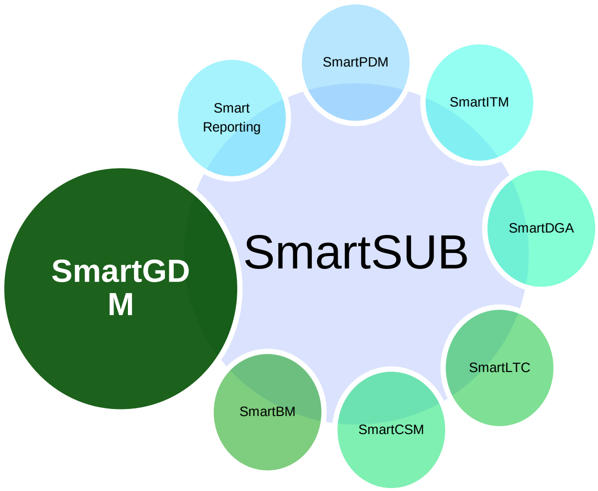
- Output from analog (RTD, CT) and digital (Dry or Powered contact switch) sensors
- Current and historic trend values for
  - In-rush motor current of fan banks for each run
  - Steady state motor current of fan banks for each run
  - In-rush motor current of pumps for each run
  - Steady state motor current of pumps for each run
  - Temperature Difference between top oil and bottom oil
- Alarms for any deviations on the monitored value from the fingerprints

Bushing Monitoring



- Output from bushing sensors and Reference VTs
- Current and historic trend values for
  - Tan δ and change in the Tan δ
  - Capacitance and change in the Capacitance
- Temperature compensated values for Tan δ and Capacitance
- Alarms for any deviations on the monitored value from the fingerprints

Gas Density Monitoring

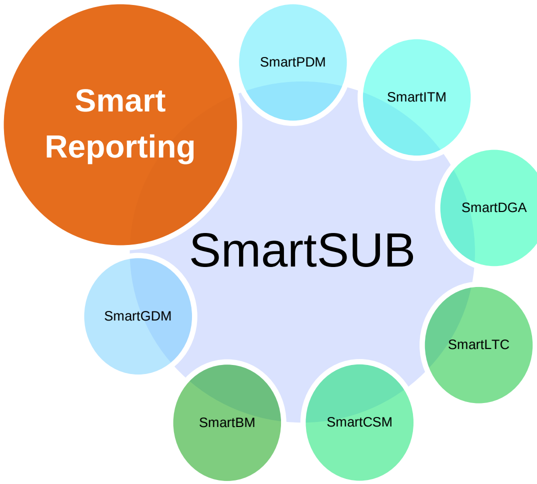


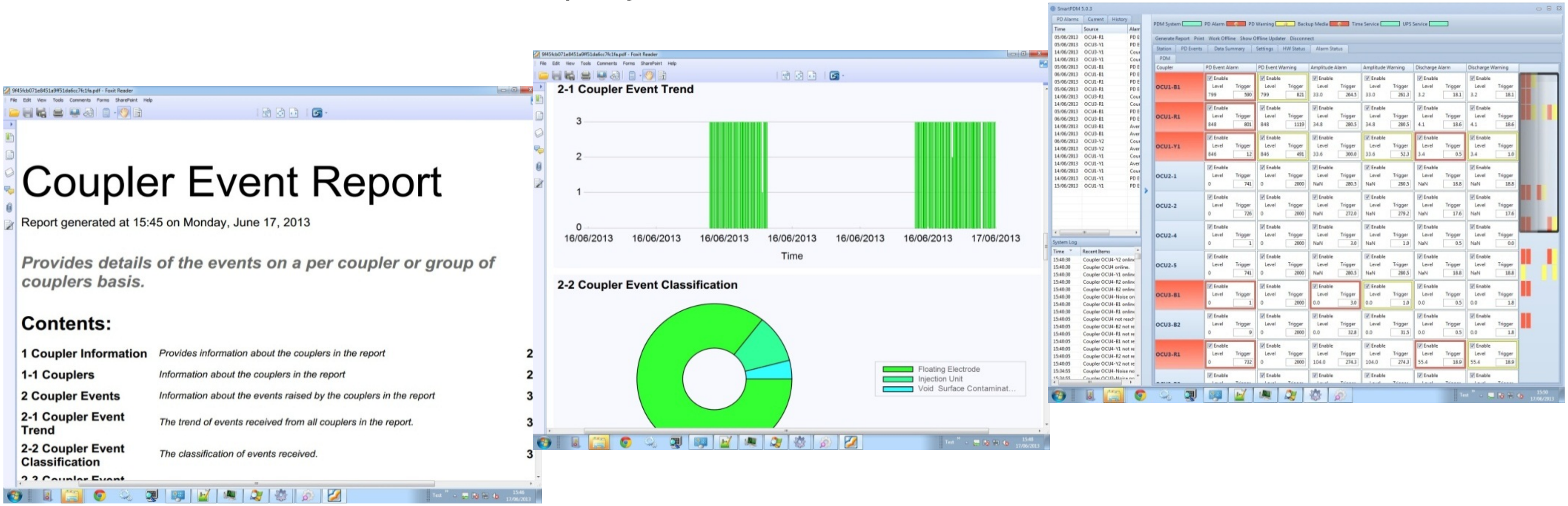
- For Gas Insulated Transformer (GIT - SF6 filled gas)
- Output from Gas Density sensor
- Current and historic trend values for
  - Gas Pressure
  - Gas Density
  - Gas Temperature
- Identifies and calculates
  - Time to Refill and Quantity to Refill for leaking chambers
  - Average Leak Rate for the entire transformer and substation
  - Total SF6 leakage estimation
- Alarms for any leak greater than normal leak rate
  - Leak rate greater than threshold
  - If pressure / density reduces more that threshold

SmartReporting

Reporting and Printing

- Automatic report generation (daily / weekly / monthly) with XLS & PDF as per customer needs
- Custom reports on viewed data within the user interface
- Enables rapid generation of on demand user custom reports to suit the requirements of the customer without the need to use third party software





Easy to use HMI

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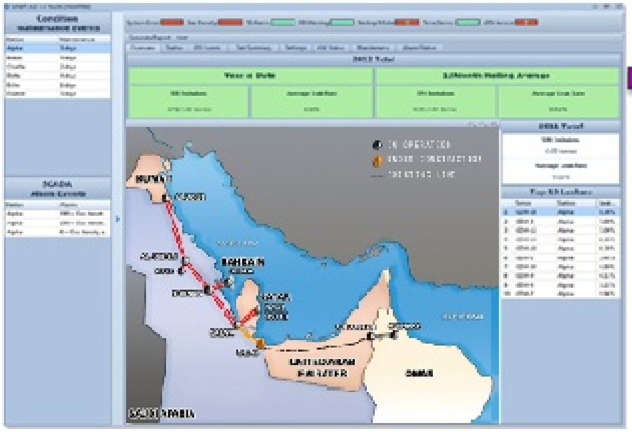
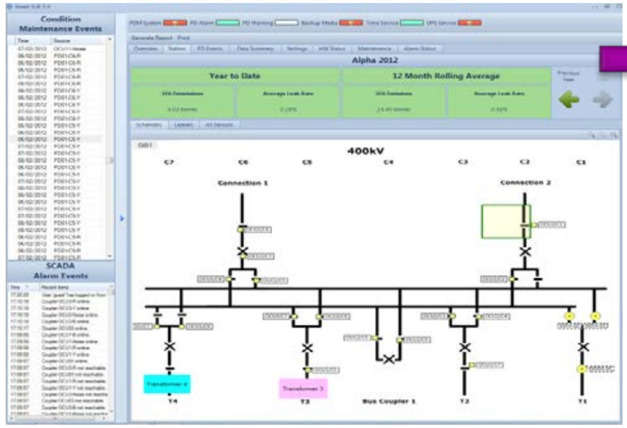
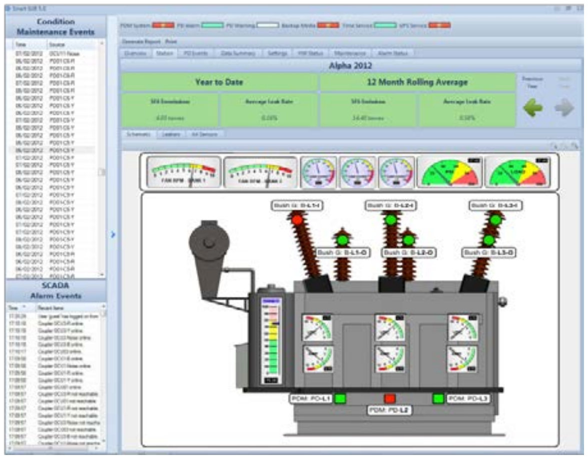
Intelligent Visualization



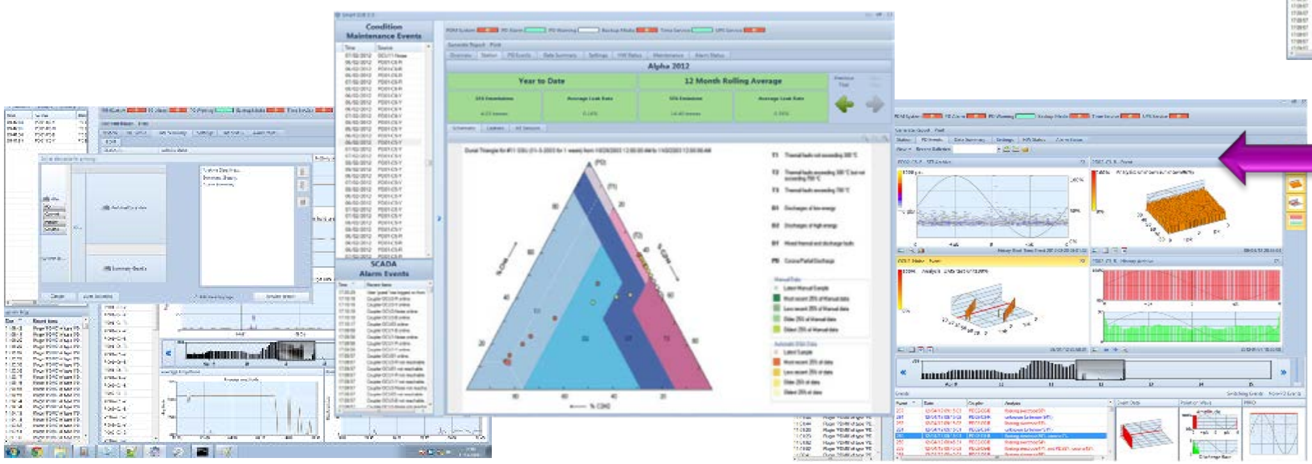
Country wide view: Showing all substations



Station level view: Line diagram showing assets



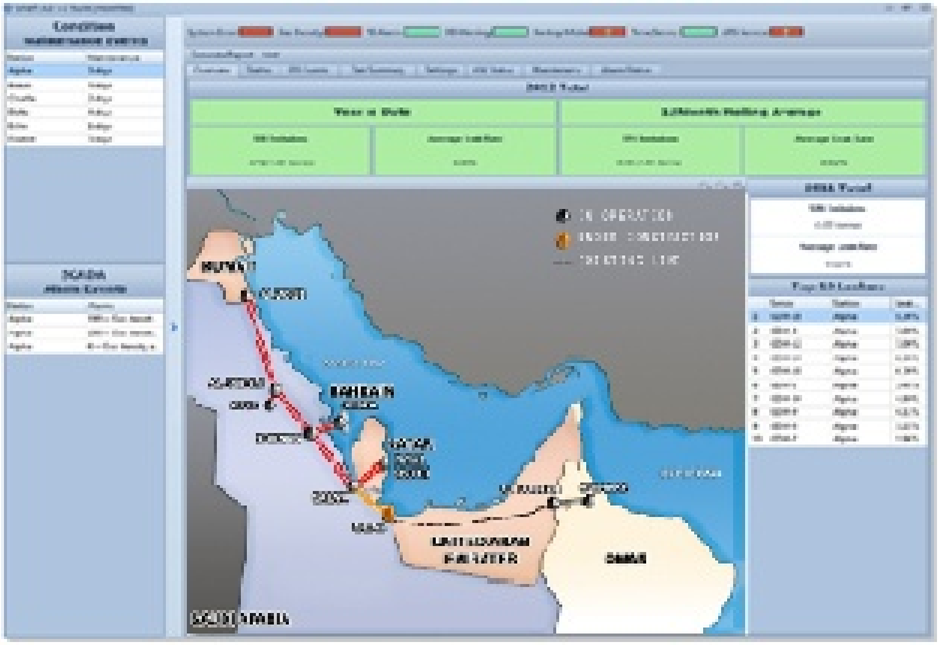
Asset Level View



Component level view: Showing all displays, data trends and other analysis for each parameter

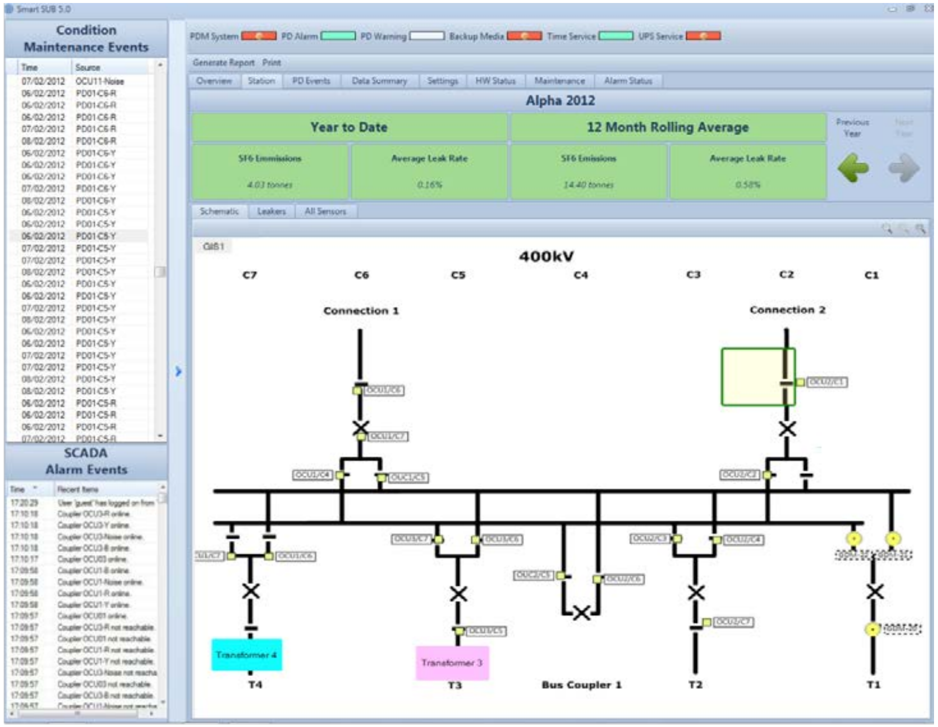
Region Level View

- **Showing all the substations of a utility across the region**
- **Intelligent substation level alarms for all monitored assets in region**
- **Facility to drill down to individual substation**
- **Station level alarm & system reporting**
- **Rollover summaries on per station basis**
- **Top 10 risk list**



SmartSUB: Substation Level View

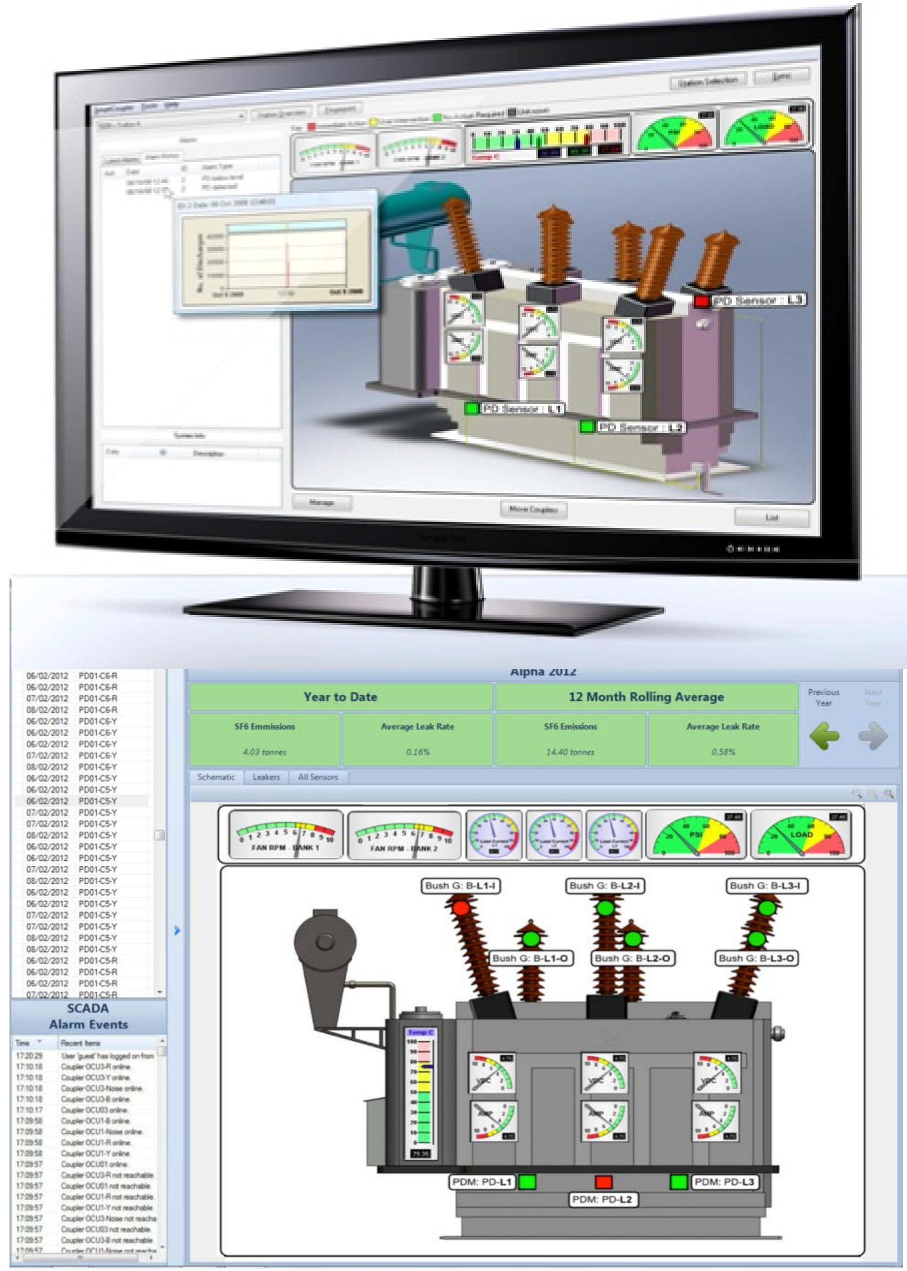
- **Showing all electric assets of a substation: Line diagram.**
- **Intelligent asset level alarms for all monitored assets in station**
- **Facility to drill down to individual assets**
- **Station level alarm & system reporting**
- **Rollover summaries on per sensor / group of sensors basis**



SmartSUB: Asset Level View

QUALITROL®
Defining Reliability

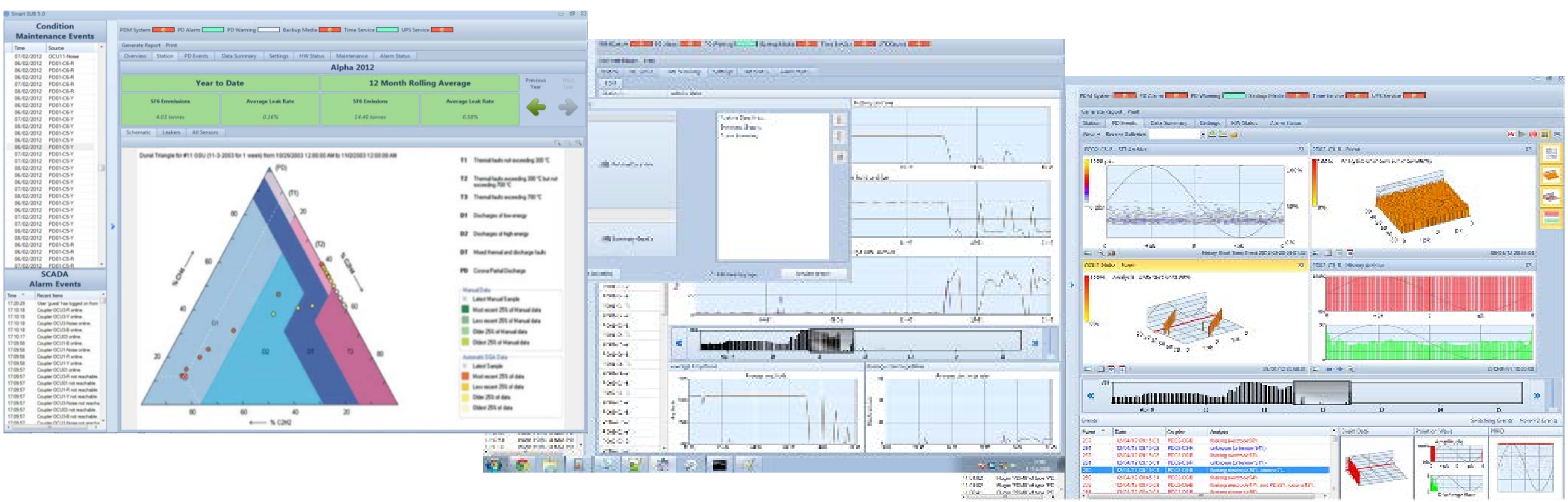
- **Live Display of all parameters of the assets (Transformer)**
- **Intelligent sensor level alarms for all monitored parameters on selected asset.**
- **Rollover summaries on per sensor / group of sensors basis**
- **Facility to select and compare individual monitored sensor trends**



SmartSUB: Individual Parameters

QUALITROL
Defining Reliability

- **Showing detailed analysis screens of the component**
- **Intelligent visual sensor level alarms complete with trending displaying trigger point**
- **Individual Analysis models**
  - **SmatPDM** - **SmatITM** - **SmartDGA** - **SmartLTC**
  - **SmartCSM** - **SmartBM** - **SmartGDM** - **SmatReporting**



CASE STUDY – PHI, USA

Pepco Holdings, Inc

Significant SAVING in Q&M $

QUALITROL
Defining Reliability

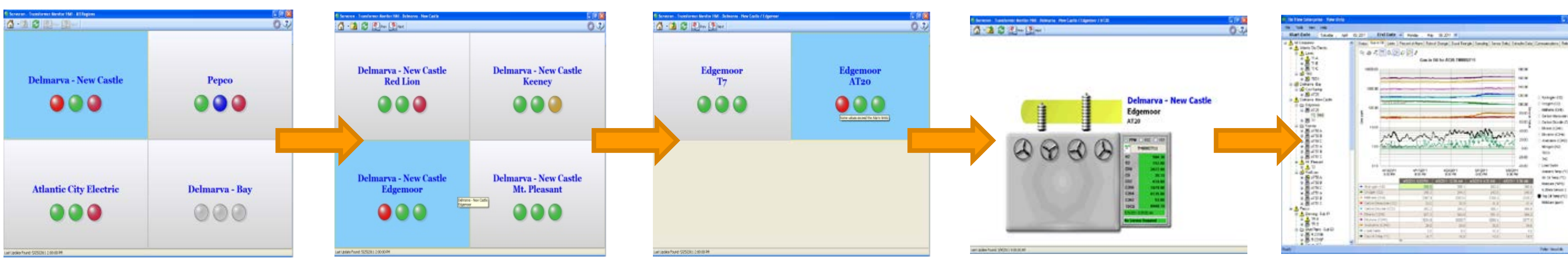
- **One failure was averted at a major Pepco substation**
  - **A 200MVA transformer began to rapidly gas when another unit was taken out of service**
  - **The unit was inspected, temporarily repaired and returned to service**
  - **Load was shifted as gassing again became unstable and the unit was later replaced**
- **Another 250MVA autotransformer at a DPL generation facility was nursed to replacement using the system**

Pepco Holdings Inc

PHI's AMM System

QUALITROL
Defining Reliability

- **Over 100 online DGA monitors**
  - **Remote monitoring of 8 fault gases (H_2, O_2, CH_4, CO, CO_2, C_2H_4, C_2H_6, & C_2H_2)**
- **At-a-glance status checking and drill-down for quick problem identification**
- **Enabling broad access to data**



Pepco Holdings, Inc

Questions?