M&D

Monitoring & Diagnostic

A two “complementary” steps approach

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Monitoring : On-Line techniques and devices to detect abnormal conditions

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Monitoring function is to avoid unexpected transformer failure and insure continuous normal operation

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Diagnostic : Application of On-Line **and** Off-Line devices & techniques to confirm and determine the exact nature of the anomaly

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Diagnostic function is to minimize unwanted downtime by making accurate condition assessment when anomalies occur

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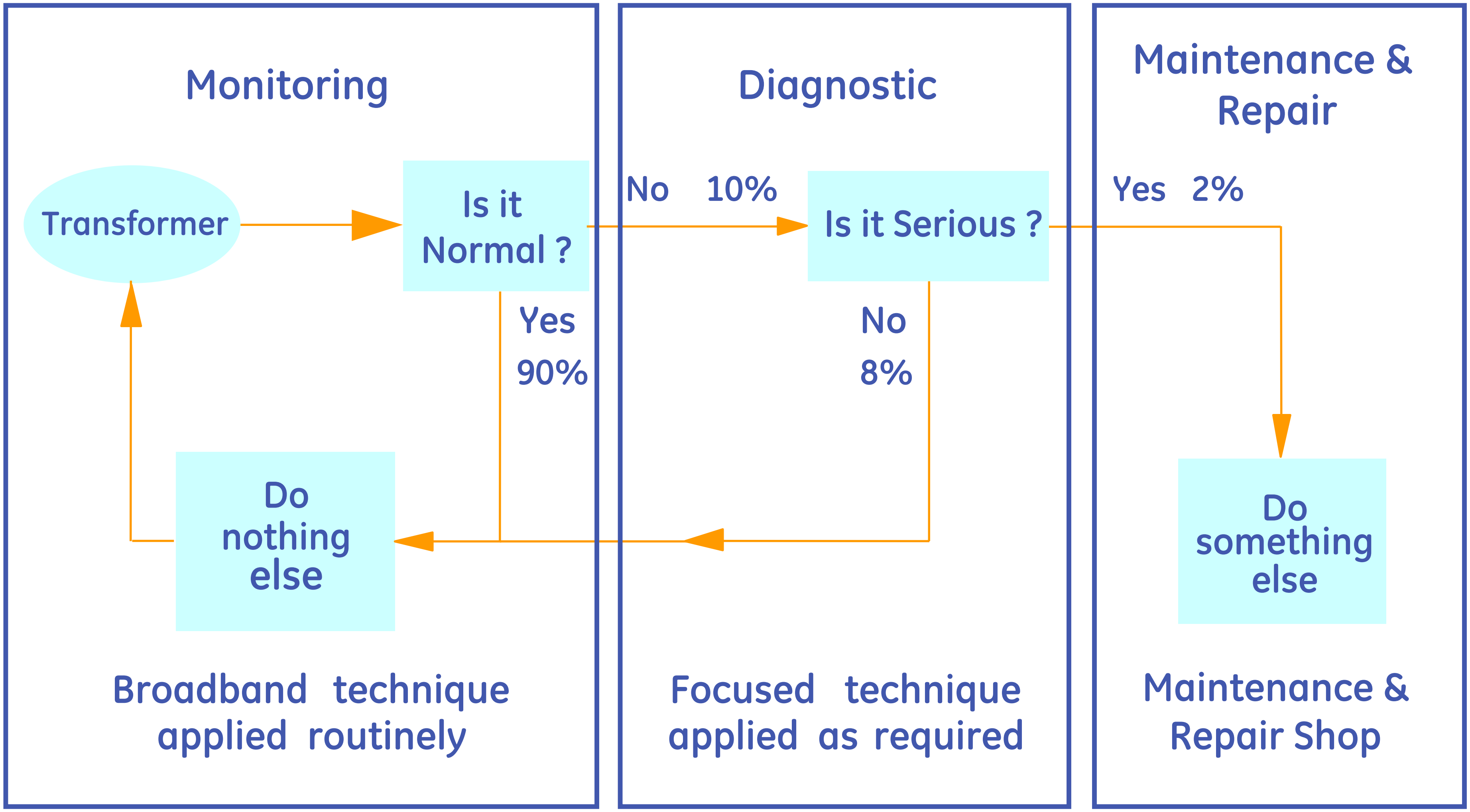
Monitoring vs. Diagnostics



M&D

How to apply this two steps approach effectively?

To answer this question, let take a look at what is inside a transformer

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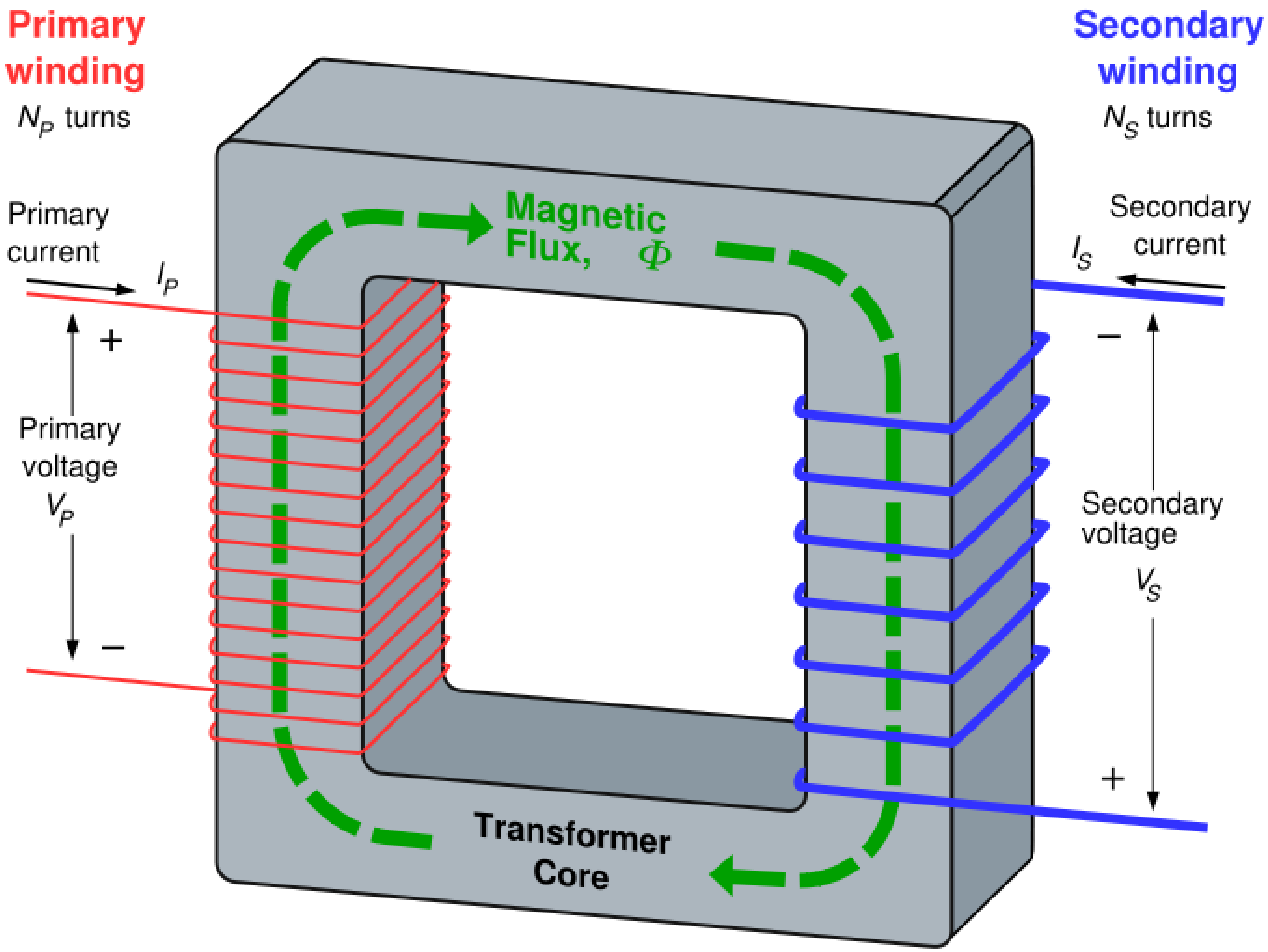
The Transformer, a simple principle



$$V_1 * I_1 = V_2 * I_2$$

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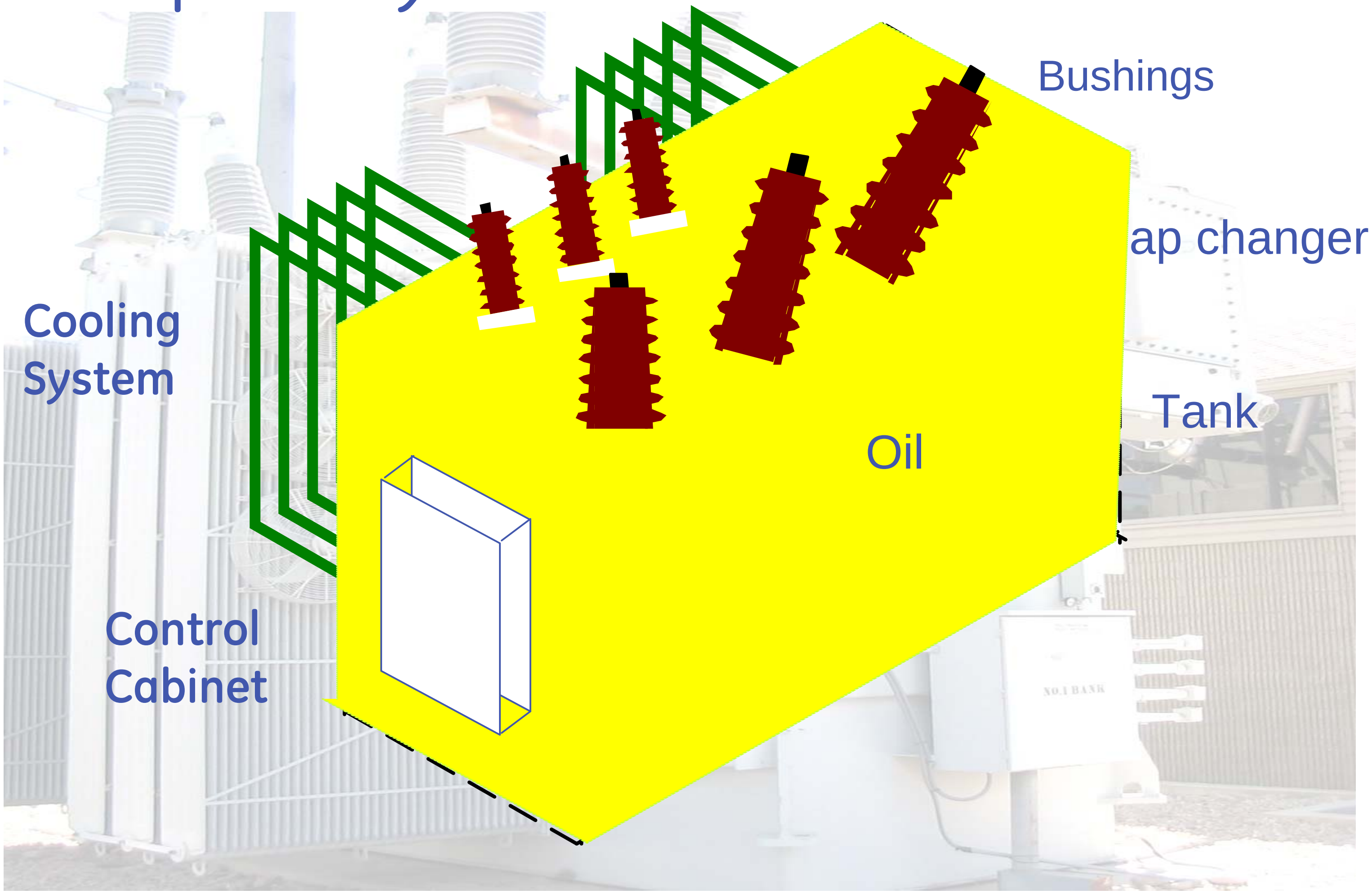
The Transformer
A complex system

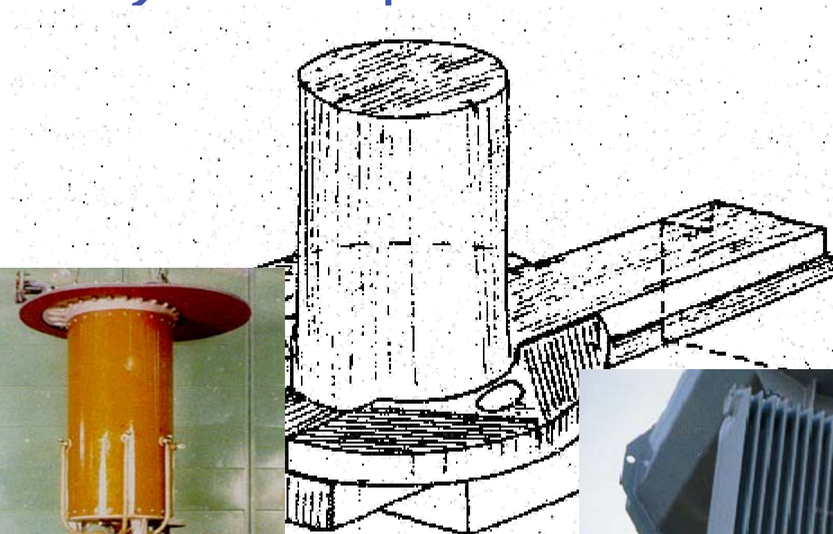


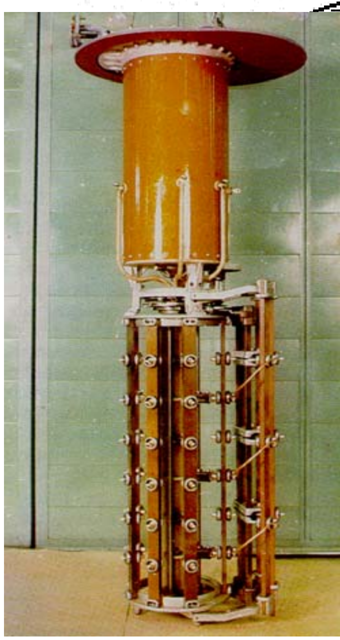
Transformer complexity

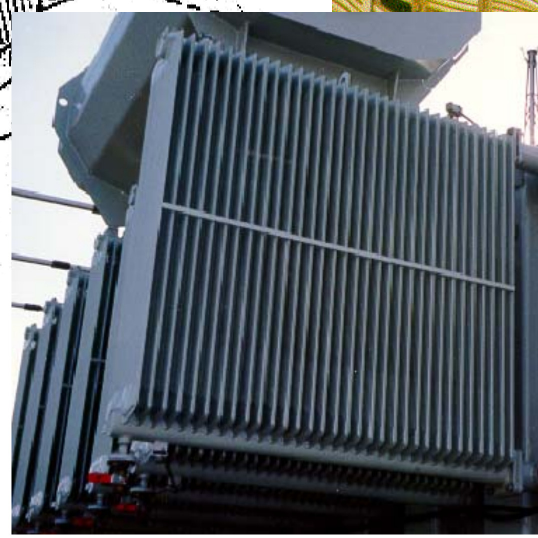
- To further complicate matter, there is also a large variety of transformer
  - Single and three phase transformers
  - Core and Shell type transformers
  - Auto and step-up transformers
  - Reactor, rectifier and phase shifter transformers
  - Large and small transformers
  - ONAN, ONAF, OFAF, WFOF....

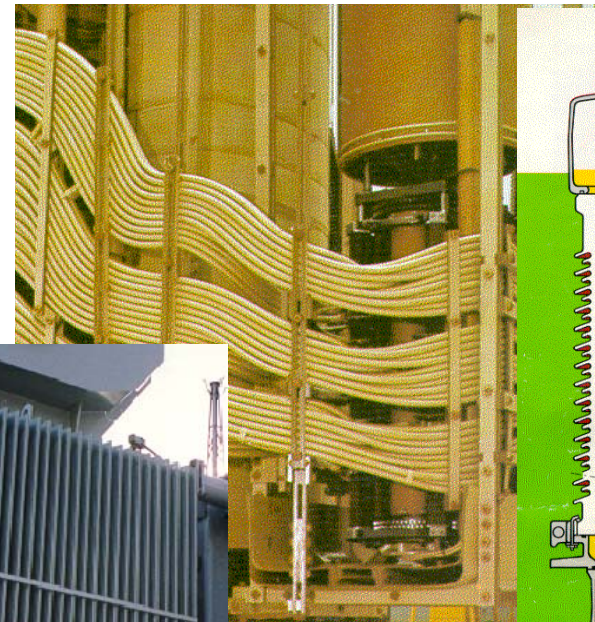
The Transformer components

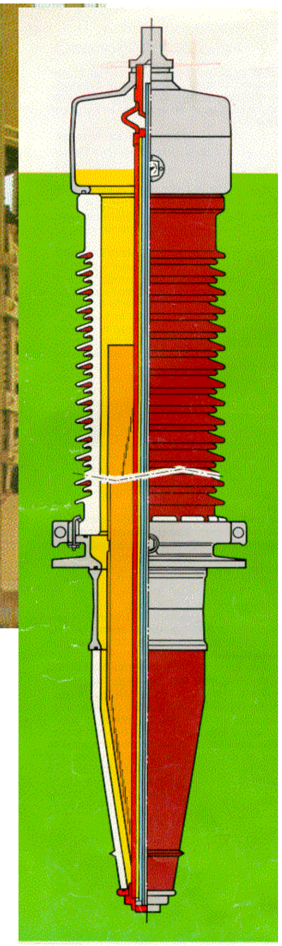
Many components…Many problems ?





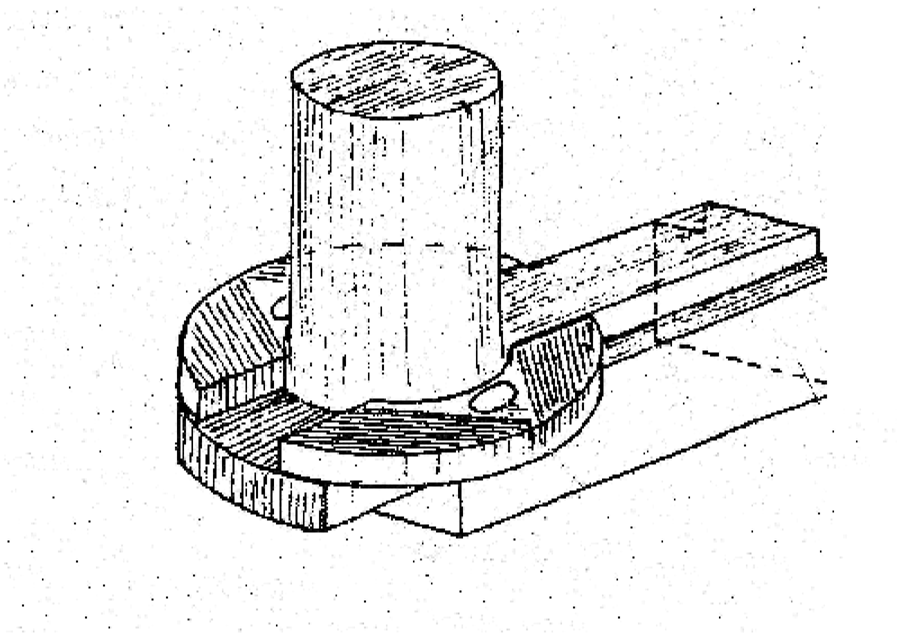






The Transformer components

Core and magnetic screen



Stray field is proportional to load

Magnetic shunt or screen may saturate at overload

Hot spot may occur in unexpected places

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Example of overheated core lamination

Overheating of lamination joints

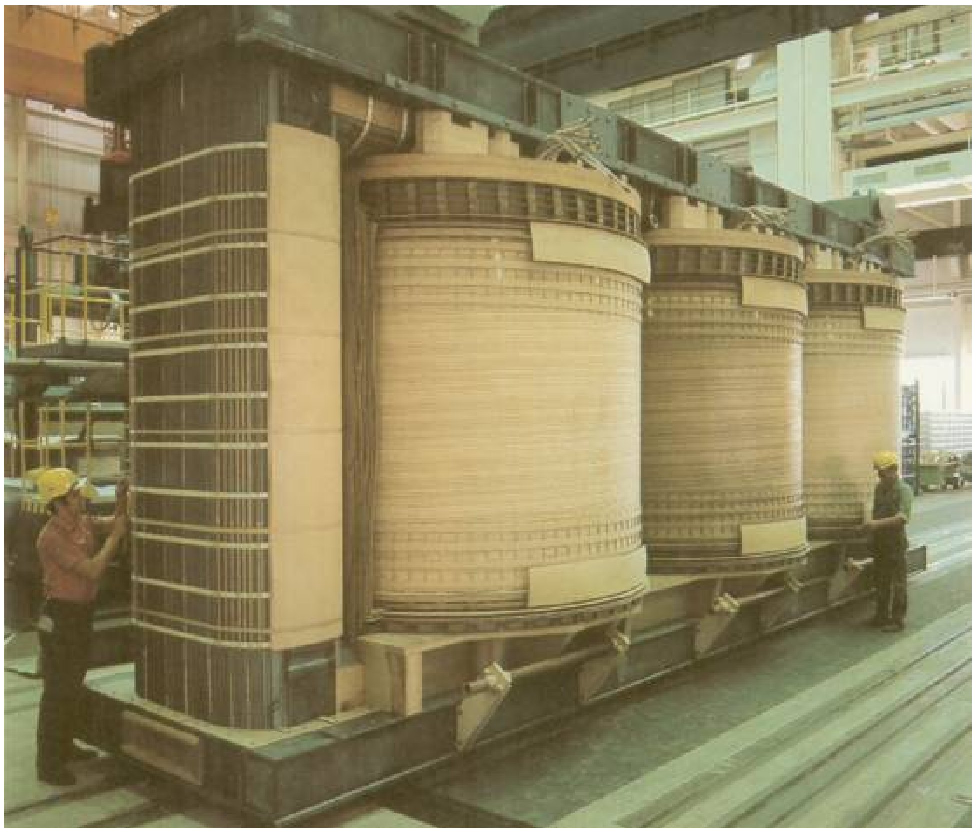
Sokolov, Cigre Colloquium, Moscow 2005

Local saturation of bottom yoke

Sokolov, Cigre Colloquium, Moscow 2005

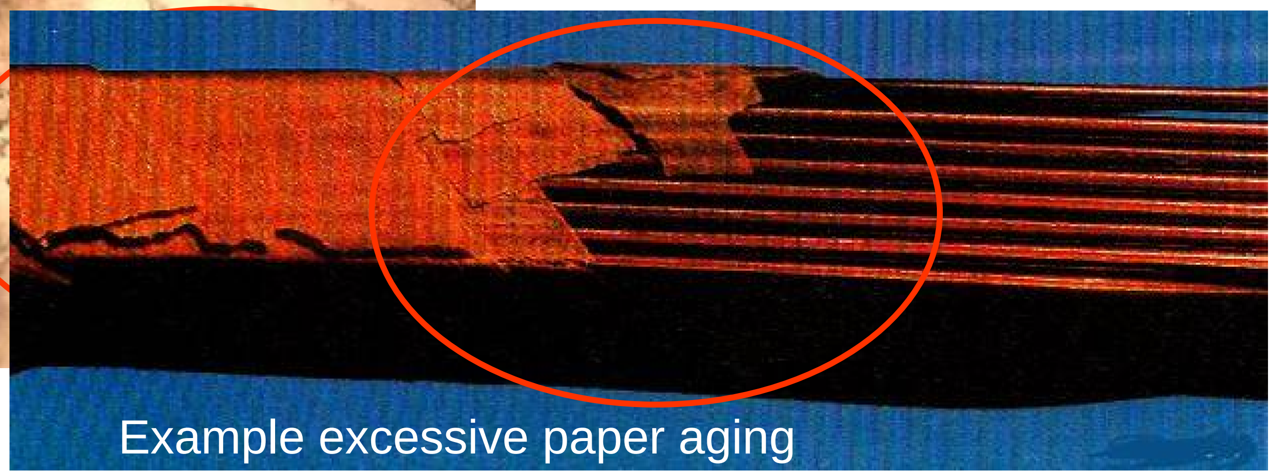
The Transformer components

Windings and Barriers

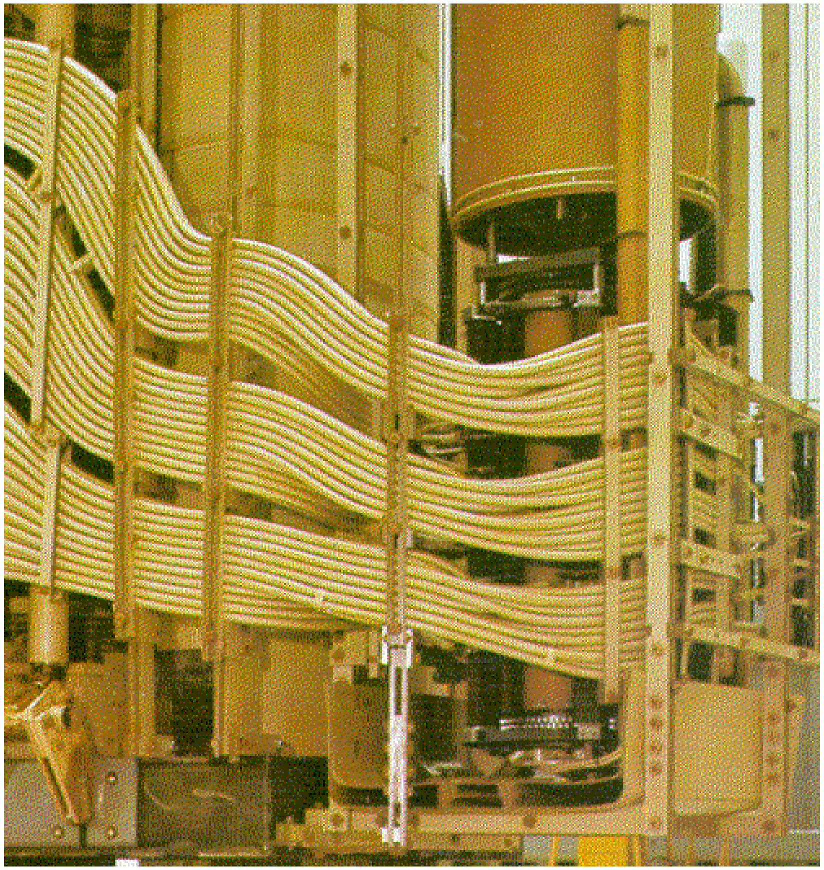


- Paper/oil insulating system insure dielectric insulation
- Damaged or wet paper could result in catastrophic failure
- Degraded oil could also lead to failure

Example of Winding Paper Degradation



The Transformer components
Leads and connections



- Lead cross section
- Extra insulation
- Restricted cooling
- Defective connections

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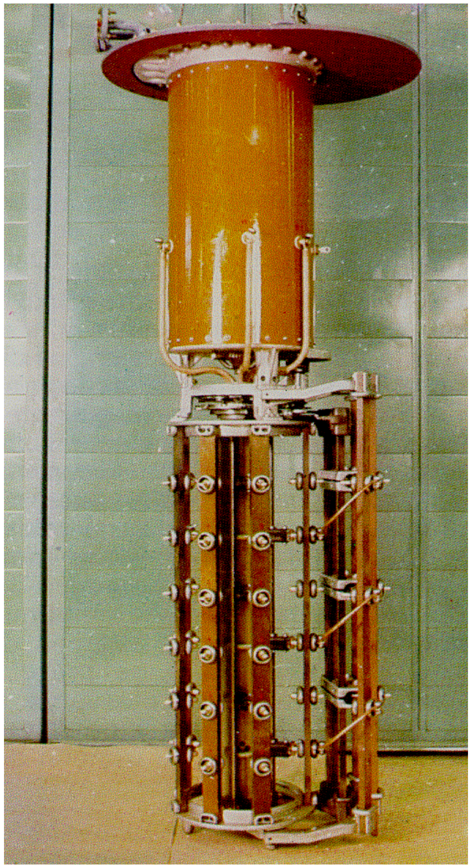
Example of overheated lead connection

The Transformer components
Tap changers



Excessive contact temperature

Increase of tap-changer contact resistance

Shorter contact life

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Example of OLTC failure

Carbon on Reversing Switch

Normal Reversing Switch

The Transformer components
Cooling System

Pump operation

Fans Operation

Cooling mode

Overload capacity

> Short term

> Long term

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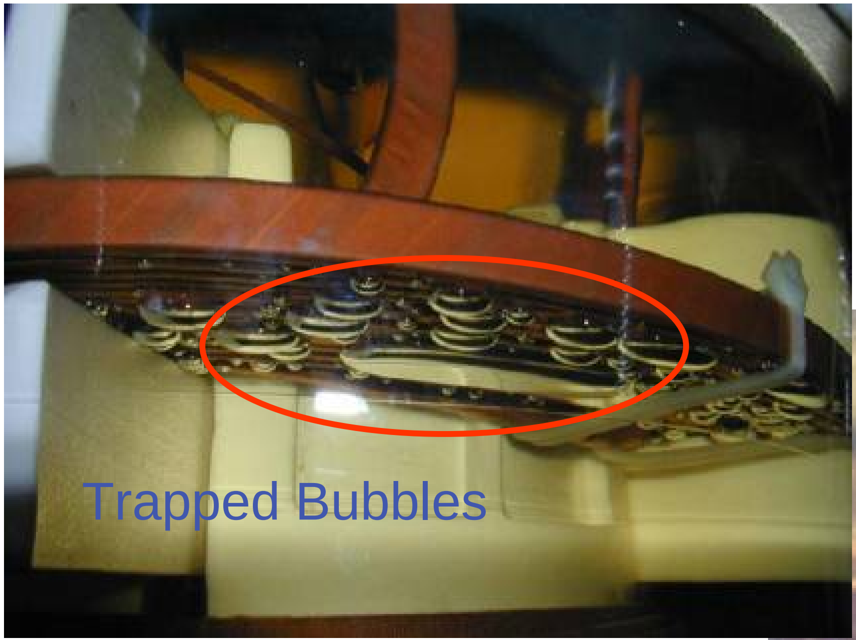
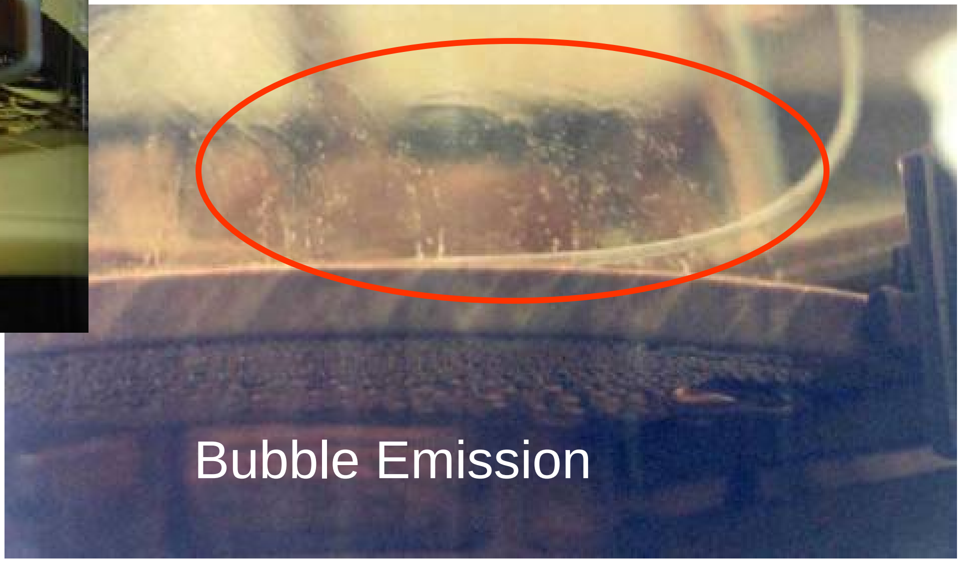
Example of Overheating





V. Davydov EPRI Moisture Seminar 2002

The Transformer components
Bushings

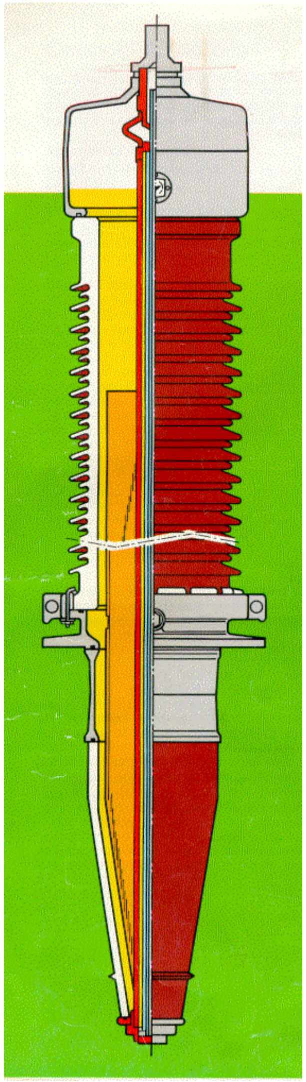
Pressure build-up

Gasket seals

Tan delta increase

Dielectric performances

Stray magnetic flux



Example of Bushing failure

Transformer monitoring rationale

- Even if Transformer are complex machine, with several possible failure points, the overall failure rate of transformer is low (1-2%).
- Most units serve year after years without problems.
- However, unexpected failure with forced outage can be very costly.
- Catastrophic failure could also cause injuries and widespread damage
- Therefore, it is necessary to take due precaution to avoid failure, even if these failures are rare and far apart.

Transformer monitoring rationale

How to monitor for failure detection ?

Problem:

- Large number of components
- Each component has its own possible failure modes

In Theory, each component could be monitored on-line with appropriate specialized technique

But, in practice, this would result in a very large and complex Monitoring & Diagnostic system

Transformer monitoring rationale

How to monitor for failure detection ?

Problem:

- Complex Monitoring & Diagnostic system are costly
- They require maintenance and the data they generate in large quantity require specialized interpretation, useless 90% of the time
- For most transformer, they are simply not a practical solution

Transformer monitoring rationale

- What is needed for monitoring is a cost effective, **broadband**, early warning system.
- The monitoring system should combine the capability to detect a wide spectrum of faults and abnormal conditions at a minimal cost in terms of installation, maintenance and supervision
- Full diagnostics on the type of fault is not needed at this stage.

Transformer monitoring rationale

- Advance Diagnostic techniques, both On-Line and Off-Line, should be reserved to the small percentage of transformer needing them, rather than being applied, needlessly and “blindly”, to a large number of units.
  - Save Time
  - Save Cost
  - Save Human resource
  - Increase Transformer availability

Transformer monitoring rationale

- So, what and how to monitor?
- We should establish a balance between the proportion of the number of potential failure mode monitored and the cost/complexity of the monitoring system
- We should cover as many transformer sub-systems as possible with as many "broadband" monitoring techniques as practically and economically possible

Transformer monitoring rationale

Global Failure rate for transformers is 1 – 2% per year

Failures are **RANDOM** by nature

There are 4 major sub-systems to a transformer

> Main Tank, Including
  - Windings
  - Oil
  - Core
  - Leads and connection

> On Load Tap Changer

> Cooling System

> Bushings

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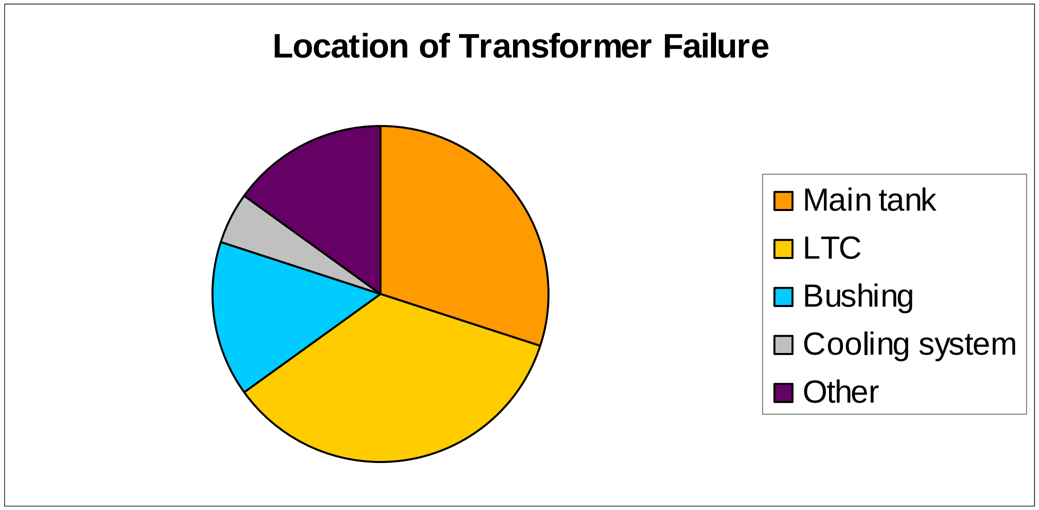
Transformer monitoring rationale



Main Tank 30%

OLTC 35%

Bushing 15%

Cooling System 5%

Other 15%

MAIN TANK: Windings failure, Partial Discharge, Excessive H2O, surface contamination, connection failure, screens failure, circulating currents, overloading hazard,

OLTC contact overheating and coking, desynchronization, excessive number of operations, mechanical damage, neutral switch inactivity

Bushing moisture penetration, oil leak, Partial Discharge, 'X' wax formation,

Cooling System clogged coolers by pollen or dust, fan/pump failure, sludge, oil leak,

Other External, such as lightning, animal interference, operation error, that are not detectable by on-line monitoring

Broadband monitoring technique for <u>Main tank</u>

- Gas-in-oil
- Moisture-in-oil
- Temperature
  - Top Oil
  - Winding
- Load

Broadband monitoring technique for On Load Tap Changer

- Temperature
- Tap Position tracking
- Reversing switch inactivity
- Gas-in-Oil

Broadband monitoring technique for Cooling system

- Top Oil temperature
- Pumps/Fans activity tracking

Broadband monitoring technique for Bushing

- Leakage current

Transformer monitoring: GE Offer

Transformer monitoring: GE Offer

GE offer a family of products for transformer monitoring:

- Hydran
  - H201Ti
  - HS2
  - HM2
  - HM2200/C
- Intellix
  - MO 150

Broadband monitoring technique for **Main tank**

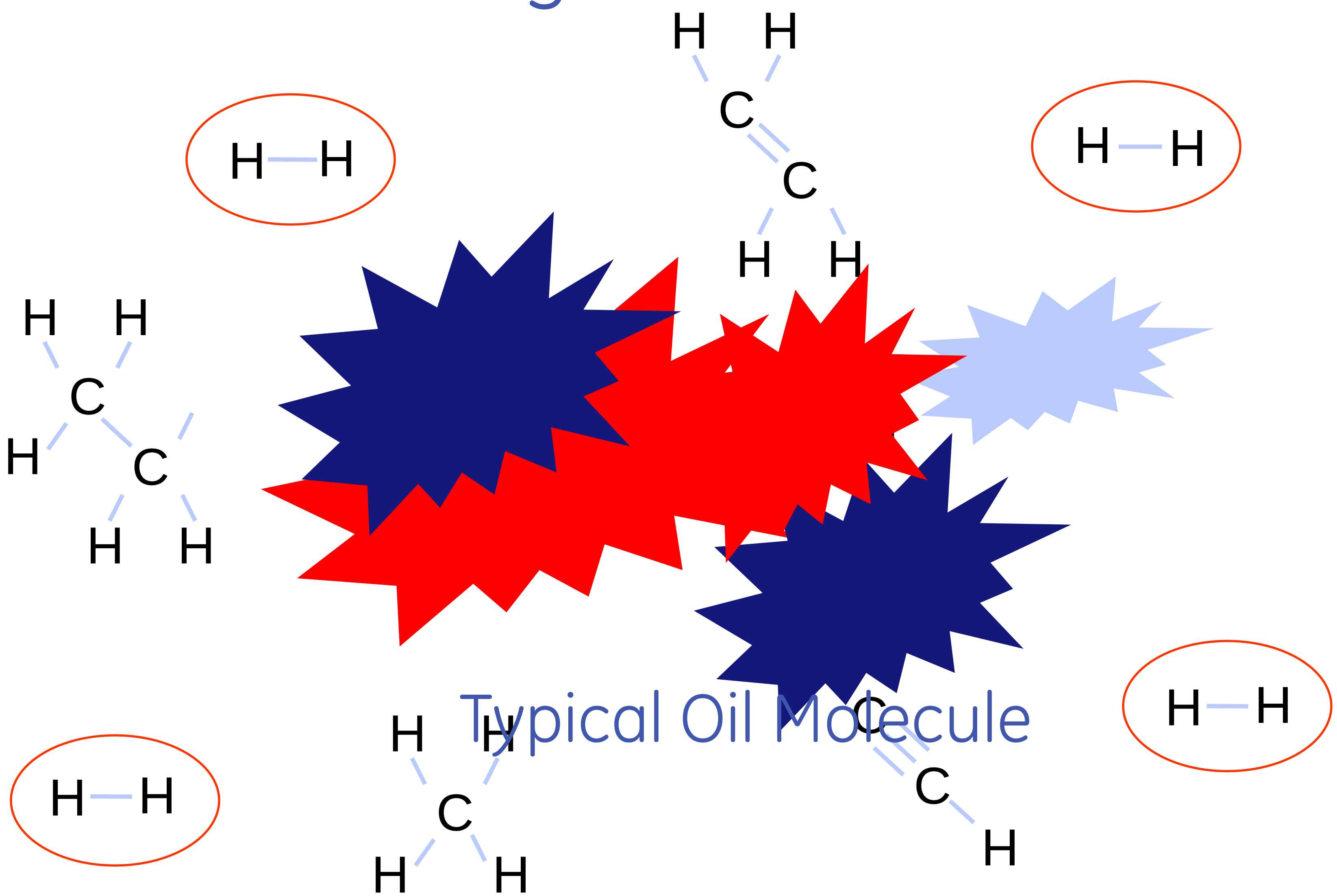
Gas-in-oil

Oil is in contact with every component in the main tank.

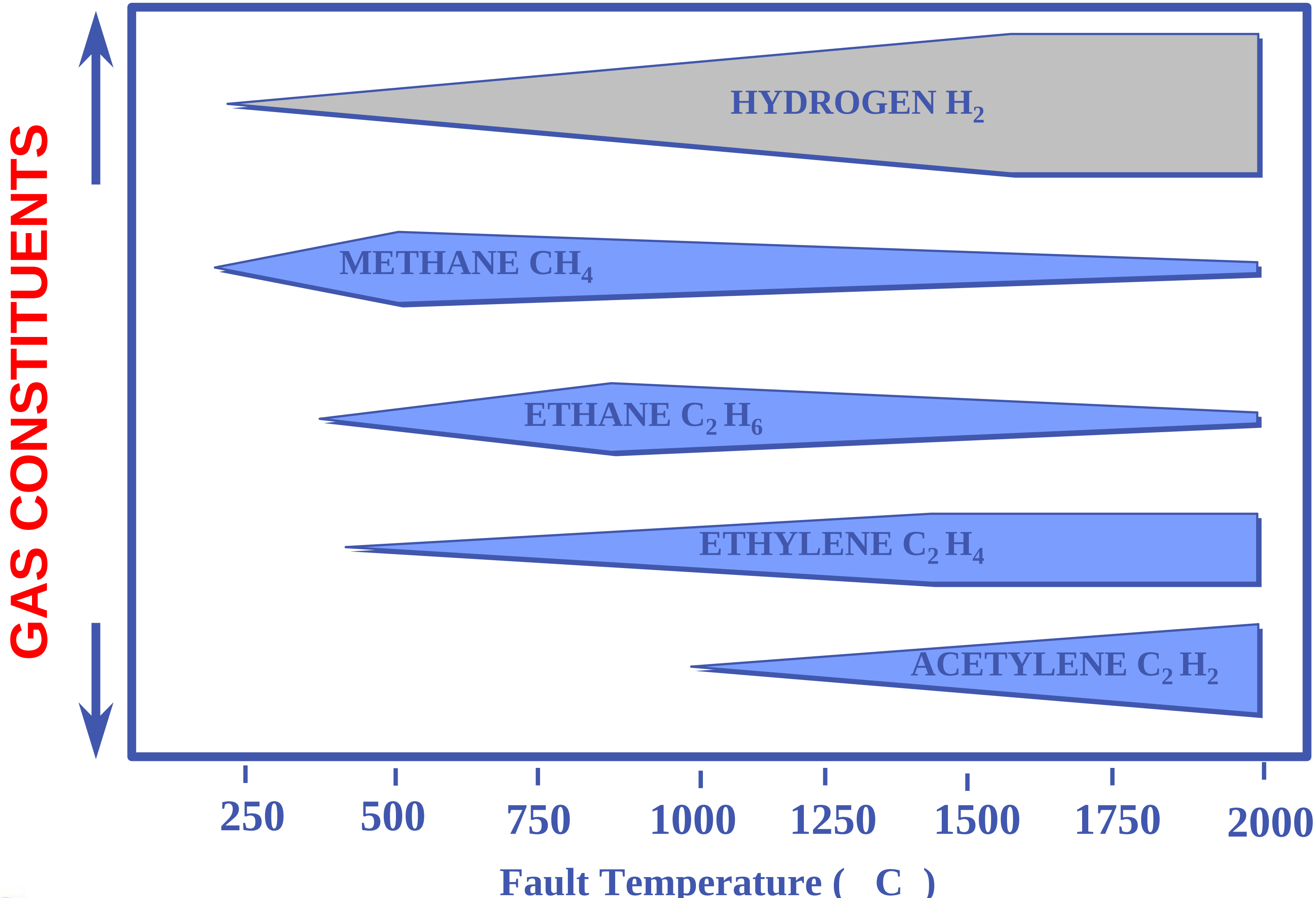
If a fault occurs in a component, oil will be degraded and gases will be generated

A sudden increase of dissolved gas level is the best indicator of a developing incipient fault

Gas in oil: oil degradation in fault



Gases Generated During Breakdown of Dielectric Oil



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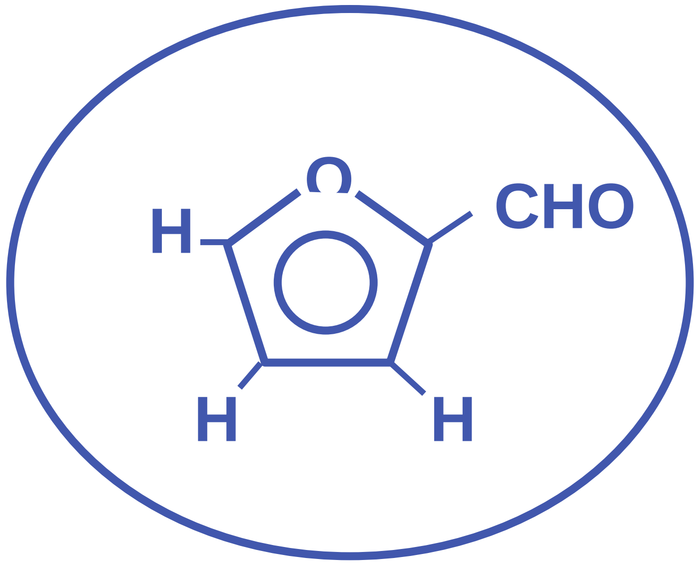
Gas in oil: paper degradation in fault

CO

CARBON MONOXIDE

HOH

WATER



FURAN

Paper Molecule

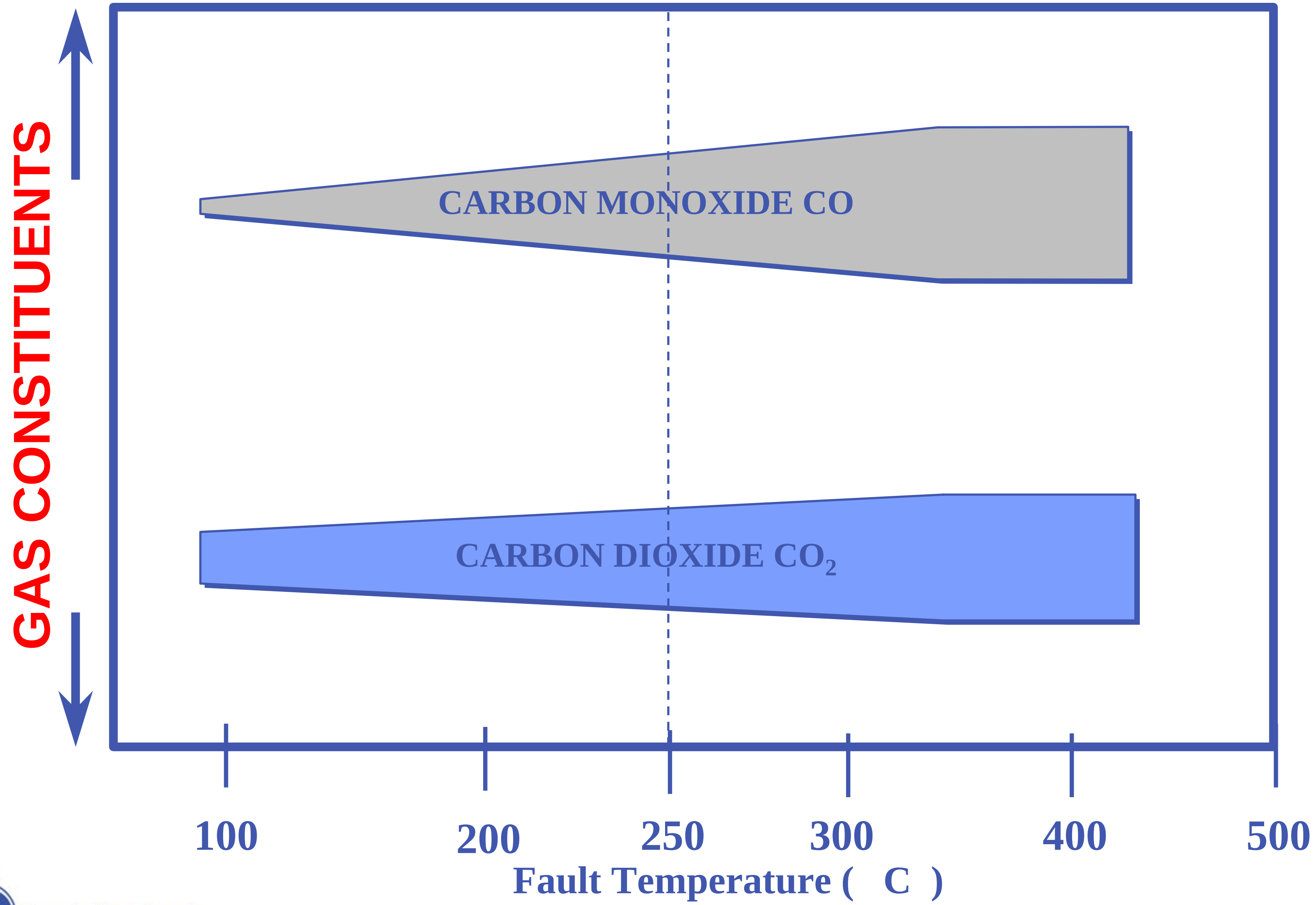
HOH

WATER

HOH

WATER

Gases Generated During Breakdown of Cellulosic Insulation



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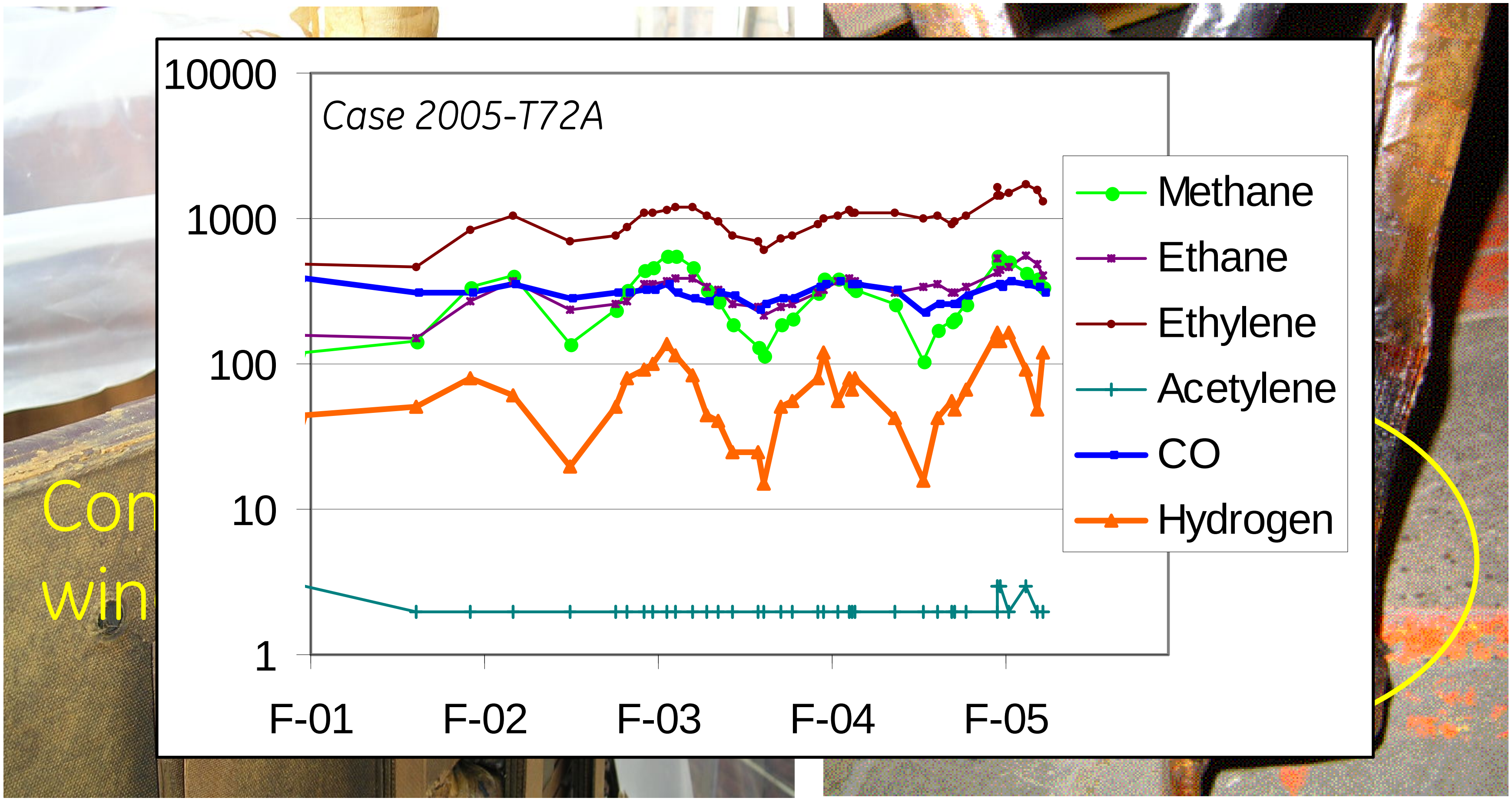
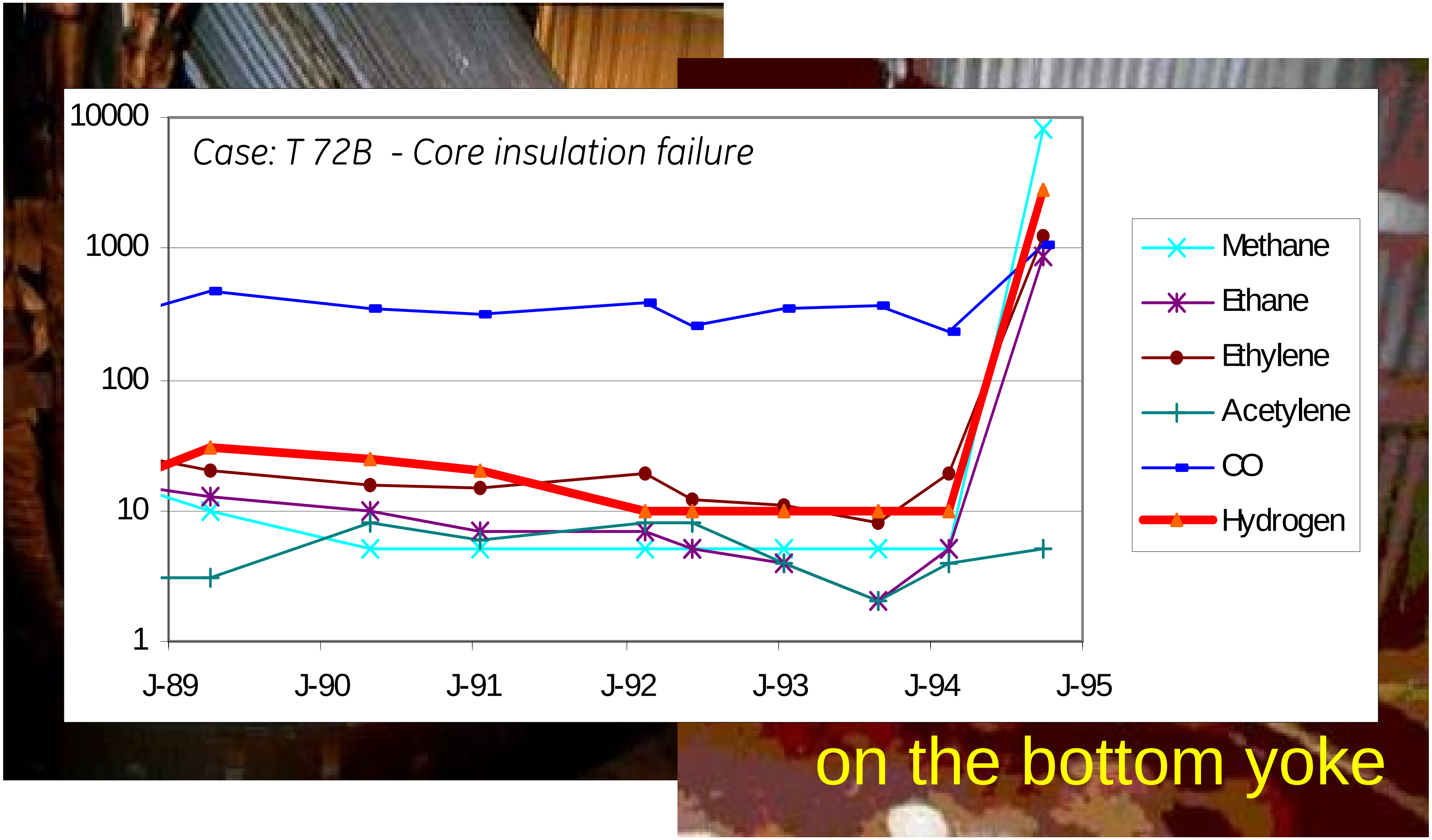
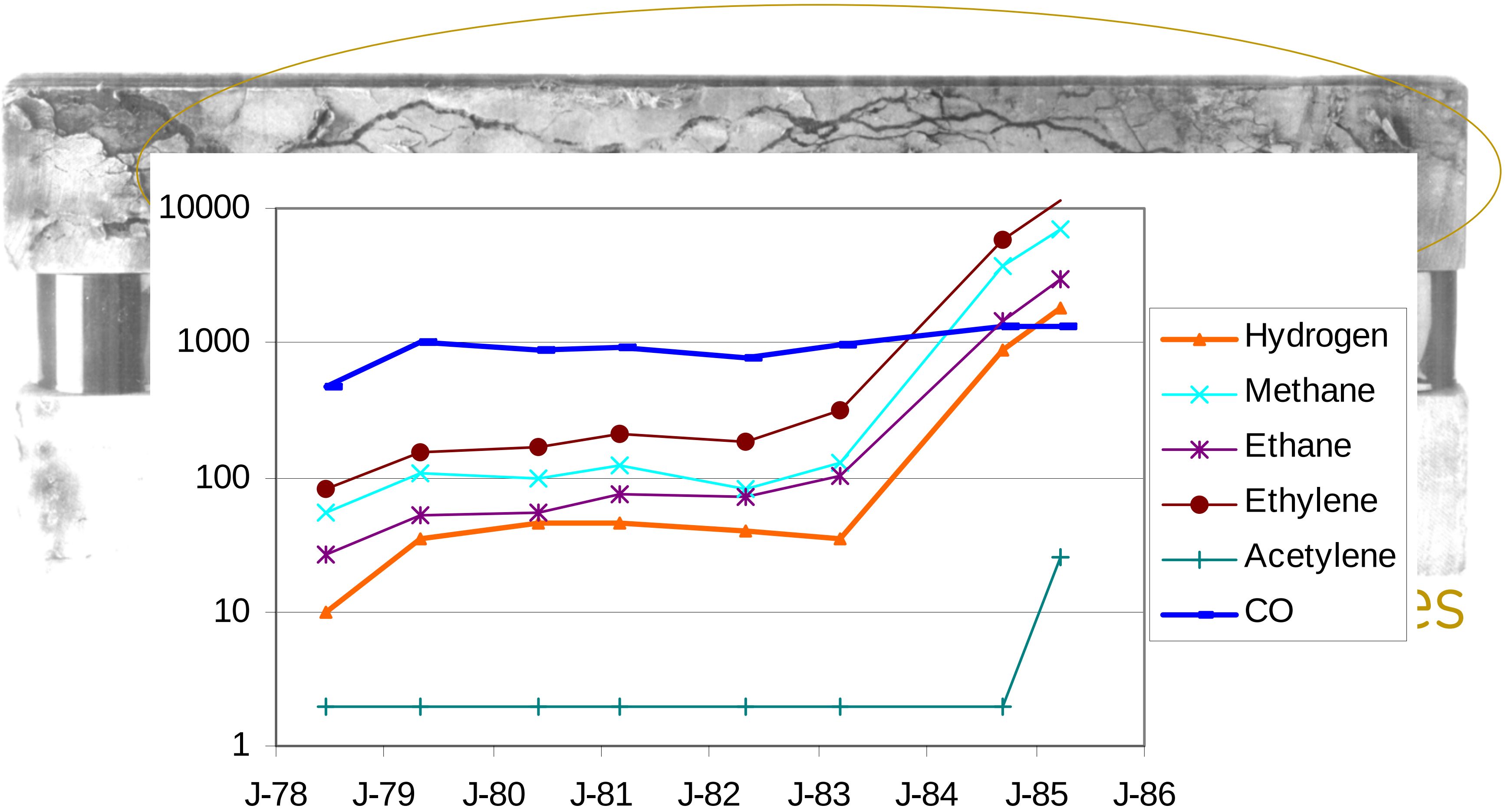
Detection of connection overheating



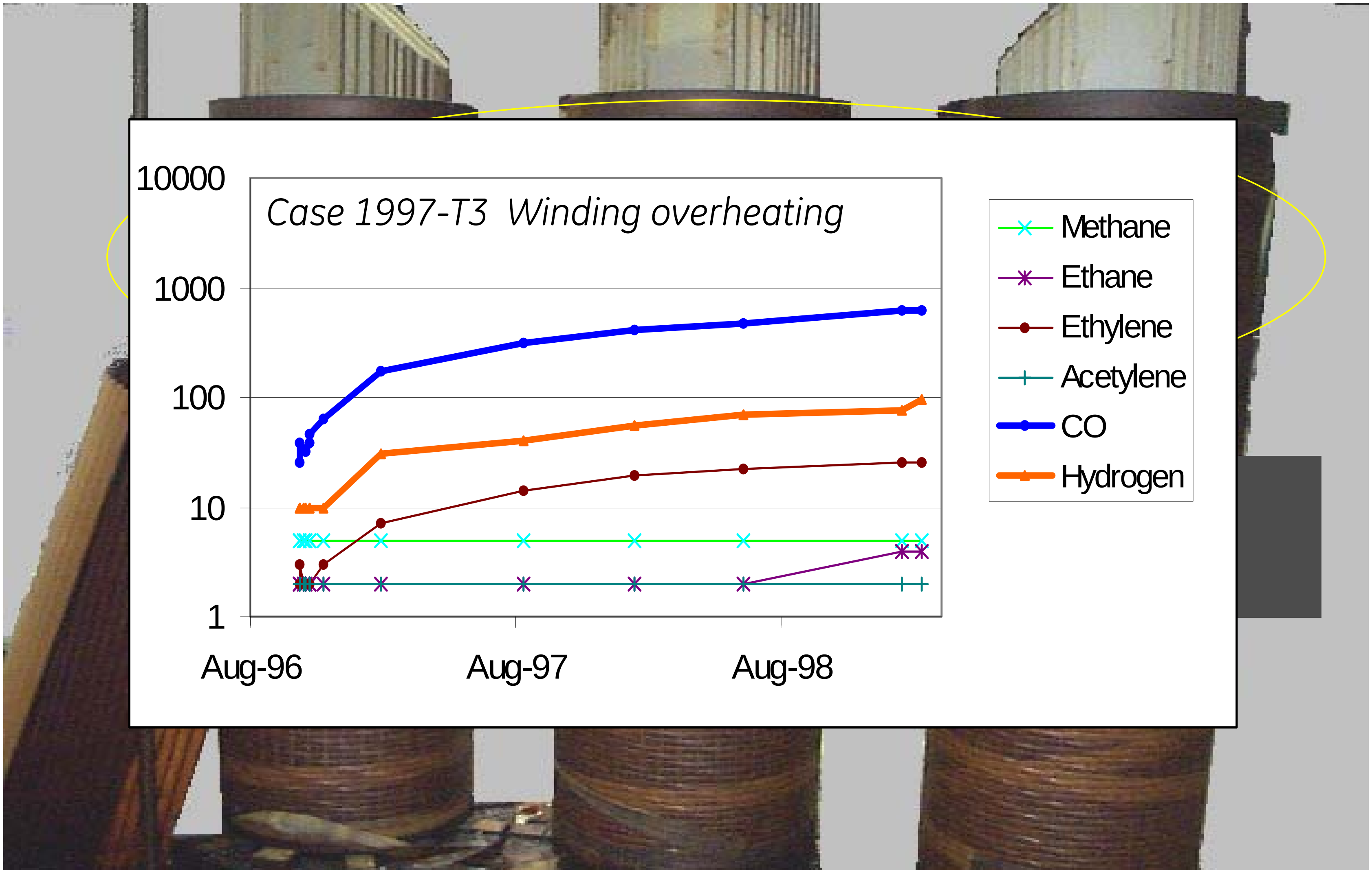
Detection of core saturation



Detection of partial discharges



Detection of winding overheating



Failure Avoidance

When the insulation system
is stressed,
gases are produced
and they will dissolve in the oil

Hydrogen from oil

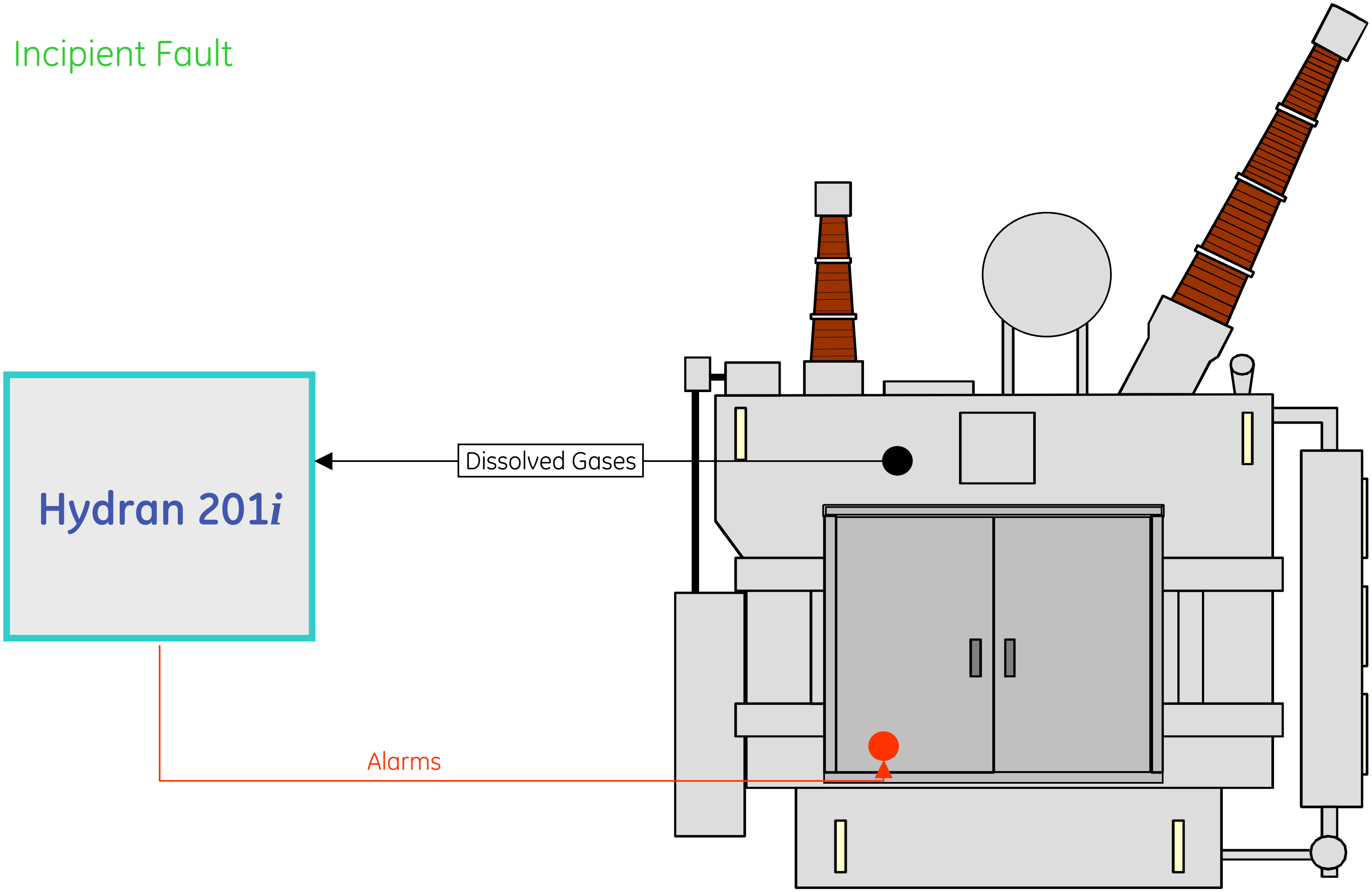
Carbon Monoxide from paper

The HYDRAN® Technology

- Detection and Monitoring of Key Fault Gases in oil
- Responds Mainly to H_2 and CO
- Detects a deviation From the Base line
- Monitors the Evolution of the gases in the Transformers, any sudden increase is an indication of an incipient fault

The Hydran H201*i* Incipient Fault Monitor

- Incipient Fault



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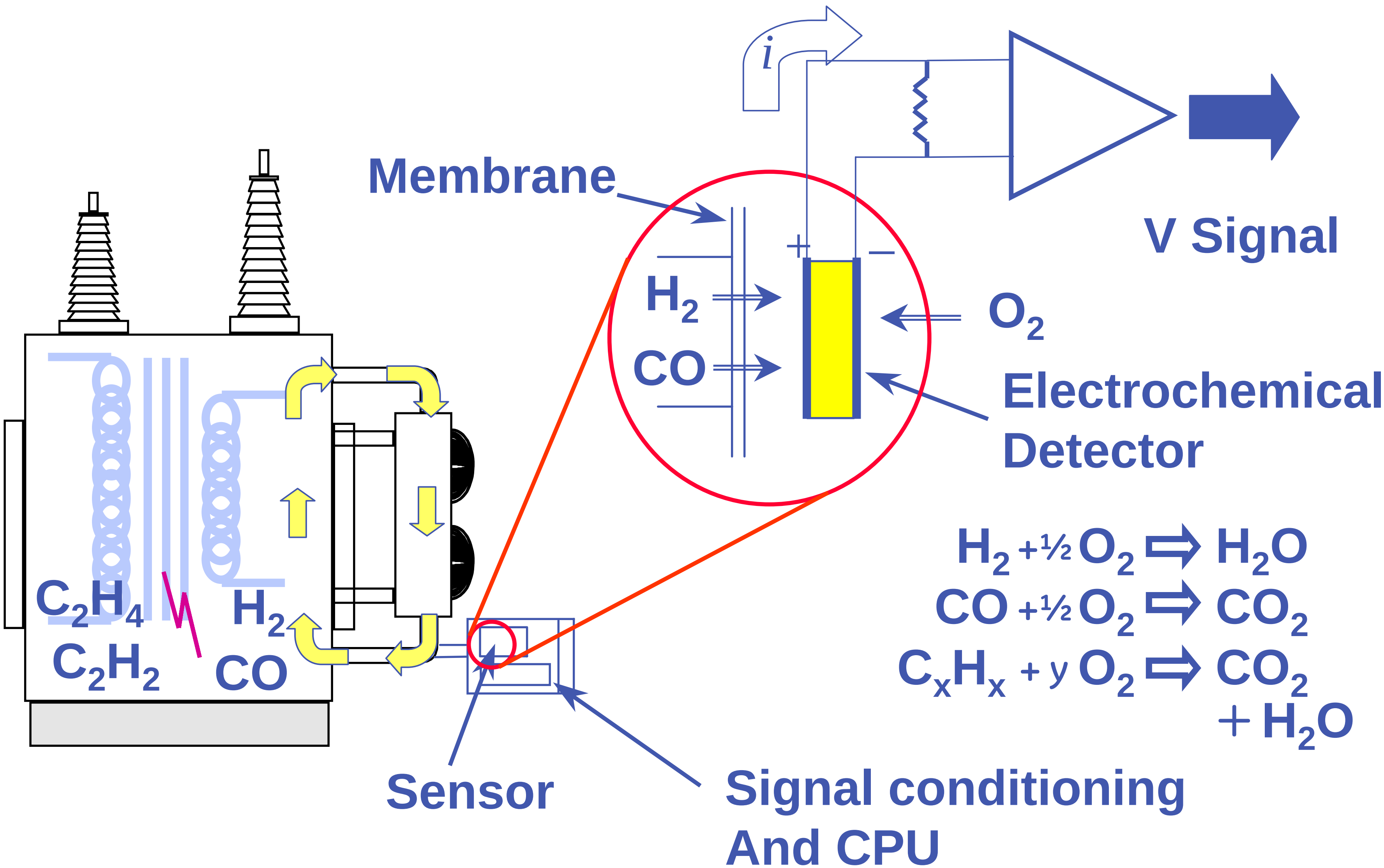
The Hydran® Technology: Gas Sensor

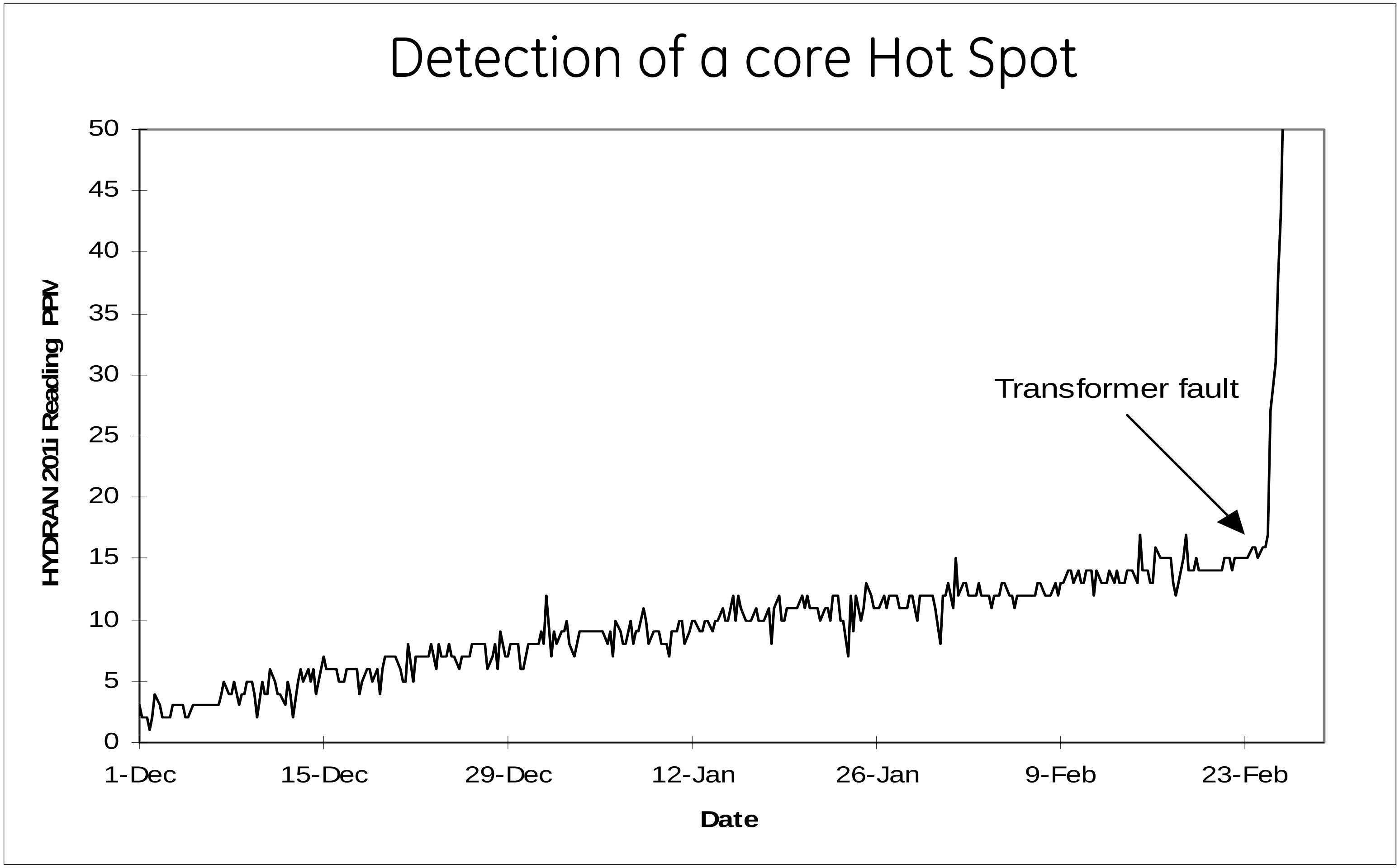


$H_2 + ½\,O_2 \Rightarrow H_2O$

$CO + ½\,O_2 \Rightarrow CO_2$

$C_xH_x + y\,O_2 \Rightarrow CO_2 + H_2O$

HYDRAN® Fault Detection



Hydran® 201*i* System

- Responds mainly to H_2 , CO
- Intelligent system, Windows configuration, software included
- Local or remote computer access
- Networking capabilities
- Up to 128 Transmitters/network
- Fully compatible with GE Harris RTU

➢ **On-line monitoring and alarming system for dissolved gases**

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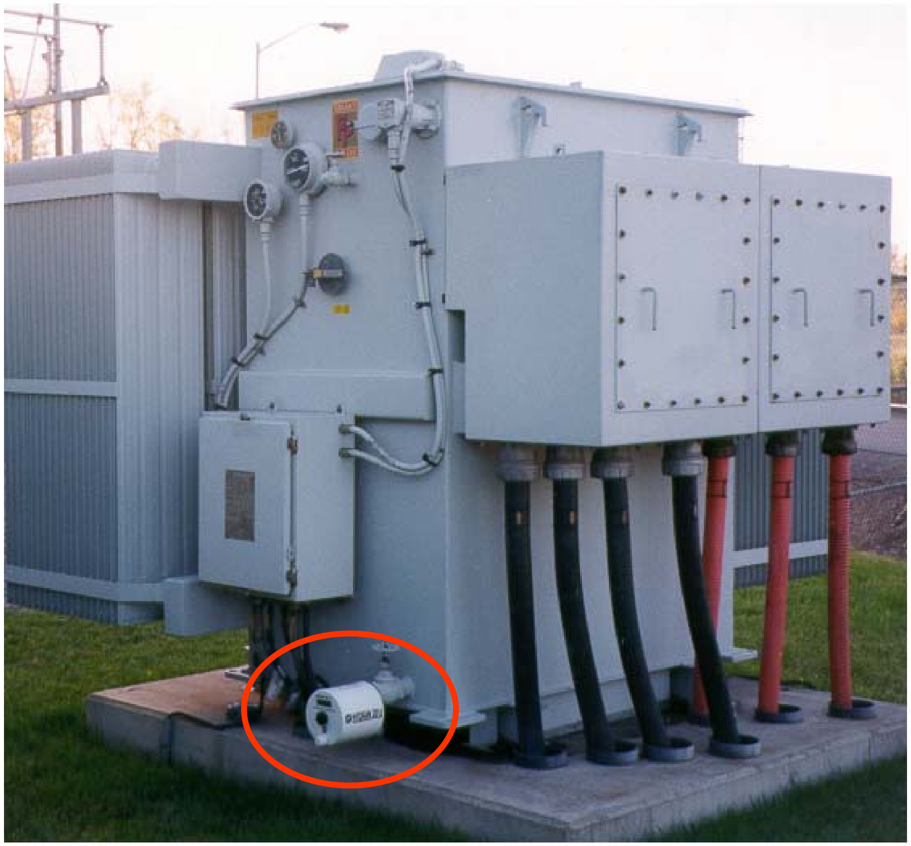
Hydran® 201T*i*

Typical Installation



Specialized monitoring technique for **Main Tank**

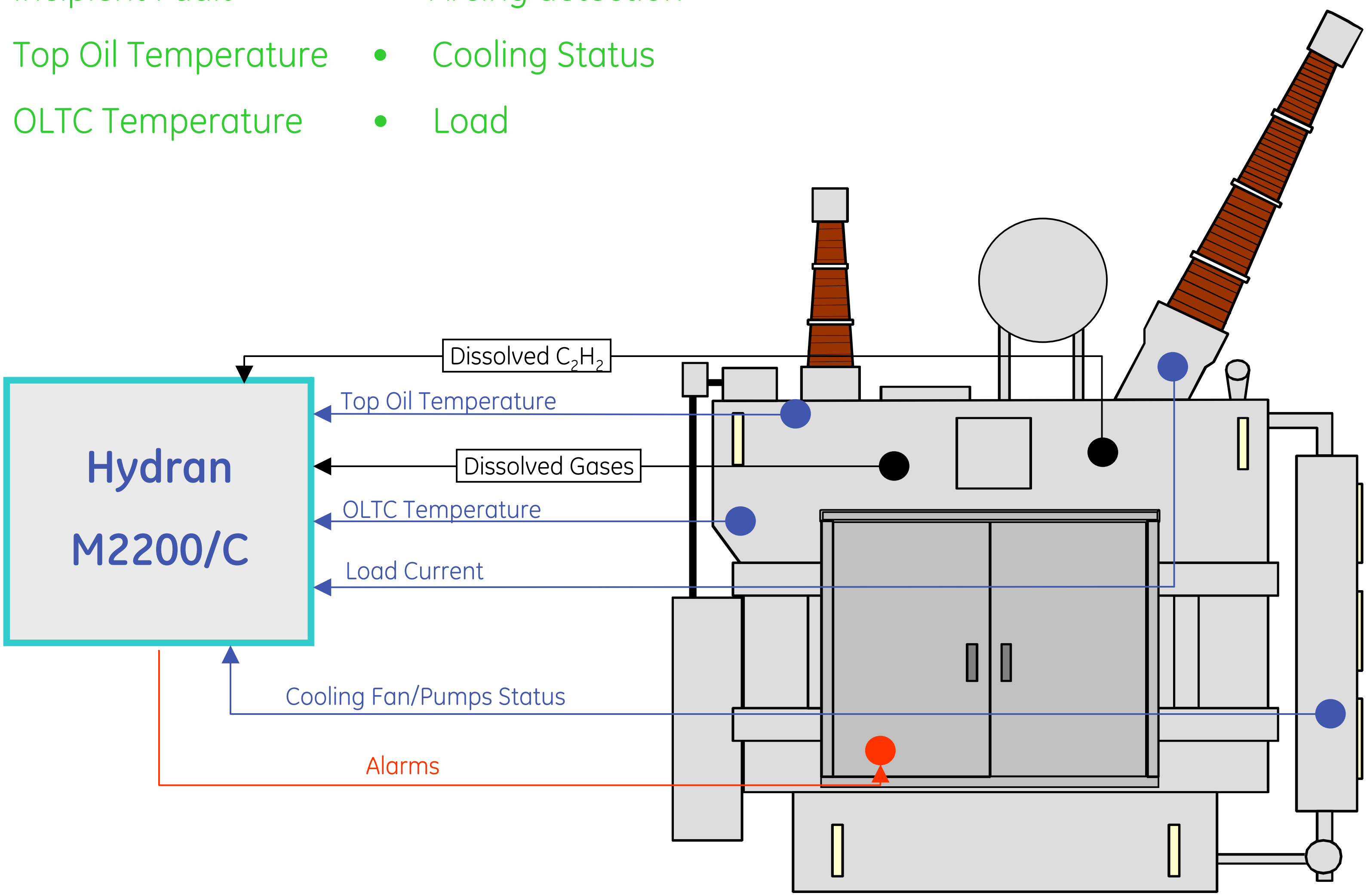
Acetylene level

Acetylene is generated in arcing and is indicator of severe problem

In some circumstance it could be necessary to monitor that gas specifically, for example if a transformer has already an history of generating Acetylene

The Hydran M2200/C Acetylene Monitor

- Incipient Fault
- Top Oil Temperature
- OLTC Temperature
- Arcing detection
- Cooling Status
- Load



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Hydran M2200/C

Cost effective & Ideal monitor for transformers suspected of having arcing problems and transformers producing acetylene

New Electronic Controller

Hydran* Multi 2010 (old) vs Hydran M2200/C (new)

- Smaller electronic controller
- Easier installation
- Controller display & multi functional push buttons
- Larger internal data logging capacity
- Possibility to have a M2200/C network
- Possibility to add moisture (in a very near future)

Hydran M2200/C

Acetylene detector

Sensor Head

- Measured Gas levels

Control Unit

- Intelligent Processor
- Data Acquisition

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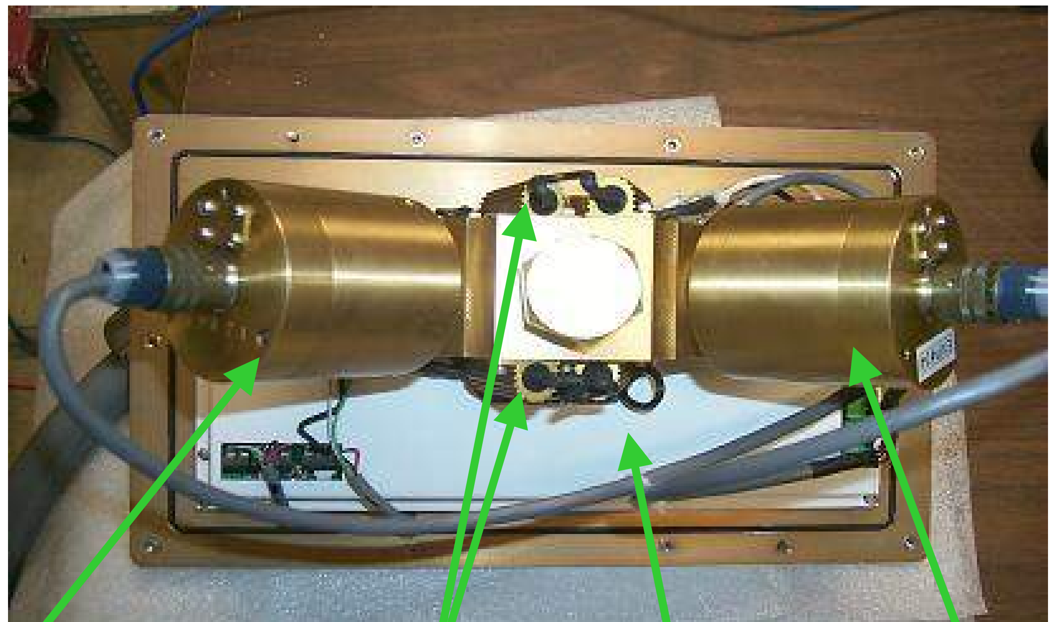
Hydran M2200/C
Sensor Head



Acetylene Sensor

Heating Elements

Interface board

Hydran Sensor

Hydran M2200/C

Sensor Head

- On-line gas-in-oil sensors that monitor incipient fault gases developing in transformer oil

- Two sensors to measure the concentration of:
  - ➢ Acetylene (C_2H_2) 100 % : Detection range: 3-200 ppm
  - ➢ A combined incipient fault gas reading of: Detection range: 25-2000 ppm
    - ❖Hydrogen (H_2) 100 %
    - ❖Carbon monoxide (CO) 18 %
    - ❖Ethylene (C_2H_4) 1.5 %
    - ❖ Acetylene (C_2H_2) 8%

Hydran M2200/C

Controller Layout

RS 232

Qty: 5 Digital outputs "Alarms"

(standard)

Qty: 4 Analog inputs (standard)

(RTD or 4-20mA)

Sensor head cable

Qty: 4 Digital inputs (standard)

AC Power

5A Fuse

3.6V Battery

Hydran M2200/C
Controller Layout

RS 485

Modem or
Ethernet card
(optional)

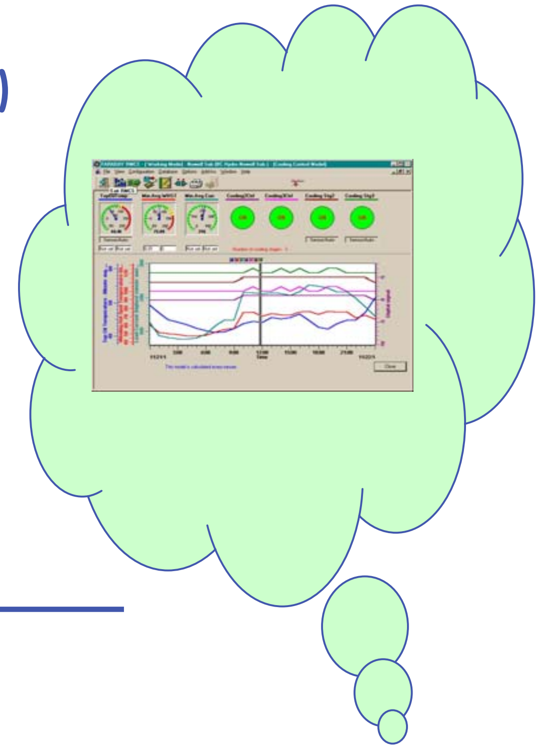
Possibility of 4
extra Digital
Inputs or 4
Analog Outputs
(optional)

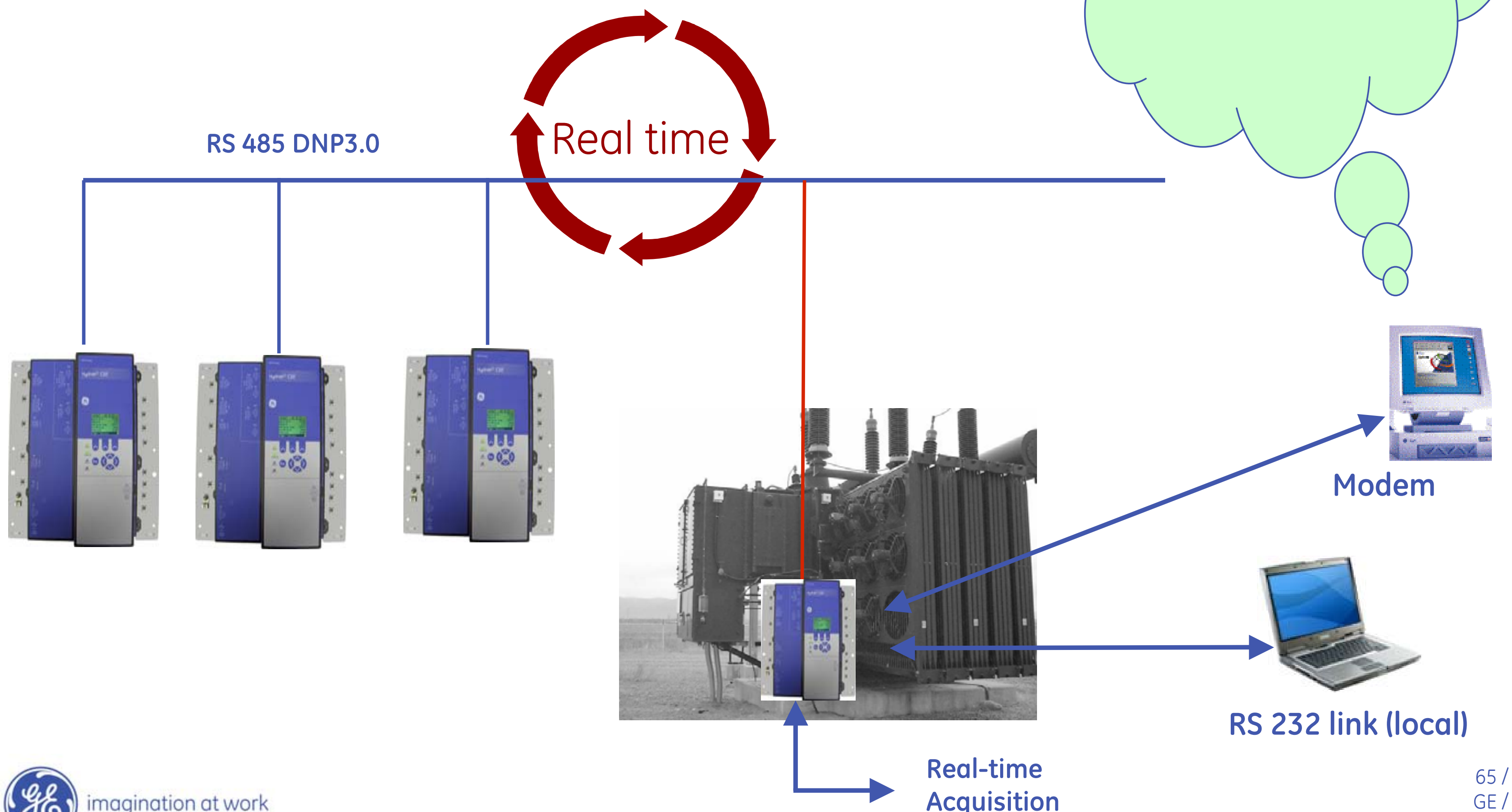
Expansion (CANBUS)

Qty: 4 System
indicators

Hydran M2200
communications

Intellix Host (GUI)





M2200/C HOST

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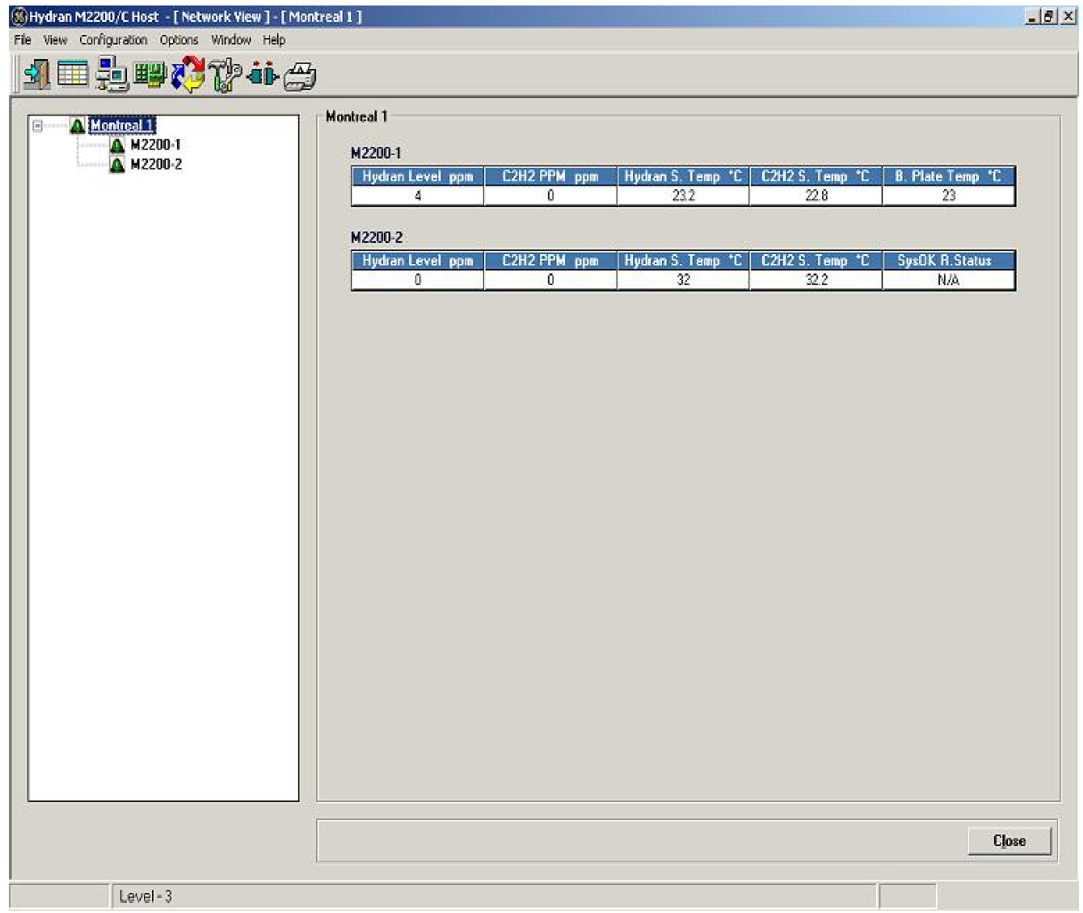
Hydran M2200 Host

GUI

- •Microsoft® Windows® - based application
- •Real-time logging and graphical display of data
- •Continuous online survey and alarm status
- •Downloading and uploading capabilities
- •Allows network and device specific monitoring



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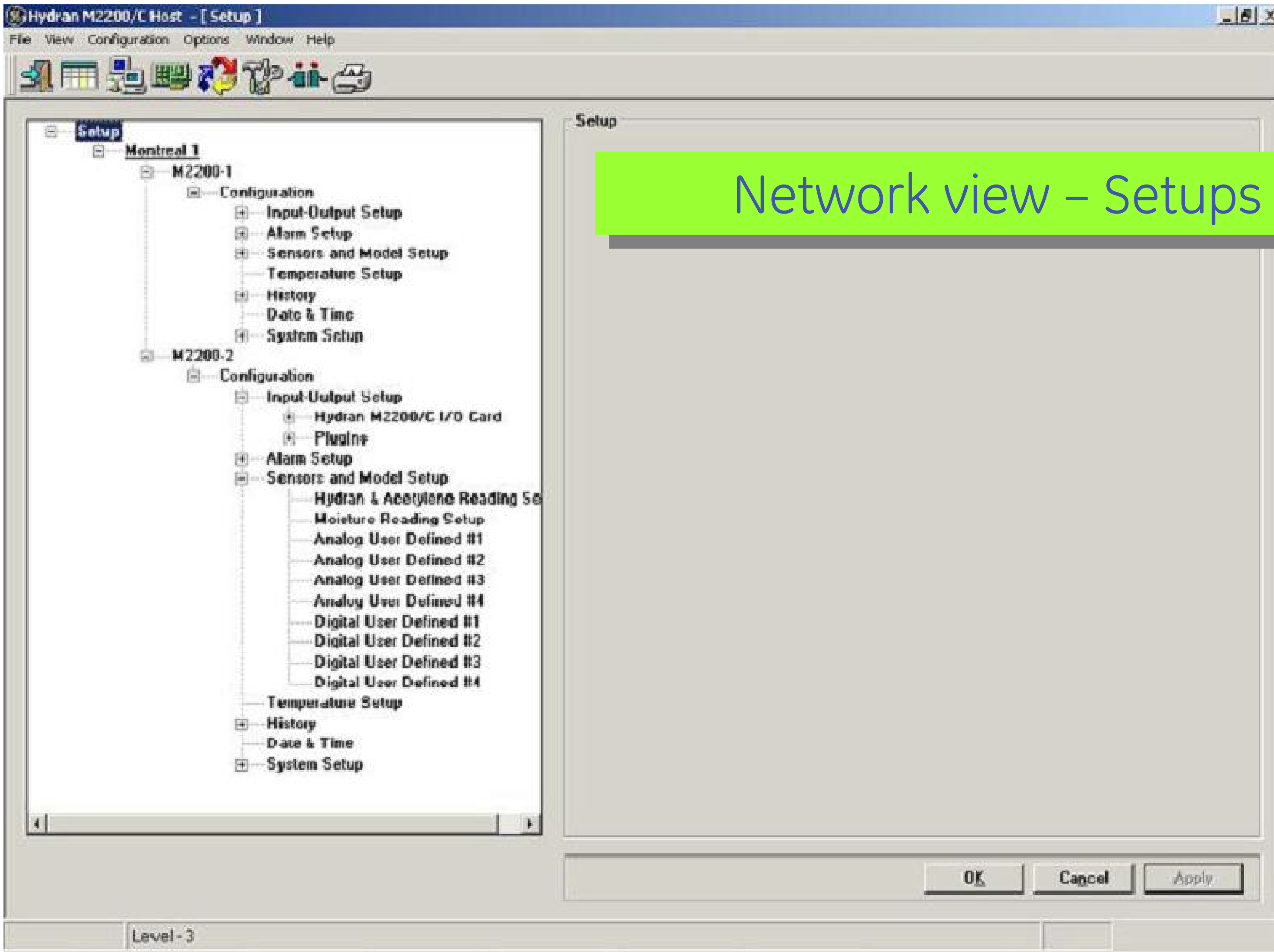
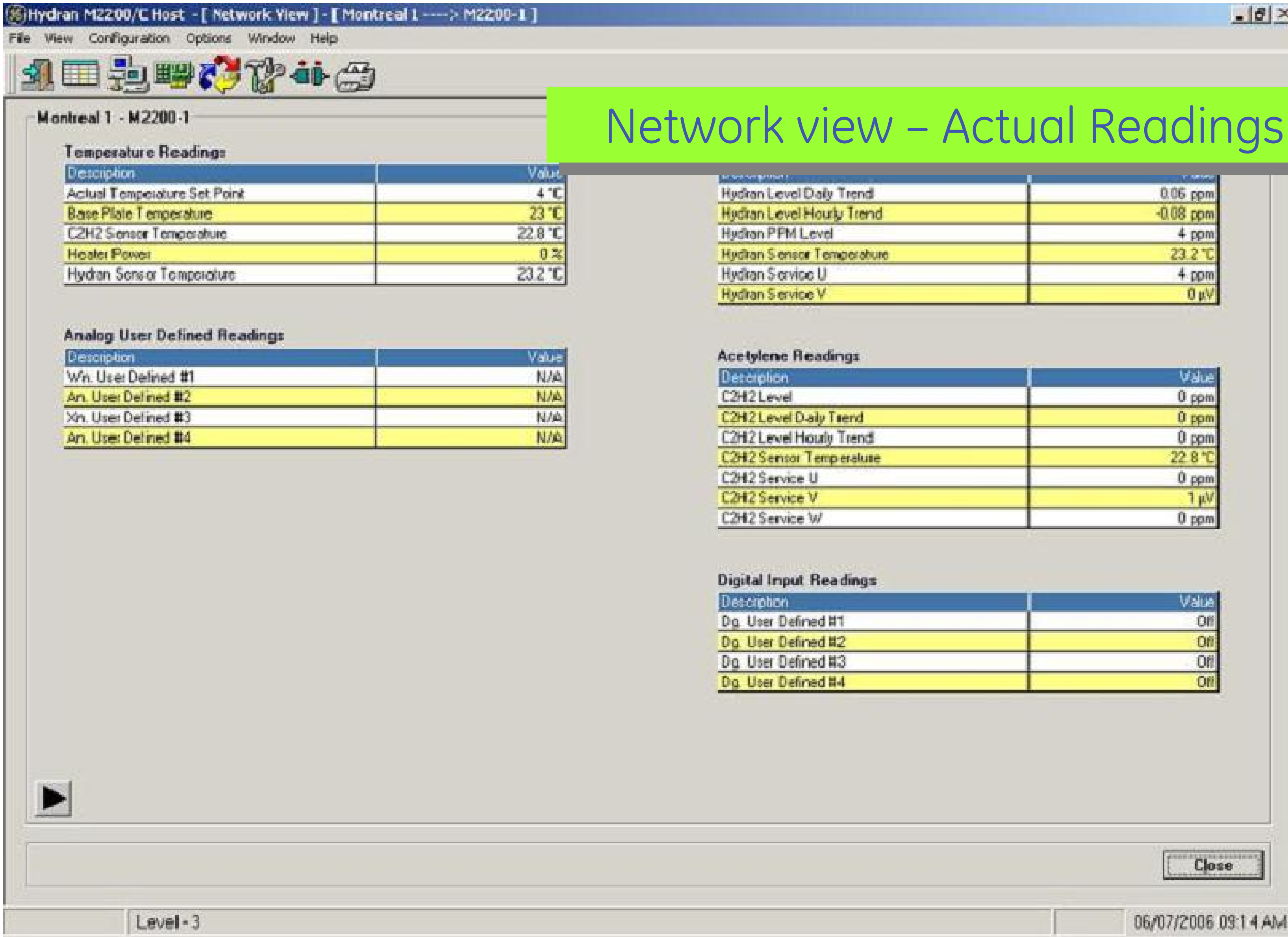
Hydran M2200 Host
GUI



Network view – Setups

Hydran M2200 Host

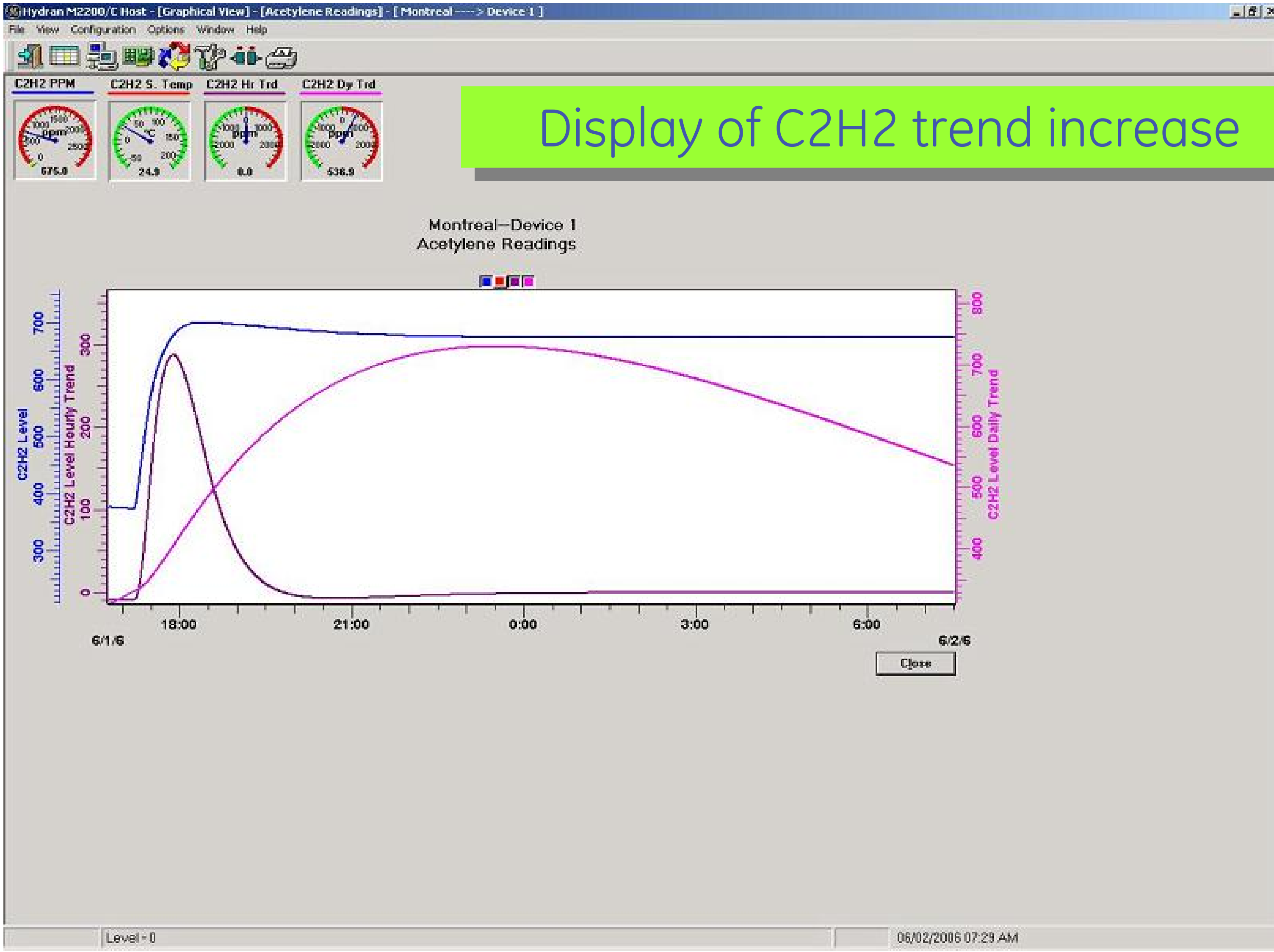
GUI



Network view – Actual Readings

Hydran M2200 Host

GUI



Display of C2H2 trend increase

Broadband monitoring technique for **Main tank**

Moisture-in-oil

Moisture degrades paper

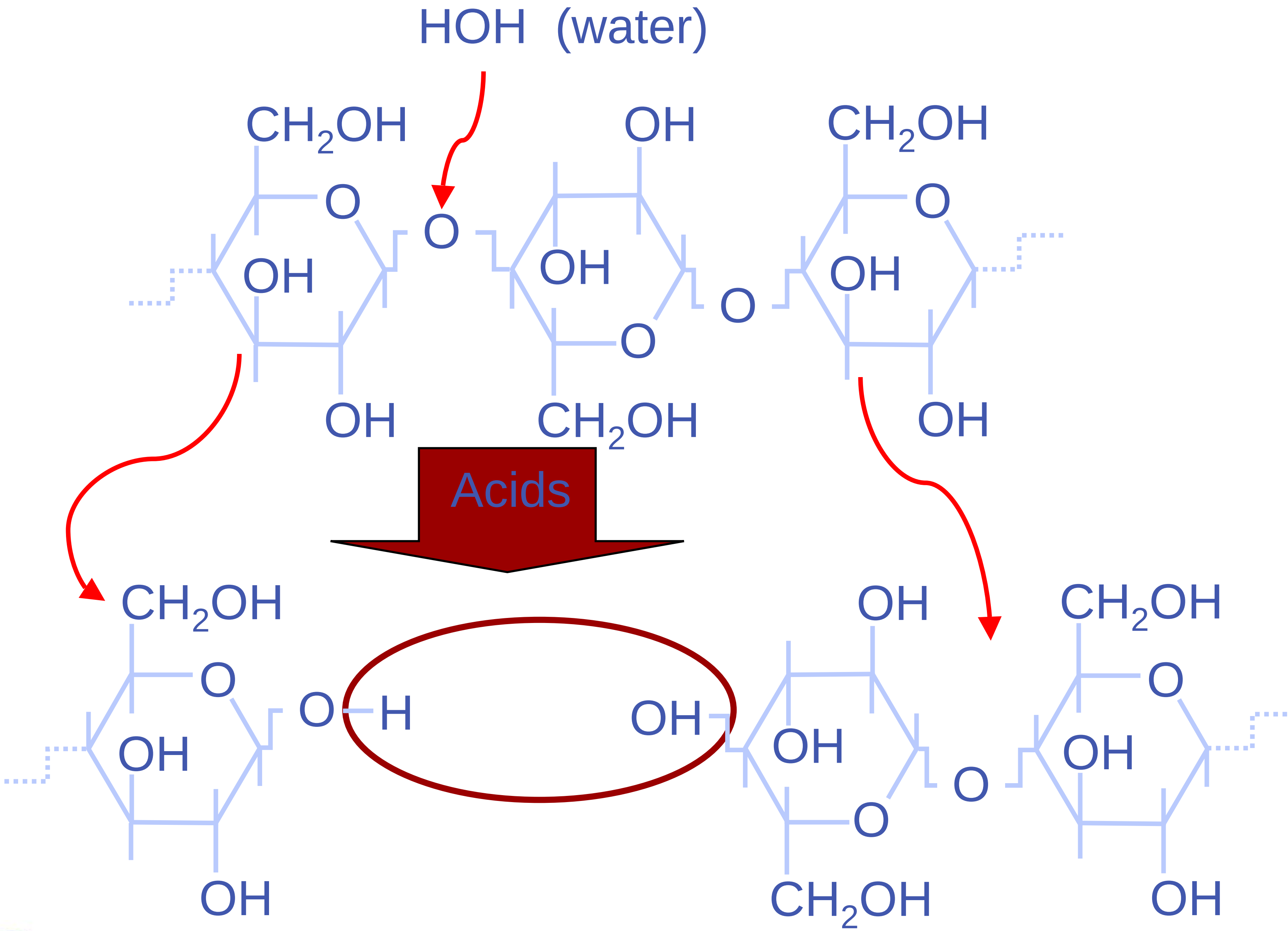
Moisture reduces dielectric strength

Moisture ages transformer faster

Moisture is everywhere

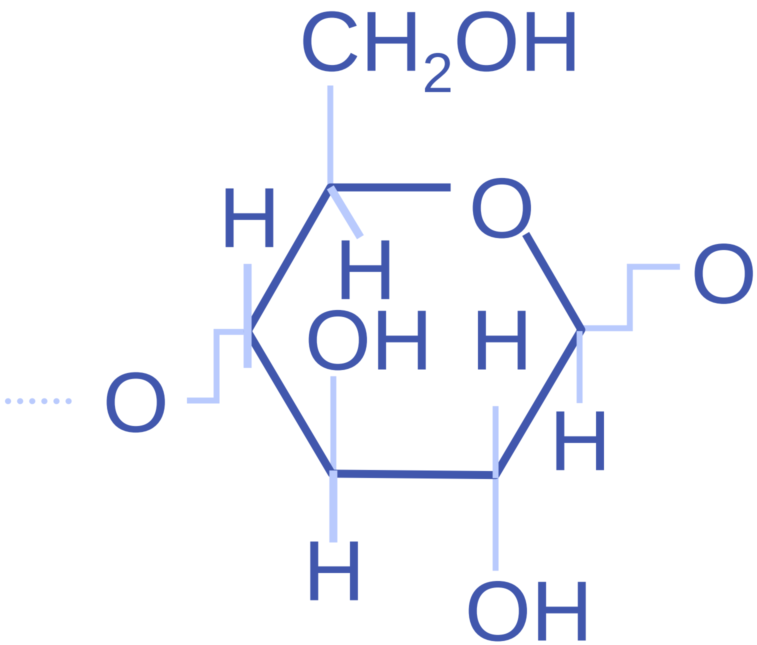
Moisture is a key element to monitor, especially in the solid insulation (paper)

Where does water come from?



imagination at work

Where does water come from?



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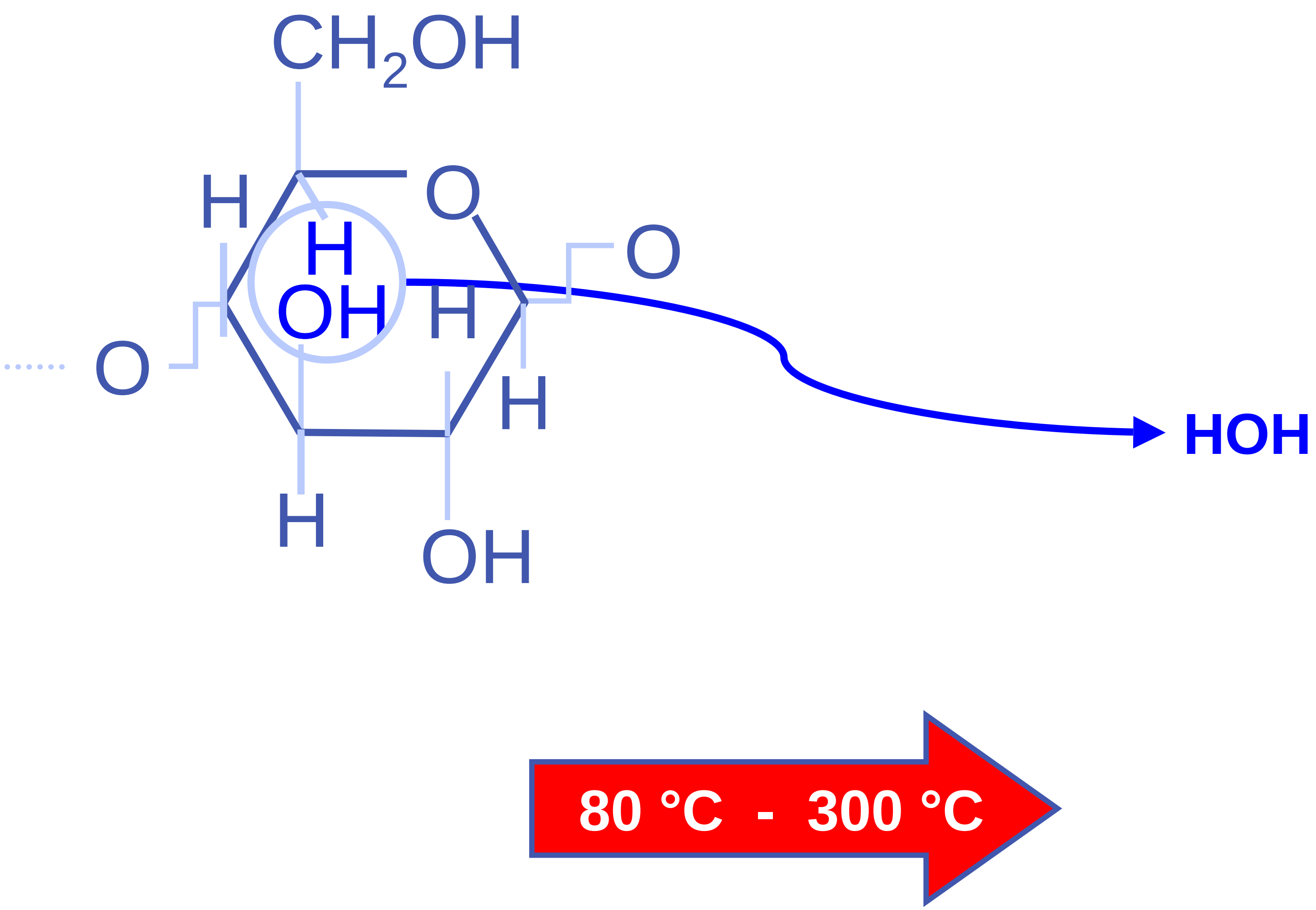

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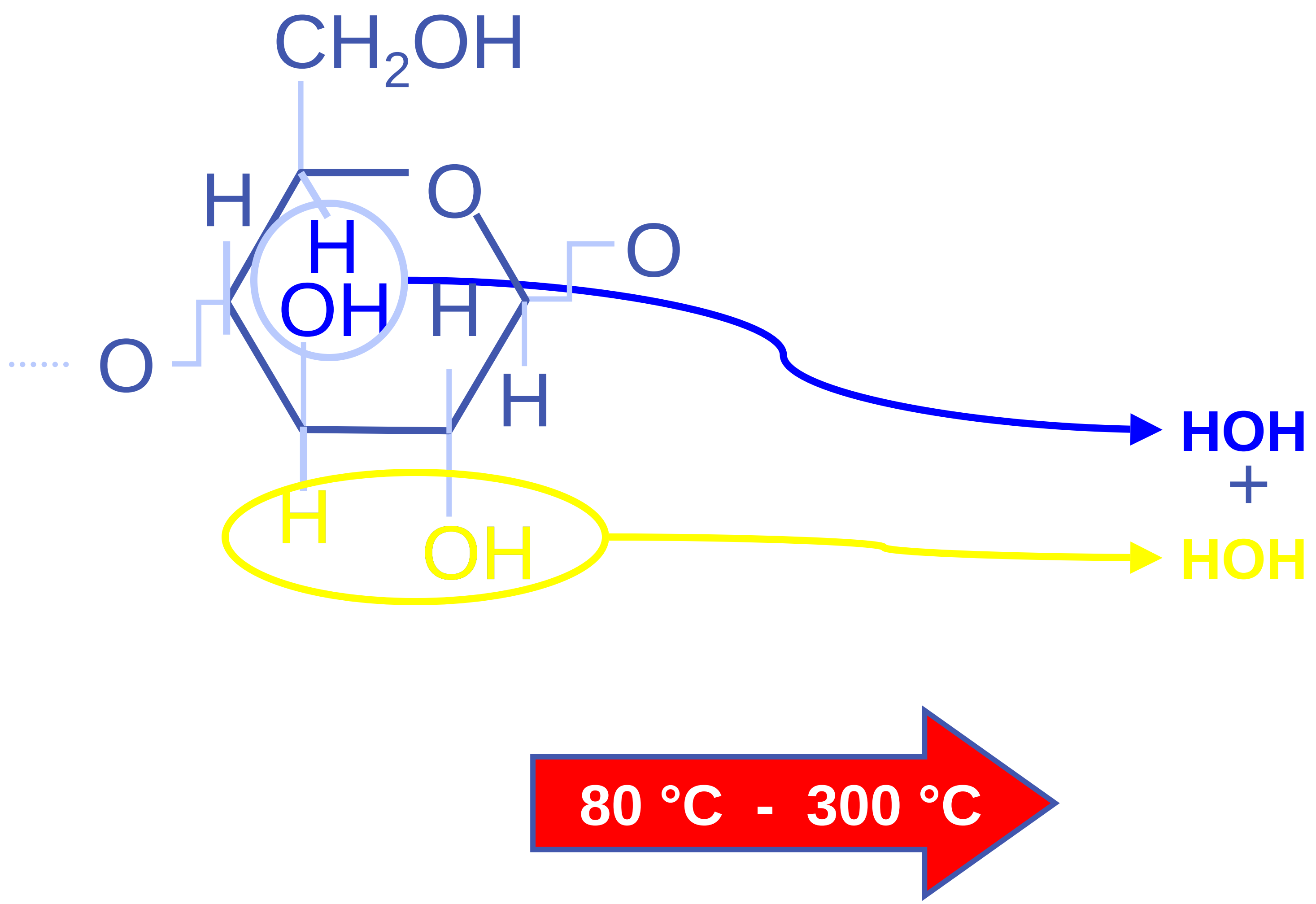

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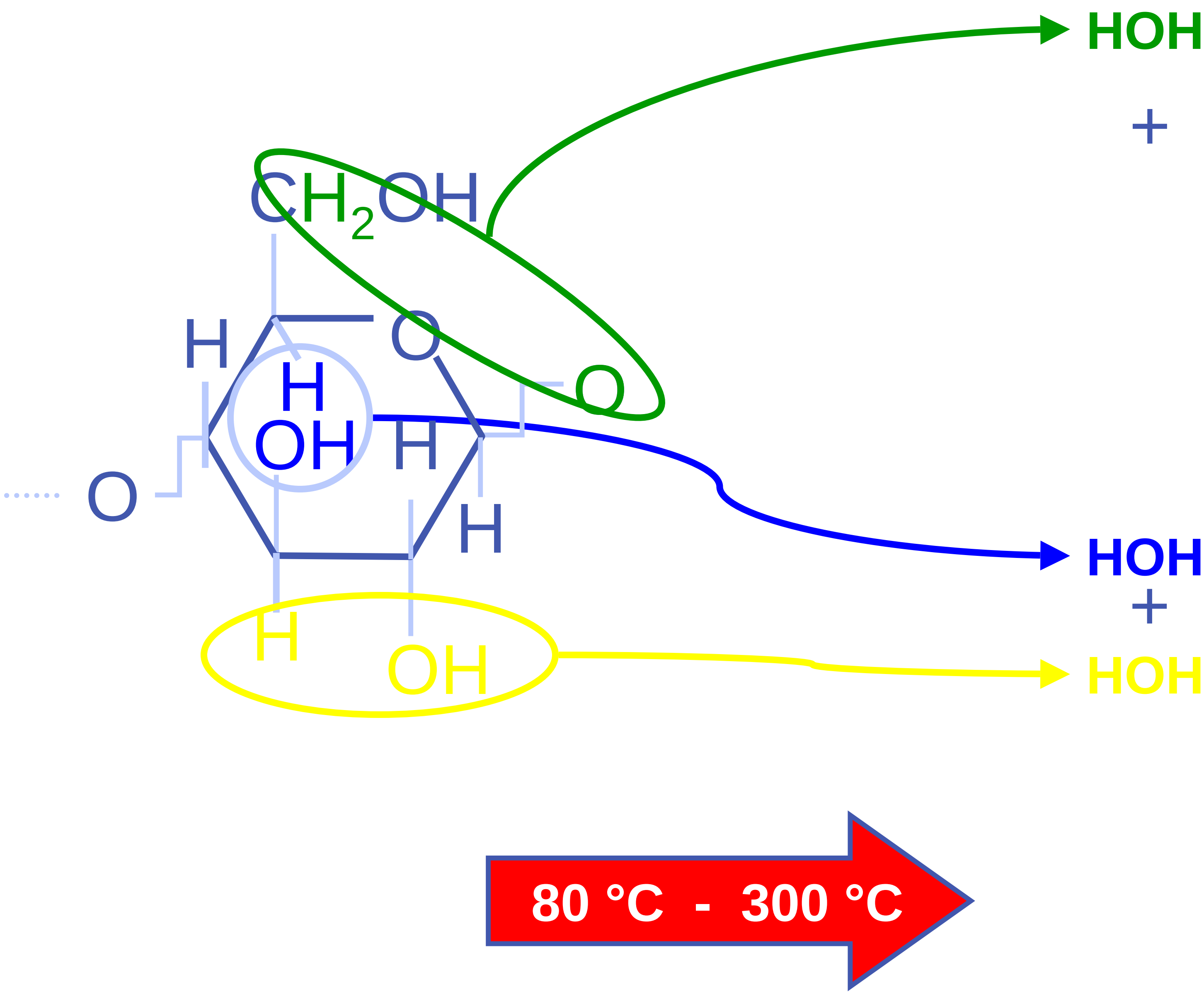

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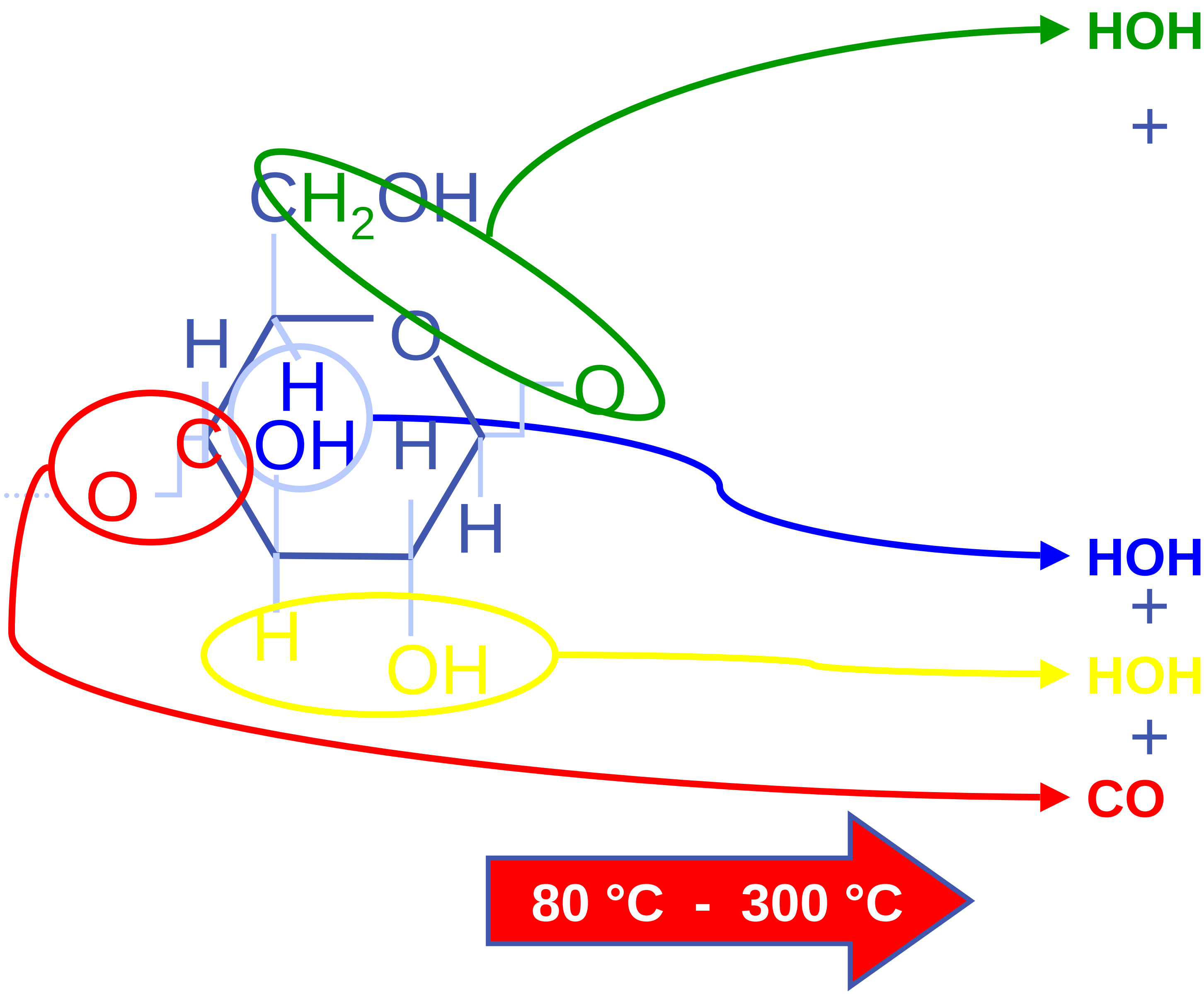

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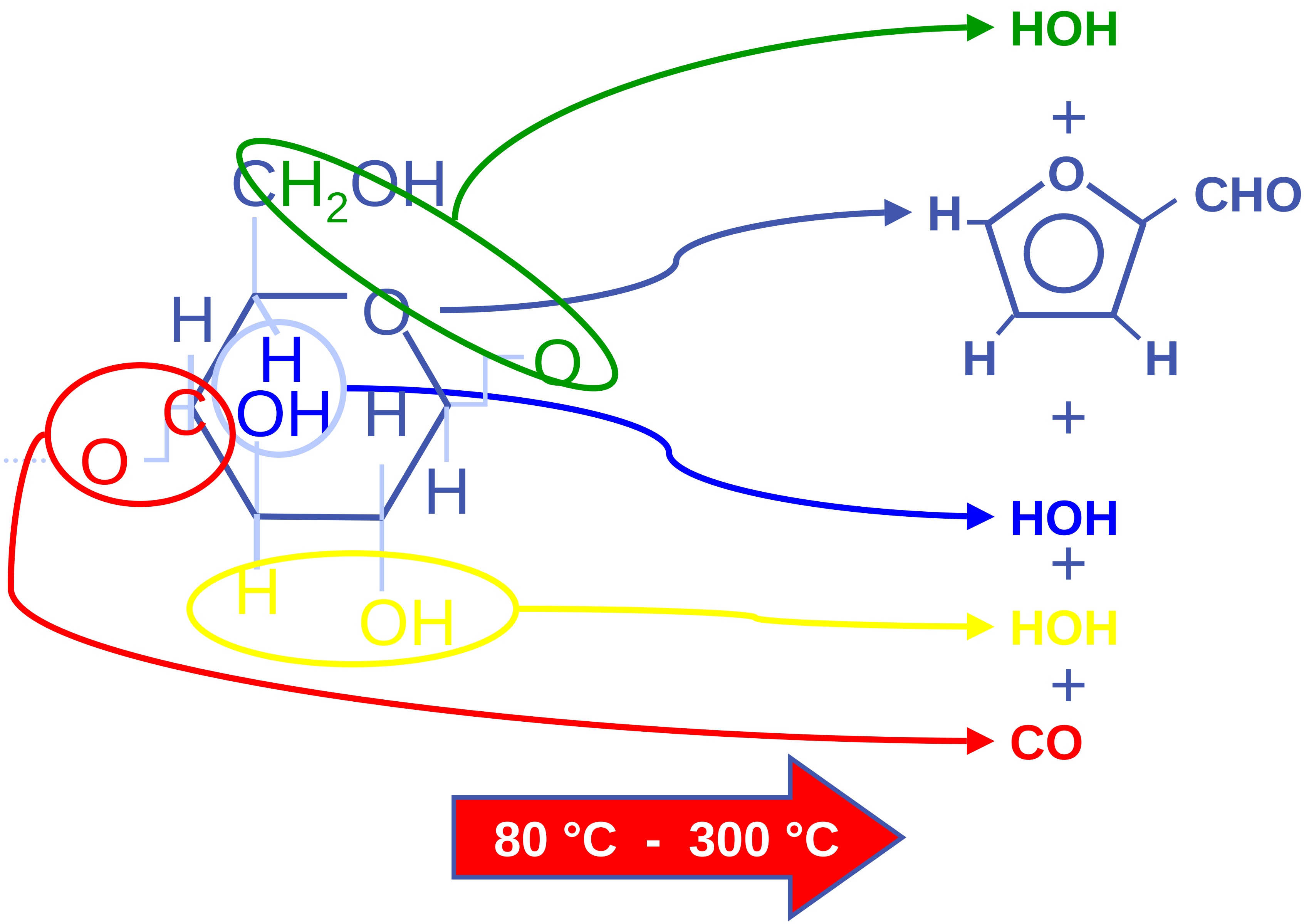
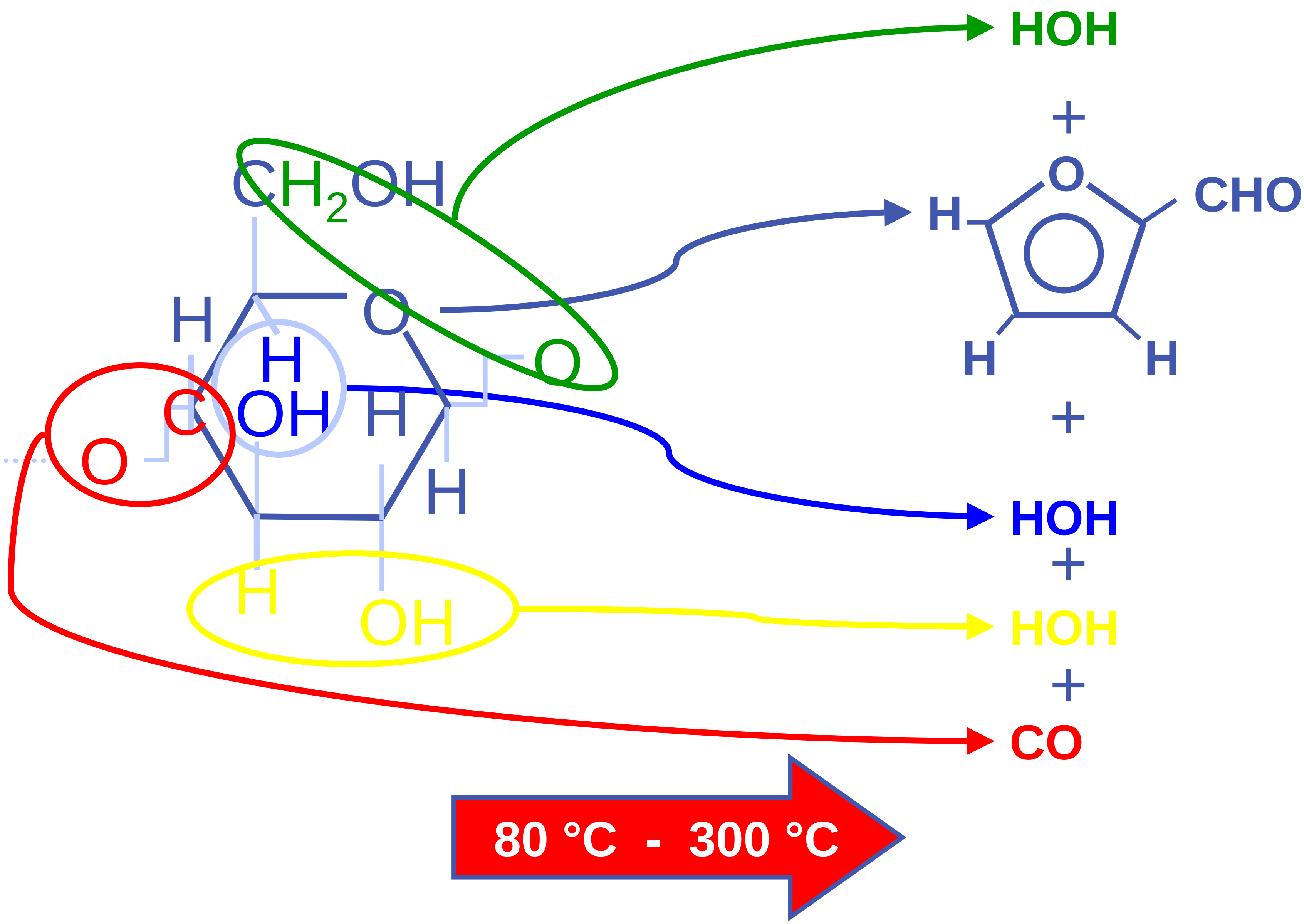
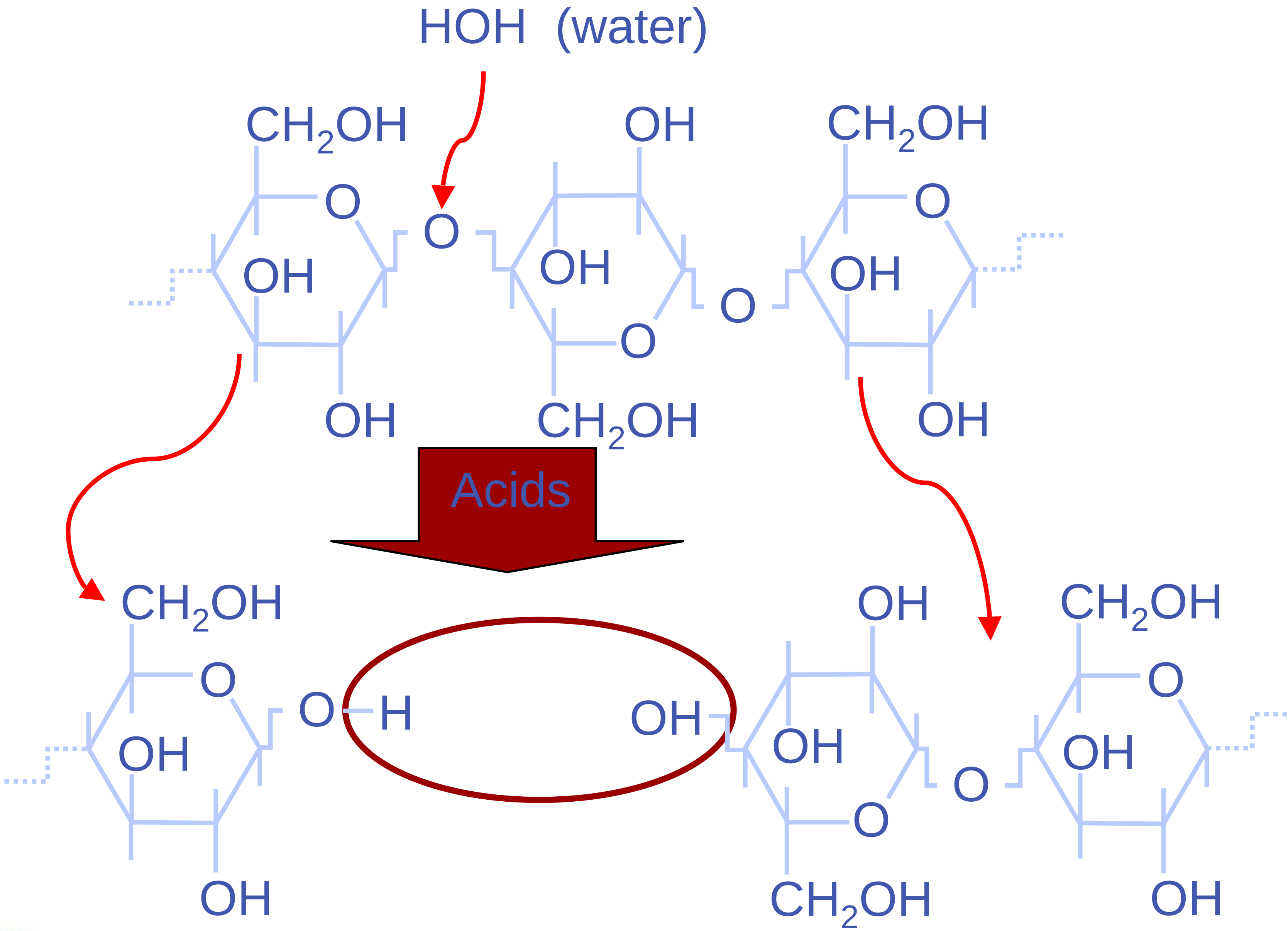


Where does water go?

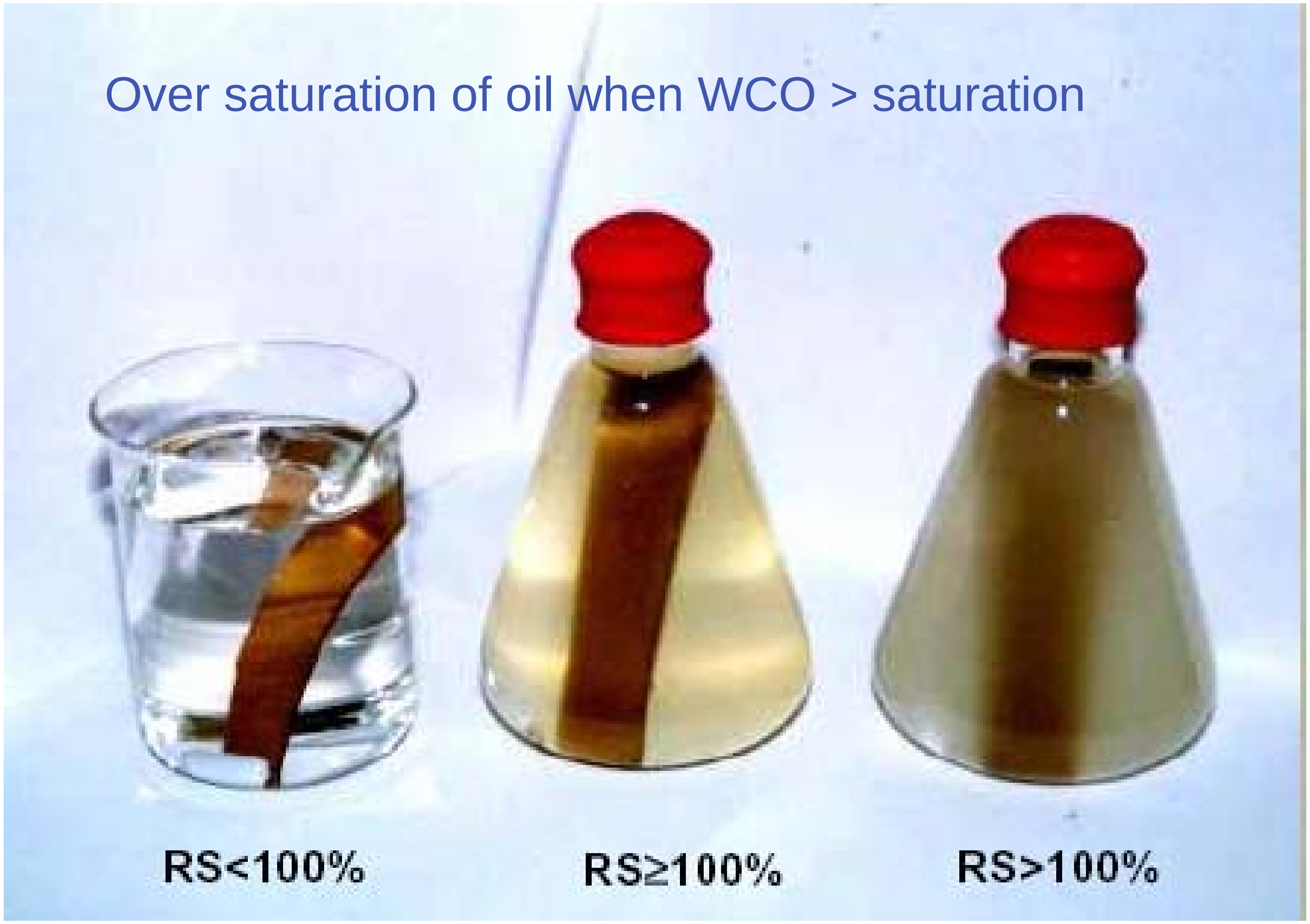


The chain reaction begins again



imagination at work

Impact of moisture in oil



V. Davydov, EPRI Moisture Management in Transformer Workshop, Nov.2002, Edison, New Jersey

Impact of moisture in oil

Sensors

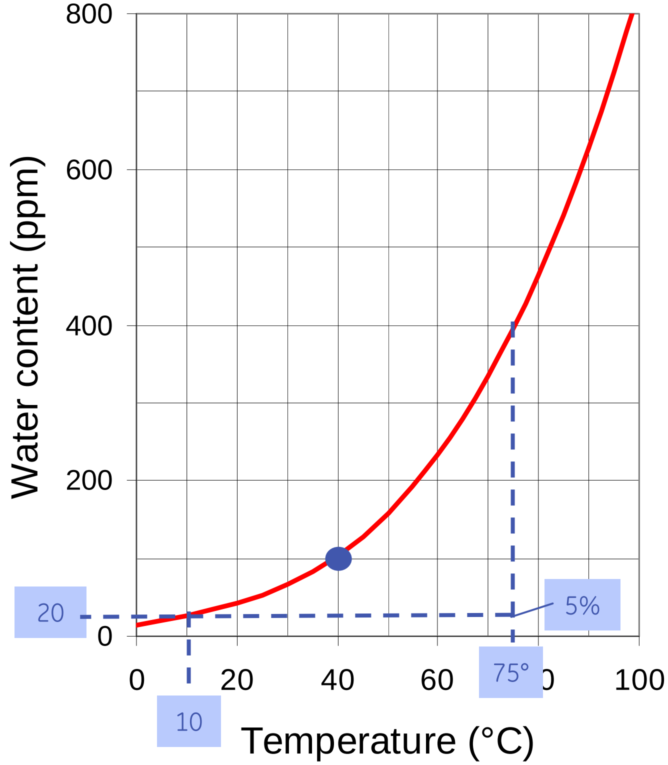
Sensor Relative Humidity (RH%)

5%

Sensor Temperature(°C)

75°C

Water-in-oil saturation curve



Output

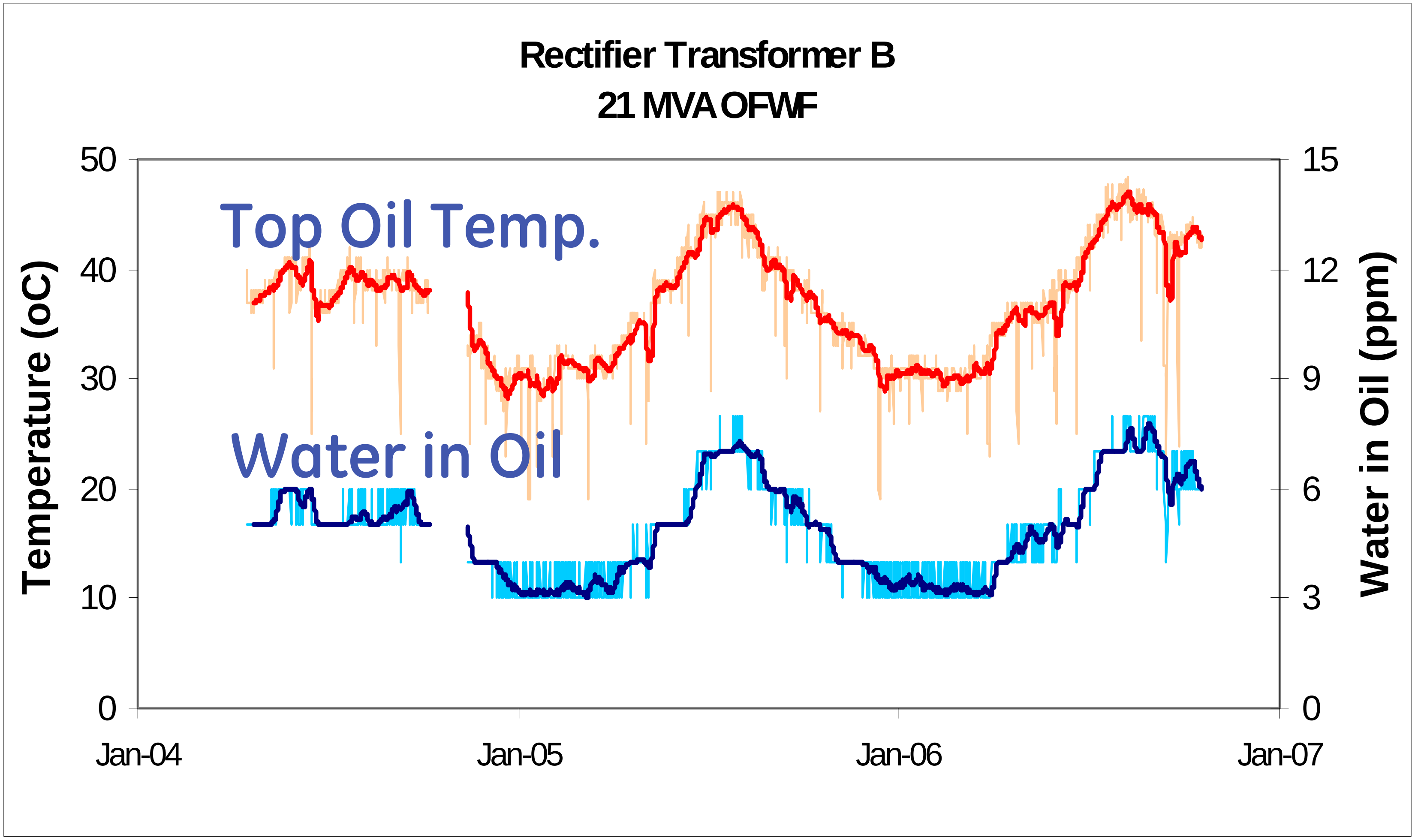
Absolute water content in oil (ppm)

20ppm

Condensation temperature (°C)

10°C

Change in water-in-oil concentration



Water content in oil varies with Temperature

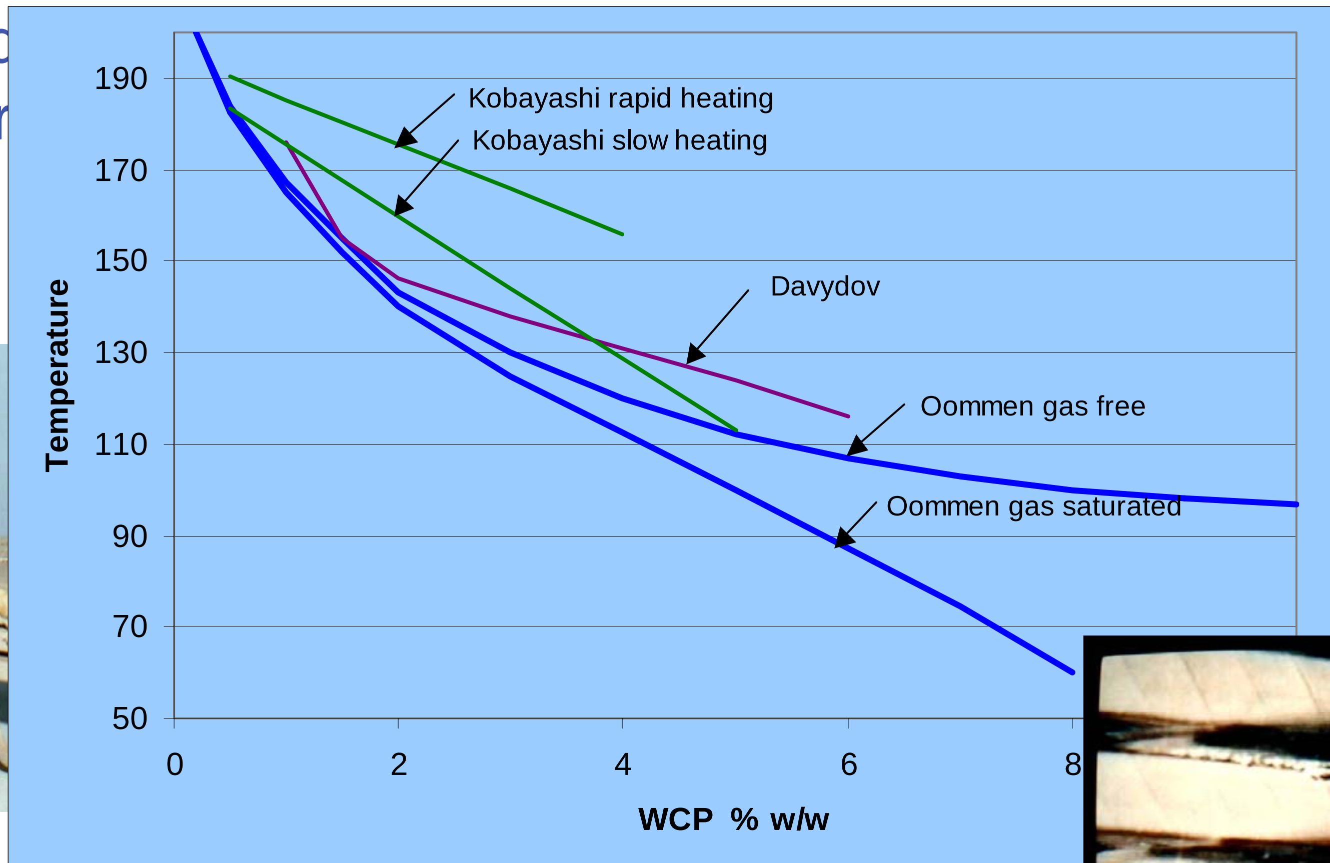
imagination at work

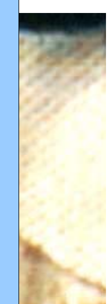
Impact of moisture in winding insulation

- Increased risk of releasing bubbles at high load

Resic
water

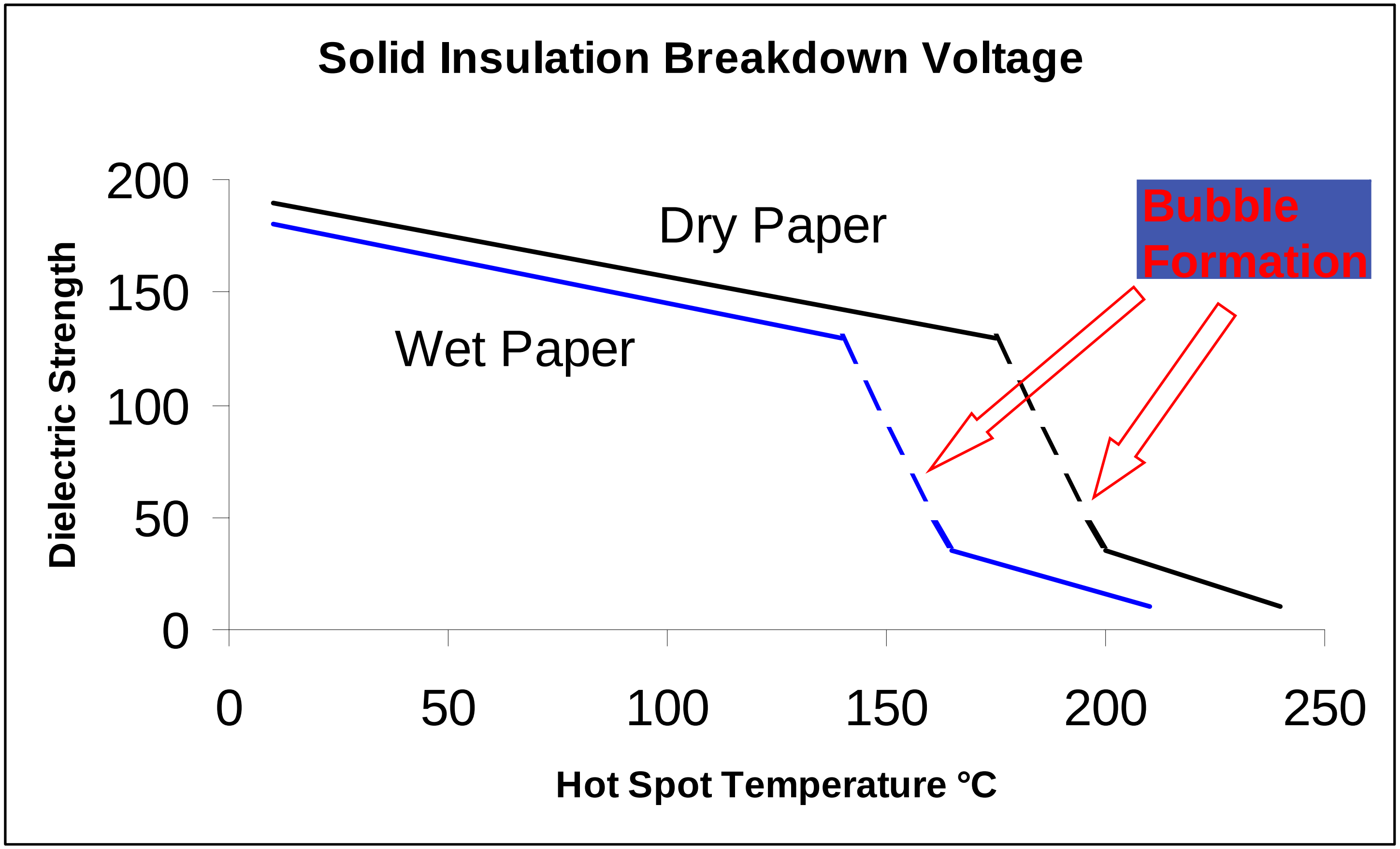
T.V.





Impact of moisture in winding insulation

Effect of temperature on dielectric strength



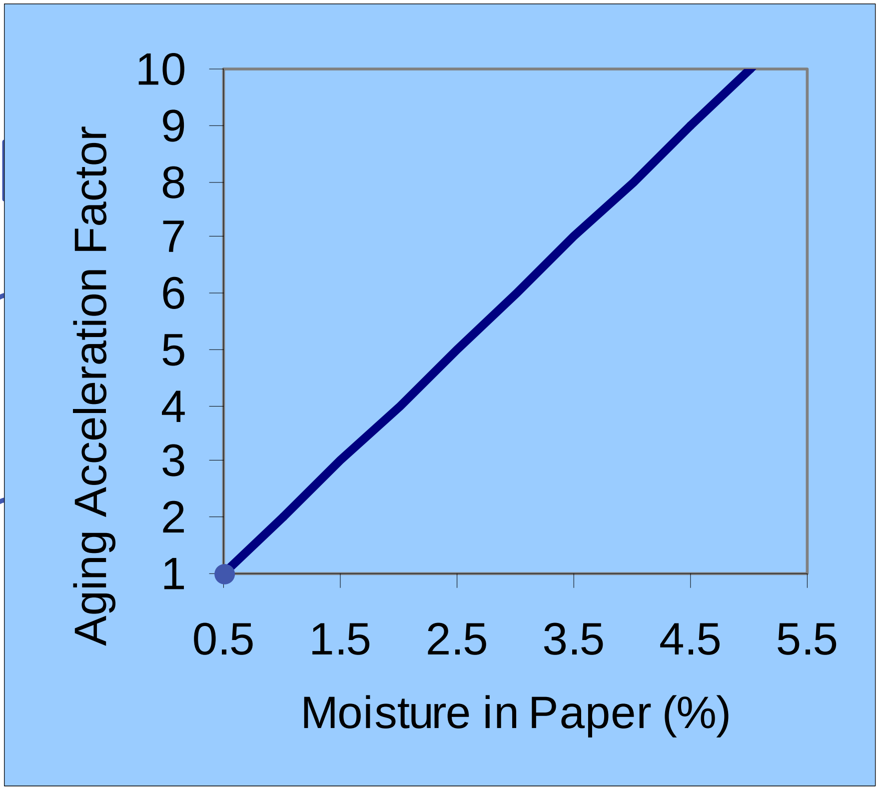
Mc. Nutt et al – EPRI® 1980

Impact of moisture in winding insulation

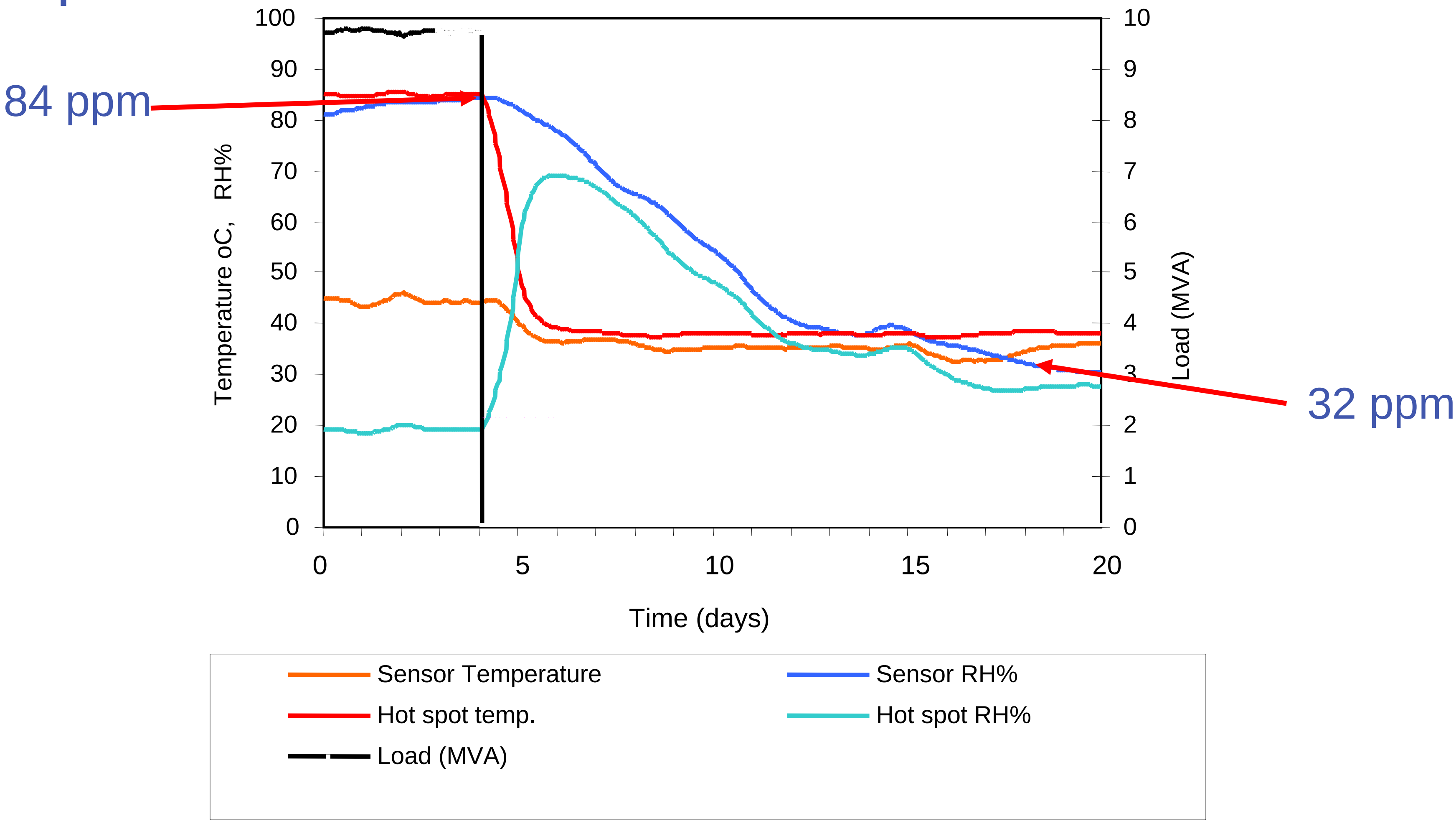
- Accelerates the rate of insulation aging

Effect is different depending on type of

IEEE C57.91 indicate th the acceleration facto be taken as proportior the water content.



Moisture inside the transformer moves back and forth between the oil and paper by diffusion as a function of temperature



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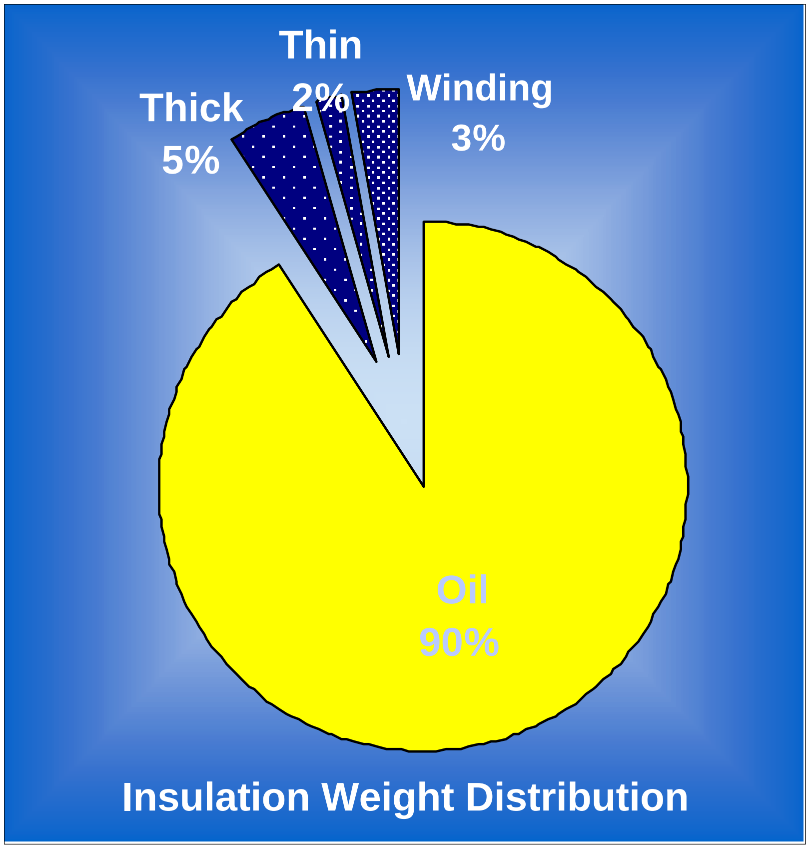
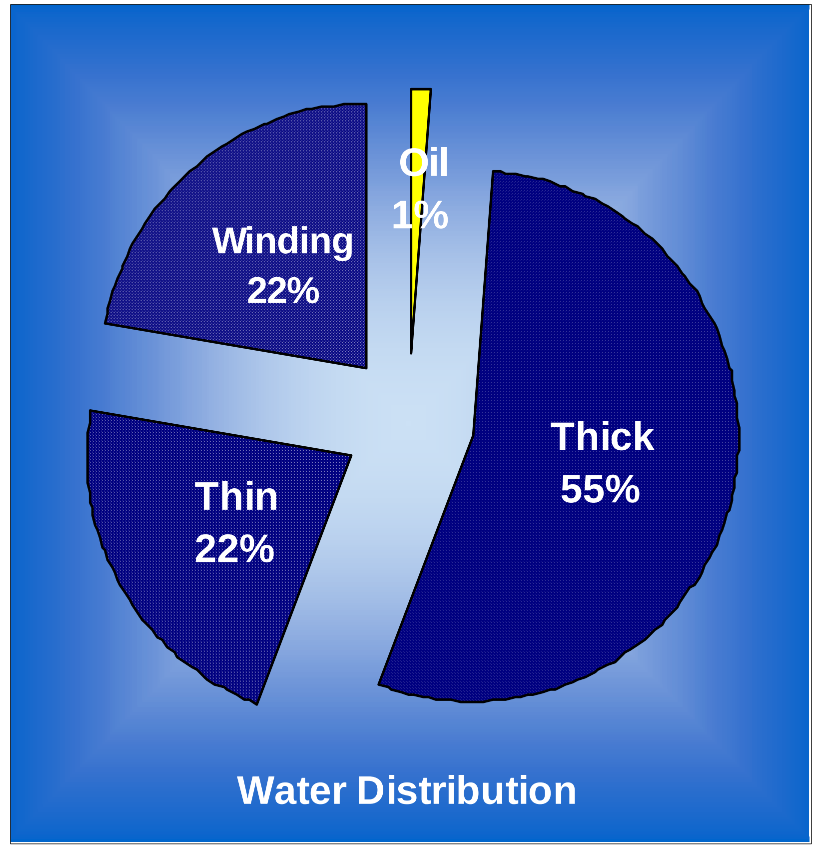
Most of the water is stored in the solid insulation





Example of water distribution in a 25 MVA transformer with 3% moisture in paper

	40°C		80°C	
Oil (25 000litre)	10 ppm	0.25 kg	80 ppm	2.0kg
Paper (2500 kg)	3 %	75 kg	2.93%	73.25 kg
Total		75.25 kg		75.25 kg

- Most of the water is in the solid insulation
- Change in water content of oil does not entail a similar change in the water content of paper

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Moisture content in transformer insulation is a persistent concern

Aging transformers tend to build-up moisture

IEEE Std 62 – 1995:

- Dry 0-2%
- Wet 2-4%
- Very Wet 4.5% +

Only moisture in oil can actually be measured

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Hydran M2

Advanced Gas and Moisture monitor

- H2 and CO
- Moisture in oil
- Trending
- 4 analog inputs
- Data Logging
- Networking
- Integrated Modem/TCP-IP

Typical HYDRAN M2 Installation

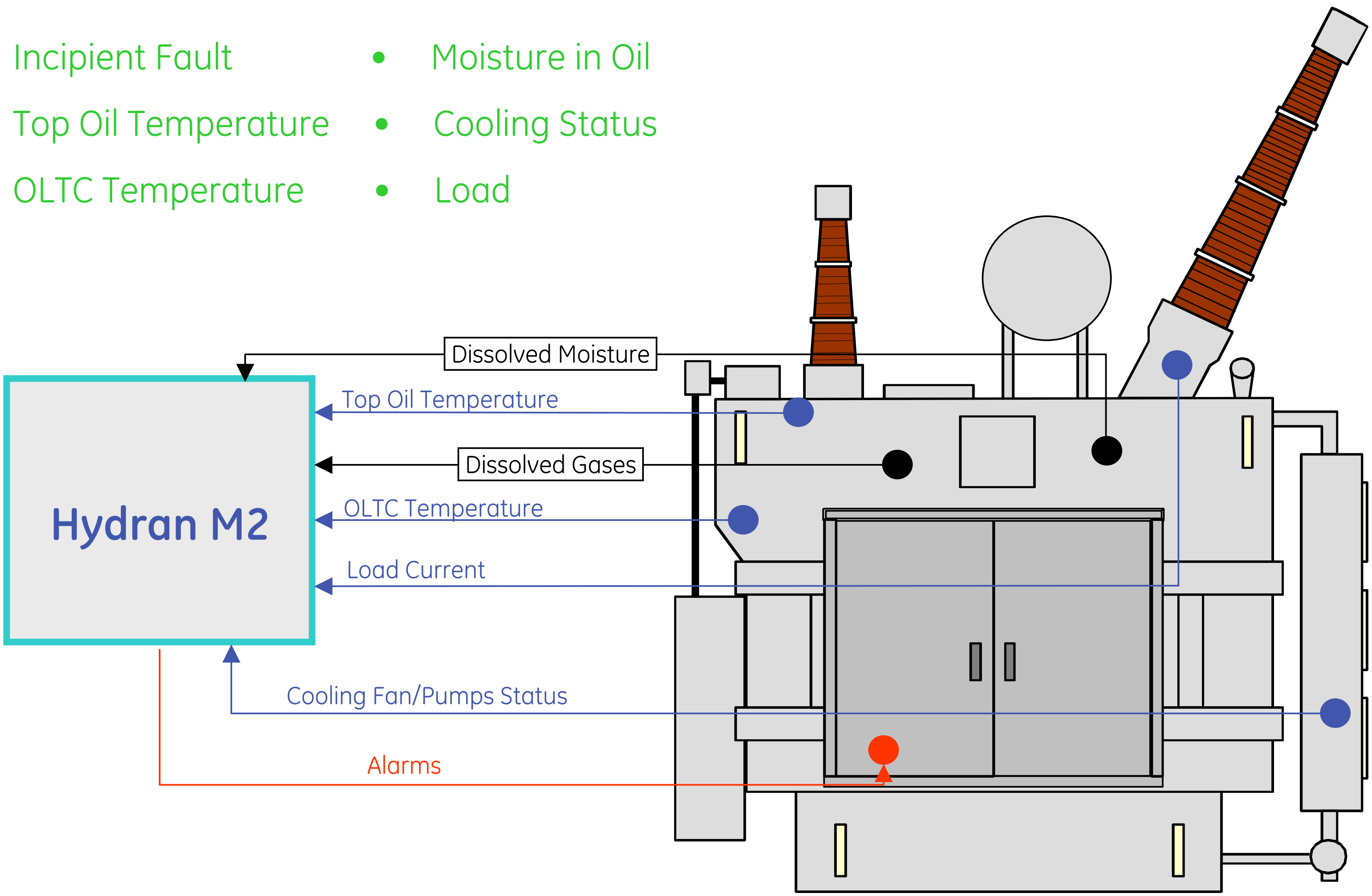
Typical HYDRAN M2 Installation

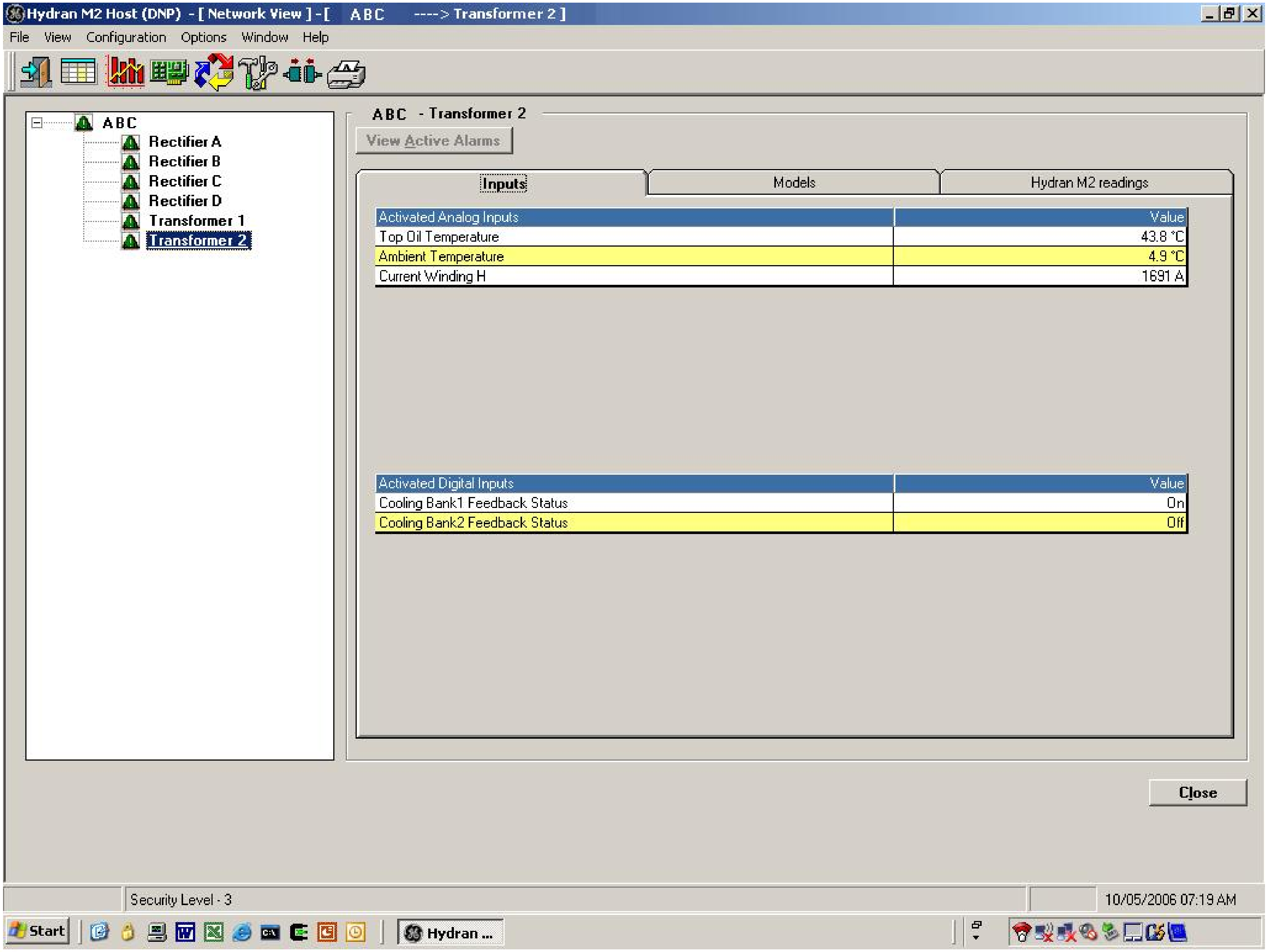
Typical HYDRAN M2 Installation

imagination at work

The Hydran M2 as Transformer Monitor

- Incipient Fault
- Top Oil Temperature
- OLTC Temperature
- Moisture in Oil
- Cooling Status
- Load




Hydran M2 Host (DNP) - [Network View] - [ABC ----> Transformer 2]
File View Configuration Options Window Help
ABC
Rectifier A
Rectifier B
Rectifier C
Rectifier D
Transformer 1
Transformer 2
ABC - Transformer 2
View Active Alarms
Inputs
Models
Hydran M2 readings
Activated Analog Inputs
Value
Top Oil Temperature
43.8 °C
Ambient Temperature
4.9 °C
Current Winding H
1691 A
Activated Digital Inputs
Value
Cooling Bank1 Feedback Status
On
Cooling Bank2 Feedback Status
Off
Close
Security Level - 3
10/05/2006 07:19 AM
Start
Hydran ...

Broadband monitoring technique for **Main tank**

Synergy

When several parameters are monitored simultaneously, it is possible to obtain more information by correlating each measurement to the others.

Analyzing data correlation allow the extraction of more significant information than just what is available in each individual parameter

Broadband monitoring technique for **Main tank**

Synergy

Problem:

Analysis of data requires time, manpower and expertise

Actual trend: Highly competitive environment and limited resources

Needed: System to reduce data and extract only significant information

Broadband monitoring technique for **Main tank**

Synergy

Solution:

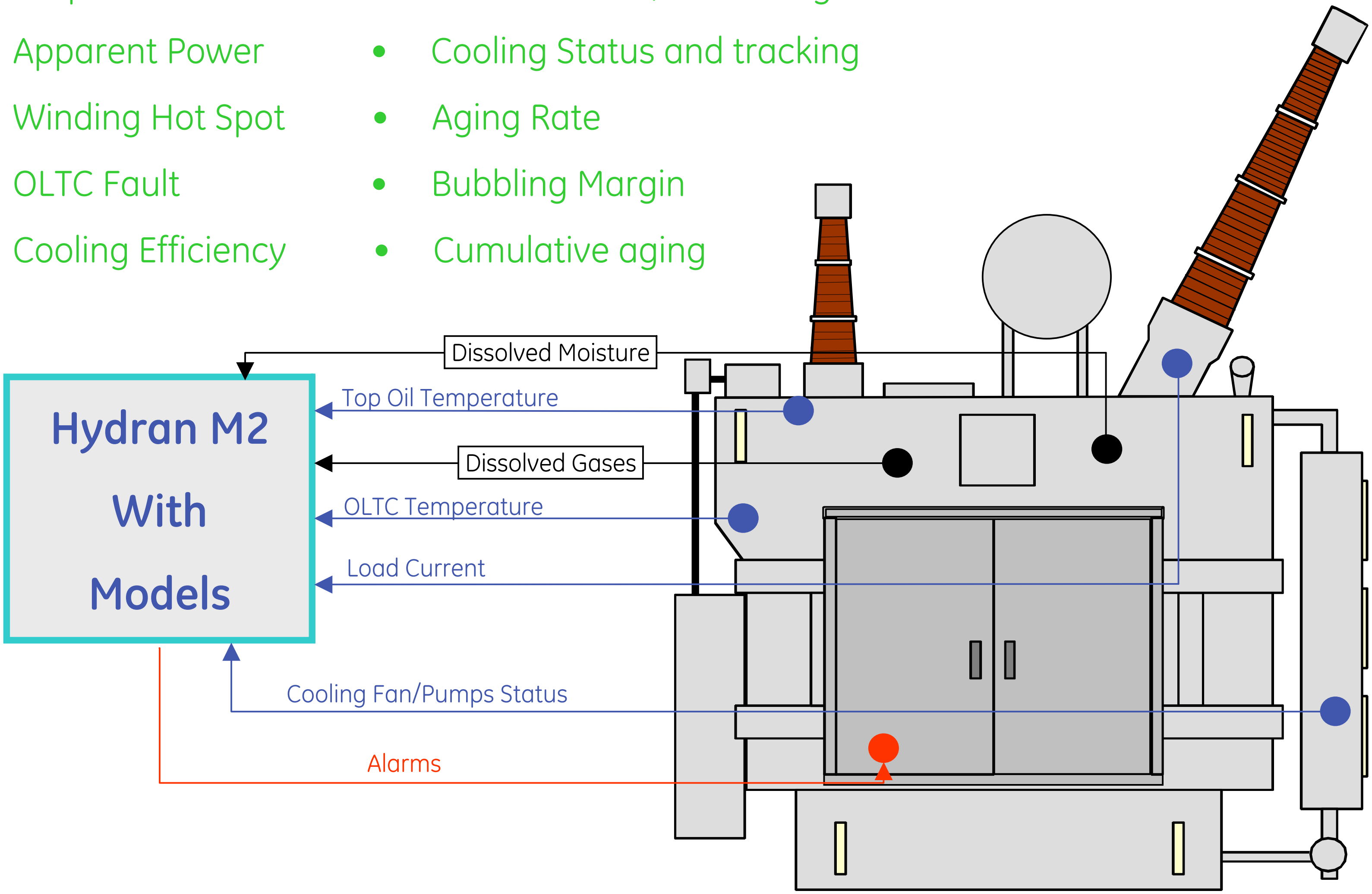
Reduce Amount of data Using Intelligent Systems

Apply on-line, real time data reduction technique with “intelligent” sensors and systems

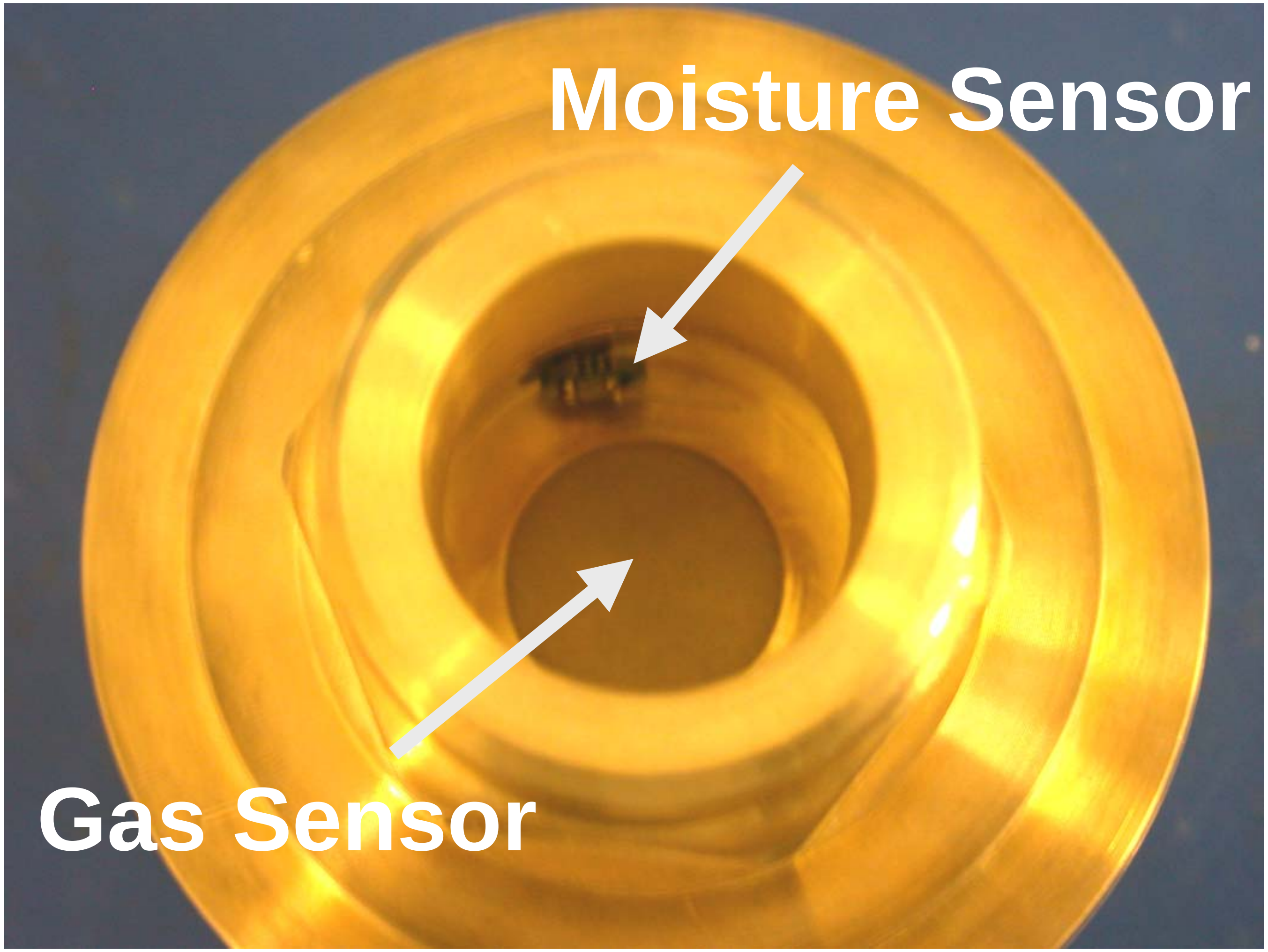
Use on-line “Models” to present to the operator only the useful information

The Hydran M2 as Advanced Transformer Monitor

- Incipient Fault
- Apparent Power
- Winding Hot Spot
- OLTC Fault
- Cooling Efficiency
- Moisture in Oil, in Windings and in Barriers
- Cooling Status and tracking
- Aging Rate
- Bubbling Margin
- Cumulative aging

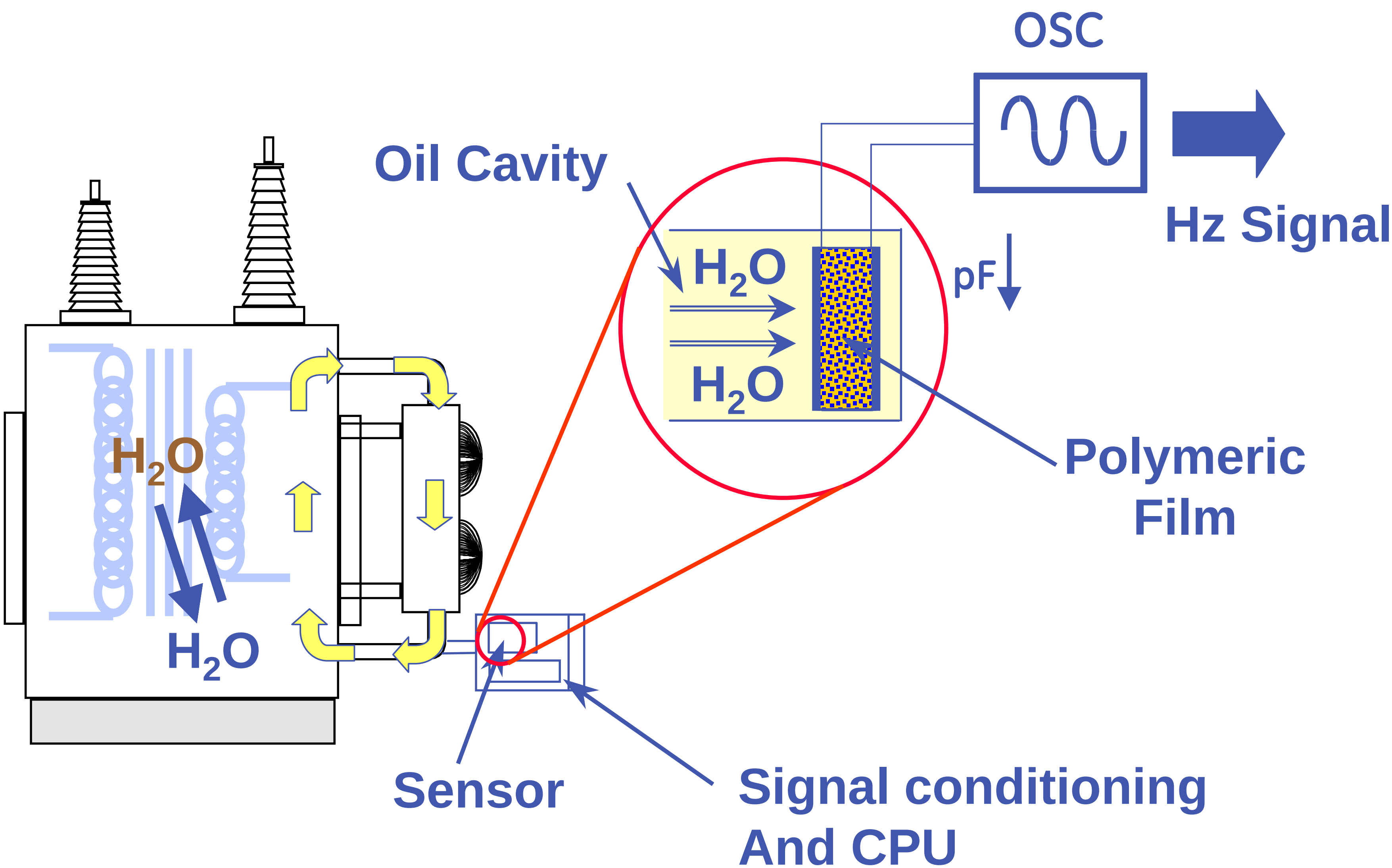


HYDRAN® S2/M2 Dual Sensor



imagination at work

The Hydran® Technology: H_2O Sensor



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The Hydran M2 as a Transformer Monitor

The addition of externals sensors combined with the use of powerful on-line models computation transform the Hydran M2 from a simple “gas fault monitor” to a complete transformer monitor

Broadband monitoring technique for **Main tank**

Temperature

High Temperatures age the insulation faster

Excessive temperatures could generate bubbling, leading to arcing

Sudden temperature drop could generate water droplets in oil, leading to arcing

Temperature is a key element to monitor

Broadband monitoring technique for **Main tank**

<u>Load</u>

Load level governs all aspect of transformer operation

Load affect all transformer components

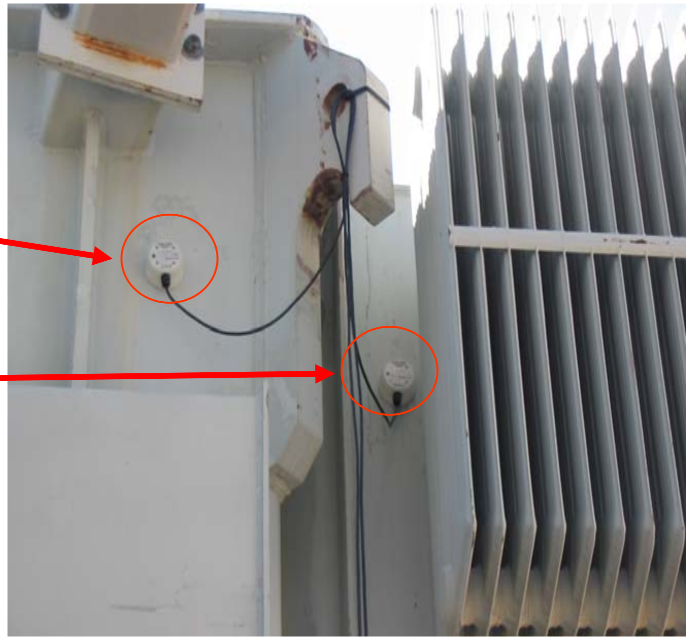
Overload does cause excessive transformer aging

Load is a key element to monitor

Temperature and Load

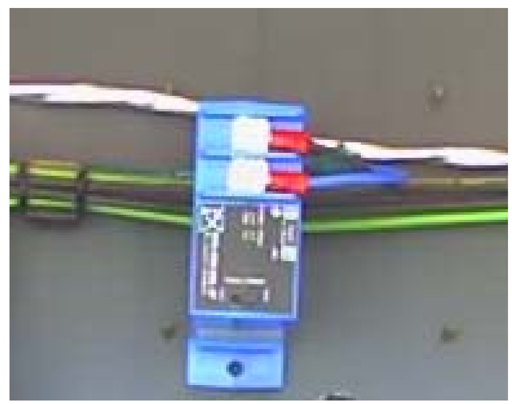
Top oil

OLTC



Ambient
Temperature
Sensor

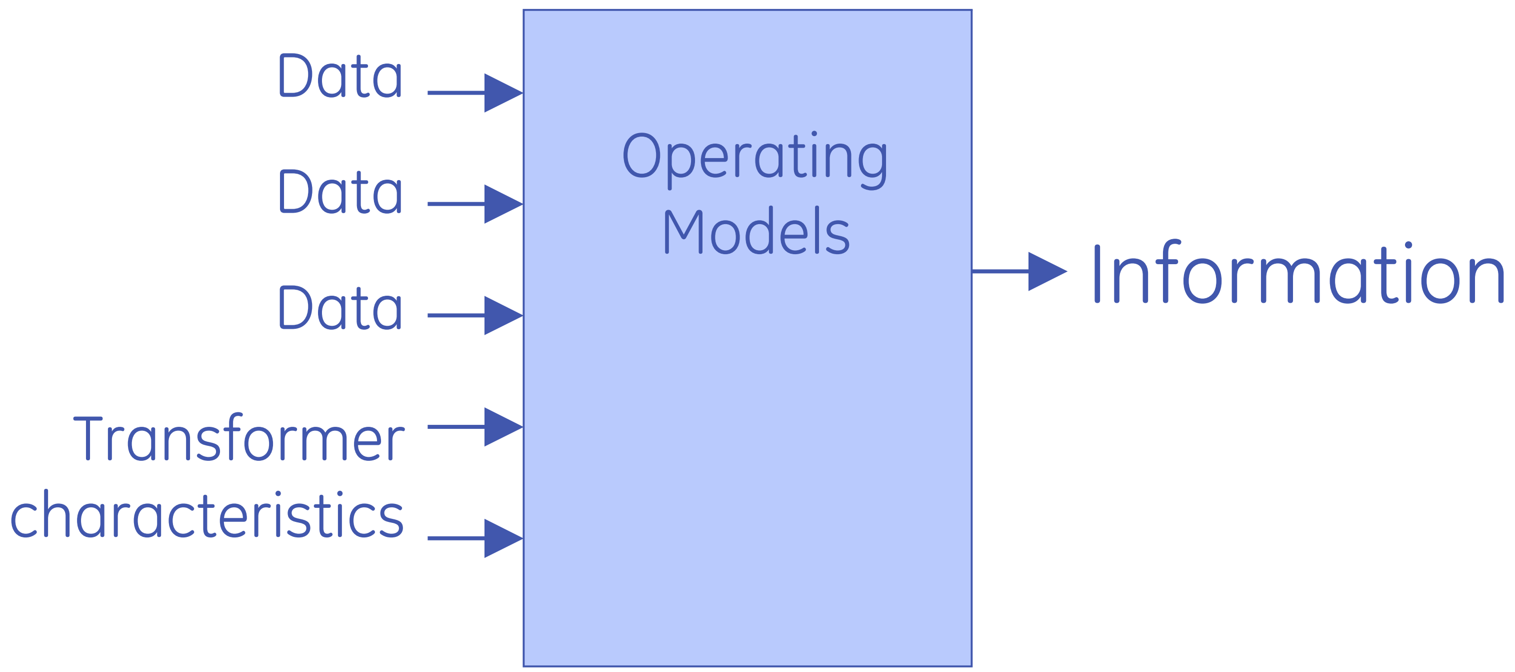
Magnetically
Mounted
Temperature
sensor



Clip-On load sensor

Transformer Model

Convert Raw Data to Useful Information



Distributed Intelligence: Models

Transformer Monitoring : DATA or Information ?

Models:

Models are based on internationally recognized standards such as IEEE® and IEC®

They perform on-line, real-time computation to convert data to useful information

They use data from test reports and heat run report to tailor each models specifically to the transformer

The Hydran M2 as Transformer Monitor

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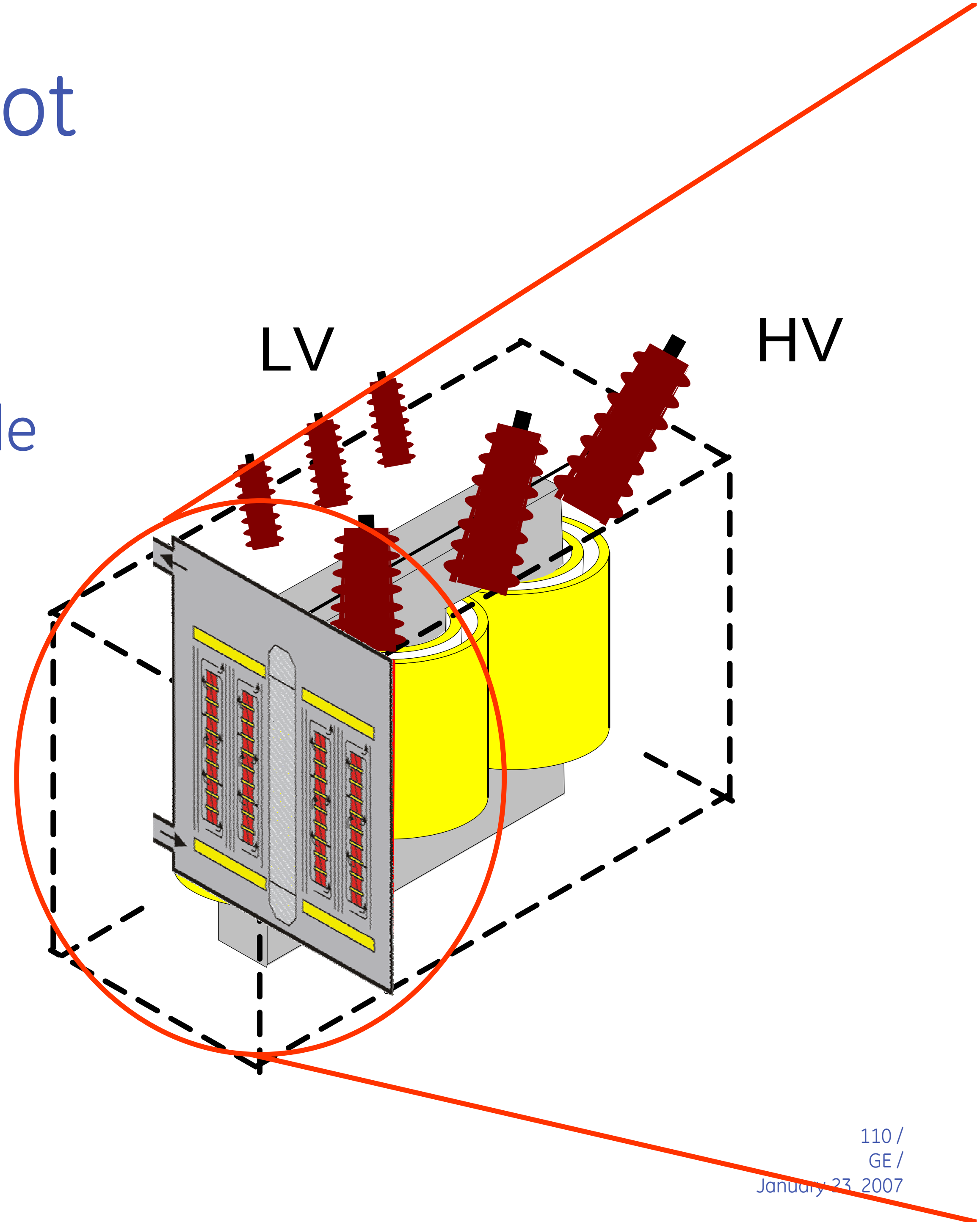
Winding Hot Spot

Consider for example a three-phase, two-winding transformer



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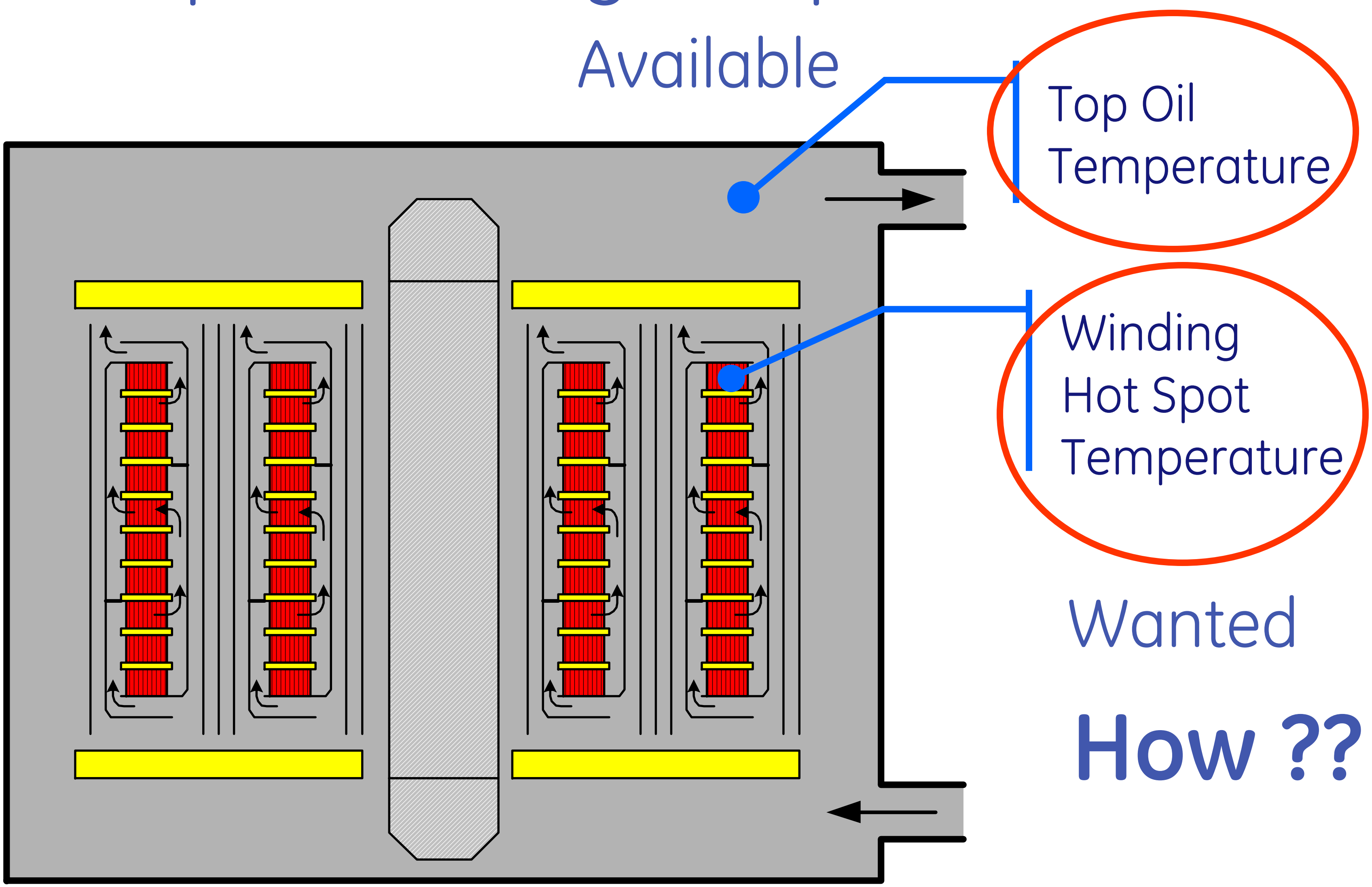
Example: Winding Temperature Model



How ??

imagination at work

Winding Temperature Model

Ultimate hot-spot tem

$\Delta\Theta_{HHu} =$

Hot-spot temperature

$\Delta\Theta_{HH} = \Delta$

Inputs needed:

- *Top oil temp.*
- *Load current on each winding*
- *Transformer characteristic*

Hot-spot temperature on winding H

$\Theta_{HH} = \overline{\Theta}$

Reset of initial windi

$\Delta\Theta_{HHi} =$

Rules:

- *Calculations in line with IEEE and IEC loading guides*

Ultimate hot-spot tem

$\Delta\Theta_{HXu} =$

Hot-spot temperature

$\Delta\Theta_{HX} = \Delta$

Hot-spot temperature

$\Theta_{HX} = \overline{\Theta}$

Output:

- *Winding hottest spot temperatures is calculated for primary windings*
- *Log of max. value with time tag*
- *Warnings and alarms*

Reset of initial hot spo

$\Delta\Theta_{HXi} = \Delta\Theta_{HX}$

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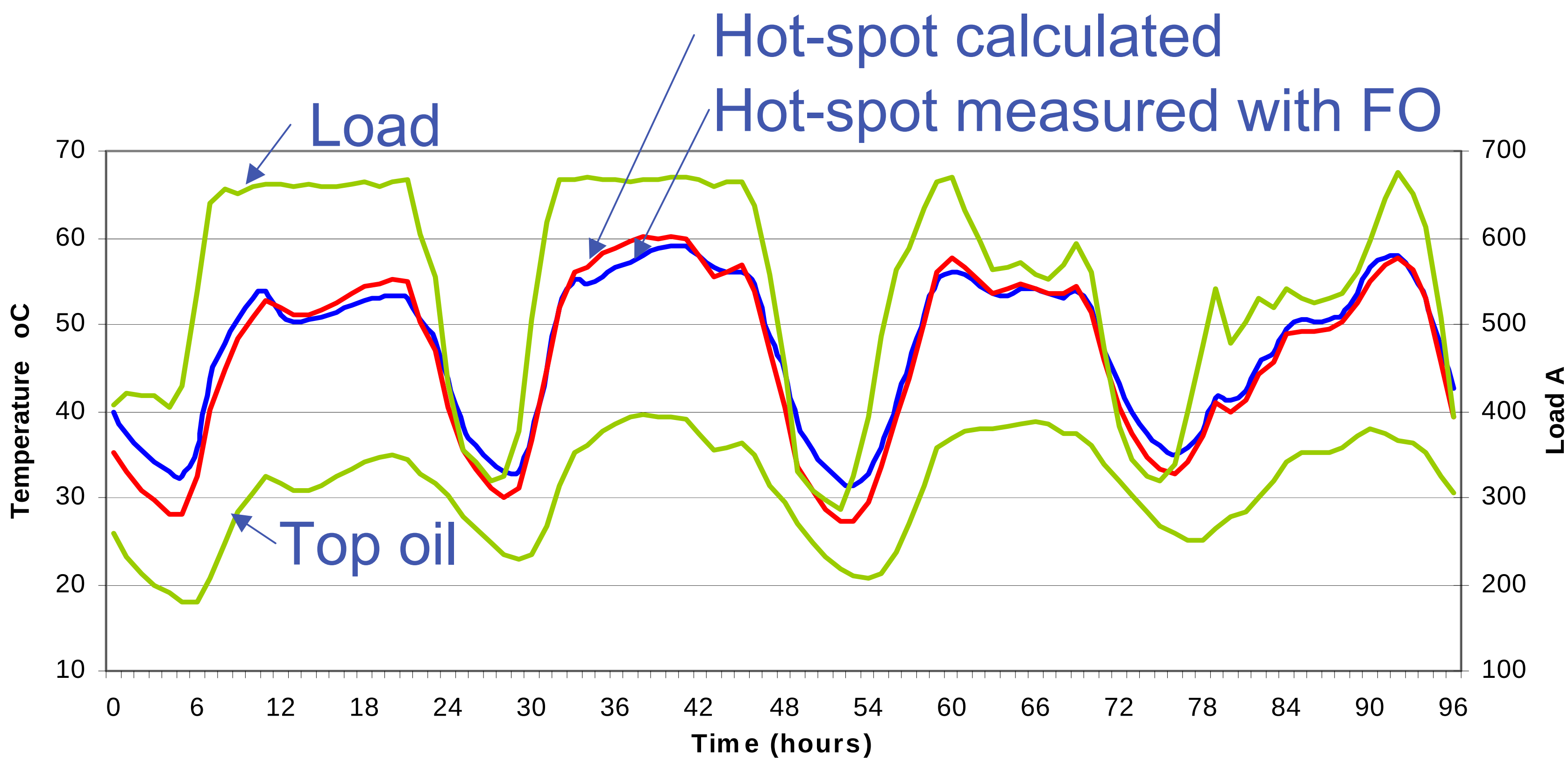
Winding hot spot temperature Model validation



Field experience with on-line moisture monitoring

US Western Utility

50MVA, Core type,
230 / 13.8 kV
55°C rise

Hydran M2 mounted
on spare cooler outlet

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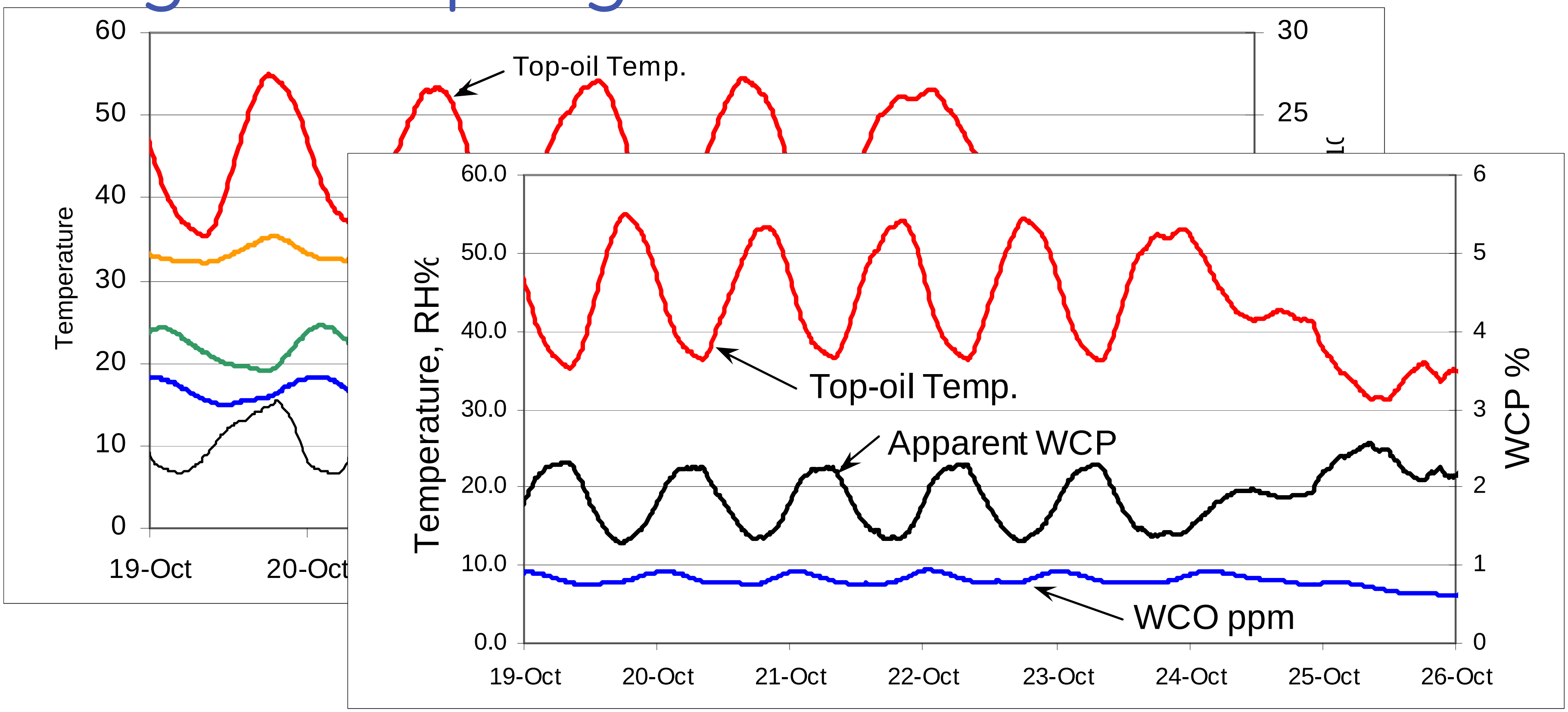
Daily variation of moisture-in-oil preclude assessment of WCP from single sampling



WCP: Min 1.3% Max 2.5%

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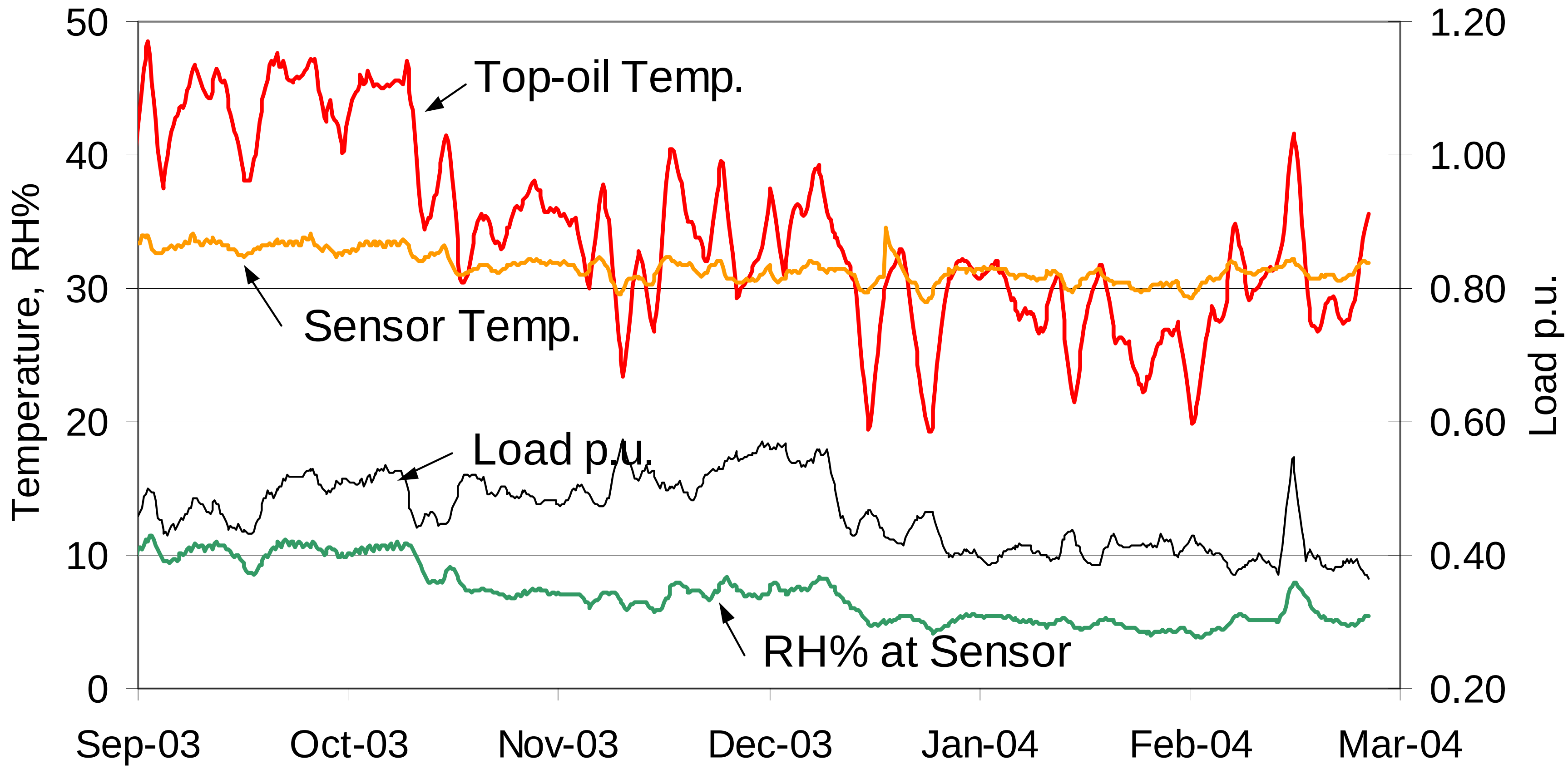
Recording of WCO over long period make it possible to assess WCP



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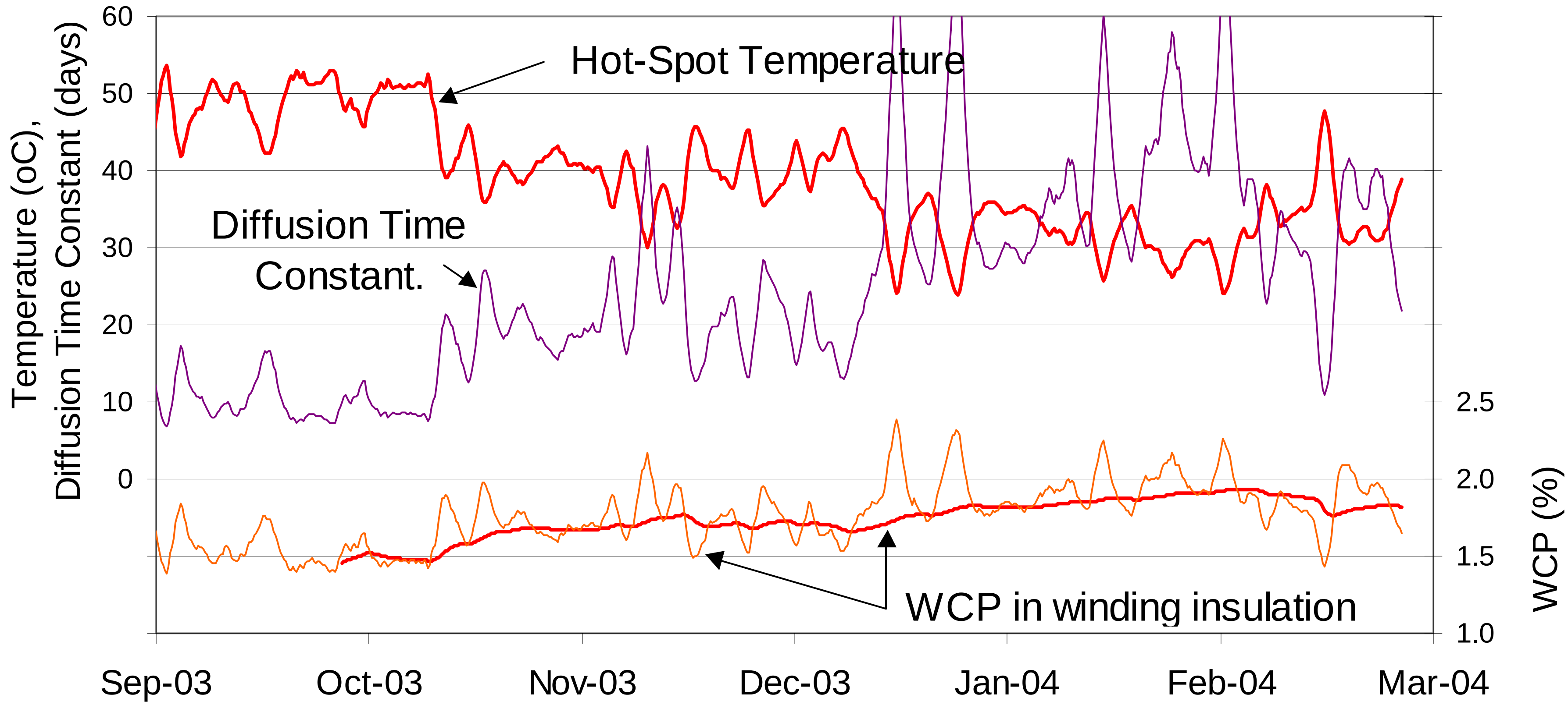
Calculation of moisture content in winding insulation in the hot-spot area



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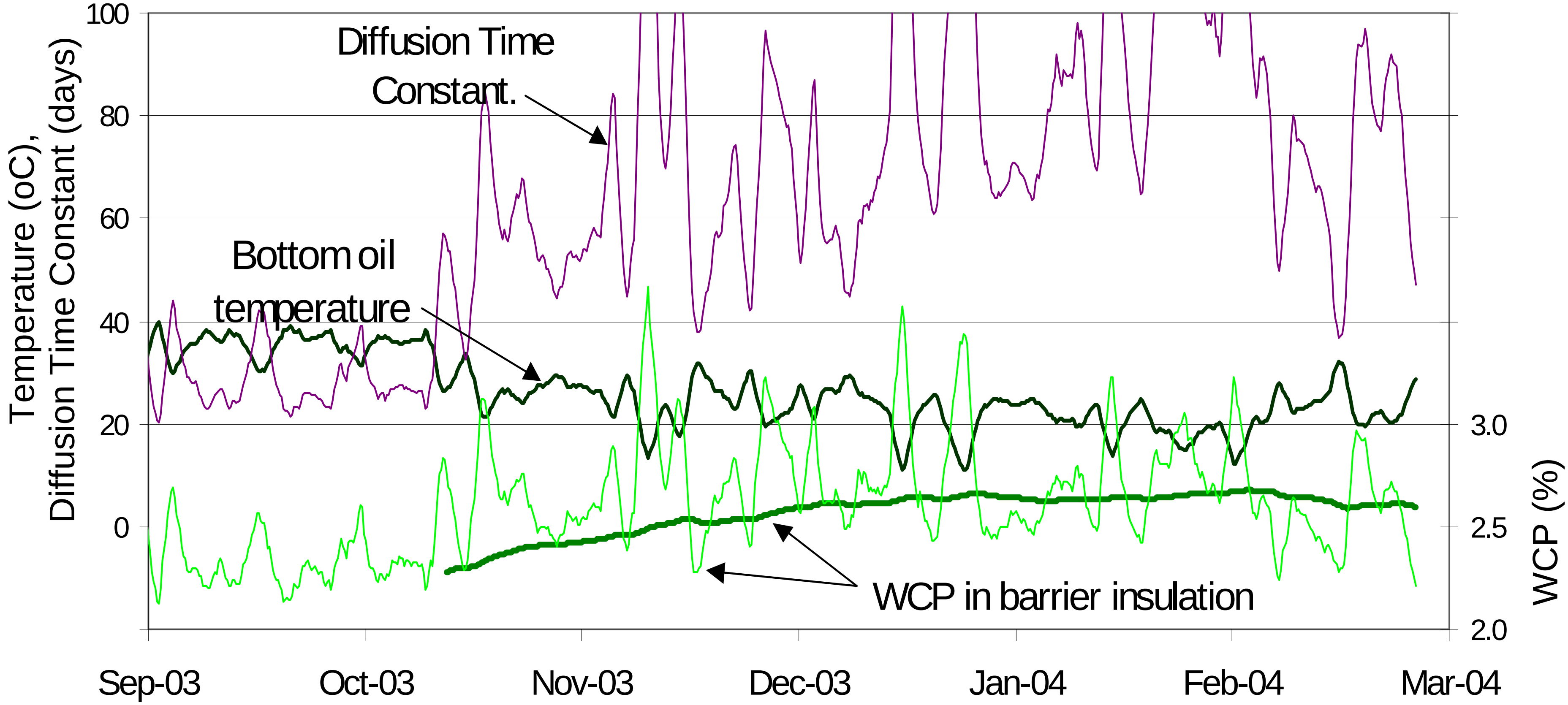
Calculation of moisture content at the bottom of main insulation barriers



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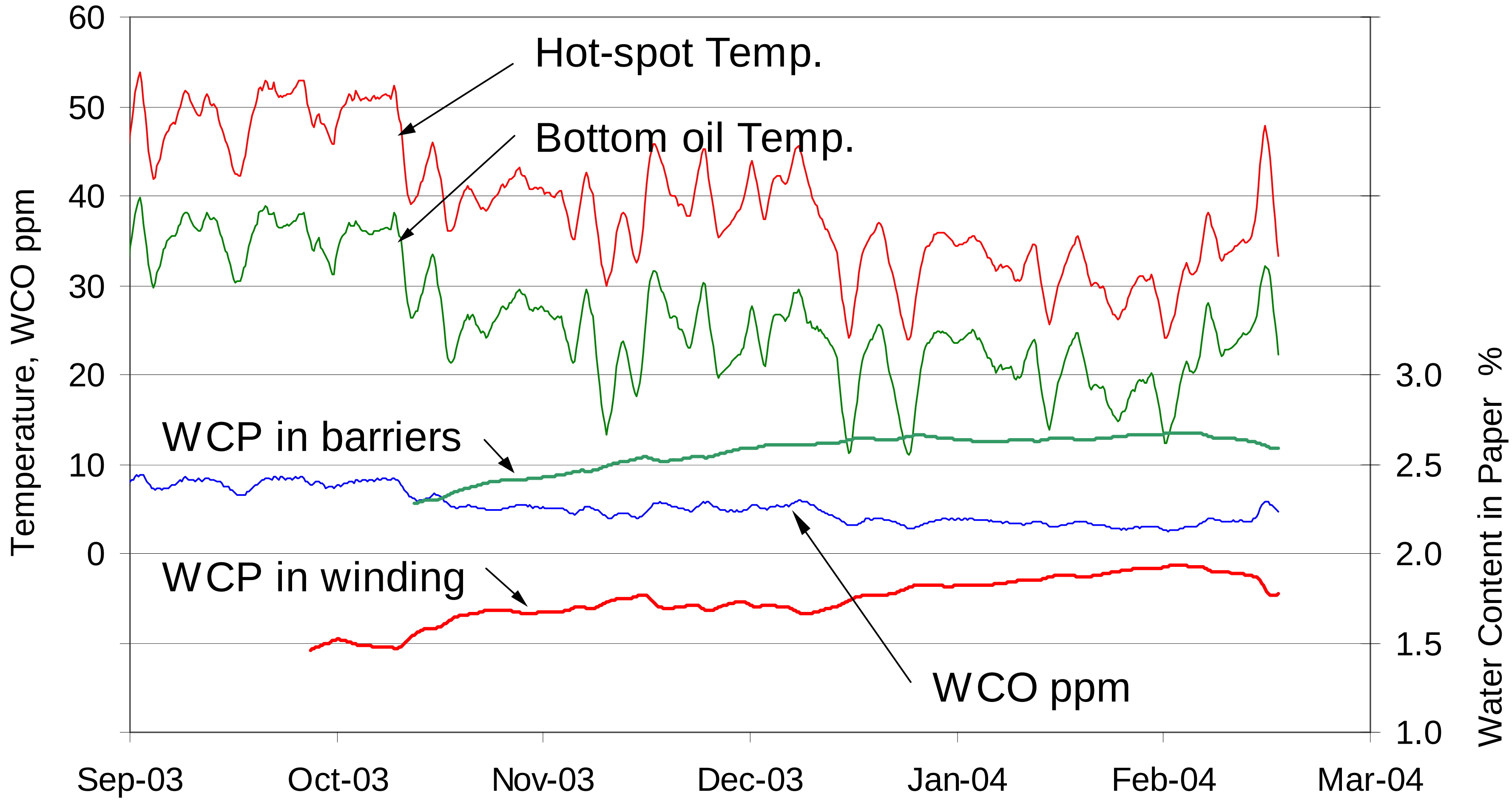
Moisture content in winding insulation and pressboard barriers have their own trend



imagination at work

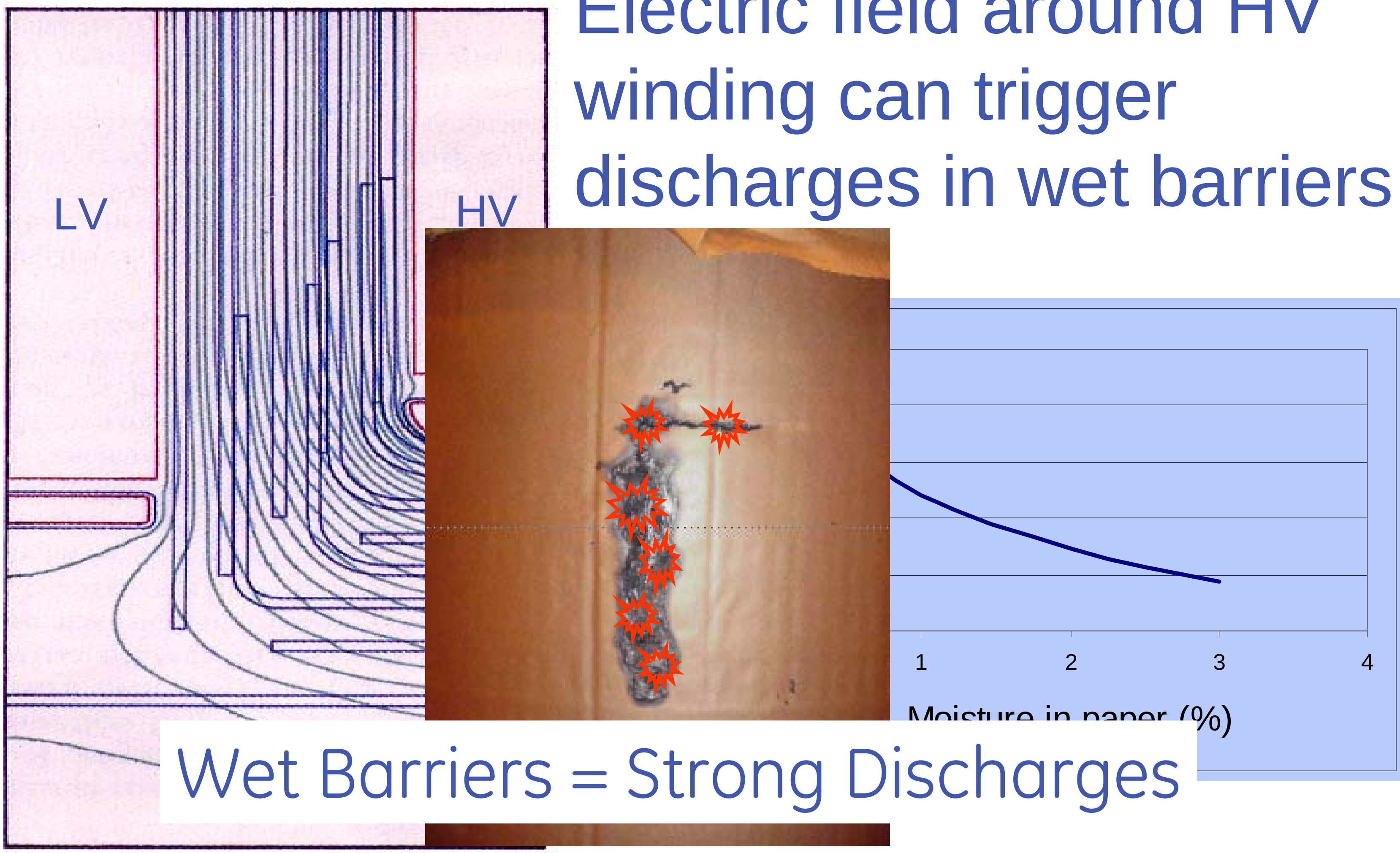
Impact of moisture in Paper

- The amount of water in paper is a very important parameter to know, as it directly determines the following:

- Aging rate of the winding insulation
- Bubbling temperature (limits the amount of overloading of a transformer)
- Dielectric resistance of the barriers at the bottom of the winding

Impact of moisture in pressboard barriers

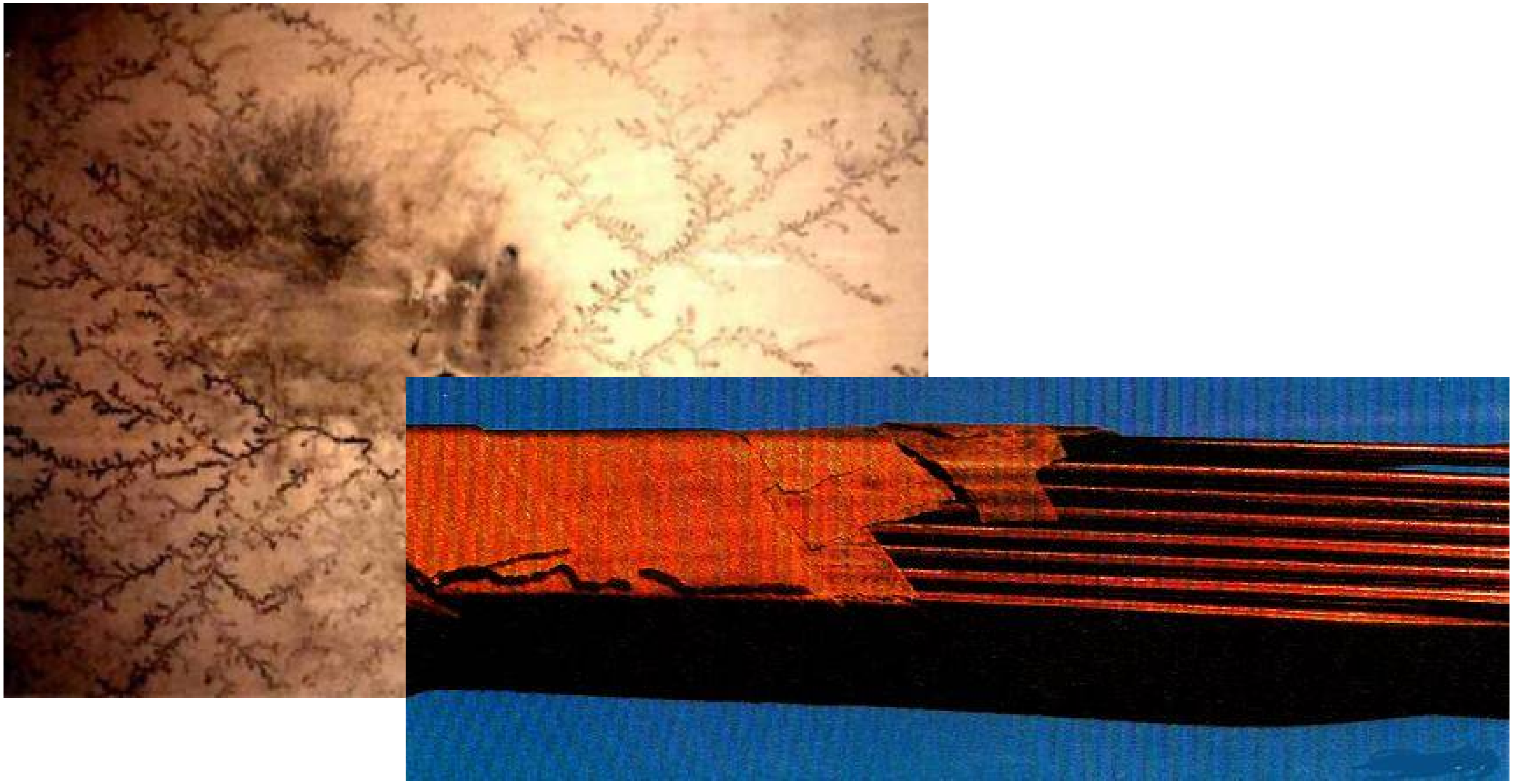
Electric field around HV winding can trigger discharges in wet barriers



Wet Barriers = Strong Discharges

Alstom T&D, Merida, 2003

Example: Moisture in paper model



Impact of moisture in winding insulation

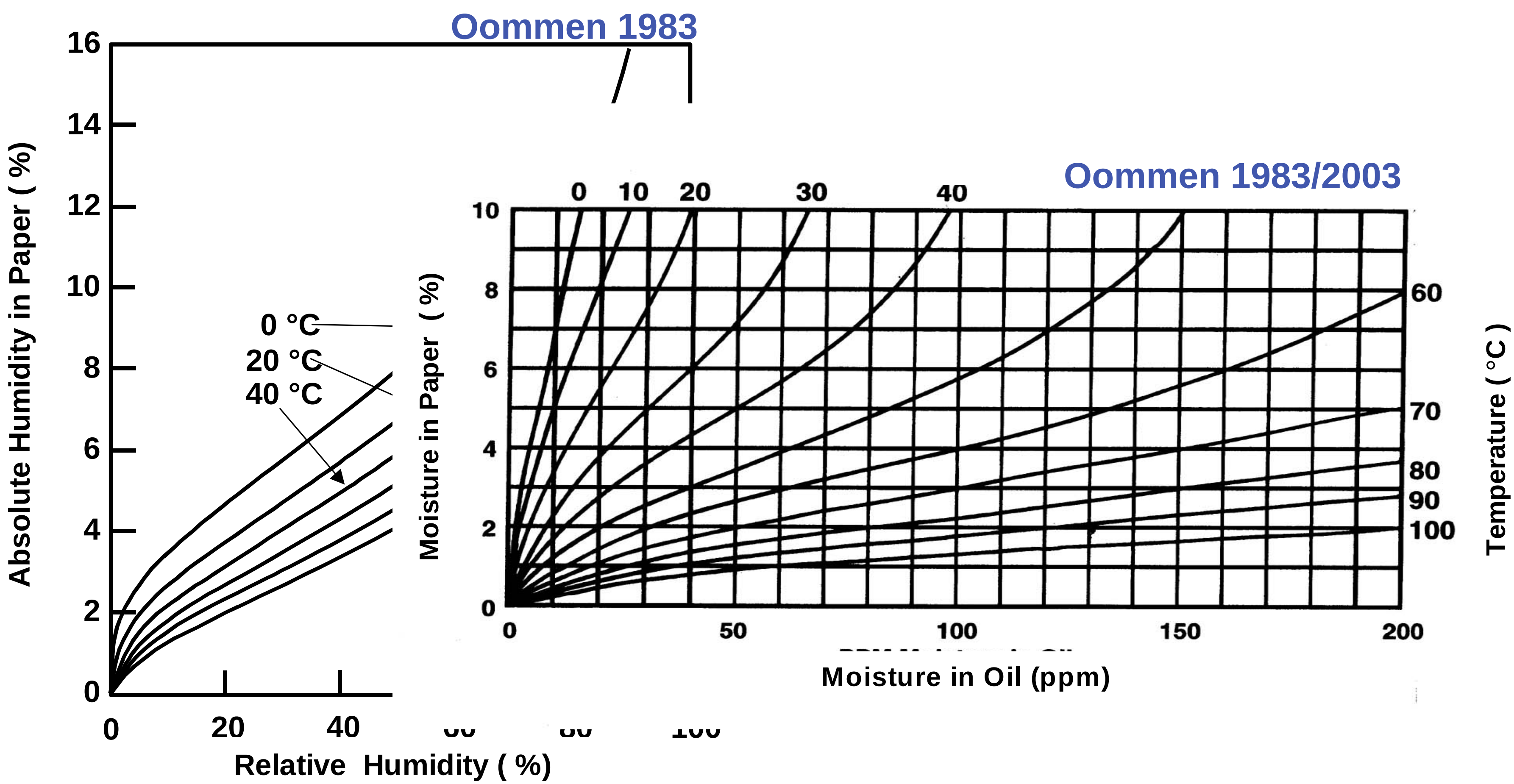
Solution:

There is a correlation between the amount of water in the oil and in the paper

However, this correlation is dynamic and is changing as a function of transformer loading

The dynamics of the distribution of water in the transformer is quite complex and changing

Equilibrium curves are available to relate water-in-oil to water-in-paper



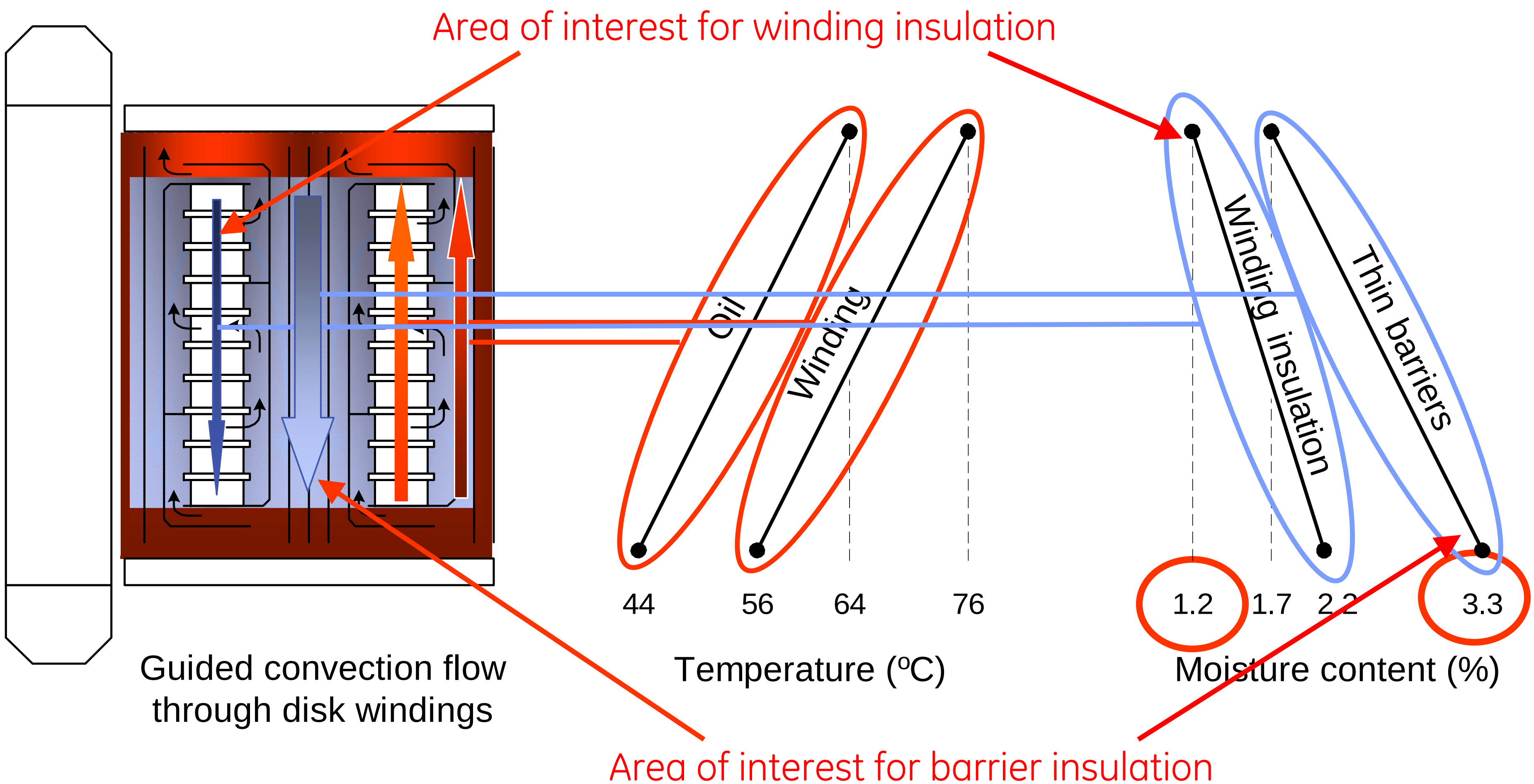
Equilibrium curves are available to relate water-in-oil to water-in-paper

- These curves assume Equilibrium exists (the moisture has stopped moving between the oil and paper)
- But this is never the case.
- Many people make errors in using these charts, ‘blindly’ without considering equilibrium conditions which must exist, and their mistakes can be costly

Equilibrium curves are available to relate water-in-oil to water-in-paper

- Paper at different temperatures inside the transformer will have different moisture level
- Different areas of the insulation system have different thickness (winding insulation versus barrier insulation)
- The Equilibrium condition therefore will take much longer for barrier insulation versus winding insulation

Moisture content in solid insulation is not uniform through the transformer

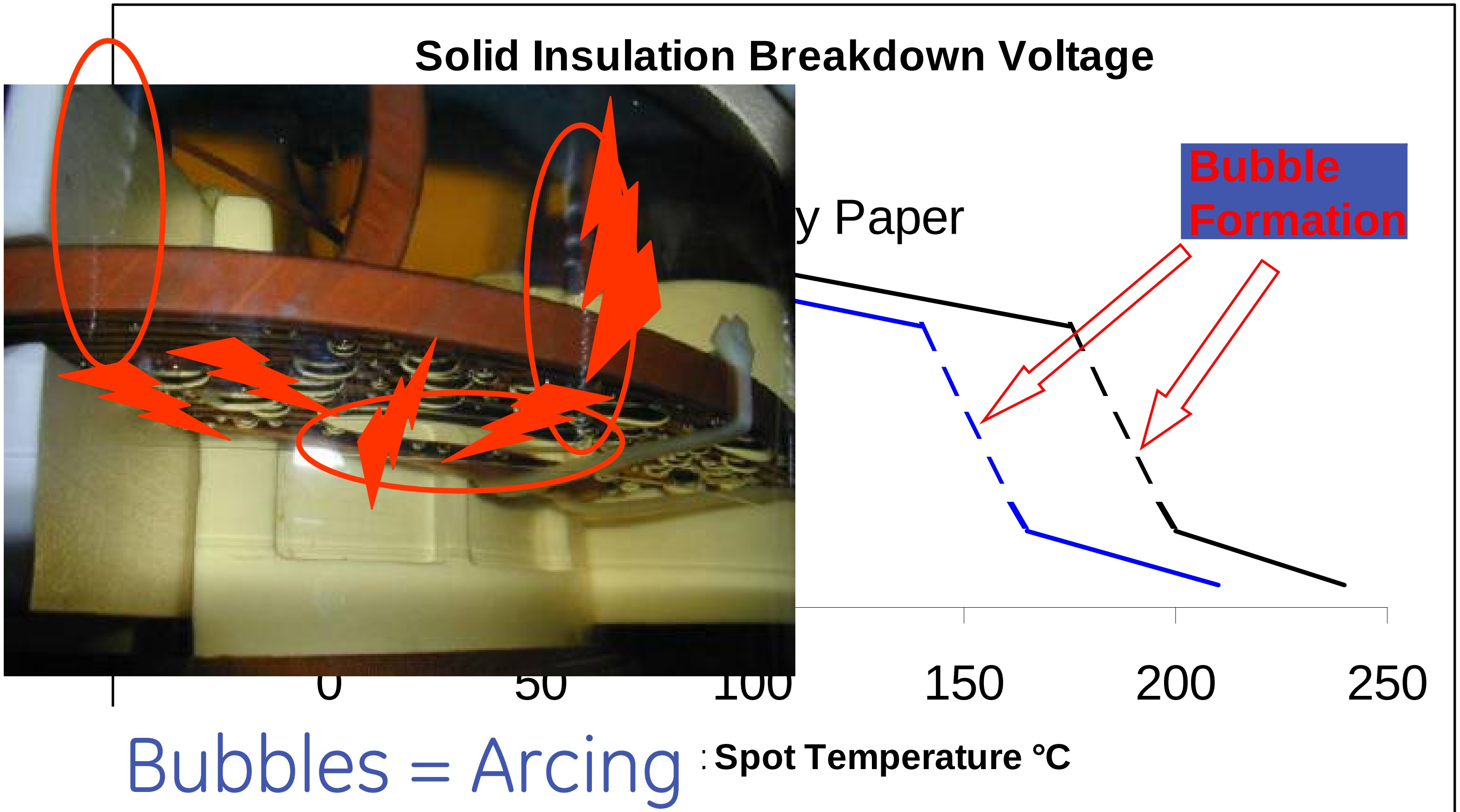


Impact of moisture in Paper

- As temperature and load change, so does the movement of water inside the transformer, between the paper and the oil
- In Practice, the perfect equilibrium needed to use the published curves almost never exist in a transformer
- Only a dynamic model, computed online in real time, can make a good evaluation of the amount of moisture in the paper, in the areas of interest

Impact of moisture in winding insulation

Effect of temperature on dielectric strength



Bubbles = Arcing

Mc. Nutt et al – EPRI® 1980

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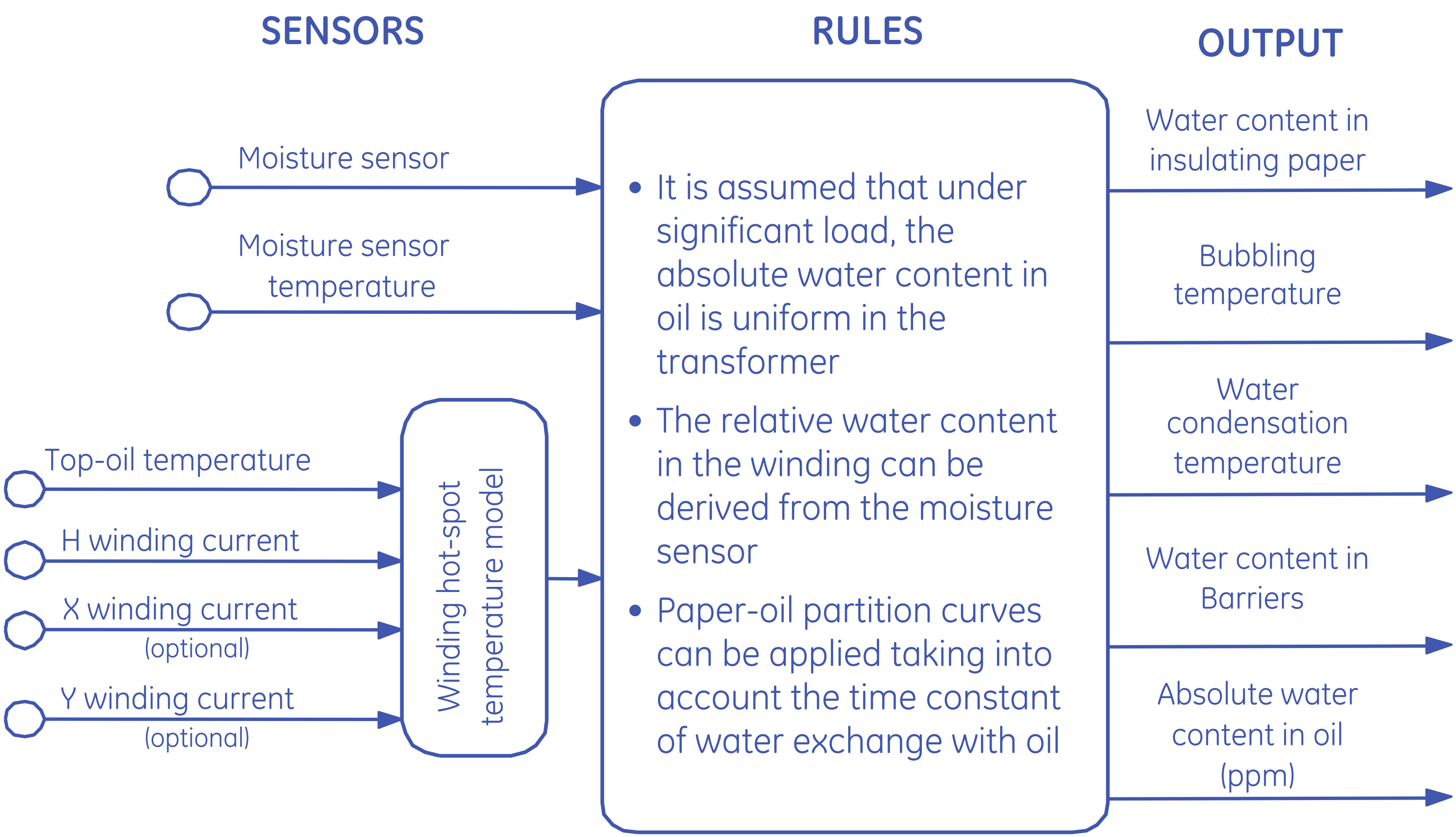
Moisture and Bubbling Model



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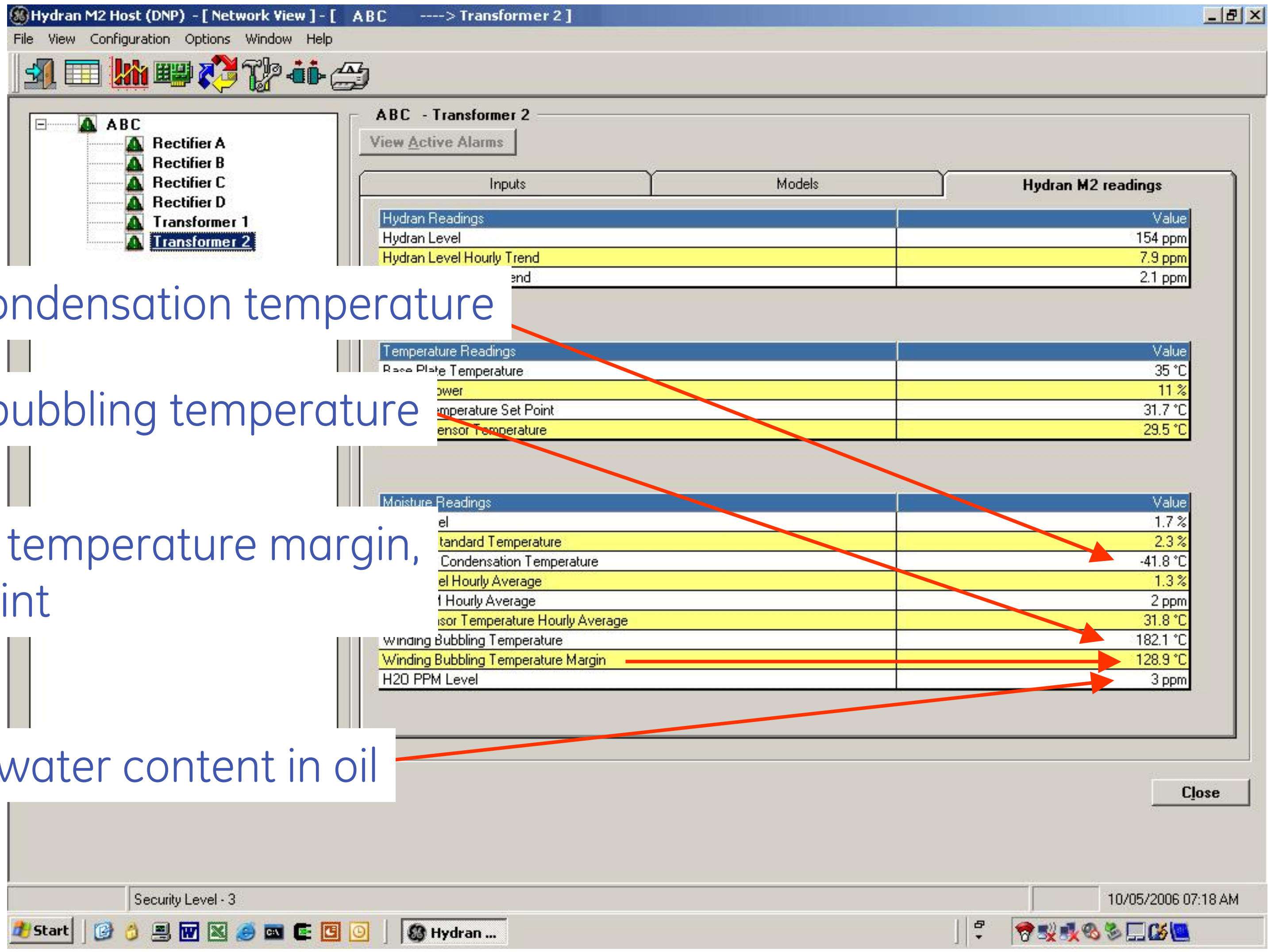
Moisture and Bubbling Model



Water condensation temperature

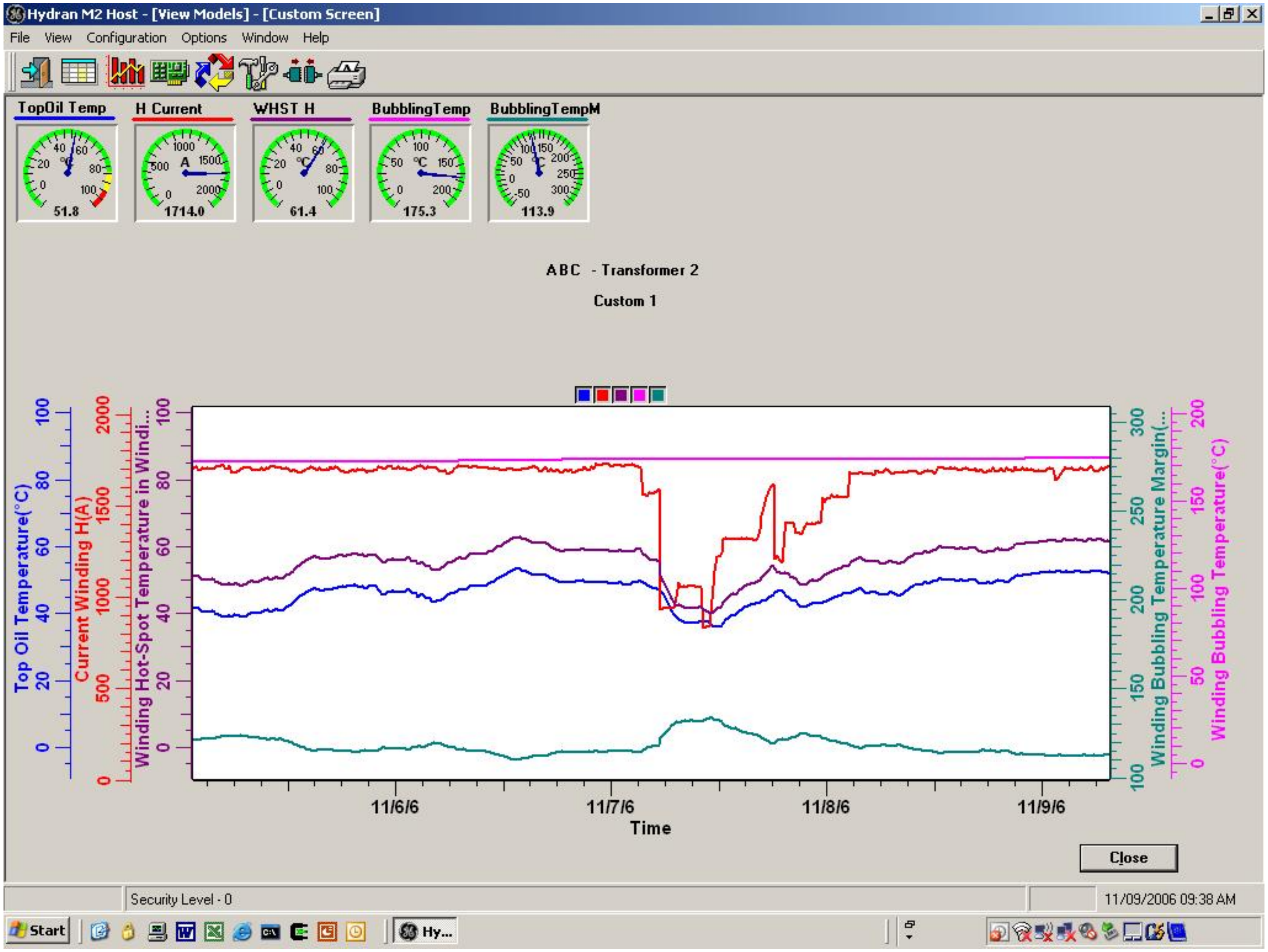
Winding bubbling temperature

Bubbling temperature margin, alarm point

Absolute water content in oil

imagination at work

Moisture and Bubbling Model



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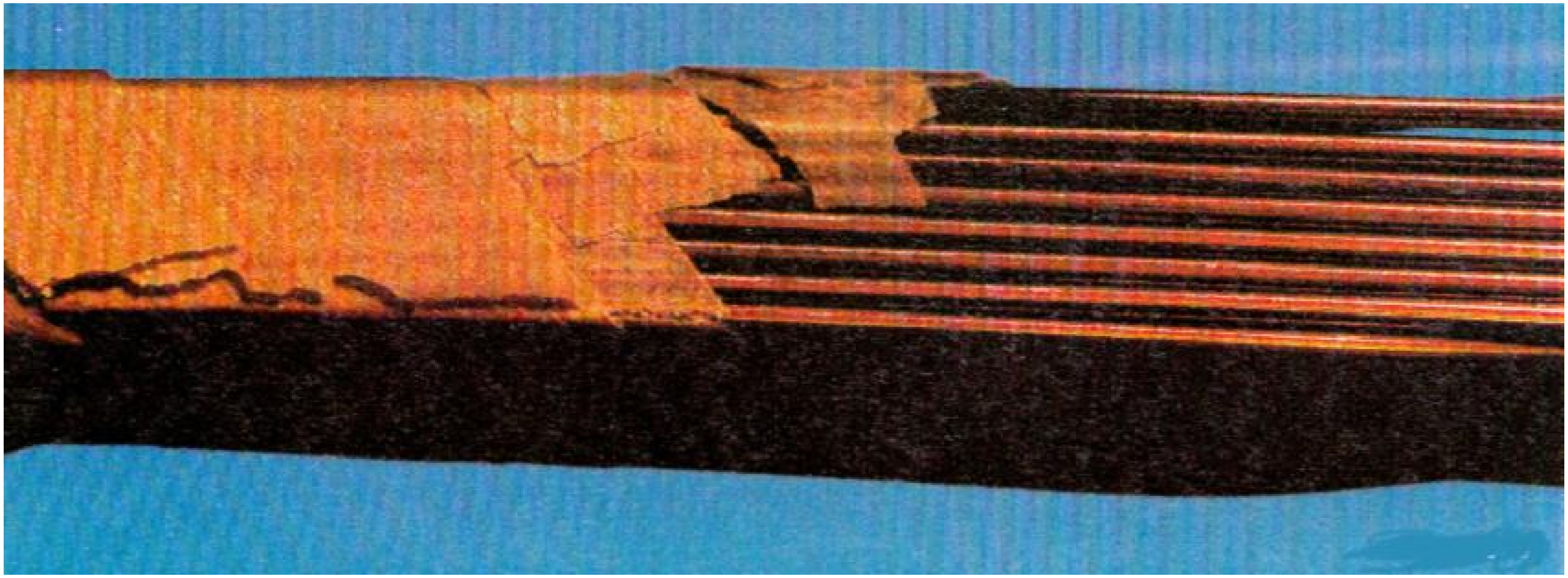
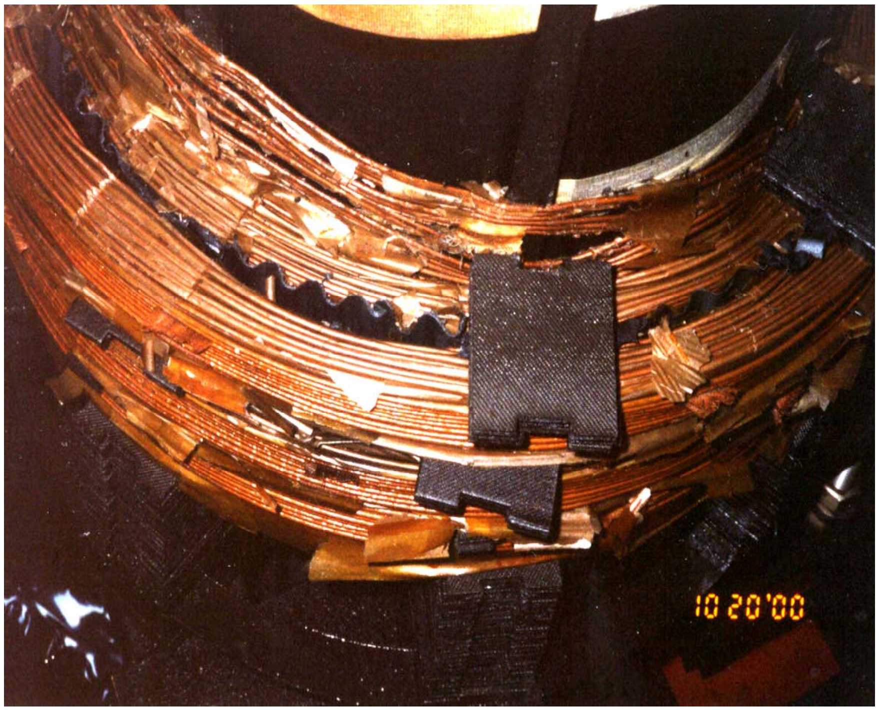
Insulation aging



- With time and temperature, winding insulation undergoes **depolymerisation**
- This process is irreversible and causes **insulation aging**

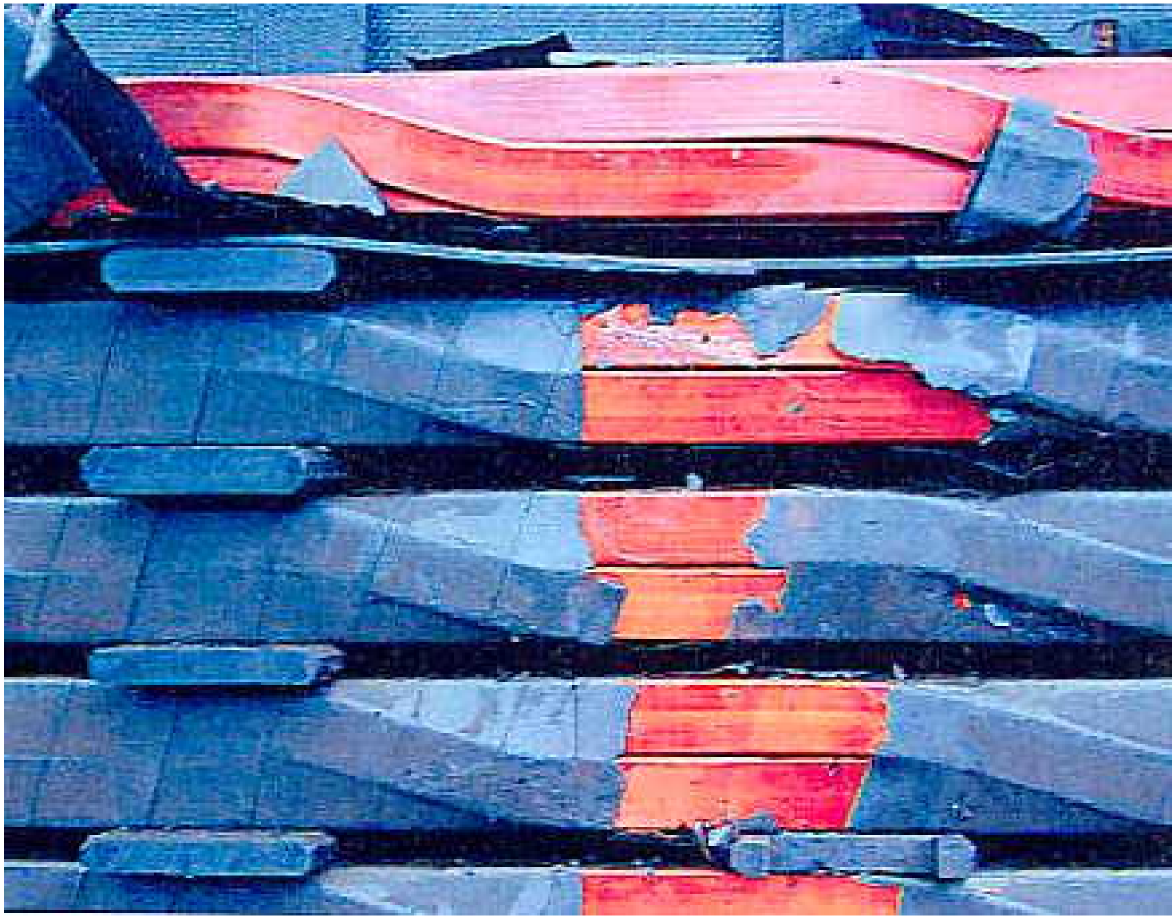
This transformers' life is over



Tensile strength of paper <u>gone</u>, result of paper aging

Evolution of fault at weak points

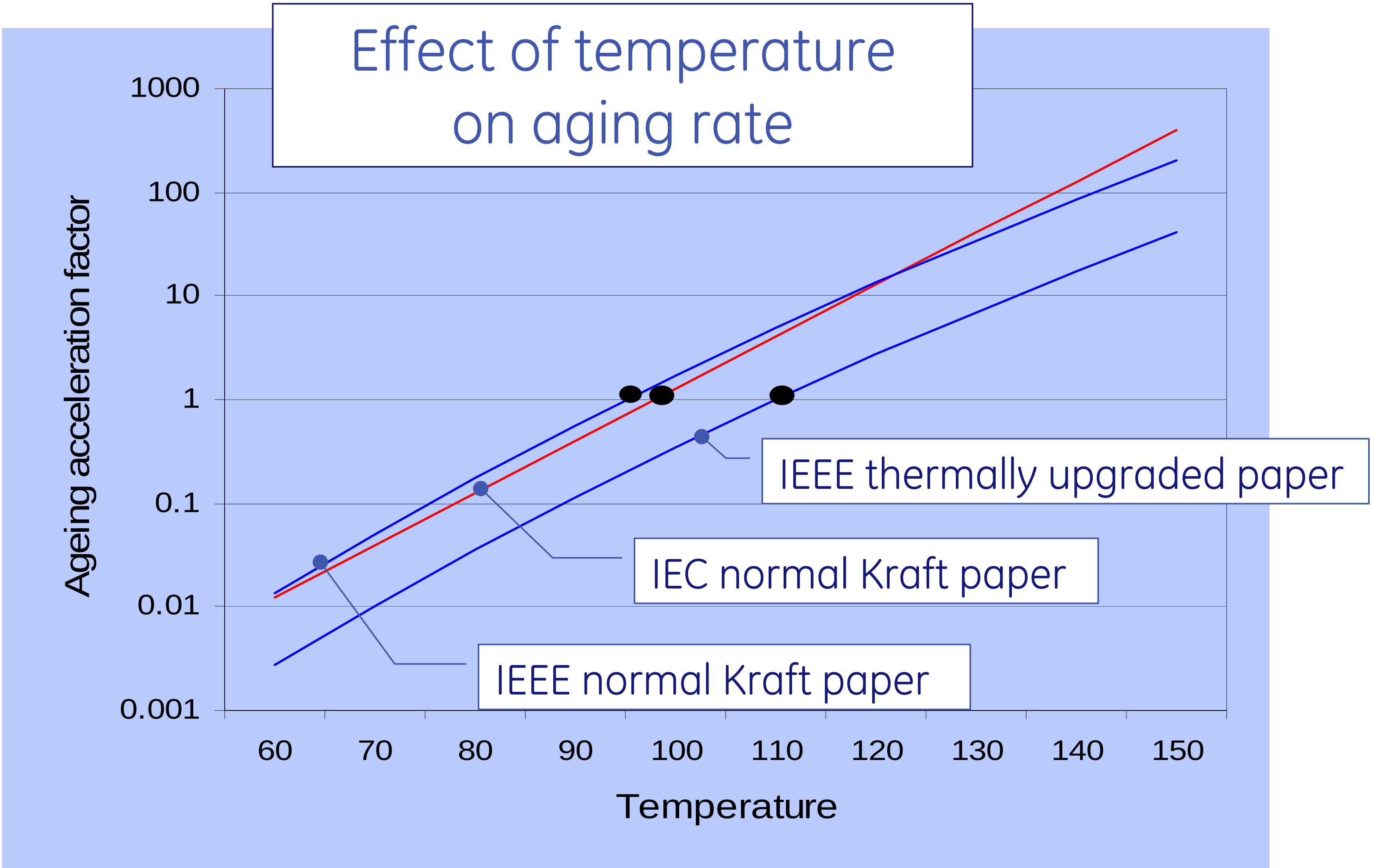
The weak points are candidates for a possible failure



V. Sokolov Cigre Colloquium 1997

imagination at work

Insulation aging



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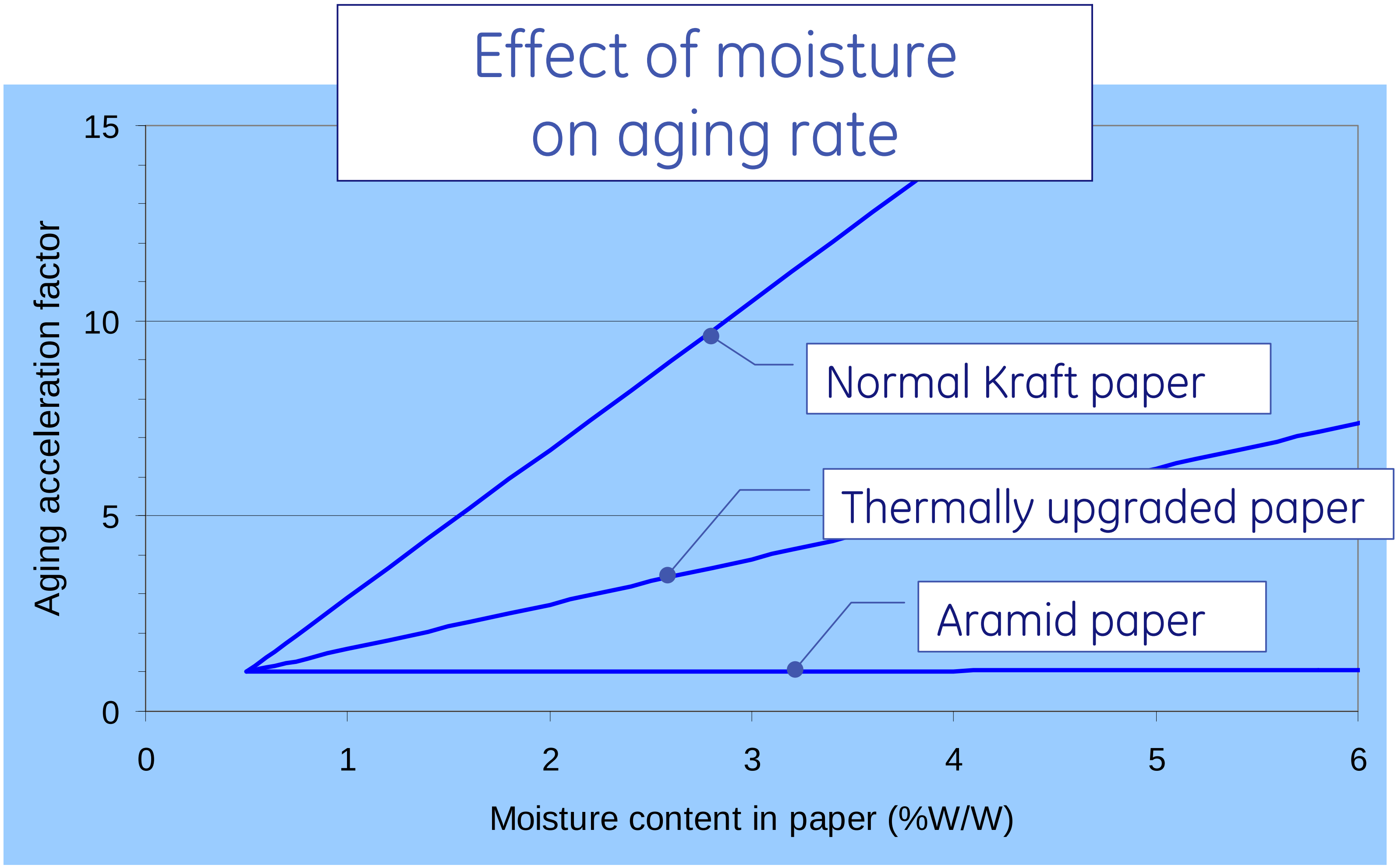
Insulation aging



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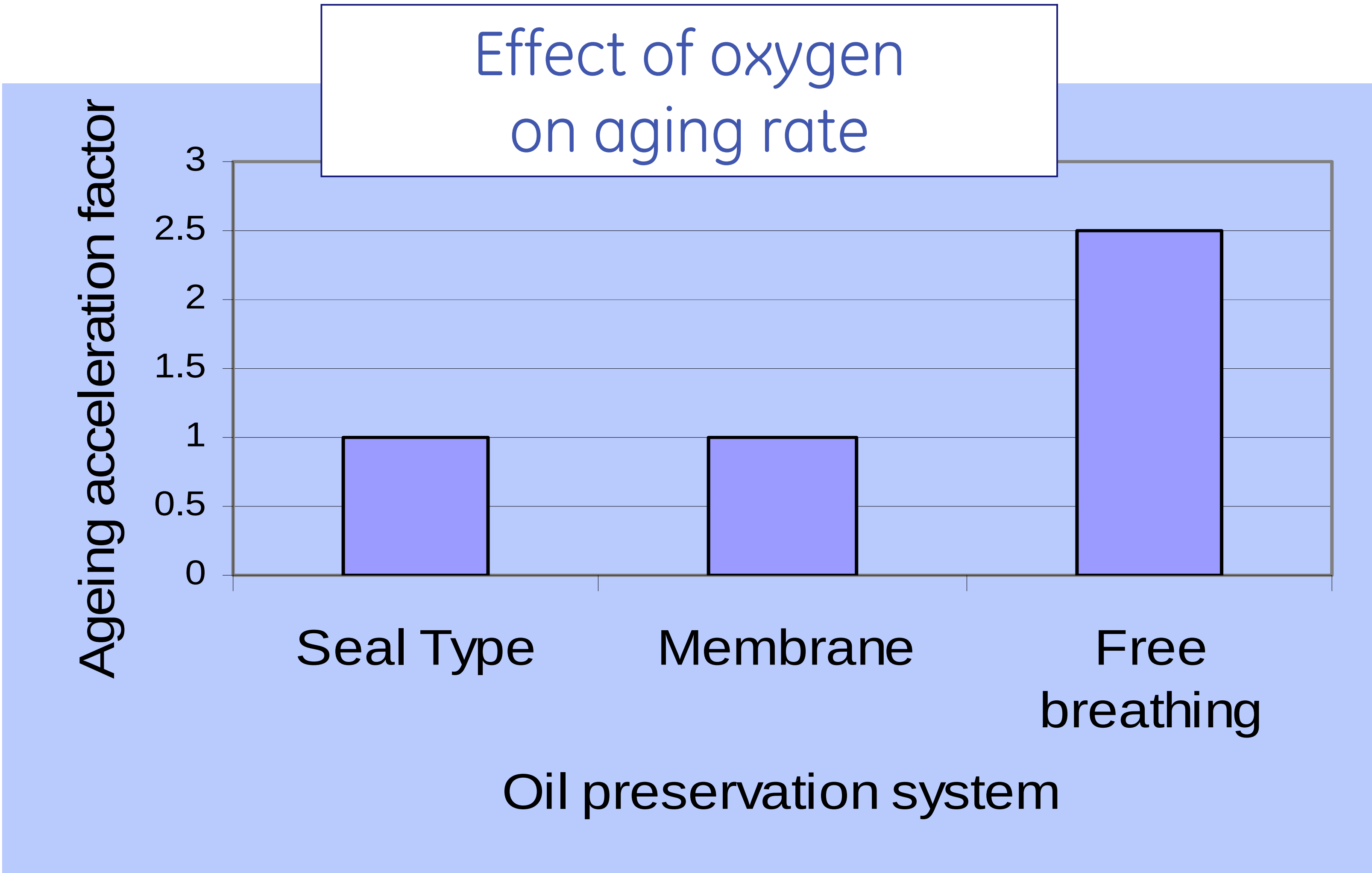
Insulation aging



Broadband monitoring technique for **On Load Tap Changer**

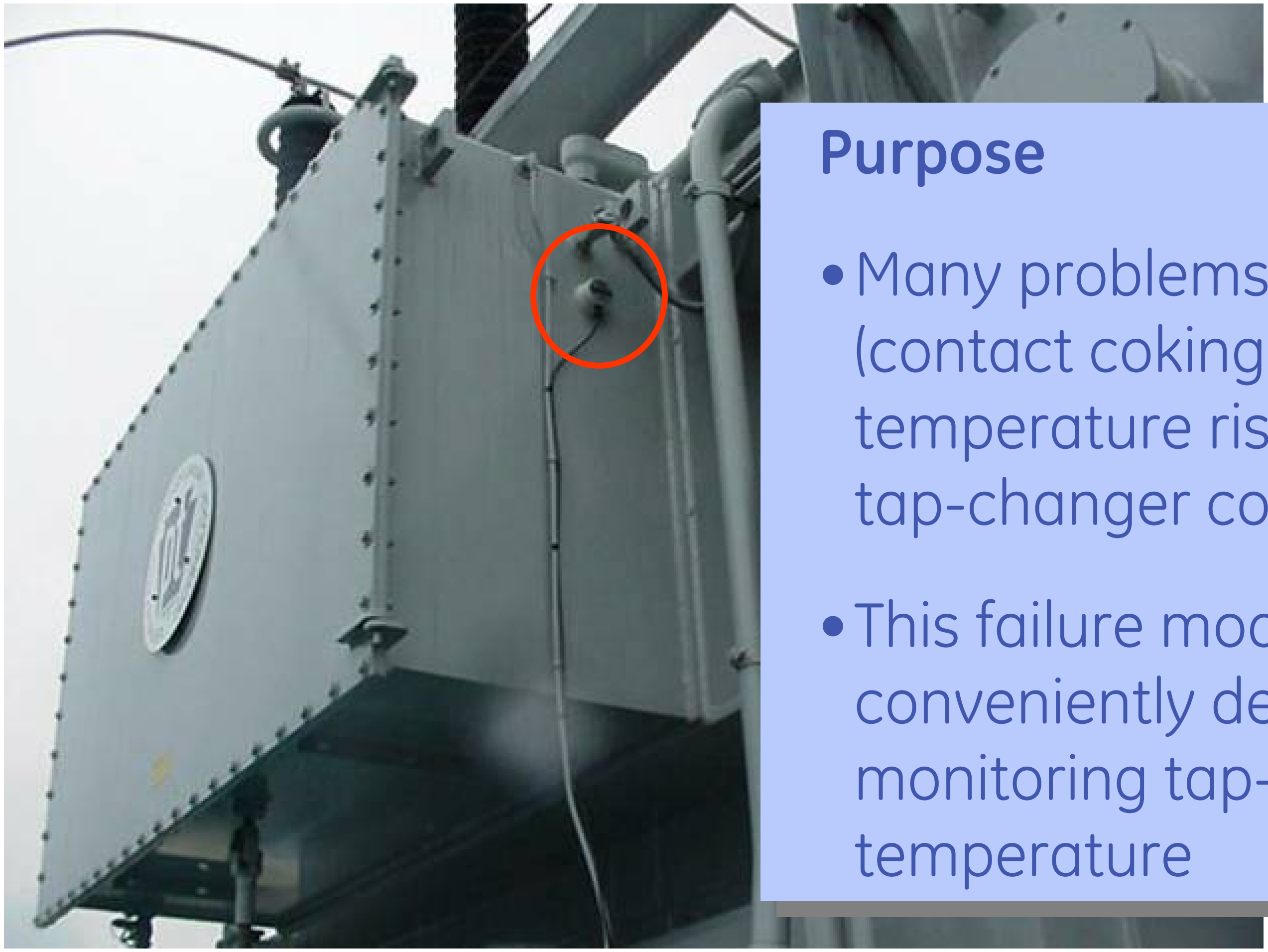
Temperature

If a contact in a tap changer degrades, it will generate heat

Abnormally high OLTC tank temperature is a good indicator of contact problem

imagination at work

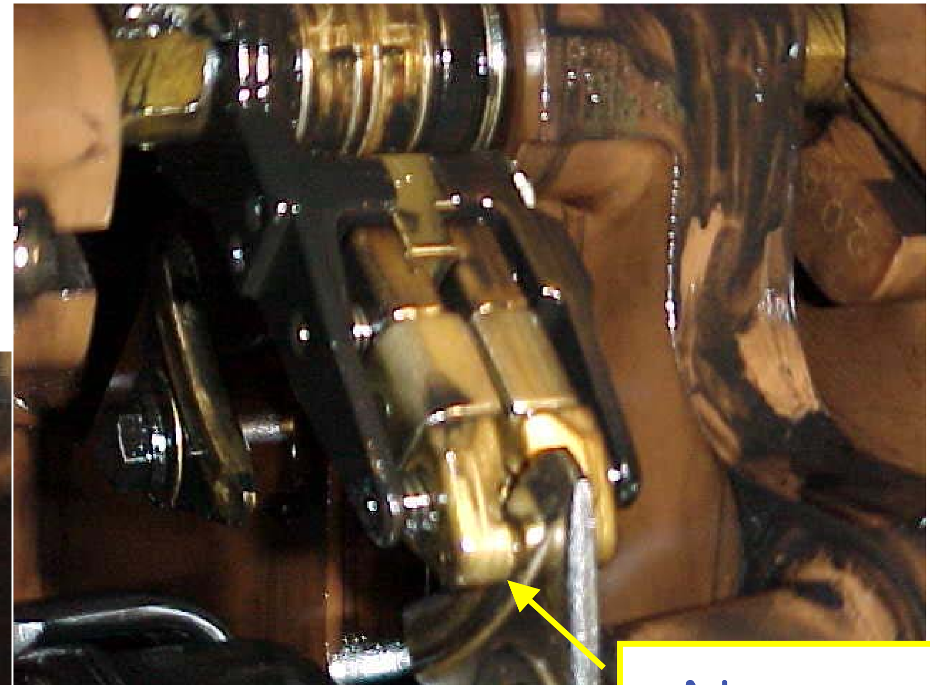
Tap changer Temperature

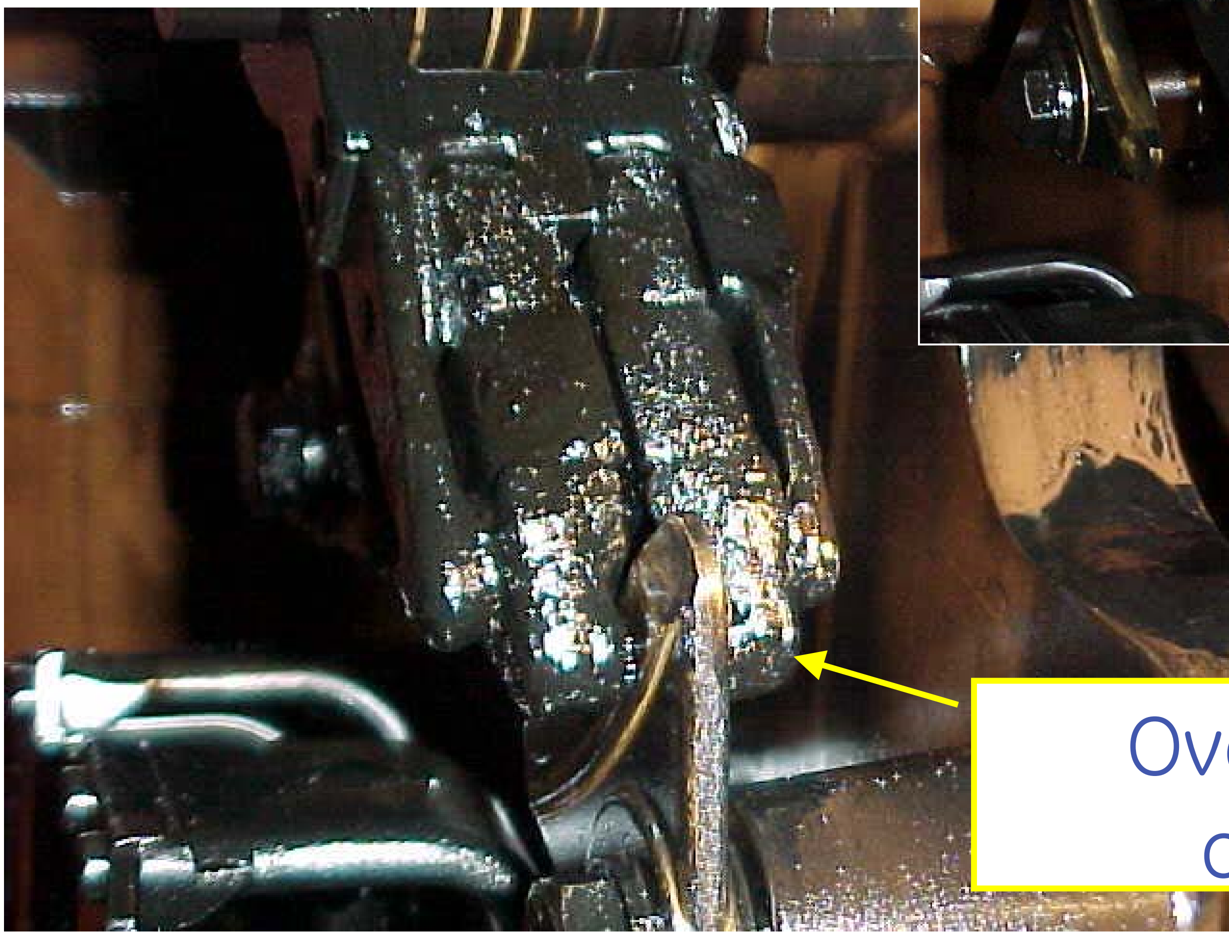


Purpose

- Many problems with tap-changer (contact coking) lead to temperature rise in the tap-changer compartment.
- This failure mode can be conveniently detected by monitoring tap-changer temperature

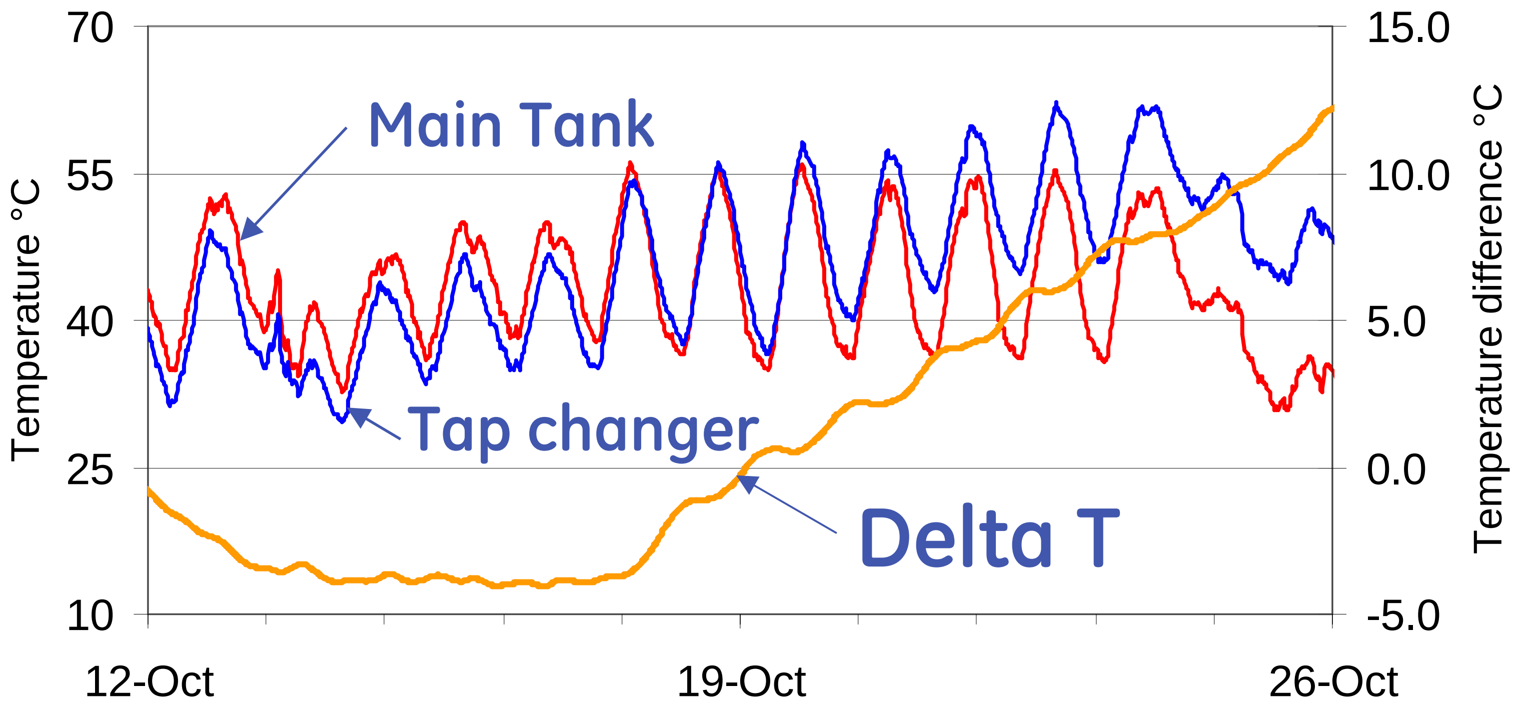
Overheating of reversing switch contacts





Tap changer Temperature Model

Example of default detection on overheating tap changer



Broadband monitoring technique for **On Load Tap Changer**

<u>Tap position & reversing switch operation tracking</u>

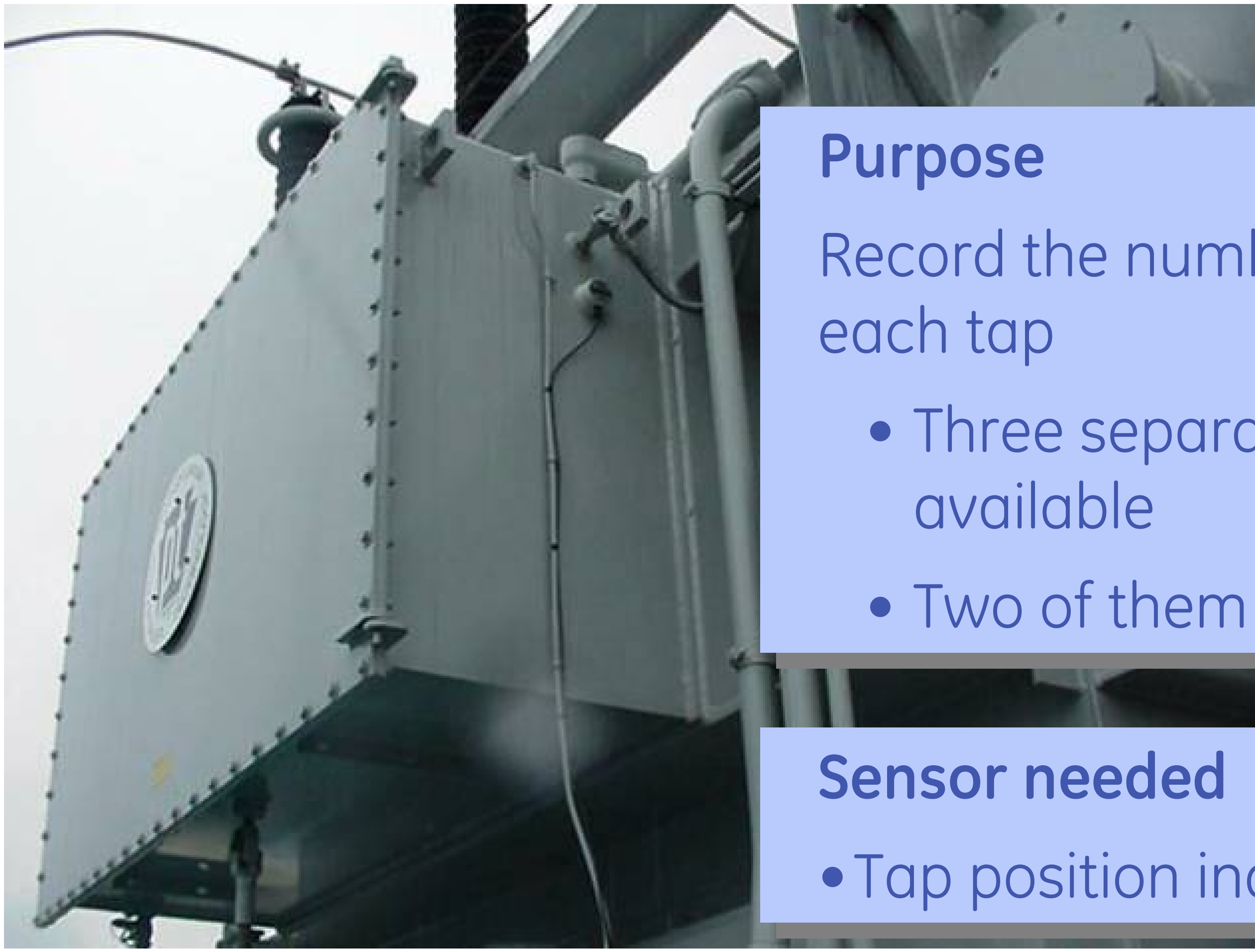
Several problems could cause an OLTC to operate too often, not often enough or in an unbalanced mode

A reversing switch that does not operate regularly will develop contact problem

OLTC Maintenance is governed by the number of operations

Tap position tracking allow the detection of several type of abnormal operation and good planning of maintenance

Tap Changer Position Tracking



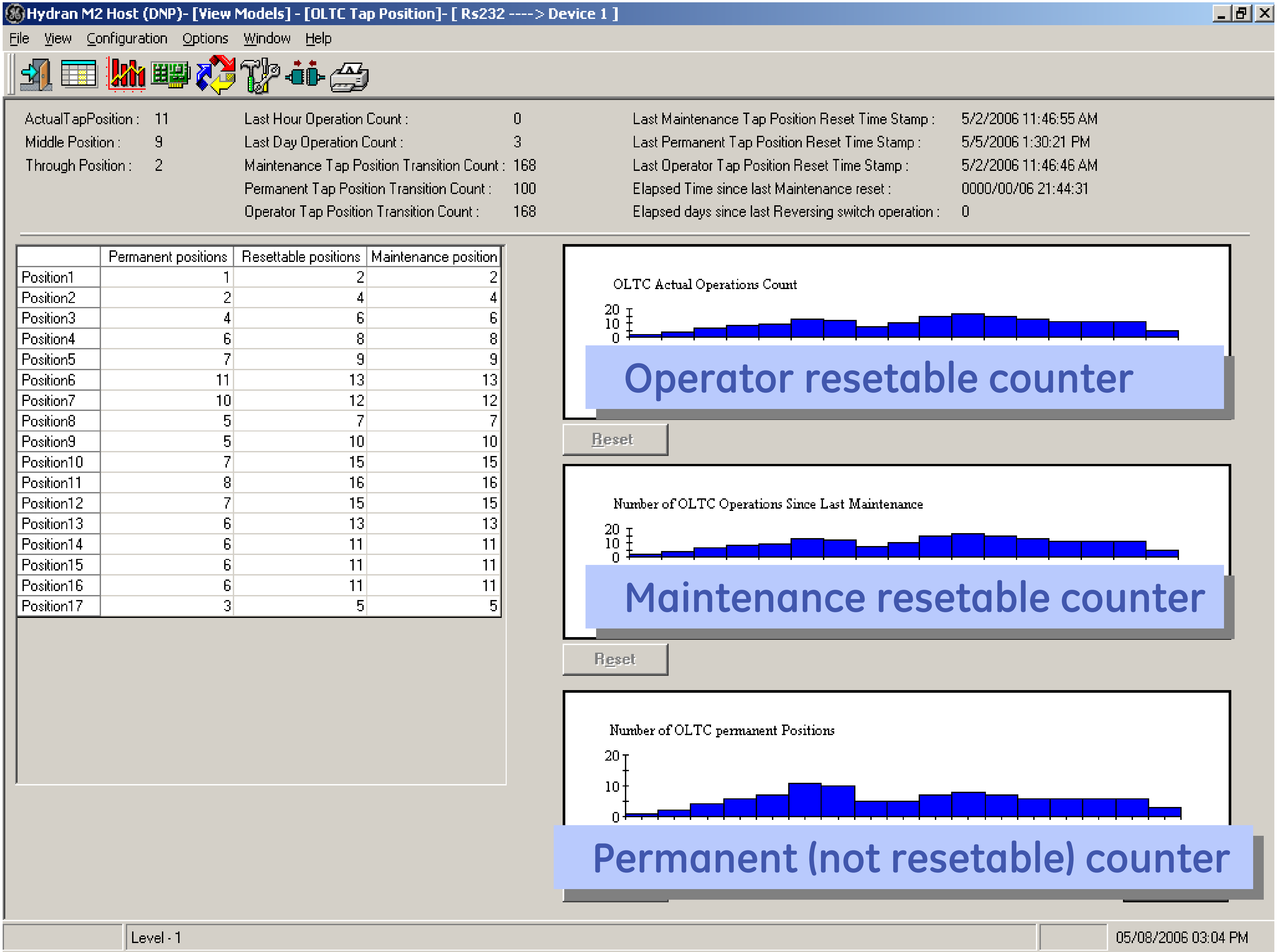
Purpose

Record the number of operations on each tap

- Three separate counters are available
- Two of them are resettable

Sensor needed

- Tap position indicator



	Permanent positions	Resettable positions	Maintenance position
Position1	1	2	2
Position2	2	4	4
Position3	4	6	6
Position4	6	8	8
Position5	7	9	9
Position6	11	13	13
Position7	10	12	12
Position8	5	7	7
Position9	5	10	10
Position10	7	15	15
Position11	8	16	16
Position12	7	15	15
Position13	6	13	13
Position14	6	11	11
Position15	6	11	11
Position16	6	11	11
Position17	3	5	5

Broadband monitoring technique for **On Load Tap Changer**

Gas-in-oil

Some type of OLTC do generate gases in “normal” operation, but most of the newer type, called “vacuum bottle” type do not, as well as the one installed inside the main transformer tank

For these type of OLTC, gas-in-oil could be used to track some of their problems

Broadband monitoring technique for **Cooling system**

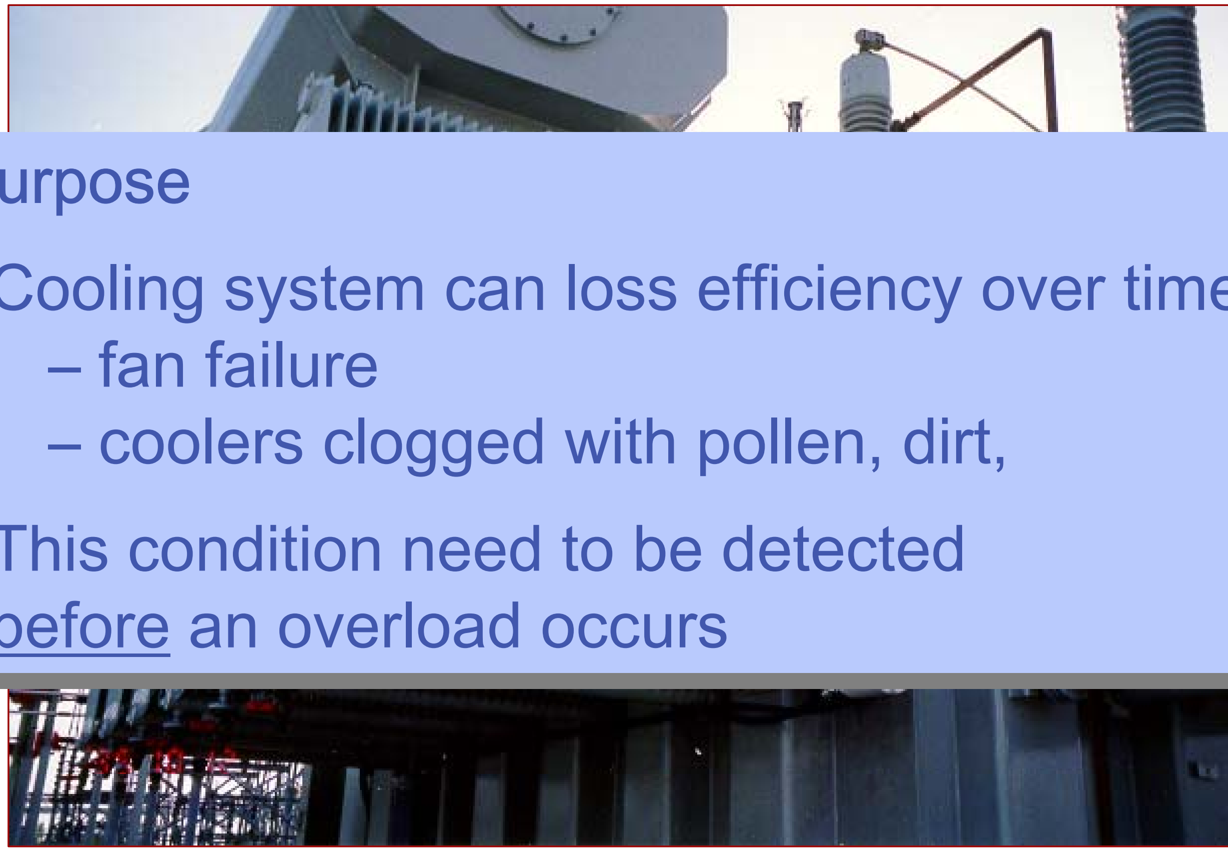
Top Oil temperature

Top oil temperature is a function of load, ambient temperature and cooling mode.

Inefficient, or defective, cooling system will result in higher top oil temperature.

Top oil temperature is a good indicator of cooling bank problems, especially when it is compared to the theoretical value obtained by on-line computation

Cooling Efficiency



Purpose

- Cooling system can loss efficiency over time:
  - fan failure
  - coolers clogged with pollen, dirt,
- This condition need to be detected before an overload occurs

Computation logic for cooling efficiency

Ultimate Top-Oil

Calculate top oil temperature considering:

- Load, ambient temperature, cooling mode, oil time constant
- Transformer characteristics

Top-Oil Actual Time Constant $\tau_{TO} = \tau_{TOR}$

Compare with actual top oil temperature

Calculated Top-Oil Temperature Rise at Time t

Raise alarm if transformer is running warmer than it should

Actual Top-Oil Te

Cooling System Alarm Condition $\Theta_{Alarm} = 1;\ f\left(\left(\overline{\overline{\Theta}}_{TO} - \Theta_{TOCt}\right) \rangle SP_{TOC}\right)$

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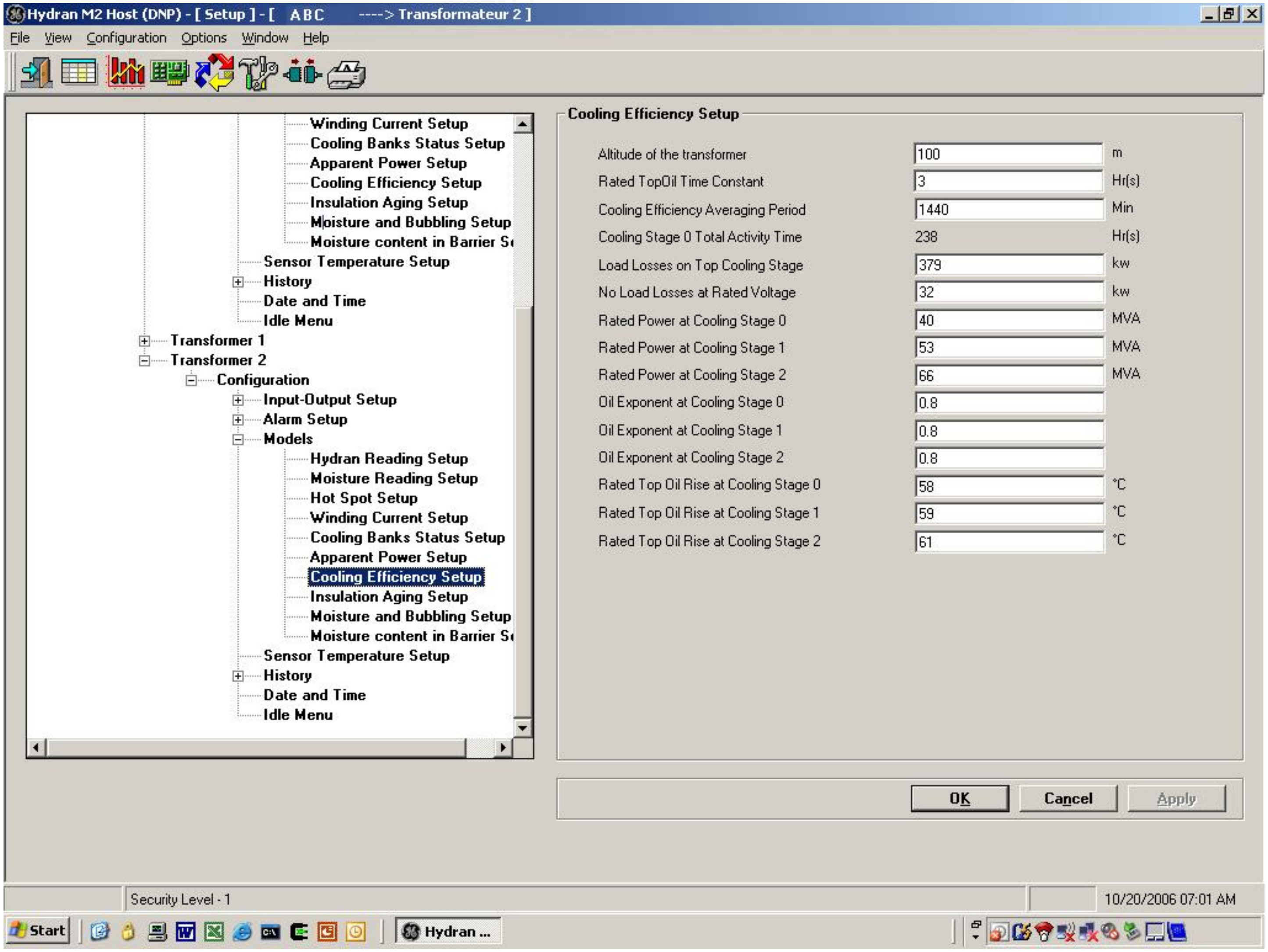
Transformer Data needed for cooling efficiency model



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Broadband monitoring technique for **Cooling system**

Pumps/Fans activity tracking

Pump and fans operation is governed by the winding hot spot temperature

Monitoring pumps/fans activity, in conjunction with windings temperature, is a good manner to detect defective cooling system control at an early stage

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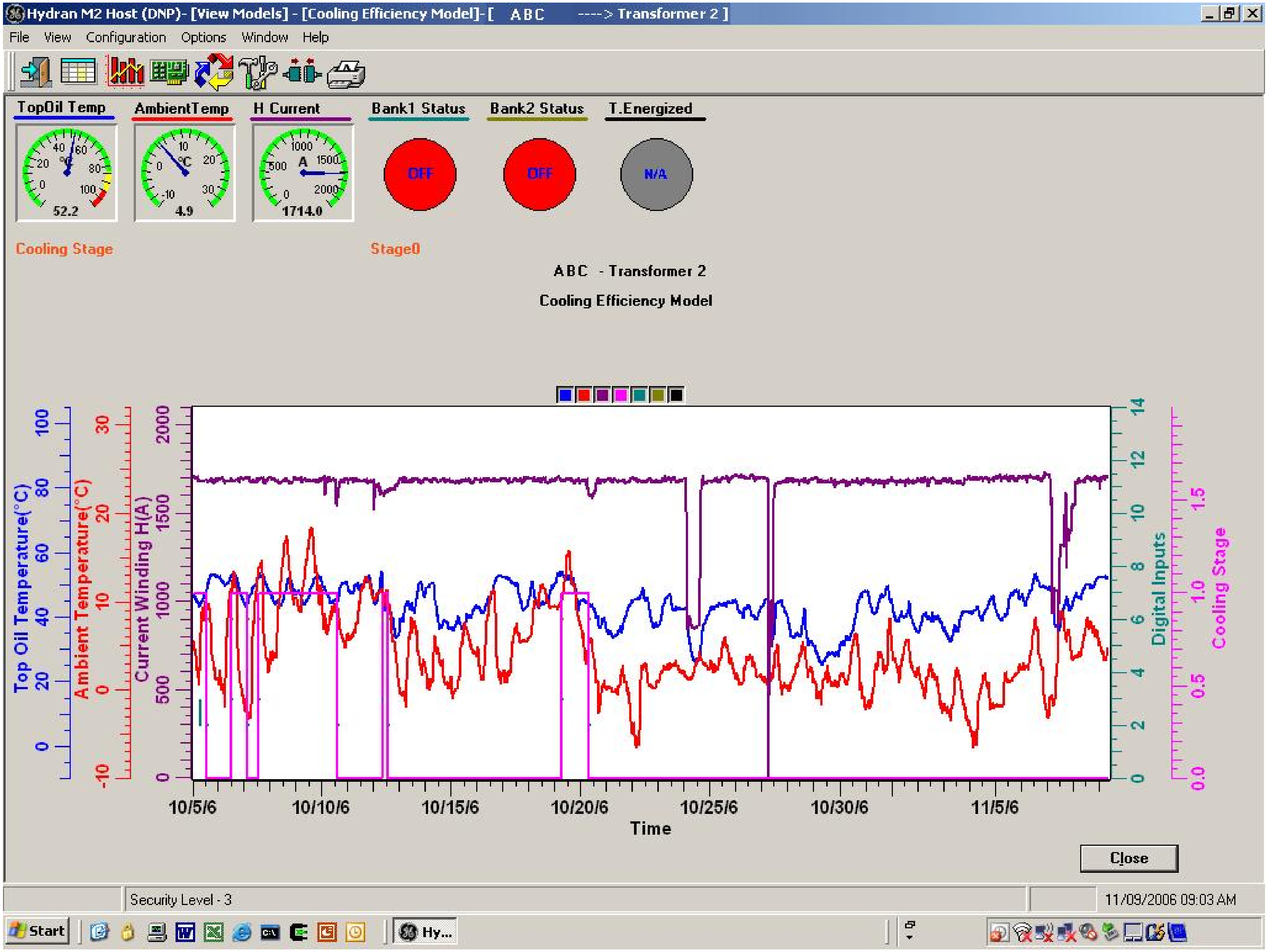
Cooling Status

•Hydran/Intellix Monitoring system can provide information on cooling bank cumulative duty

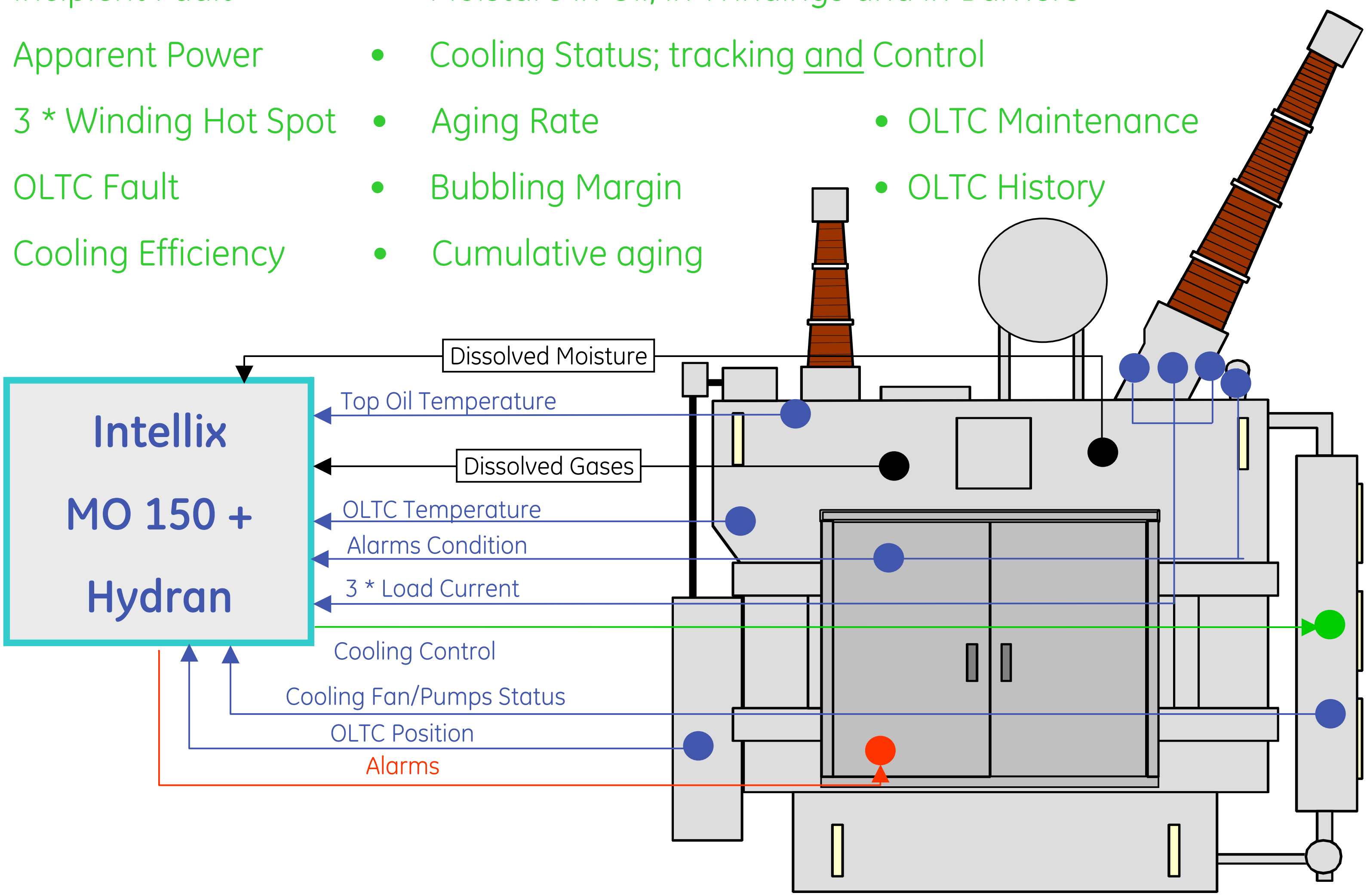

Hydran M2 Host (DNP)- [View Models] - [Cooling Efficiency Model]-[ABC ----> Transformer 2]
File View Configuration Options Window Help
TopOil Temp
AmbientTemp
H Current
Bank1 Status
Bank2 Status
T.Energized
52.2
4.9
1714.0
OFF
OFF
N/A
Cooling Stage
Stage0
ABC - Transformer 2
Cooling Efficiency Model
Top Oil Temperature(°C)
Ambient Temperature(°C)
Current Winding H(A)
Digital Inputs
Cooling Stage
10/5/6
10/10/6
10/15/6
10/20/6
10/25/6
10/30/6
11/5/6
Time
Close
Security Level - 3
11/09/2006 09:03 AM
Start

What about Cooling Control?

•Intellix MO150 Monitoring system can provide intelligent cooling control

The Intellix MO150 Advanced Transformer Monitor

- Incipient Fault
- Apparent Power
- 3 * Winding Hot Spot
- OLTC Fault
- Cooling Efficiency
- Moisture in Oil, in Windings and in Barriers
- Cooling Status; tracking and Control
- Aging Rate
- Bubbling Margin
- Cumulative aging
- OLTC Maintenance
- OLTC History



Intellix MO150

A reliable and cost effective approach for transformer monitoring and management

Intellix MO150

State of the art models On-Line Transformer Models

- Winding (Hot-spot) Temperature model on 3 Windings
- Cooling Status & Control model
- OLTC Thermal model
- OLTC Position model
- Apparent Power (MVA) model
- Insulation Aging model
- Moisture and Bubbling model
- Cooling Efficiency model

Models Matrix

	Analog Input											Digital Input		
	Hydran gas level (ppm)	Relative Humidity (%RH)	Sensor Temperature (°C)	Top Oil Temperature (°C)	Load Current Winding H (A)	Load Current Winding X (A)	Load Current Winding Y (A)	OLTC Tap Position	OLTC Tank Temperature (°C)	Ambient Temperature (°C)	Bottom Oil Temperature (°C)	Status of Coding bank #1	Status of Coding bank #2	Transfomer Energized
Transformer Insulation Models														
Winding H Apparent Power					X									
Winding H Apparent Power						X								
Winding H Apparent Power							X							
Winding H Hot-Spot Temperature				X	X									
Winding X Hot-Spot Temperature				X		X								
Winding Y Hot-Spot Temperature				X			X							
Insulation Aging		X	X	X	X									
Water-Oil Condensation Temperature		X	X	X	X									
Moisture Content in Winding Paper		X	X	X	X									
Winding Bubbling Temperature		X	X	X	X									
Winding Bubbling Temperature Margin		X	X	X	X									
Moisture Content in Insulating Barrier		X	X								X	(X)	(X)	
Cooling System Models														
Cooling System Status												X	X	
Cooling System Control				(X)	(X)	(X)	(X)					X	X	
Cumulative Operation Time												X	X	
Cooling Efficiency				X	X					X		X	X	(X)
Tap Changer Models														
OLTC Tap Position Tracking								X						
OLTC Temperature Differential				X					X					

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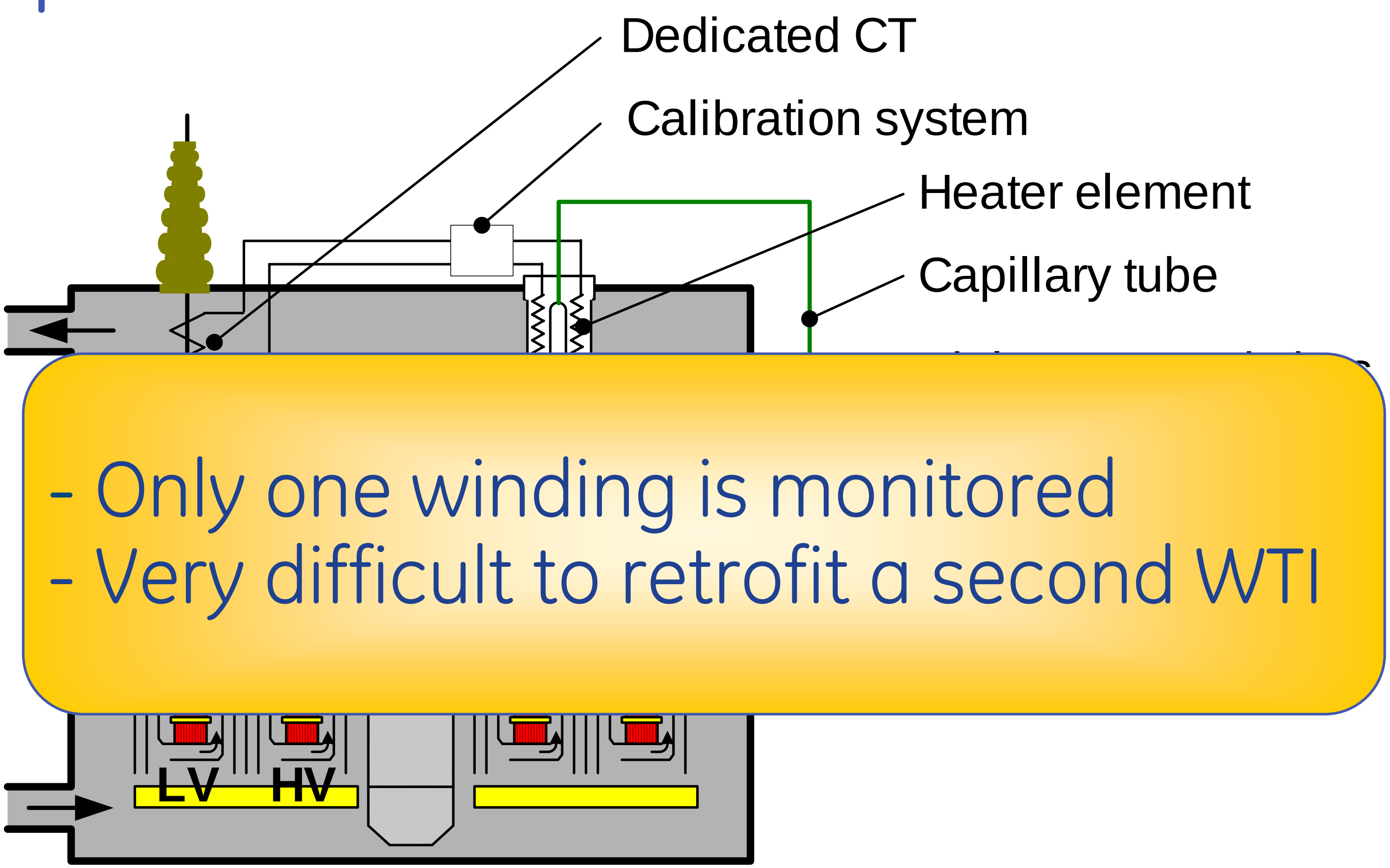
Specialized control technique for **Transformer**

Cooling bank control

Proper cooling bank operation is essential for the proper operation of the transformer.

The use of models, allow for advance control and monitoring dedicated to the cooling bank operation

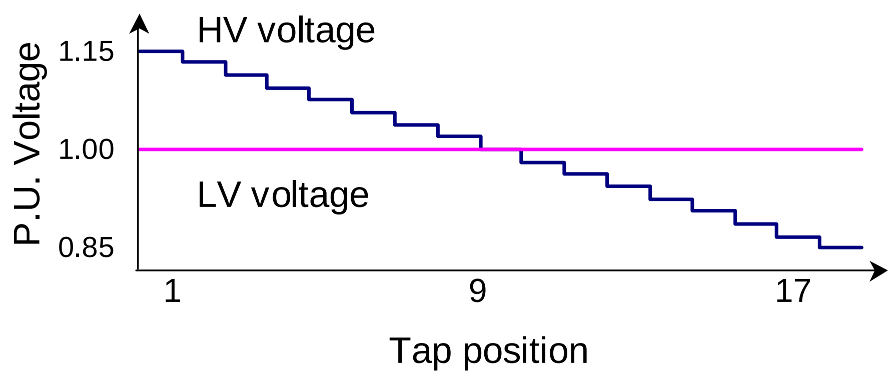
Limitations of traditional winding temperature indicator

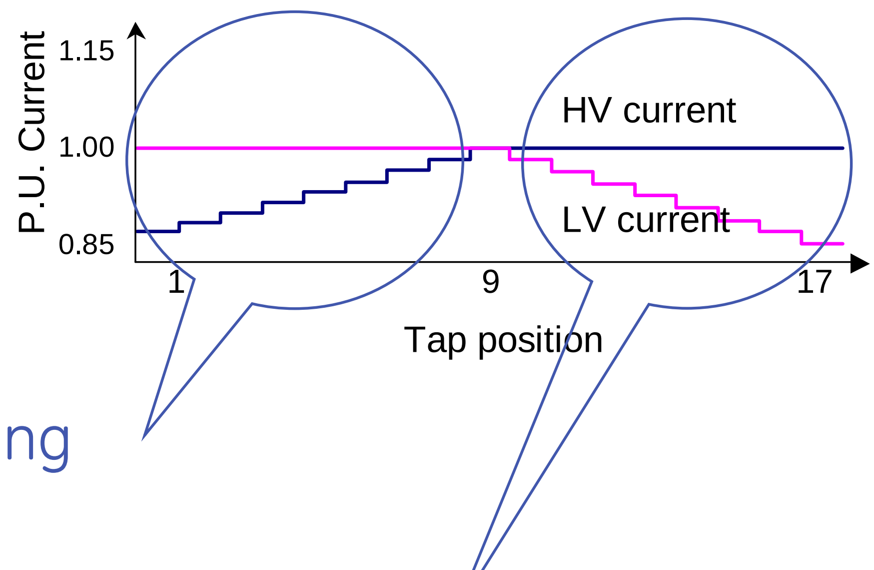


- Only one winding is monitored
- Very difficult to retrofit a second WTI

Utility concern

A majority of transformers with tap changers have reduced capacity on some taps



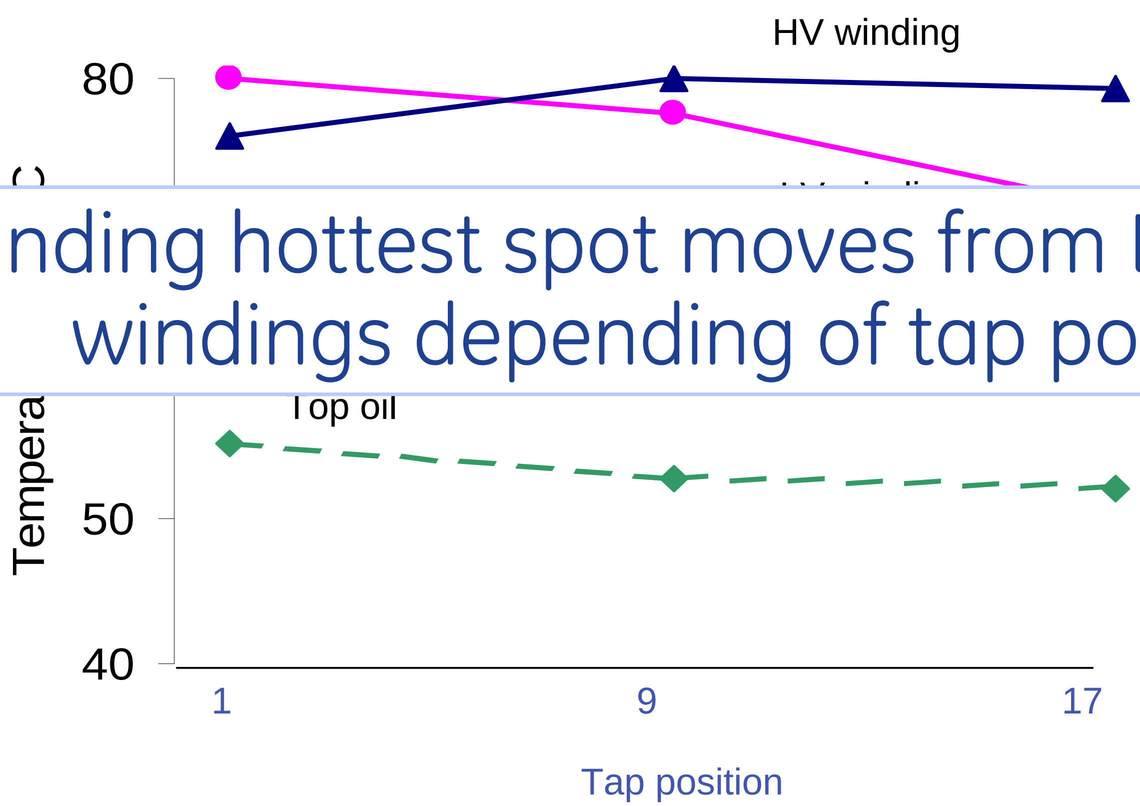


On taps 1 to 9 current in HV winding is lower than rated HV current

On taps 9 to 17 current in LV winding is lower than rated LV current

Utility concern

The winding being monitored may not be the hottest one



Winding hottest spot moves from LV to HV windings depending of tap position

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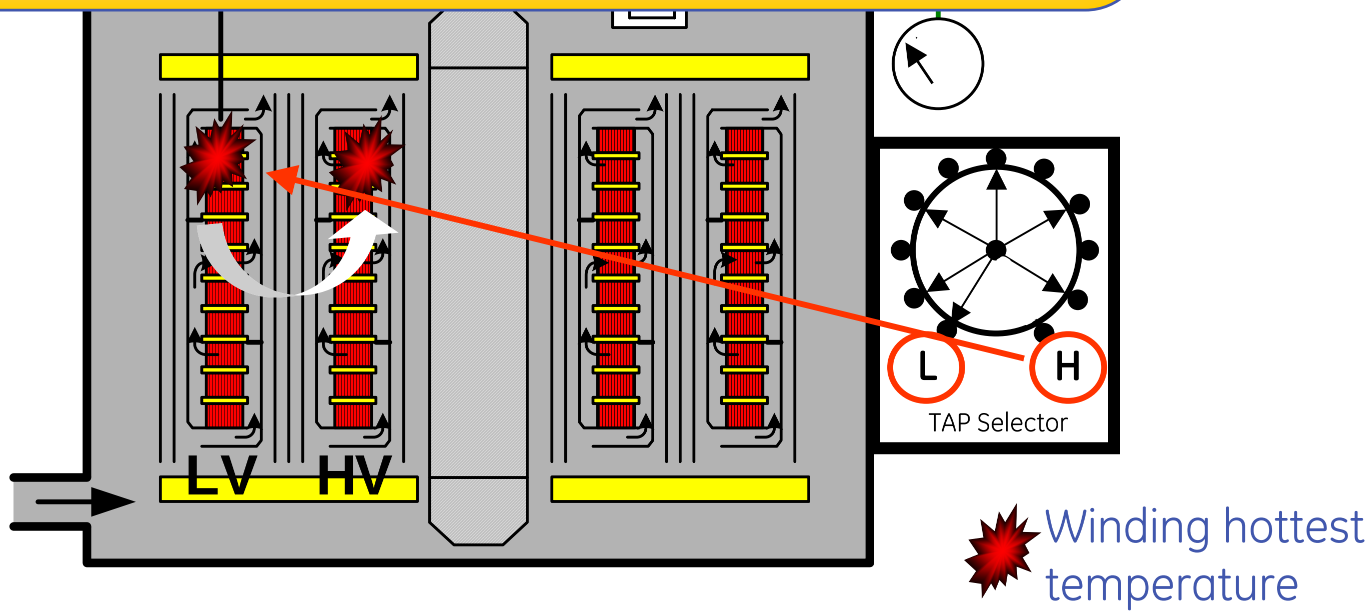
Moving winding hottest spot

Depending on tap position winding hottest spot moves from LV to HV and vice versa



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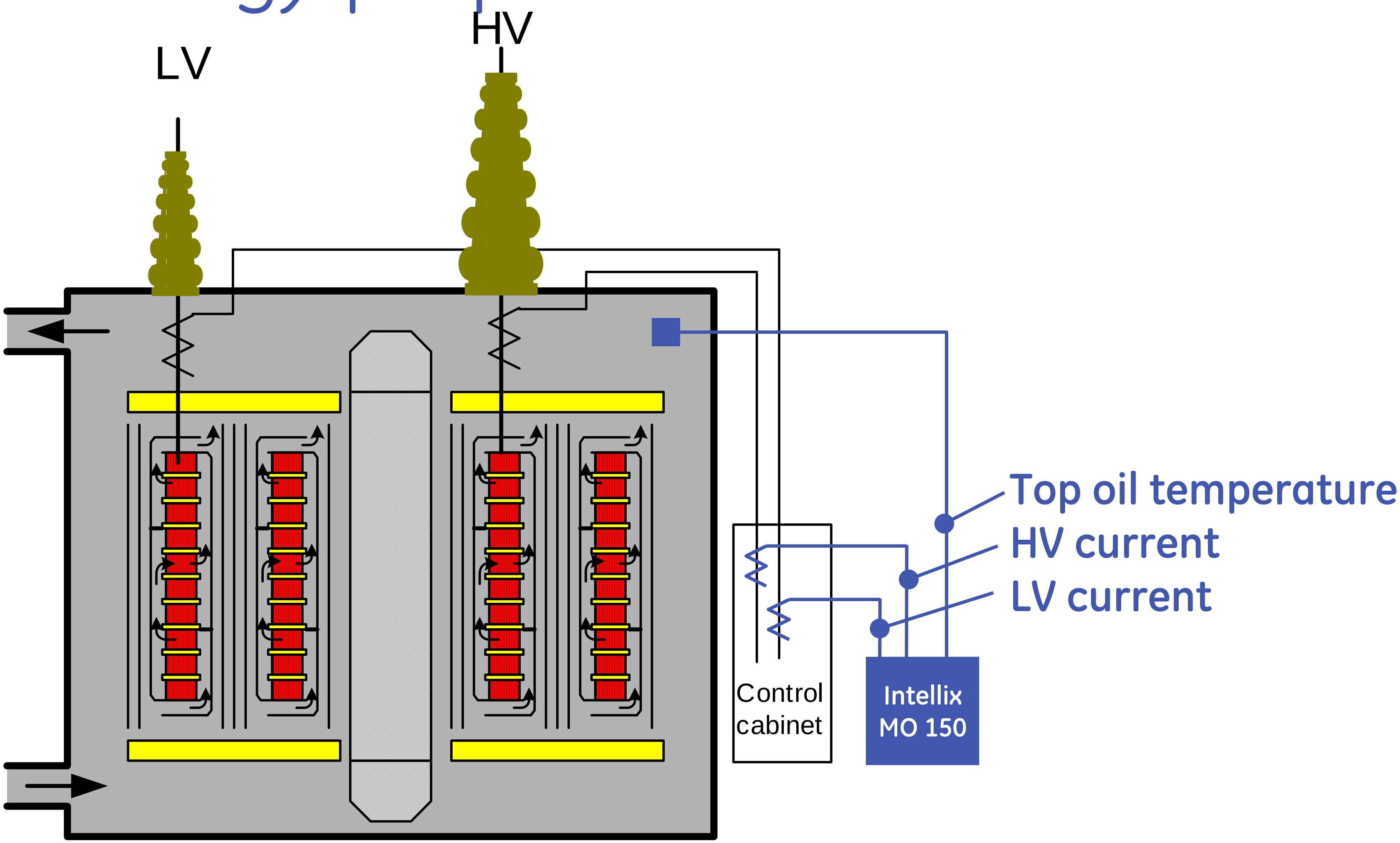
GE Energy proposed solution



Non-intrusive sensors

Specialized control technique for **Transformer**

Cooling bank control

Inputs of;

- Top Oil temperature
- Load current, minimum 1 phase of each winding up to 3 windings
- Compute winding hotspot temperature for all windings where load is measured

Specialized control technique for **Transformer**

Cooling bank control

Each stage of cooling now started by “OR” function

Set point for either:

- Top Oil temperature
- Winding hotspot temperature
- Load current

Specialized control technique for **Transformer**

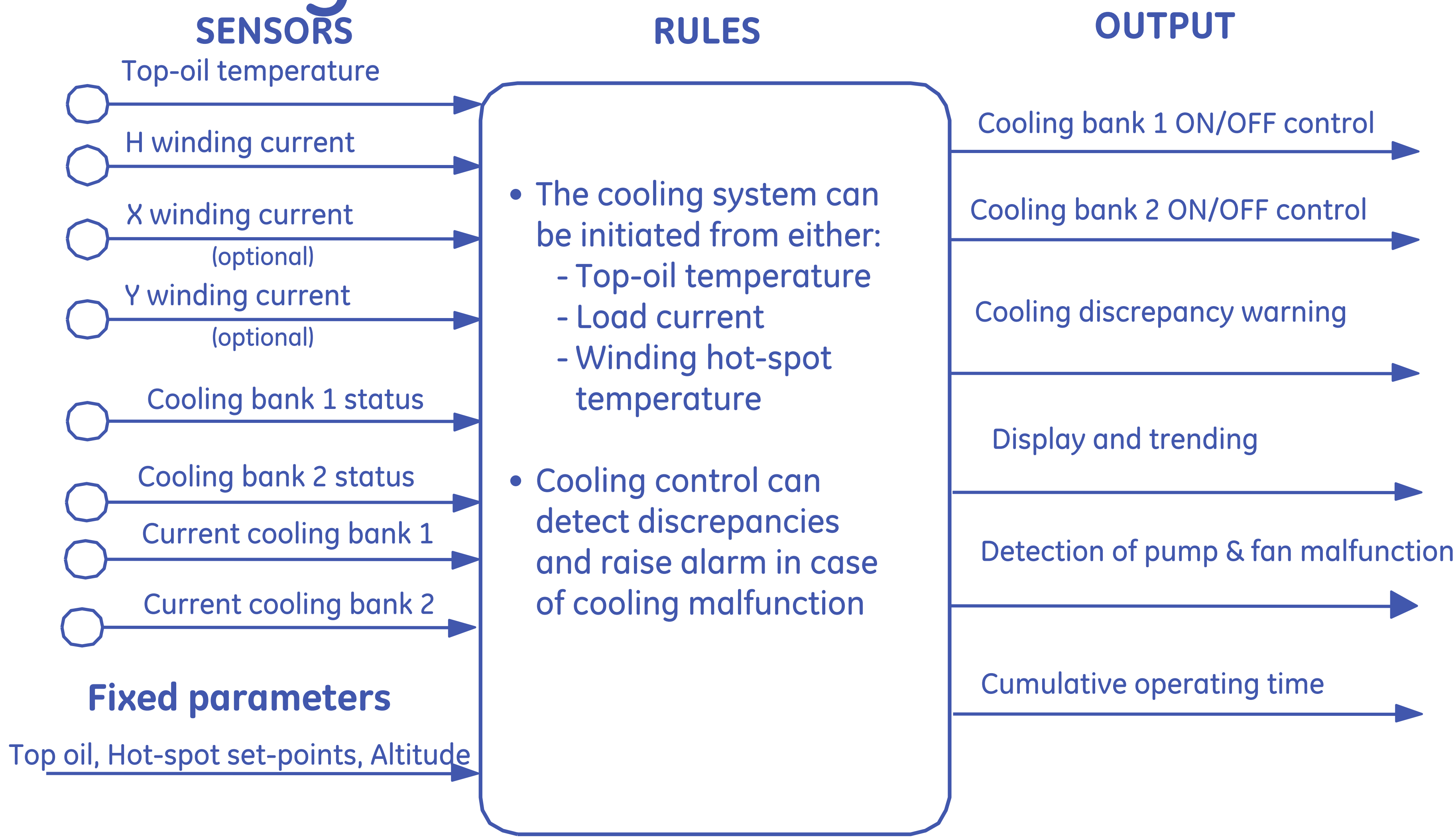
<u>Cooling bank control</u>

Each stage of cooling now turned OFF by “AND” function (ALL must be lower than set point)

Set point for:

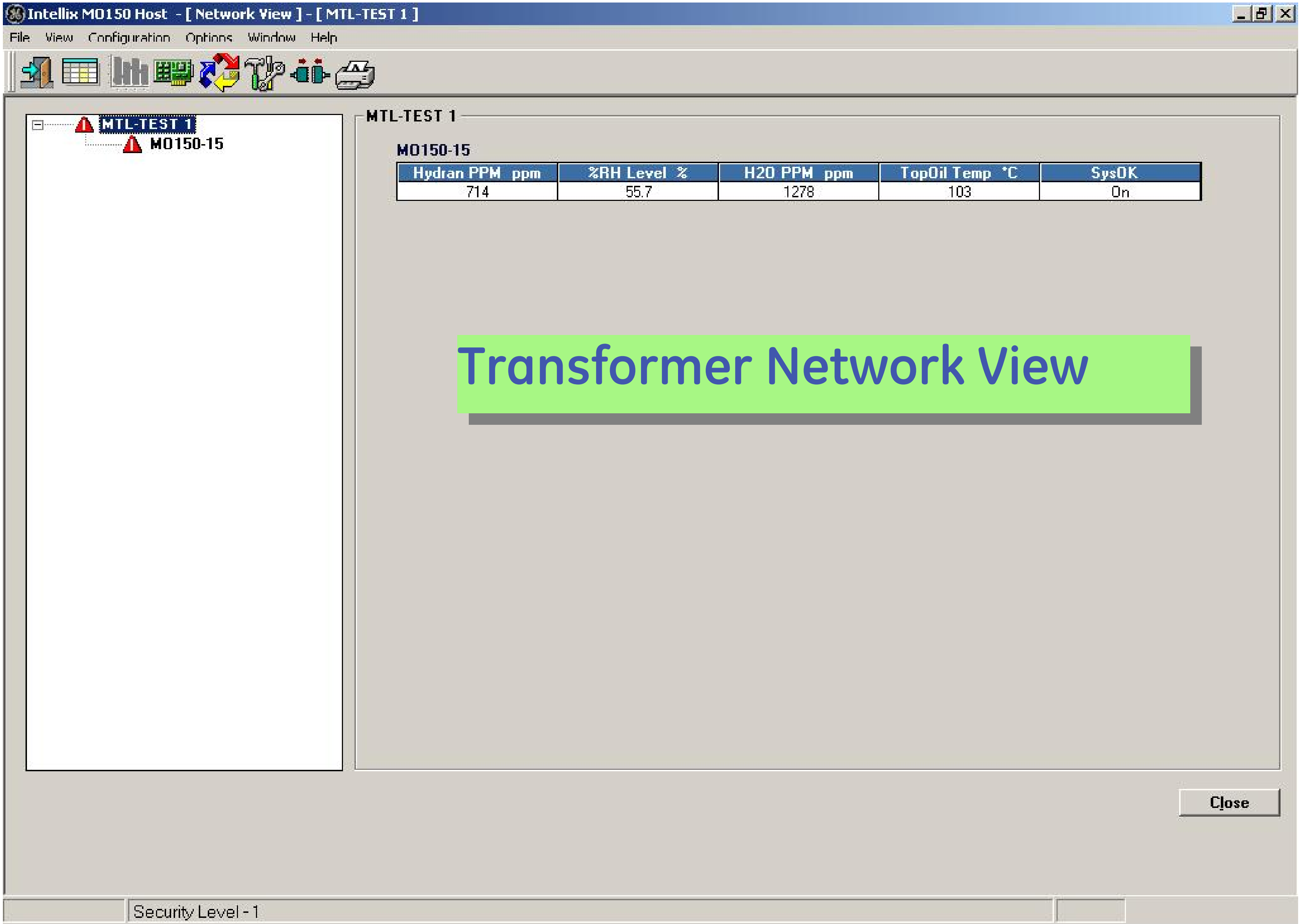
- Top Oil temperature
- Winding hotspot temperature
- Load current

Cooling Status & Control Model



Enhancement: -cumulative operating time: -detection of malfunction: -exercising routine: -cooling control the rated current is adjusted to altitude

Transformer Network View



Intellix MO150 - Features

- Microprocessor based
- Self-diagnostic features
- Self-test twice a month
- Complete fail-safe cooling control relays
- System fail contact
- Sensor problem detection by advance process of comparing readings
- Universal switching power supply
- DNP3 protocol
- Can be installed directly on the transformer

Intellix MO150 - Features

Memory Storage

- More than 100 days of short term logs (every 15 mins)
  - Top oil, ambient and WHSP temperatures
  - H, Y and X winding currents
  - Status of the cooling system
- More than 3700 historical alarms and events
- More than 4900 service logs (once a day at midnight)
  - Same as short-term(above) plus cooling banks running time

Intellix MO150 - Input & Output Layout

Qty: 8 Analog inputs (RTD or 4-20mA)

Qty: 2 Digital inputs for cooling bank status

Power Supply

Qty: 3 Load current inputs

Qty: 2 Load current for cooling Bank 1 & Bank 2

Qty: 3 Digital outputs "Alarms"

Qty: 2 Digital outputs Cooling Control

3.6V Battery

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Intellix MO150 - Communication Layout

RS 485

Internal modem card or Ethernet card

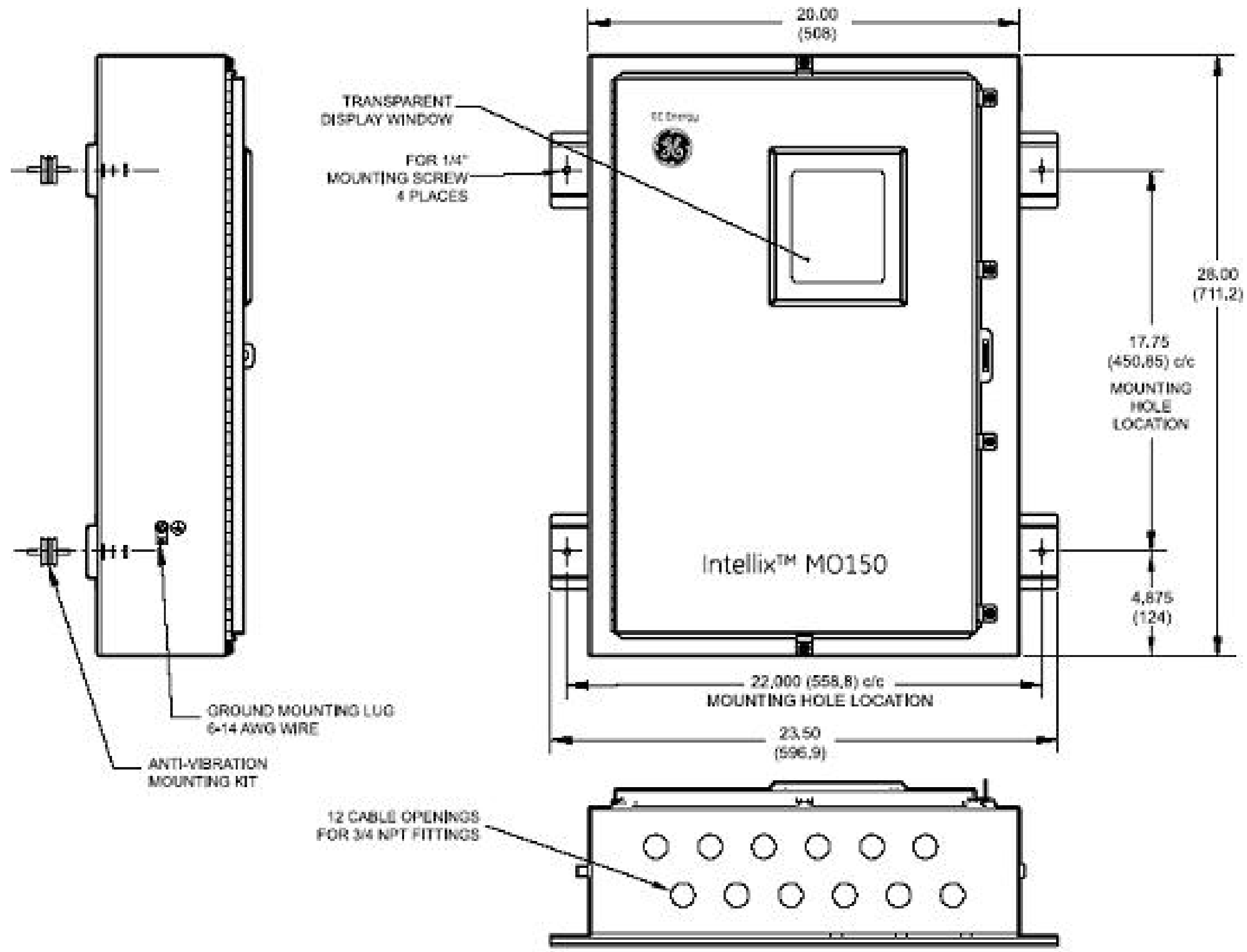
(optional) Qty: 4 extra analog outputs or inputs

Expansion (CANBUS)

RS 232

Hydran MO150

Cabinet



- Stainless steel
- Type NEMA 4X

Hydran M0150

Cabinet

Qty: 8 Analog inputs (RTD or 4-20mA)

Power Supply

UP to 3, load current inputs (H.X.Y)

RS232 for PC connection

Hydran M2150

Cabinet

Keypad for local configuration, alarm setting, data viewing Alarm Ack.

Power Supply

Back lit LCD display

Scrolling data/ calculations/alarms

RS232 for PC connection

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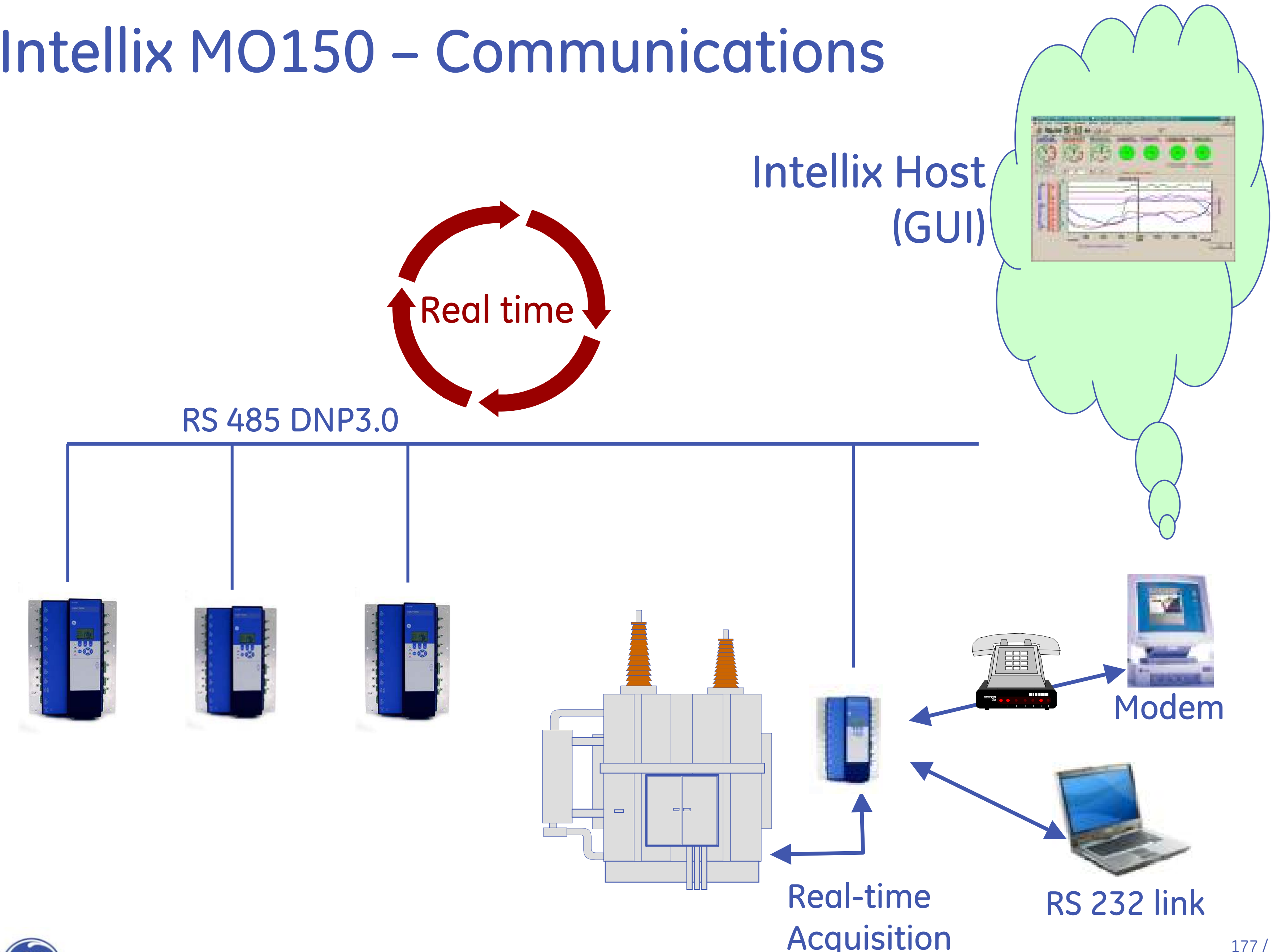
Intellix MO150 – Communications



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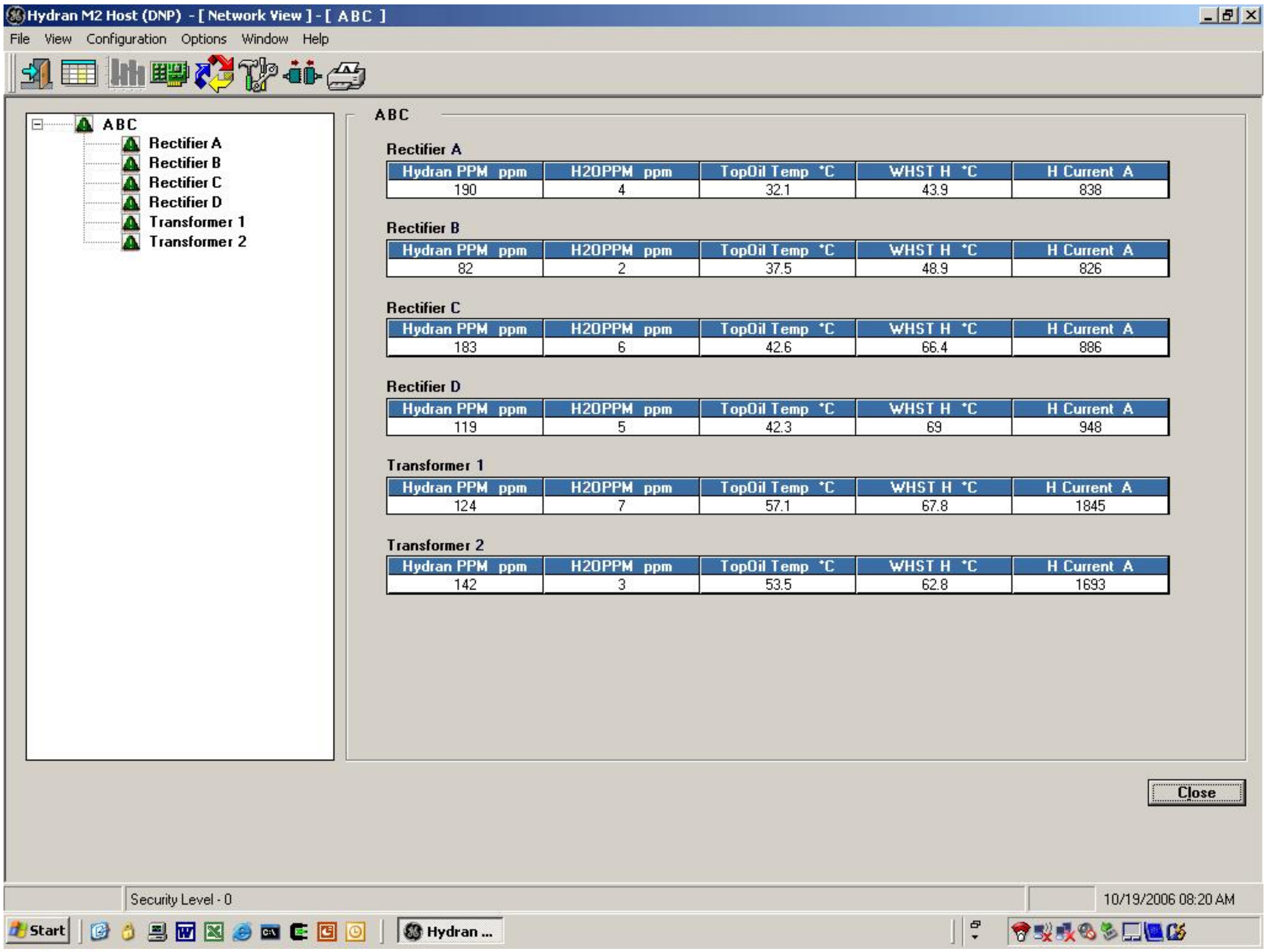
Intellix MO150 – Communications, real time survey



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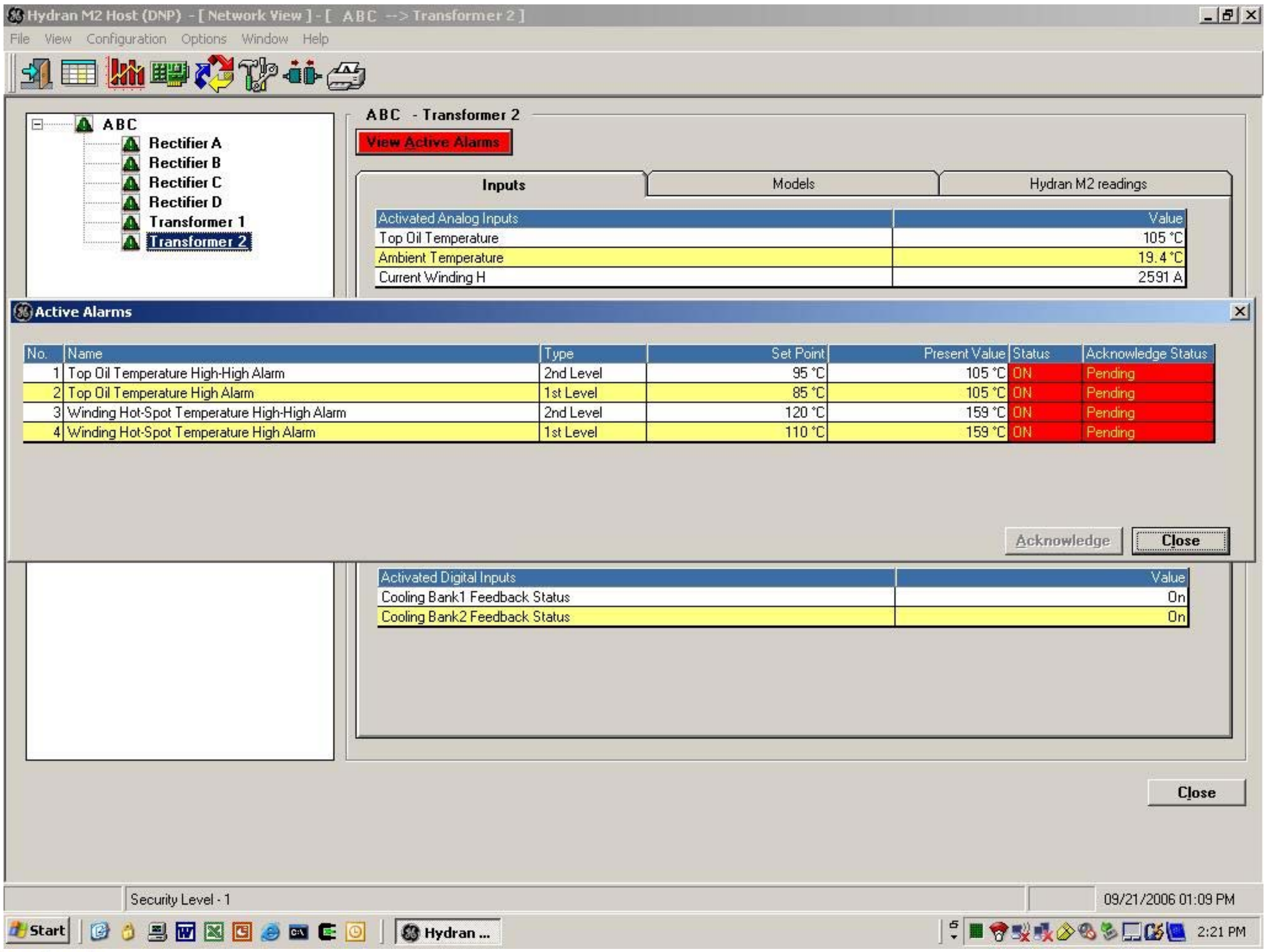
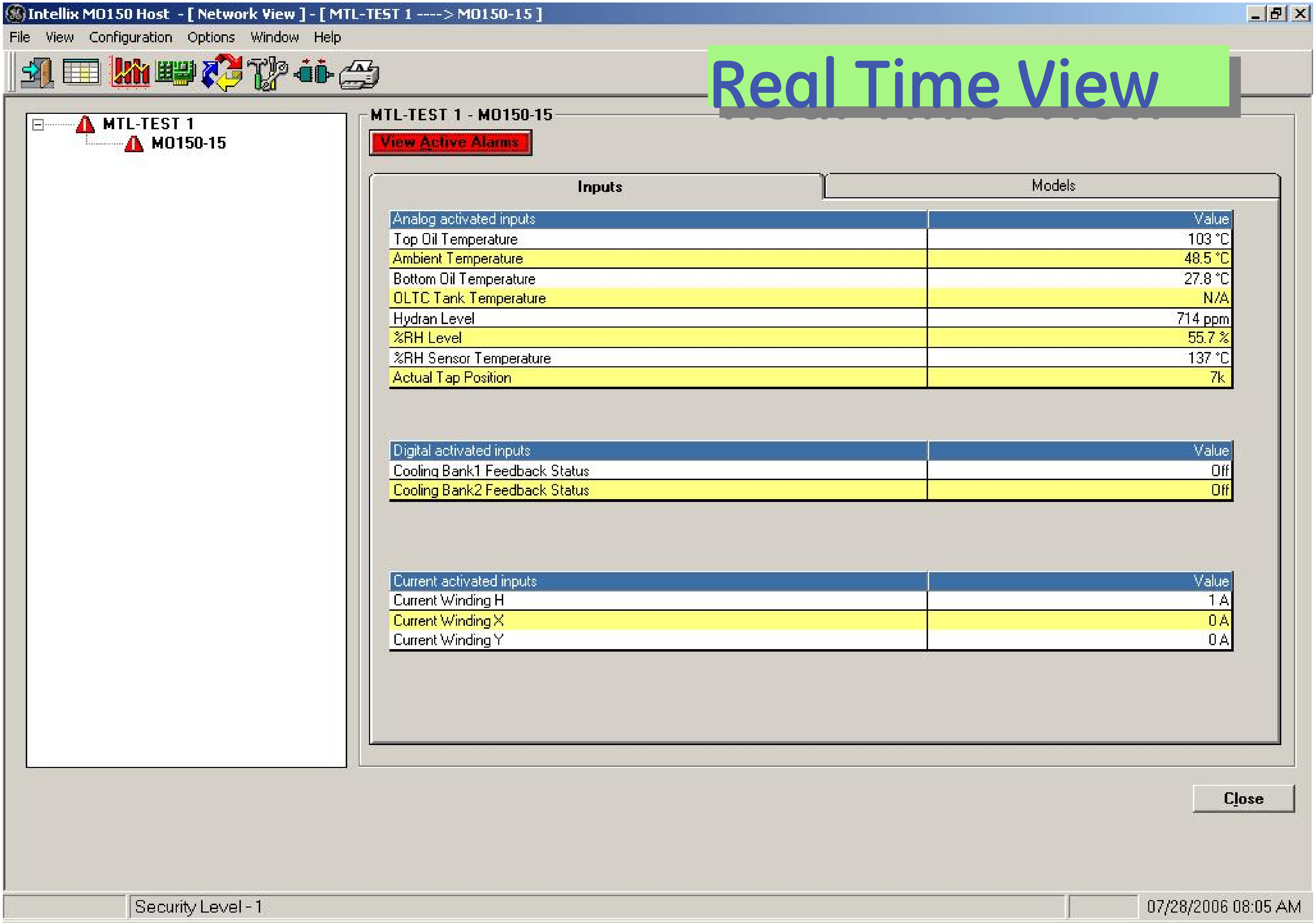
Intellix MO150 – Communications, example of alarms



Real Time View



Winding Hot Spot

Cooling Efficiency

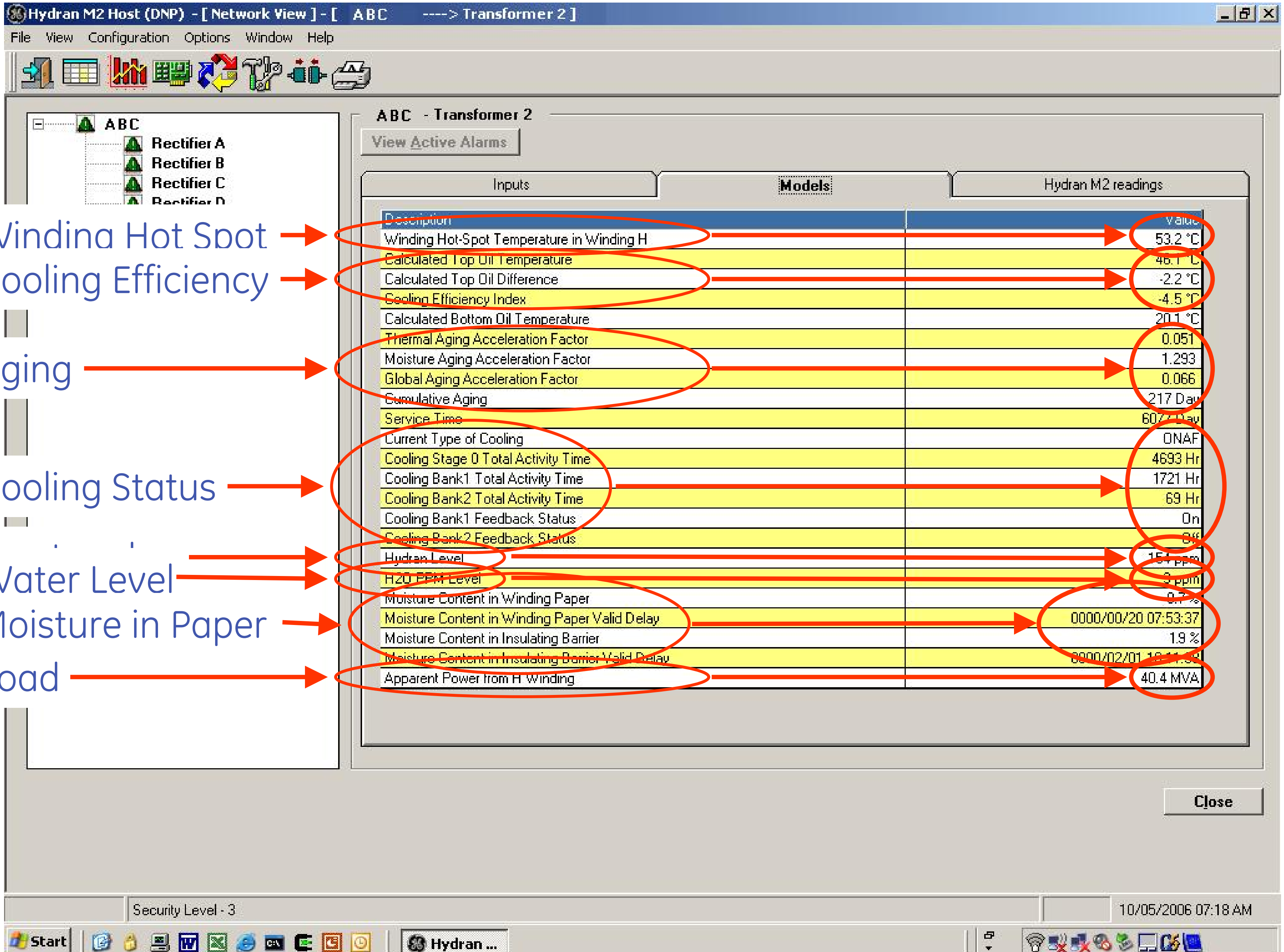
Aging

Cooling Status

Water Level

Moisture in Paper

Load



Description	Value
Winding Hot-Spot Temperature in Winding H	53.2 °C
Calculated Top Oil Temperature	46.1 °C
Calculated Top Oil Difference	-2.2 °C
Cooling Efficiency Index	-4.5 °C
Calculated Bottom Oil Temperature	20.1 °C
Thermal Aging Acceleration Factor	0.051
Moisture Aging Acceleration Factor	1.293
Global Aging Acceleration Factor	0.066
Cumulative Aging	217 Day
Service Time	607[illegible] Day
Current Type of Cooling	ONAF
Cooling Stage 0 Total Activity Time	4693 Hr
Cooling Bank1 Total Activity Time	1721 Hr
Cooling Bank2 Total Activity Time	69 Hr
Cooling Bank1 Feedback Status	On
Cooling Bank2 Feedback Status	Off
Hydran Level	15[illegible] ppm
H2O PPM Level	3 ppm
Moisture Content in Winding Paper	0.7 %
Moisture Content in Winding Paper Valid Delay	0000/00/20 07:53:37
Moisture Content in Insulating Barrier	1.9 %
Moisture Content in Insulating Barrier Valid Delay	0000/02/01 1[illegible]
Apparent Power from H Winding	40.4 MVA

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In Conclusion

GE offer several products for transformer monitoring

We did here an overview of transformer monitoring, part of our product line and how these products could be applied to this important function of utility management

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