Challenges for Power Transformers

THE FUTURE OF THE POWER SYSTEMS AND THE ELECTROMECHANICAL INDUSTRY'S ROLE

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Challenges for Power Transformers

1. Reliability
2. Efficiency
3. Technologies
4. Diagnostic and Continuous on-line Monitoring

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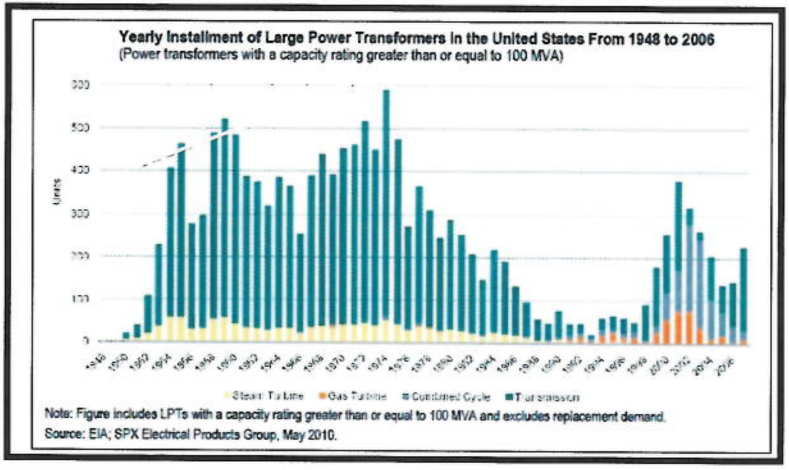
1. Transformer Reliability

Reliability in the context of an ageing transformer population

Typical Power Transformer population profile (example shown: US)

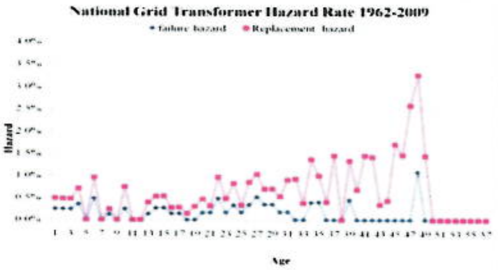


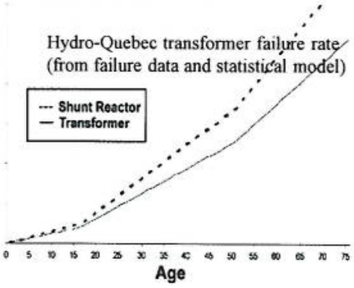
Yearly Installment of Large Power Transformers in the United States From 1948 to 2006
(Power transformers with a capacity rating greater than or equal to 100 MVA)

Note: Figure includes LPTs with a capacity rating greater than or equal to 100 MVA and excludes replacement demand.
Source: EIA; SPX Electrical Products Group, May 2010.

1. Transformer Reliability

Relation between failure rate and age ?





Hydro-Quebec transformer failure rate
(from failure data and statistical model)

Difficulties to maintain transformer average age at its current level
- Financial and human resources constraints
- Necessity to insure service continuity

More stress
- More cables, GIS, wind farms
- Network topology evolution: remote energization, ferroresonnance, fast TRV, harmonics, reverse power flow, GIC, etc.

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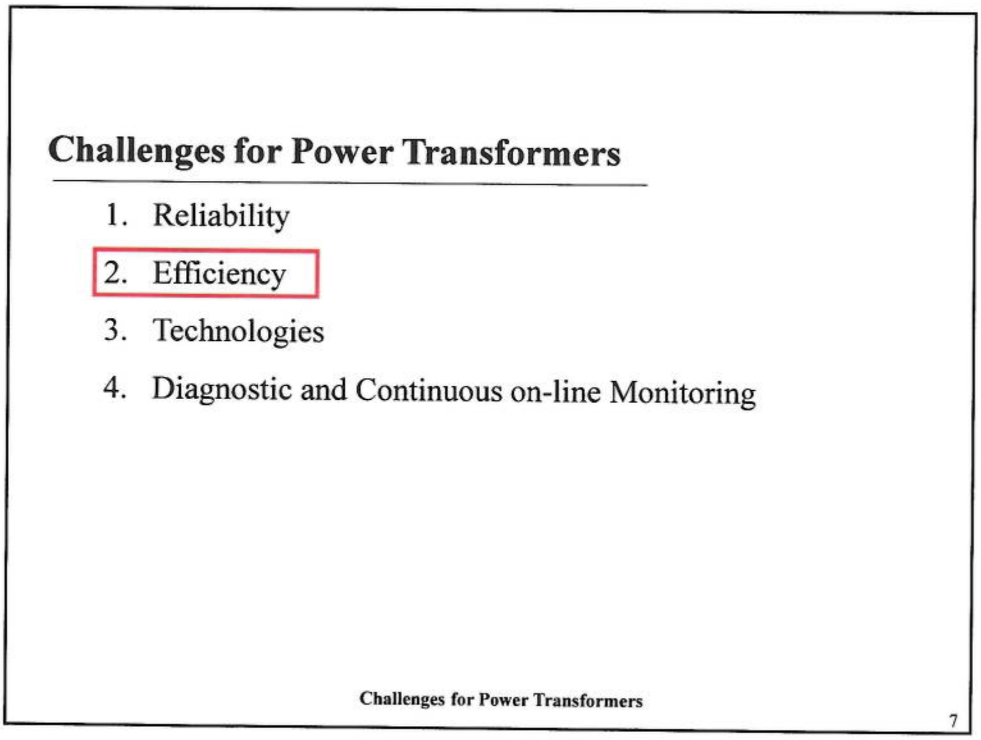
1. Transformer Reliability

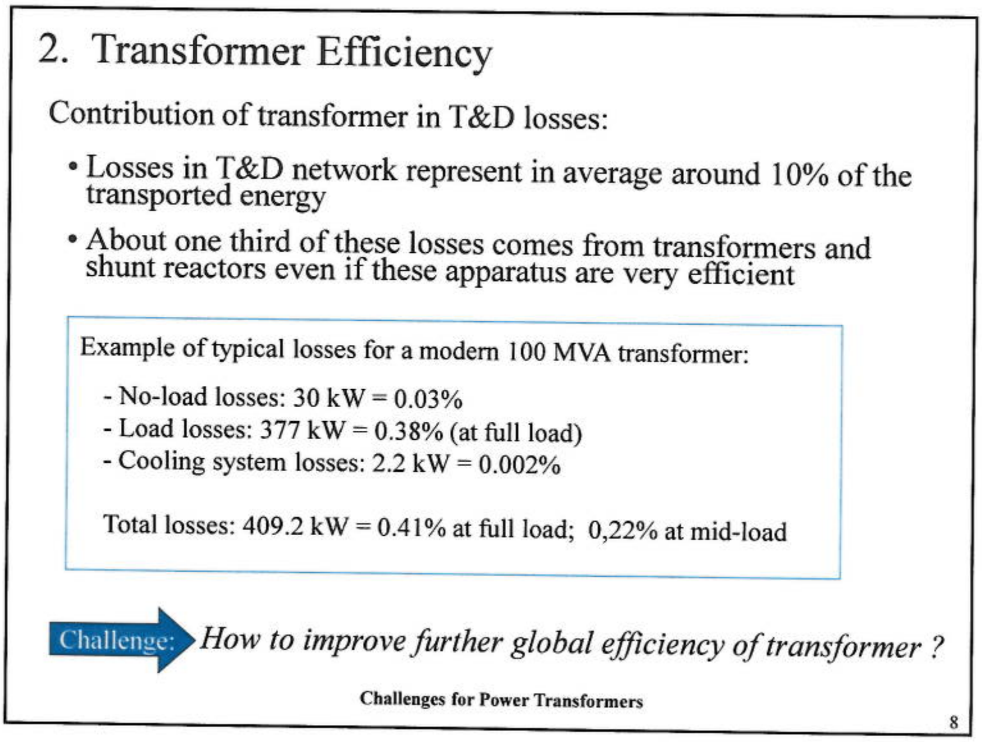
Challenge: *Maintain an acceptable reliability in such context*

- **Risk assessment**
  - Information: failure data, causes, link between reliability and age
  - Condition assessment: diagnostic techniques, ranking a fleet of transformer, how to use the results, how to link the ranking with risks
  - Mitigation strategies: condition monitoring, spare transformers
- **Maintenance and reinvestment strategies**
  - Replacement, Refurbishment, Life extension…
  - Technical and economical issues
  - How to factor the value of reliability in the acquisition costs
- **New stresses assessment**
  - Use of appropriate transformer models
  - Simulations of transformer interaction with the network
  - Existing transformers: mitigation techniques, if needed
  - New transformers: Adapted specification, design and test program



Challenges for Power Transformers

1. Reliability
2. Efficiency
3. Technologies
4. Diagnostic and Continuous on-line Monitoring



2. Transformer Efficiency

Contribution of transformer in T&D losses:

- Losses in T&D network represent in average around 10% of the transported energy
- About one third of these losses comes from transformers and shunt reactors even if these apparatus are very efficient

Example of typical losses for a modern 100 MVA transformer:

- No-load losses: 30 kW = 0.03%
- Load losses: 377 kW = 0.38% (at full load)
- Cooling system losses: 2.2 kW = 0.002%

Total losses: 409.2 kW = 0.41% at full load; 0,22% at mid-load

Challenge: *How to improve further global efficiency of transformer ?*

2. Transformer Efficiency

Transformer efficiency is:

Minimising electrical losses…

while minimizing…

- Dimensions
- Weight
- Quantity of material
- Noise
- Maintenance requirement
- Costs

… and maximizing

- Reliability
- Life expectancy

Impossible to meet all these objective at the same time

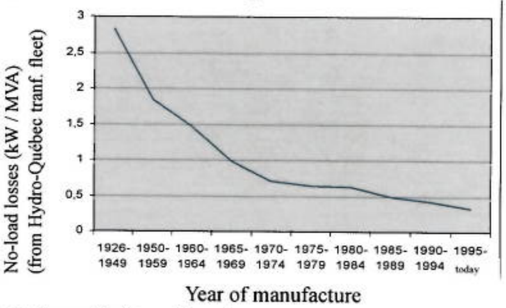
Challenge: *Find the best compromise with a long term perspective*

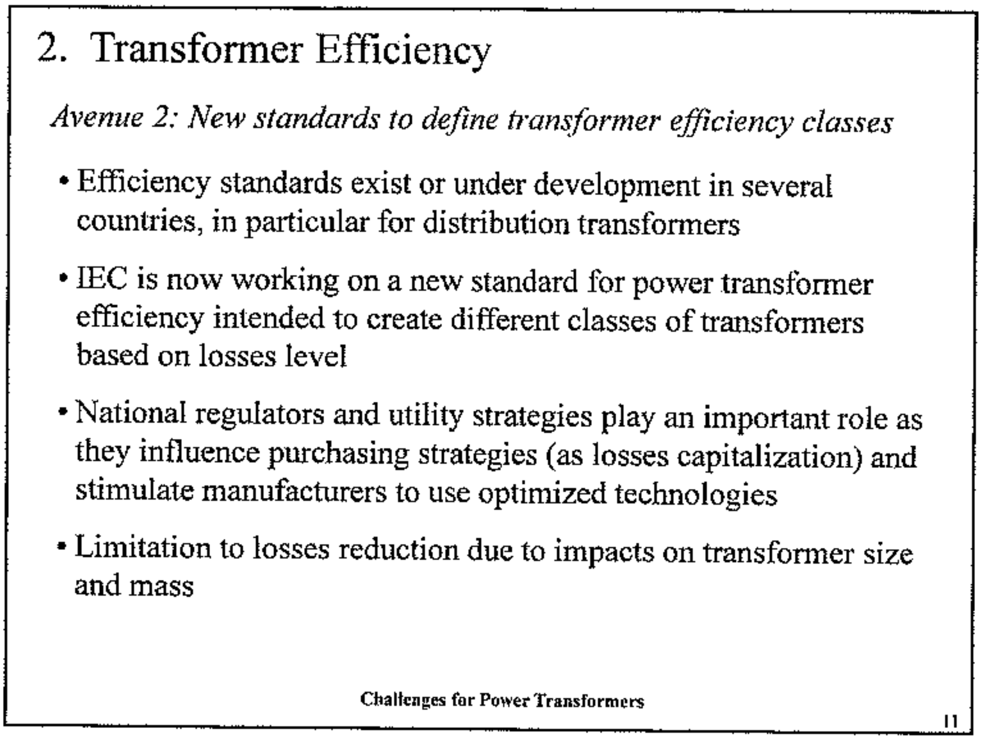
2. Transformer Efficiency

Avenue 1: Utilisation of "loss capitalization" techniques

- Loss capitalization: take into account transformer losses in the procurement process to get most efficient solution in the long term
- Modern transformers show significant improvements due to improved core material and better assembling techniques
- Transformer replacements have a positive effect on transformer fleet losses; further effects by the use of loss capitalization

Transformer losses by year of manufacturing (Hydro-Quebec fleet)

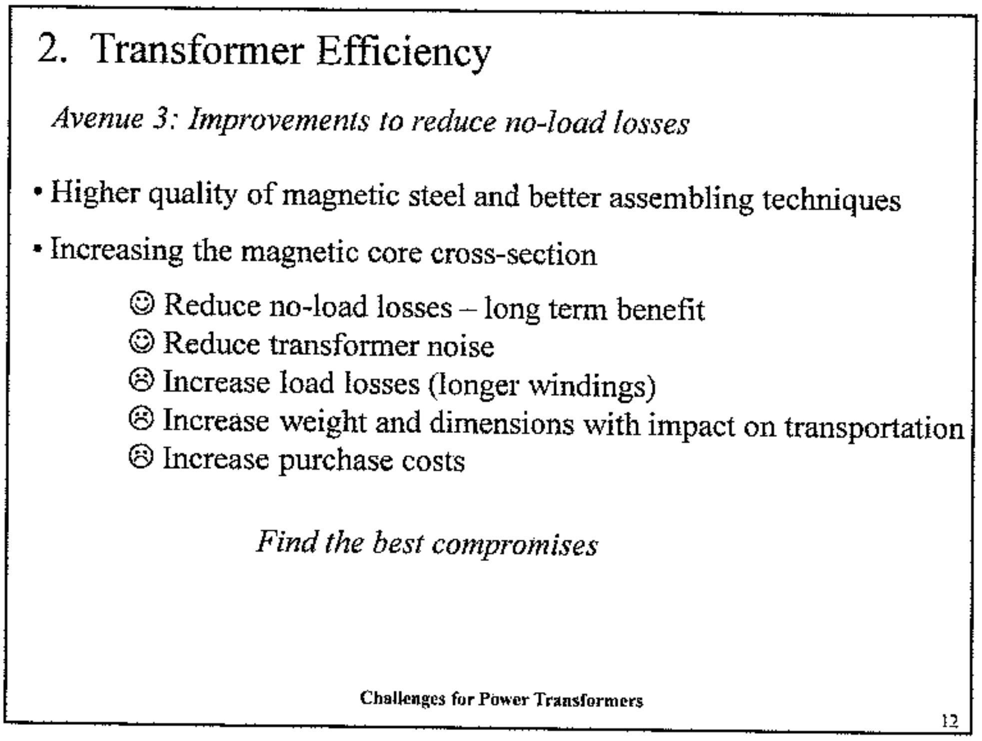




2. Transformer Efficiency

Avenue 2: New standards to define transformer efficiency classes

- Efficiency standards exist or under development in several countries, in particular for distribution transformers
- IEC is now working on a new standard for power transformer efficiency intended to create different classes of transformers based on losses level
- National regulators and utility strategies play an important role as they influence purchasing strategies (as losses capitalization) and stimulate manufacturers to use optimized technologies
- Limitation to losses reduction due to impacts on transformer size and mass



2. Transformer Efficiency

Avenue 3: Improvements to reduce no-load losses

- Higher quality of magnetic steel and better assembling techniques
- Increasing the magnetic core cross-section
  - ☺ Reduce no-load losses – long term benefit
  - ☺ Reduce transformer noise
  - ☹ Increase load losses (longer windings)
  - ☹ Increase weight and dimensions with impact on transportation
  - ☹ Increase purchase costs

Find the best compromises

2. Transformer Efficiency

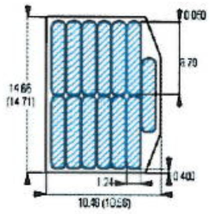
Avenue 4: Improvements to reduce load losses

- Increase conductor cross-section to reduce conductor resistance.

  ☺ Reduce load losses – long term benefit
  ☹ Increase weight and dimensions with impact on transportation
  ☹ Increase purchase costs - raw material availability

Find the best compromises

- Since end of years 80's, Continuously Transposed Conductors (CTC) are used to replace cooper conductors to reduce eddy losses.



- Control of transformer leakage flux and optimal use of magnetic shielding

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2. Transformer Efficiency

Avenue 5: High-Temperature Superconducting transformers

HTS transformers below 10 MVA are now being tested in the U.S. and Japan.

☺ Smaller and lighter

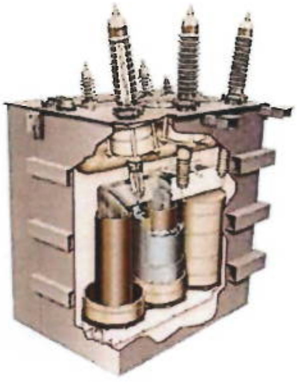
☺ Less audible noise

☺ Less losses

☺ A certain current limiting capability

☹ Not ready now for commercial utilization

☹ The overall costs (purchase, maintenance, etc.) and service life of such transformers are poorly understood.



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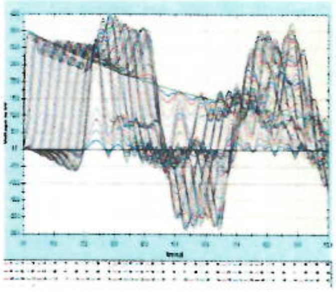
3. Transformer Technologies

Advanced software used for transformer design

Most manufacturers are using advanced software to evaluate:

- Insulation performance
- Thermal performance
- Short-circuit performance
- Mechanical performance (tank, structure, etc.)



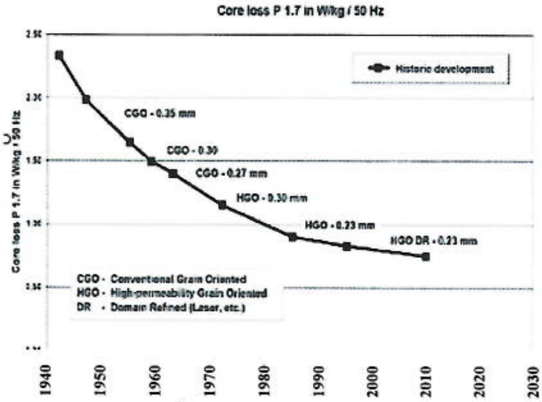
These advanced tools should allow an optimum design for a better reliability with optimized use of material

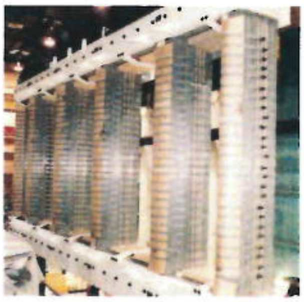
Challenge: *Transformer designers should keep the basic knowledge even if they use these powerful tools*

3. Transformer Technologies

Core magnetic steel – Evolution and future

- Thin Grain-Oriented Steel in the early 30's
- High Permeability – Grain oriented in the late 60's
- Domain-refined in the early 80's





Challenge: *Stabilization of the evolution ? Next step ?*

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3. Transformer Technologies

Core magnetic steel – Evolution and future

Use of amorphous steel

- growing in popularity for distribution transformers
- a vitrified metal alloy manufactured with very thin laminations
- reduced no-load losses by 60% to 70%
- unfortunately not currently applicable for power transformers

Challenge: *Continue R&D for improved material applicable to power transformers*

3. Transformer Technologies

Windings solid insulation

- Kraft Paper: used since more than 100 years
- Thermally Upgraded Paper: introduced by Westinghouse in the 60's (Insuldur) and became very common in North America in the 70's but not common in Europe
- Other material as aramid is used for special application (high temperature)
- CTC conductors: in use since the 80's
- More recently: paperless CTC conductors for low voltage windings

Challenge: *Long-term experience with paperless CTC conductors*
Extended used of high temperature solid insulation

3. Transformer Technologies

Insulating Fluid

The vast majority of transformers is using mineral oil

Alternative oil:

- No longer used: PCB (polychorobiphenyl) - 60's
- Replaced by silicone oil particularly in Japan - 80's,
- Synthetic ester, developed - late 70's
- Natural ester: popular for distribution transformers - 90's

Advantages of synthetic and natural ester:

- better biodegradability
- less flammable than mineral oil

Alternative to oil: SF6 transformers - used in some countries

3. Transformer Technologies

Insulating Fluid

Challenges:

- *Specification of new mineral oil*
- *Alternative oils required adapted transformer designs – not possible to simply replace mineral oil in existing transformers*
- *Performance at low temperature of natural ester*
- *Need for oil containment: depends on local regulation*
- *Management of different types of oils as existing units use mineral oil*
- *Reclamation of alternative oil have not been demonstrated*
- *Cost reduction of SF6 Transformers*

3. Transformer Technologies

Bushing

- The vast majority of installed power transformers bushings are made of oil-paper insulation core and a porcelain insulator envelope
- This technology is very reliable but has important safety disadvantages if a bushing failure occurs:

  - Porcelain may be projected violently
  - Porcelain rupture may let a large opening where the transformer oil may go out and may be a cause of fire
  - Bushing failure is the major cause of transformer fire

3. Transformer Technologies

Bushing

- Since the 60's, an alternative growing in popularity is to use a core made of resin impregnated paper with an external envelop (insulator) made of silicon
- This technology has a positive impact on safety, reduce the risk of fire and has a better seismic performance, especially for very long bushing


735 kV RIP bushing

Challenge: *Long-term reliability comparable to conventional technologies ?*

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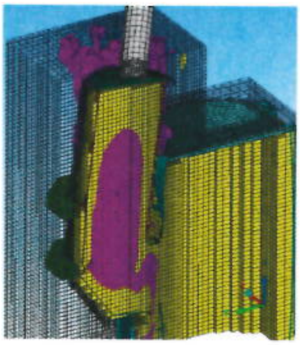
3. Transformer Technologies

Tank

- Transformer tank should be designed to reduce to minimum the risk of fire and should retain the most part of the oil in case of transformer failure
- The tank should resist to the energy of arc developed during a transformer fault that is function of:
  - faulted current intensity
  - faulted current duration
  - arc voltage that is function of arc length

3. Transformer Technologies

Tank



Challenges:

- *Tank design made to contain the insulation liquid in case of internal fault*
  - *Take advantage of the wall flexibility*
  - *Adequate structural reinforcement*
  - *Use of recent modelization tools*

Note: Some experiences reported are using reinforced tanks with venting compartments or multiple rupture discs all around the tank

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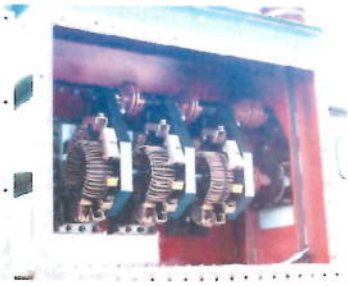
3. Transformer Technologies

On-Load Tap Changer



Interruption in oil

- Conventional technologies used for about 100 years
- Require frequent maintenance mainly because of oil degradation

Interruption in vacuum

- Originally introduced in North America by GE in the 60's for inductive types
- Reintroduce in the last two decades by OLTC manufacturers for resistive types
- Require almost "no-maintenance" for common transformer applications

Challenges:

- *Long-term reliability of the vacuum bottles*
- *SC circuit capability and DC interruption performance*
- *Solid state technologies ?*

3. Transformer Technologies

UHV Transformers

- The previous implementation of a new voltage level (735 kV) requires several years of adjustments, especially for transformers
- For this new step (1200 kV), insulation coordination of the projects required several compromises to keep technical and economical parameters in an acceptable range
- Example of technologies used (1200 kV):
  - Surge arrestor with reduced ratio between voltage operation and voltage conduction
  - Circuit breaker with closing resistances

Challenges:
- *Insulation levels, specification and design*
- *Manufacturing*
- *Long-term reliability in operation*

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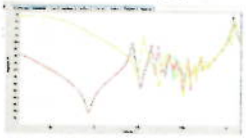
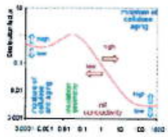
Off-line Diagnostic



Frequency Response Analysis

- Test procedure and configuration now normalized by IEC

Challenge: *Need to improve interpretation – more objective criteria*



Advance insulation diagnostic techniques

- Several techniques available: PDC, RVM, FDS

Challenge: *Continue to gain experience - interpretation*

UHF Detection for partial discharge measurement

- Continue to gain experience

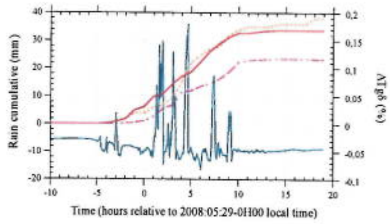
Challenge: *How can it be used for acceptation tests ?*

->Fault localisation by combining UHF with acoustic

4. Diagnostic and continuous on-line monitoring

If applied adequately, Continuous On-Line Monitoring technology may have the following significant advantages:

- Continuously tracking condition rather than monitor condition at time intervals
- Detect change of measured parameters shortly after its occurrence
- Generate an automatic warning if preset limits or trends are exceeded
- In case of unexpected failure, perform a "black box" function



4. Transformer Monitoring

Other parameters

The most popular monitoring parameter is Continuous DGA On-Line Monitoring, but other discrete systems are available and can be combined with DGA monitors.

Examples:

- Systems supporting mathematical models designed to calculate additional information such as winding hot spot temperatures, rate of ageing of paper insulation, moisture content in paper or barriers, and effectiveness of the cooling systems
- Monitoring of bushings by measuring the leakage current through capacitance tap (where capacitance taps are available)
- OLTC monitoring including mechanical conditions of the drive system, contact wear, temperature differential, dissolved gas analysis, tap position tracking/counting, acoustic techniques, etc.
- Partial discharge detection using electrical, acoustical, or UHF signals

4. Transformer Monitoring

Challenges:

- *Adapt corporate culture to these new ways of doing*
- *Fine selection of monitored parameters*
- *Convert data to useful information with good human interface*
- *Avoid false alarms*
- *Reduce installation costs – particularly for retrofit application*
- *Maintenance requirement and long-term reliability compare with the monitored transformer*
- *System compatibility – sensors, acquisition systems, communication protocols & technologies, database, algorithms, interpretation, etc.*

Thank you for your attention

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