CIGRE sessions 2022, Paris
Key Take Aways

A2 Power Transformers and Reactors

cigre
For power system expertise

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Content

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2. Session 2022 PS1 paper review
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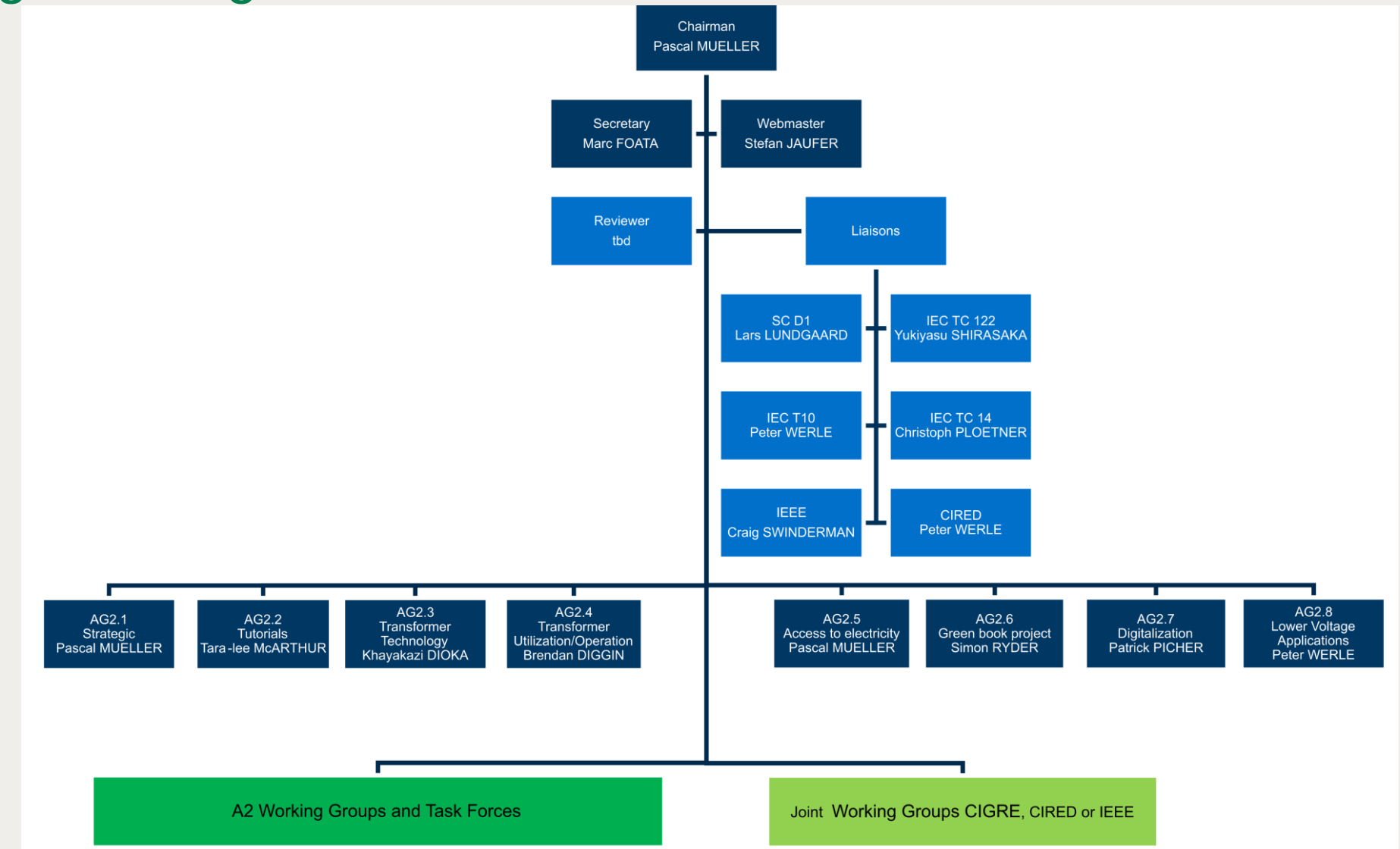
5. Other insights

For power system expertise

Cigre A2 organisation

- Study Committee A2 membership is currently composed of:
  - Chair and Secretary
  - 24 Regular Members
  - 6 Additional Regular Members
  - 18 Observers
  - 7 National Representatives
  - 17 Working Group Convenors
  - 2 Task Force Convenors
  - 8 Advisory Group Convenors
  - 5 Liaison Officers (IEEE, IEC TC10, TC14 and TC122 and Study Committee D1)

Cigre A2 organisation



Cigre A2 new publications

WG	Title	Publication status
A2/D1.51	Improvements to PD Measurements for Factory and Site Acceptance Test of Power Transformers	February 2022
Task Force	The Condition of Solid Transformer Insulation at End-of-Life	Electra April 2022
A2/C4.52	High-Frequency Modelling	Currently under review by SC
A2.55	Transformer Life Extension	Final TB sent to CIGRE - Publication pending
A2.56	Transformer Efficiency	Under review
AG2.6	Green Book on Transformer Procurement	Published

Cigre A2 new working groups & task forces

WG / TF	Title	Approval
A2/D2.65	Transformer Digital Twin	February 2022
A2/D1.66	Breathing systems of liquid filled transformers and reactors	March 2022
A2/D1.67	Guideline for online dissolved gas analysis monitoring	July 2022
Task Force	Power Transformer Tank Specification for Passive Protection Against Internal Arc	Approved
A2.68	Failure Survey of Lower Voltage Generator Step Up Transformers	‘22-’25
A2.69	Guide for Transformer Maintenance - Update	‘22-’24
Task Force	Transformer Field Noise Measurement	‘22-’23

Paper session

1) Experience and new requirements for transformers for renewable generation
   - Number: 15
   - (Co-)authors: Manufacturers (9), Users (4), Universities (5)
     Research institutes (3)
   - Geo: America‘s (3), Europe (11), Asia (3)

2) Beyond the mineral oil-immersed transformers and reactors
   - Number: 16
   - (Co-)authors: Manufacturers (15), Users (5), Universities (1)
     Research institutes (1)
   - Geo: America‘s (5), Europe (10), Asia (5), Africa (1)

Paper session

3) Best practices in transformers and reactors procurement
   - Number: 12
   - (Co-)authors: Manufacturers (5), Users (7), Universities (1)
   - Geo: America‘s (3), Europe (4), Asia (4), Africa (1)

PS 1: Experience and new requirements for transformers for renewable generation

PS 1: Experience and new requirements for transformers for renewable generation

It‘s recognized that, due to the connection of renewable and alternative energy sources, the requirements for power transformers will change:

- Overvoltage and underfrequency
- Variable and reverse power flow
- Inverter-based loads may have complex schemes

PS 1: Design

Paper ID	Title
10251	Validation of a White-box model of a Distribution Transformer through impulse voltage transfer measurements including non-standard test conditions
10356	White-box Models Development for Insulation Design and Providing Transformers Withstand to High-Frequency Resonant Overvoltages
10433	Design and Operation Consideration for Selection of Transformers for Solar Photovoltaic Plant Applications
10771	Design of a 24-pulses 250 Mvar Thyristor Controlled Transformer
10839	Design challenges for large offshore wind turbine transformers
10884	Mobile Load Flow Reactor for 220kV

PS 1: Design

- Papers 10251 and 10356 describe modelling techniques for simulating the effects of transient overvoltages within transformer windings. In both papers, calculation results are compared with measured data.
  - 10251 considers standardized voltage waveshapes in combination with non-standardized test setups
  - 10356 considers overvoltages within transformer windings due to resonances e.g. between the transformer inductance and cable capacitance
- Paper 10433 describes the possibility to reduce the total cost of ownership (TCO) of transformers used in large PV-plant, owing to the fact that they only operate at high load/high temperature conditions for a relatively short period in a 24-hour load cycle.
- Papers 10771, 10839 and 10884 describe special transformer/reactor designs for application in a thyristor-controlled-transformer, mobile reactor and nacelle of a wind turbine respectively.

PS 1: Operating conditions

Paper ID	Title
10127	Advantages of the loading and ambient temperature profile assessments for solar collector power transformer based on dynamic loading model
10216	New Method for Effective Grounding Design Using Grounding Transformer for the Microgrid with Inverter-based Distributed Energy Resources (DERs)
10256	Reverse Power Flow Impacts for Legacy Power Transformers
10943	Statistical Analysis and Grouping of Measured Power Transformer Overvoltages
11065	Impact of Transient Voltage Generated by Valve Commutation on HVDC Transformer
11139	Bubble Formation in Power Transformers – a Potential Risk for the Future Network Reliability?

PS 1: Operating conditions

- Paper 10127 presents the idea of optimizing the rating of transformers using in PV plant by allowing a certain extent of overloading. In this regard, it takes a similar viewpoint as 10433.
- Paper 11139 describe potential risk of bubble formation during times of high loading that may occur in networks with a large penetration of distributed energy resources (DER's) and the resulting substantial load variations.
- Papers 10256 and 11065 describe the effects that reversed power flow (mainly in axially split, dual low voltage) and transient overvoltages generated by valve commutation (converter application) may have on power transformers.
- Papers 10216 and 10943 present specific considerations for networks with inverter based DER's:
  - Earthing and protection against earth faults (10216)
  - Overvoltages (10943) - relates to papers 10251 and 10356

PS 1: Maintenance and diagnostics

Paper ID	Title
10100	Condition Assessment of HVDC converter transformers at limited time of outage applied to the Fenno–Skan 1 transmission system
10249	Investigations on Vacuum Tap Changer Failures of Converter Transformers and Maintenance Suggestions
10953	On-line differential partial discharge measurements of condenser bushings on power transformers

PS 1: Maintenance and diagnostics

- Paper 10100 presents the results of a condition assessment of Fenno-Skan 1 HVDC-link.
- Paper 10249 presents the results of a failure investigation into 6 OLTC-failures that occurred in HVDC-transformers.
- Paper 10953 presents the results of electrical PD-measurements on bushings that were performed on-line.

PS 2: Beyond the mineral oil-immersed transformer and reactors

PS 2: Beyond the mineral oil-immersed transformer and reactors

Arguably, esters should not be called ‘alternative’ anymore:

- Solutions are available for up the highest ratings
- Globally, a strong growth of ester-filled transformers and reactors (mostly natural ester is mentioned)
- Performance is reported to be at least equal or better than mineral oil, although it must be noted that papers are not always in agreement and claims sometimes lack a proper foundation
- DGA is possible

PS 2: Beyond the mineral oil-immersed transformer and reactors

Others:

- Gas-To-Liquid
- Gas (air, nitrogen)
- Silicon rubber

PS 2: Esters

Paper ID	Title
10130	A Proposal to Reduce Greenhouse Gas Emission in the Electrical Power Transmission Sector in Brazil: A Calculation Method Based on the Use of Natural Ester in Power Transformers
10437	Experience on Design, Manufacturing & Type Testing of First 420 kV Class Ester Fluid Filled Shunt Reactor
10505	Beyond the top oil temperature limit
10535	Technological Development of Vegetable Oil (Rapeseed Oil) Immersed Transformer
10688	Development of Transformer using Natural Ester for a Modular Substation
10772	Supporting development of transformers with natural esters by comprehensive evaluation of insulation systems
11022	Design of innovative resilient transformers for maximum operating flexibility
11064	Testing Challenges with Ester Insulating Liquids
11140	Analysis of new dielectric fluid alternatives using the design of a thermal distribution test platform model and CFD methods.

PS 2: Esters

- Paper 10130 presents the results of a study showing that natural esters have significantly smaller carbon footprint than mineral oil.
- Papers 10505, 10772, 11022 and 11140 focus on thermal aspects of ester-filled equipment:
  - Thermal performance of winding insulation (10505 and 10772)
  - Benefits of ester in combination with high temperature insulation for applications where weights and dimensions are of great concern such as resilient transformers (11022)
  - Performance of ester as a coolant (11140)
- Paper 11064 discusses gas-in-oil analysis of synthetic ester liquids
- Papers 10437, 10535, 10688 present case studies

PS 2: Others

Paper ID	Title
10277	A New Solution of Higher Energy-Efficient Dry-Type Transformers with Silicon Rubber Casting Technology
10534	Winding Insulation Characteristics of Gas Filled Transformers With SF_6 Alternative Gas
10803	420 kV Shunt Reactors for Reactive Power Compensation Explaining the Trends Favoring Air-Core Dry-Type Technology
10810	Evaluation and Implementation of HV Dry-Type Shunt Reactors into a 420kV Transmission Grid
10864	Dry-type 145 kV transformers: safe indoor substations with improved environmental performance
11125	Type Testing of 80 MVA Power Transformer with a new Bio-based, Biodegradable and Low Viscosity Insulating Liquid

PS 2: Others

- Paper 11125 presents a case study of a power transformer filled with a biodegradable, bio-based hydrocarbon insulating fluid that is fully compliant with IEC 60296. Benefits from other biodegradable insulating fluids such as esters are:
  - a higher biodegradability
  - onerous design changes or not required
  - excellent thermal properties owing to its low viscosity
- Paper 10534 describes an R&D-project aiming to replace SF6 in gas filled transformer for more environmentally friendly alternatives (dry air or nitrogen).
- Paper 10277 and 10864 presents insulating systems used for dry-type transformers:
  - conventional epoxy-resin capable of U_m = 145 kV (10864)
  - silicon rubber (10277)
- Papers 10803 and 10810 present a particular case study of a 420 kV air-core shunt reactor installed in the German transmission system.

PS 2: Last but not least

Paper ID	Title
11066	Qualification of Insulating Liquids for Power Transformers and Tap-Changers

- A comprehensive overview of the work that is still needed

PS 3: Best practices in transformers and reactors procurement

PS3: main topics (14 papers)

- Procurement: specification, selection, qualification, inspection (5 papers)
- Transformer technology: design, manufacturing, testing (6 papers)
- Case study (1 paper)
- Transients (PS1 subjects, 2 papers)

PS3: Procurement: specification, selection, qualification, inspection

Paper ID	Title
10438	Procurement of Transformers and Reactors-Best Practices Adopted to Achieve highest availability & reliability goal
10573	Experiences and Risks when Dealing with Remote Inspections of Factory Acceptance Tests on EHV Inductive Equipment
10840	RTE's experience on transformers and reactors procurement
11126	Procuring transformers and reactors under a dynamic environment for a sustainable network – the Eskom way
10131	High Voltage Bushings For Transformers And Shunt Reactors Considering Local Conditions – Brazilian Transmission Network Case

PS3: Procurement: specification, selection, qualification, inspection

- 10438 (Powergrid India), 10840 (RTE France) and 11126 (Eskom South Africa) all describe the process & approach used by the these TSO's to enhance the reliability and availability of the fleet. Main focus areas:
  - Supplier selection & qualification, based on technical, financial, quality, operational & maintenance criteria & audits.
  - Development of detailed technical specifications, together with performance parameters (efficiency, loss capitalization,…)
  - Design review, manufacturing inspections.
  - Testing:
    - Factory acceptance testing
    - Short circuit testing (standard for every RTE design)

PS3: Procurement: specification, selection, qualification, inspection

- 10573 (Interconexión Colombia) offers an overview of how remote inspections and factory acceptance testing can be handled, with the author's own experience.
  - Risks and benefits to be evaluated
  - Technical challenges (synchronous, asynchronous, video & screen capturing,…)

- 10131 (CHESF, Brazilian TSO) describes the difficulties for specifying and procuring suitable bushings for their transformers and reactors, mainly because of the discrepancy between IEC and the Brazilian standards, and the fact that standard bushings are mainly based on the IEC.
  - High ambient temperatures
  - Specific overload regimes and temperature limits
  - 60Hz network

PS3: Transformer technology: design, manufacturing, testing

Paper ID	Title
10122	Impulse Testing of Power Transformers - Impact of Internal Varistors built into On-load Tap Changers
10314	Introduced the Development of low-Noise (50dBA) Technology for 154kV Class Power Transformers
10436	Complexities in Design and Manufacturing of Transformers with Low MVA, High Voltage Class
10506	State of the art in short-circuit for transformers
10841	Simplified tool to assess transformer behaviour to GIC and other DC disturbances
10842	Qualification test for power transformers GIC capability

PS3: Transformer technology: design, manufacturing, testing

- 10841 and 10842 are about GIC and other DC-disturbances, causing partial saturation in transformer cores and consequent hot-spots: how to evaluate (risk-assessment) and test the thermal influence.
- The other are touching specific design features:
  - Low noise design (10314): vibration uncoupling, use of constrained layer damping, resonance modelling (and avoidance)
  - Challenges in design of low-MVA high voltage transformers (10436)
  - 10506 discusses a manufacturer's view on the short-circuit evaluation of transformer designs, in the margin of the new revision of IEC 60076-5
  - 10122 is about an alleged failure, which turned out to be (only) the functioning of OLTC built-in varistors (ZnO's)

PS3: Case study

Paper ID	Title
11059	A Case Study of Earth Fault on The Power Transformer Caused by Human Error and Inadequate Design in the Interlock System

- Failure investigation after an earth switch was closed by an operator while the transformer was energized.
  - Interlocking

Other insights (from exhibition, GDM)

- Alternative fluids
  - SF6 will be phased-out, what about mineral oil in the future?
  - Natural esters, synthetic esters, new bio-fluids, recycled oil, GTL,…
- Digitalization
  - Can have benefits, e.g. increased thermal monitoring for more accurate dynamic loading, early fault detection with DGA devices
  - Questions about reliability and maintenance costs
    - Electronic devices for 10-15 years vs. transformers for 40-60 years
    - Software/hardware updates put huge pressure on OPEX budgets
  - Should be a means, not a purpose
- With the energy transition going on, with the integration of high number of RES the future fleet will need to be **resilient** for the future challenges.
  - Bi-directional power flow
  - Harmonic disturbances
  - Introduction of new devices (HVDC-grid, breakers, cables, inverter-based devices, synchronous condensers,…)
  - Transients
- Close cooperation and open dialogue between customers and manufacturers is required to make this happen !


Thank you
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