SC A2 POWER TRANSFORMERS AND REACTORS

PS2 - Beyond the Mineral Oil-Immersed Transformer and Reactors

Paper A2 11022_2022

DESIGN OF INNOVATIVE RESILIENT TRANSFORMERS FOR MAXIMUM OPERATING FLEXIBILITY

R. SZEWCZYK[1] - PL, J.-C. DUART[1] – FR, A. O'MALLEY[2] – US, K. KAINEDER[3] - AT, R. MAYER[3] - AT, E. SCHWEIGER[3] - DE

[1] DuPont, [2] Consolidated Edison Co. of NY, [3] Siemens Energy

Motivation

Utilities seek innovative transformer designs with

- Better efficiency,
- Higher loading capability,
- Safer and more flexible operation,
- Improved resilience.

All those characteristics, within the space constraints of existing substations.

The previous successful developments resulted in a new advanced series of fast-deployable area station transformers up to 90 MVA and 132 kV.

Transformer design challenges

Achieve maximum operating flexibility with a fast-deployable, lighter-weight unit that would fit in an existing tight substation space.

- Fast deployment (less than a week) for emergencies,
- Two high-voltage levels (132 and 65 kV), three low-voltage levels (13.8, 28 and 35 kV) in combination with low-voltage LTC and a narrow impedance band,
- Power rating up to 93 MVA and high overload capacity of up to 200%,
- Quiet operation,
- Maximum transport weight of 200 000 lbs. (91 t),
- Substations with tight spaces and difficult access,
- Filled with synthetic ester liquid, Midel® 7131.

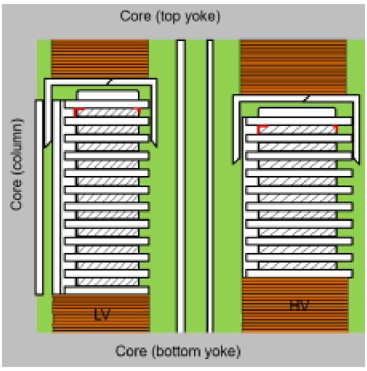
Approach

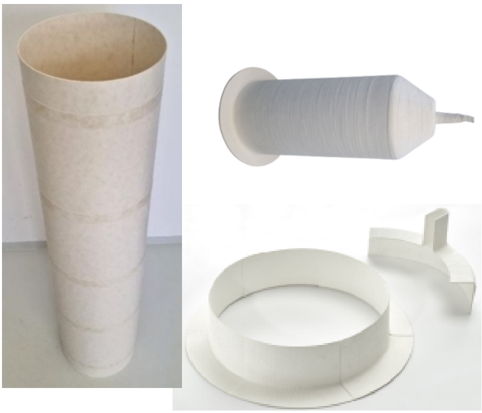
- Combination of newly developed materials and solutions,
- Application of new technologies and materials undergoing intense upfront testing to ensure that the new materials are compatible in the transformer,
- Design tools updating and verification via tests of transformers of various sizes,
- Sophisticated electrical and mechanical tool landscape capable of optimizing the transformer design within the given constraints,
- Innovative and highly experienced designers creating a breakthrough transformer design,

Advanced insulation system

The higher temperatures allowed with ester liquids may require extensive use of aramid material for insulation components. This includes winding cylinders and components of HV end-insulation structures, like stress rings, molded caps, collars, snouts, spacer blocks or clamping plates.

Advanced insulation systems in new power transformers may go beyond typical "hybrid insulation systems" and new category called "hybrid plus" could be defined (close to "full high temperature" insulation system).





Aramid based components of new advanced insulation system (photo courtesy of Schweizer and Isotek)

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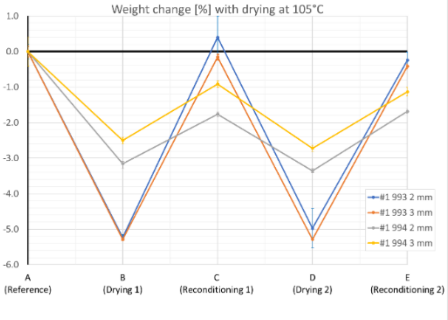
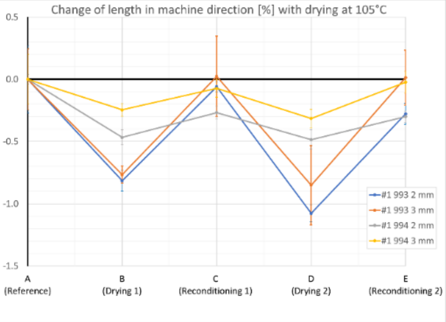
Aramid based winding cylinders

Shrinkage evaluation

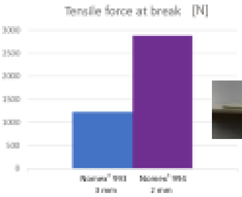
Laboratory experiments tested impacts of typical drying processes on various grades of aramid pressboard (medium-density and high—density aramid pressboard in 2-mm and 3-mm thickness). High-density board proven to be more adequate for winding cylinder construction.





Bonding at scarfed joints

New available large sheets of high-density aramid board reduce number of glued joints. Bonding verification proved superior performance vs. medium-density large sheets.



Failure phenomena shown

Cylinder shaping

After thorough process optimization, the component manufacturer is now able to shape the cylinders in diameter as small as 280 mm. Bending the board to such a small diameter results in significant stress on the glued joints. The manufacturer verified the integrity of the component through thermal cycling (drying and cooling down).

Example of tall winding cylinder with small diameter, made of high-density aramid board.

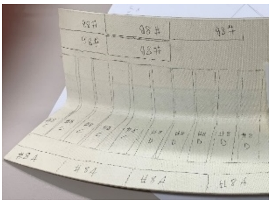
(photo courtesy of Schweizer and Isotek)

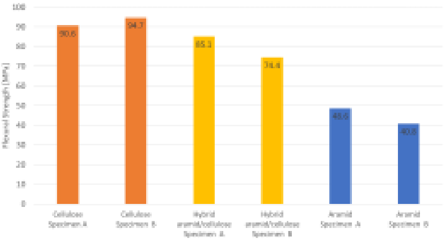
Wet formed insulation parts

The new available wet aramid board was evaluated for two typical forming processes:

- Machine forming for angle rings (caps and collars),
- Hand molding for more complex combined shapes, like winding exit snouts or wall bushings.

The lab tested flexural strength of wet-formed aramid did not precisely match the strength of the cellulose. However, the practical inspection of components showed the performance matching the quality of conventional cellulose-based angle rings.





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Transformer design – active part

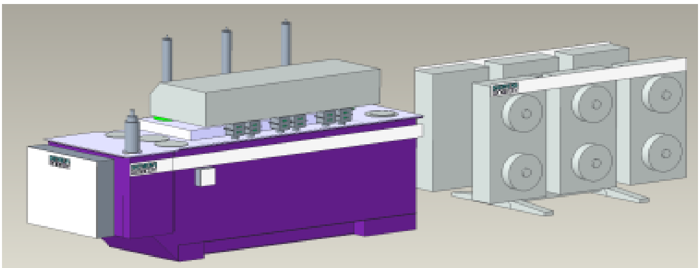
- The sophisticated electrical and mechanical tool landscape was capable of optimizing the transformer design within the given constraints,
- Design based on the latest insulation material and insulation component developments,
- Stringent noise requirements and complex winding geometry requiring a massive core of low-noise, grain-oriented magnetic steel grade, with cooling ducts of a high-thermal class material,
- Various voltage levels on HV and LV sides, and the necessity of LV regulation leading to a complex winding design within a small footprint,
- Multitude of narrow impedance bands and voltage levels requiring up to eight individual windings per phase,
- DETC accommodating the changeover of voltage levels and avoiding handling of liquid during deployment. Design including four DETCs and one OLTC,
- Highly efficient routing of the lead structure essential to accommodate the heating effects from stray flux.

Transformer design – external design

The plug-and-play features are crucial for the successful deployment of grid resilience units.

These features include, but are not limited to:

- HV side with dry-type plug-in bushings to avoid handling of insulating liquid,
- LV substation connections with direct cable connections to increase the flexibility when positioning the unit in the substation,
- Low-profile conservator designed so that it can remain mounted on the transformer for transportation and operation without interfering with the required HV clearances,
- Cooling equipment readily transportable,
- Liquid-filled connection pipes between components that cannot be transported together connected via quick-connect piping to reduce the assembly time,
- Connections to auxiliary equipment realized by heavy-duty plug connectors.



Preliminary design of 93 MVA emergency response area station transformer (graphic by Siemens Energy)

Conclusion

- **The requirements led to research for a combination of newly developed materials and solutions. Extensive test programs have been implemented,**
- **The innovative resilient transformer design will demonstrate maximum operating flexibility by advanced construction with upgraded materials,**
- **The application of upgraded materials, highly sophisticated design tools and experienced designers offer a new level of transformer design for high-end applications,**
- **Breakthrough innovations could also be used in standard transformer types at the power utility to create new optimized and standardized solutions with either reduced size or higher load capability, or both,**
- **The presented concept of a resilience multi-ratio transformer can be applied to extra high-voltage (EHV) large generator step-up transformers (GSU), too.**