CIGRE UK A2 Research Dissemination

Thermal and Electrical Modelling for Cast Resin Dry-type transformers

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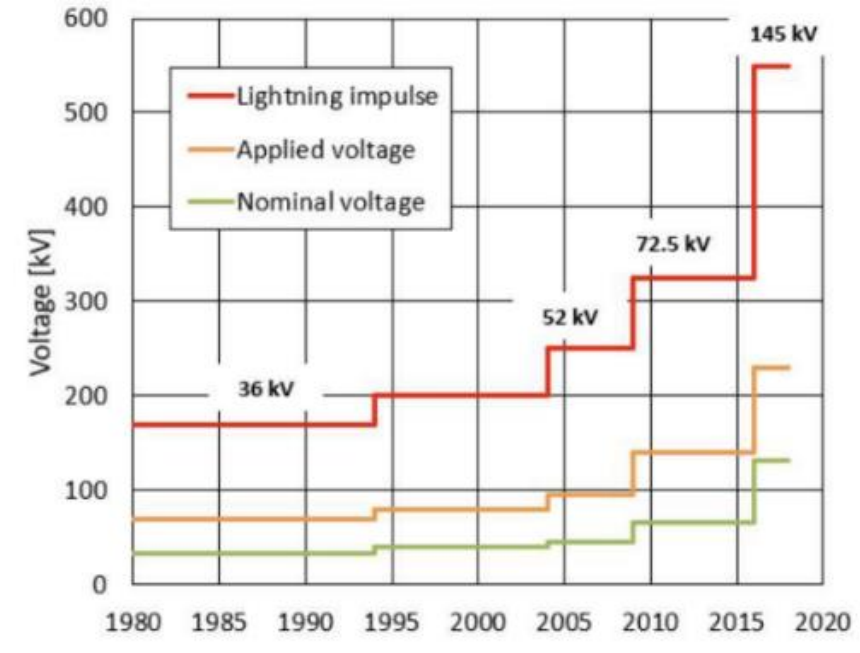
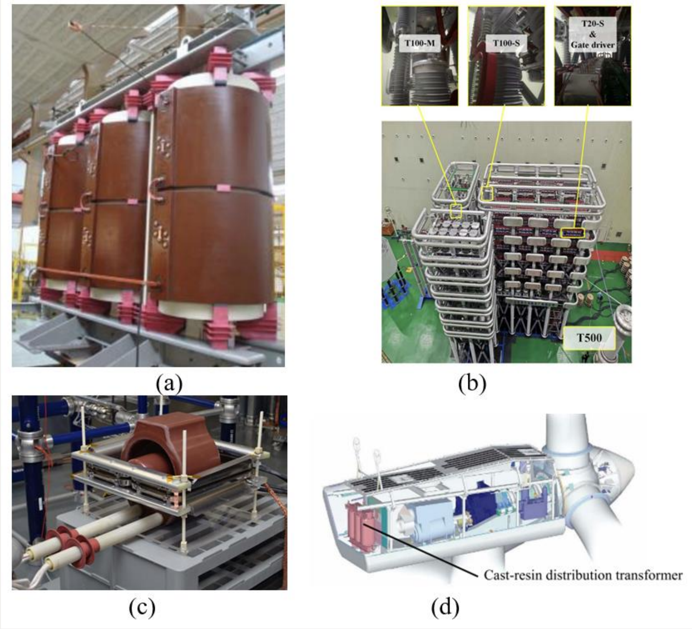
Development of Dry-type Transformers



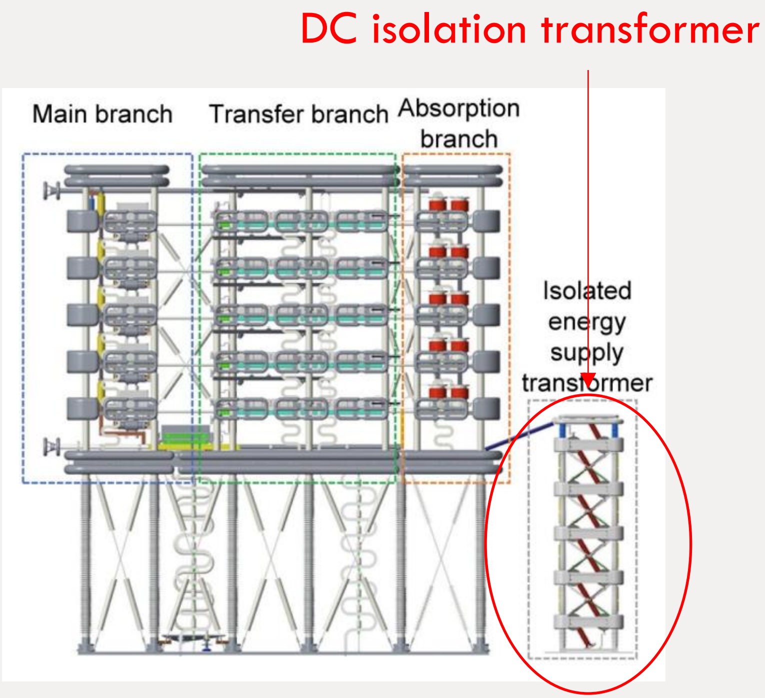
Insulation level development for dry-type transformers [1]



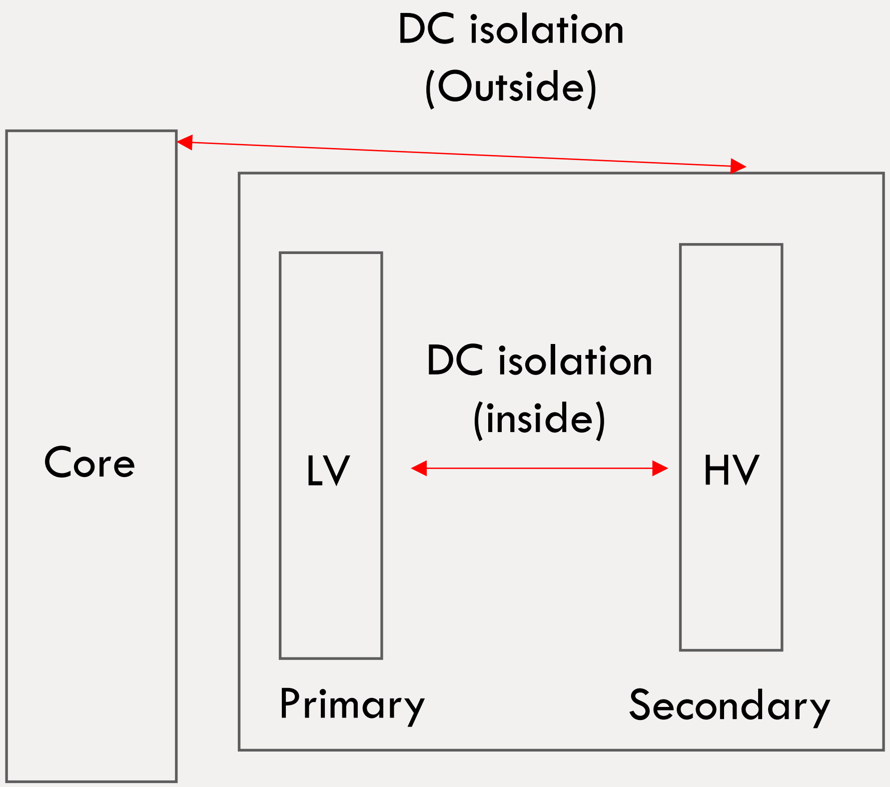
Application of dry-type transformers in (a) power distribution [2] (b) DC circuit breaker [3] (c) DC-DC conversion [4] and (d) wind turbine [5]

- The voltage and power levels for dry-type transformers are up to 145 kV and 63 MVA (ABB Hi-Dry, 2017)
- The increasing voltage and current levels bring challenges to thermal and electrical designs of dry-type transformers.

DC Isolation Transformers

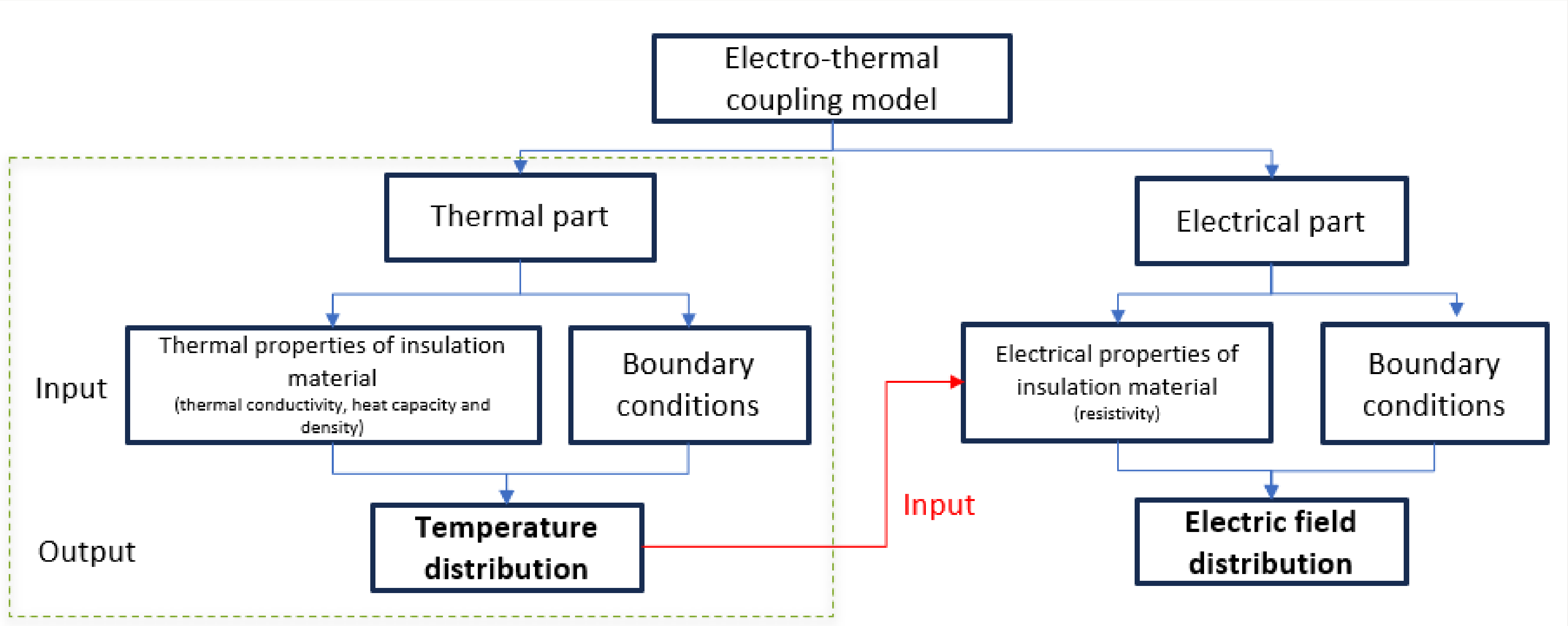


Structure of HVDC circuit breaker and DC isolation transformer [6]



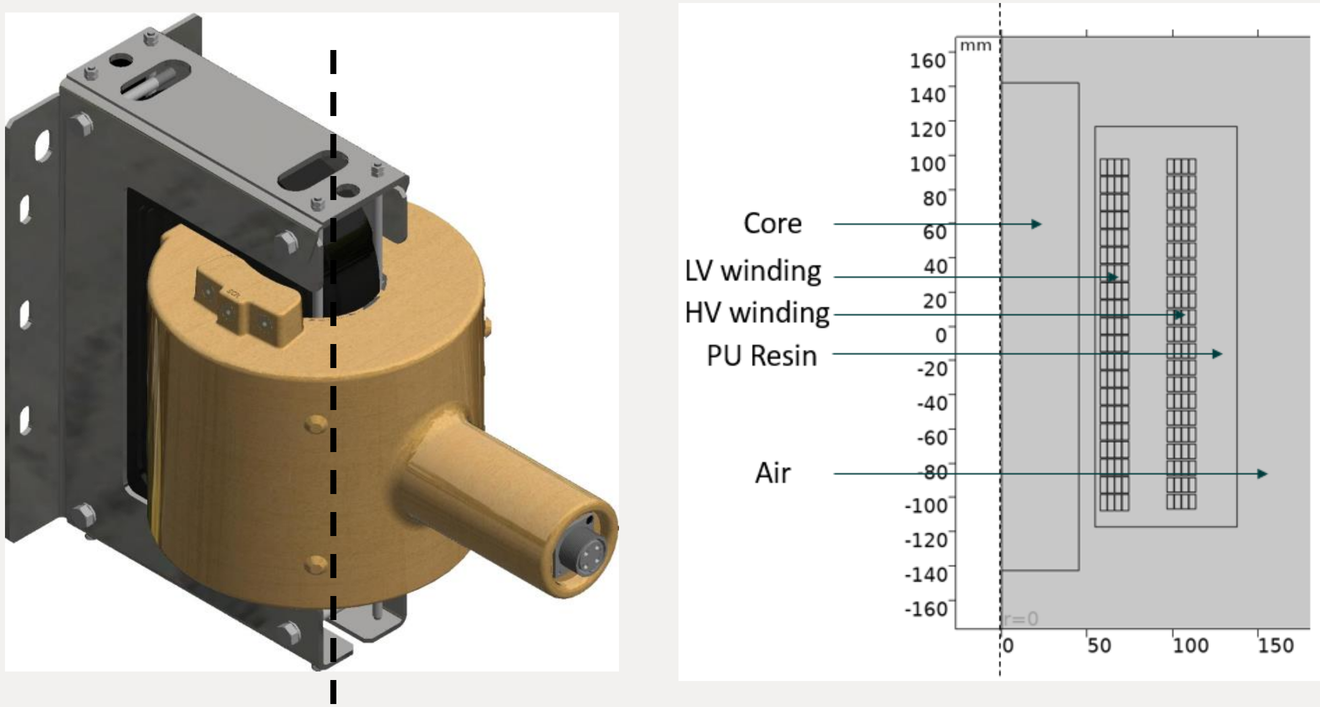
- High Voltage DC Isolation Transformers are used to provide AC power to the load that are operated at a DC voltage above ground potential.
- The DC voltage (up to hundreds kV) is much higher compare with AC voltage level (220 V).
- Under DC stresses, the electric field is temperature and electric field dependent. Therefore, it is important to understand the temperature distribution and electric field conductivity.

Electric Field Model

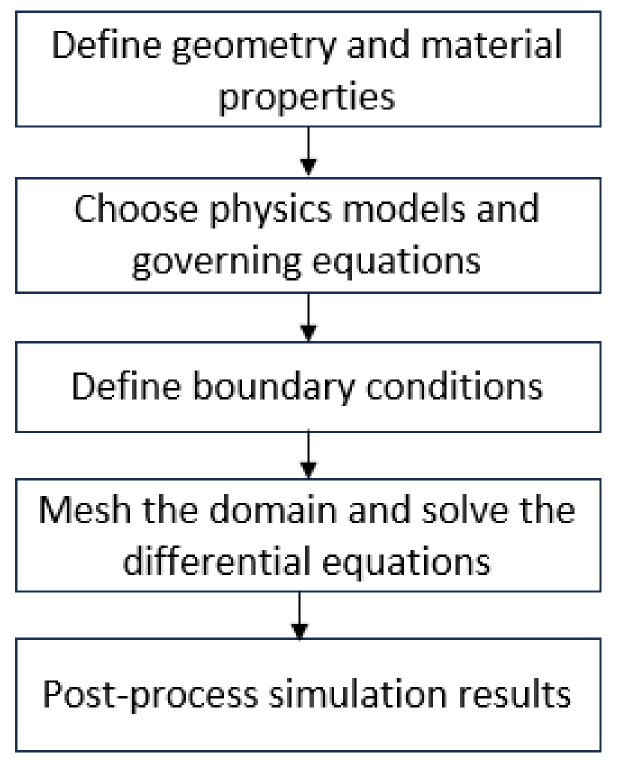


- An electro-thermal model is necessary to accurately simulate the DC electric field strength by considering the influence of temperature and electric field strength on conductivity of insulation materials.

Thermal Modelling



8 kVA 208/220 V cast resin dry-type transformer



Define geometry and material properties

Choose physics models and governing equations

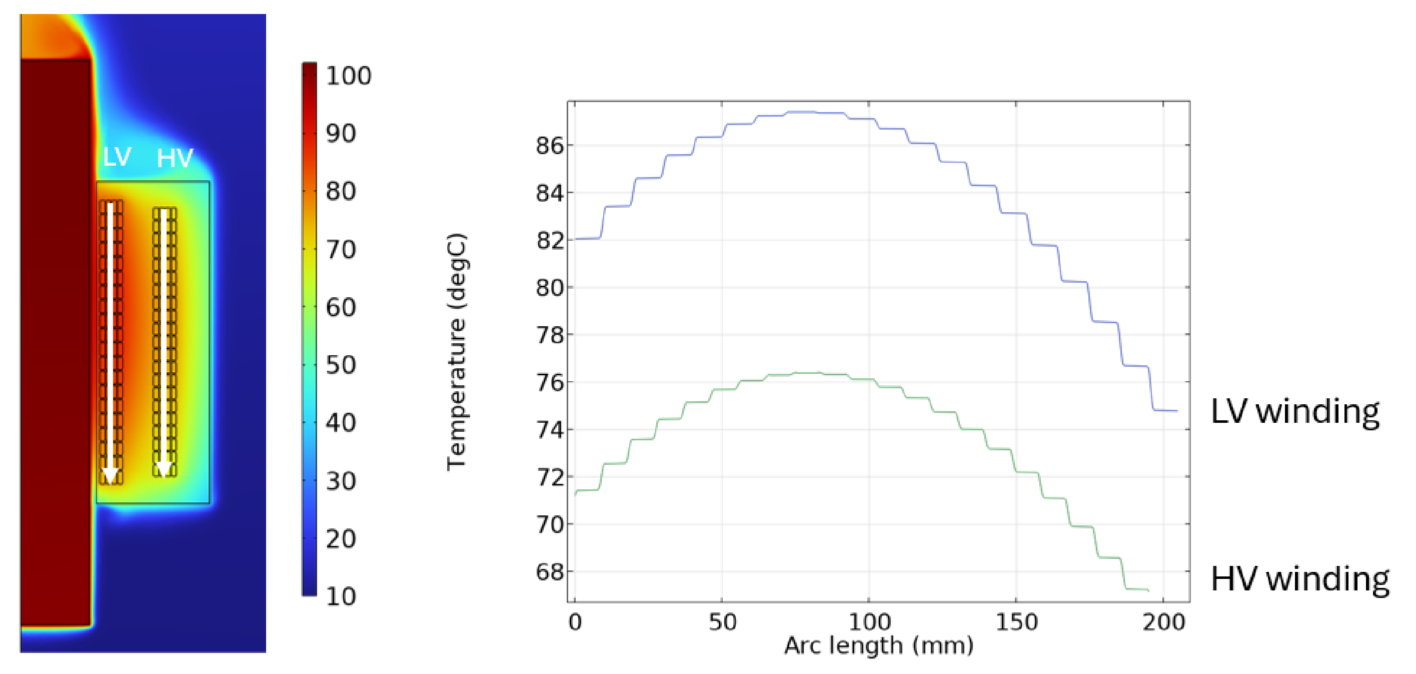
Define boundary conditions

Mesh the domain and solve the differential equations

Post-process simulation results

- This steady-state thermal model of an 8 kVA 208/220 V cast resin dry-type transformer based on finite element method to investigate the temperature distribution and hot-spot temperature.
- The winding loss is calculated based on I^2R, the core loss is calculated based on 2.45 W/kg in the datasheet.

Temperature Distribution and Hot-Spot Temperature



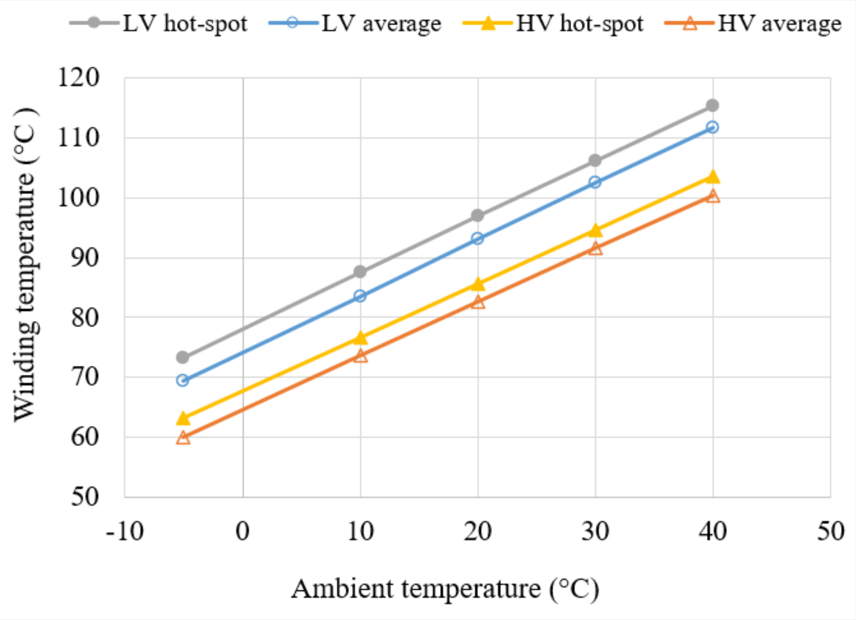
- The measured direction is from top to bottom in the winding centre for both LV and HV windings, the maximum temperature occurs at the inner top area of LV winding.
- The hot spot temperature is around 13 °C higher than the lowest temperature for HV and 9 °C for HV winding

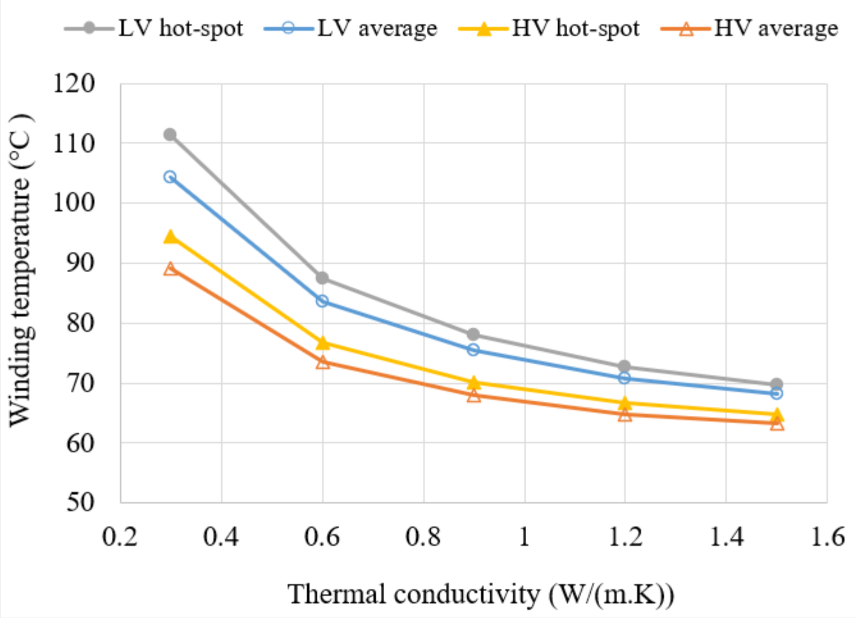
Thermal Model Validation

Temperature (°C)	Average LV	Average HV	Maximum LV	Maximum HV
Simulation	83.8	73.6	87.5	76.7
Test	80.3	76.1	NA	NA
Difference	3.5	-2.5	NA	NA

- The stable average winding temperature within 1K/h was recorded based on IEC 60076-11.
- There was less than 5% difference between the average temperature obtained from simulation and experiments.

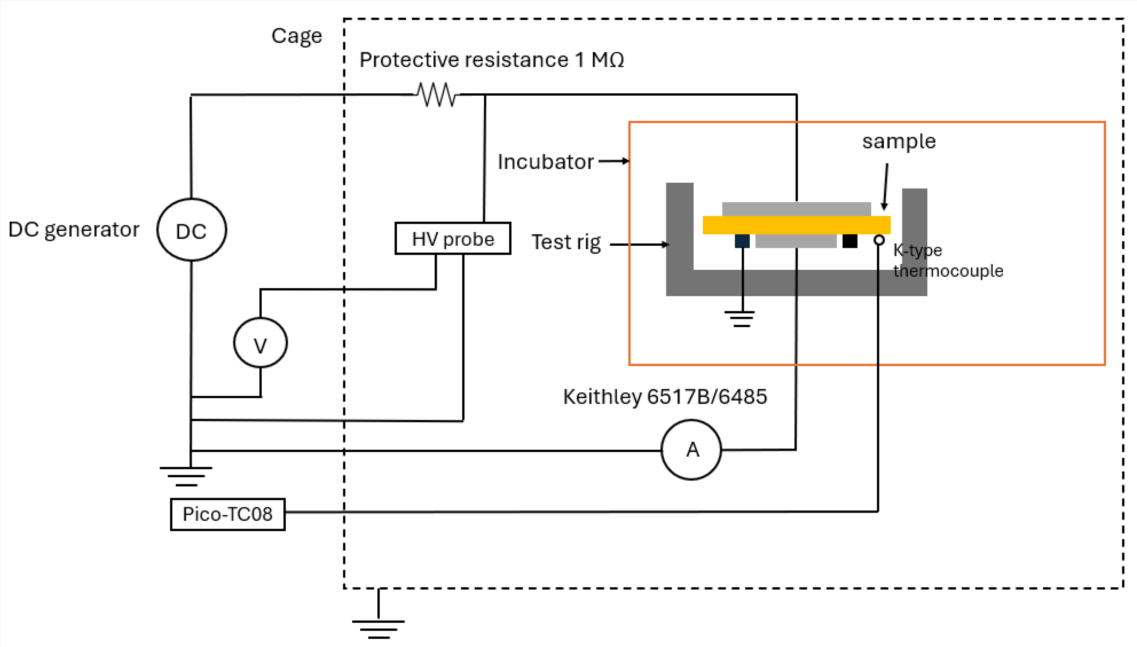
Influence of Ambient Temperature and Thermal Conductivity

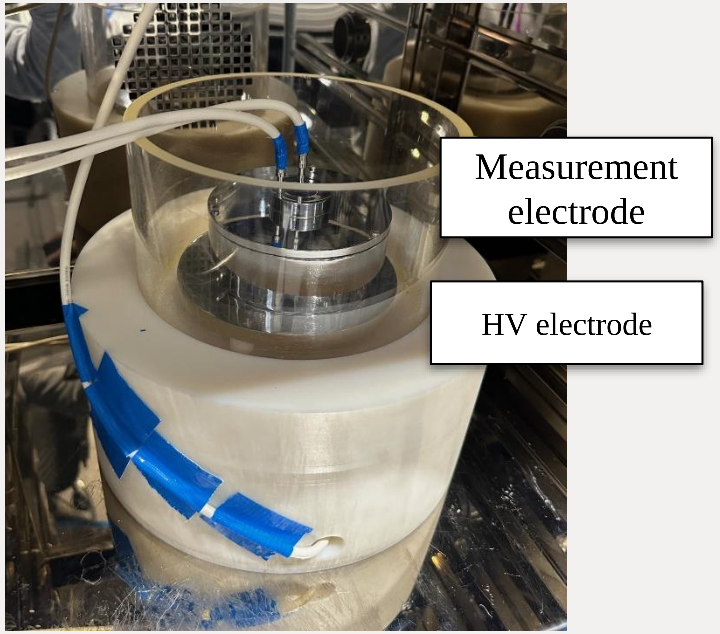




- The difference between hot-pot temperature/average winding temperature and ambient temperature remains constant.
- When the thermal conductivity increases, both hot-spot temperature and average winding temperature decrease rapidly first, and then decrease slowly and become saturate.
- While application of conductive fillers brings benefits to thermal performance, their influence on other dielectric and mechanical aspects must be evaluated during the design optimisation process.
- Hot-spot factor (hot-spot temperature rise / average winding temperature rise) is between 1.02 and 1.07 for call cases, which is different from the assumed hot-spot factor in IEC 60076-12 (1.25).

Conductivity Measurement



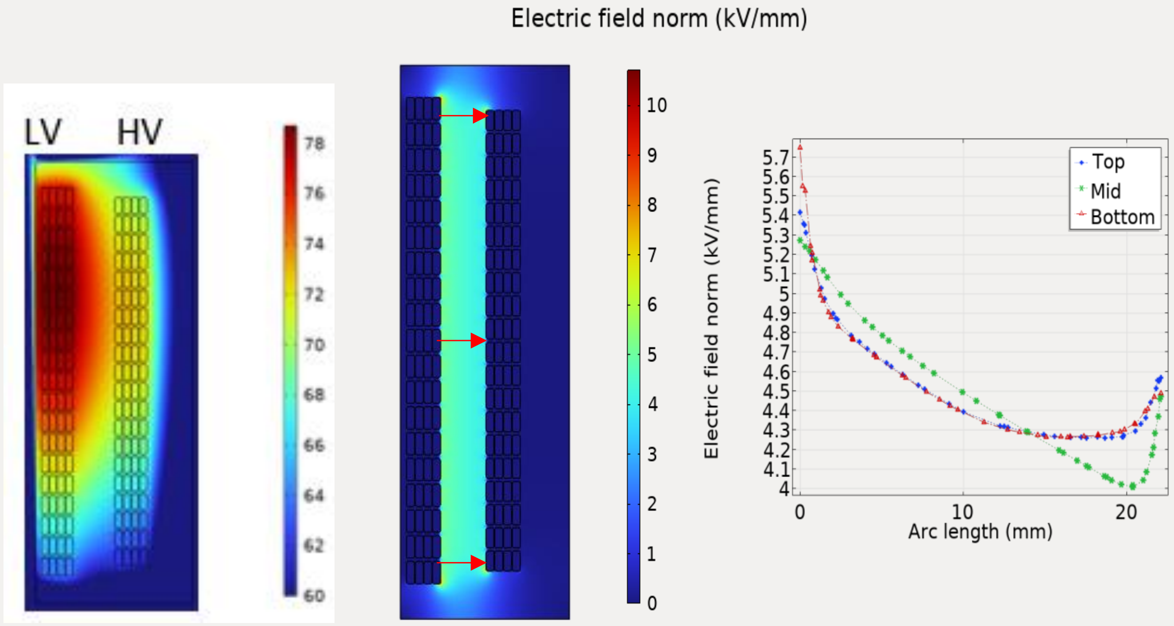


- Experiment procedure follows IEC 62631-3-1 volume resistance measurement of solid insulation material.
- The stable conductivity was measured under various temperature and electric field strength and curve-fitted by hopping theory model which is:

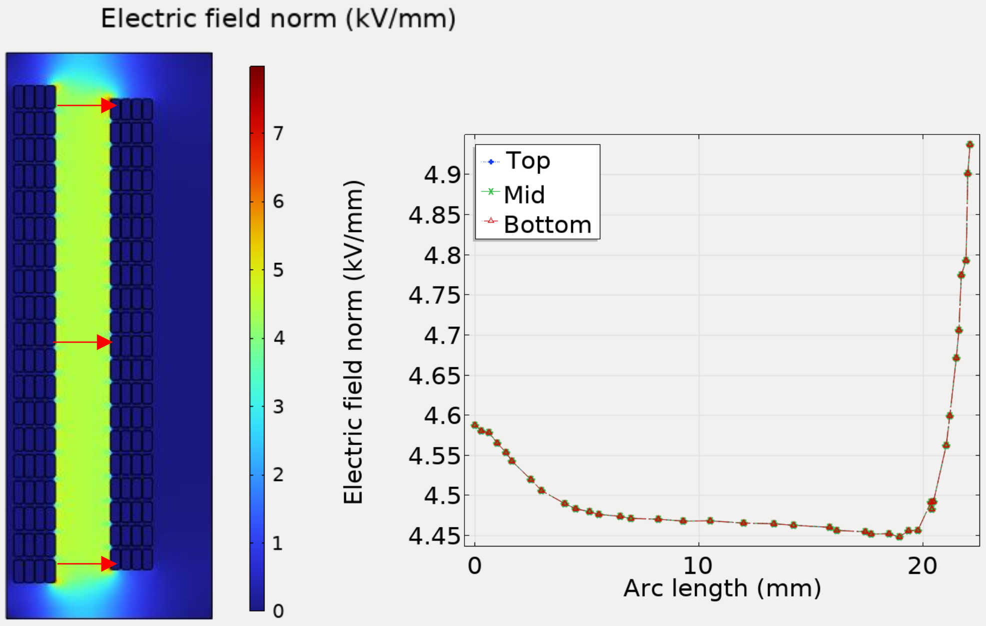
$$\sigma(E,T) = Aexp(\frac{-\varphi q}{k_B T})\frac{\sinh(B|E|)}{|E|}$$

where A and B are constants, φ is thermal activation energy in eV; q is elementary charge (1.6e-19), k_B is Boltzmann constant (1.38e-23) T is temperature in Kelvins, E is electric field in V/m.

DC Electric Field Simulations



Electric field distribution under constant conductivity



Electric field distribution under various conductivity

- For electrostatic model (constant conductivity), the electric field gradually decreases from LV winding and HV winding.
- For electro-thermal model (various conductivity), the electric field is uniformly distributed from LV winding to HV winding.
- Under DC stresses, the electrical conductivity around LV winding is higher than that around HV windings, which results in the electric field around the LV winding decreases.

Conclusions

- Both thermal and Electrical modelling are applied for thermal and electrical designs for cast resin DC-isolation transformers.
- For thermal design, the difference between hot-spot temperature/average winding temperature and ambient temperature keeps almost constant.
- Hot-spot factor varied depending on design and operation conditions.
- For electrical design, the influence of temperature and electric field strength on conductivity should be considered for electric field calculations.

References

[1] C. Roy, R. Murillo, L. Cebrian, M. Berrogain, J. Brewer, and J. Williams, "Dry-type 145 kV transformers: safe indoor substations with improved environmental performance," in *CIGRE A2-10864*, Paris, 2022.

[2] M. Berrogain and M. Carlen, "Dry-type transformers for subtransmission," 2013.

[3] U. Kaltenborn and T. Miessler, "On-site testing and PD diagnosis of cast-resin distribution transformers," in *2020 International Conference on Diagnostics in Electrical Engineering*, pp. 1-5, 2020.

[4] T. B. Gradinger, U. Drofenik, and S. Alvarez, "Novel insulation concept for an MV dry-cast medium-frequency transformer," in *2017 19th European Conference on Power Electronics and Applications*, IEEE, pp. 1-10, 2017.

[5] X. Zhang *et al.*, "HV isolated power supply system for complex multiple electrical potential equipment in 500 kV hybrid DC breaker," *High Voltage,* vol. 5, no. 4, pp. 425-433, 2020.

[6] Zhang, S., Fan, Y., Lei, Q., Wang, J., Liu, Y., & Zhan, T. Insulation structure design and electric field simulation of 500 kV isolation energy supply transformer for HVDC breaker. *High Voltage*, *7*(1), 185-196, 2022.