Hot stuff

ABB and the Technical University of Dresden collaborate on the thermal design of power equipment

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We live in a world where technological developments are advancing at the speed of light. These advances are making components more compact and as power requirements increase, thermal aspects are becoming ever more important. Temperature can be a limiting factor beyond which operation is not guaranteed. In the area of electrical power equipment, accurate knowledge of thermal behaviour is essential to predict reliability and performance in its environment.

Much research has been undertaken, particularly by the Technical University of Dresden, concerning the thermal behaviour of power devices like switchgears, transformers and bus bars systems. Using thermal networks and additional computational fluid dynamic simulations, the temperature distribution of a new or modified product design can be predicted and used for product dimensioning and optimization. This leads to improved products and reduces the need for time consuming and costly thermal tests and design.

Since the early 1990's, ABB has been benefiting from this research to improve and expand products in its electrical power equipment portfolio.

Two of the most important criteria in power equipment design are the electric field and the related dielectric design of insulating systems. As devices become more compact, and optimization is now a critical parameter in product design, the effect of electrical currents, and thus the effect of temperature on the product lifecycle must be considered. There is no doubt that product performance will be affected if temperatures exceed specified limits.

Conventional current conductors, for example, have an electrical resistance and therefore the greater the power loss, the greater the heat generated. To overcome these losses, accurate temperature distributions of all electrical power products are necessary.

Of course equipment manufacturers are interested in engineering devices where the isolating and conductor materials are used close to their thermal limits.

But electro-thermal losses are an intrinsic problem in today's electrical grids and can lead to high temperatures in the conducting paths and electric insulations. Maximized heat losses and the allowable thermal flow from the conductor to the environment may result in temperatures that exceed those specified by the manufacturer (or in the accepted standards) for conducting and insulating materials and electrical connections. To avoid this, the maximum permissible ambient temperatures during nominal load conditions must be considered.

> Electro-thermal losses are an intrinsic problem in today's electrical grids and can lead to high temperatures in the conducting paths and electric insulations.

Certain steps can be taken to improve thermal flux in devices and between several devices in a system. For example, designers should:

- Use high-temperature materials for insulators.
- Use materials with a high electrical conductivity for conductors.
- Choose an intensive temperature heat sink, eg, ventilation; forced cooling; or cooling sections (radiator box, heat pipes, Peltier elements etc.).
- Optimize conductor arrangement because of current displacement and proximity effects.
- Design long-term stable electrical connections and contacts.

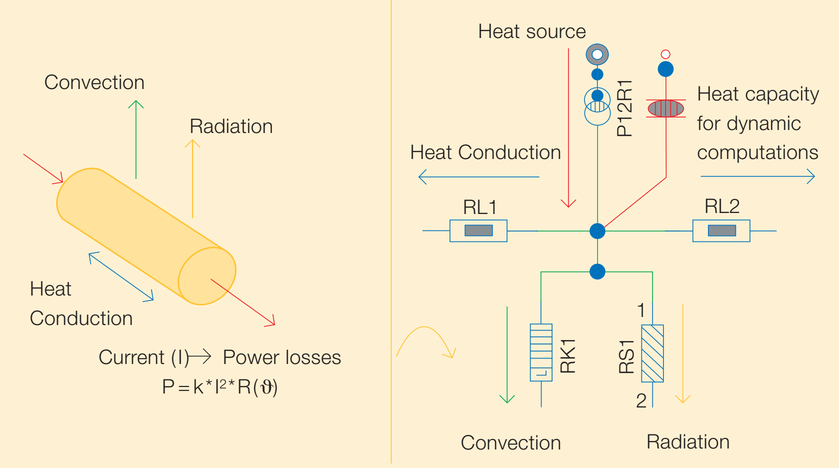
However the optimization of a new device by trial and error has always been very costly. A more cost effective way of predicting thermal behaviour is by using simulations.

In the 1950's researchers at the Technical University of Dresden (TUD) began to investigate new means by which the thermal behaviour of electrical equipment (in particular electrical generators and motors) could be calculated. The investigation led to the development of a tool that modelled the behaviour of both an electrical and thermal field. This tool broke complex problems into discrete elements which could then be described using simple physical correlations.

A key part of a Thermal Network is heat transfer via convection, and further developments allowed TUD to formulate a description of heat convection and radiation using so-called similarity functions. The similarity approach dates back to 1883 when Osborne Reynolds (a Professor at what is now the University of Manchester) first described the laminar and turbulent flow of liquids. In the 1920's, the well-known Thermal Machines Laboratory at Dresden University utilized and further developed this theory for steam engines and steam turbines, and in 1959, the first complex thermal

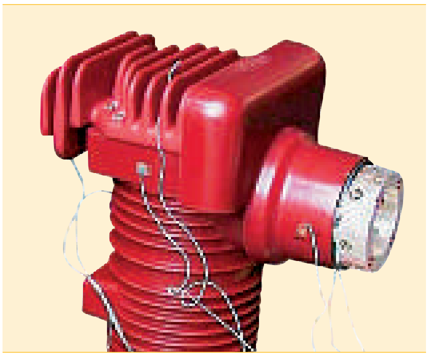
1 The Thermal Network Method (TNM).

Electrical Parameter			Thermal Parameter		
Potential difference	$\Delta\varphi$	V	Temperature difference	$\Delta\vartheta$	K
Electrical current	I	A	Heat flow	P	W
Electrical resistance	R_{el}	Ω	Thermal resistance	R_{th}	K/W
Electrical capacity	C	As/V	Heat capacity	C_W	Ws/K

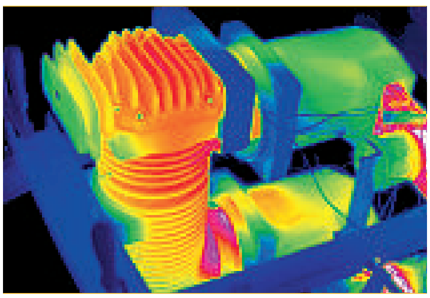


2 A reality check:
Test run on a simulated device:

(a) Wiring with thermocouples



(b) Infrared picture of MV-breaker.



networks were used to predict heat generation in motors and transformers. Over the following years, these networks were applied to more complicated structures such as switchgears, cable routes and high-voltage switch-yards. As a result, TUD has put together a thermal library that enables engineers to calculate and simulate complex electro-thermal problems using the Thermal Network Method (TNM).

Thermal Network Method (TNM)

The Thermal Network Method (TNM) is based on the analogy between the electrical and thermal field and has been used for many years to predict temperature increases in power devices. The complex geometries of switchgear arrangements, for example, are substituted by a network of integral elements representing the heat generation in conductors as well as heat transfer via conduction, radiation and convection [1].

TNM is currently used in ABB as a basic design tool for: medium Voltage switchgears; instrument transformers; fuses and fuse canisters; ring-main-units; cable connectors; vacuum breakers; and generator circuit breakers.

With the introduction of a computational network solver, the TNM was able to accurately predict the thermal behaviour of complete power devices. As computational power continued to increase in the 1990's designers were able to incorporate thermal capacitances thus allowing the dynamic behaviour of complex systems to be simulated. For electrical devices this feature is important for the prediction of an overload condition.

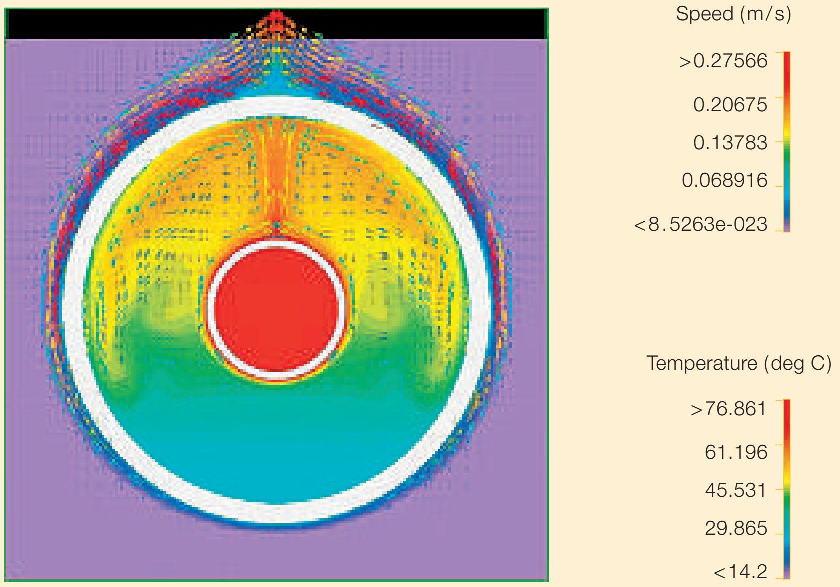
Each simulation is dependent on the quality of the models used so these must be as accurate as possible. The most reliable way of validating the models is by experiments and in particular temperature measurements which are made using thermocouples or infrared spectrometry [2]. A good model with a high degree of granularity can be accurate to within 1° Kelvin. Once a validated parameterized network has been created, engineers can easily investigate the influence of different factors, such as material and surface properties, mass transfer conditions and varying dimensions, on temperature increase.

Many are questioning the superiority of new tools such as multiphysics simulation tools (which use Computational Fluid Dynamics (CFD)) over TNM. It is true to say that certain physical problems, like the convection between two tubes, are more accurately modelled using CFD [3] rather than by the similarity approach of TNM.

The strength of CFD lies in its ability to accurately simulate individual physical structures like the convection between two tubes [3]. However, the more complex the system, the greater the computational time required. To be more specific, complex system simulation may take weeks or even months.

However, by integrating individual component results obtained using CFD into the similarity approach of TNM, the thermal behaviour of complex systems such as MV switchgears or HV Gas Insulated switchgears can

[3] Flow vector graphic with horizontal positioning of cylindrical conductors.



[4] ABB's circuit-breaker system type HECS.

History

The Institute of Electric Power Systems and High Voltage Engineering, Technical University of Dresden.

- *1894:* Institute for Electrical Engineering founded by Johannes Görges.
- *1919:* Ludwig Binder initiates a separate High-Current and High-Voltage Laboratory.
- *1928 – 1930:* Ludwig Binder creates the largest High-Voltage institute in Germany.
- *1945:* Buildings completely destroyed.
- *1945:* High-voltage hall rebuilt with a 2 MV impulse generator and a 1.5 MV alternating voltage source.
- *1951:* Institute for High-Voltage Engineering separated under Fritz Obenaus.
- *Up to 1963:* Basic work done for the 400 kV-AC-transmission system.
- *1968:* Mosch succeeds Obenaus and starts the development of SF_6-insulated switchgears (GIS).
- *1978:* Major research activities in the field of the electro-thermal stresses of power equipment under Helmut Böhme.
- *1980s:* New concepts for the measurement of partial discharges developed by Eberhard Lemke.
- *1990:* Institute of High-Voltage and High Current Engineering was founded.
- Continuous research work on electro-thermal problems under Helmut Böhme, Helmut Löbl, Steffen Grossmann.
- Research work on insulation materials under Martin Eberhardt, Josef Kindersberger and Steffen Grossmann.
- *2003:* Two institutes amalgamated to form the Institute of Electric Power Systems and High Voltage Engineering.

Today's research areas:
- High Voltage Engineering (polymer insulation, motor insulation, transformer insulation).
- High Current Engineering (long-term behaviour of electrical contacts, electro-thermal simulation.

be determined in less than a minute for static simulations and a little longer for dynamic simulations.

The advantages of both methods mean that complex physical problems can be solved using CFD methodology. The derived model will be verified by experiments and will then undergo a major parameter study. A new model for the TNM can be developed out of this parameter study and used for fast system calculations.

So how does ABB Benefit

Over the years TUD has clearly established itself as a center of excellence in the field of high current technology (see box). In addition the university is exceptional in its ability to transfer this knowledge into industrial applications, and as a leader in power and automation technologies this is of tremendous importance to ABB.

TNM is currently used in ABB as a basic design tool for: medium Voltage switchgears; instrument transformers; fuses and fuse canisters; ring-main-units; cable connectors; vacuum breakers; generator circuit breakers; GIS; dry transformers; HV-bushings; LV-contactors; and line switches.

Perhaps a good example of how TNM has benefited product development is ABB's new platform for Generator Circuit Breakers, HECS 4.

"Breaking" the current in a power station in order to protect grid equipment from damaging power surges requires the most powerful circuit breakers in the world. The circuit-breaker system type HECS has been developed as a system suitable for application in all types of power plants and is guaranteed for 20,000 close/open operations compared to its predecessors' 15,000 operations. In addition it:
- Is based on a modular concept.
- Has a reduced footprint.
- Is lighter.
- Has increased short circuit current.
- Has increased numbers of operations.

Thomas Schoenemann, Head of ABB's R&D High Current Systems is convinced that these new features could only have been implemented due to the good results from the TNM simulations. "Controlling the heat-flow in a high current system is the key to an

optimized design. By simulating the thermal behaviour of the breaker, we can optimize individual customer orders."

The future

ABB's Power Device Technologies corporate research program is currently working together with TUD in the areas of:
- Complex simulation of medium-voltage switchgears.
- Thermal design of high current systems.
- The long term behaviour of electrical contact systems.
- Thermal simulation of high voltage Gas Insulated Switchgears (GIS).

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