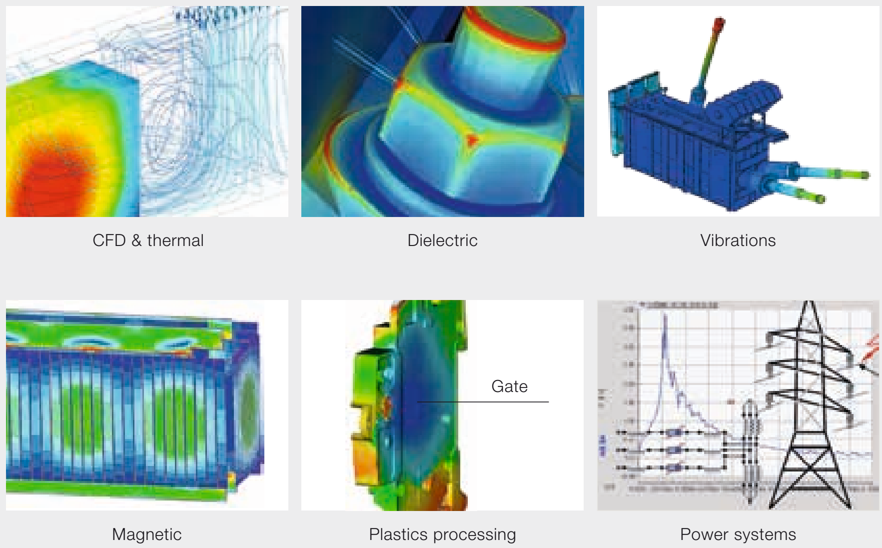
Reality predicted

Simulation power for a better world

GEORG SCHETT, MAREK FLORKOWSKI, ARTHOUROS IORDANIDIS, PETER LOFGREN, PIOTR SAJ – Simulations play a pivotal role in today's research and engineering work. Advances, both in computer power and computational techniques, are constantly expanding the range of simulation applications as well as their accuracy. The scope of applications ranges from multiphysics through system study to manufacturing and production processes. Most of the cases discussed in the present issue of *ABB Review* are concerned with computing spatial and temporal distribution of physical quantities such as electromagnetic, flow and temperature fields. This article looks at some of the principles involved.

1 Examples of types of simulation areas and tools



The main purpose of simulations in engineering design is to understand phenomena taking place in a real physical object or system and to optimize the design process → 1. The overall process starts with the digitization of the real object and ends with implementation of the digital information gain in design changes → 2.

Simulation methods

There are many different methods of performing simulations:

- Mesh based (geometrical discretization)
- Meshless
- Systems and networks studies
- Production process analyses
- Others

Mathematical modeling

Mathematic modeling is the first step in a computer simulation. In this phase, the physical problem is described in terms of mathematical equations. Only the physical phenomena described by the equations can be captured in the simulation. The challenge of mathematical modeling is to find a balance between the complexity of the real system and the engineering rationale required for the application of the model in product design. Correct mathematical description of the physical phenomena is a subject of theoretical (or mathematical) physics – a scientific field in the overlap of physics and mathematics.

Preprocessing

Preprocessing is the step of preparing the geometry for simulations. This is another idealization step in which the geometry is simplified to the point that, on the one hand it retains the relevant geometrical features, and on the other allows the generation of an appropriate mesh. From this point onward the real geometry is replaced by a meshed geometry. Creation of a high-quality mesh is one of the main bottlenecks in the industrial application of simulations. Indeed, real industrial geometries are typically very complicated and not easy to cover adequately by a computational mesh. Moreover, if the created mesh has a poor quality, it will likely hinder the convergence of the simulation or lead to physically incorrect solutions.

Solution

The equations of the mathematical model are solved numerically on the computational mesh. The discretization method transfers the model equations from the continuum to the discrete domain. Finite and boundary element methods (FEMs and BEMs, respectively) are typically used by ABB for mechanical and electromagnetic computations, whereas finite volume methods (FVMs) are common for computational fluid dynamics (CFD). These are the methods most commonly used in ABB's computational methods for field calculations, but numerous commercially available and academic tools based on other discretization methods do also see use. It is also common that technology companies (such as ABB) develop dedicated computational methods and solvers for their specific engineering needs[1].

Post-processing

Post-processing is the phase of visualizing the obtained results and is an integral part of the simulation process. In general, it involves visual presentation of simulation results, usually in the form of a 2-D or 3-D map (contours) showing the distribution of a quantity obtained from the calculations. Dynamic behavior of the simulated object or process can be visualized by animations. Such a spatiotemporal presentation of the computed physical quantities makes simulations particularly suited and attractive for analyzing complex physical phenomena in real devices. However, besides the field visualizations, presentation forms such

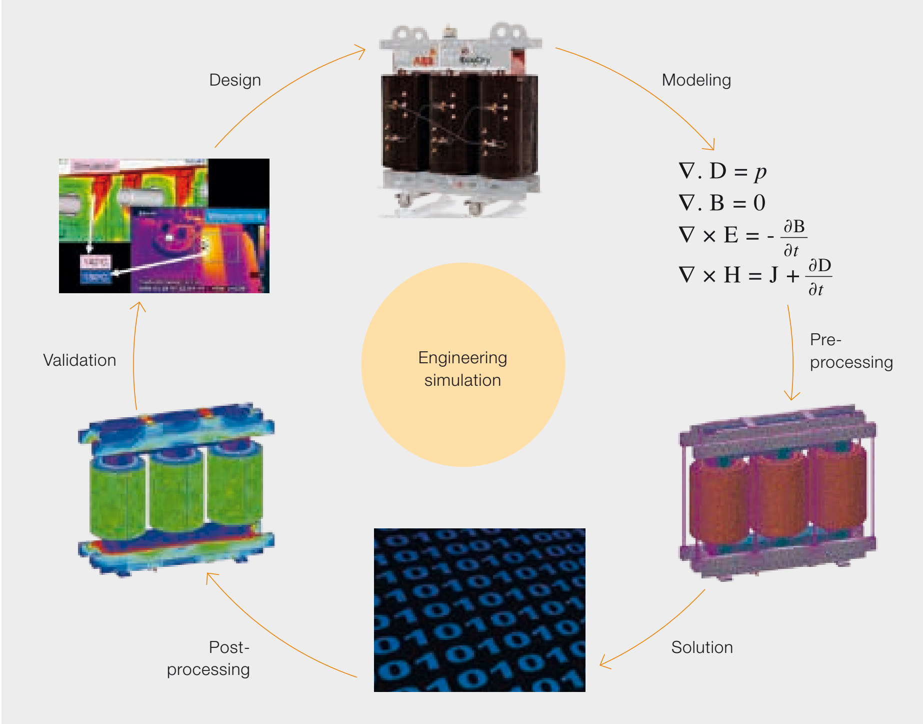
Title picture

Simulation plays a vital part in the design and development of new products. The title picture shows the assembly of corona shields in ABB's UHV (ultrahigh voltage) test hall in Ludvika, Sweden.

Footnote

1 See also "Simulation toolbox: Dielectric and thermal design of power devices" on page 16 and "Switching analysis: Simulation of electric arcs in circuit breakers" on page 34 of this edition of *ABB Review*.

2 Schematic representation of a simulation process cycle



as point plots and time-space averaged quantities are also of great importance since they can be directly compared to the measurements. Recent rapid growth in digital 3-D imaging technologies has also opened new capabilities for visualization of computational data.

Validation

The relative simplicity of gaining a comprehensive insight into complex physical phenomena by simulation exposes its main pitfall: Simulations can return false results bearing no relevance to the real physical phenomena, or so-called "nice colorful pictures" with incorrect or even misleading information. Such spurious solutions can be a result of deficiencies at every step of the simulation process: the wrong model, oversimplified geometry, inaccurate material data, an inappropriate mesh and an inappropriate solver.

To assure the match between the simulated results and real physics, a validation should be conducted. This final check is normally achieved by comparing the computed and experimental results. The process of validation is complicated by the limited number of parameters that can be measured directly. In spite of the difficulties, the validation step is mandatory, since validated simulations are distinguished by their predictive power (this is in contrast to calibrated simulations, where the validity of the results is always questionable outside the range of calibration).

Design

Finally, the simulation loop is closed by extracting information from the simulations and making design changes based on the data. At this stage the tremendous potential of simulations can be exploited to facilitate product development. First of all, simulations provide understanding of the details of the physical phenomena, and are hence of great importance for the designers. Additionally, simulation results can be obtained much faster than prototype building and testing. A great strength of simulation lies in the ability to perform parametric studies that replace expensive trial-and-error loops in classical design processes.

Simulation at ABB

ABB, as a leading technology company, has introduced a variety of simulations into its research and development activities.

A good example is the short-circuit testing of the largest ABB step-up transformers. It is critical that such a transformer can withstand the electromagnetic forces originating from the high short-circuit currents. Due to the very high energies involved, there are only few facilities in the world where such transformers can be tested. The challenge is augmented by the very large dimensions of these transformers that impose severe constraints on their transportation. Obviously, such testing is associated with very high costs and time requirements. It is remarkable to note that recent progress in simulation has led to changes in international standards, making it acceptable to demonstrate short-circuit withstand capability through computations (IEC 60076-5).

Another example of advanced coupled field simulations – providing an extraordinary insight into the physical phenomena taking place in the device – are arc simulations in circuit breakers. The circuit breakers are designed to withstand and interrupt short-circuit currents of up to hundreds of kA within tens of ms. Testing these is not only costly and time consuming, but the number of measurable parameters is also very limited. ABB can run coupled electromagnetic / fluid dynamic / mechanical simulations to capture the true behavior of the breaker during fault current interruption[2]. As a result of the simulations, the designers obtain full insight into the flow conditions in the breaker. They can measure the pressure and voltage at any point within the breaker and can compute forces acting on the critical components. This is a powerful technique, enabling the emergence of

Advanced and complex simulations of multi-physical phenomena occurring in breakers, transformers, motors, drives, robots, electrical power systems and many others are carried out routinely at ABB. The globally distributed experts contribute onsite to both speed up the development phase and minimize the expensive testing effort.

breaker designs of even greater reliability. Finally, almost all ABB products deal with voltages. Although at the lowest voltage levels, dielectric insulation can be handled by simple design rules, at high voltages design work is virtually impossible without calculations of the electric field. Therefore, 2-D and 3-D electric field computations are indispensable parts of the design process in many ABB development processes.

Use of such tools reduces the dielectric stress on the critical parts of products and thus avoids breakdowns and failures. Until recently, such computational investigations have been done by running a set of simulations in order to select the best parameters from this often limited set. Today, due to the progress in optimization methods and computing power, optimal solutions can be found by combining electric field computation with an automated optimization. Such advanced methods have already been integrated into ABB design tools such as Simulation Toolbox and are revealing their huge potential[3].

Due to the importance of simulation and its rapid growth in ABB's research and development efforts, global internal simulation conferences have been organized within the company in order to share experiences and best practices. At these events, ABB has also learned from the leading companies within related industries such as automotive, aircraft and consumer industries.

With the skills and experience acquired, ABB has further optimized its simulation environment by:

- Making core simulation tools easily accessible to all engineers
- Sharing simulation clusters for large and CPU-intensive simulations
- Holding virtual forums for sharing best practices
- Providing simulation support for less experienced development teams

Today ABB can confidently assert that it is in a strong position when it comes to applying simulation and using it to develop the best products for customers. This issue of ABB Review reports on a wide range of advanced simulations ranging from electromagnetic effects in transformers to the processing of plastics.

Future simulation trends

The progress in simulation was made possible by progress in software and hardware, mainly processors, storage and communication. In the past, highly complex simulation could be run only on supercomputers or big clusters, whereas more and more frequently high-power desktop computers are sufficient today. The computing power of supercomputers will soon be measured in exaFLOPS, and high-performance notebooks can today already reach already the level of terraFLOPS – a magnitude that was hard to imagine as little as a decade ago. Simultaneously, due to new graphics processors, an enormous development can be observed in post-processing and visualization including the animation of results. This trend is continuing, as can be observed for example in the incredible computational power of today's mobile devices. Cloud computing is maybe still in its incubation stage, but in the near future complex simulations will be started from desktop or mobile devices and calculated somewhere in the cloud.

Future areas of simulation are unlimited, going beyond new designs, system study and production optimization. One can imagine in the near future that on-site simulations could be based on mobile services, that full parametric multiphysical optimization will be possible, or even 3-D printers equipped with simulation and optimization modules to recalculate objects on the fly prior to printing.

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Footnotes

2 See also "Switching analysis: Simulation of electric arcs in circuit breakers" on page 34 of this edition of *ABB Review*.

3 See also "Simulation toolbox: Dielectric and thermal design of power devices" on page 16 of this edition of *ABB Review*.