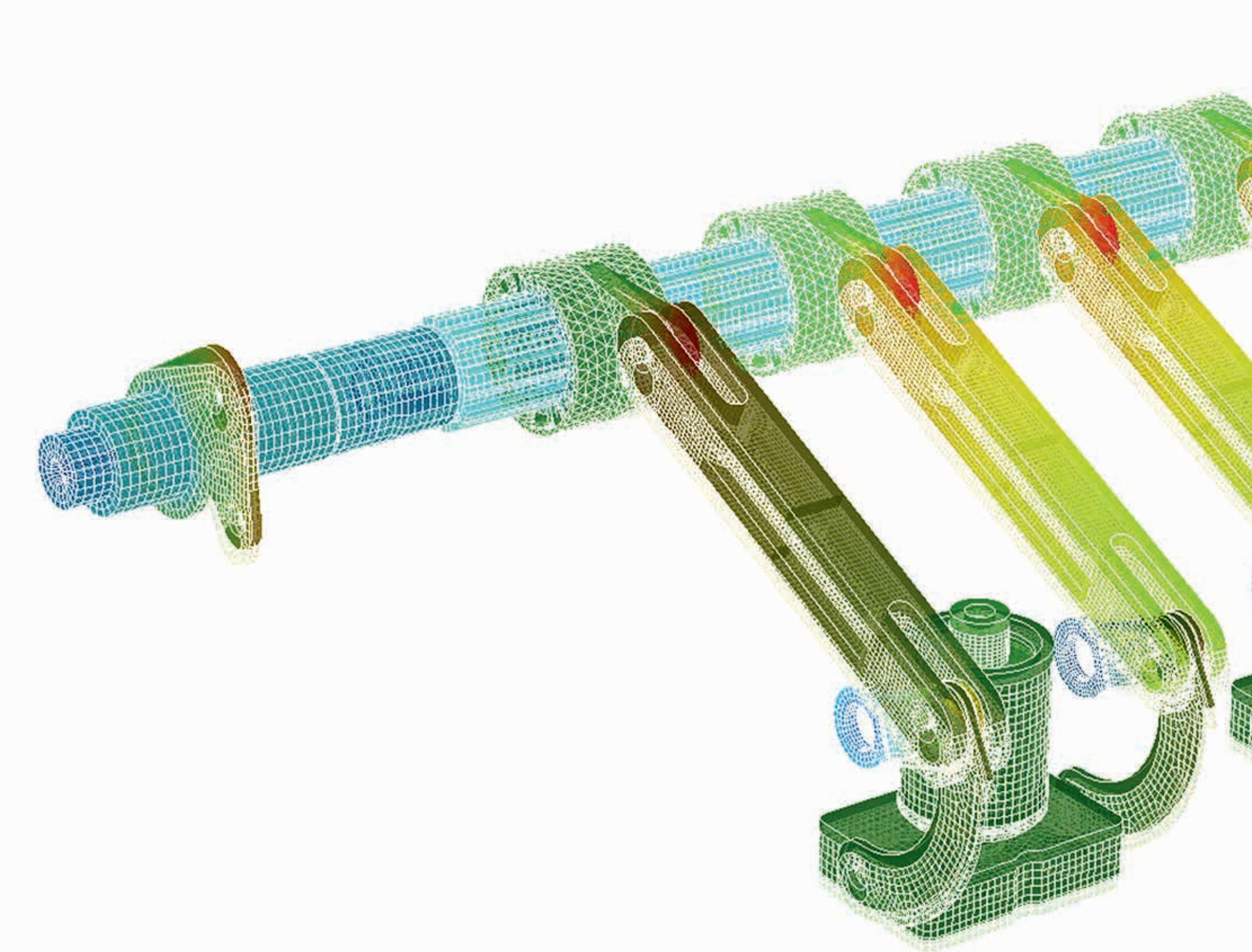


Model matrix

Modularized simulation concepts for breaker analysis and optimization

GRZEGORZ JUSZKIEWICZ, CHRISTIAN SIMONIDIS, GREGOR STENGEL, LUKASZ ZIOMKA, SAMI KOTILAINEN – Computer simulation tools have long been used in product development. Increasingly, engineers are facing situations in which simulations from different physical disciplines must be combined. Medium-voltage and high-voltage circuit breaker development is a good example of this: Mechanical, gas flow, tribological, hydraulic and electromagnetic effects all have to be taken into account during design and test phases and, ideally, each of these should be simulated in concert with the others. Moreover, coil-actuated breakers can be controlled electronically, so the control aspect also has to be woven into the design and analysis of the product. Traditionally, each domain had a dedicated simulation tool and dedicated experts who cooperated and exchanged simulation data and knowledge at appropriate junctures. However, the complexity of modern breaker design demands that these simulation domains be organized inside a structure that guarantees real-time and dynamic transferability, transparency and reusability as well as model object libraries and interfaces that are easy to use.

In the postprocessor, the user can view all predefined field outputs, show or hide part instances, create cross-sections and define custom views.

In today's multinational development environment, simulation tools must be used across disparate organizations by engineers with different levels of expertise. Moreover, they should be utilized in the most efficient manner possible – one in which best practices can be easily captured and repetitive model-building tasks are automated or eliminated. Two main approaches to this are employed at ABB for circuit breaker design.

Tools and environment

The first approach is provided by the breaker simulation toolkit (BST) – a set of user-defined subroutines built into the commercial multibody simulation tool MSC.ADAMS. The subroutines define commonly used circuit-breaker components such as operating mechanisms, linkage components, dampers, etc. The BST components are fully parametric, which enables various design studies to be run, and are easily accessible from the graphical user interface of MSC.ADAMS.

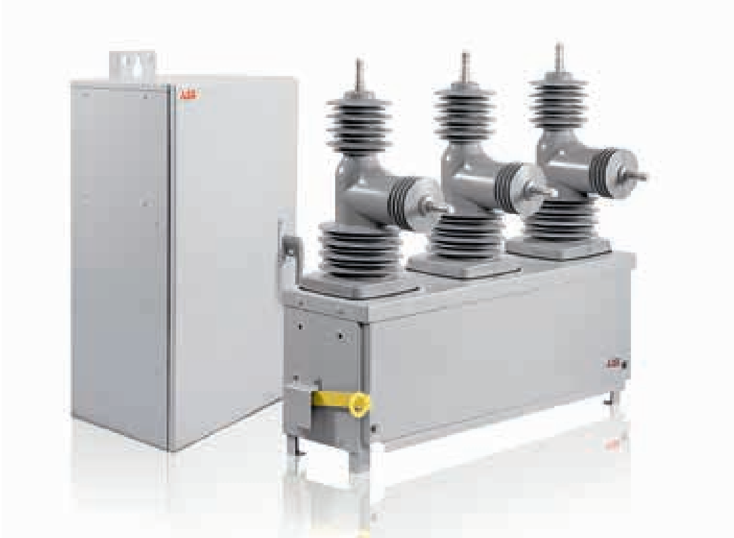
A slightly different approach is taken by the interrupter libraries implemented in the Dymola platform – a commercial modeling and simulation environment based on the open Modelica modeling language. Here, the entire thermodynamic behavior of the interrupting chambers is modeled from standard components and stored in a central library. In this way, all of the development variants are available during the development project and, as the final design is released, it is stored and made available to various external users when necessary. External users cannot change the variants and model encryption protects sensitive information. This approach offers the benefits of a quick devel-

In today's multinational development environment, tools must be used across disparate organizations by engineers with different levels of expertise.

Title picture
To quickly get an insight into the complex physics of breaker behavior, diverse simulation tools have to be harnessed to work together in a structured setup that facilitates tool chaining and runtime variable exchange between the tools. But the interaction of tools that simulate completely different physical domains is a complex matter, so how can it be managed?

An alternative to chaining is the fully coupled approach. Coupling addresses the requirement to have realistic real-time and dynamic interaction of physical domains.

1 The elements of the three-phase ABB Gridshield recloser. The RER620 protection and control unit (bottom right) is standard with the recloser.



opment process while ensuring the same variant of the product is available to all users.

Sometimes it is necessary to have flexibility when handling the components (ie, selected parts of the whole assembly) of the system to be simulated. In the case of MSC.ADAMS or Dymola, component object geometry is represented by a mass point ("lumped mass") with predefined inertia moments and components themselves treated as rigid entities. Simulations based on finite element analysis (FEA) methods then offer accurate calculations of stresses, strains and many other variables for components represented in a discrete way. Interactions between components can be formulated in terms of connector elements and in terms of contact behavior.

Contact modeling is of great importance when there are complex interactions between parts of the assembly – one can predict possible collisions between components and evaluate the maximum contact pressure.

ABAQUS is one example of a commercial FEA package that can provide this flexible modeling of multibody systems. Because ABAQUS represents the system in finite element form, additional effort is required from the user for mesh generation, definition of relations between components, material assignment, load characterization and boundary condition setup. The open-source Python scripting language can be used to automate some of these steps. In addition, sophisticated features of the finite element model can be defined by user subroutines. Besides this, FEA also offers a hybrid method for multibody system modeling whereby some components are represented by rigid bodies and others by flexible ones. This can make calculation times much shorter than in the case of full flexible body modeling.

The tools and environment necessary for complex simulations are thus available. The task remains to organize these in such a way that tools from very different physical domains are made to work in concert to produce the very best simulation results.

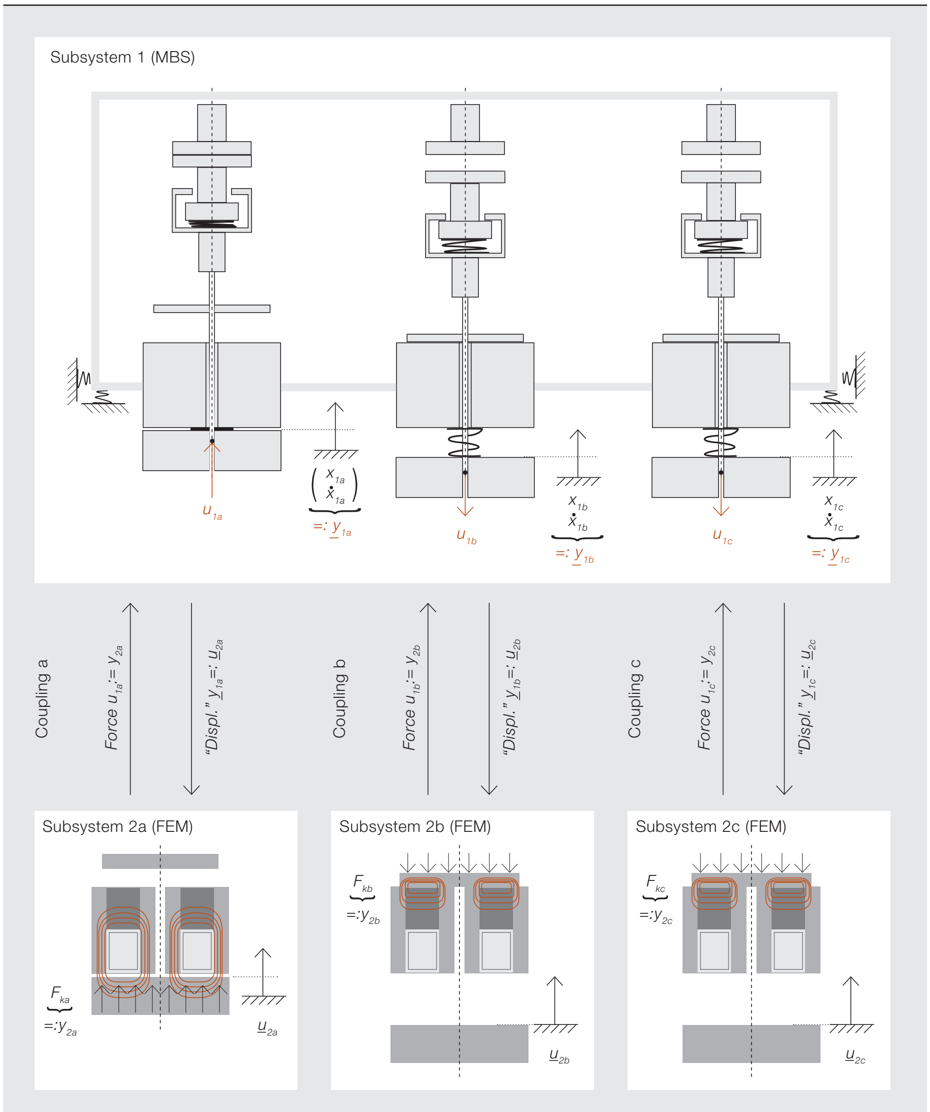
Tool chaining and model coupling

During product development, the output of one simulation can often be used as input to another. This is called tool chaining. In the case of mechanism simulations, results from rigid body calculations (eg, MSC.ADAMS) can be transferred to an FEA package (eg, ABAQUS) so that particular details may be scrutinized. Another example is when output from a thermal simulation is supplied as starting data for a full fluid dynamics simulation.

An alternative to chaining is the fully coupled approach. Coupling addresses the requirement to have realistic real-time and dynamic interaction of physical domains. Two approaches to this are prevalent:

In the first, the overall physical equations are implemented in a single appropriate multiphysics software tool, using realistic models of nonlinear external forces instead of simplifications such as lookup tables.

2 ABB Gridshield Recloser – simulation scenario



During product development, the output of one simulation can often be used as input to another. This is called tool chaining.

In the second, mono-disciplinary submodels are built up in dedicated tools and coupled together in the mathematical sense. The physical-domain-related equations of the submodels are solved by their own particular time-integrator and information related to the state of both systems is exchanged at certain synchronized times. This so-called co-simulation enables the computation of complex physical interactions, facilitates reuse of submodels and efficiently concentrates expert knowledge in particular physical domains.

Coupling environment

ABB has created a simulation environment that makes use of both in-house and commercially available coupling routines to enable co-simulation between the worlds of multibody mechanics, structural mechanics, fluid dynamics and transient electromagnetics. Analysis of the interaction of magnetic diffusion effects and mechanism dynamics is one particular, and important, tool not widely available in current multiphysics offerings. To compensate for this, ABB has developed an appropriate environment in cooperation with universities to allow the coupling of COMSOL (an FEA package tailored for coupled phenomena) with MSC.ADAMS.

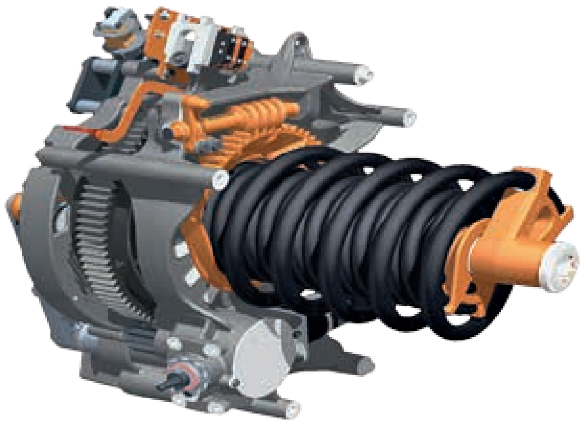
Co-simulation and breaker design

A recent coil-actuated product, the ABB Gridshield® recloser, has been simulated using co-simulation → 1. This simulation scenario involves several subsystems → 2. The electromechanical analysis carried out in this product development provides a good example of coupled simulation.

The first step in such an analysis is to evaluate current density and Lorentz force distribution. The second step involves the calculation of stress and displacement of parts subjected to Lorentz forces.

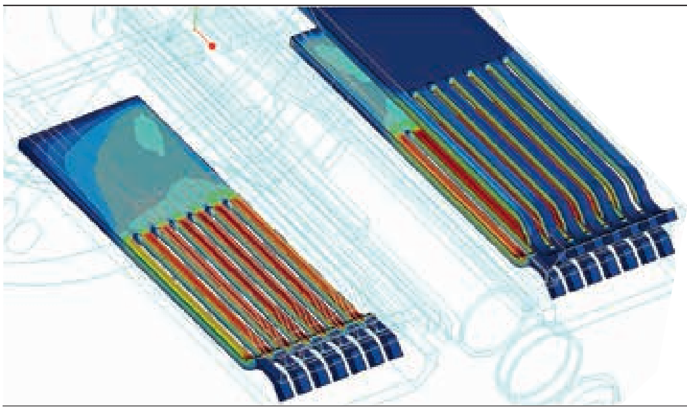
Lorentz forces, power losses and current densities can be computed using Simulation Toolbox, an ABB-internal software. For stresses and displacements there are two tools that can be used: the mechanical solver embedded in Simulation Toolbox or ABAQUS. The latter allows customized simulation: More field outputs can be added, nonlinear material properties can be defined and a modal analysis can be performed to check eigenmodes and natural frequencies. Simulation Toolbox uses PTC Creo Simulate as a preprocessor and postprocessor. PTC Creo Simulate allows 3-D virtual prototyping that enables structural and thermal properties of a design to be tested early on in the design process. In the postprocessor, the user can view all predefined field outputs, show or hide part instances, create cross-sections, define custom views and so on.

3 ABB MSD1 drive

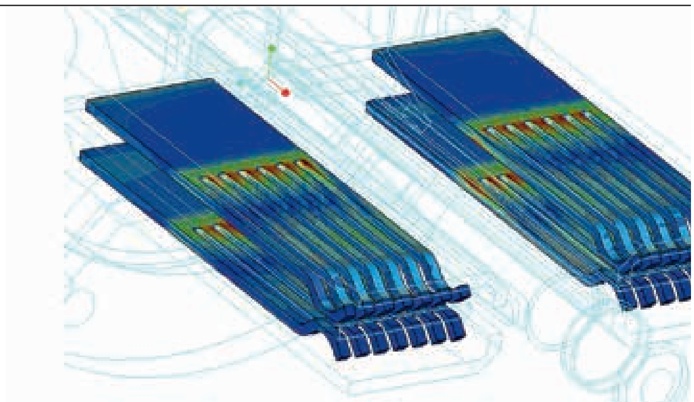


4 ABB MSD1 drive – displacement field view

5 Breaker contact fingers – Lorentz force and stress field view



5a Lorentz force density



5b Stress field distribution

Example – breaker drive

The MSD1 drive is mounted on a high-voltage circuit breaker and is responsible for opening and closing the circuit breaker contact → 3. The energy required to open and close the contact is stored in three springs. Two of the springs are used to close the contact and one (the outer one) to open it. When they are released, the energy stored in the springs causes rotation of the main shaft of the drive. This shaft operates the contact mechanism inside the circuit breaker.

This device (or its components) can be modeled using several different simulation tools (viz., MSC.ADAMS, Dymola, ABAQUS). Moreover, these tools can be coupled together – output from one solver can be used as input to another. The ABAQUS output for a displacement field calculated in this way is shown in → 4.

Example – breaker contact fingers

Another example of co-simulation is found in the electromechanical simulation of the breaker components. The idea of this simulation was to evaluate current and Lorentz force density. Evaluated forces were transferred to an FE (finite element) structural code so the stresses and displacement could be evaluated. An example of current density and stress field distribution is shown in → 5.

Future framework

Modern simulation tools offer a wide range of powerful methods that can be used to solve the complex problems encountered during the development of sophisticated products. Tools that simulate several different physical regimes can be coupled and chained by using externally and internally developed software and plugins. This synergic methodology leverages the strengths of the individual tools and delivers a simulation technique that is much more than the sum of its parts. Importantly, this modular simulation approach produces accurate and useful results within a reasonable calculation time. Work is ongoing to increase the convergence of these simulation tools and to further integrate them into one coherent framework. Thus, they will be even easier to implement and engineers of varying degrees of expertise in different organizations will be able to exploit this synergy to produce even better products.

Grzegorz Juszkiewicz
Lukasz Ziomka
ABB Corporate Research
Krakow, Poland
grzegorz.juszkiewicz@pl.abb.com
lukasz.ziomka@pl.abb.com

Christian Simonidis
Gregor Stengel
ABB Corporate Research
Ladenburg, Germany
christian.simonidis@de.abb.com
gregor.stengel@de.abb.com

Sami Kotilainen
ABB High Voltage Products
Baden, Switzerland
sami.kotilainen@ch.abb.com