Multi Body Simulation - As One Aspect Of The Model Formulation And Simulation Of Current Limiting Power Circuit-Breakers

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Abstract

The modelling of several physical sections and their interactions are required in order to simulate electrical switching devices. This presupposes on the one hand the connection of different software packages and on the other hand a self-contained mathematical solution for the complex behaviour of the system.

With the Klöckner-Moeller modelling and software concept it is possible to abstract the subsystems based on behavioural models and thus find a uniform mathematical formulation of these subsystems.

The implementation of the multi body system in this concept is illustrated with the example of the simulation of the switching behaviour of current limiting power circuit-breakers.

1. Introduction

Current limiting power circuit-breakers (fig. 1) are used to connect and disconnect electrical power networks or installation modules and to protect these networks against overload and short-circuit.

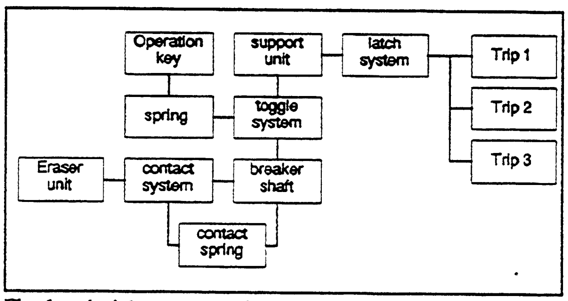

Fig. 1 principle structure of current limiting circuit-breakers

In the event of a short-circuit the contact system is opened very quickly (<2...5ms), so that the inner electrical resistance of the switching device increases very much through the created electrical arc. As a result of this, the actual (let-through) current is reduced as well as the short-circuit duration and consequently the dynamic and thermal load of the installation and equipment.

In the recent years the computer aided simulation becomes more and more important for the development and optimization of switching devices.

The description of the electrical arc, which is required for the simulation of the switching behaviour of current limiting circuit-breakers, causes the greatest problems. The formation, movement, form, size and conductivity of the arc depends on extremely complex interactions with the other physical subsystems of the circuit-breaker, see fig. 2 [1].

An essential factor results from the movement characteristics of the contact system, which is driven both by electrodynamical forces as well as the breaker mechanism.

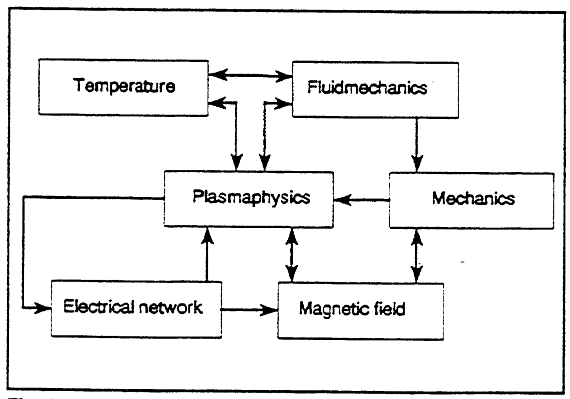

Fig. 2 Interactions of the physical sections in circuit-breakers

2. Modelling and software concept

Due to the complexity of the physical phenomena and the multitude of interactions following problems must be considered in order to model the circuit-breaker as an electrical control element:

- linkage of the subsystems at physical level (forces, current, temperature, pressure etc.) and
- linkage at the level of material properties (permeability, conductivity, gas-density etc.).

Consequently the separated treatment of the subsystems requires boundary conditions, which must be derived from the interactions between the subsystems. But a lot of the boundary conditions of the separated subsystems are not defined and have to be specified by a rough estimate of the interactions. In addition nonlinear links exist between the subsystems due to the material properties.

Different numerical algorithms (such as finite differences, finite volumes, finite elements and of course multi body systems) must be used due to the different mathematical representations of the subsystems, which are the often nonlinear differential equations (conservation laws).

It can generally be said that there are no practicable hardware and software concepts available for the simulation of complex systems and their interactions up to now. For this reason the modelling and software concept was developed, according to fig. 3 [2].

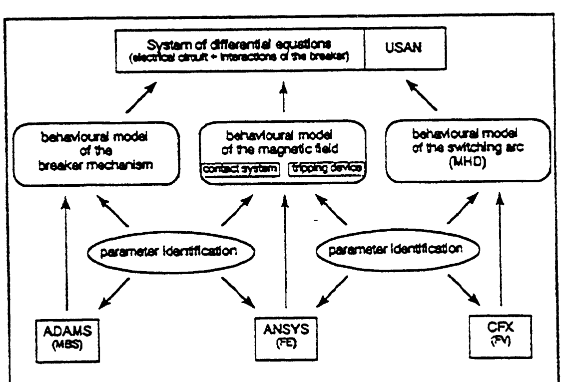

Fig. 3 Modelling- and software concept

The aim of this concept is to combine the different methods of modelling (special program systems, behavioural descriptions and modelling based on experiments) in order to use all opportunities to simulate complex systems.

The simulation packages, shown in fig. 3, can be used to solve static and dynamic problems in the field of mechanics (ADAMS™ [3], ANSYS®[4]), temperature and magnetic fields (ANSYS®) and fluidmechanics (CFX [5]). These program systems allows very detailed and exact calculations depending how well the subsystems can be demarcated.

For the simulation of different coupled physical areas are used behavioural models. These models reflect the transmission behaviour for a limited statement of the problem for one or more subsystems. With this description form it is possible to directly use physical-mathematical models with a different degree of abstraction, hypothesis or measurement results.

The benefit of this method is the inclusion of all forms of linear or nonlinear state equations of the different physical sections. Thus all subsystems can be handled at one model level. It is also possible to develop and validate these behavioural models independently of each other [6].

In order to derive behavioural models from the special simulation tools it is necessery to transfer these models to a lower order in the form of value tables, equations or transmission functions.

This normally requires a restriction to integral values and ordinary differential equations in order to describe the physical facts. [7, 8].

With the help of idealized concentrated energy stores it is still possible to replace the partial differential equations with ordinary differential equations. For this, the transfer of non-homogeneous fields in non-bounded spaces (i.e. nonlinear magnetic field in air) is still problematic in the mathematical domain of behavioural description.

The goal of this concept is also to use the modelling based on experiments and the extensive know-how, in addition to the theoretical modelling for the numeric simulation. The use of the experimental model building enables parameters for generally known physical laws to be identified or the derivation of abstract mathematical relations (Black Box models).

All these behavioural models are then brought together in the program system USAN [9], which works with a behavioral description language, something like VHDL. The created total model of the switching device is based on a number of submodels, which are largely identical with the derived behavioural models. The submodels are interconnected by so-called "energy gates" (input/output relations of the energy stores), like current, force, displacement or temperature. Thus it is not necessary to describe the complex behaviour of the whole system, but only the transmission behaviour of the individual subsystems. This model representation is often used in control engineering where it is called block-orientied-modelling [10].

3. Examples

3.1 A simple USAN-Modell

The boundary of the behavioural models can be chosen irrespective of the physical sections under consideration.

The modelling stategy described above can be illustrated by means of a simple dynamic system as shown in fig. 4.

Whilst only a complicated description of the physical system in its entirety is possible, the transmission behaviour of the energy stores can be determined at once. Constraints can be formulated as force connections in form of independent algebraic equations. Consequently, the parts are decoupled and can be handled as separate blocks with their input/output conditions [11]. This treatment allows a simple formulation of static or dynamic structures such as kinematic loops.

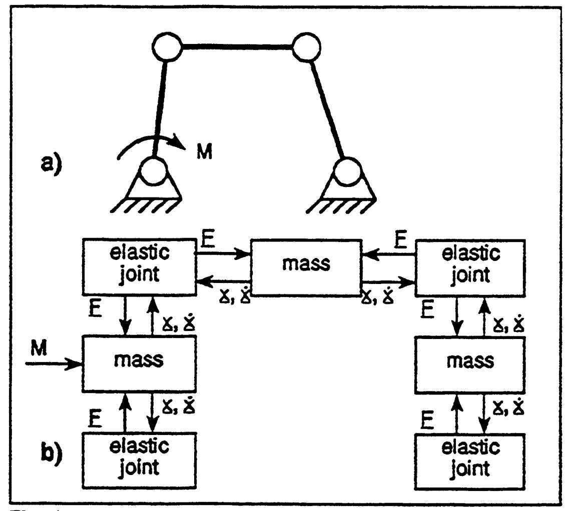

Fig. 4 Comparsion physical (a) and behavioural model (b)

Even the enlargement of joints with friction and clearences only requires an addional term in the subsystem 'elastic joint' [12] and an additional torque term in the momentum balance in the subsystem 'mass'. Equations for describing the interactions or constraints are never necessary (by user or program!).

From the practical point of view, larger systems, with more complicated constraint conditions or friction and impacts, are not practicable for modeling in USAN.

3.2 Simulation of the breaker mechanism with the help of ADAMS

Breaker mechanisms in circuit-breakers provide the necessary contact force to carry the current as well as the opening movement of the contact system in the event of a fault.

In this way the latch releases the preloaded breaker mechanism by different tripping systems and/or the contact system opens itself as a result of the high electromagnetic forces.

A minimal delay time is necessary for the series "tripping system - latch - breaker mechanism - contact system" to ensure high current limiting. Furthermore a high separation velocity between the moveable and fixed contacts is needed too.

The simulation model (fig. 1 and 5) enclose to this:

- the tripping system, is transfering the information of a fault across the phase monitoring bridge, the tripping lever and a force store to the latch,
- the latch, is locking or releasing the breaker mechanism via the support unit
- the breaker mechanism, which produce a toogle system due to the control curve of the breaker shaft, one lever and the mechanism spring and
- the contact system.

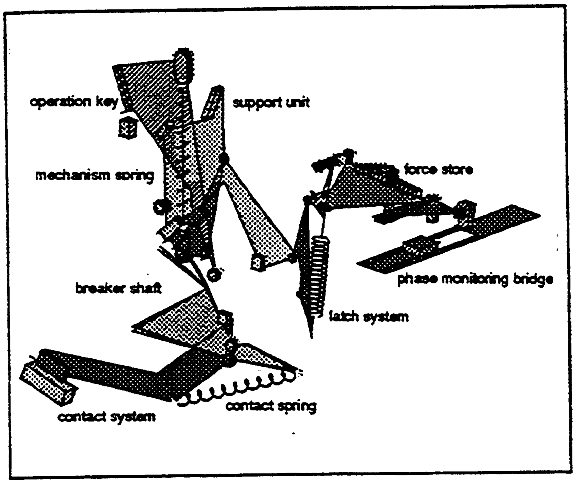

Fig. 5 Simulationsmodell

The breaker mechanism and the contact system is modeled 2-dimensionally, because all axes are lying in one plain. The breaker mechanism is a five bar mechanism during the tripping operation. It is reduced to a four bar mechanism in the On- and Off-position respectively. The complete model contains 16 parts, which are connected by 16 joints and 43 force definitions.

The definition of external forces, which depends on inner states (positions, forces, etc.) is particulary important for simulation of breaker mechanisms.

Friction must be considered on joints, springs and impacts, and as a result, the number of friction forces/torques is large. Thereby the determination of the friction coefficients of the different material combinations is problematic. Furthermore the modelling of the stick-slip transition and the determination of the force direction on Curve-Curve-Statements and Point-Curve-Statements is difficult.

Impacts represent a further problem regarding practical modelling, because the application of the known impact laws (such as Hertzian theorie) is not possible. The determination of the effective masses are affected by the parts which are directly involved with the impact and their "neighbouring" parts. There are also translational and rotational components of the impact velocity. Therefore tangential impulse components, which are poor modeled with external forces, also exist in addition to the normal components.

Some particular parameter combinations caused numerical problems as result of the large number of impacts in very short time delays (14 in 30 ms). For this reason, the solver have to be very robust and very small time steps have to choose in order to reflect a continuously impact force during the impact phase.

The damping coefficient was adjusted in terms of energy dissipation due to the internal friction and due to small plastic deformations in the zone of contact. The disadvantage of this assumption in connection with the elastic impact forces is that the moving behaviour during the impact phase is falsified. However, the energy balance of the parts is correct and consequently the balance of the system too.

The availability of other models for describing impacts (i.e. Newtons law or elasto-plastic impact laws, such as Batujew/Panowko [13]) would be helpful.

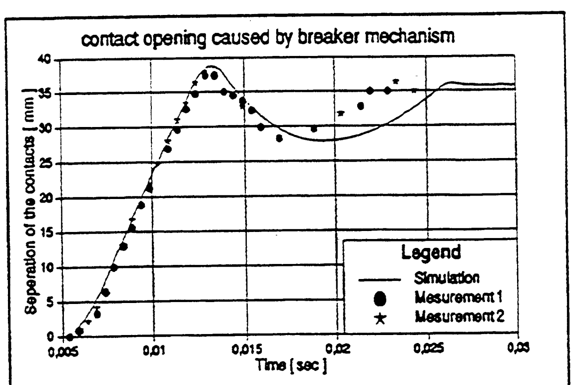

Fig. 6 Comparsion between simulation and measurement

The movement of the contact system and the breaker mechanism was recorded by a high-speed camera in order to validate the simulation results. The tripping of the switching device was done by a high-current-transformer (range of current 2..5 kA). Figure 6 contains a comparsion between the simulation and the measurement.

This model was not only created to derive a behavioural model, but also to analyze the mechanism itself. The ADAMS-model have been also used to determine the acting forces on the parts in order to define the constructive dimensions as well as the input for FE-calculations. This point is very important, because the experimental determination of inner forces or velocities is not possible due to the fast moving operations and the central arrangement in the switching device. The moving behaviour itself was also optimized. One example is the shortening of the delay time of the latch system by one millisecond.

3.3 Derivation of the behavioural model of the breaker mechanism

The breaker mechanism has two intersections to other subsystems. The first one is between the trips an the phase monitoring bridge. This bridge is driven by an electromagnetic trip in the event of a short-circuit. Here the velocity of the bridge is approximately the same, but the moment of impact of the bridge and the trip depends on the intensity of the current, see fig. 7.

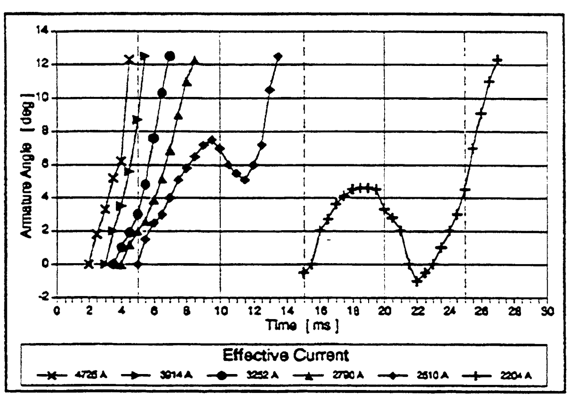

Fig. 7 Tripping characteristic for low short-circuit currents

The intersection "breaker mechanism (bm) - contact system (cs)" is particulary important to create a behavioural model of the breaker mechanism. The moveable contacts are rotary mounted in the breaker shaft and preloaded by the contact springs, see also fig. 8.

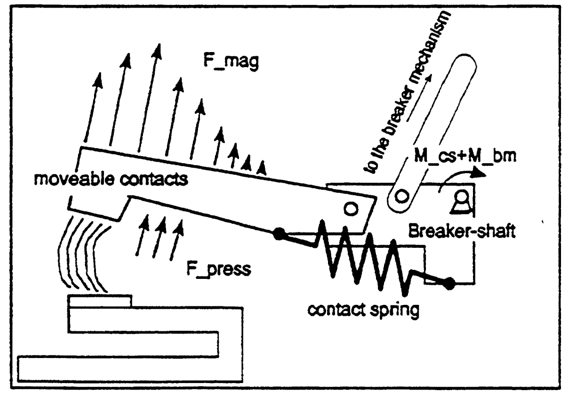

Fig. 8 intersection breaker mechanism (bm) - contact system (cs)

The breaker shaft is also rotary mounted to a fixed bearing and is the output drive of the breaker mechanism. There is a reaction from the contact system to the breaker mechanism via the breaker shaft due to the mounting of the moveable contacts and the contact spring. According to this the rotary angle of the breaker shaft cannot be used as an intersection, but only the torque on the shaft caused by the breaker mechanism, see fig. 9. The movement of the breaker shaft results from the sum of the breaker mechanism torque and the torque from the contact system. These are caused by the contact force (in the closed case), the electrodynamic forces of the magnetic field and the pressure resulting from the gas pressure gradient of the electric arc.

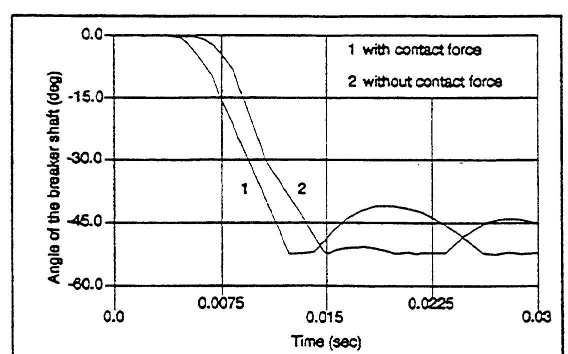

Fig. 9 Tripping movement of the breaker shaft with and without contact forces

The above mentioned intersections to the breaker mechanism must be also described in form of transmission moduls.

The time characteristic (delay time) of the magnetic trip can be derived by measurements (fig. 7) or FE-analysis.

The determination of the electromagnetic forces, which act on the moving contacts, is more complicated. These forces depend on the current path (position of the moveable contact system and the position of electrical arc), the actual current and the permeability of the iron parts. For estimations without ferromagnetic parts it is possible to calculate these forces with the law of Biot-Savart in USAN directly. The use of iron parts requires FE-calculations [14] (fig. 10) or measurements.

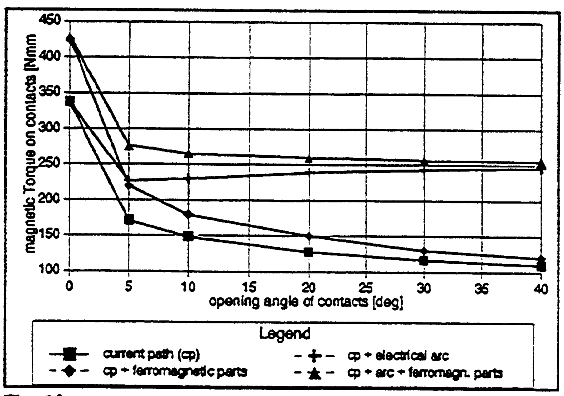

Fig. 10 magnetic caused opening torque

All the behavioural models for the simulation of the circuit-breaker are then brought together in USAN, as shown in figure 11.

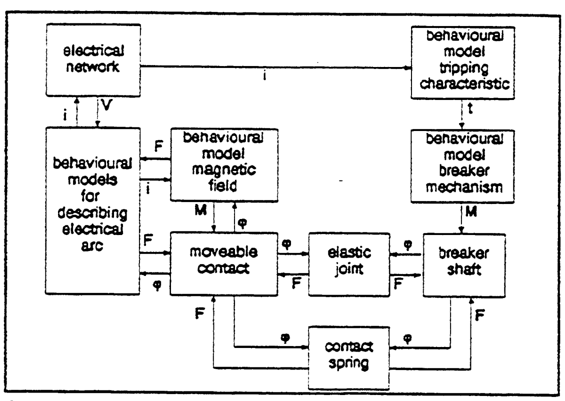

Fig. 11 model structure in USAN

4. Conclusion

Complex systems and their interactions must be often solved in a self-contained form. With the help of behavioural models it is possible to connect different physical sections and to simulate this system on one model level and with only one simulation tool.

The special simulation packages can and should be used to derive the transmission behaviour of the subsystems. Those models can be often created from the 'normal' models for analyzing the subsystems without the need to create a new model. Therefore the behavioural models can be developed and validated separatly by the different specialists.

The possibility of including measurements and know-how in order to find models is very important for an effective modelling, simulation and validation process. The possibilities and requirements of this model strategy have been presented with the example of the (mechanical) switching behaviour of current limiting power circuit-breakers. The fragmentation in independent physical or functional submodels is not ideal, but it is a transparent kind of building simulation models of complex systems.

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