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SIMULATION OF INTERACTION BETWEEN SWITCHING ARC AND SWITCHING MECHANICS IN SF_6 SELF-BLAST CIRCUIT BREAKERS

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ABSTRACT

This paper deals with the investigation on the interaction between a switching arc and the switching mechanics in SF_6 self-blast circuit breakers. The commercial CFD package FLUENT is used to simulate the hot gas flow inside the interrupter unit introducing a spring drive-, a valve- and a simplified arc model. The results of the simulation are verified by measurement data.

Index Terms - SF_6 self-blast circuit breaker, CFD simulation, hot gas flow, modelling of switching mechanics

1. INTRODUCTION

CFD programs are more and more used to optimize the gas flow during arc extinction in high voltage circuit breakers. In case of self-blast circuit breakers the development of the hot gas flow in the interrupter unit is influenced by the limited mechanical force due to the drive and the varying flow geometry during the switching off process including the opening and closing of flow passages by several valves. Furthermore the gas flow depends on the switching arc and on the ablation process at higher currents. The consideration of all relevant physical effects leads to highly complex models. The main focus during these investigations lies in the interaction between switching arc and switching mechanics at low currents. For that, the CFD software FLUENT is applied to simulate the gas flow introducing a useful arc model and a model for the switching mechanics.

2. MODELLING

2.1. Simulation model

From the analysis of the switching off process in SF_6 self-blast circuit breakers with respect to the main focus of the investigations, sub models for the switching mechanics and the switching arc were developed and coupled to the CFD software by Fluent based User Defined Functions (UDF), see Fig. 1.

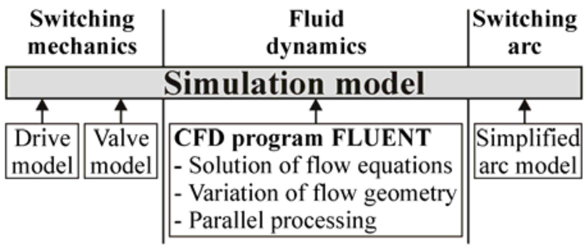

Fig. 1: Scheme of model structure

Fig. 2 shows the solution domain of the simulation model.

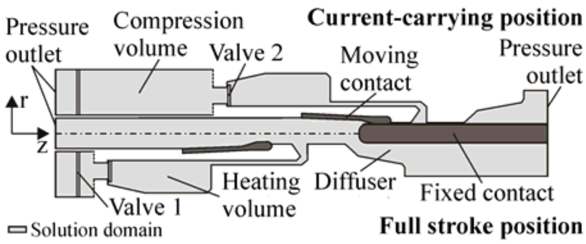

Fig. 2: Schematic diagram of simulation model

For the simulation of the solution domain variation from the current-carrying position to the full stroke position FLUENT provides two features. The first one allows adjacent parts of the mesh like for instance the nozzle diffuser and the volume between the fixed and moving contact to slide relative to one another. Furthermore the second feature can be used to model flows where the shape of the solution domain is changing with time due to motion on the domain boundaries like for instance the valves. So the computional geometry can be changed in a continuous way.

2.2. Drive model

For the spring drive mechanism a 2D model is used, with one degree of freedom, characterised by the angle φ, see Fig. 3.

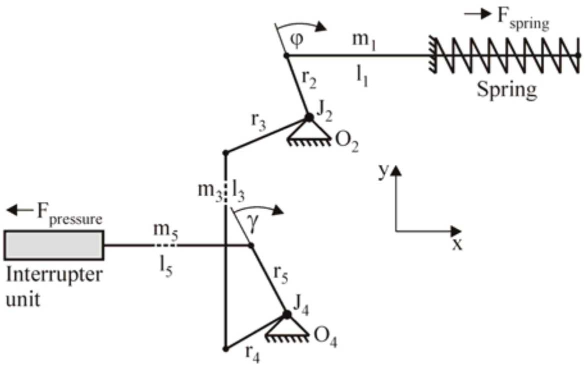

Fig. 3: Scheme of drive mechanics

Due to the existence of conservative forces as well as non-conservative forces, the Lagrange's equations are as follows

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\varphi}}\right) - \frac{\partial L}{\partial \varphi} = Q\,, \tag{1}$$

whereas L is the Lagrange function according to

$$L = T - U\,. \tag{2}$$

In eq. (1) the term Q represents the generalised forces of non-conservative nature (the pressure force, the friction force and a force component due to a hydraulic damper which is not shown in Fig. 3). The pressure force is calculated by the summation over the cross section area at the right end of the compression volume (see dashed lines in Fig. 2) and the cross section area of valve 2. In eq. (2) the term T summarises the parts concerning the kinetic energy as follows

$$T = m_1 \cdot \frac{\dot{x}^2}{2} + J_2 \cdot \frac{\dot{\varphi}^2}{2} + \ldots \tag{3}$$

and U concerning the potential energy (by the gravitational force and by the spring force) as follows

$$U = m_3 \cdot g \cdot y + \ldots \tag{4}$$

The evaluation of the derivatives for the Lagrange function taking into account the terms for T and U and eq. (1) leads to the equation of motion for the drive system in Fig. 3. This equation is integrated during the simulation of the switching off process. As a result of this integration the interrupter unit velocity is estimated in each time step. With this velocity value the variation of discretisation of the simulation model from time step to time step is updated in a continuous way. In [1] a similar approach is applied whereas the drive is only considered by a 1D model.

2.3. Valve model

Fig. 4a shows the scheme concerning the modelling of the valve operation.

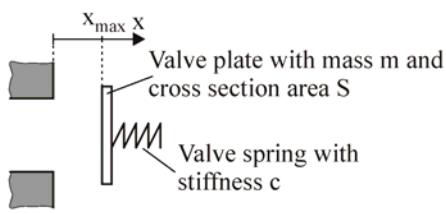

Fig. 4a: Scheme for modelling of valve plate motion

The movement of the valve plate is calculated using the equation of motion according to

$$m \cdot \frac{d^2 x}{dt^2} = c \cdot x + \sum_i \int_{S_i} p_i \, dA_i \,. \tag{5}$$

Using the calculated valve plate velocity the valve plate is moved and the mesh in front of and behind it is updated in every time step in a continuous way, see Fig. 4b.

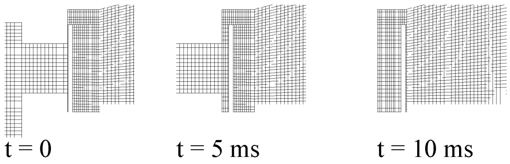

Fig. 4b: Mesh variation near valve 2

Another approach can be found in [2] where the valve operation is realized by the method of filling and evacuation of the annular holes based on the pressure difference between front and rear of the valve.

2.4. Simplified arc model

The simplified arc model is based on the arc power P_{arc}, obtained from measurements of arc voltage and current, which is impressed as a volumetric heat source in the nozzle throat during the simulation of the switching off process. This is done according to eq. (6)

$$P' = \frac{P_{arc}}{V_{NT}} . \qquad (6)$$

V_{NT} in eq. (6) represents the volume between the fixed and the moving contact inside the nozzle, generated during switching off or on process. The losses due to radiation are realised by a Discrete Ordinate model with constant absorption coefficient and the losses due to convection and conduction by the flow solver. In order to take into account the real gas effects, a 14-species-model of SF_6 for a wide temperature and pressure range is used.

3. RESULTS

Simulations of no-load and on-load switching off processes have been carried out to investigate the interaction between the switching arc and switching mechanics.

3.1. Reaction of switching arc to the spring drive mechanism

Fig. 5 shows the comparison of measured and simulated pressure data inside the compression volume (CV). Measurement data of the arc power are used as an input for the simulation of on-load processes, see Fig. 5.

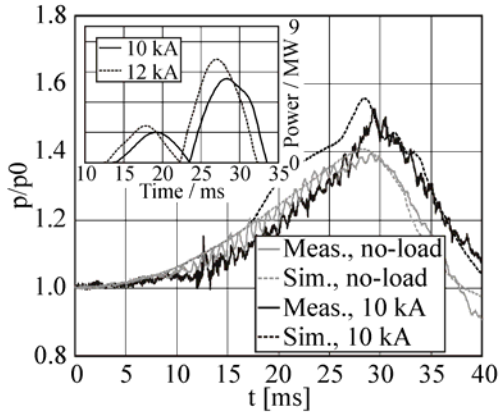

Fig. 5: Measured and simulated pressure trends in the CV at no- and on-load process

In Fig. 6, the comparison of measured and simulated interrupter unit velocities at no-load and on-load switching off processes is shown.

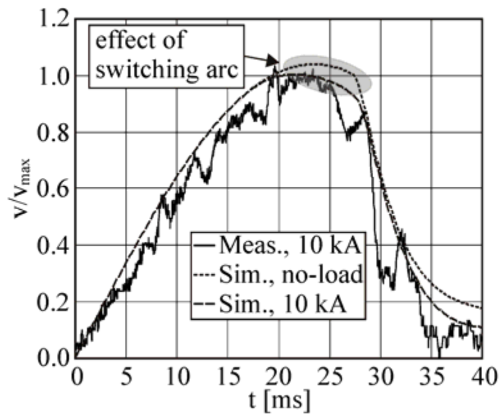

Fig. 6: Measured and simulated interrupter unit velocity at no- and on-load process

The comparison between the measured and simulated interrupter unit velocity shows a good agreement and validates the used drive model.

Furthermore the simulated pressure distribution for the no-load process correlates well with the respective measured curve. For $17 < t\,[ms] < 29$ the simulated pressure distributions for the on-load process differs from the measurement. This is caused by the use of the simplified arc model by what the pressure build-up in the nozzle throat and thus in the heating volume is overestimated.

An increase of the pressure inside the interrupter unit is generated by the switching arc, see Fig. 5. For $0 < t\,[ms] < 17$, the simulated pressure distributions coincide, while for $t > 17$ ms, the simulated pressure for the on-load process is higher than for the no-load process. This behaviour results from the fact that the arc power increases in the first half wave, see Fig. 5. Near the maximum value of the arc power in the second half wave the simulated pressure distribution for the on-load process reaches its peak value.

The effect of the switching arc causes a pressure rise inside the interrupter unit resulting in an increased pressure force. This pressure force decelerates the drive motion, as can be seen in Fig. 6. Therefore the simulated velocity distribution in case of the on-load process differs from the no-load process.

3.2. Reaction of switching arc to the functioning of valves

The pressure conditions inside the interrupter unit are strongly controlled by the operation of two valves (valve 1 and valve 2 in Fig. 2). Fig. 7 shows the comparison of simulated valve characteristics and Fig. 8 shows the comparison of simulated pressure distributions in the CV and the heating volume (HV) at no- and on-load process.

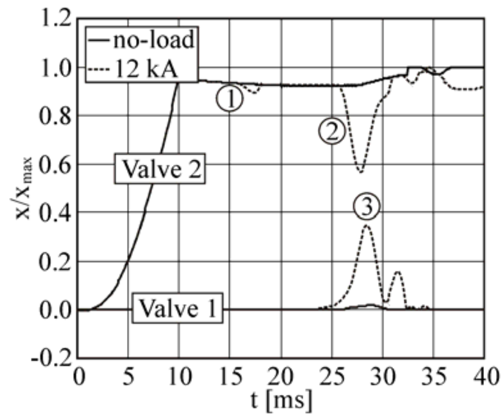

Fig. 7: Simulated valve characteristics at no- and on-load process

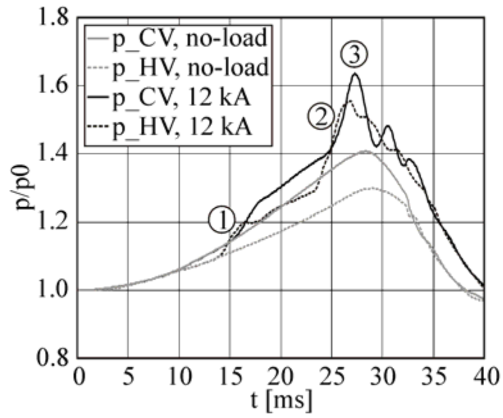

Fig. 8: Simulated pressure trends at no- and on-load process

In case of the no-load process, valve 2 opens, reaches its end position at $t = 10$ ms and remains open until the end of the switching off process, see Fig. 4b and Fig. 7. Valve 1 remains closed. In case of the on-load process, the valve characteristics are entirely different. Due to the increase of the arc power in the first and second half wave, (see Fig. 5), the pressure in the HV is higher than the pressure in the CV (circle (1) and (2) in Fig. 8). This causes a closing of valve 2 to $x/x_{max} = 0.6$ in the second half wave (circle (2) in Fig. 7). By the closing of valve 2 a strong pressure increase in the CV (circle (3) in Fig. 8) and an opening of valve 1 (circle (3) in Fig. 7) to $x/x_{max} = 0.4$ is forced. The decrease of the arc power after 30 ms leads to a pressure decrease inside the HV by what valve 2 opens again to its end position and valve 1 closes.

4. CONCLUSION

The simulation of the hot gas flow inside the interrupter unit of a SF_6 self-blast circuit breaker was realized using the commercial CFD package FLUENT introducing a model for the switching mechanics and for the switching arc. The comparison between the measured and simulated interrupter unit velocity shows a good agreement and validates the used drive model. The use of the simplified arc model leads to a slight overestimation of the pressure build-up in the interrupter unit. It was found, that the pressurization inside the interrupter unit, generated by the switching arc, leads to a deceleration of the spring drive mechanism and thus to a visible change in the simulated valve characteristics.

It is planned to replace the simplified arc model by a dynamical arc model for further investigations.

5. ACKNOWLEDGMENT

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