Arc Simulation at Shunt-Reactor Switching in H.V. Circuit Breakers

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High energy re-ignitions occur in h.v. circuit breakers, when interrupting shunt-reactor currents. The escalating high frequency over-voltages, which are proportional to the arcing time, are stressful both to the reactor and the circuit breakers. We simulated the electric, thermal and flow field inside the thermal chamber and determined the reduced electric field distribution. Analysing the simulation results the main factors to improve the shunt-reactor breaking capacity are demonstrated.

Keywords: arc simulation, circuit breaker, shunt reactor switching

1 INTRODUCTION

Shunt reactors are commonly employed in substations to prevent excessive overvoltage when the system load significantly decreases. At heavy load usually the reactor is switched off. Shunt reactor switching means a severe duty for both the circuit breakers and shunt reactors. In each interruption a complex interaction takes place among the circuit breaker, the source side and reactor (load side) circuits. This interaction results in over-voltages dependent on system parameters and circuit breaker characteristics. Depending on the application the switching operation may be frequent (typically > 100 times/year) or infrequent (<10 times/year). For frequent operation application of special switching device is suggested.

In some applications the shunt-reactor is either most of the time switched on or most of the time switched off, and is switched only for certain cases. General h.v. circuit breakers with modified design have been used for these applications. The aim of these modifications is to reduce the number of high energy re-ignitions produced during the opening process, to avoid any arc re-ignition except between arcing contacts and to avoid arc interruption at the second current zero passing.

2 PHENOMENA AT SHUNT-REACTOR SWITCHING

Re-ignition of a circuit breaker occurs when the TRV applied to the circuit breaker is higher than the withstand voltage between the arcing contacts during opening. It was observed that re-ignitions for high voltage SF_6 circuit breakers normally occur at small arcing times, typically less than 4ms. The small reactor currents, typically 300 A or less, are relatively easy to interrupt for modern interrupting devices such as circuit breakers. But there are some circumstances that make the shunt reactor switching a special one. When the current is extinguished, the shunt reactor voltage oscillates toward zero at the reactor natural frequency (1 to 5 kHz). Since the system supply voltage is at 50 or 60 Hz, the high frequency of the reactor causes the reactor voltage to rapidly depart from the system voltage creating a very steep and high magnitude TRV. This high and fast TRV will cause the interrupter to reignite until there is sufficient contact gap with dielectric strength for complete interruption. These potentially high energy re-ignitions mean high stress to the shunt reactor, causing turn to turn overvoltages, resulting in premature failure of the shunt reactor and flashover inside the circuit breaker.

3 INVESTIGATION OF SHUNT-REACTOR SWITCHING

The precise simulation of shunt reactor current interruption is out of the scope of present investigation, because it would need more information of network elements and circuit breaker specific features, like current chopping tendency. Nevertheless it was observed that the chopped current and the maximum overvoltage are proportional to the arcing time. The maximum arcing time when the arc extinguishes is the so called “re-ignition window". This is characteristic to the shunt reactor current interruption capability, because repeated re-ignitions always occur in this period and the involved voltage-escalation is proportional to the time.

The aim of our investigation was not to determine the electrical transient during shunt reactor switching, but to reveal those physical processes and interrupter characteristics, which are responsible for overvoltage and failure.

Applying CFD simulation, a method for improving shunt-reactor breaking capacity is to be demonstrated.

4 METHOD OF SIMULATION

The applied method of simulation (MC3) is described in [3]. We have simulated the electric, flow and thermal fields between the arcing contacts and investigated when the reduced electric field (E/ρ) maximum (regularly on the tip of the pin arcing contact) falls below a critical value $(E/\rho)_{cr}$, which is the condition of breakdown (E is the electric field and ρ is the gas density). Electric arc effect was supposed during the "re-ignition window".

5 PARAMETERS OF SIMULATION

To demonstrate the simulation of shunt-reactor switching ability, a general high voltage circuit breaker model with commonly used parameters was applied, namely:

Rated voltage: 145kV;
Rated current: 40kA;
Frequency: 60Hz

In simulation we used the test circuits defined by IEC_62271-110 in paragraph 6.115.6 [1].

The standard defines two load circuits with

#1 315A and
#2 100A rated currents

The two-parameter prospective TRVs of load circuits are also defined by IEC[1].

At 145kV rated voltage the $\boldsymbol{u_c}$ peak voltage is 337kV. The $\boldsymbol{t_3}$ time parameters are 126μs and 224μs, respectively for load circuit #1 and #2 (tolerances are +0% and -20%). The equation of the fitted TRV was:

$$U_{sr}(t) = U_c \cdot e^{-\alpha t} \cdot [1 - \cos(\omega \cdot t)]$$

where α_1=5334 1/s; ω_1=22356.3 1/s
and α_2=3000.37 1/s; ω_2=12575.6 1/s
for load circuits #1 and #2.

The fitted TRVs are represented in Fig.2. In simulation the more severe TRV (load #1) was applied.

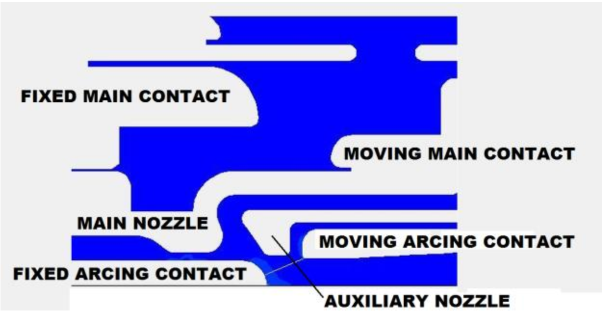

Fig.1: The simulated circuit breaker model

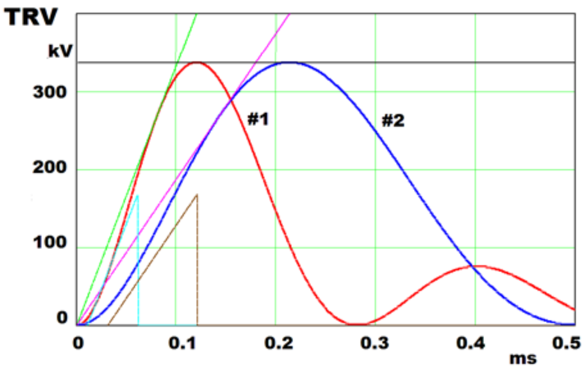

Fig.2: The two-parameter prospective TRVs of load circuits defined by IEC [1]

6 SIMULATION RESULTS

We carried out simulations with 2, 3, 4, 5, 6, 10, 12 and 13ms arcing times. Although most of the repeated arc re-ignition and voltage escalation occur at small arcing times where contact gap is short, there may be another dangerous period around the second current zero (at long arcing times).

Fig. 3 and 5 represent the ratio of (E/ρ) over $(E/\rho)_{cr}$ around the arcing and main contacts. The red color means a ratio to be equal to or greater than one, i.e. where the reduced electric field reaches or exceeds the critical value. The blue color represents the zero value, where the electric field is negligible.

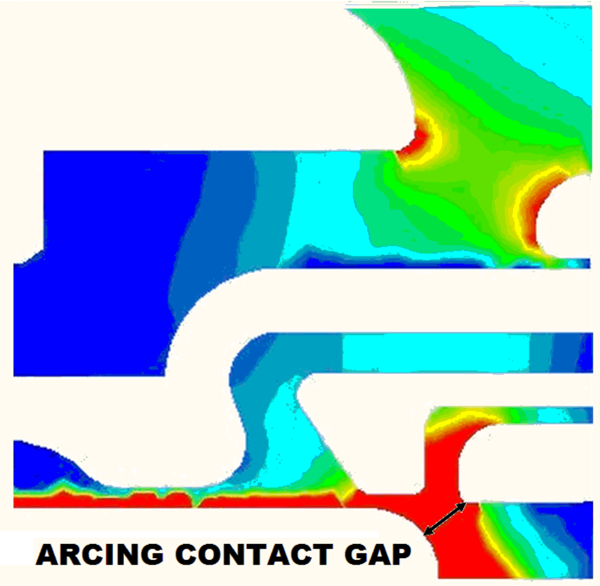

Fig.3: The ratio of reduced electric field to the critical one at 2ms arcing time

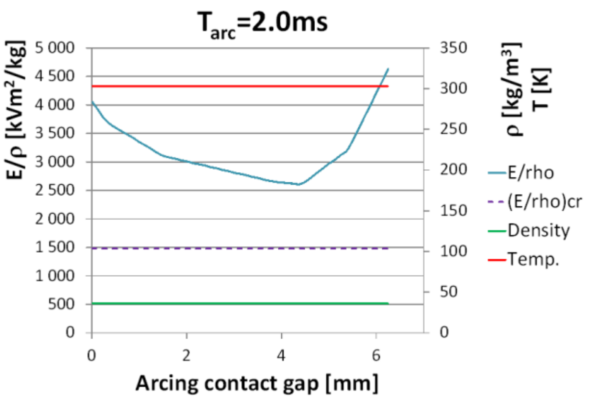

Fig.4: The distribution of simulated quantities between the arcing contacts at 2ms arcing time

Simulation results at 2ms arcing time can be seen in Fig. 3 and 4. The distribution of simulated quantities along the path between the arcing contacts is represented in Figure 4. The reduced electric field is over the critical value along the path. The arc will not be extinguished till this time.

At 3ms arcing time (see Fig. 5…7), the reduced electric field is over the critical one in the whole arcing contact gap (Fig 6).

Between the main contacts the electric field is also high, except a short region in the middle. Knowing the nature of breakdown in inhomogeneous electric field, a breakdown may evolve.

At 4ms arcing time the reduced electric field is far below the critical value between the arcing contacts (see Fig.8) and between the main contacts, as well.

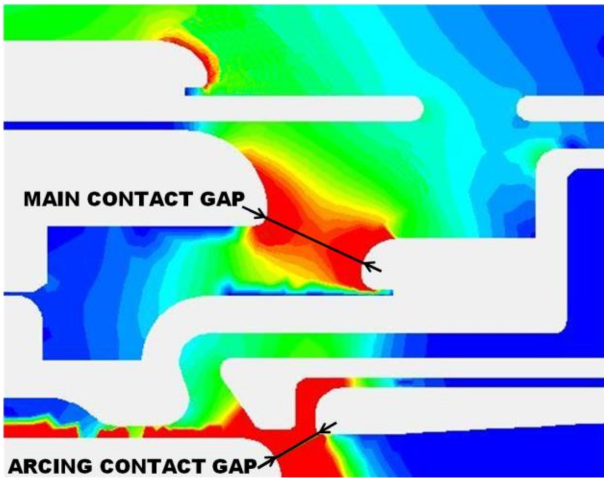

Fig.5: The ratio of reduced electric field to the critical one at 3ms arcing time

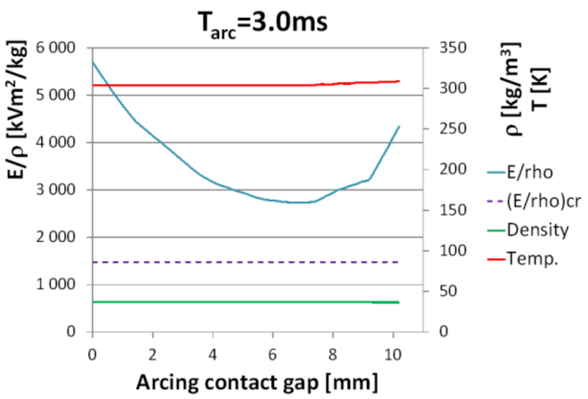

Fig.6: The distribution of simulated quantities between the arcing contacts at 3ms arcing time

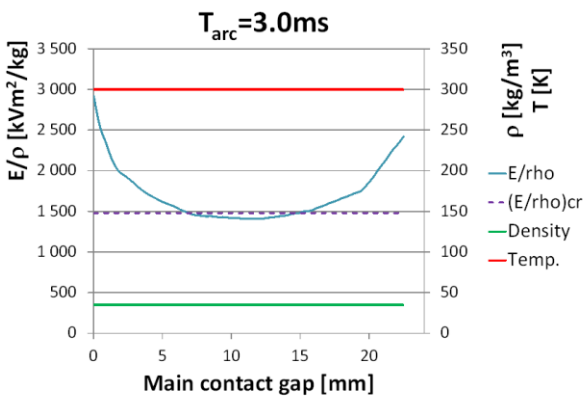

Fig.7: The distribution of simulated quantities between the main contacts at 3ms arcing time

The mass density and temperature along the path between contacts are also represented in Fig.4, 6, 7 and 8. It can be seen that their values are almost constant along the path between the contacts. The density is slightly, but the temperature is not dependent on the arcing time.

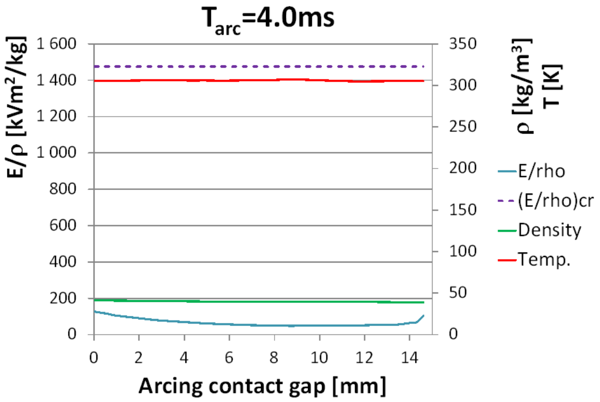

Fig.8: The distribution of simulated quantities between the arcing contacts at 4ms arcing time

7 CONCLUSION, DISCUSSION

- At 2ms arcing time the reduced electric field is over the critical one along the path between the arcing contacts, thus the arc will definitely reignite.
- At 3ms arcing time the reduced electric field along the path between the arcing contacts exceeds the critical one (Fig. 6), so the arc will reignite.
- At 3ms arcing time a flashover between the main contacts is also possible. In front of the main contacts the reduced electric field is over the critical one in substantial parts of arc length (See Fig. 5 and 7). Arc re-ignition elsewhere than between arcing contacts is not allowed! Precise prediction of flashover such cases can be made applying the method based on leader theory and described in [3].
- At 4ms arcing time the reduced electric field is far below the critical one along the path between the arcing contacts and between the main contacts, as well (Fig. 8).
- At longer arcing times (up to 13ms) the reduced electric fields were far below the critical one everywhere. It means that there is no probability of current re-ignition at the second current zero crossing (which is not allowed!)
- Evaluating the simulated results, it can be diagnosed that the “re-ignition window” is between 3 and 4ms, which is acceptable value to avoid too high overvoltages.
- Coordination between the main and arcing contact motion should be improved to avoid the possibility of arc re-ignition between the main contacts.
- The presented arc simulation technique seems to be a good tool for improving shunt reactor switching capability of high voltage circuit breakers.
- The temperature dependence of dielectric strength can be neglected in simulation of shunt-reactor switching.

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