Research on the transient regime of SF6 circuit breakers in MATLAB

D Ciulica

Politehnica University of Timisoara, Department of Electrical Engineering and Industrial Informatics, 5 Revolution Street, Hunedoara, 331128, Romania

E-mail: dumitruciulica@yahoo.com

Abstract. In this paper is presented a Matlab application for studying the connection and disconnection of circuit breakers. The application has a graphical user interface where it is possible to modify the simulation parameters of the connection and disconnection operations. The simulation parameters can be changed in an intuitive way. The application can also be used for educational purposes to study phenomena that occur during the connection or disconnection process.

1. Introduction

Circuit breakers are very important circuits in power electrical systems. They can handle faults that, if not properly managed, can cause power system failures. Simulating the operations that occur when connecting the disconnection these breakers, is very useful because testing under laboratory conditions is difficult. Obviously it is necessary to test the breakers in laboratory conditions. But coupled with model-based simulation of breakers, testing becomes more effective. Circuit breakers models are based on equations describing the behavior of the electric arc that occurs when the circuit breaker contacts are separated. At that point the interruption process begins and an electric arc at very high temperature is produced. In the case of SF6 breakers, the arc is produced in the gas. In this paper we study the connection and disconnection of SF6 breakers in Matlab.

An SF6 breaker has the structure shown in Figure 1. Quenching technique - SF6 Autopuffer is shown in Figure 2 [1], [2].

To make a study of the connection and disconnection times of the SF6 circuit breakers, a Matlab graphical interface has been implemented.

The circuit breakers must disconnect the fault currents without re-firing the electric arc. When disconnecting electrical circuits in or out of the circuit, an arc arises between the contact elements of the switching devices (switches) whose parameters (voltage, current density, duration) depend on the conditions in the extinguishing chamber, i.e., the type of extinguishing medium. The electric arc leads to additional stress caused by the transfer of energy from the electric spring column to the conductive or insulating components of the apparatus. This demand is manifested by overheating that may require contacts of the circuit breaker. Also, when switching electrical switching equipment, an electric arc may arise between the contact elements, but if the shutter speed is sufficiently high, the thermal effect of this process is insignificant.

In the dynamic switching process the most important phase is the extinguishing of the electric arc. Extinction of the AC arc is facilitated by the passing of the periodic current through zero at times when the de-ionisation of the electric arc is maximum.

In high-voltage equipment the electric arc is elongated and the extinguishing processes are influenced by the characteristics and parameters in the extinguishing chamber.
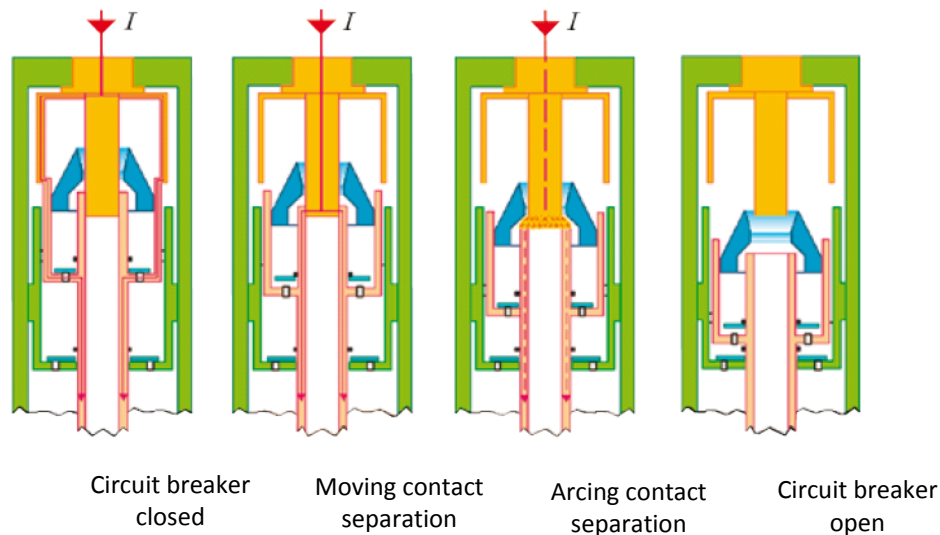

| Circuit breaker closed | Moving contact separation | Arcing contact separation | Circuit breaker open |

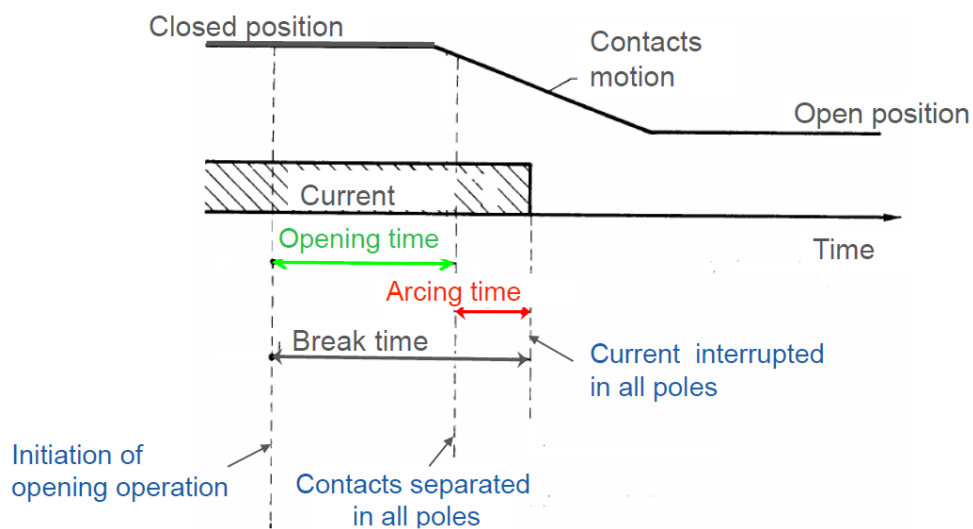**Figure 1.** Circuits breakers functioning

Figure 2. Quenching technique - SF6 Autopuffer

Extinction of the electric arc depends on the following parameters [3], [12]:
- the power supply system features;
- the currents value which, from the point of view of temperature, influences the circuit breaker behaviour;
- the transient recovery voltage (TRV), ur(t), which strains the dielectric between the contacts of the switching equipment;

- the specific parameters of the circuit breaker, such breakdown voltage in the extinguishing chamber which express the speed of restoring the dielectric rigidity and electric arc voltage, ua(t), which depend on the degree of cooling and on the extinguishing medium.

When the electric current passes through the arc, the following phenomena occur:

- the arc temperature and its conductivity drop rapidly, which leads to the restoration of the dielectric strength of the space between the contacts;
- Increasing the breakdown voltage (maximum value);
- the transient recovery voltage (TRV) appears [3], V_r (t) – because of the permanent source voltage (pulsation ω) and the free circuit voltage of the disconnected circuit.

The definitive extinction of the electric arc takes place when:

$$i_a(t)=0 \qquad \text{and} \qquad V_r(t)<V_s(t) \tag{1}$$

$V_r(t)$- is the transient recovery voltage

$V_s(t)$ –Arc re-ignition voltage

Figure 3 shows the equivalent electrical circuit diagram of the interruption process in the event of a short circuit produced at the terminals of the switch. In most cases, the short-circuit currents are practically inductive, because the parameters of the electric lines respect the inequality $\omega L \gg \omega R$.

In Figure 4, the origin of time (t = 0) is considered to be the moment of passing the current of the short-circuit current ik (t), which corresponds to the peak value of the supply voltage curve 1; curve 2 represents the restoring transient voltage containing the voltage of the power supply to which the free oscillatory circuitry is added.
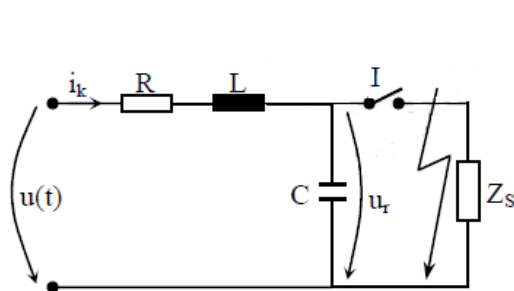

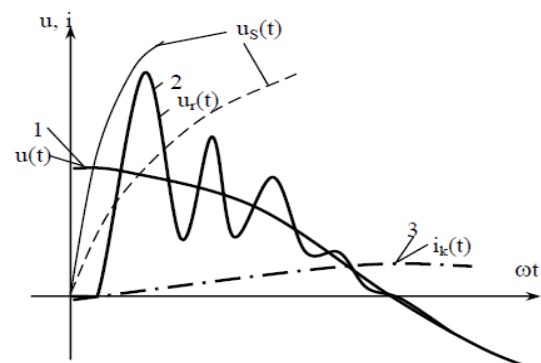**Figure 3.** The equivalent electrical circuit diagram of the interruption process

Figure 4. Transient mode switching off to a short to switch terminals

$i_k(t)$= short-circuit current

$u(t)$= voltage

$u_r(t)$= recovery voltage

$u_s(t)$= time variation of strain voltage

-------- re-ignition

_____ extinction,

Figure 5 shows the Transient Disconnection at a short circuit at long distance.

2. Simulations in Matlab

To study the connection / disconnection process a simulation was done in Matlab. The graphical user interface of the Matlab application is in Figure 6. Simulation was made for the three-phase case.
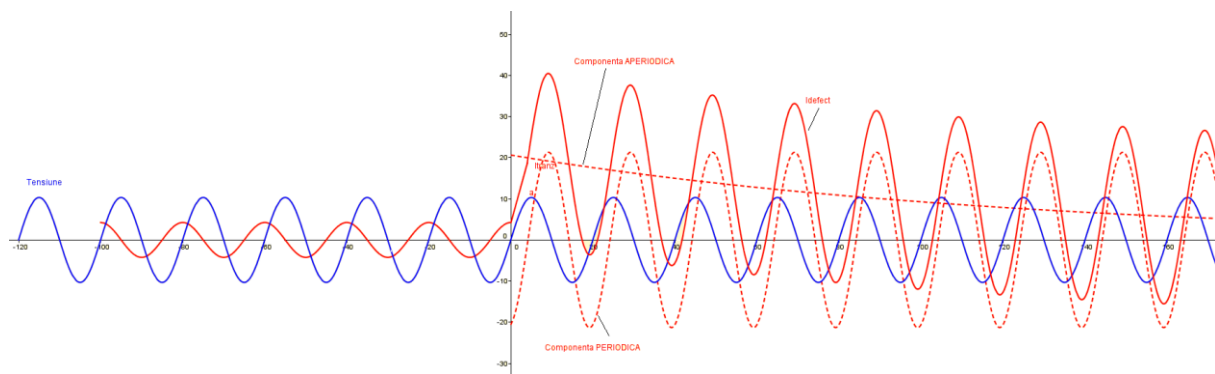
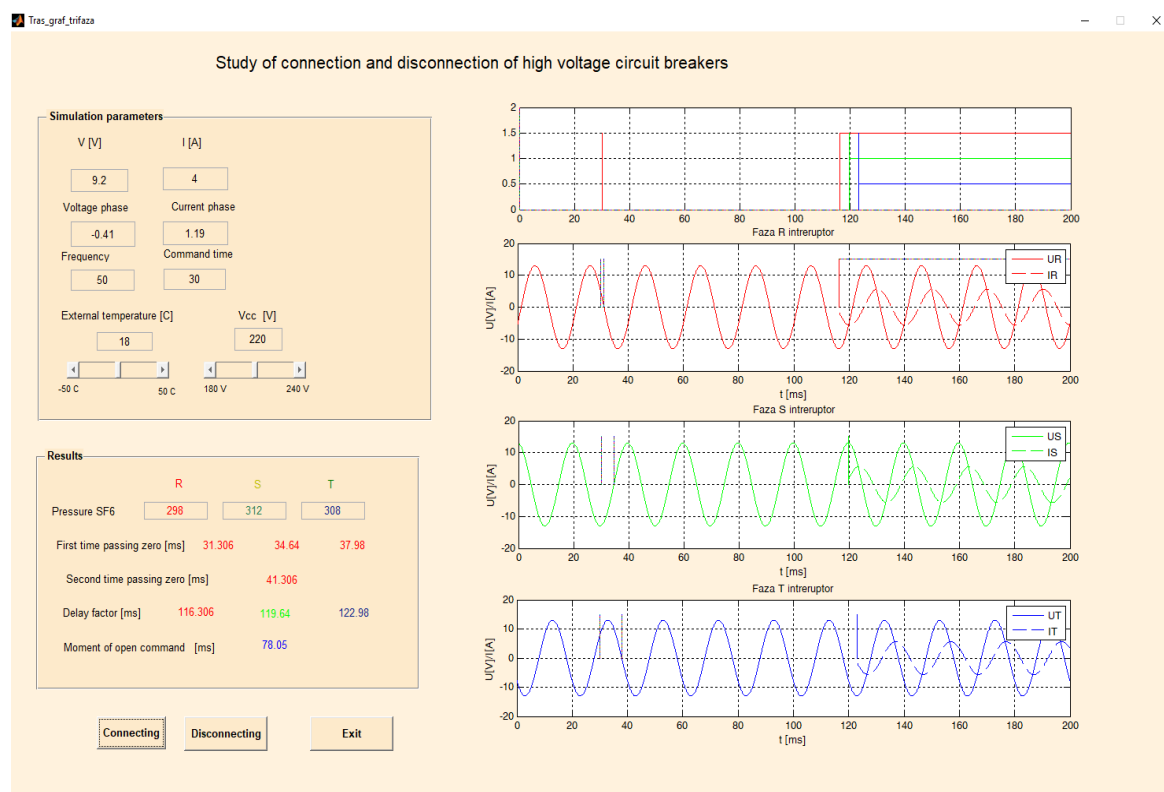**Figure 5.** Transient Disconnection at a short circuit at long distance

Figure 6. The GUI for the application that shows the connecting of the breaker

The GUI input application introduces the voltage, current, voltage and voltage phase and frequency values. In the simulation, the three phases are assumed to be symmetrical.

In order to be able to see when the circuit breaker is connected or disconnected, enter the command time (expressed in ms). Other parameters to be entered are: Supply voltage, External temperature, voltage of c.c. DC power supplying the circuit breaker to the circuit breaker. After the simulation, the three graphs will be displayed on the graphical forms of voltage variation on the three phases. It also calculates the time of zero transition on the three phases and the delay factors. Figure 7 shows the graphical simulation interface for disconnection.
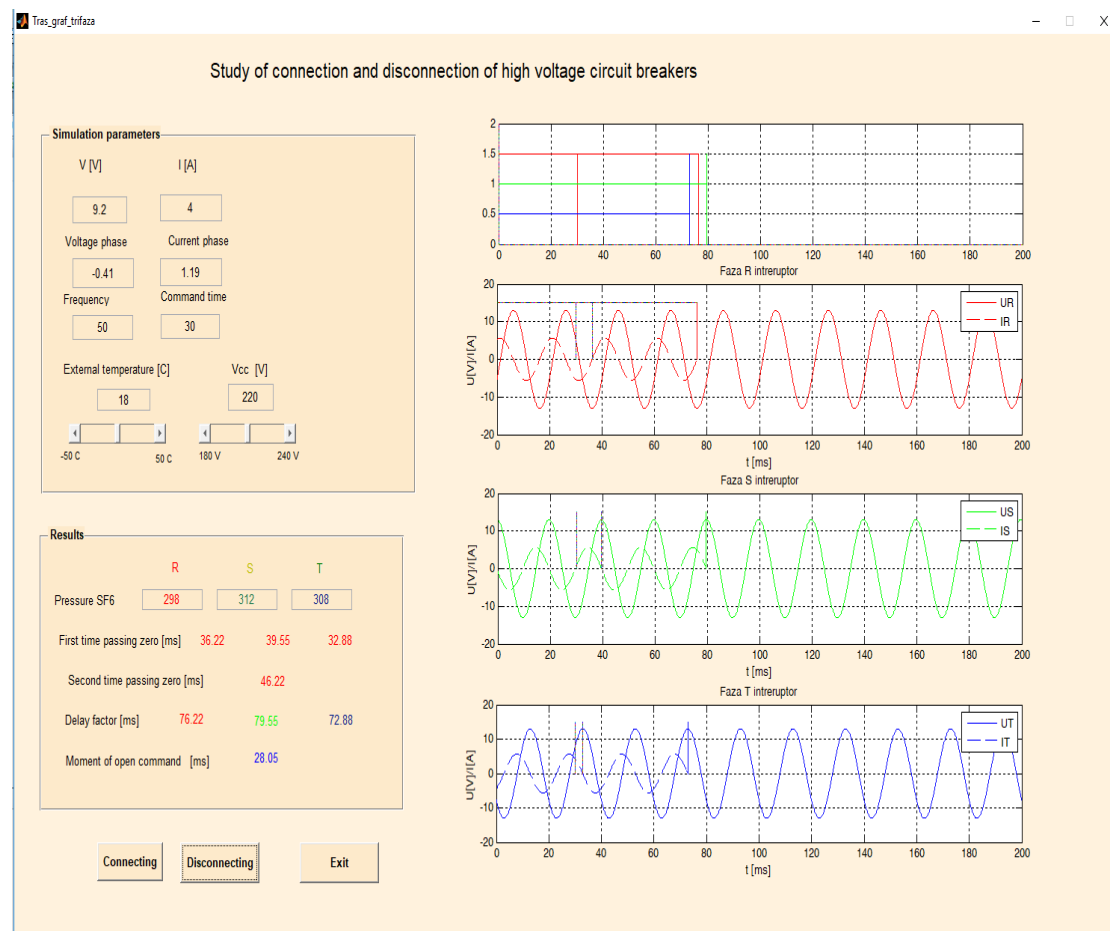
Figure 7. The GUI for the application that shows the disconnecting of the breaker

The circuit breakers are equipped with a two-way contact for temperature-compensated SF6 gas density control, their signals will be transmitted to the control-command system. The simulation also shows the coefficient variation according to temperature, on a graph.

For the determination of the zero-passing moment the voltage starts from the moment when the closing command is given and the time t is incremented by 0.01, it is checked which branch of the sinusoid is the voltage value at the moment t positive or negative.

A verification cycle is performed by incrementing the time in the step of 0.01 until the voltage value u becomes zero so the first zero crossing of the voltage across phase R is found. Increment the tzero time by 0.01 and apply the same algorithm as the one for determining the first zero crossing and find the tzero2 i.e. the second zero crossing of the voltages then verify that the difference between the two passes by zero is equal to the half-period calculated from the input frequency. For calculating the delay coefficient due to external temperatures, the input value is interpolated with a vector containing this coefficient based on the measured values stored in the vector. To calculate the coefficient of delay, the input value with a vector containing this coefficient is interpolated based on the measured values stored in a vector.

For calculating the delay coefficient due to SF6 pressures, the value entered with a cPh vector containing this coefficient is interpolated according to the measured values stored in the vector Ph this is done for all three phases.

Calculate the total delay time as equal to the sum of coefficients due to temperature, SF6 pressure and c.c. from the clutch coil. All calculated items are plotted for each phase.

3. Conclusions

Based on the simulations obtained, the following conclusions were identified: Simulating the closing time for SF6 circuit-breakers depends largely on the switch type. For each type of switch, its characteristics must be raised depending on the temperature, the supply voltage with d.c. the actuating coils, and the hydraulic agent pressure. Since the switch operates under normal conditions, ie the temperature within the range of 0 ° C + 40 ° C, we can approximate this coefficient to 72 milliseconds for the closing operation. To check these times, it is necessary to use auxiliary contacts that copy the position of the circuit breaker contacts very fast and accurate. The calculation algorithm for the connection time is simple. It is all about calculating the seven time points and applying the command to the switch's coil as soon as possible. Measurement with high precision by means of existing transducers in the temperature and voltage. The simulation was done for all three phases.

References

[1]   Havar Mammadov, Tahir Lazimov and Samir Imanov 2009 *Improved model of circuit-breaker's dielectric strength restoration*, 6-th International Conference on Electrical and Electronics Engineering ELECO, Bursa, Turkey, November 5-8

[2]   ***http://www.ewh.ieee.org/soc/pes/switchgear/presentations/tp_files/20172_Tutorial_AC_HV _Circuit_Breakers_Dufournet.pdf

[3]   Uglešic I, Filipovic-Grcic B, Milardic V and Ivankovic I 2009 *Transient recovery voltage of 400 kv sf6 circuit breaker when clearing short-line fault*, Proceedings of the 16th International Symposium on High Voltage Engineering, Cape Town, South Africa, August 24-28

[4]   Mahajan N S, Patil K R and Shembekar S M 2013 Electric Arc Model for High Voltage Circuit Breakers Based ob Matlab/Simulink, *International Journal of Science, Spirituality, Bussiness and Technology* **1**(2)

[5]   Grega Bizjak, Peter Zunko and Dusan Povh 2004 Combined Model of SF6 Circuit Breaker Udes in Digital Simulation Programs, *IEEE Transacyions on Power Delivery* **19**(1)

[6]   Tian Lia and Huawei Li 2018 Simulation of Electric Arc Characteristics Based on MATLAB/Simulink, *IOP Conf. Ser.: Mat. Sci. Eng.* **452** 042080

[7]   Sharma S and Bhardwaj H 2012 How to maintain sf6 circuit breaker, *International Journal of Scientific Research Engineering &Technology* **1** 030-035

[8]   Marcin Szewczyk and Stanislaw Kulas 2007 *Investigation on circuit breaker influence on transient recovery voltage*, 42nd International Universities Power Engineering Conference, Brighton, United Kingdom, September 4-6

[9]   Ziani A and Moulai H 2013 *Arc quenching Equations Solving in HV Circuit Breakers by a General Diagram Bloc Model*, 3rd International Conference on Electric Power and Energy Conversion Systems, Yildiz Teclmical University, Istanbul, Turkey, October 2-4

[10]   Panoiu C, Panoiu M, Muscalagiu I and Iordan A 2010 Visual Interactive Environment for Study the Power Electronics Using PSCAD-EMTDC Simulation Program, *Computer Applications In Engineering Education* **18**(3) 469-475

[11]   Panoiu M, Panoiu C and Deaconu S 2008 *Study About the Possibility of Electrodes Motion Control in the EAF Based on Adaptive Impedance Control*, 13th International Power Electronics And Motion Control Conference, Poznan, Poland, September 1-3, pp 1409-1415

[12]   Ciulica D 2018 Connection time study for 400 kV circuit breakers with SF6, *IOP Conf. Ser.: Mat. Sci. Eng.* **477** 012015

[13]   Namjoshi Y 2013 *Auto-Calibration of a Sf6 Circuit Breaker for Point-on-wave Switching an Application of Signal processing to Switchgear*, International Conference on Electrical and Electronics Engineering, Goa, India, January 27, pp 14-18

[14]   Sharma S and Bhardwaj H 2012 How to maintain sf6 circuit breaker, *International Journal of Scientific Research Engineering & Technology* **1** 030-035