Optimizing the switching time for 400 kV SF6 circuit breakers

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Abstract. This paper presents real-time voltage and current analysis for optimizing the wave switching point of the circuit breaker SF6. Circuit Breaker plays an important role in power systems. It provides protection for equipment in embedded stations in transport networks. SF6 Circuit Breaker is very important equipment in Power Systems, which is used for up to 400 kV due to its excellent performance. The controlled switching is used to eliminate transient modes and electrodynamic and dielectric charges in the network at manual switching of capacitor, shunt reactors and power transformers. These effects reduce the reliability and lifetime of the equipment installed on the network, or may lead to erroneous protection.

1. Introduction
SF6 has excellent dielectric and arc-quenching properties and it is used as insulating medium for high voltage distribution systems. Favorable electrotechnical, chemical and physical characteristics of gas have greatly influenced the development of switching technology. SF6 is an alternative to other conventional isolation and extinguishing media, such as e.g. oil and air. At the same time, SF6 compared to oil reduces the risk of danger (e.g. fire, explosion) to personnel and the environment. A global assessment, considering all ecological, economic, safety and technological aspects, has shown that SF6 is still an excellent choice as an insulating environment. The existing SF6 technology in power transmission and distribution is the result of decades of optimization and mainly contributes to the further development of economically efficient distribution [1].

The switching time for the circuit breakers is calculated by a program installed in the Bay Control Unit (BCU) of the control unit located in each cell of the power station and receives the command from the user to close or open the switch at the point on the voltage or current taken as a reference. The method is also called synchronous switching or controlled switching [1], [2].

2. SF6 circuit-breaker
The SF6 switch is frequently used due to its excellent performance. Due to the special properties of SF6, this extinguishing medium is used in power equipment such as high dielectric strength, arc extinguishing capability, excellent thermal stability and good thermal conductivity. The operation of the SF6 Switch is also dependent on the SF6 pressure and if the actuator is with oil depends on its pressure. In addition, the switching phenomenon relies heavily on the angles where the phases are CLOSE or OPEN. By this we understand that the sequence and angles of switching phases for a specific task are important. In this case, for capacitive load, closing is done on the peak voltage when the current is zero at phase. New applications are being researched that adapt dynamically to different angles based on the type of load. The selection of switching time of the switch for the switching point on the feature depends on the following parameters: DC voltage at the control coils, SF6 pressure, oil
pressure in the actuator, load type, frequency of the reference phase in which we take the Phase R as a reference [3].

2.1. Controlled switching
The controlled switching is used to eliminate transient regimes and electrodynamic and dielectric charges at manual switching of capacitor batteries, shunt reactors and power transformers. An important aspect of all switching controlled applications is the accuracy obtained during arc processing and breakage. The uncontrolled closure or opening of the circuit breakers may result in wear to the equipment. Switching control provides an efficient solution taking into account the current values; the control unit optimizes the switching operations of the switch using the instantaneous voltage curve or the instantaneous current curve [4]. The operation of opening an inductive or capacitive load can result in electric arc re-ignition and overvoltage. When closing an inductive load in the case of un-optimized switching, overcurrent may occur.

2.2. The switching point on the feature
The switching point at zero pass characteristic is a method of eliminating the transient effects occurring in controlled time switching operations. The closing or opening commands of the circuit breaker are delayed so that the closing or opening of the contact takes place at the optimum time characteristic of the phase angle. With this method we can increase the performance and lifetime of the switch. In the following example (Figure 1) there is presented the operating principle of a system for commanding a LEA (aerial electric line). To avoid transient effects, choosing switching moment is depending on the capacitive load of the LEA and it must be at zero voltage travel. For simplicity, only one phase [5-7] is considered.

![Switching Block Diagram](image)

**Figure 1. Switching Block Diagram**

2.3. Typical switching times

2.3.1. Closing Time. The time from excitement of the closing coil until the active contact of the switch is closed.

2.3.2. Opening time. The time from energizing the opening coil to separating the active switch of the circuit breaker.

2.3.3. Make /Break Time. The time elapsed from excitement of the closing coil until the current starts to circulate in the main circuit.
2.3.4. **Pre-arching Time.** From the start of the main circuit current until the ignition is reached.

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\text{Pre-arching time} = \text{Closing time} - \text{Make time}
\]

2.3.5. **Arcing Time.** The time at which the electric arc burns at the contacts of the circuit breaker during its opening.

2.3.6. **Dielectric strength decrease rate.** Dielectric strength drop rate, circuit breaker characteristics that describe the voltage slope when closing a circuit breaker

2.3.7. **Dielectric strength increase slope.** The dielectric resistance increase slope, characteristic of the circuit breaker that describes the slope of the increase of the resistance to the opening of a circuit breaker. The dielectric resistance increase slope defines the minimum arc time required for the inductive load interruption without ignition [6-10].

2.4. **The advantages of this method**

The main advantage of this method is the reduction of the transient switching effects, with implicit reduction of voltages in the system and its equipment. The decrease of the transient stresses, e.g. on a power transformer, will prolong the life of the equipment [7]. In addition, the circuit-switched circuit-breaker itself will have reduced breaking currents, which will result in reduced circuit breaker wear. For capacitor, filter and reactant coil batteries, the number of load switching operations can usually be doubled before a scheduled repair, compared to uncontrolled operation [11], [12].

3. **Control system**

The role of the control system is to provide controlled (synchronous) switching commands to the OPEN and CLOSE coils of the switch. Successively controlled switching reduces mechanical and electromagnetic wear suffered during normal switching operations by reducing ignition currents to shut-off and re-ignition during opening. Given the precise inputs (temperature, pressure, auxiliary voltage, etc.) over the switching time, the compensation is integrated into the calculation algorithm, ensuring performance for all types of loads.

Due to phase shifts, the system is designed to calculate and send the switching commands separately at each phase of the switch. The monitoring of the ignition and re-ignition currents ensures a successful synchronous switching of the circuit breaker. The operating principle uses the zero crossing of a sinusoidal signal. A voltage signal will be used as a reference before closing and a current or voltage signal can be used before opening. When switching characteristics are identical for each phase, there is a constant time delay (T / 6) between the synchronous commands in each phase, for example in the sequence "R, T, S" (1/3 of a global cycle).

As soon as a CLOSE command is received, the command is held and a time delay is applied, waiting for the first zeroing of the voltages. If no zeroing is detected within the preset time interval, the synchronous interruption is interrupted and CLOSE is executed on the three phases simultaneously.

If there is a zero crossing in the default delay range and no other faults are detected, the CLOSE synchronous commands for each phase are emitted after the calculated time delays. The calculated time delays are measured from the zero crossing and are compensated for the variable effects and variations of switch characteristics for each phase. Auxiliary switch contacts are monitored for timing analysis, if a sequence error is detected, the synchronous command is interrupted, and a three-phase switching is performed. Figures 2 and 3 show the opening operation and the closing operation with a respective control system.

The operational principle of the OPEN operation is the same as for CLOSE with the difference that it can be used as a reference signal for a zero-pass current and that the recharged currents [13], [14] are monitored.
Figure 2. Opening operation of circuit breaker with a control system [6]
1 – Open command, 2 – Identify the zero point of the current, 3 – Delay time, 4 – Command to breaker opening coil, 5 – Opening time, 6 – Separating contacts, 7 – Arc time, 8 – End of current flow

Figure 3. Closing operation of circuit breaker with a control system [6];
1 – Closing command, 2 – Identify the zero point of the voltage, 3 – Delay time, 4 – Command to the breaker closing coil, 5 – Closing time, 6 – Touch contacts, 7 – Begin of current flow, 8 – Timp Pre-arcing

4. Compensation in the control system
When the switch has a constant functioning in its behaviour, with variations in external conditions, corrections can be made for them. The verification of systematic mechanical variations is according to variations in ambient conditions, such as the influence of idle time, temperature variation, variation of coil voltage, hydraulic fluid pressure change and SF6 gas pressure change. Ambient temperature variations can be compensated by suitable transducers. The need for compensation depends on the angle variation and the actual operating conditions. For frequent operation, adaptation control may be good enough to gradually consider small variations. The system can compensate the expected operating time of the circuit breaker for variations in temperature, pressure, SF6 gas pressure, and auxiliary power supply.
5. Results
The most important variables influencing the mechanical operation time of the circuit breaker are the control voltage on the CLOSE and OPEN coil (U), the ambient temperature where the circuit breaker (T) is located, and the hydraulic pressure (p) for the actuators hydraulic.

Table 1. Limits variables for circuit-breaker

| Limits                | Limits  | Current values |
|-----------------------|---------|----------------|
|                       | min     | max            | Pole A | Pole B | Pole C |
| Frequency             | 48      | 52             | 50     |        |        |
| Control voltage [V]   | 187     | 255            | 242    |        |        |
| Trip voltage CLOSE [V]| 187     | 255            | 242    |        |        |
| Trip voltage OPEN [V] | 154     | 255            | 241    |        |        |
| Hydraulic pressure [bar] | 0   | 400            | 335    | 335    | 341    |
| Temperature [°C]      | 40      | 80             | 17.5   |        |        |

Table 2 shows the measured values in the closure process of the respective circuit breaker, it is noticed that the closing times are approximately equal to the three phases.

Table 3 shows the reference contact delays and the duration of the signal given by this reference contact. Table 4 shows the set-up time according to the phase shift in degrees between the phases.

Table 2. Value variables for circuit-breaker close

| CLOSE                | Pole A | Pole B | Pole C |
|----------------------|--------|--------|--------|
| Initial values       |        |        |        |
| Closing times [ms]   | 79.8   | 79.5   | 79.8   |
| Hydraulic pressure [bar] | 330 |        | 330    |
| Trip voltage [V]     | 240    |        |        |
| Temperature [°C]     | 20     |        |        |

Table 3. Value compensation for circuit-breaker close

| CLOSE                | Pole A | Pole B | Pole C |
|----------------------|--------|--------|--------|
| Delay reference contact [ms] | -18.4 | -18.7 | -18    |
| Reference contact signal duration [ms] | 8.9   | 9.5   | 8.9    |
| Reference contact travel [mm]       | 0      | 0      | 0      |

Table 4. Adjusting time function phase shift/pole closing

| Pole A | Pole B | Pole C |
|--------|--------|--------|
| phase shift/pole [o] | 90     | 210    | 150    |
| phase shift/breaker [o] | 10   |        |        |
| adjusting time [ms]   | 14.3   | 13     | 12.7   |

In Figure 4, it can be seen that the closing command is given at the passage of phase reference A by zero, the following signals and sizes are presented.
Figure 4. Closing phase A- shunt reactor

Cmd R- Displays commands transmitted by BCU to pole A
Ref R – Display of the reference contact signal at pole A
HSO-R- Display of the reference contact signal at pole A
UB-R Analogue Bar Signal Signal Signal Signal Signal Signaling for Field Phase Switch A
UI-R Display analog line voltages for pole A
Is-R Analog line current display for pole A

Table 5. Value variables for circuit-breaker open

|                         | Pole A | Pole B | Pole C |
|-------------------------|--------|--------|--------|
| Closing times [ms]      | 21.6   | 21.4   | 21.1   |
| Hydraulic pressure [bar]| 330    | 330    | 330    |
| Trip voltage [V]        | 240    |        |        |
| Temperature [°C]        |        | 20     |        |

Table 6. Value compensation for circuit-breaker close

|                        | Pole A | Pole B | Pole C |
|------------------------|--------|--------|--------|
| Delay reference contact [ms] | 6      | 6.2    | 6.1    |
| Reference contact signal duration [ms] | 3.1    | 3.2    | 3      |
| Reference contact travel [mm]       | 0      | 0      | 0      |

Table 7. Adjusting time function phase shift\pole closing

|                        | Pole A | Pole B | Pole C |
|------------------------|--------|--------|--------|
| phase shift\pole [o]   | 90     | 210    | 150    |
| phase shift\breaker [o] | |        |        |
| adjusting time [ms]    | 7      | 7      | 7      |
As shown in Figure 5, the zero sweep current of any phase can be evaluated as an opening reference. Separation of circuit breaker contacts takes place sooner than extinguishing the electric arc. The operational opening is as follows:
- The opening command is issued
- The BCU follows the current curve crossing (zero zero in the negative range) by synchronizing the phase position of the current.
- After the opening time has elapsed, the contacts open and the flow of current flows without additional spring
- The current flow ends after the arc-electric time at the zero current flow.

![Figure 5. Opening phase A- shunt reactor](image)

6. Conclusions
Existing SF6 switches are located outside where other equipment can be monitored for ambient temperature such as autotransformers, so the required BCU temperature can be read from the control command system (SCADA).

Considering that the last types of SF6 circuit-breakers have a spring-operated actuator so it can be removed from the hydraulic pressure sensor.

Depending on the type of cell that is fed line, BC, AT is installed a program characteristic of each type of task.

Action has to be done on each independent phase

The program does not have to act when the command is issued from the protections from the cell-mounted automation.

The program may send error messages if there are defects in one of the sensors that use and block the program's malfunction.

Since this program runs in parallel with the SCADA systems, it must act only after checking the interlocks in the BCU both locally and remotely.

Under normal operating conditions, operating characteristics could be constantly compensated over a long period of time by using the features of factory tests.

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