

# To Research on Application and Maintenance of Sulfur Hexafluoride (SF6) Circuit Breaker

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**Abstract** — Circuit breakers play an extremely important role in power systems, and Sulfur Hexafluoride (hereinafter referred to as SF6) gas is the medium for the main functions of circuit breakers, and it has the functions of insulation and arc suppression. After the excavation of SF6 and reports on its application in electric power equipment and recently related literature, inspiring the author to summarize - the unique characters of SF6 and the arc suppression and operation principle, and explained some proper terms on the nameplate of the circuit breaker, all those combine an article, which can be prone to understand, at the same time it is easy to navigate of international journal on the website. In addition, for the abnormal situation of the connecting circuit breaker between the two busses in the substation, the “time constant” formed by the equivalent resistance and inductance value of the DC component of the zero-sequence fault current is related to the breaking time of the circuit breaker. Finally, combined above mentioned character with the points that must be paid attention to maintenance and being repaired on SF6 breaker in during, those things will be compiled into an article, which can be used as a reference for technical personnel in the field of power engineering.

**Keywords** — Breaker Breaking Time, Circuit Breaker, Sulfur Hexafluoride (SF6), Time Constant As.

## I. INTRODUCTION

After the advent of SF6, because of its excellent insulating properties, the largest use in high-voltage circuit breakers, where, in addition to providing what the most effective function to suppress the arc. it has been researched and developed and applied to power system equipment. It not only improves the arc suppression strength, but also changes the structural volume of the equipment and reduces the investment cost of equipment. This article takes the characteristics of SF6 as the X axis, the easy-to-understand operation structure description as the Y axis, and the author's many years of maintenance experience as the Z axis as a reference for technical personnel in the power field. In addition to this paragraph, this article is divided into - literature review, introduction of SF6 gas characteristics, SF6 circuit breaker, maintenance suggestions, review, references.

## II. LITERATURE REVIEW

SF6 gas is a synthetic artificial inert gas developed by two French chemists, Moissan and Lebeau in 1900. The characteristics of this gas have a very high degree of insulation for electrical equipment, which is 2.5 times that of air, and the arc suppression capacity is 100 times that of air.

Stability very strong. Since the mid-1960s, it has been widely used in high-voltage electrical equipment as an insulating medium, and it is suitable for power supply equipment in densely populated areas and high-rise buildings because of its small footprint and the advantages of not being affected by weather changes and different environments. Especially in recent years, the excellent development results have led to the publication of many related technical papers and the use of effect analysis reports in international journals. So, the author collects relevant literature, extracts its advantages and disadvantages, and explains its individual uniqueness in this paragraph.

Heiermeier and Raysaha [1] describe that if the power equipment in service is not designed according to international standards, it may cause the lack of normal operation of the circuit breaker. In particular, theoretical evaluation involves the calculation of transmission network parameters, power flow and dynamic analysis, etc. to verify that theoretical evaluation is helpful before actual measurement. Cheetham *et al.* [2] describe the definition and interpretation of circuit breaker tasks and arc suppression media and their proper names. Fofana [3] describes the importance of liquid insulators to the insulation, arc suppression, and heat dissipation of power equipment, and the daily inspection can evaluate the life of the equipment. Park and Ha [4] described the relationship between nozzle ablation of SF6 gas circuit breaker, nozzle structure change and injection energy, and the data can be obtained from experimental measurement and simulation prediction. Liu *et al.* [5] described that the adaptive control of moving contacts of SF6 gas circuit breaker can improve its service life and the remaining life cycle of the circuit breaker can be estimated according to the data. Kamei and Takai [6] stated that the state maintenance process can obtain the SF6 leakage situation from the self-inductor and compared with the traditional detection method, it proves that it is feasible and high. Rudsari *et al.* [7] describes the use of coil current and contact stroke waveform as a fault identification system, which uses neural network and support vector machine (SVM) to compare and verify a diagnostic method between health and fault. Xiang *et al.* [8] stated that when the power system is faulty, the breaking time of the circuit breaker is verified to directly affect the breaking capacity of the circuit breaker when the DC time constant of the zero-sequence current exceeds the standard time constant of the circuit breaker. Mitrik and Kádár [9] describe the high-voltage switchgear design algorithm based on “system theory” with parameter weights. This method only needs to modify the parameters in



the program to achieve the desired design effect [10]. According to the simulation test, if the filling ratio of SF<sub>6</sub>/CF<sub>4</sub> mixed gas is incorrect, the setting of the density meter does not match and the pressure in the tank is too high, the sudden drop of atmospheric temperature will cause the low pressure or lockout alarm to fail.

### III. INTRODUCTION TO THE CHARACTERISTICS OF SF<sub>6</sub> GAS

Before the introduction of the circuit breaker, the characteristics of SF<sub>6</sub> gas as an insulation and arc suppression medium will be explained one by one.

- 1) Suffocation: SF<sub>6</sub> is an odorless, colorless, tasteless and non-toxic gas in its pure state. But it removes oxygen from the atmosphere and can suffocate without warning if the normal oxygen level falls below 13% from 21%.
- 2) Toxicity from arcing: When the SF<sub>6</sub> gas is arced, it will decompose into toxic substances, which are metal fluorides into white or brown powder, with the smell of rotten eggs.
- 3) Character: SF<sub>6</sub> is one of the heaviest gases. Compared with air, under the same temperature and pressure within a certain range, it has the following advantages: high heat transfer coefficient, 5 times higher density, and 1.6 times higher cooling capacity.
- 4) Dielectric strength: With a certain distance between electrodes, under one atmosphere, the dielectric strength of SF<sub>6</sub> is three times that of air, and it increases with the increase of pressure; under three atmospheres, the dielectric strength is equivalent to that of transformer insulating oil. SF<sub>6</sub> is used in circuit breakers and requires heaters to prevent gas liquefaction, which will decrease due to liquefaction, thereby reducing the dielectric strength.
- 5) Arc suppression: SF<sub>6</sub> is 100 times better than air in arc suppression efficiency and has high heat capacity to absorb the temperature rise caused by arc.
- 6) Arc breakdown: Normally, SF<sub>6</sub> will not cause corona and arc unless the corona is continuous until it exceeds the initial voltage of corona and arc and decomposes. The products of decomposition are poisonous. If a small amount of arc products is operated normally, they will recombine into SF<sub>6</sub> gas, and if they cannot be recombined, they will be removed by the molecular sieve filter material.
- 7) Arc decomposition products - SF<sub>4</sub>, S<sub>2</sub>F<sub>2</sub>, SF<sub>2</sub>, SOF<sub>2</sub>, SO<sub>2</sub>F<sub>2</sub>, SOF<sub>4</sub> and HF, etc., all of which are highly corrosive and toxic.
- 8) The negative charge of the gas provides a lower arc time constant, required for the medium to recover its dielectric strength after the final current is zero.

### IV. SF<sub>6</sub> CIRCUIT BREAKER

Inheriting from the above reference descriptions, knowing its advantages in the application of electrical equipment and using it as an insulating medium to replace insulating oil or air, this paragraph will introduce its purpose and operating principle as a circuit breaker in the power system.

- 1) Purpose: As a switch on the power system, it is used as an isolation device for power dispatching and

maintenance.

- 2) The SF<sub>6</sub> circuit breaker is mainly composed of six parts: the conductive part of the circuit breaker, the arc suppression unit, the insulating part, the auxiliary connection device and the electrical control and operation structure.
- 3) The operation principle of SF<sub>6</sub> circuit breaker is divided into two types: "opening operation" and "closing operation".

The more detail introduction of each item is as follows:

#### A. Open Operations

The inner arm in the support cylinder is controlled by the spring operating mechanism to pull the insulating rod downward so that the main contact head (moving) is separated from the auxiliary contact head (solid) to generate an arc. When the arc burns to generate a high temperature, high-pressure gas (SF<sub>6</sub>) flows into the cylinder from the gas storage tank (pressure 14 kg/cm<sup>2</sup>) and is ejected from the main contact to eliminate the arc so that the circuit is opened.

#### B. Closed Operation

Controlling the inner arm of the support cylinder through the spring operating mechanism pulls the insulating rod upward to move the main contact to the auxiliary contact until it is tightly closed, but the pressure in the cylinder is 2.8 kg/cm<sup>2</sup>, waiting for the next opening operation.

#### C. Arc Suppression Principle

When the solid and moving contacts are opened, the arc is generated, and SF<sub>6</sub> gas is used as the arc-extinguishing medium, which has electronegativity to absorb free electrons. The conductive free electrons in the arc are captured by the gas, forming fixed negative ions, causing the medium between the contact points to be quickly filled to enhance its dielectric strength to achieve arc extinction. When the arc is extinguished, SF<sub>6</sub> decomposes, and its decomposition products recombine to form the original gas when cooled.

Fig. 1 shows the components of a typical SF<sub>6</sub> circuit breaker. It consists of solid and moving contacts enclosed in a cylinder chamber filled with SF<sub>6</sub> gas. The chamber is connected to the SF<sub>6</sub> gas storage tank. When the circuit breaker is opened, the valve mechanism allows high pressure SF<sub>6</sub> gas to flow from the gas storage tank to the arc suppression chamber. The auxiliary (solid) contact head is a hollow cylindrical contact with a horn; the moving contact head is also a hollow cylinder with a rectangular hole on the side for SF<sub>6</sub> gas to discharge the arc along. However, the solid and moving contact heads and the tips of the horns are all coated with "copper tungsten arc-resistant" material. Since SF<sub>6</sub> gas is expensive, it is repaired and recovered by suitable auxiliary systems after each circuit breaker operation. When the circuit breaker is in the closed position, the contact heads are surrounded by SF<sub>6</sub> gas with a pressure of 2.8 kg/cm<sup>2</sup>; when the circuit breaker is opened, an arc is generated between the contacts and the valve is opened synchronously to allow the SF<sub>6</sub> gas with a pressure of 14 kg/cm<sup>2</sup> to flow from the gas storage tank to the arc chamber. The conductive free electrons in the arc are captured by the gas, forming fixed negative ions, causing the medium between the contact points to be quickly filled to enhance its dielectric strength to achieve arc extinction.



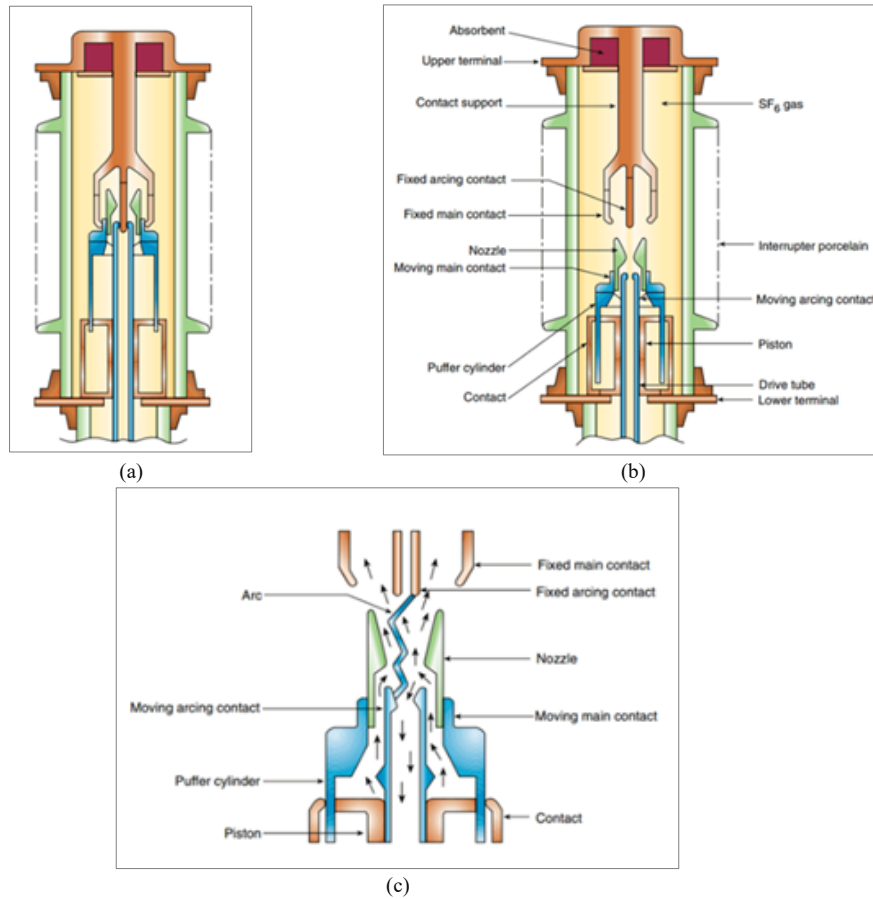


Fig. 1. Integrated: a) Closed position; b) Open position; c) Arc suppression schematic diagram [12].

#### D. Power Circuit Breaker Structure

The above-mentioned circuit breaker is single-phase. If it is applied to the power system, each single-phase needs to be integrated and driven by a spring mechanism to form a power circuit breaker (three-phase). It is installed on a common base, but the spring mechanism and the electrical control part share a box and are placed in front of the lower part of the base. Single phase of three column inflatable chambers is respectively connected by valves and pipelines to a common high-pressure gas storage (SF<sub>6</sub>) tank, the pressure of which is displayed through monitoring and control, and the gas is compensated at any time.

#### E. Circuit Breaker Specifications

In this paragraph, the conditions that have 145kV voltage level circuit breaker should meet are presented in Table I. If any of the specifications is not met, the circuit breaker will not be able to operate normally on the power system.

TABLE I: CIRCUIT BREAKER SPECIFICATIONS

Name	Unit
Rated voltage	145kV
Rated frequency	50/60 Hz
Rated normal current	4000 A
Short-circuit current	40 kA
Short-circuit break current	104 kA
Duration of short-circuit	3 s
Opening time	28 ms
Closing time	≤ 70 ms
Breaking time	50 ms
Ambient temperature	-30 ~ +40 °C

Explanation of opening time and breaking time on Table I is as follows; The opening time is the time for opening load current under normal conditions, and the breaking time is the time for opening the fault current when the power system fails. In addition, when a fault occurs in the power system, the composition of the zero-sequence fault current is as in (1), the AC component part is shown in (2), the DC component part is shown in (3), from which known that the time constant generated by the equivalent resistance and inductance of the line is related to the breaking time of the circuit breaker, (4) describes the zero-sequence line impedance value at fault, (5) describes the zero-sequence  $\theta$  angle at fault, and (6) describes the zero-sequence time constant at fault. Fig. 2 below shows the relationship between fault zero sequence current composition and decay and breaking time. [13] Therefore, the design specifications of the circuit breaker are also different depending on the location of the circuit breaker, such as the transmission line or the connection (between the bus bars).

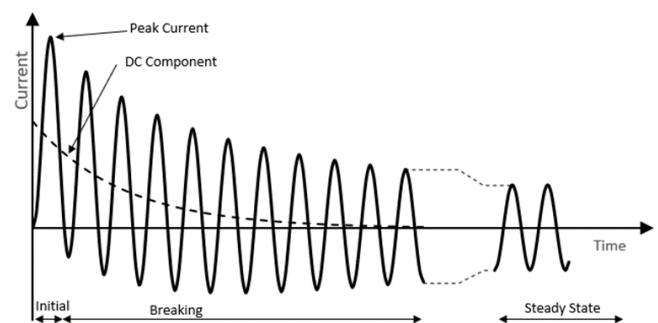


Fig. 2. The relationship between fault zero sequence current composition and decay and breaking time. [13].



$$i(t) = i_{ac}(t) + i_{dc}(t) \quad (1)$$

$$i_{ac}(t) = \sqrt{2}V/Z \sin(\omega t + \alpha - \theta) \quad (2)$$

$$i_{dc}(t) = -\sqrt{2}V/Z \sin(\alpha - \theta) e^{-t/T} \quad (3)$$

$$Z = \sqrt{R^2 + \omega L^2} = \sqrt{R^2 + X^2} \quad (4)$$

$$\theta = \tan^{-1}(\omega L/R) = \tan^{-1}(X/R) \quad (5)$$

$$T = L/R = X/\omega R = X/2\pi fR \quad (6)$$

(1)-(6) are explained as follows:

- 1) Z is the zero-sequence equivalent impedance when the power system is faulty.
- 2) R is the zero-sequence equivalent resistance when the power system is faulty.
- 3) L is the zero-sequence equivalent inductance when the power system is faulty.
- 4) T is the zero-sequence time constant of the power system fault.
- 5)  $\alpha$  is the offset angle of the DC component of the zero-sequence current when a fault occurs.

From (3), we know that when  $\alpha$  is equal to  $\theta$ , the DC component of the zero-sequence current is zero [11].

#### F. Insulation Withstands Voltage and Pressure Density

The relationship between the insulation withstands voltage and the pressure density of the circuit breaker, the insulation between the components in the tank is maintained above the pressure density (about  $10^5$  pa) to ensure the normal operation of the equipment. If the pressure density is low for some reason, flashover accidents will occur due to insufficient insulation of the equipment. In Fig. 3 is shown the pressure density from  $10^{-3}$  pa (unit) to  $10^6$  pa, the corresponding withstand voltage value from 90 kV to 80 kV, which the curve of relationship is shown concave the lowest where is at 1.5 kV (at  $10^3$  pa). 1 atmospheric pressure is equal to  $10^5$  Pa (unit kg/cm<sup>3</sup>) is also equal to 6.0886 kg/cm<sup>3</sup>.

Because of its special relationship, it is necessary to pay attention to the change of pressure density during maintenance and repair operations [14].

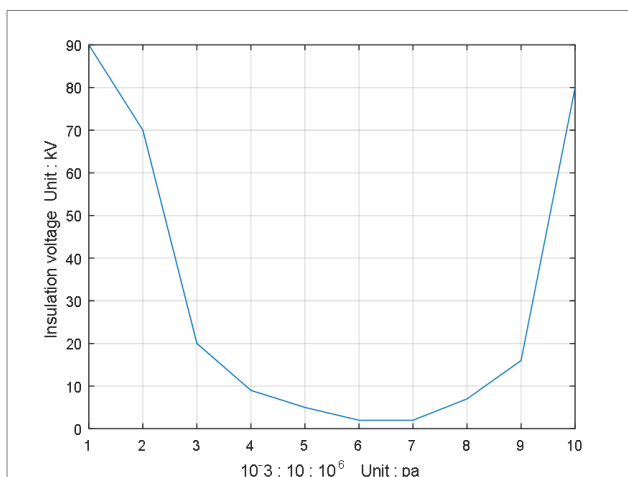


Fig. 3. Relationship between insulation withstand voltage and pressure density.

#### V. MAINTENANCE TREATMENT

Circuit breaker maintenance is divided into two types: normal maintenance and post-accident treatment. Whether it is implemented or not is related to the operation of the circuit breaker and the safety of personnel. As a result, this paragraph lists some precautions for maintenance operations for reference.

- 1) Usually at least once a year or after every 500 operations, and if an accident occurs, it should be dealt with immediately. In addition to standard operating procedures for SF6 gas recovery operations, the relevant precautions must also comply with the guidelines.
- 2) The operating mechanism, air compressor equipment, heater and other related accessories need to be inspected daily on site.
- 3) Handle maintenances: The procedure for handling non-faulty SF6 in the manual is as follows: remove SF6 from the circuit breaker, filter and store it as a liquid, and then refill the circuit breaker after maintenance is completed. No special clothing or precautions are required.
- 4) Troubleshooting: Abnormal SF6 gas smells like rotten eggs, which can cause nausea and irritate the eyes and upper respiratory tract, so it cannot be exposed for a long time.
- 5) Arc products: The arc product is poisonous, white or lime-like powder, which will cause irritation or fluoride burns' if it contacts with the skin. It must be rinsed immediately, and if there is no water, suck it up with a vacuum cleaner.
- 6) Clothing and Safety Equipment: Special work clothes and gloves should be worn when handling and moving SF6 arc products. Disposable is recommended, but normal work clothes can be worn and will need to be washed after work.
- 7) Waste disposal: All materials used during SF6 arc product clean-up operations should be placed in waste drums and disposed of as hazardous waste.

The SF6 high-pressure storage tank is equipped with indicators and alarm systems for monitoring and heaters to prevent the high-pressure gas from being liquefied due to a sudden drop in temperature and affecting the characteristics. The spring-operated connecting rod links the three phases separately through a common plate and can be disassembled to adjust the closing time of the fixed and moving contact points of the individual phases, but the difference in the closing time of the three phases must be within the allowable range. SF6 gas is a controlled product, no matter it is lost due to equipment damage or leakage, the gas flow direction must be recorded for future reference [14].

#### VI. CONCLUSION

Circuit breakers play an extremely important role in power systems. However, after SF6 is used as an arc suppression and insulation medium in power system equipment, it is widely used by power companies because of its unique characteristics to reduce the size of the equipment and reduce the cost of installation.



In addition to many years of experience in serving power companies and referring to recent literature reports on SF6 circuit breakers, the author made a report on the relationship between the time constant formed by the equivalent resistance and inductance of the DC zero-sequence fault component and the breaker breaking time when the system fails. Therefore, the design specifications of the circuit breaker are also different depending on the location of the circuit breaker, such as the transmission line or the connection (between the bus bars). Another example case occurred in the process of SF6 circuit breaker equipment shutdown and maintenance, because two chambers must open in Standard Operating Procedures, but only one was opened. so that the pressure density dropped while the gas was absorbed from chamber, since the insulation withstand voltage was insufficient and caused an equipment failure accident. Therefore, proposed the relationship between withstand voltage and pressure density. The article studies the principle and characteristics of SF6 arc suppression, related auxiliary equipment, maintenance precautions, and is a reference for technical personnel in the power field.

#### CONFLICT OF INTEREST

Authors declare that they do not have any conflict of interest.

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