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# SF6 Circuit Breakers: A Comprehensive Study of Mechanisms and Benefits

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***Abstract***

*This report presents an assessment of the dependability of sulfur hexafluoride ($SF_6$) circuit breakers in substations for the transmission, with the considered potential areas of deterioration identified in the device. The aging process has a tangible impact on the equipment, potentially diminishing its strength and increasing the likelihood of malfunction. The reliability of the equipment cannot be determined solely by its age, as its actual condition is influenced by wear and the maintenance it has received. This document identifies the areas of deterioration, emphasizing the need for preservation measures, and establishes their defined limits for SF6 gas circuit breakers. The important assistance of this approach is to facilitate an evaluation of the current state of a circuit breaker by examining the quantifying of its numerous areas of deterioration, enabling the recognition of condemning equipment that should be prime concern in maintenance preparation. A circuit breaker failure could result in the failure of the power system, leading to significant disruption and substantial pecuniary losses. Conservation based on the reliability of circuit breakers helps minimize failures, reduce unavailability, and enhance the strength of power systems.*

**Keywords:** Circuit breakers, sulfur hexafluoride, short circuit, protection, power systems

## INTRODUCTION

A high-voltage circuit breaker is designed to use sulfur hexafluoride ($SF_6$) as its interrupting medium that utilizes $SF_6$ gas as its arc-quenching medium. This gas is valued for its exceptional insulation properties and its effectiveness in douse arcs, making it a suitable choice for high-voltage electrical power systems. In the event of a fault in the electrical grid, the $SF_6$ gas is pressurized and then discharged to cool down and douse the arc that forms between the contacts of the circuit breaker, ensuring a secure and dependable interruption of the current flow. Due to their efficiency, reliability, and capacity to manage high power loads, $SF_6$ circuit breakers are extensively employed in power distribution and transmission systems, playing a crucial role in improving the stability and security of modern electrical grids. Circuit breakers are utilized to isolate faulty sections of the system as part of the protection with the help of the relaying process. Essentially, a circuit breaker is comprised of fixed and moving contacts that come in touch with one another to carry current when the loop of the circuit is shut down. The electrodes, serving as the current-carrying contacts, make contact with each other due to spring pressure when the circuit breaker is shut. Under regular operating conditions, the circuit breaker arms can be opened or closed for system switching and maintenance. To open the circuit breaker, one simply needs to apply pressure

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to a trigger in the event of a malfunction in any part of the system, the trip coil of the breaker is activated, leading to the separation of the moving contacts from each other using a specific mechanism, thus breaking the circuit.

## LITERATURE REVIEW

$SF_6$ circuit breakers have a historical origin dating back to the mid-20th century, a time characterized by notable progress in high-voltage engineering. Initial investigations revealed the exceptional dielectric characteristics of $SF_6$ gas in contrast to conventional insulating substance [1]. Pioneering work conducted by engineers like Nagai and Ito during the 1960s and 1970s laid the groundwork for the real-world implementation of $SF_6$ in circuit breakers, showcasing its efficacy in extinguishing arcs and providing insulation [2].

Technological advancements over the decades have refined the design and functionality of $SF_6$ circuit breakers [3]. Research has focused on improving the efficiency of arc quenching mechanisms and enhancing the reliability of these devices under varying electrical loads [4]. Innovations such as self-blast interrupter units and improved gas handling systems have been extensively documented in journals like *IEEE Transactions on Power Apparatus and Systems*. These improvements have significantly reduced the size and operating energy of circuit breakers while maintaining high performance [5].

$SF_6$ circuit breakers, while offering technical advantages, have faced criticism over environmental issues. The gas is known to be a powerful contributor to greenhouse gas emissions, and its release into the atmosphere presents substantial environmental hazards [6]. Efforts have been made to investigate alternative solutions and strategies to reduce $SF_6$ leakage, including the enhancement of sealing methods and the creation of substitute gases with reduced global warming potentials [7].

Regulatory entities such as the European Union have enforced stringent regulations to oversee and manage $SF_6$ emissions, leading to continuous exploration of eco-friendly approaches. Recent literature extensively discusses the critical importance of operational efficiency and reliability in $SF_6$ circuit breakers. Comparative studies have revealed that these circuit breakers surpass traditional oil and air circuit breakers in terms of arc quenching speed and dielectric strength [8].

Furthermore, research has focused on the lifecycle management of $SF_6$ circuit breakers, highlighting the significance of predictive maintenance techniques and real-time monitoring systems to improve operational longevity and reliability [9]. The significance of operational efficiency and reliability in $SF_6$ circuit breakers have been thoroughly explored in recent literature. Comparative studies have demonstrated the superior performance of $SF_6$ circuit breakers in arc quenching speed and dielectric strength when compared to traditional oil and air circuit breakers [10]. Additionally, research has emphasized the importance of predictive maintenance techniques and real-time monitoring systems in the lifecycle management of these breakers to enhance their operational longevity and reliability [11].

## METHODOLOGY

To begin the process, the first step is to carry out an extensive review of literature in order to gain insights into the historical background, technological progressions, and present-day developments associated with $SF_6$ circuit breakers [12]. The subsequent stage encompasses the development of experiments aimed at evaluating the effectiveness and dependability of $SF_6$ circuit breakers across different scenarios [13]. This encompasses the establishment of a regulated setting in which a range of factors, including voltage, current, and pressure, can be methodically altered. High-voltage testing facilities, complete with essential diagnostic equipment, are utilized to replicate fault scenarios and gauge the reaction of the $SF_6$ circuit breakers [13]. Sophisticated simulation tools and modelling software are utilized to forecast the behavior of $SF_6$ circuit breakers in various scenarios. Computational models are created to replicate the physical and chemical processes that occur during arc quenching and insulation, aiding in understanding the dynamics of $SF_6$ gas and its interaction with other components. Validation of these models is carried out by comparing simulation results with experimental data [13].

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To address environmental concerns, methodologies for assessing the impact of $SF_6$ gas emissions are implemented, including measuring gas leakage rates and evaluating sealing mechanisms' efficiency. Life cycle assessment (LCA) techniques are used to analyze the environmental footprint of $SF_6$ circuit breakers from production to disposal, while research explores alternative gases and designs to reduce environmental impact [14]. Reliability analysis involves studying the failure modes and maintenance requirements of $SF_6$ circuit breakers. Methods like failure modes and effects analysis (FMEA) and reliability-cantered maintenance (RCM) are employed to pinpoint crucial components and anticipate possible malfunctions. Data from long-term operational records are analyzed to develop predictive maintenance models that enhance the reliability and lifespan of the circuit breakers. Diagram of a circuit breaker is shown in Figure 1. Field testing is conducted to validate the laboratory and simulation results, involving the installation of $SF_6$ circuit breakers in actual power distribution networks and monitoring their performance over time. Schematic process of circuit breaker is shown in Figure 2. Data collected from field tests provide insights into real-world operating conditions and help refine the experimental models.

**Case 1**

If a fault occurs in the secured circuit, the relay associated with the current transformer (CT) will be activated, causing its contacts to close. This will allow direct current to pass through the cut circuit from the source. Once the trip coil of the breaker receives power, the circuit breaker's operating mechanism will be activated, resulting in an automatic opening process. The spring in the operating mechanism can be charged either manually or electrically. Furthermore, the auxiliary switches of the breaker are mechanically linked to its operating mechanism. The contact transition is synchronized with the breaker's operation. Auxiliary contacts are essential for the operation, indication, and supervision of the trip circuit.

**Case 2**

The current rating for short circuit is more, short circuit current that a circuit breaker can resist before its contacts are opened to clear the fault. During a short circuit, mechanical and thermal stresses are exerted on the current-supplying components of the circuit breaker. Insufficient cross-section and contact area of the guiding parts can result in permanent damage to both the insulation and guiding parts of the circuit breaker. As per Joule’s law of heating, the degrees rise is directly proportional to the square of the short circuit current, contact resistance, and the time of the short circuit current. The short circuit current will flow through the circuit breaker until the fault is cleared by opening the contacts. The thermal stress in the circuit breaker is directly related to the duration of the short circuit, hence the breaking capacity of the circuit breaker is dependent on the working time. Determining the damaged level in any part of the electrical transmission system makes it easier to select the appropriate rated circuit breaker for that specific section of the network.

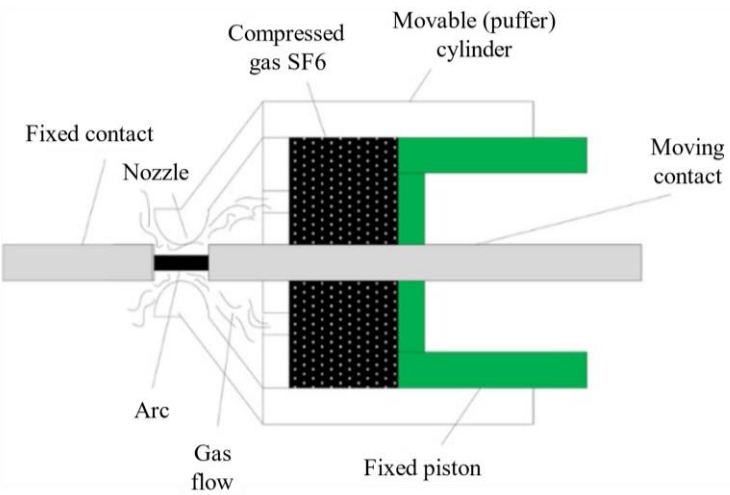


**Figure 1.** Diagram of circuit breaker [10].

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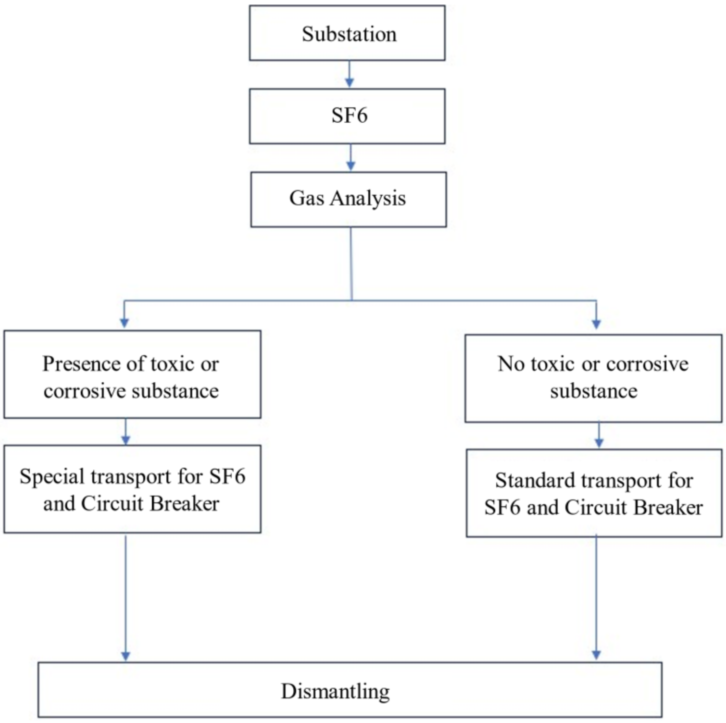


**Figure 2.** Schematic process of circuit breaker.

### *Circuit Breaker's Duty Cycle or Rated Operating Sequence*

This document outlines the operational requirements for the mechanical functioning of a circuit breaker. The rated operating duty sequence for a circuit breaker is as follows: O denotes the availability operation, CO signifies the shutting operation time, immediately succeeded by another availability operation without any deliberate time delay. The time 't' between two operations is crucial for restoring initial conditions and preventing excessive heating of conducting parts within the circuit breaker. For a circuit breaker designed for first auto reclosing duty, 't' equals 0.3 seconds unless stated otherwise. If the evaluated duty cycle of a circuit breaker is 0 to 0.03 min – CO – 3 min – CO, it means that after an opening operation, the circuit breaker closes after 0.3 seconds, then opens again without any intentional delay. Subsequently, the circuit breaker closes after 180 seconds and promptly cuts without any deliberate delay time.

### *Short Circuit Making Capacity*

The fault current in a system has the potential to reach up to two times of its symmetrical fault amount at the moment of a fault occurrence. When a circuit breaker is turned on under faulty conditions, the short circuit section of the system becomes joined to the origin. The initial cycle of the current when the circuit breaker closes have the highest amplitude, approximately double the magnitude of the symmetrical fault current waveform. The contacts of the breaker must be able to withstand this peak current value during the first cycle of the waveform when the breaker is shut under fault. Therefore, a selected breaker should have a short circuit making capacity rating. The rated short circuit making current of a circuit breaker is expressed in maximum peak value, which is always higher than the rated short circuit breaking current of the circuit breaker. Typically, the short circuit current is 2.5 times greater than the short circuit breaking current.

## RESULTS AND DISCUSSION

The concentration of $SF_6$ gas in a sample, measured by an $SF_6$ analyzer, is a critical parameter typically reported in volume percent (%). In electrical equipment, the typical range for $SF_6$ gas concentration is between 98% and 99.9%. Moisture in $SF_6$ gas can negatively impact its insulating properties and lead to corrosion in electrical components.

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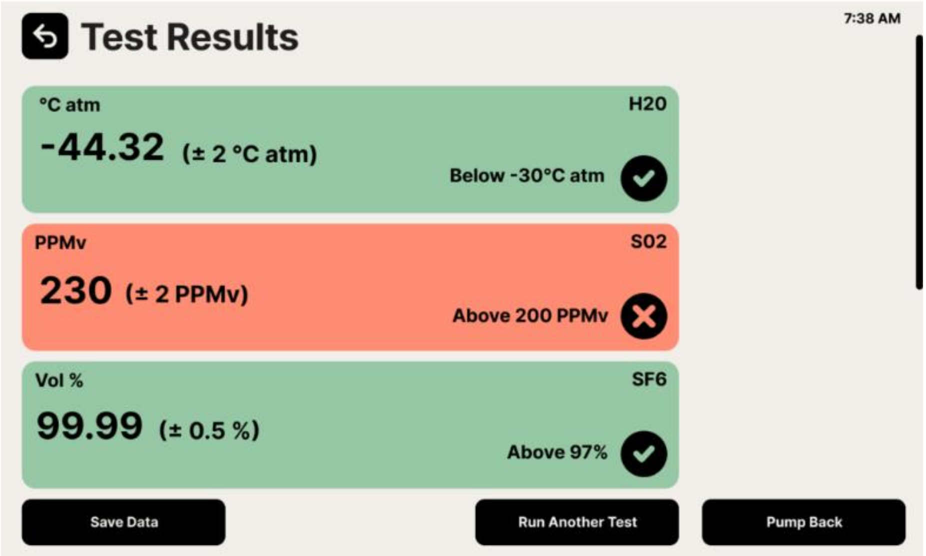


**Figure 3.** Test results [11].

A device for analyzing $SF_6$ can determine the moisture content in parts per million by volume (ppmv) or the dew point temperature, which indicates the temperature at which moisture transitions into liquid form. High levels of sulfur dioxide in $SF_6$ gas, measured in parts per million by volume (ppmv), indicate decomposition of $SF_6$ due to overheating or arcing. This decomposition produces toxic byproducts that can damage equipment and pose health risks. Prompt identification and resolution of the decomposition cause are crucial to prevent further damage and ensure safe circuit breaker operation. Test results are shown in Figure 3.

## CONCLUSION

In brief, circuit breakers are essential components that play a important role in maintaining the safety and dependability of electrical systems. They are engineered to safeguard electrical circuits from potential damage caused by overloads or short circuits by halting the current flow upon detecting a fault. This not only prevents possible fire risks and equipment harm but also guarantees the safety of individuals utilizing electrical appliances. Contemporary circuit breakers are available in a variety of types and capacities, customized for diverse applications and settings. It is imperative to comprehend the specific needs of an electrical system when choosing the suitable circuit breaker. Furthermore, routine maintenance and testing are vital to ensure that circuit breakers operate effectively and offer consistent protection over time. To summarize, the efficient installation and upkeep of circuit breakers are essential for electrical safety and effectiveness. By providing protection against electrical faults, circuit breakers help uphold the integrity of electrical systems, safeguard valuable equipment, and, most importantly, ensure the well-being of individuals.

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