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Analysis of High Voltage Circuit Breakers in Power System Transmission

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Abstract

This paper presents a configuration and analysis of high voltage circuit breakers (HVCB) in power system transmission, which addresses the performance of high voltage circuit breakers using statistical tools to analyze the number of operations, reliability studies to analyze the reliability and failure rate in order to know which class of circuit breaker has the most excellent quenching medium, and also modeling the transmission network. As the need for transmission systems increases, the use of circuit breakers (CB) also increases with high breaking capacity. In this scenario, Matlab Simulink is used as a tool to simulate the operational mechanism of the breakers. This study shall focus on various classes of high-voltage circuit breakers (coil, vacuum, and SF6) that can fulfill the needs of CB stable operation switching and its operational analysis. Results show an improvement in power system operation.

Keywords: *High Voltage Circuit Breaker (HVCB), Bulk Oil Circuit Breaker (BOCB), Axial Blast Air Circuit Breaker (ABAC), Relay Logic Circuit (RLR)*

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Background of the Study

The electrical power system is the wheel that drives the economy of every country, which is to say that anything that interrupts the supply of the power system will adversely affect the national economy of a country. In order to prevent contingency or unplanned downtime of the entire circuitry in the power system network, if not protected with the necessary protective instrument, damage or explosion will be too expensive for the power system components like the power transformer, auto-transformer, generator (Turbine), relay devices, etc. The availability and reliability of a power system network depend greatly on the performance of the protective instrument for quick, excellent isolation and current interruption capability that is capable of sensing the flow of overcurrent. When faults like overcurrent and voltage surge occur on transmission lines, the ability of the power system network to isolate the faulty circuit from the healthy circuit depends solely on the performance of the circuit breaker (Gupta, 1989).

Electric power is transmitted from the generating stations to the consumers via a complicated network (or system) of transmission lines. Circuit breakers are an essential part of such a network system in that they provide flexibility by performing two main functions, namely: switching, which involves the opening of circuits that may or may not be carrying load current. The second function is protection, which involves the opening of circuits that may or may not be carrying fault current. Furthermore, circuit breakers under load current act as control switches for the on/off of a system load. In the case of fault current, the breaker switches off the system, thereby protecting it from contingencies such as damage to the system or even total collapse, as the case may be. Hence, in studying circuit breakers, it is imperative to know the terminology and methods of operation of fuses as they relate to electrical systems (Alison and Motor, 2012). Each of the breaker features must be able to perform its relative function so as to enable the circuit breaker system to function effectively. For instance, the closing control circuit must do more than merely close the breaker; it must control this closing mechanism by initiating the closing stroke, cutting off the closing power, and sealing in the breaker fully each time the closing operation is activated to maintain a steady state of supply to the required application on utility.

Literature Review

An overview of a circuit breaker as an automatic switch that protects electric motors, household wiring, long-distance power lines, and other electric circuits against damage caused by too much electric current may be traceable to the origin of electricity itself. Frink and Kozlovic (2014) But as time went on, advances in engineering technology led to the design of sophisticated circuit breakers with capacities ranging up to 750 kV. The opening mechanism employed includes electromagnets and temperature-sensitive devices. As the contact opens, an electric arc leaps across the open contacts, and current continues to flow through the arc until it is extinguished. In an oil circuit breaker, the contact is immersed in oil, which extinguishes the electric arc. In the case of an air blast circuit breaker, a blast of compressed air blows out the arc, while in a magnetic circuit breaker, a magnetic field deflates and breaks the arc (Frink and tiawa 2015).

One major problem associated with this class of breakers is their low voltage capacity rating, which limits their application. CBs are principally for outdoor applications, where they have been found to operate up to the highest voltages (Kozlovic, 2014). However, one major problem with this class of breakers is that the decomposition product reacts with the metal part of the breaker and thus damages it slowly (Henry, 2008).Vacuum circuit breakersin these breaker types, the fixed and moving contacts are enclosed in a permanently sealed vacuum interrupter. The arc is extinct as the contacts are separated in a high vacuum. It is mainly used for medium voltages ranging from 11 kV to 33 kV (Bratkowsk, et al, 2015).

One powerful approach, which has been investigated for several years at the High Voltage Laboratory at the ETH-Zurich, is model-based diagnosis", which predicts, simulates, and explains the resultant behavior of the system from the structure, causality, functionality, and behavior of the system by using a model of the device. The simulated behavior is used to compare the breaker with the observed behavior of the device, to evaluate the condition of the breaker, and at the same time to generate a diagnosis (Jankowetz and Feter, 2007). operational mechanism of circuit breakers Circuit breaker operational mechanisms is divided into six main groups identified by the source of their closing power: manual, solenoid, motor, springs, hydraulic, and pneumatic.

Materials and Method

Material

This explains the design of circuit breaker applications in terms of voltage and current carrying capacity as well as the material adopted for CB data selection, such as the software simulation Matlab Simulink, statistical tools for the analysis, the system laptop, consumables, and the HV circuit breaker.

Modeling of Transmission Network with Circuit Breaker

MATLAB is powerful analysis software that has the capability of modeling power system components using the Sim Power System Toolbox.

Inside the simulink package in MATLAB. In this toolbox, any available power system components, such as a three-phase transformer, three-phase load, three-phase source, circuit breaker, etc., can be used in AC and DC applications. Matlab was used to design and also analyze the overall transmission network model developed along with the overcurrent relay model, which helps us investigate the operation of the circuit breaker when clearing a 3-phase fault that is introduced in the system. Figure 1 shows the developed model of a transmission line and a load.

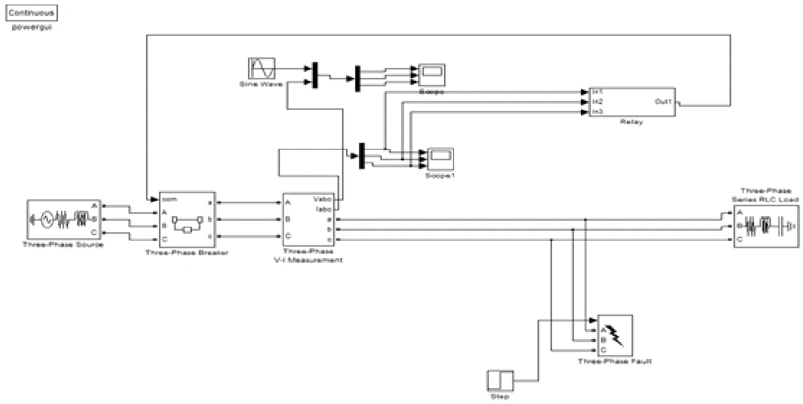

Fig. 1: Overall Transmission Network

Figure 2 shows the internal logic of an overcurrent relay developed using flip flops, relational operators, with the power system, transmission line, circuit breaker, load, etc. data used in this simulation. Note that the main purpose of this model and simulation is to experience the performance characteristics of a circuit breaker in a power system network in the event of a fault condition. The relay senses the fault in this model.

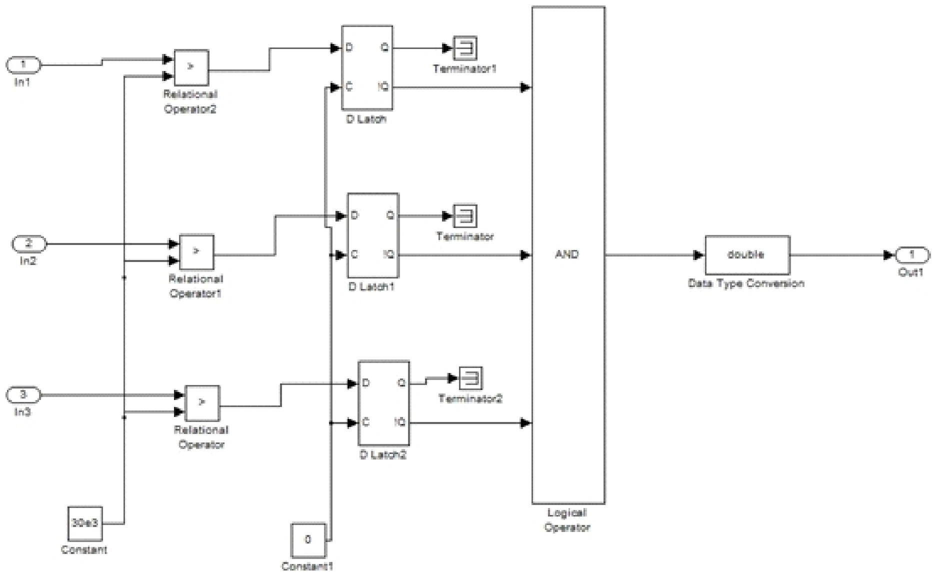

Fig. 2: Relay Logic Circuit

Mathematical Expression of Circuit Breakers

The mathematical expression of circuit breaker as obtained by the Cassie and Mayr equation presents the variation in the conductance of the arc by a differential equation with magnitude such as arc voltage and arc current.

By Cassie model, the mathematical equation is given as;

$$\frac{1}{gc}\frac{dg}{dt} = \frac{1}{Tc}\left(\frac{u^2}{U_c^2} - 1\right) \qquad 1$$

Where;

g= the arc conductance, in Siemens
U= the arc voltage, in volts
Tc= the arc time constant, in seconds
Uc= the constant arc voltage, in volts.

Similarly, Mayr model presents the mathematical expression above by equation two as below;

$$\frac{1}{gm}\frac{dg}{dt} = \frac{1}{Tm}\left(\frac{ui}{P} - 1\right) \qquad 2$$

Where;

g= the arc conductance, in Siemens
U= the arc voltage, in volts
I=the arc current, in Ampere
Tm= the arc time constant, in seconds
P= the cooling power, in Watts

By substituting equations 1& 2

$$\frac{1}{gc}\frac{dg}{dt} = \frac{1}{Tc}\left(\frac{u^2}{U_c^2} - 1\right) \qquad 3$$

$$\frac{1}{gm}\frac{dg}{dt} = \frac{1}{Tm}\left(\frac{ui}{P} - 1\right) \qquad 4$$

$$\frac{1}{g} = \frac{1}{gc} + \frac{1}{gm} \qquad 5$$

Where;

gc= the arc conductance describes by Cassie model, in Siemens
gm= the arc conductance describes by Mayr model, in Siemens
g = the total arc conductance, in Siemens

By combination and elimination of like terms in equation (3) and (4)

$$\frac{1}{g} * \frac{dg}{dt} = \frac{1}{T}\left(\frac{u^2}{U_c^2} - 1\right) * \left(\frac{ui}{P} - 1\right) \qquad 6$$

$$\frac{1}{g} * \frac{dg}{dt} = \frac{1}{T}\left(\frac{u^2}{U_c^2} - \frac{U_c^2}{U_c^2}\right) * \left(\frac{ui}{P} - \frac{P}{P}\right) \qquad 7$$

Eliminate the like terms

$$\frac{1}{g} * \frac{dg}{dt} = \frac{1}{T}(1) * \left(\frac{ui}{P} - 1\right) \qquad 8$$

It is observed that both the Cassie and Mayr equations are solutions of the general arc equation involving the Black Box model. These equations represent the variation in the conductance of the arc using a differential equation obtained from physical considerations and the implementation of simplifications. Mayr assumed that the arc has a fixed cross-sectional area and loses energy only by radial thermal conduction; in contrast, Cassie assumed that the arc has a fixed temperature and is cooled by forced convection. The *Cassie model* is mainly applied when studying the behavior of the arc conductance in the high-current time interval with the plasma temperature at 8000K and above, while the *Mayr model* is used for modeling the arc in the vicinity of current zero when the temperature of the plasma is below 8000 K.

Thus, a mathematical arc equation is obtained as a combination of equations (3, 4 and 8) as below**:**

$$\frac{1}{g} * \frac{dg}{dt} = \frac{1}{T}\left(\frac{ui}{P} - 1\right) \qquad 9$$

Where:

g= arc conductance
u= arc voltage
I= arc current
P,T: parameters of the model.

Modelling of Transmission Network Using Cassie/Mayr Arc Model

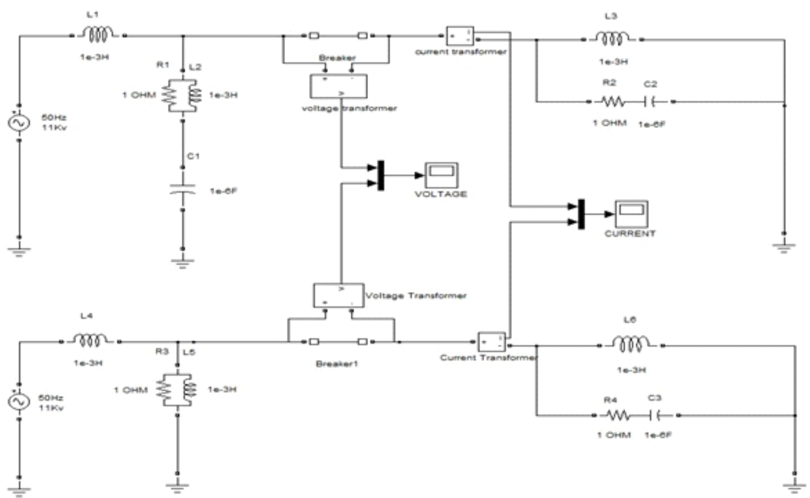

Fig. 3: Cassie Mayr are Model Network

The performance of Circuit breakers in a power system is analyzed by representing the circuit characteristics as a function of electrical parameters in figure 3 such as current and voltage. This analysis involves a combination of complicated power system circuits and equations.

The Cassie and Mayr arc model using MATLAB or Simulink is applied in this project to investigate the behavior of arc formation during interruption processes (separation circuit contact and or closing operation). The use of this model and simulation tool helps to improve the performance of a system by reducing the need for prototype development and testing. This model is not suited to design circuit breaker interrupters but is very useful to simulate arc current interruptions in the network.

Data Presentation and Analyses

This session explains the various ways adopted for the realization of this paper and also the analysis of the data obtained.

Data Analysis on Bar Chart

Table 1: Number of Operation in PHCN Afam work Centre, 2022

Breaker	**Number of Operations in 2022**											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SF6 Gas	52	42	50	35	10	31	44	45	51	52	62	45
VCB	18	22	Replaced	1	0	1	10	38	38	30	19	29
OCB Type	7	13	Contact replaced	1	0	1	19	26	28	1	6	1

Sources: PHCN Afam Work Centre Equipment Office, 2022 at 33kv

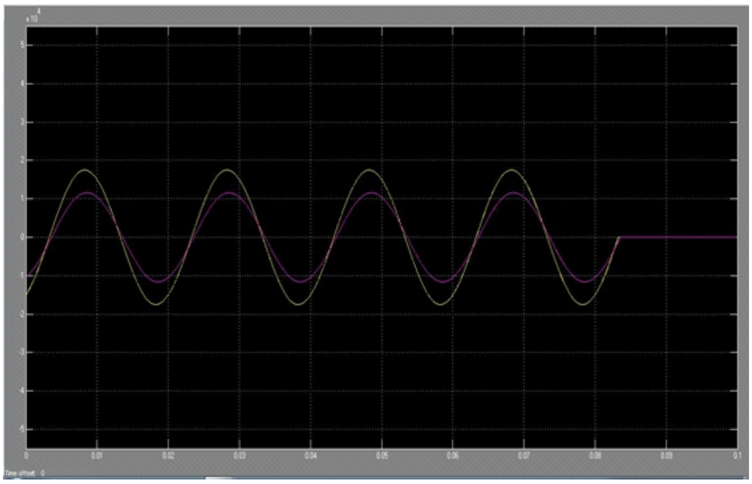

Fig 4. Simulation of Arc Current against Time

The 3-phase fault block introduces fault after 0.05 sec by a step signal. When fault current enters the relay block, the fault current goes through the relational operator block, which compares with the pre-set value, or if fault current increases above the pick-up value, the Boolean outputs to the AND gate via the D-latch flip-flop. If the three inputs to the AND gate are high, then the high output from the AND gate, which may be called a trip signal, eventually goes to the 3-phase circuit breaker, which will interrupt the 3-phase transmission line. As soon as the trip signal is received, the faulty part will be isolated from the healthy section.

Table 2: Number of Operation in PHCN Afam Works Centre, 2022

Breaker	Number of Operations in 2022											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SF6 Gas	18	14	16	11	3	9	15	15	10	8	8	10
VCB	6	22	Replaced	1	0	1	10	Replaced	38	30	19	29
OCB Type	7	13	Contact replaced	1	0	1	19	26	28	Replace	6	1

Sources: PHCN Afam Work Centre Equipment Office, 2022 at 33kv FEEDER

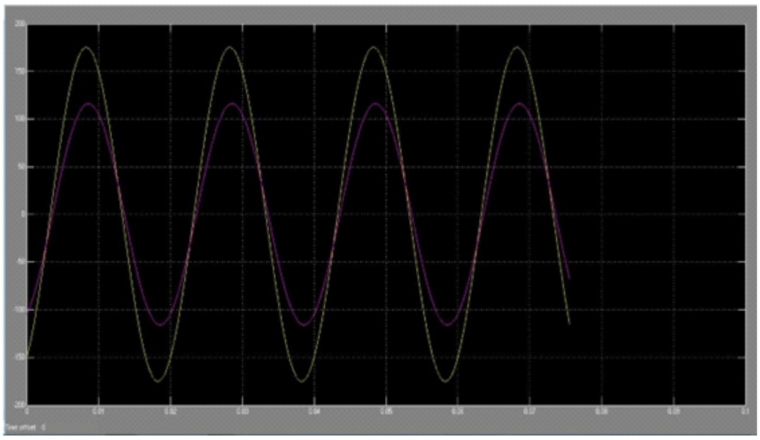

Fig. 4: Simulation of Arc Voltage against Time

If the phase current is below the pickup value, then the 3 output of the D Latch flip flop is low, and the output of the AND gate is not high, so no trip signal is generated from the relay block, ensuring uninterrupted supply in the transmission line. The performance characteristics of an over current relay and circuit breaker were evaluated at a location with a 3-phase fault. The modeling and simulation of overcurrent relays and simulation of Over current relay and Simulink offers effective means for explaining the behaviors of a circuit breaker. It is shown that these models offer effective means for explaining the functionality of overcurrent over current relay and circuit breakers under various operating scenarios.

Conclusion

In this paper, emphasis was placed on the ways and methods by which the application and maintenance of circuit breakers can be done to improve the system stability limit of a power system substation. The main function of a circuit breaker in any power system is to clear faults. It serves to open the faulted circuit or part and thereby remove it from the sound part of the power system network. They clear faults very rapidly in order to promote power system reliability. Fast clearing of faults raises the power system stability limit. Circuit breakers facilitate the re-distribution of loads, inspection, and maintenance of the system. They also break efficiently, shorting circuit currents without giving rise to dangerous overvoltage's. As a protective device, a circuit breaker safeguards the entire power system and connected equipment.

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