Indonesian Journal of Electrical Engineering and Computer Science
Vol. 8, No. 1, October 2017, pp. 213 ~ 220
DOI: 10.11591/ijeecs.v8.i1.pp213-220

Types of Circuit Breaker and its Application in Substation Protection

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Abstract

Power system consists of the generation, transmission, distribution, and substation. All the power system component requires suitable protection devices as the protection system to protect the system during fault occur. In this paper, the circuit breaker has been selected as one of the protection devices in several applications. The types of circuit breaker that has been reviewed in this paper are oil circuit breaker (OCB), air circuit breaker (ACB), sulphur hexafluoride (SF6) circuit breaker, vacuum circuit breaker, and DC breaker which are hybrid DC breaker and solid-state DC breaker. Normally, the systems or the circuits disrupted or damaged by the fault. To implement the protection system in the system or circuit, the type of faults and cause of faults should be known to overcome the fault. To provide the suitable voltage for the consumer, the substation is needed to control the voltage transmitted at high voltage from the generating station. Protection system is also required in a substation.

Keywords*: Circuit breaker; oil circuit breaker; air circuit breaker; sulphur hexafluoride circuit breaker; vacuum circuit breaker; hybrid DC breaker; solid-state DC breaker*

1. Introduction

Generating and supplying the power electric to the user is the aim of the electrical power system. To construct and manage to send the energy to the utilization point, it must be had reliability and economy. The reliability and the security of supply would be questioned if the bad disturbance happened in a modern society in a long run if the bad disturbance always happened. Since the power system the involved in the generation, transmission, distribution and residential, so it needs protection to avoid damage to electrical appliances and lose one's life.

In electrical engineering, the power system is one of the exclusive fields which deal with shortest and the fastest time to trip and isolate the faulty area in the power system so that the fault does not affect the system directly. As a result, the system remains their stability and reliability. The essential elements of protection is a sensor to identify the fault condition and a device to initiate tripping signal to the Circuit breaker [1]. The protection system must fulfill the requirements of rapidly and automatically disconnect the faulty section of the power network, and minimize disconnection or interruption of power supply to the consumer. Ability to trip if the fault occurred in power system should be had in power system protection which is circuit breaker. The ability of tripping for circuit breakers are reliability, selectivity, sensitivity, speed and stability.

2. Circuit Breaker

A circuit breaker also known as the automatically operated electrical switch that functions when a fault detected by interrupting the current flow. There are various sizes of circuit breaker which are from small devices up to large switchgear that used to protect low current circuit until high voltage circuit. Four types of circuit breaker will discuss in this paper which as

Received June 21, 2017; Revised August 17, 2017; Accepted September 3, 2017

mention in the introduction; oil, air, SF6, and vacuum circuit breaker [2]. The basic operation of the circuit breaker as shown in Figure 1.

1. A circuit breaker has two contacts which are a fixed contact and a moving contact.
2. In the normal conditions, these two contacts stay in the closed position which is these two contact is touched each other.
3. When a circuit breaker is required to isolate the faulty parts in the system, the moving contact moves to disturb the normal condition circuit.
4. During the two contacts separate, the current flow will be interrupted. As a result, an arcing formation formed between the contacts.
5. The closed chamber is to place the contacts and in that closed chamber is contained the insulating medium which is gas or liquid. This insulating medium is to quench the arc.

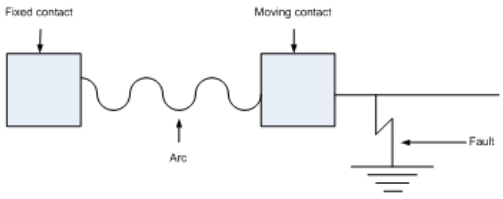

Figure 1. Basic circuit breaker operation

2.1. Oil Circuit Breaker

This type of circuit breaker is one of the oldest types of circuit breaker among the other. The construction and architecture of the oil circuit were very simple and it consists of the combination of water and oil that filled the two wooden barrels. The two vertical blades that consist in the contacts are connected at the top and arranged. To close the circuit, the vertical blades contact would drop into the stationary contact. From the simple beginning construction, the oil circuit breaker was improved and refined without change the basic characteristic simplicity of construction and the main capability for large current interruption [3]. The oil circuit breaker widely used in power system. The oil circuit breaker has two types which are bulk oil circuit breaker and low oil circuit breaker. Bulk oil circuit breaker consumes a large amount of oil in its tank. On the other hand, low oil circuit breaker only uses less oil compared to the bulk oil circuit breaker [4]. The concept operation of the oil circuit breaker is simple compared to the other circuit breaker. Figure 2 shows the basic concept of the oil circuit breaker. The oil circuit breaker also very cheap and very reliable in operation. This oil circuit breaker does not require any special devices that are applied for controlling the arc that caused by moving contact. An arc is formed between the separated contacts when the current carried by the contacts in the oil are separated. The concept is, during the normal operating conditions, the current was flowing when the contact of the oil circuit breaker closed. Besides, when the fault occurs in the system, an arc is struck between the contacts because the contacts of the breaker are moving apart from each other. A large amount of heat liberated in the circuit breaker caused by the arc formed during the fault occurs. This arc also causes the very high temperature that vaporized. Arcing will be extinguished when the distance between two contacts achieve its maximum distance. The elimination of arcing is depended on the voltage recovery and the current of the arc itself [5].

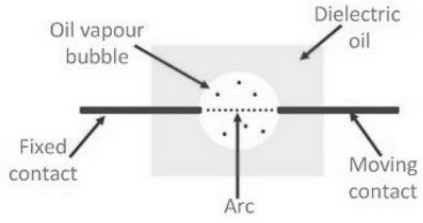

Figure 2. Basic concept of the oil circuit breaker

2.2. Air Circuit Breaker

Air Circuit Breaker also known as ACB is the type of circuit breaker that works at the high atmospheric pressure of the air. ACB is developed after the oil circuit breaker and replaced the oil circuit breaker completely for medium voltage level. In France and Italy, ACB can be chosen and more preferred until the rating of ACB up to 15kV. To avoid the risk of fire by oil, the ACB is a good choice. In America, the ACB is used widely up until the rating ACB 15kV, then the development of vacuum and SF6 circuit breaker take place [6].

The Air Circuit Breaker (ACB) working principles is different from the other type of circuit breakers. The main objective of the circuit breaker is to create a situation where the contact gap will withstand the system recovery voltage to prevent the reestablishment of arcing after the current is zero. This ACB also does the same aim but in a different method. ACB creates an arc voltage more than the supply voltage to interrupting arc. The minimum voltage required to maintaining the arc is known as the arc voltage. This ACB using three different ways to increase the arc voltage. The first ways are by cooling the arc plasma. When the plasma temperature decrease, the mobility particle of plasma also decrease and required more voltage gradient to maintain the arc. Second is to increase the length of the arc path, increasing of path resistance and the arc voltage is no avoidable. Third, to increase the arc voltage, the arc is splitting up into the number of series arcs.

2.2.1. Cross-blast Circuit Breaker

In this breaker, the blast flows directly at the accurate angle to the arc. The concept of this cross blast is consist of the fixed contact and moving contact. When the moving contact starts to move opposite to the fixed contact, the operating will produce arching between the contacts. The blast will flow between the contact and eliminate or quenching the arc that produces.

2.2.2. Axial Blast Circuit Breaker

The axial blast circuit breaker also has the combination of operation of the fixed contact and moving contact. The movement of the moving contact is supported by the spring closing which functioned to attract back the moving contact to its original position. This structure of the axial blast circuit breaker consists of an arching chamber, air valve, air reservoir tank, and series insulator. Figure 3 shows the conceptual diagram of the axial blast circuit breaker.

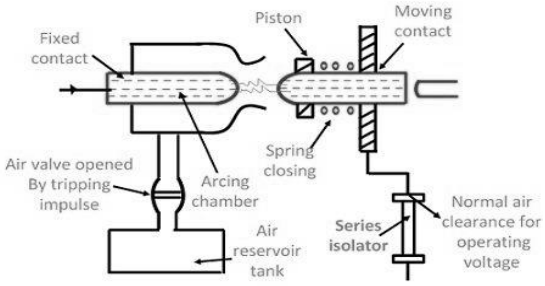

Figure 3. Conceptual diagram of the axial blast circuit breaker

During normal operating condition, the two contacts which are fixed and moving contact are in closed position. In this condition, the arching chamber is connected with the air reservoir tank through air valve because the air valve is closed during the normal operating condition. During the fault condition, the tripping pulse is produced and cause the air valve to open. When the air valve is opened, the air is pushing away the moving contact opposite the spring pressure. The moving contact extracted the distance from the fixed contact and struck an arc. While this operation occurs, the ionized gases had been taking away by the high pressure of air blast. As a result, the arc was extinguished [7-10].

2.2.3. SF6 Circuit Breaker

This type of circuit breaker using gas that known as sulphur hexafluoride (SF6). This type of circuit is high voltage circuit breaker due to the excellent to quench the arc and isolation properties. So that, it is widely used as a protection in high voltage [11]. This gas was selected because of the characteristics of this gas that has high electro-negativity. The type of SF6 circuit breaker that is widely used in power industry is the puffer types of SF6 circuit breaker. Figure 4 shows the puffer type of SF6 circuit breaker working principle.

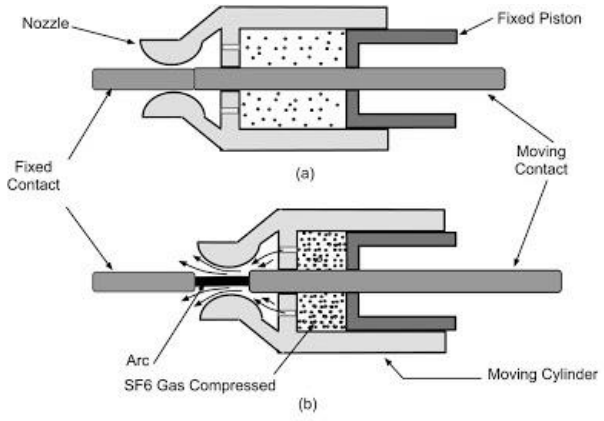

Figure 4. Puffer type of SF6 circuit breaker working principle

From the Figure 4 above, this SF6 circuit breaker consists of two types of contact which are fixed contact and moving contact. In this configuration, the position of the cylinder is unfixed or movable but the piston in the fixed position. The cylinder is combined with the moving contact as it can moving with that contact. When the moving contact starts to moves, the SF6 gas starts compressed due to the fixed position of the piston. Arc will be produced. The electronegativity of the SF6 is high and as a result, it can absorb the free electron. Absorption happened when the molecule of SF6 collides with the free electron and form the negative ion [12-15].

2.2.4. Vacuum Circuit Breaker

This vacuum circuit breaker is also known as the VCB is one of the circuit breakers that categories in the medium voltage level. The operation of this circuit breaker has a different principle from other circuit breakers. The arc quenching takes place in a vacuum. The opening and closing the contact and related arc interference take place in a vacuum chamber known as a vacuum interrupter [16]. The main goal of all CB is to quench the arc produced when the contacts separated. In VCB, the dielectric strength of vacuum is much higher than the SF6. Since the dielectric strength is high then the arc can be quenched within the small gap. When the two contacts are separated, it is not separate instantly. It happened in a microsecond and so the surface of the contacts become the hot spot. In high temperature, the metal vaporized and create the conducting path for the arc. Since the ionization does not occur in a vacuum, then the arc will be eliminated. After the current becomes to zero, this VCB will generate high dielectric strength to avoid the reestablishment of arc [17]. The previous research of this circuit breaker was conducted by using software and build the breakers modelling to observe all parameters that involve in this VCB. Below is some of the result of the observation of the behaviour of the VCB.

Form Figure 5, the first output waveform of the transient voltage has measured. This measurement of the simulation VCB is being used to determine the parameters of the breaker in terms of dielectric withstand. The second waveform in Figure 5 shows the simulation result for the voltage obtained at the developed breaker within the transformer system. The comparison has been made in term of phase, it is because the current chopping is analysed within the phase. Unfortunately, the voltage restrike observation for the other phase is not matched for the comparison since virtual current chopping interrupts the initial current. That current chopping is

affected by the capacitive coupling. In the simulation, this capacitive coupling between the phases higher compared to the other simulation result. These phenomena occur due to the standard transformer model was added with stray capacitances in the transformer simplification model [18].

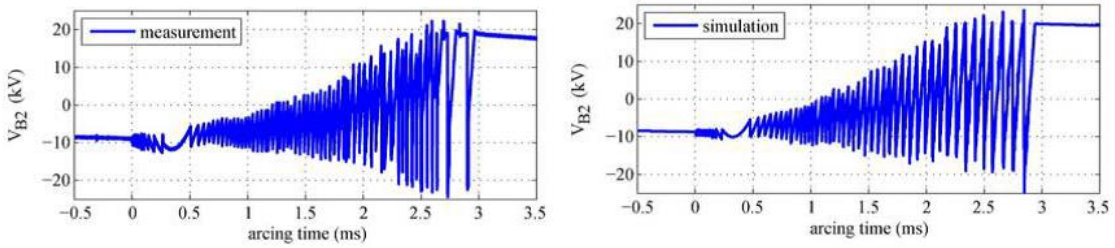

Figure 5. Transient voltage during opening

Other research, they approached to minimize overvoltage and inrush currents at VCB switching, the technology of controlled switching is of great importance. The main idea of controlled switching is closing or opening an electrical network at optimal instants. Besides that, they also develop the simulation model of a circuit breaker where the principles of controlled switching can be realized and the main parameters of real vacuum circuit breakers can be considered [19].

3. Circuit Breaker for DC Grid

Positive technology improvement of power electronic devices is also the main factor in the transition to a new electrical power source within the application of the DC grid. To maintain the safe grid operation, DC breaking concept are required within the operation system. There are several types of the DC breaker concept that available and usually used in DC grid [20]. The DC breaker that discussed in this subtopic is Hybrid and Solid-state DC breaker.

3.1. Hybrid DC breaker

The hybrid DC breaker system consists of the combination main breaker with the bypass system. The bypass for this hybrid DC breaker consists of the series connection of ultra-fast disconnector and load commutation switch. In this DC breaker, the important semiconductor part is separated into a few sections for full voltage and current breaking capability that consist of individual arrester bank. Besides, the disconnecting CB will interrupt residual current at the same time will also be islanded the fault condition within the DC grid after the fault clearance [21]. This function is to cover the arrester banks within main semiconductor breaker to overheat.

During it a routine condition of the hybrid DC breaker, the current only flow passing the bypass that consists of the series connection of load commutation switch and fast disconnector. When the DC fault occurs, the fast disconnector immediately opens and the load commutation switch also will fast- functioned to direct the current flows towards the main breaker. The main DC breaker will play it important function to block the current from flowing when the mechanical switch in the fast disconnector opens [21-24].

3.2. Solid State DC Breaker

This solid state CB usually used in dc application system of high voltage supply. The advantages of this DC breaker are it has a fast response of switching speed, efficient current interruption, and it capable of withstanding in high voltage condition [25]. The other advantages compared to the other circuit breaker is it has lack of mechanical component. Due to this less mechanical component, this solid-state topology becomes more responsive and effective which performs to a less turn off time. Besides, the maximum voltage across the inductor can form the maximum overvoltage that can permit the demagnetization process to be efficiently response.

The basic configuration of this solid-state circuit breaker consist of thyristor instead of integrated gate commuted thyristor for semiconductor devices [26].

Uninterruptible Power Supply (UPS) has been widely used in industry. Due to the fast development and innovation of the technology, the UPS capacity increases dramatically. The previous power electronic researcher had to do some innovation to enhance consistent reliability and capability of UPS system. This Super UPS had been introduced to overcome the problem. This super UPS has two independent energy source that activates the system. Furthermore, power electronic converter was also used to increase the reliability of the UPS system [26]. Due to the short circuit current growth in the super UPS, the fast response DC breaker like the solid-state DC breaker is required [27].

4. Protection System Evaluation Process

In Malaysia, 11kV are supplied for the consumer installation. TENAGA NASIONAL BERHAD (TNB) is the main electricity supplier in Malaysia. To propose the new protection system for the consumer or utilities should the line up with some procedures that has been fixed by the TNB. The protective device and the protection system plays its quality as main consideration to fully functioned in the protection system in term of it reliability. The supplier should provide the appropriate and match protection scheme. The processes of evaluation are shown in Figure 6.

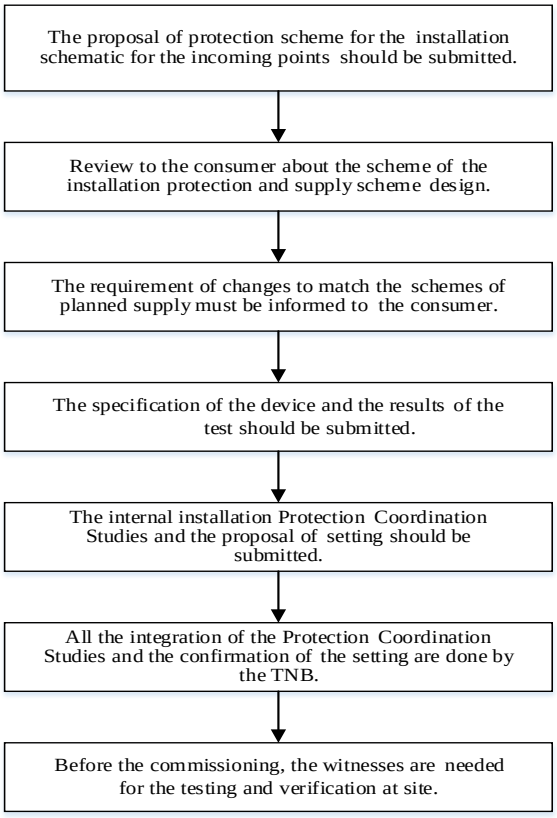

Figure 6. Flowchart of protection system evaluation process

4. Conclusion

Several types of circuit breaker had been reviewed as the selected protection device. Form the reviewed that has been done through this paper, the observation result of the circuit breaker application, there are several conclusion that can be made. First, each circuit breaker has its categories within the low, medium, and high voltage that are widely used in power

system protection. Second, each type of transmission fault have their effective circuit breaker to eliminate the fault with its configuration depends on the fault characteristic. Third, the fault does not have it fixed parameter and fixed causes. The natural phenomenon is not the only fault factor, but it has several another factor that can causes fault such as human mistakes, instrument error, and installation and setting error. Last, substation is needed to control the voltage transmitted at high voltage from the generating station. Protection system is also required in a substation.

Acknowledgement

The authors would like to thank the Ministry of Higher Education, Malaysia (MOHE), and the Office for Research, Innovation, Commercialization, Consultancy Management (ORICC), Universiti Tun Hussein Onn Malaysia (UTHM) for financially supporting this research under the FRGS grant No. 1529 and IGSP U667.

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