An Overview of the Topologies of DC Circuit Breakers in DC Microgrids

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Received: 09.09.2023 Accepted:22.10.2023

Abstract- Enter an A notable step towards precisely matching the load demand with dispersed technology for the destiny strength machine is the expansion of DC micro grids. Due to the capabilities benefits of DC machines over AC technology, DC micro grids are an effective solution for the unanticipatedly rising need for DC packages and loads. However, the significant demands placed on its safety undercut the growing advantages of the developing DC micro grid system. DC micro grid topologies that change over time significantly impact the current safety protocols. This problem is also exacerbated by the fault types and contemporary nature of defects. The DC micro grid protection is also challenged by the short-term, rapid development of fault modernity, which greatly impacts the safety layer for expensive mass and power converters. The DC link capacitor of the converter has discharged, which is the cause of this. The DC circuit breakers' subroutine was restrained from zero crossings of fault currents. Conduction loss, the need for operating speed, fault modernity coping capabilities, and value are the main factors preventing DCCB deployment. This study has explicitly analyzed the current tactics alongside the jurisdiction for the safety requirements towards the proclivity of future DC micro grids in order to handle all of the events relating to the safety of DC micro grids.

Keywords: DC circuit breakers; DC microgrids; hybrid DC beakers; solid state DC breakers; mechanical DC breakers.

1. Introduction

Authors This is particularly true at the point of consumption, where the majority of loads, including LED lighting, battery energy storage (BES), photovoltaic (PV) and fuel cells, as well as many distributed power sources, are designed from the ground up to operate on direct current (DC). DC systems also have less of an influence on public utility networks since frequency regulation and reactive power flow may be maintained with a single point of interconnection to the AC grid at a reduced cost and risk. Examples include the integration of renewable energy sources into electrical utility grids using multiterminal High Voltage DC (HVDC) distribution channels in Europe and China, the use of mobile transportation infrastructure for vessels, planes, and cars that have integrated energy and power control, and the supply of electricity of remote locations using local DC micro grids that integrate solar power and battery energy storage into shared and residential electrical systems. Creating the ideal safety feature for DC micro grids has proved to be a considerable challenge because of the characteristics of the DC fault current, which can unexpectedly spike to even more than one hundred times the normal current upon sudden fault start. To address this issue, it is necessary to have an acceptable grounding structure, a quick and effective fault detection technique, fault current restriction technology, and an appropriate DC circuit breaker.

2. DC Microgrids

Economic considerations, including the liberalisation of electricity markets and the privatisation of state-owned power firms, as well as environmental and social concerns that have led to a move away from fossil fuels and nuclear energy, have all had a substantial impact on the electrical system since 2000. This change has led to a larger reliance on renewable energy sources due to the frequently competing economic and environmental reasons, which has the potential to fundamentally alter how power networks function. To balance production and consumption, information and communication technologies (ICT) must be used; these conventional power grids combined with ICT are referred to as smart grids [1, 2, 3]. Smaller portions of the electric grid known as microgrids can help to keep this equilibrium. The MicroGrid is in responsible of voltage stability and power congestion when connected to the main grid, whereas the main grid is in charge of issues with frequency, angle, and inertia. All of the MicroGrid's components, including frequency, angle, voltage, power flow, and profit, must remain stable while it is isolated from the main grid. Comparatively harder than when connected to the main grid, this. Because of their erratic production and distribution, renewable energy sources are particularly challenging to integrate into the electricity system. Also, many remote areas lack access to electricity, but solar and wind energy have the potential to provide electricity, improving social inclusion and quality of life. [12,13].

By reducing the use of carbon-based resources such as coal or wood, the move to electricity-based energy consumption helps to protect local ecosystems. This transformation, however, introduces considerable technological obstacles for renewable energy applications in stand-alone grid operations. Renewable energy sources' intermittent and non-dispatchable nature can lead to insecurity and oscillations in energy generation. The MicroGrid idea has been proposed as a feasible solution to these challenges. This idea entails the use of energy storage devices in conjunction with renewable energy sources to offer users with consistent, continuous, sustainable, and high-quality power, hence enhancing the overall system's dependability, resilience, and availability [3]. Many of the existing electricity system challenges might be addressed by microgrids. Yet, considerable effort remains to be done to make them a widespread reality. DC MicroGrids have the advantage of being compatible with renewable energy sources (solar, wind, fuel cells), storage (supercapacitors, batteries), electric car and electronic loads, all of which have a DC characteristic. When linked to a DC grid, fewer converters are required, and the system is simpler, resulting in cheaper materials and better efficiency (less energy loss). A DC MicroGrid's simplified architecture reduces the need to manage reactive power, frequency, and harmonic distortion. A control structure that depends on the interaction of converter current flow is built, with the DC bus voltage been assigned top priority, even if network synchronization is also not required. The current power system is designed for alternating current; thus, the DC MicroGrid presents a challenge. A hybrid AC/DC microgrid, which is a compromise between DC and alternating current, permits easier integration of these new devices with existing electrical system [14,15].

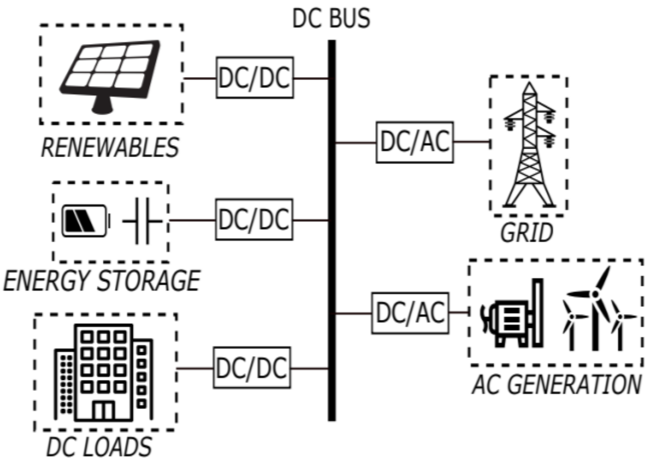

Fig. 1. Common DC microgrids architecture

3. DC Circuit Breakers:

DC circuit breakers are specifically designed to protect electrical devices that use direct current (DC). This is because DC has a constant voltage output, whereas alternating current (AC) has a voltage that fluctuates multiple times per second.

3.1 Applications:

- Circuits powered by batteries, like those found in homes with solar panels, can be found in residences in remote areas that do not have access to an electrical grid.
- Both gas and electric cars contain electrical components, such as a fuse box with DC circuit breakers.
- Electric vehicle charging stations.
- An Uninterruptible Power Supply (UPS) system typically utilizes batteries to store energy as DC. This energy is then converted to AC to power AC devices.
- The setup of photovoltaic solar panels, the associated control system, and the battery banks that store the energy they generate are all important components.
- DC Electric machines.
- Machines that utilize electric arc welding technology come in various forms.
- LED lamps that are highly efficient.
- The main difference between interrupting alternating current and direct current is that DC circuit breakers require a system to extend and disperse the electric arc to break it, due to the constant voltage making the arc more persistent. In contrast, AC circuit breakers are simpler to interrupt as the current alternates and have zero values in each cycle.

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3.2 Distinction Between a DC Circuit Breaker and an AC Circuit Breaker

Direct current (DC) and alternating (AC) power can be used with circuit breakers. Unlike AC, which often alternates between positive and negative voltage at a frequency of 60 or 50 hertz, DC has a voltage output that is continuous. Electric grids typically supply AC electricity, while specialized commercial or battery-based systems usually utilize DC power. The following graph illustrates the difference in behaviour between an AC voltage supply and a DC voltage supply.

There is no difference in terms of superiority between AC and DC electricity delivery, as each is suitable for different purposes. AC is ideal for generating power, sending it over long distances, and powering high-power motors. On the other hand, DC is more suitable for working with batteries, solar power systems, and precision machinery that can be more easily regulated with direct current. Additionally, lighting fixtures are very versatile; sometimes, different versions of the same lamp are available for both AC and DC.

The arc-extinguishing point is more effective for a DC circuit breaker, one of the key differences being between DC and AC. The electrical arc is persistent and harder to stop in a DC circuit because the voltage is constant. Therefore, DC circuit breakers must include additional arc-extinguishing methods, such as a system that extends and utilizes the electrical arc to make interruption easier. In contrast, AC circuit breakers are simpler to interrupt as the current alternates and reaches a value of 0 in each cycle.

3.3 Operation of a DC Circuit Breaker

Circuit breakers for DC systems operate on the same principles of thermal and magnetic protection as those for AC systems:

A DC circuit breaker's thermal protection trips the circuit breaker when an electric current running through it exceeds the rated value by heating and expanding a bimetallic contact, which causes the circuit breaker to trip. Due to the greater heat produced by the higher current, which opens the electric contact, the thermal protection operates more quickly. This safeguard against overload current, which is just marginally more than the average operating current, protects against it.

At the point when high shortcoming flows are recognized, magnetic security trips the DC electrical switch immediately. This is like the appraised breaking limit of an air conditioner electrical switch, which is the greatest shortcoming flow that can be interfered. While managing DC circuit breakers, it is vital to take note that the flow being cut off is consistent, so the electrical switch should open the electric contact further to break the shortcoming flow. Attractive security in a DC electrical switch is utilized to defend against short circuits and deficiencies, which are considerably more serious than over-burden.

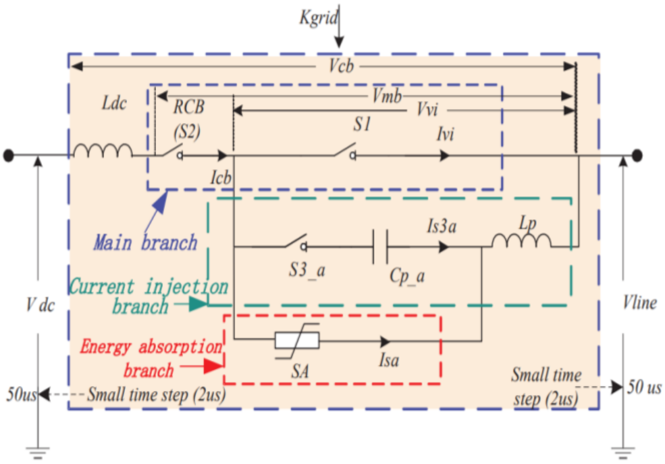


Fig. 2. Principle of operation of mechanical DC circuit breakers

3.4 Mechanical DC Circuit Breakers

The general layout of a mechanical HVDC circuit breaker with current source insertion is shown in Fig. 2. This circuit breaker consists of three branches and a DC inductance Ldc:

- The main branch is composed of S2 residual current switch and S1, a high-speed mechanical vacuum interrupter.
- There is a current insertion branch that comprises Cp_a (capacitor), an inductor Lp and a S3_a (switch) in a switchable parallel resonant circuit.
- to absorb energy and prevent overvoltage, a capacitor Cp_a is connected to the surge arrester to form the energy absorption branch.

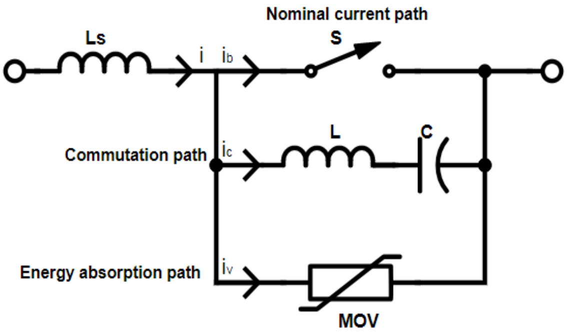


Fig. 3. Mechanical DC breaker's structure

3.4.1 Principles of Time Sequence and Operations

S1, S2, and S3 a, among other switches shown in Fig. 2, are modelled using a few crucial characteristics relating to mechanical delays and switching currents. The primary switch (S1) is typically in the closed position, and network protection provides an external trip signal. The protection system detects a fault two milliseconds after the fault is applied and sends a signal to the DCCB in the form of a progressive "0." An open switch is represented by a soft "0," whereas a closed switch is represented by a soft "1." After a mechanical delay is imposed after receiving the trigger signal, the switch begins to open. The bare minimal current necessary to preserve arc life is switch switching current. If the current is higher than this, the switch will remain in the low resistance closed position. A high resistance open state is reached by the switch if the current drops below the switching current. Fig. 3 demonstrates that switch states, in-circuit voltages, and circuit breaker behaviour and timing may all be seen. The primary switch's voltage is Vvi (S1). The voltage known as Vmb exists between the differential switch and the primary switch (S1) (S2). The system voltage is known as Usys, while the residual current switch (S2), voltage across the main switch Vcb (S1) and the induction Ldc are denoted. As the current (Icb) reaches its maximum during a fault current interruption, the fast switch (S3) shuts, injecting a reverse current into the main switch (S1), which removes the current in the switch major. Simultaneously, S1 switches from closed to open, which will allow Vvi and Vmb to reach maximum values. The surge arrester SA absorbs the current flowing through S2 and progressively reduces it until it reaches zero. As a result, S2 transforms from closed to open. The Vmb voltage then reaches the same level as the system voltage at that point. The voltage between the main switch Vvi terminals drops as S3 changes from closed to open, approaching the system voltage. In response to grid protection trip signals, the DCCB follows a specified timed sequence of open/close actions, as indicated in Figure 3.

One of the most significant advances in mechanical DC circuit breakers has been the development of arc-fault detection systems. These systems are designed to detect and interrupt arcing faults before they cause damage to the circuit. Recent research has focused on the development of improved algorithms for arc-fault detection, as well as the integration of these systems into existing DC circuit breaker designs [13].

Another area of research has focused on developing new materials for DC circuit breakers. In particular, research has focused on the use of composite materials, such as carbon fibre and Kevlar, to improve the reliability and performance of DC circuit breakers. These materials have been shown to improve the performance of DC circuit breakers and reduce their size and weight. Developing innovative control systems for DC circuit breakers has also been the subject of research. These systems are designed to provide improved control over the operation of the circuit breaker, allowing for more precise control of the current and voltage. This has enabled improved safety and reliability, as well as improved energy efficiency[14,15]. In 2018, a study by Wang et al. [16] examined the performance and design of a mechanical DC circuit breaker. The study found that the breaker had a high breaking capacity and a low operating temperature. In 2019, a study by Zhang et al. [17] investigated the application of a mechanical DC circuit breaker in a photovoltaic system. The study found that the breaker had a high breaking capacity and a low operating temperature. A study by Li [18] examined the design and performance of a mechanical DC circuit breaker for automotive applications. The study found that the breaker had a high breaking capacity and a low operating temperature. Wang in this research investigated the application of a mechanical DC circuit breaker in an industrial system. The study found that the breaker had a high breaking capacity and a low operating temperature [19].

This paper examines the design of mechanical DC circuit breakers. It discusses the various components of the breaker, such as the contact system, arc chutes, and trip mechanisms. It also examines the different types of breakers, including thermal-magnetic, hydraulic-magnetic, and solid-state breakers. The paper then looks at the different ratings of DC breakers, including their interrupting capacity, voltage rating, and current rating [20].

Singh discusses the use of these breakers in renewable energy systems, electric vehicles, and other industrial applications. It also examines the advantages and disadvantages of using mechanical DC circuit breakers in these applications. Furhter, In this study the author looks at the various testing and certification standards for mechanical DC circuit breakers. It examines the standards set by the International Electrotechnical Commission (IEC) and the Underwriters Laboratories (UL). It also looks at the various tests used to evaluate the performance of these breakers, such as the short-circuit test, the temperature rise test, and the dielectric strength test. It examines the use of advanced materials, such as carbon nanotubes, for improving the performance of these breakers. It also looks at the development of new trip mechanisms, such as the use of artificial intelligence for fault detection and protection [21].

The design of mechanical DC circuit breakers has been improved by using new materials such as high-temperature superconductors, nanomaterials, and advanced composites These materials have enabled the design of more efficient and reliable mechanical DC circuit breakers with improved performance. For example, high-temperature superconductors have been used to reduce the size and weight of mechanical DC circuit breakers, while nanomaterials have been used to improve their electrical and thermal properties. Additionally, advanced composites have been used to reduce the contact resistance and improve the arc-quenching performance of mechanical DC circuit breakers [22, 23, 24].

New technologies including laser cutting, CAD (computer-aided design) and 3D printing have been used in conjunction with novel materials to enhance the design of mechanical DC circuit breakers. These technologies have enabled the design of more efficient and reliable mechanical DC circuit breakers with improved performance. For example, 3D printing has been used to reduce the size and weight of mechanical DC circuit breakers, while laser cutting has been used to improve their electrical and thermal properties. CAD has also been used to mechanical DC circuit breakers to lower contact resistance and enhance arc-quenching performance [25,26,27].

In these studies, the performance of mechanical DC circuit breakers has been improved by using new control strategies such as intelligent control and fault detection. These strategies have enabled the design of more efficient and reliable mechanical DC circuit breakers with improved performance. For example, intelligent control has been used to reduce the size and weight of mechanical DC circuit breakers, while fault detection has been used to improve their electrical and thermal properties [28,29].

3.5 Solid State DC Circuit Breakers

As power electronics has improved, a variety of solid-state power switches that may be employed as the current switching element in DC solid state circuit breakers have been created. DCCBs can use IGBTs, IGCTs, SCRs, or GTOs, although IGCTs and IGBTs are the favored alternatives for DC solid-state circuit breakers [1-3]. The basic SSCB bi-directional circuit breaker design is seen in Figure 4, which contains a current-rated branch with IGBT switches linked in parallel with a diode and an energy-absorbing channel with a metal-oxide varistor [3]. The SSCB with an IGCT is shown in Figure 5. During normal functioning, solid state switches are in the conductive state. The di/dt is constrained by a series inductor when a fault happens. The parallel power sink branch restricts the voltage across the switches while the control circuit recognizes the failure and turns off the semiconductor devices. IGBTs and diodes have significant conduction loss because of their high on-resistance [4].

The design of self-powered DC solid-state circuit breakers has been updated. To interrupt the fault current, this innovative SSCB idea employs normally active static switches. The increasing terminal voltage is recognized when the fault occurs [5].

The rapid current decreases due to parasitic inductance that occurs when the power electronics static switch is turned off was investigated for its effect on overvoltage transients through semiconductor switches. They suggested separating surge protection and energy absorption by connecting a snubber with an additional high voltage in parallel to the IGBT. As there is less parasitic inductance when the MOVov is close to the switch, there is a greater voltage drop across the MOVov, which directs current to the MOVE. The suggested solid state circuit breaker was modelled and tested with PSCAD [6].

A solid-state circuit breaker (SSCB) uses a self-powered broadband solid-state switch (WBG). The issue is found by measuring the voltage differential between the switch's drain and source rather than keeping an eye on the current that is passing through it. The SSCB control circuit doesn't need an external power source when it's functioning normally, but when a problem arises, power is cut off and kept off until the fault is fixed. To demonstrate the effectiveness of the suggested SSCB, a SiC JFET with a nominal voltage of 1200 V was used to interrupt and cut a fault current of 125 A in just one microsecond [7].

Design improvements have been made to the IGCT to lower on-state conduction losses and boost current capacity in a fault event. With a voltage drop of 0.9 V at 1 kA and a blocking capacitance of 2.5 kV, normal operation conduction losses were less than 1 kW. In the event of a failure, the IGCT had a current capacity of 6.8 kA at the voltages of 1.6 kV [8].

The snubber of the solid-state switch is necessary for surge protection. Charge-discharge, type I suppression discharge, and type II suppression discharge are the three types of snubbers that have been suggested. Each is made up of a resistor, a diode and a capacitor. The peak current and voltages of the suggested snubbers were compared, and Type I discharge suppression was found to be the best fit [9].

The primary advantage of SSDCBs is their ability to provide higher levels of protection than traditional mechanical circuit breakers. SSDCBs are able to detect and respond to faults much faster than mechanical circuit breakers, allowing them to provide better protection against short-circuits and other faults. Additionally, SSDCBs are able to provide better protection against over-currents and over-voltages, as well as providing better protection against arc-faults [30].

Another advantage of SSDCBs is their increased reliability. SSDCBs are able to provide better protection against wear and tear, as well as providing higher levels of accuracy and repeatability. Additionally, SSDCBs are able to provide better protection against environmental conditions, such as temperature and humidity [31].

Finally, SSDCBs are able to provide increased flexibility. SSDCBs are able to be customized to meet the specific needs of a system, allowing for better control and monitoring. Additionally, SSDCBs are able to be integrated into existing systems, allowing for easier installation and maintenance [32].

Al-Majeed et al. presents a novel design of an SSDCB based on a three-level voltage source converter (VSC). The proposed design is capable of providing fast and reliable protection against short circuits and overloads. The implementation and design for the SSDCB control system is also discussed by the authors. The results of the simulations and experiments show that the proposed design is effective and reliable [33].

Y. Li in this study, a new SSDCB design is proposed that uses a modified three-level VSC topology. The proposed design is capable of providing fast and reliable protection against short circuits and overloads. The authors also discuss the design and implementation of a control system for the SSDCB. The results of the simulations and experiments show that the proposed design is effective and reliable [34].

Author presents a novel design of an SSDCB based on a three-level VSC. The proposed design is capable of providing fast and reliable protection against short circuits and overloads. The authors also discuss the design and implementation of a control system for the SSDCB. The outcomes of the simulations and experiments demonstrate how dependable and efficient the suggested system is [35].

In a 2018 study by J. Wang et al. the authors investigated the performance of a solid-state DC circuit breaker in a laboratory environment. The authors used a series of tests to evaluate the breaker’s ability to detect and interrupt overcurrent and short circuits. The outcomes demonstrated that the breaker was capable of reliably and repeatedly detecting and interrupting overcurrent and short circuits. The authors also noted that the breaker was able to operate at higher current levels than traditional mechanical circuit breakers [36].

In another 2018 study by M. Zhang et al., the authors developed a novel solid state DC circuit breaker on a thyristor-based topology. The authors evaluated the performance of the breaker in a laboratory environment and found that it was able to detect and interrupt overcurrents and short circuits in a reliable and repeatable manner. The authors also noted that the breaker was able to operate at higher current levels than traditional mechanical circuit breakers [37].

Research is also being conducted into the use of solid-state DC circuit breakers in distributed energy systems. These systems require the use of breakers that can handle high fault currents and provide fast and reliable protection. Research is also being conducted into the use of solid-state DC circuit breakers in renewable energy systems, where their ability to provide fast and reliable protection is of particular importance [38].

Recent research has focused on improving the performance of solid-state DC circuit breakers by developing new device technologies and control strategies. Wide bandgap (WBG) semiconductors, such as silicon carbide (Si) and gallium nitride (GaN), for instance, provide the possibility of faster switching rates and increased efficiency in novel device technologies. In addition, advanced control strategies such as model-based control and artificial intelligence (AI) can be used to improve the accuracy and reliability of the breaker [39,40].

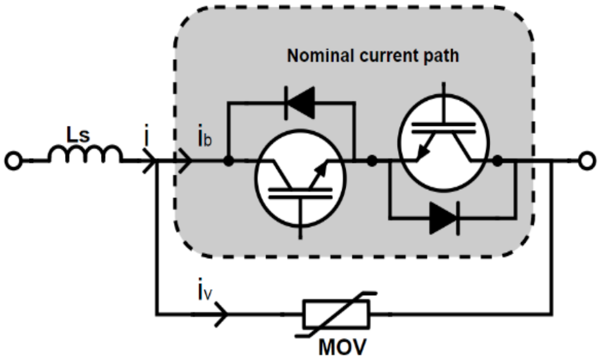


Fig. 4. Structure of a DC solid state circuit breaker

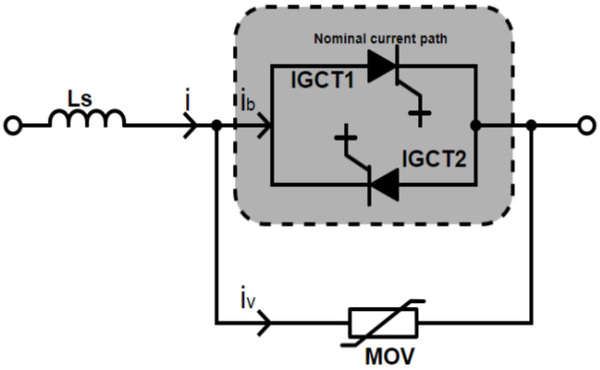


Fig. 5. Structure of IGCT based DC solid state circuit breaker

3.5.1 Working of DC Solid State Circuit Breakers

As seen in Figure 4, solid-state DC breakers are fast-acting and do not entail arcing. Thermal capacity is restricted in totally regulated devices. The devices must be linked in series or parallel to disperse the high quantities of energy. Yet, various difficulties must be addressed in order to assure static and dynamic stability. (1) The absence of synchronization between the firing signals causes the devices to operate asynchronously, generating an imbalance in the electrical components, causing some of them to overheat and fail. (2) The DC breaker may malfunction as a result of challenges in regulating the voltage and current for each electronic device in addition to a lag in the transmission time of each control circuit, which are both caused by the devices' various switching characteristics. (3) Because of the high conduction loss, voltages and current imbalances, high cost and synchronized firing control concerns, switching loss issues might be costly. This makes implementing DC breakers problematic since they are frequently coupled with a large number of electrical gadgets that can generate considerable switching losses.

A diagram of a solid-state circuit breaker is presented in Figure 5. This breaker is made up of a line of solid-state components to manage the DC bus voltage. A rapid inverse-time controller is responsible for sending out the gate drive signal to the switches in the interrupter, which open and close in a synchronized manner.

SSDCBs offer a number of advantages over traditional circuit breakers, including fast and reliable protection, compact size, and low maintenance requirements. However, they are still more expensive than traditional circuit breakers and require more complex installation procedures. Additionally, they are not suitable for use in applications that require high-voltage protection. Nevertheless, recent advances in SSDCB technology have made them a viable option for many applications.

3.6 DC Hybrid Circuit Breakers

A DC circuit breaker that has excellent interrupting abilities and minimal conduction losses has been developed. The primary breaker is made up of numerous IGBT switches with parallel surge arrestors, as shown in the figure, and the bypass branch is made up of a load commutation switch (LCS) connected to an ultrafast mechanical disconnector (UFD). Conduction losses are reduced more than they would be by an SSCB when the primary breaker is kept in the off position and the current passes through the bypass branch. The UFD opens and the LCS closes in response to a fault, enabling the fault current to pass to the main breaker. The voltage ratings of the LCS are reduced by the proposed bypass branch design. At ABB facilities, the proposed hybrid DCCB was tested, and the intended outcomes were attained. A 9-kA fault current was stopped by the UFD in less than 5 ms. The interrupting capacity of first-generation semiconductor devices was limited to 9 kA, however second-generation semiconductor devices may increase this to 16 kA.

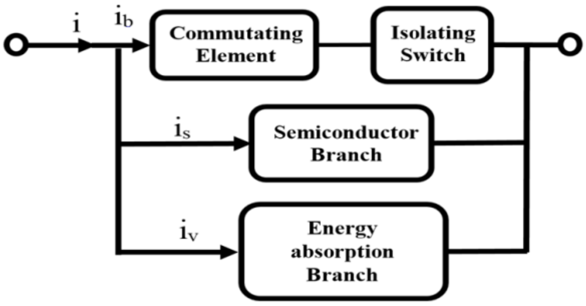


Fig. 6. Structure of DC hybrid circuit breakers

DC systems' features, including as minimal power losses, no reactive power, and low harmonics, have made them appealing for long-distance point-to-point transmissions or across marine cables. In addition, there has been a greater emphasis on the use of DC systems in multi-terminal DC grids, DC distribution systems, and DC microgrids. The growing demand for offshore wind farms has forced the development of new and inventive methods for large-scale wind power integration. The DC distribution system, made possible by advances in voltage source converter technology, looks to be a potential alternative for this purpose, since it allows for the development of a DC grid with many terminals [1]. DC microgrids may more effectively offer high-quality electricity to residential, urban, rural, and commercial sites by leveraging distributed renewable energy sources such as solar PV systems and wind farms. Using a single DC bus for all loads and sources decreases the number of redundant power conversion steps, resulting in reduced heat waste and potentially cheaper costs than AC-based distributed energy resource implementations. The difficulty of fault current interruption has been one major barrier to the DC grid's adoption despite its many benefits. The majority of AC breakers are worthless in the DC grid since there is no natural current-zero crossover, in contrast to the AC grid. A DC source with infinite strength, a line resistor and inductance, a circuit breaker, and a short point make up the equivalent circuit of a DC grid during a short circuit defect shown in Figure 2. While the short current is constrained in AC systems by large generators and transformers with high inductance, a DC grid's low impedance allows the short circuit fault to spread more quickly. On the other side, DC grids don't have as much inductance. The short circuit current will rise significantly and quickly. With a DC grid voltage of 400V, a line resistance of 10m, and an inductance of 0.8mH, a short circuit current of about 9000A is projected to occur within 20 microseconds. The true DC short current will be limited by the DC source converter. The voltage source converters must operate at an appropriate DC voltage level in order to be effective. The DC converter joins the grids for AC and DC. It is normally advised that the DC converter's voltage output be at least 80–90% of the target DC voltage in order to ensure stability. Low voltage can prevent the DC converter from performing its function, resulting in high current or voltage demands on the converter that may even have an impact on the voltage of the connected AC grid. This can also result in a voltage collapse in the DC grid. A DC short circuit problem has the potential to almost completely eliminate the DC voltage [5].

Mazzucco, at the University of Padova in Italy developed a new type of hybrid DC circuit breaker based on a combination of a thyristor and a mechanical switch. This new type of circuit breaker was designed to provide a high level of reliability and safety, while also reducing power losses. The researchers tested the circuit breaker in a laboratory environment and found that it was able to successfully interrupt a DC current of up to 600A [41].

At the University of California, San Diego, researchers created a novel kind of hybrid DC circuit breaker based on the combination of a thyristor and a superconducting switch in a different study. This new type of circuit breaker was designed to provide a high level of reliability and safety, while also reducing power losses. The researchers tested the circuit breaker in a laboratory environment and found that it was able to successfully interrupt a DC current of up to 1000A [42].

In this study, at the University of Tokyo developed a new type of hybrid DC circuit breaker based on a combination of a thyristor and a semiconductor switch. This new type of circuit breaker was designed to provide a high level of reliability and safety, while also reducing power losses. The researchers tested the circuit breaker in a laboratory environment and found that it was able to successfully interrupt a DC current of up to 1500A [43].

A hybrid DC circuit breaker was created by Li et al. using a vacuum interrupter and a solid-state switch combination. According to the study, compared to a conventional AC circuit breaker, the hybrid DC circuit breaker had a quicker response time and a larger breaking capacity. Furthermore, in both systems, the hybrid DC circuit breaker was able to offer trustworthy defense against short circuits and over-currents [44].

The researchers in these studies, examined the performance of a hybrid DC circuit breaker under various fault conditions. The findings demonstrated that the breaker could identify and stop DC faults in less than 10 milliseconds and could sustain a short circuit current of up to 10 kA. The hybrid DC circuit breaker provides a dependable and affordable option for DC power systems, according to the authors' findings [45,46,47].

The performance of hybrid DC circuit breakers in contrast to conventional AC circuit breakers was examined by the authors of these research. Also, the effectiveness of hybrid DC circuit breakers in a wind and PV system was evaluated. The study found that hybrid DC circuit breakers had a higher breaking capacity, a faster response time, and a higher degree of protection against over-currents. The authors concluded that hybrid DC circuit breakers could be a viable alternative to traditional AC circuit breakers [48,49,50].

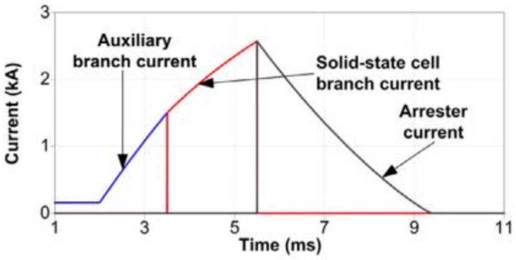
Chen et. al. describes solid-state circuit breakers are the most common type of hybrid DC circuit breaker. They use semiconductor switches to rapidly open and close the circuit, providing fast and reliable protection. However, they are limited in terms of their current-carrying capacity and require careful design to ensure reliable operation. Mechanical circuit breakers use mechanical contacts to open and close the circuit, providing higher current-carrying capacity. However, they are slower to operate and require more maintenance [51].

Hybrid DC circuit breakers combine the advantages of both solid-state and mechanical circuit breakers. They use both semiconductor switches and mechanical contacts to open and close the circuit, providing fast and reliable protection with high current-carrying capacity. Hybrid DC circuit breakers are also more compact than traditional AC circuit breakers, making them suitable for use in space-constrained applications [52].

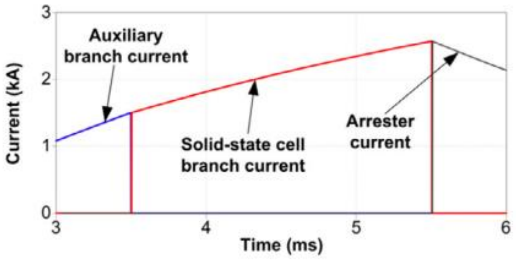
The current state of the art in hybrid DC circuit breakers is focused on improving their performance and reliability. This includes the development of new materials and designs, as well as the use of advanced control algorithms. Additionally, research is being conducted into the use of hybrid DC circuit breakers in renewable energy systems, such as solar and wind power [53].

3.6.1 Working of DC Hybrid Circuit Breaker

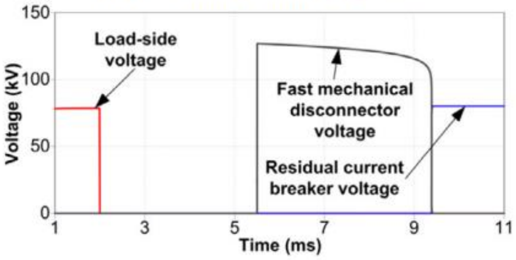
During normal operation of the DC system, the current IG current passes through the mechanical switch branch. The LC switching inductor lacks the energy of the pre-charged DC switching capacitor. The system current flows through the closed high-speed mechanical switch, the LC switching inductor, and the diode D1 while the semiconductor current is 0 since the thyristor T1 is deactivated. In the event of a DC failure, the IG system current will spike suddenly. The full-drive semiconductor T2 and thyristor S1 both turn on simultaneously when the system current exceeds the detection threshold Idet. Inductor IL, capacitor IC, and voltage VC of the switching capacitor will decrease as a result of the switching capacitor's action on the switching inductor LC, which will also be discharged.



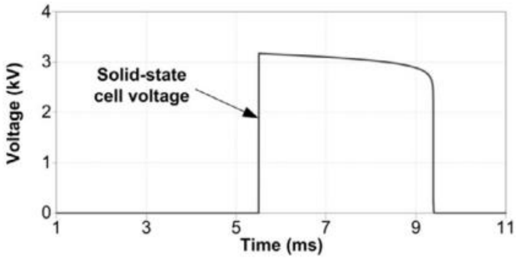
(a) Auxiliary branch, solid-state cell branch and arrester currents



(b) Zoomed version of Fig. 2a



(c) Voltages across the load, the FMD, and the RCB



(d) Voltage across a solid-state cell

Fig. 7. Working of DC hybrid circuit breaker

No current flows in the semiconductor branch because the voltage of the mechanical switching branch and the voltage of the switching capacitor are identical. As the DC switching capacitor contains more energy than the LC inductor does, part of the energy will remain there even after the LC has completely demagnetized. The capacitor's voltage VC exceeds the semiconductors on voltage when the inductor LC magnetizes the capacitor CC in a negative direction. This happens because the inductor IL's current reverses when this happens. The system current will therefore be sent from the mechanical switch branch to the semiconductor branch. The capacitor CC is also being negatively charged by the negative current flowing via the inductor IL.

The mechanical switch may be opened without current because diode D1 stops negative current from flowing through the inductor. Again when the mechanical switch has opened totally, the thyristor is deactivated and any residual energy is retained in the DC capacitor. When the current IL of inductor decreases to zero it will happen. When the circuit breaker DC voltage Vb rises, current is transmitted from the semiconductor branch to the varistor branch. The semiconductor branch and the varistor branch both get current as the circuit breaker DC voltage Vb increases. The system's magnetic energy is subsequently completely dissipated by the varistor, which interrupts the fault current.

4 Conclusion:

DC breakers, which helped the notion of DC micro grid take off, came into existence with the improvement in power electronic components. Mechanical DC breakers, Hybrid DC circuit breakers and solid-state DC breakers are just a few of the several types of DC breakers that are used. For creating artificial zero crossing, mechanical DC breakers uses artificial resonance, whereas the concept of zero crossing is used in AC circuit breakers to extinguish the arc. To stop the main current route, power electronics switches or devices are used in solid stated DC circuit breakers. Whereas both solid and mechanical switches are used in hybrid DC circuit breakers for interrupting the path of current which is the main objective.

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