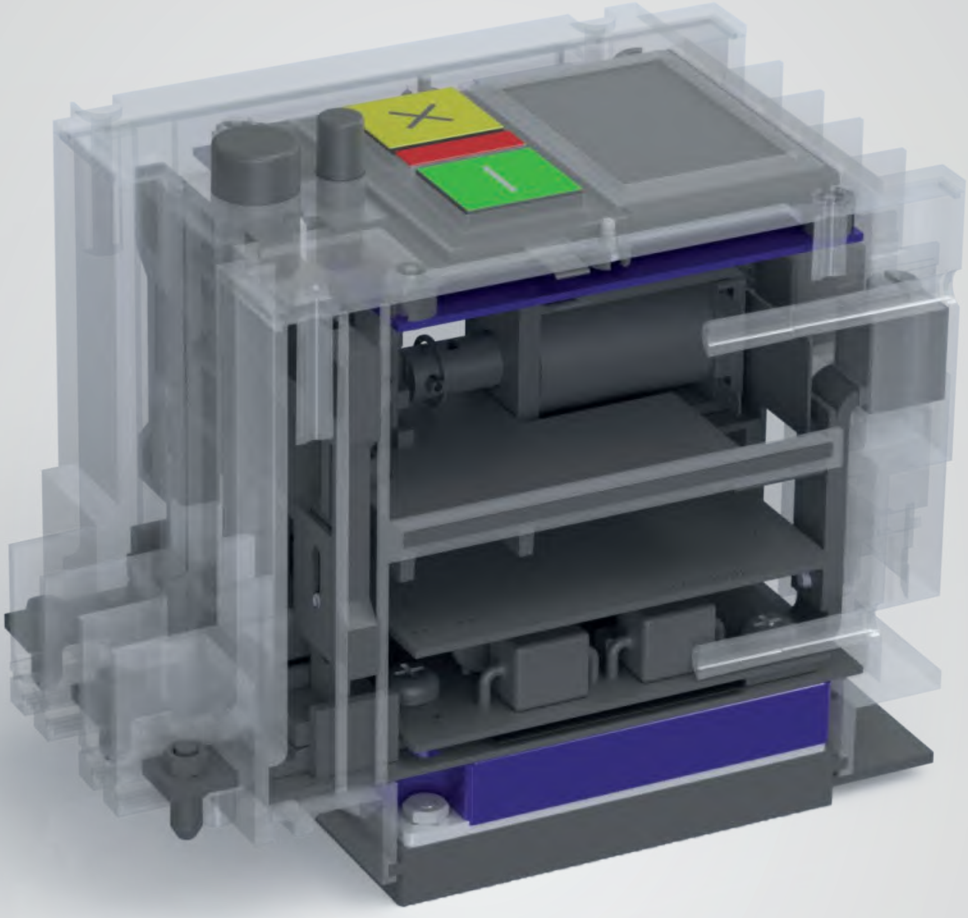
A New Era of Solid State Circuit Protection

by **Binesh Kumar**



With an aging power grid, and continuing shift to electrification due to the global awakening of sustainable energy, power systems are undergoing a transformation, giving rise to new technologies and industries. One of the technologies that have paved the way for new innovative solutions aiding in the power systems transformation is Solid State Technology. This term was coined in the late 1960s when the era of semiconductors began and was attributed to the flow of electricity using semiconductors as opposed to gasses in vacuum tubes, hence the term 'solid-state'. Since then, the terminology has been applied to various other industries and systems with architecture that is made up of solid, non-moving components. With material science advancements, solid-state technology is now playing a crucial role in the modern power systems transformation. After revolutionizing the semiconductor industry, the technology is now penetrating the power systems protection, in the form of Solid State Circuit Breakers (SSCBs), which we cover in this article.

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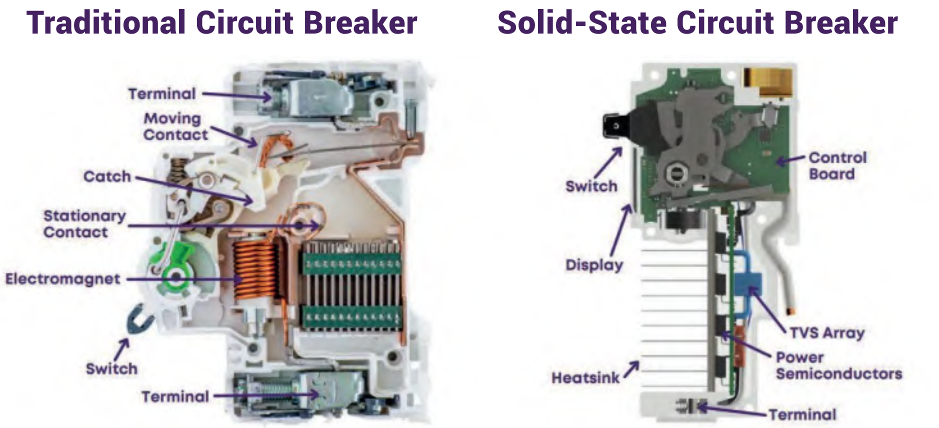

Figure 1.
Anatomy of traditional circuit breaker (left) vs. solid state circuit breaker (right)

Traditional Circuit Breakers

The circuit breaker was invented by Thomas Edison in the late 1800s. Circuit breakers are analogous to the neurons of power distribution. Power flows through hundreds of breakers before it is delivered to the end customers. There are different types of circuit breakers for high-voltage, medium-voltage and low-voltage applications. Low-voltage circuit breakers such as molded case circuit breakers or miniature circuit breakers are the ones we typically see in residential panelboards. The primary use of these breakers is circuit protection in the event of overload, short circuit and ground faults. The construction of these breakers consists of a frame, contacts, lever, trip unit and an actuator mechanism.

The trip unit includes a thermal bimetallic strip that deflects in the event of an overload, thereby opening the contacts. A short circuit fault results in an electromagnetic trip opening the contacts directly.

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A key point to note in the case of these traditional circuit breakers is that they switch the circuit causing arcs, and the breakers deploy various mechanisms to extinguish the arcs during the switching of mechanical contacts, such as using arc chambers, arc deflectors etc. This results not only in wear and tear but also could have safety implications in the event of a failure. The transients during these events could propagate through the power systems causing havoc to upstream and downstream equipment. These circuit breakers are also static in nature and cannot be configured as per the application or any changes to the infrastructure loads.

Although there have been functionalities added to the circuit breaker over the last century, the fundamental tripping technology behind it has not changed since it was first patented by Edison.

Solid State Circuit Breakers

To overcome the drawbacks of traditional circuit breakers, and to pave the way for the next era in power systems circuit protection, Solid state circuit breakers (SSCBs) were invented and commercialized in recent times. SSCBs were on research papers for a long time but commercialization was not feasible until recently when the semiconductor advancements had to get to a point where the form factor and efficiency got within the desired range for commercial feasibility.

Solid state circuit breakers utilize power semiconductors to make and break the circuit. This is a fundamental shift in how circuits can be protected, since these semiconductors can be switched in the order of nanoseconds as opposed to milliseconds as in the case of traditional circuit breakers. These solid state devices are operated in the saturation region as they are acting as switches in this application.

Figure 1. shows the differences between a traditional and solid state circuit breaker. As shown, the traditional breaker has numerous moving parts that are subject to wear and tear over the lifetime, whereas the SSCB has no moving parts as part of the trip mechanism since the primary switching devices are the semiconductors.

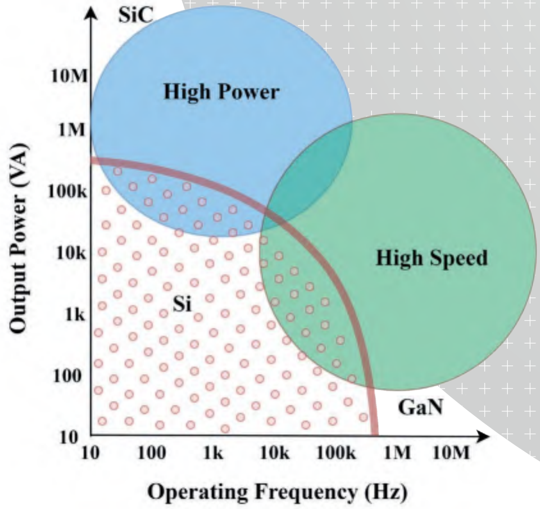

Figure 3.
Comparison between Si, SiC, and GaN

Wide bandgap (WBG) semiconductors are semiconductor materials that deploy a larger energy band gap than traditional semiconductor materials such as silicon. This is the energy gap existing between the upper limit of the valence bond and the lower limit of the conduction band. Due to this, they can be operated at much higher voltages, frequencies and temperatures. Figure 2 shows the difference in the construction between the semiconductor and metal. The bandgap plays a key role in the operation of a semiconductor material.

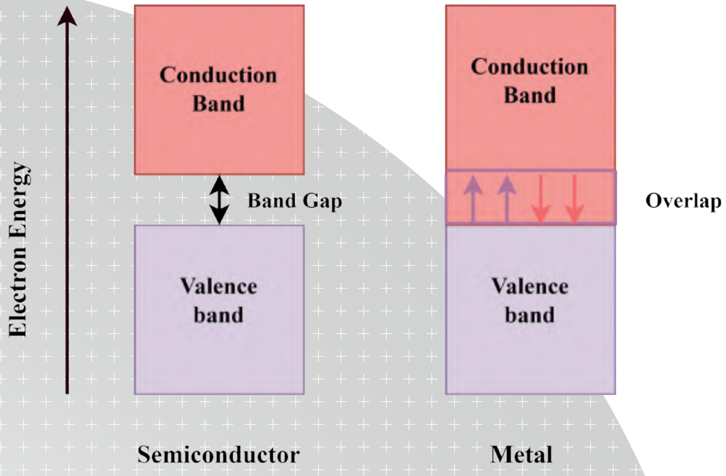

Figure 2.
Band gap of semiconductors

Some of the common WBG materials include silicon carbide (SiC) and gallium nitride (GaN). The bandgap is typically around 1.12eV for Si, while it is 3.39eV for GaN and 3.26eV for SiC [1]. Aside from GaN having a higher energy band than the SiC as mentioned above, GaN has higher electron mobility by about 30%, which is a measure of how fast electronics can move through the semiconductor material. This makes GaN more suitable for frequency RF applications that require the semiconductor to switch in the gigahertz range [2]. SiC on the other hand is more suitable for higher power applications since it has higher thermal conductivity (the ability to transfer heat). Therefore, SiC devices are obvious choices for solid state circuit breakers. Figure 3 depicts how Si, SiC and GaN correspond with each other across the various operating frequencies and output powers.

Construction of Solid State Circuit Breakers

Solid state devices are the heart of SSCBs, as they are used to make and break the electrical circuit. Figure 4 shows the construction of a common power device used for solid state circuit breakers, the MOSFET, using the SiC substrate [3].

Some of the key parameters for the power device for the SSCB application include the ON resistance

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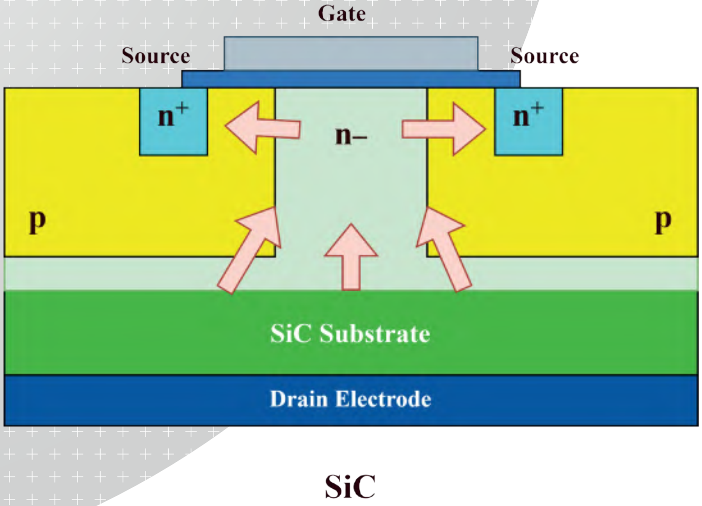

Figure 4.
Construction of SiC MOSFET Device

(RdsON) and thermal conductivity. These devices, typically made of WBG, have the ability to operate at high voltage and temperature operating conditions. While these power devices are the heart of the SSCB, the brains are composed of microprocessors, which provide the actuation intelligence to the SSCB. Due to this, the SSCB can act as smart devices with network capabilities added, enabling advanced functions such as remote control, metering, scheduling, etc. To enable full circuit protection functionalities, current, voltage and temperature monitoring mechanisms are incorporated, making the system function as a cohesive unit. The human machine interface consists of a button assembly and a display. An air gap mechanism is provided on the line side to provide galvanic isolation, which can then be locked out and tagged out in the event of maintenance and service downstream. This results in one of the key operating differences between traditional circuit breakers and solid state circuit breakers, which is the standby state. This is the state where the air gap is engaged but the semiconductor is in the off state [4].

The SSCBs can then be grouped and networked in a panel along with other SSCBs, making a smart panelboard, which can then be accessed by the outside world with the help of a user interface. This smart panel can then be used for intelligent load control and managing distributed energy resources such as solar and wind turbines, as well as for EV Charging applications.

SSCB Features

Utilizing solid state devices for circuit breakers open up a wide range of features that could not otherwise be realized by conventional circuit breakers. Some of the key features of SSCB include:

1. **Building visibility:** SSCB can be used for adding more visibility into the building, such as power metering with high accuracy. These can be then incorporated into building management systems (BMS).
2. **Remote control:** The network capability along with the standby state of the SSCB can be used to remotely control the SSCB and in turn the loads connected to the SSCB. The ability to reset circuit breakers remotely can provide significant cost benefits by limiting downtime in the infrastructure in the case of a fault.
3. **Scheduling:** Since the SSCB panelboard can be networked to the outside world, schedule routines can be added to the SSCB, thereby adding automation to the load controls, switching them at the specified times of the day for reducing peak energy costs or other use cases.

Figure 5.
100 A Frame Size SSCB

4. **Added protection features:** In addition to the circuit breaker protection functionalities such as overload, short circuit protection, other protection features such as over/under voltage protection, over/under frequency protection can be added to the circuits, bolstering the safety mechanism to the circuits and loads.
5. **Motor controls:** Induction motors have high inrush current when they are started across the line. This can prove detrimental to not only the motors themselves but also the equipment downstream and devices on the same power line. Hence motor starters such as a soft starters or variable frequency drives (VFDs) need to be used to ensure the current inrush is limited to acceptable levels. Since SSCB has a similar construction as a soft starter, it can be used to consolidate all the motor control devices such as circuit breaker, soft starter, overload protector all into one device. This can be accomplished by ramping up the voltage as the motor starts before fully turning it on when the synchronous speed of the motor is achieved.

The Intelligence added on top of the solid state platform makes the SSCB a Swiss army knife in circuit protection.

SSCB Benefits

Some of the main benefits of SSCB are outlined below:

1. **Arc flash mitigation:** Since the SSCB can be switched using the wide bandgap semiconductor material, the switching times are in the order of nanoseconds. As a result, arc flash during a short circuit fault condition is mitigated or even eliminated since the breaker does not allow energy to build up in the circuit.
2. **Configurability:** The intelligence added to the SSCB can help in ultimate configurability where the rating of the breaker can be adjusted dynamically. For example, A 100 A frame size breaker can be configured to operate anywhere between 15 A to 100 A, which is a paradigm shift from the traditional approach, where breakers have been static without the ability to change the breaker rating.
3. **No maintenance:** Since SSCB breaks and makes the circuit without moving parts, there is no wear and tear and hence there are no maintenance requirements making it highly attractive in the industry where maintenance has been a cost and time burden to operations.
4. **Smart capabilities:** With all the features discussed in the above section, the SSCB can be also termed as a smart breaker, with its multitude of capabilities making it an ideal device for the different applications.
5. **Device integration:** Modern distribution using smart grids can become very complex due to the number of devices required to perform the various functions. For example, a typical system consists of a protective relay, under/over voltage relays, meters, circuit breakers, control elements, networking devices etc. With the advent of SSCB, all these devices can be integrated into one device, which is analogous to going from a rotary phone which had just one function of making a phone call to a smartphone which has multiple functions added to the device on top of its primary function.

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Applications

With the versatility of the SSCB, it has numerous applications in different industry sectors. Some of the key

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applications include but are not limited to the following:

1. **Distributed energy resource management:** With the transition from a centralized grid to a decentralized grid, SSCB will be a crucial part of the technology integration to enable this transition. This is accomplished by using the SSCB panel as the central control panel for managing the distributed energy resources and battery storage.
2. **Industrial applications:**
   a. Motor Control Center (MCC): SSCBs with their superior control capabilities, can be used for motor controls as a unified device. This can replace the traditional MCC since it consolidates the various components of the MCC into one device, thereby saving real estate and cost in industrial application.
   b. Automatic transfer switches (ATS): The networking capabilities of SSCB open up a unique application, the ATS, where two SSCB can be operated in tandem, thereby enabling a seamless transfer of energy from primary source such as the utility grid to an alternate source such as a generator or green energy sources, and vice versa. The speed of SSCB can make it an ultra switch where there is no power glitch in this transition since the load can be switched from one source to the other in microseconds and can do a closed transition switching.
3. **EV charging:** The digital control of SSCB can prove a significant benefit in EV charging applications where the SSCB can be directly used as the electric vehicle supply equipment (EVSE). This helps solve some of the major challenges in setting up wide scale charging infrastructure, such as cost, safety, complexity and scalability [5]. This new topology of EV charging architecture, where the circuit breaker is directly used as the EVSE yields several advantages such as safety at the dispenser since the power is switched at the distribution panel as opposed to the dispenser out in the parking lot. This central control of chargers enables intelligent energy management functionalities, reducing OPEX and CAPEX for setting up wide scale charging infrastructure, in turn reducing burden to the electric grid.

Conclusion

The benefits that solid state circuit breakers provide over traditional breakers as explored in this article make them inevitable for wide-scale integration as the world adopts the new ways by which power is generated and distributed, going from a centralized, unidirectional grid to a decentralized bidirectional smart grid. Semiconductor research continues to bring down the cost for WBG production and increase efficiency, overcoming the current drawbacks in terms of the cost and thermal limitations of the SSCB. Nevertheless, it is hard to put a price to the value of human safety, where the SSCB outshines any traditional devices by mitigating arc flash and saving human lives when fault conditions occur.

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