

A Cost Effective Hybrid Circuit Breaker Topology for Moderate Voltage Applications



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Abstract Compared to mechanical circuit breakers, with respect to speed and life, solid state circuit breakers based on modern high power semiconductors offers considerable advantages. During a short circuit the voltage profile of the power grid can be improved since the fault current is reduced. The distortion in voltage caused by a three-phase short circuit can be limited to fewer than 100 μs . In this paper, a theoretically approached active thyristor circuit based on a new hybrid topology of connecting the semiconductor devices in series and parallel is proposed. This permits an increase in supply voltage and fault clearance without arcing. In turn, and to get benefit from a current limitation, the circuit breaker is realized with the extinction of an electrical arc when the breaker is opened. Hence the proposed topology has led to a wider integration of solid state circuit breakers (SSCB) in existing power grids because of their cost effective nature when compared to turn-off semiconductor devices.

Keywords Circuit breaker · Fault current · Voltage profile · Electrical arc
Active thyristor circuit · Hybrid circuit breaker · SSCB

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1 Introduction

1.1 Circuit Breaker

An electrical switch that is operated automatically to protect electrical circuits from overload or short circuit.

Circuit breaker importance: As the power system network is very complex, it requires protection switchgear in order to operate the system safely and efficiently in both normal and abnormal situations. The circuit breaker acts like a switch along with the fuse, having added advantages with complex features.

1.2 Mechanical Circuit Breaker

The circuit breaker consists of two contacts which are placed in an insulating medium. The insulating medium facilitates two basic functions:

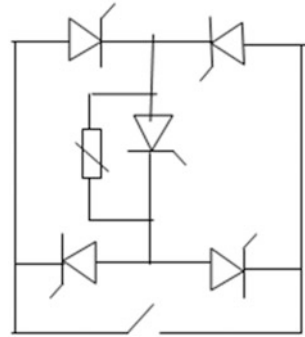
- (1) Quenching the arc established between two contacts when the circuit breaker is operated.
- (2) Providing insulation between contacts and also with the earth.

Even though mechanical circuit breakers play a vital role in power system protection, their major drawbacks are listed as i. Requirement of frequent reconditioning of the quenching medium after every operation. ii. Complexity in maintenance of compressor plants. iii. Chance of explosion when the hydrogen and oil combine with air during arcing. iv. The dielectric strength of the oil is reduced due to arcing. v. A breaker like the SF₆ is costly due to the insulating gas (SF₆).

2 Technological Advancement of Circuit Breakers

2.1 Hybrid Circuit Breakers

A theoretically approached active thyristors circuit based on a new hybrid topology by connecting the semiconductor devices in series and parallel is proposed. This permits an increase in supply voltage and fault clearance without arcing. In this study the advantages and disadvantages of mechanical switch-based hybrid circuit breakers and semiconductor-based circuit breakers are considered so as to obtain an improved version of a SSCB owing to less conduction loss. To achieve fast and longer life systems, modern power electronic devices are finding the best fit instead of conventional mechanical part of the circuit breakers. The thermal loss created due to voltages drops is the major drawback for static circuit breakers. The fault current gets interrupted by deflected branch current in the semiconductor device,

Fig. 1 Hybrid circuit breaker

created due to a small arc voltage drop when the mechanical switch gets opened. IGBTs (integrated gate turn-off thyristors) are being successfully used for moderate voltage applications (Fig. 1).

2.2 DC Solid State Circuit Breaker

A DC SSCB has two terminals connected to the dc source. The voltage generated by the circuit breaker is proportional to the circuit current which is utilized to control a solid state switch which in turn interrupts the circuit. The enhancement of turn-off time is achieved by the feedback of the regenerative voltage.

2.3 Solid State Circuit Breaker

The inclusion of sensible loads in the electrical system leads to power quality issues. Moreover, handling of short circuits in moderate voltage grids is an important issue in improving the power quality.

The use of power semiconductor devices can reduce the short circuit current along with voltage distortions in the event of short circuit failure.

Merits of SSCB:

1. Operating Speed and life of a SSCB is superior to mechanical circuit breakers.
2. Voltage profile will be improved during a short circuit because of the reduction in fault current.
3. No arcing and restriking is present.
4. Eco friendly since there is no chance of ionization of gases or oils.
5. Highly reliable since no moving parts and low on maintenance.
6. Small in size, weight, running cost, and response is fast.

7. For a better power quality profile in distribution systems, solid state technology is used. The reaction time of solid state switches is less when compared to mechanical switches.

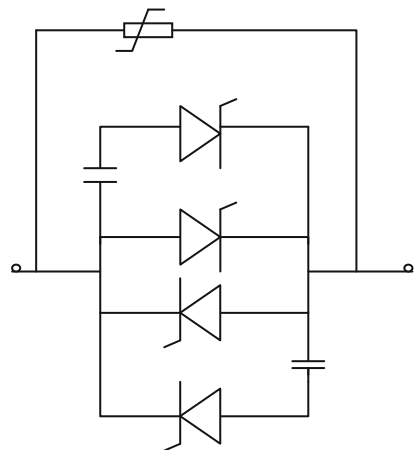
3 Topologies

3.1 Topology 1

Topology 1 uses modern high power semiconductors like gate commutated turn-off thyristors (GCT) instead of mechanical circuit breakers. In self turn-off converters, thyristors like GTOs, GCTs, and IGBTs were used using forced turn off. These topologies are utilized for an adequate amount of time despite their complexity. The limitation of a forced commutation circuit is its switching frequency and also the switching sequence. Application related to solid circuit breakers the behavior of the switching is on smaller side because of the absence of switch at high frequency. During the short circuit period the solid circuit breaker must be turned off actively and should be ready for the next turn-off period after various line periods. Therefore the limitation with respect to forced commutation circuits will be on par least important in solid circuit breakers applications. Initially, for forced commutation circuits a standard topology is proposed. The addition of a varistor is the only difference when compared to inverter classical solutions. These varistors are used to reduce the size of the capacitor and also to keep the breakdown voltage of the device under permissible limits (Fig. 2).

The two main thyristors are in the ON state under normal conditions of operation and these two thyristors also offer greatly reduced on-state losses. Precharged

Fig. 2 Topology 1



capacitors are used in this topology. In the case of a failure the auxiliary thyristor is fired, which is associated with the main thyristors. With this operation the current is commutated instantly followed by the capacitor discharge. Therefore the SCR current is forced to go to zero. This gives rise to condition where the thyristor is turned off at the zero crossing. To turn off the short circuit current successfully, the commutation capacitor with stored energy becomes more critical. With this design of the commutation circuit, precharged voltage can be selected which proves to be one of the added advantages.

3.2 Topology 2

Various design topologies are developed to reduce the capacitor number so as find an economical solution (Fig. 3).

In order to avoid a second capacitor in this case the two additional thyristors are used. Switching of the capacitor in the required direction is achieved by firing the two thyristors. This topology behavior is the same as a standard forced commutation circuit.

3.3 Topology 3

A transformer with very low inductance is used in this topology and also the thyristors have a maximum voltage of 1.5 kV along with the capacitor as shown in Fig. 4. A second path is associated with a semiconductor switch. In this paper GCTs are used. In this topology we may find that the requirement for thyristors and the transformer is not necessary but these find their importance when the losses in

Fig. 3 Topology 2

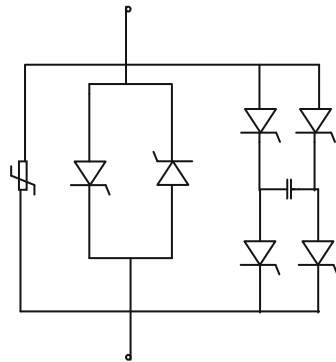
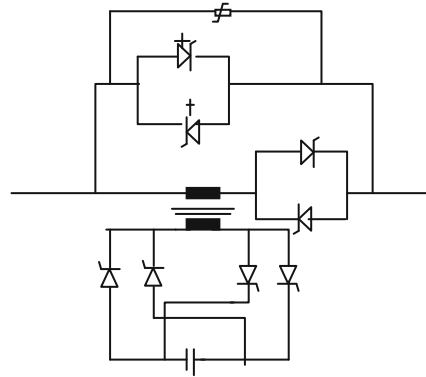


Fig. 4 Topology 3

the GCTs are considered as these losses are very high in power grids. A second advantage of this solution is that much smaller, i.e. cheaper, and symmetric GCTs can be used in this application, because the on-state behavior of the GCTs is of no relevance during normal operation. Other benefits of this topology are the smaller size, availability, cost, symmetric GCTs are used in this application due to on-state behavior of GCTs is at a low importance under normal operating conditions.

The thyristors and inductance carry current during normal operation. In the event of a failure the auxiliary circuits are turned on. A capacitor with stored energy is able to demagnetize the inductance during a failure and the current in the active circuitry is forced to come down to zero. The short circuit current in the GCTs is turned off once the main thyristor crosses the hold-off interval.

Due to the small leakage inductance of the transformer, the capacitor required for the current commutation process is very small when compared to convectional forced commutation circuits. To demagnetize the leakage inductance and to prevent positive voltage caused by the GCT, sufficient energy is stored inside the capacitor.

The voltage at the primary winding is responsible for the commutation time of the current to the auxiliary path. Current commutation time in the auxiliary path is affected by the primary voltage of the transformer. Since the hold-off time of a thyristor strongly depends on the current fall time or slew rate, an optimal operation point exists where the turn-off time is minimal. Since thyristor hold-off time depends on slew rate an optimal operation will exist with minimal turn-off time.

4 Technical Comparison Among Topologies

Topologies 1 and 2 offer exactly the same performance. However, selection based only on the technical performance of the two topologies is not reasonable.

To demagnetize the current topology 3 does not adopt large capacitors when compared to topology 1 and 2. Interruption to the line current is provided directly in

topology 3 with active a device which does not increase the di/dt in the hold-off period. Compared to convectional commutation circuits the GCTs commutate the current more rapidly leading to reduced current peaks.

The on-state losses in topology 3 due to transformer resistance are much less and can be neglected. Hence by taking the technical aspects into consideration, topology 3 provides the best performance when compared to the solutions presented earlier.

5 Economical Comparison of Topologies

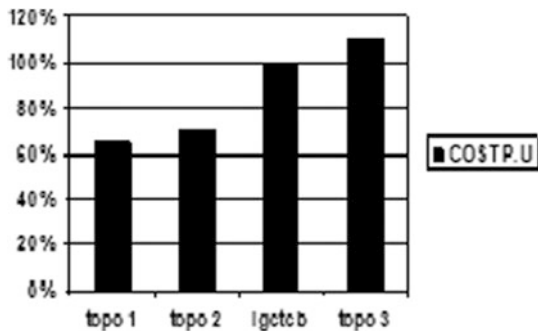
A predominate role is played by economic factors in the design and adaptability of new technologies in the industry. Therefore an unavoidable economic comparison of the different topologies is presented (Fig. 5).

In this comparison chart the cost of GCT is related with all per unit costs. While investing, the cost for mechanical built-up, cooling, control is taken into consideration. Since the investment cost of varistors protection systems is very low, the variation in cost of the different topologies can be neglected.

The cost is calculated for a transmission power of 25 MVA with a blocking voltage of 32 kV and a hold-off time interval of 500 μs .

Therefore it is very much true that conventional circuits provide the lowest cost of investment compared to other systems. The step of using a thyristor bridge to reduce the commutating capacitor in topology 2 was taken to reduce the cost and turned out to be more costly than topology 1.

Fig. 5 Cost analysis



6 Conclusions

In this paper, different solutions for a cost effective hybrid circuit breaker topology for moderate voltage applications are presented. Even though forced commutation circuits are not the latest technology, the application in moderate voltage SCB requires improvements. Compared to the latest turn-off devices, thyristors provide more advantages, such as extremely low on-state losses and low-cost trigger circuits. Active turn-off devices offer fewer advantages when compared to an active current limiter.

Since the varistors are cheap the overall impact due to the charging circuit is negligible and also the on-state losses are very low compared to a GCT circuit breaker. Due to the existence of natural redundancy reliability of SCR circuits is very high, in the event of commutation failure the thyristors will commutate at the preceding zero crossing. Therefore circuit breaker failure is quiet unlikely.

To fulfill the required necessary functions of the latest breakers, a varistor coupling based is the best fit. Aiming for rapid reclosing a topology with constant charging capacitor is presented.

A requirement for additional diodes in the phases of the grid is much costlier when we go topology using varistor coupling for all phases. However, to compensate the leakage current of the capacitor there is no need for any voltage source.

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