

FRIENDS Devices and their Coordination

R. L. Meena, Arindam Ghosh and Avinash Joshi

Abstract-- The paper discusses various aspects of Flexible, Reliable and Intelligent Electrical eNergy Delivery System (FRIENDS) devices and their coordination to improve power quality by using power electronics based semiconductor devices. Static Current Limiter (SCL) and Static Circuit Breaker (SCB) are protecting devices while Static Transfer Switch (STS) is a network controlling device. Static Switch is the basic building block of all protecting and control FRIENDS devices. The SCL and SCB are simulated for an 11 kV radial distribution system. Coordination issues for protection using FRIENDS Devices are simulated for 11 kV generic distribution system. The single phase STS is simulated for both SCR and GTO based topologies and results are compared. Digital simulations for FRIENDS devices are performed using PSCAD/EMTDC software package (version 3.1.7) on a personal computer.

Index Terms— FRIENDS, Power Quality, PSCAD/EMTDC Simulation, SCB, SCL, STS.

I. INTRODUCTION

POWER QUALITY issues are currently receiving a great deal of attention in the light of distribution generation, deregulation, liberalization and privatization of the electrical energy market. For AC transmission and distribution system, power quality broadly refers to maintaining a near sinusoidal bus voltage at rated magnitude and frequency. The power quality of a supply voltage can deteriorate due to very high-speed events such as voltage impulses/transients, high frequency noise, waveshape distortion, voltage swells and sags or due to simple total power loss. Each type of electrical equipment will be affected differently by the power quality issues. Problem of poor power quality can be solved by power electronics based FRIENDS devices. The word FRIENDS stands for Flexible Reliable and Intelligent Electrical eNergy Delivery System [1]. With FRIENDS, the power system can be operated without interrupting the power supply by flexibly changing the distribution systems configurations after the occurrence of a fault. Power electronics based *static switch* shown in Fig. 1 is the building block for all FRIENDS devices. Static current limiting and breaking devices protects the distribution

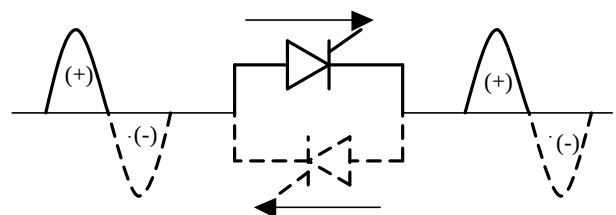
system fast and efficiently. STS transfers supply between two or more ac sources when applied at critical facilities. GTOs are used for Static Current Limiter

(SCL) and Static Circuit Breaker (SCB) where instantaneous current has to be interrupted [2]. SCRs are used for Static Transfer Switch (STS) where transfer of power from one source to another is performed. GTOs can be used for STS instead of SCRs to make them faster.

The protective devices must switch off the smallest portion of network without affecting the majority of loads. This objective is accomplished through primary and back up protection using inverse time overcurrent relays [3]. This basic principle of coordination must be kept in mind while placing SCL and SCB. For power quality related problems caused by voltage sags and swells, lightening strikes and other system related disturbances, in many instances, the use of a STS can be one of the most cost effective solutions. The objective of the paper is to simulate FRIENDS devices in PSCAD/EMTDC software package and study their coordination aspects to determine their placement location in a generic distribution system. Also operating parameters are calculated for providing a fast and reliable protection.

II. STATIC SWITCH

This is the combination of two anti-parallel thyristors as shown in Fig. 1. Assume that an alternating current flows from the left to the right of the static switch. The positive half cycle current is passed by the thyristor that is in forward biased condition. Similarly the negative half cycle current is passed by the other thyristor. Thus each thyristor conducts for half cycle and remains in the off state for another half cycle. The current flowing through static switch can be interrupted by blocking the firing signal. The current will then be interrupted at its next zero crossing. When thyristors are replaced by GTOs, the operation will be faster because current can be forced to zero at any instant, therefore eliminating the need to wait till the next zero crossing. This characteristic is mandatory for current limiting and breaking devices. For load transferring thyristors are sufficient but GTOs may transfer faster than thyristors.



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coordination problem. The main SCL/SCB features for protection coordination are

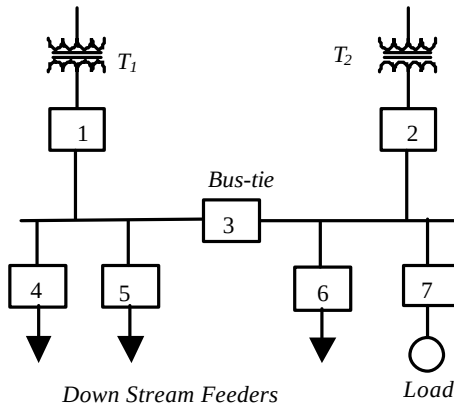


Fig. 5 A generic distribution system

- It must limit the short circuit current such that it does not exceed the interrupting rating of any down stream protecting devices
- It must allow sufficient fault current to flow such that it can clear the fault any down stream over current protection device.
- It must maintain the fault current with in a specified limit till a down streams device clear the fault.
- The limiter must reset automatically after the fault is cleared.
- It must relatively free from maintenance.

VII. SIMULATION STUDIES

Digital simulations for static protection and control devices are performed using PSCAD/EMTDC software package (version 3.1.7) on a personal computer. For SCL and SCB we have considered a simple radial distribution system (test system) that is supplying an R-L load as shown in Fig.6. The line to neutral voltage is 6.35 kV (rms) and the system frequency is 50 Hz. The feeder has a resistance of 3.025Ω and a let-through inductor of 38.5 mH while the load resistance and inductance are given by 60.5Ω and 770.3 mH respectively. This implies that for a base voltage of 11 kV (L-L) and a base MVA of 1.0, the feeder impedance is $0.025 + j0.1$ per unit and the load impedance is $0.5 + j2.0$ per unit. The pre fault current in the steady state is 24.25 A (rms), i.e., 0.462 per unit. For a short circuit fault ($V_i = 0$), only the feeder impedance limits the load current, which has the peak of about 1200 A, i.e., more than 20 per unit.

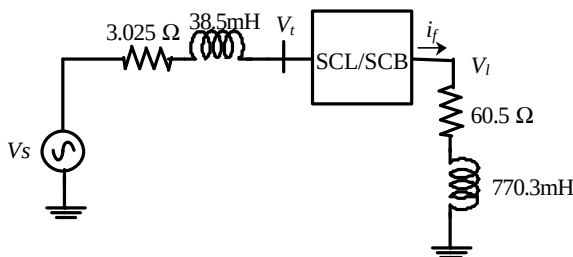


Fig.6 Radial distribution protected by SCL/SCB.

The simulation for single-phase STS is done similarly using the topology shown in Fig 4. In this case the short circuit fault is assumed to occur at the input of SW_1 as shown in the above mentioned figure.

The test system for the study of protection coordination is shown in Fig. 8. Generators G_1 and G_2 are supplying power at 19.05 kV (line-to-neutral, rms) to the incoming feeder via 19.05 kV/6.35 kV (line-to-neutral, rms) transformers to the bus 1 and bus 2 respectively. These buses are connected by a Bus-tie SCB 3. The system frequency is 50 Hz. The each incoming feeder has a resistance of 27.225Ω and an inductance of 346.5 mH while the transformer has leakage inductance of 346.5 mH referred to the primary side.

Down stream feeders 4, 5 and 6 each have the sum of feeder and load resistance of 60.5Ω and inductance of 770.3 mH. The load supplied through SCB 7 has resistance of 30.25Ω and inductance of 385.15 mH.

This implies that for a base voltage 33 kV (L-L) and a base MVA of 1.0, the incoming feeder impedance is $0.025 + j0.1$ pu and the leakage inductance of the transformer is $j0.1$ pu. The impedance of each of the downstream feeders 4, 5 and 6 is $0.5 + j2.0$ pu and the load labeled 7 impedance is $0.25 + j1.0$ pu. The steady state current in the feeders 4, 5 and 6 is 24.30 A (rms), i.e., 0.463 pu. Load 7 draws 48.60 A (rms) i.e. 0.926 pu. If the bus-tie is in closed position, the same amount of current will be supplied by the both sources which is 60.625 A (rms), i.e., 1.1575 pu. By the network topology 12.15 A, i.e., 0.2315 pu current is passing through bus-tie. This power delivery system is simulated in PSCAD/EMTDC software package and proper coordination is achieved.

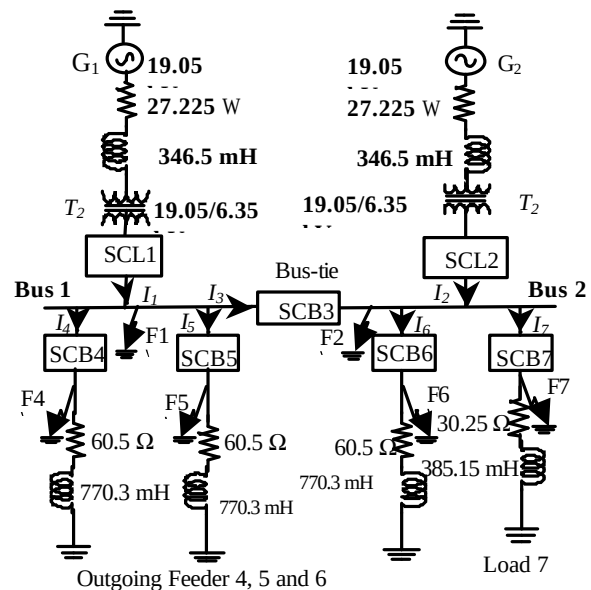


Fig.7 Test distribution system.

VIII. SIMULATION RESULT AND DISCUSSION

The simulation studies have been divided into following four cases

1. Case-a: Static Current Limiter (SCL)
2. Case-b: Static Circuit Breaker (SCB)
3. Case-c: Static Transfer Switch (STS)
4. Case-d: Coordination Issues

In all cases the operation of the protective devices and their coordination issues has been studied using the per phase equivalent circuit for a short circuit fault at or near the load terminal. Successful operation of the protective devices has been illustrated by waveforms of voltages and currents in the test system.

Case-a: Static Current Limiter (SCL)

The SCL is connected in line to limit the fault current. The value of the let-through inductor is chosen as 500 mH and the clipping voltage level of the ZnO arrester is chosen as 6.9 kV. The system response to a short circuit at the load terminal at time $t=0.21$ sec is shown in Fig. 8. The load voltage falls to zero immediately and the load current free wheels to zero in local loop. The feeder current magnitude is sensed and the GTO based static switch is commutated as soon as the current reaches 40 A (0.76 pu). The current through the let-through inductor can not rise instantaneously. Therefore initially the feeder current passes through the ZnO arrester. Later the feeder current flows through the let through inductor and the arrester in parallel. As seen in figure the feeder current has to a peak of about 105 A (2 pu). Thus the fault level is reduced from the value of about 20 pu to 2 pu by the use of SCL. The voltage across the Static Switch is limited to 6.9 kV by the arrester. Again the fault current is the sum of the current I_i and I_z . The arrester current dominates this current.

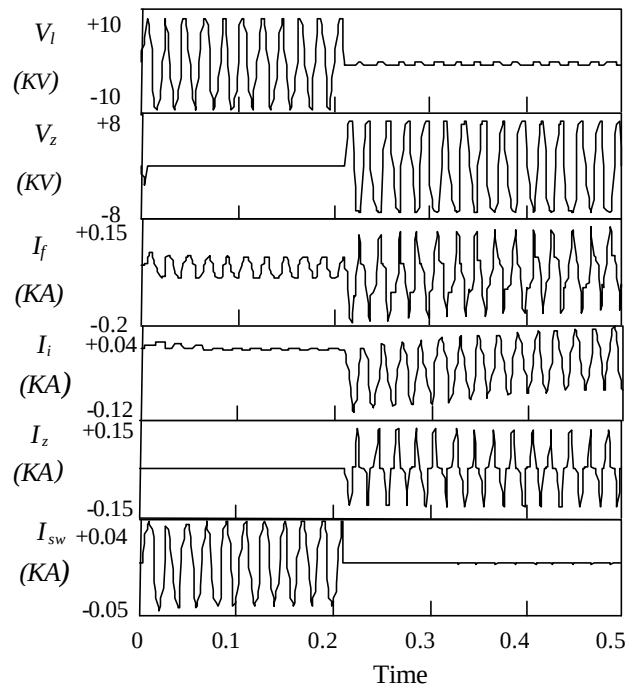


Fig.8. SCL protected system response for an arrester clipping voltage level 6.9 kV.

If the arrester voltage level is increased to 13.8 kV, the system response is shown in Fig.9. Now the let through inductor current is predominantly the fault current. It may be noted that increasing the voltage level reduces the arrester current. This will however increase the voltage across the Static Switch. In Fig.9 it is 9 kV which is the about the peak of the system voltage because the arrester clipping voltage level is higher than the peak of the system voltage.

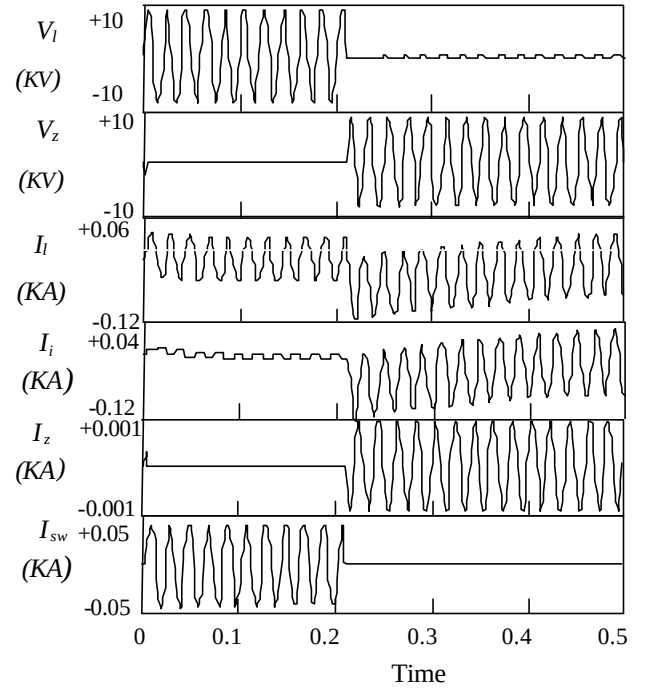


Fig.9. SCL protected system response for an arrester clipping voltage level 13.8 kV.

Case-b: Static Circuit Breaker

The SCB is simulated for the same feeder as in case-a above. Simulated result is shown in Fig 10. The fault is created at $t = 41$ ms. The fault current flowing to feeder through VCB is sensed and compared with a specific limit.

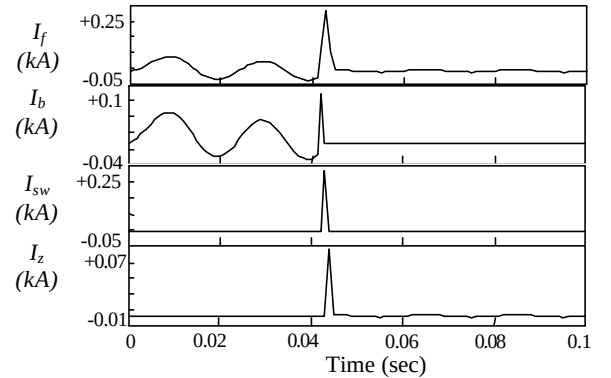


Fig.10 System response with SCB.

The GTO based Static Switch is turned on when the feeder current crosses the limit. At the same time a trip signal is given to the VCB and it is assumed to turn off on its own. The turn off time is very small and may be neglected. The GTO based Switch is kept on for a short fixed time interval (1.25 ms) as there is no current limiting inductor in this topology. At the end of this interval the switch is commutated. The total time interval to interrupt the fault current depends upon the time instant when the fault occurs and the value of the current limit. The total interrupting time for the fault at time $t = 41$ ms is observed to be 4 ms, which is much smaller than that of the mechanical circuit breaker. In this topology the arrester current is smaller than SCL topology as GTO is used to interrupt the fault current.

Case-c: Static Transfer Switch

The system topology for this case is shown in Fig. 4 and it is assumed that a fault occurs on the preferred feeder. Simulation result for thyristor based STS switch is shown in Fig.11 with make-before break strategy. The typical transfer time is observed to be 8 ms but this is not a constant for all the conditions. It varies from 7 ms to 12 ms and depends on many factors. Some of these factors are: relative magnitude of source voltages and their phase difference, feeder impedance, load impedance, fault detection time, whether the load is passive or active etc.

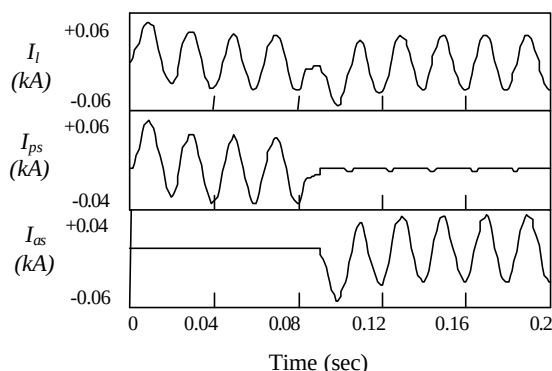


Fig.11 Make-before-break switching with thyristor based STS.

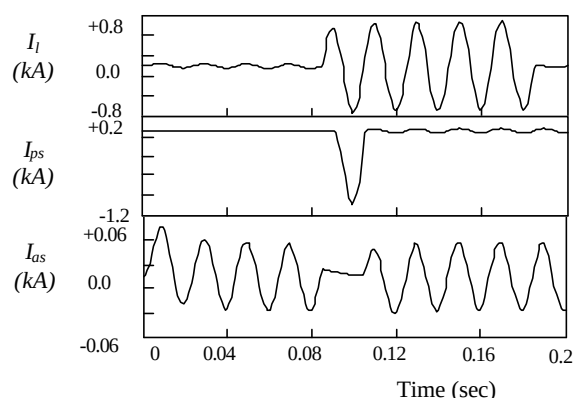


Fig.12 Current during incorrect transfer for a fault in the preferred feeder.

MBB strategy is also not applicable for all the operating conditions as this may lead to temporary transfer of the fault from unhealthy side to healthy side which cause large current

to flow through STS components. This is shown in Fig.12. This may damage the STS and destroy the power quality of the sensitive load. To eliminate the possibility of such large current flowing in switches, the transfer in that case has to be delayed till the current through outgoing switch to become zero.

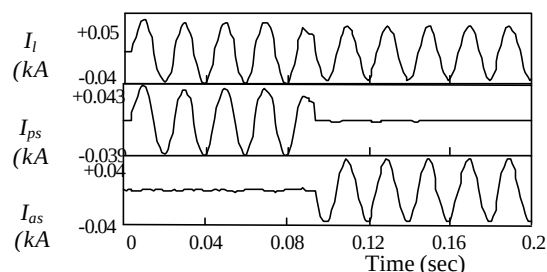


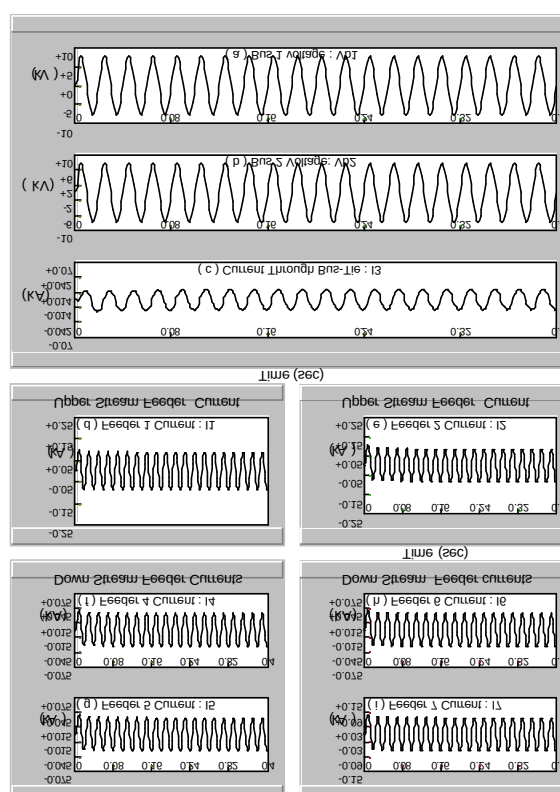
Fig. 13 Make-before-break switching with GTO based STS.

Simulation result when GTOs are used instead of SCR is shown in Fig. 13. The operation is independent of fault instant and other operating conditions. The load transfer time is 6ms, which is almost constant for all the switching conditions. This is 2 to 6 ms less than that of the SCR case discussed above.

Case-d: Coordination Issues

The simulated Steady State response of the Test System is shown in Fig. 14. The system is examined for various unhealthy conditions, which are summarized in Table 1 and results are discussed.

The SCL 1 and 2 provide primary protection for the fault at the bus and back up protection to the down stream feeders and load. Similarly SCB 3 functions differently for bus fault and fault at feeders. For the fault at bus it is compulsory for this to isolate the healthy section from unhealthy section within a short time. But in case of fault at the feeders, which



are primarily protected by the SCBs connected to the concerned feeder, SCB 3 provides back protection.

Fig 14 Steady state response of the test system.

Table I. Various Faults and Coordination of Protection Devices.

Fault	Location	Instant (sec)	Primary Protection Devices	Pick up Current (Primary) pu	Back up Protection Devices	Pickup Current (Backup) pu
F ₁	Bus 1	0.11	SCL 1 & SCB 3	2.0 & 2.5	-----	-----
F ₂	Bus 2	0.12	SCL 2 & SCB 3	2.0 & 2.5	-----	-----
F ₁ & F ₂	Bus 1 & 2	0.115 & 0.153	SCL 1&2 & SCB 3	2.0 & 2.5	-----	-----
F ₄	Feeder 4	0.1197	SCB 4	2.0	SCL 1 & SCB 3	6.0
F ₅	Feeder 4	0.1197	SCB 5	2.0	SCL 1 & SCB 3	6.0
F ₆	Feeder 6	0.141	SCB 6	2.0	SCL 2 & SCB 3	6.0
F ₇	Load 7	0.135	SCB 7	2.0	SCL 2 & SCB 3	6.0

To achieve the goal, the current settings of SCL 1 are chosen to be 120 A (i.e. 2 pu) of the normal rms value of the current I_1 as primary protection. For the back up protection of down stream feeders 4 and 5, the current settings are taken as 144 A (i.e. 6 pu) of their normal rms values. The SCLs operate for 5 cycles of the supply. The current setting of SCB 3 are 30 A (2.5 pu) for primary protection and 6 pu of the normal rms current of the corresponding feeder and load for back up protection. The current setting of SCB 4, 5, 6 and 7 are fixed at 2 pu of the normal values of rms currents of the respective feeders and load. The detailed simulation results for the fault at feeder 4 are shown in Fig. 15. Similar results have also been obtained for faults at other locations given in Table I [4].

Fig 15 System response for fault at feeder 4.

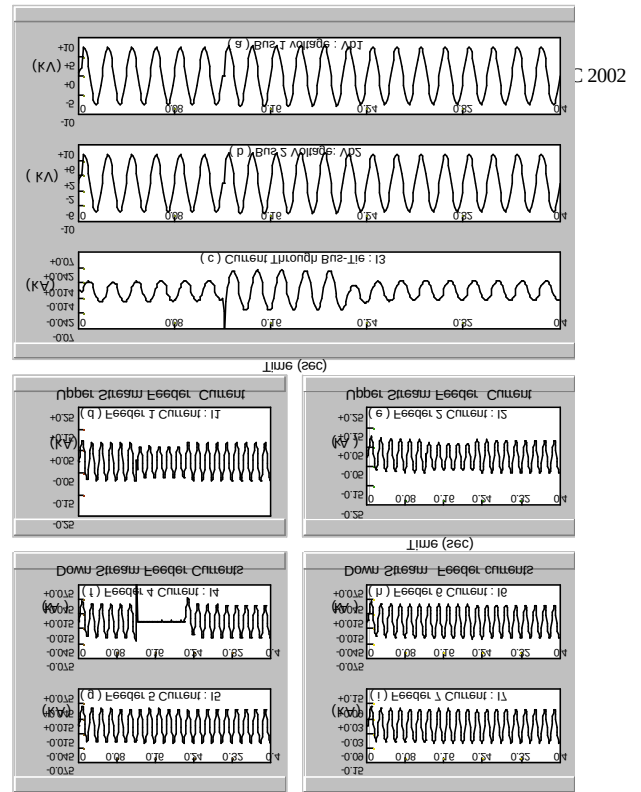
IX. CONCLUSION

The topologies of the various FRIENDS devices; SCL, SCB and STS have been described and their operation has been simulated. The clipping voltage of the ZnO arrester influences the current sharing between the ZnO arrester and the let-through inductor of the SCL. A higher clipping voltage increases the current through the let through inductor. In the SCB, the static switch is normally off, thus reducing the conduction losses. The current is shown to be interrupted within 4 ms which is much faster than the mechanical circuit breakers.

In the STS, the GTO based static switch is shown to be faster than the thyristor based switch. It further simplifies the control strategy. The simulation results demonstrate the coordination of test system for various faults.

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