REVIEW: SOLID STATE BREAKER (SSB) TECHNOLOGY

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ABSTRACT

Advanced current interruption technology, utilizing high power Solid-state Breakers (SSB), offers a viable solution to most of the distribution system problems that result in voltage sags, swells, and power outages. Solid-state, fast acting (sub-cycle) breakers can instantaneously transfer sensitive loads from a normal supply that experiences a disturbance to an alternate supply that is unaffected by the disturbance. The alternate supply may be another utility primary distribution feeder or a standby power supply operated from an integral energy storage system. In this application, the SSB acts as an extremely fast conventional transfer switch that allows the restoration of power of specified quality to the load within ¼ cycles.

Keyword: - *SSB, Power system protection.*

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1. INTRODUCTION

A survey of the requirements of potential applications of the SSB in distribution systems indicated that for the majority of cases the current interrupting device has to be able to conduct fault currents (full or limited) for a period of time (10 to 15 cycles), repeatedly (3 to 4 times, consistent with the fault clearing sequences of existing distribution recloses), in order to maintain coordination with conventional protection equipment in the system. Therefore, with the exception of specific applications, e.g. substation bus tie breaker, where protection coordination is not required, an SSB that must interrupt before its current interrupting rating is exceeded (at 2500A peak for commercially available devices) cannot be used alone as a general purpose distribution SSB. This situation will change once high-speed sectionalizes are developed for use with the SSB.

Figure 1 shows the potential SSB applications. Most of the applications require the SSB to conduct inrush and fault currents for several cycles and to disconnect faulty source-side feeders in less than half cycle. The capability of the SSB to provide this performance is dependent primarily on the rating and operating characteristics of the power semiconductor devices used for the AC switches making up the breaker. At the power levels associated with 15-kV and higher voltage class systems, commercially available Gate Turn-off (GTO) thyristors and conventional Thyristors (SCRs) can be used for the AC switch.

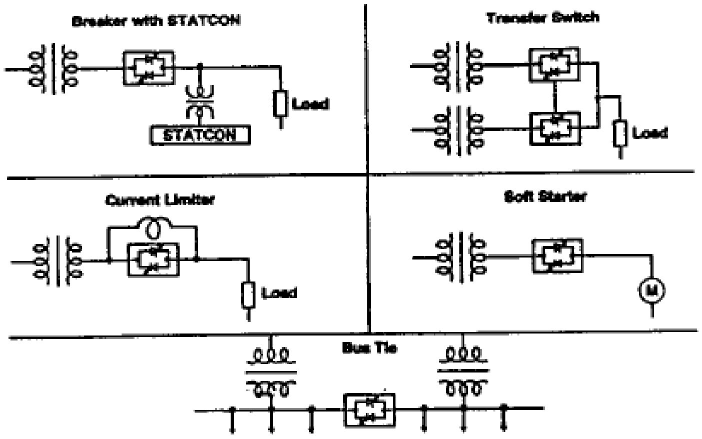

Fig.1:- SSB Applications.

2. DIFFERENT TECHNOLOGY FOR SOLID STATE BREAKER (SSB)

To prevent voltage decrease of distribution systems, the principle and fundamental characteristics of a solid-state current limiter using GTO thyristors [1] were investigated. Basic components of the apparatus were a fast solid-state switch and a current limiting impedance of low resistance in parallel with the switch. Experimental results of the test current limiter showed the fault current was limited successfully, regardless of Dc component size. The time from detection of fault occurrence to interruption of the fault current by the solid-state switch was 40 ps. This time was very short in comparison with that before the fault current reached a large value. Thermal rise of the solid-state switch for conduction was solved by a self-cooling apparatus using a non-combustible cooling liquid.

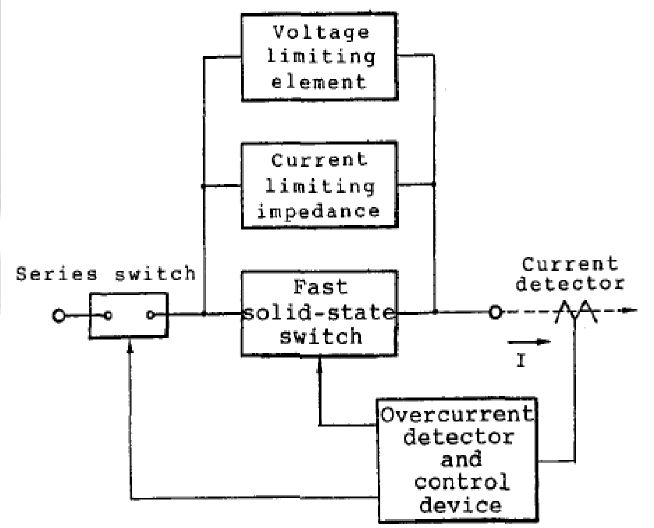

Fig.2:- Block diagram of the solid-state current limiter [1].

The major component of solid-state current limiters and circuit breakers is the high voltage solid-state switch consisting of power semiconductor devices with fast current turn-off capability. Gate turn-off thyristors are available commercially in sufficiently high power ratings for distribution system applications. MOS-controlled thyristors are in development for future high power switch applications.

Under normal load conditions. the GTO’s [2] are gated continuously and maintained in full conduction. When a fault occurs on the load side of the CLD. a control circuit activated by the instantaneous magnitude and/or rate-of-rise of current initiates a turn-off for the GTO’s. Because GTO’s respond within a few microseconds of the control signal and are capable of turning off current considerably higher in magnitude than the maximum continuous current. fault current is quickly limited before it reaches a destructive level. Immediately after the GTO's turn off, the current will be diverted into the snubber capacitor. Which limits the rate of rise of voltage across the valve until it reaches the clamping level established by the,, zinc oxide arrester. This voltage also appears across the let-through reactor." and once the clamping voltage level is reached. The reactor current rises linearly until it reaches the instantaneous level of the current flowing in the line. While the current is building up in the reactor, it is decreasing in the zinc oxide arrester. During this time the arrester absorbs energy corresponding to the energy which is eventually stored in the let-through reactor at the end of the period when the arrester ceases to conduct. After this time the line current is limited by total effective series impedance, which includes the source impedance. The impedance of the let-through reactor and the line impedance of the fault. When the fault is cleared and the line current drops back to normal, the GTO's will be turned back on at an instant when the voltage across them is a t or close to zero. avoiding high-magnitude discharge (dump) currents from the snubber capacitor. When the GTO valve turns back on, the current in the let-through reactor will be briefly trapped, but will decay in a fraction of a second.

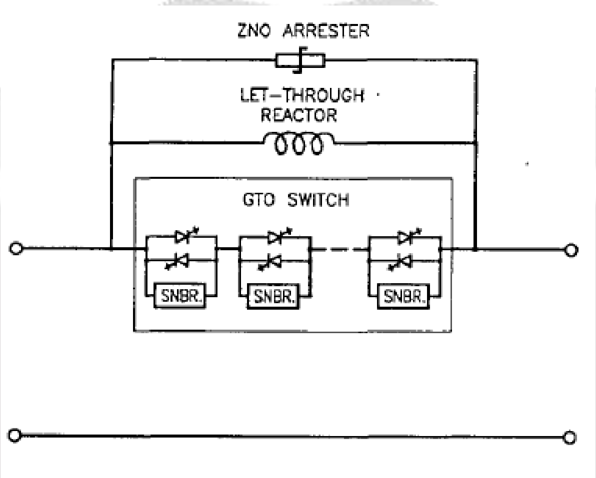

Fig.3:- GTO-based CLD for a 15 kV Circuit [2].

Author demonstrates, through the use of electromagnetic transient simulations [3], the key issues in the application of solid state devices for fault control and protection in the distribution systems. Three types of topologies have been considered viz. a Bus Tie Breaker, a transfer Switch, a Fault Current Limiter, but only two have been discussed in detail; the Bus Tie Breaker is taken to be a special case of the Fault Current Limiter. The control scheme for each topology has been designed and studied, with emphasis on the detection schemes and the responses to various system and load parameters. All simulations have been carried out using the PSCAD/ EMTDC program.

Utility distribution networks, sensitive industrial loads, and critical commercial operations all suffer from various types of outages and service interruptions which can cost significant financial loss per incident based on process down-time, lost production, idle work forces, and other factors. The types of interruptions which are experienced can generally be classified as power quality related problems caused by voltage sags and swells, lightning strikes, and other distribution system related disturbances. In many instances,[4] the use of a Solid- State Transfer Switch (SSTS) and/or a Distribution Level Static Compensator (D-STATCOM) can be some of the most cost-effective solutions for these types of power quality problems.

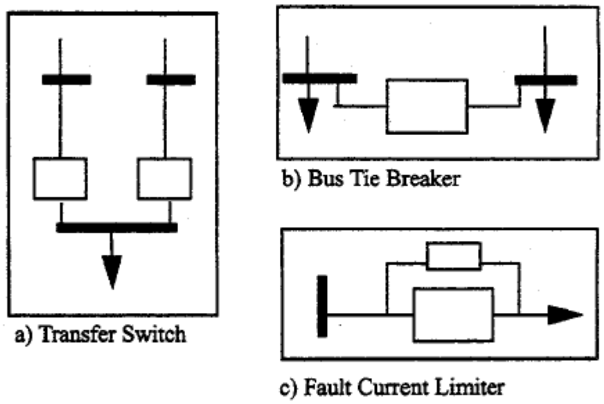

Fig.4:- Various applications of the Solid State Breaker [3].

The SSTS, which essentially consists of a pair of thyristor switch devices, enables seamless transfer of energy from a primary source to an alternate source in order to avoid service interruption upon a deficiency in power quality. The D-STATCOM, which consists of a thyristor-based voltage source inverter, uses advanced power electronics to provide voltage stabilization, flicker suppression, power factor correction, harmonic control, and a host of other power quality solutions for both utility and industrial applications.

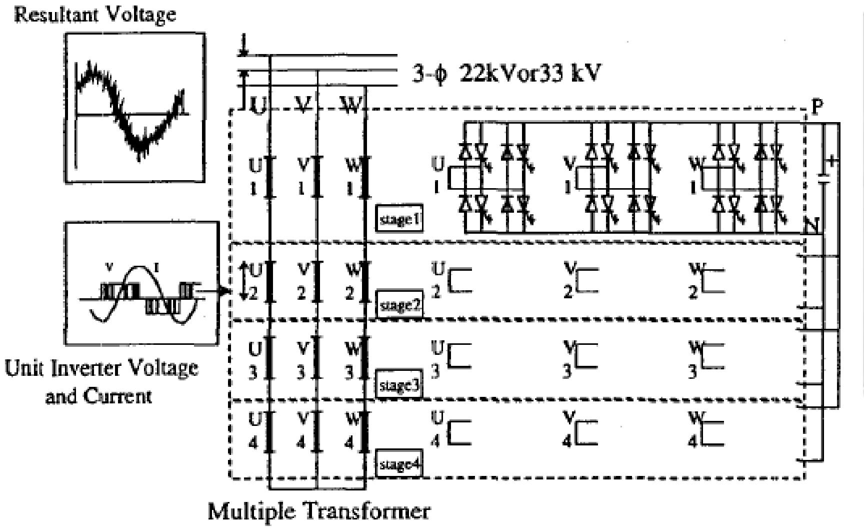

Fig.5:- Main circuit configuration for 20 MVAr compact D –STATCOM.

A fully integrated, solid state, energy transfer switch [5] assembly is presented. The assembly has a peak forward and reverse voltage rating of 30kV and a peak current rating of 20kV - other possible ratings using the same approach. The switch is constructed using series connected gate turn off (GTO) thyristors, which are optimized for pulse power applications. The design philosophy is discussed along with details of the device ratings and testing carried out.

Author presents a harmonic study on a newly developed solid-state fault current limiter [6]. Using this device, the supply voltage sag is reduced when a short-circuit fault occurs on a cable feeder in the downstream network, hence improving the power quality. The device will eventually isolate the faulted part from the healthy network. Harmonics caused by the fault current limiter are analyzed and a method is proposed to prevent undesirable harmonic interactions. Analytical and experimental results are compared with existing regulations. It is verified that, with precautions, the operation of the solid-state fault current limiter will not cause problems to either the supply network or the loads.

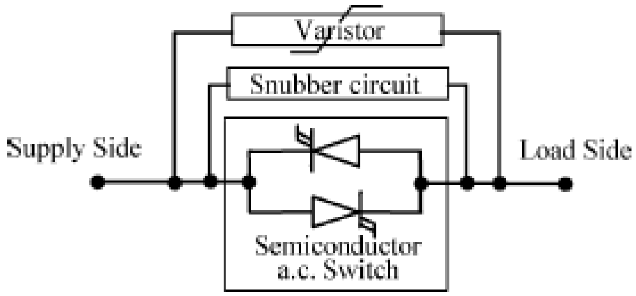

Fig.6:- Construction of FCLID [6].

State-of-the-art mechanical circuit breakers in medium-voltage systems allow a safe handling of short-circuits if the short circuit power of the grid is limited. Using delayed turn-off times, the circuit breakers can be coordinated with lower level protection gear. Hence, a high availability of the grid can be guaranteed. However, during a short-circuit a significant voltage sag can be noticed locally in the medium-voltage grid. Sensitive loads such as computers will fail even if the voltage returns within a few seconds. A semiconductor circuit breaker, however, is able to switch fast enough to keep voltage disturbance within acceptable limits. The optimization and selection of power electronic switch topologies is critical. Different semiconductors are briefly compared considering the requirements of a solid-state switch integrated into a 20-kV medium-voltage grid [7]. Based on these semiconductor characteristics, various switch topologies are developed, which are compared under technical and economic aspects. It is shown that solid-state circuit breakers offer significant advantages when compared to present solutions and can be used in today's medium-voltage power systems.

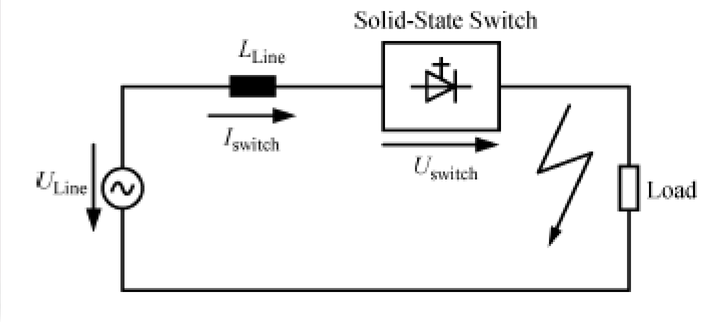

Fig.7:- Basic single-phase equivalent circuit [7].

Author describes the development of a solid-state fault current limiting and interrupting device (FCLID) suitable for low-voltage distribution networks [8]. The main components of the FCLID are a bidirectional semiconductor switch that can disrupt the short-circuit current, and a voltage clamping element that helps to control the current and absorb the inductive energy stored in the network during current interruption. Using a hysteresis-type control algorithm, the short-circuit current can be constrained according to a predefined profile. Insulated-gate bipolar transistors and diodes are used to construct the semiconductor switch. Varistors are used as the voltage clamping element. An effective method is adopted to improve the current sharing between parallel varistors in order to provide the required capability of energy absorption. An overall protection scheme for the FCLID is described. A prototype FCLID for 230-V single-phase, or 400-V three-phase, applications is developed and tested. Analyses and experiments are carried out to define the stresses that the main components in the FCLID are subject to. The results show that the developed prototype is capable of limiting a 3-kA prospective short-circuit current to 120 A for a period of 0.8 s, without exceeding the thermal limits of the chosen switches and varistors.

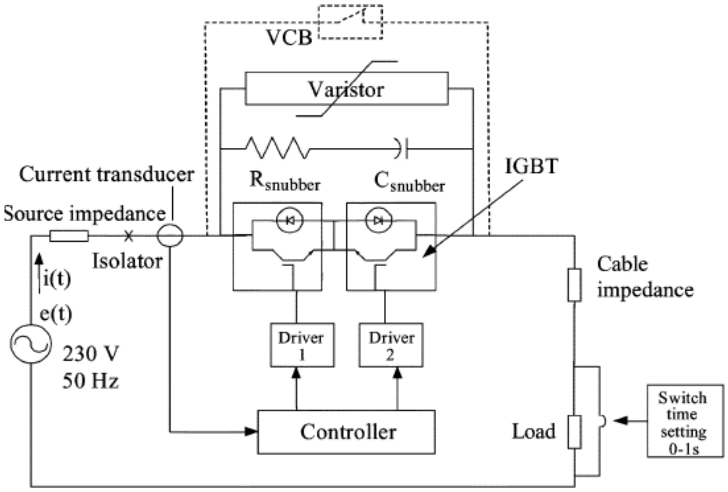

Fig.8:- Schematic diagram of the FCLID [8].

Author formulating solid-state breakers (SSB) [9] in electric power distribution systems by using GUI-based environment of MATLAB/SIMULINK. Utilization of MATLAB software simplifies problem solving complexity and also reduces working time. In this paper, a 22-kV power distribution feeder with a load having the SSB for protection is situated. A thyristor-based circuit breaker is modeled. Detail of the power circuit and its firing control part is demonstrated in graphical diagrams using elements of the MATLAB’s Power System Blockset (PSB). Test against a fault condition to verify its use is carried out. The results show that, with a moderate sensing technique to monitor voltage and current of the protected feeder, the SSB can interrupt fault instantaneously.

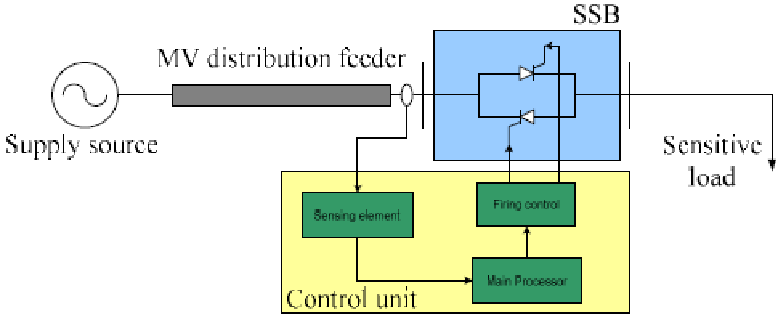

Fig.9:- Control structure of the SSB [9].

3. CONCLUSION

The outcome of the paper is expected to advance the development of SSB technology, focusing strictly on utility distribution applications that improve customer power quality. It is expected that this prototype demonstration test will provide operating data for the SSB in a real distribution system operating environment. Additionally, it will be possible to predict feeder power quality improvement that will be possible with additional custom power controllers and downstream intelligent protective devices.

4. REFRENCES

[1] Ueda, T., Morita, M., Arita, H., Kida, Y., Kurosawa, Y., & Yamagiwa, T. (1993). Solid-state current limiter for power distribution system. IEEE Transactions on Power Delivery, 8(4), 1796-1801.

[2] Smith, R. K., Slade, P. G., Sarkozi, M., Stacey, E. J., Bonk, J. J., & Mehta, H. (1993). Solid-state distribution current limiter and circuit breaker: application requirements and control strategies. IEEE Transactions on Power Delivery, 8(3), 1155-1164.

[3] Woodley, N., Sarkozi, M., Lopez, F., Tahiliani, V., & Malkin, P. (1994). Solid-state 13-kV distribution class circuit breaker: planning, development and demonstration.

[4] Reed, G. F., Takeda, M., & Iyoda, I. (1999, January). Improved power quality solutions using advanced solid-state switching and static compensation technologies. In Power Engineering Society 1999 Winter Meeting, IEEE (Vol. 2, pp. 1132-1137). IEEE.

[5] Golland, A., Wakeman, F., McDonald, I., & Lakin, T. (2001, June). Integrated 30 kV solid-state switch for pulse power applications. In Pulsed Power Plasma Science, 2001. PPPS-2001. Digest of Technical Papers (Vol. 2, pp. 1055-1058). IEEE.

[6] Ahmed, M. M. R., Putrus, G. A., Ran, L., & Xiao, L. (2004). Harmonic analysis and improvement of a new solid-state fault current limiter. IEEE Transactions on Industry Applications, 40(4), 1012-1019.

[7] Meyer, C., Schroder, S., & De Doncker, R. W. (2004). Solid-state circuit breakers and current limiters for medium-voltage systems having distributed power systems. IEEE transactions on power electronics, 19(5), 1333-1340.

[8] Ahmed, M. M. R., Putrus, G., Ran, L., & Penlington, R. (2006). Development of a prototype solid-state fault-current limiting and interrupting device for low-voltage distribution networks. IEEE Transactions on Power Delivery, 21(4), 1997-2005.

[9] Kulworawanichpong, T. (2003). Modeling and Simulation of a Solidstate Breaker for Medium-voltage Feeder Protection using MATLAB’s Power System Blockset. In *Proc. 2003 IEEE Bologna PowerTech Conference* (pp. 30-35).