Fault Analysis of Multi Bus System with Three Phase Solid State Circuit Breaker

A.Kalai Murugan, *Research Scholar, Sathyabama University, Chennai*,India,
Ph:+919789978397, Mail: murugaakalai@gmail.com

Dr.R.Raja Prabu, *Professor, B.S.Abdur Rahman University, Chennai. India*

***Abstract* — Mechanical Circuit Breakers are being used to protect the power system from abnormal conditions. Due to increased distributed energy generation in medium voltage systems, handling of short circuits becomes problematic as the short circuit power is increased. Hence in future classical mechanical circuit breakers will not be able to handle these current. It has already proven that the usage of power semiconductor devices could lead to reduced current values and voltage distortion during a short circuit failure. These solutions use modern high power semiconductors to replace mechanical circuit breakers. Solid state circuit breakers, based on modern high power semiconductors, offer enormous advantages when compared to mechanical circuit breaker with respect to speed and life. This increases the voltage quality and also improves the transient stability during short circuit as the solid state circuit breakers works faster than the present mechanical circuit breaker. A new topology developed for SSCB can be used to protect the power system to enhance reliability. This paper presents different three phase fault analysis of a power system with solid state circuit breaker to estimate the performance of the SSCB during abnormal conditions. The simulations on the model two bus system have been performed to access the effectiveness of SSCB during faults. It is shown that SSCB is an effective choice which can replace the existing mechanical circuit breaker. The results of Double line and LLG faults are presented.**

***Index Terms*— Solid State Circuit Breakers (SSCBs), Simulation, Power Semiconductors**

I. INTRODUCTION

There is a rapid development in the field of electrical power systems, in which large amount of interconnection involved for consuming continuity of supply good voltage regulation. The capital investment involved in the power system for the generation , transmission and distribution of electrical power is so great that proper precautions must be taken to ensure that the equipment not only operates as nearly as possible to peak efficiencies, but also that it is protected from accidents. The modern power system is very complex and even though protective equipments form 4 to5% of the total cost involved in the power system, they play a very important role in the system design for good quality of reliable supply.

The integration of sensible loads, e.g., computers, embedded controllers in desktop as well as in industrial applications results in an increased importance of power quality in electrical grids. Short time interruptions, e.g., due to lightning or short circuit in neighboring circuits, have little influence on the statistic and are simply not taken into account. The handling of short circuits is an important issue to increase the power quality. Power quality is concerned with such effects as availability, voltage distortion, and deviations from normal values (voltage, frequency) over short period of time. The handling of short circuits in the grid is of great importance in order to provide safety and to achieve high availability on the one hand and high power – quality on the other [1].

With the advancement of power system, lines and other equipment operate at high voltages and carry large currents. When a short circuit occurs on the system, heavy current flowing through the equipment may cause considerable damage. The present solutions dealing with short circuit protection are mechanical circuit breakers. After having detected a short circuit or overload situation, some time elapses prior to open the switches mechanically. Subsequently, an arc occurs, which initially has little impact on the current. The current can only quenched at its natural zero crossing that the plasma is significantly cooled down to avoid resignation. As a result, turning off a short circuit will take at least 100 ms (without detection time). Handling short circuits becomes problematic when considering the increased short circuit power resulting from distributed energy generation in medium voltage systems. As a consequence, it is likely that in the near future classical mechanical circuit breakers will not be able to handle to these currents.

In the mechanical circuit breaker, peak current cannot be influenced. Therefore, all network components have to withstand the peak current during the switching period. This current reaches peak values, which are typically 20 times higher than the maximum operating current. This current is below the transient peak current value but can still reach values up to ten times the nominal value. It is also noted that mechanical circuit breakers have a maximum short-circuit current rating. This current limit forces the grid designers to limit the short-circuit power of the grid, e.g., by using additional line inductances. However, these measures also reduce the maximum transferable power and the stiffness of the grid, leading to an increase in voltage distortions. The number of high-current short-circuit clearances is limited to about 10 to 15 times for mechanical devices. During the short-circuit time, the voltage on the complete medium-voltage grid is significantly reduced. Due to the long turn-off delay of the breaker, sensible loads require UPS support to survive this sag, which is costly and might not be feasible for a complete factory plant. Power electronic converters and systems can be regarded as one solution to increase power quality in the grid and to integrate distributed renewable energy sources in to today’s power systems [1]-[6]. It has already proven that the usage of power semiconductor devices could lead to reduced current values and voltage distortions during short circuit failure. In addition to limiting the fault current, the SSCB can also limit the inrush current (soft start capability), even for capacitive loads ,by gradually phasing in the switching device rather than making an abrupt transition from an open to closed position. A SSCB can offer the following advantages: limited fault current, limited inrush current (soft start), even for capacitive loads, repeated operations with high reliability and without wear- out, reduced switching surges, improved power quality for un faulted lines. So, solid state circuit breakers based on the power semi conductors potentially offer enormous advantages when compared to conventional solutions, since a solid state circuit breaker is able to switch in a few microseconds [2]. Analysis of fault is very pivotal for the stable operation power system. The three phase fault analysis is carried out in a multi bus system with the solid state circuit breaker to evaluate the performance of the solid state circuit breaker during abnormal conditions.

II. BASIC CIRCUIT OF SSCB AND ITS BEHAVIOR

To analyze the fundamental behavior of the proposed solid state circuit breaker, a single phase equivalent circuit is shown in fig.2a, is used. The grid is represented by voltage source and line impedance. In this example, a pure resistive load is shorted by an ideal short circuit with zero resistance to represent a fault. The typical wave form of the current in and voltage across the SSCB are shown in Fig.2b. At approximately 2 ms, a short circuit occurs and the current rises fast. After a small delay time, SSCB opens. The energy stored in the line inductance is dissipated in high energy varistors, which are connected in parallel with the semiconductors. Consequently, the current decreases. When the current reaches zero, the switch has to block the line to neutral voltage of the grid.

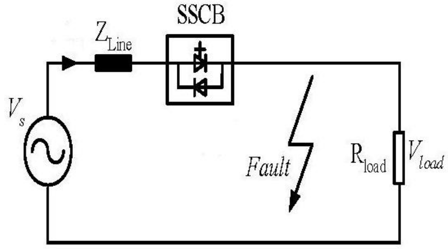

Fig.2a Single phase equivalent circuit of SSCB

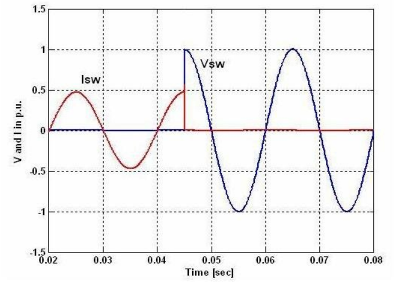

Fig.2b Voltage across and Current in Ideal Circuit Breaker

The fault current is

$$i_f = \frac{V_m X}{Z^2} e^{t/\tau} + \frac{V_m}{Z} Sin(\varpi t - \phi)$$

III. THE POWER ELECTRONIC DEVICES

A power electronic device enables the production of power management modules that can handle all of the electronic power control and conversion functions required to move power from the generating and storage sources to the ultimate loads. Some ideal requirements of power devices for use in the converters are

- Adequate blocking voltage
- High turn off current and surge current capabilities
- Adequate isolation voltages withstand
- Reverse conducting and active switch in one module

- Low conduction and switching losses
- Suitable for parallel and series operation
- Fast switching; tolerance to dV/dt and dI/dt
- Good thermal performance
- Ease of production and control

These requirements differ in some points to those for power devices for use as circuit breakers. Low conduction losses are far more important than switching losses, because the ability for fast repetitive switching is not necessary in the circuit breaker. In contrast to the points above, a reverse blocking feature meets the requirements of devices for circuit breakers in AC systems.

The ease of protection and control is especially important for a fast acting circuit breaker. The grid voltage is typically much higher than the maximum blocking voltage of present semiconductors although the ratings have increased significantly. Consequently, the several semiconductors have to be connected in series. Since a high reliability is of utmost importance, redundant devices will be integrated [7]. Only devices in press-pack housing are useful because they assure that the switch is still operational after a single semiconductor has failed. Today different semiconductors IGBT, GCT, GTO, and IGCT can fulfill the requirements.

In contrast to inverter applications, the switching behavior is a minor issue in this application. The conducting behavior and conduction losses are essential. As a result, the IGBT has a disadvantage in circuit breaker application. Especially, the on state losses of IGBTs are significantly higher than the losses of a thyristor based semiconductor (up to 3 times higher per device). However, the IGBT has the advantage that it limits the current internally. Hence the current cannot exceed a certain value. In contrast to this, the current is not limited in a thyristor based semiconductor and the turn off capability is limited. Thus, the deduction time has to be short to assure a safe turn-off. Considering the stray inductance of a medium voltage transformer and the speed of today's deduction technology this time delay can be minimized to not critical values. It becomes obvious that the thyristor based semiconductors, such as GCT and GTO, are a much better choice for a solid state switch because they have much lower on-state losses.

When just considering the losses, only the special GCT would be chosen for the circuit breaker. Although the losses of the GTO are higher, the investment costs are lower. So for the design of the solid state circuit breaker, the GTO still has to be considered. The SSCB must be actively turned off only when a short circuit occurs and the circuit breaker only needs to be ready for a second turn-off after several line periods. As a consequence, the disadvantages of forced commutation circuits become far less critical in SSCB applications. Hence, they can be an interesting solution for SSCBs. Presently; thyristors are available with blocking voltages up to 12kV. The GCT solution consists of four modules in series per phase, which are able to block each 9 kV. Furthermore, each module may consist of two 4.5-kV GCTs connected in series and a single phase diode rectifier to reduce the number of active switches.

It was already shown that the costs associated with losses have a major impact on the overall system and operation costs [8]. Hence, due to the reduced on-state losses, the overall lifecycle costs of the SSCB can be significantly reduced. In addition, a forced air-cooling can be used instead of water-cooling. Consequently from the economical point of view, a thyristor switch could be more competitive when compared with GCT switches. Considering the importance of cost in industrial applications, thyristor based systems have a higher chance of being integrated into existing power grids.

Although a complex auxiliary circuit is needed to enable an active turn-off process, thyristors also offer an economical advantage compared to a GCT solution considering the investment cost, since expensive gate drivers and isolation circuits can be avoided with light triggered SCRs. Of course, the turn-off interval of a thyristor switch is longer compared to a GCT circuit breaker, therefore leading to increased short circuit currents [9]-[11]. However, considering the rather large time constants in 50 or 60 Hz power systems it was found that, the lack of speed (1 ms compared to 400 µs) can be tolerated. Overall, these considerations lead to conclusion that forced commutation circuits still can offer an interesting alternative for circuit breaker applications in medium voltage systems.

Fast acting electronic fault limiter is presented by Kunde (2003). Integration of Solid State Switches into medium voltage grid is given by Meyer (2003). Custom power protection device controlled by neural network is given by Tosi (2000). Automated recent neural network design is given by Pilo (2000). The above literature does not deal with modeling and simulation of SSSCB using Simulink. An attempt is made in the present work to model of three phase SSCB using Simulink in multi bus system.

IV. SIMULATION RESULTS

The simulation model of two bus system under healthy conditions is shown in the Fig. 4a. The corresponding waveforms are shown in Fig.4b. The solid state circuit breaker is in closed condition since there is no fault.

The circuit diagram with line to line fault is shown in Fig.4c. The line to line fault is created between the lines a and b at t = 0 sec .The line voltage waveform are shown in Fig.4d.The voltage V_{ab} is zero since the lines a and b are connected. At t >0.5sec , the trip circuit opens the SSCB. When the breaker is opened, the voltages become zero. The current waveforms are shown in fig. 4e. The magnitudes of the currents I_q and I_b are equal since they are connected by a fault. The current in c phase is lesser since there is no fault on phase c. The current is reduced to zero at t=0.5sec since the breaker is opened.

The Simulink model with the LLG fault is shown in Fig.4f. The fault is connected between lines a,b and to the ground point. The line voltages are shown in Fig.4g. The line voltage V_{ab} is zero since the fault occurs on the line a and b. The sensing circuit senses the fault and trips the solid state circuit breaker at t=0.5sec. The current and voltages are reduced to zero since the supply to the load is disconnected.

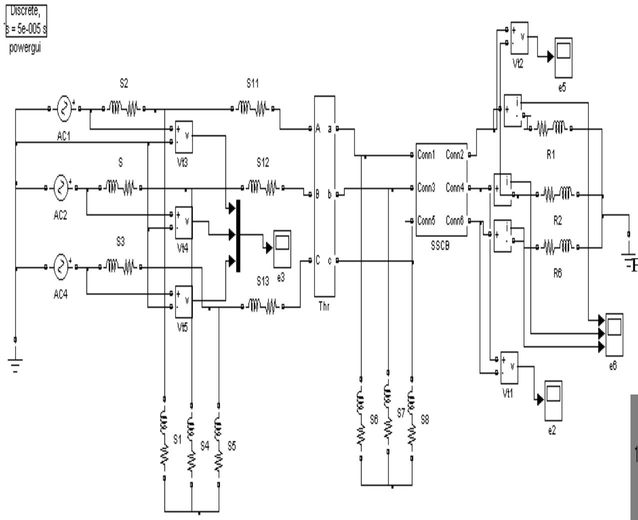

Fig. 4a Two bus system with SSCB – healthy condition

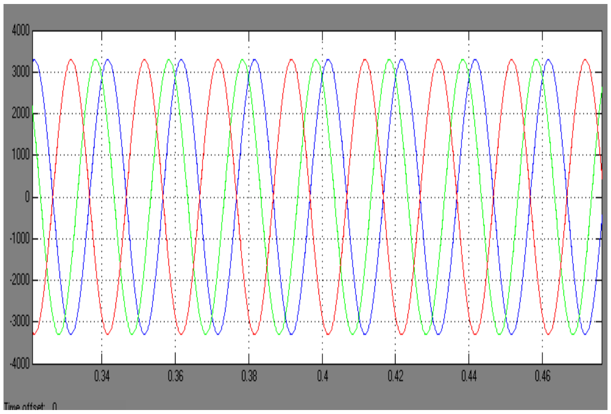

Fig. 4b Voltage waveforms – healthy condition

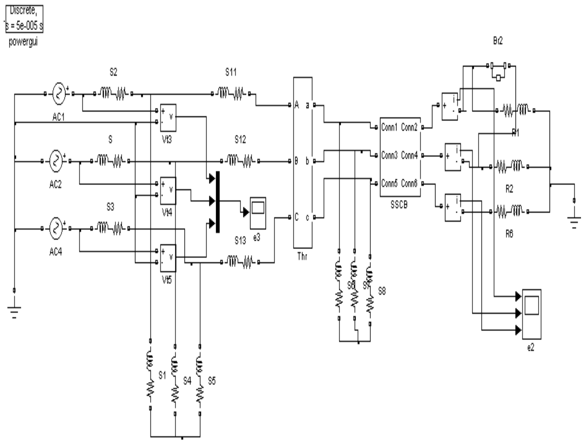

Fig. 4c Two bus system with SSCB – LL fault

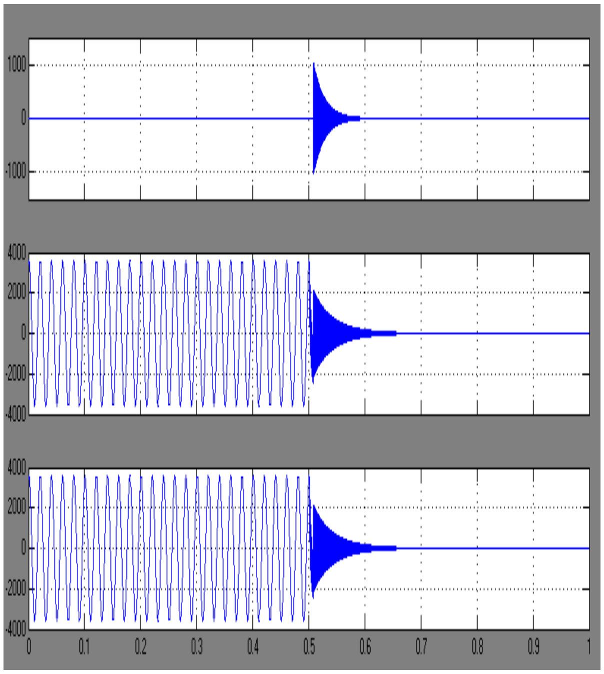

Fig. 4d Line voltage waveforms of ab, bc & ac – LL fault

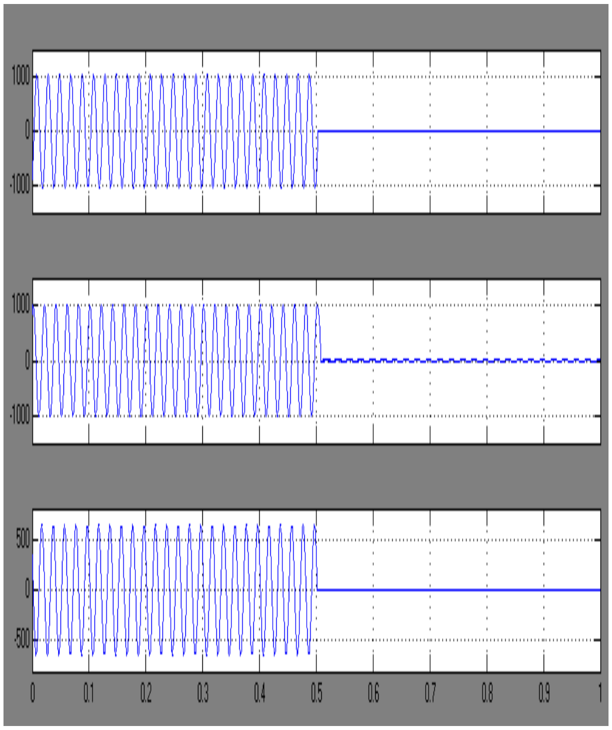

Fig. 4e Line Current waveforms of a, b, c – LL fault

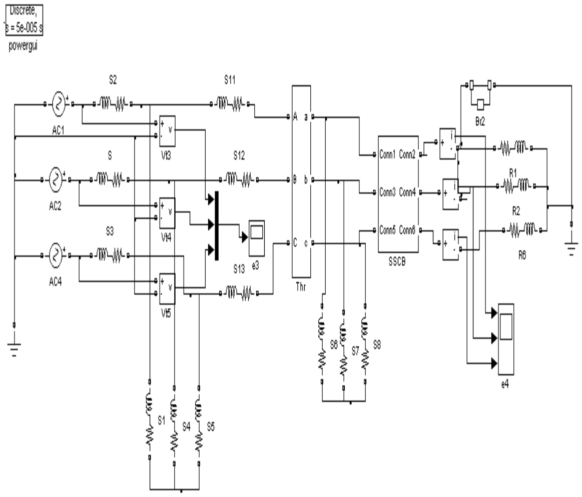

Fig.4f Two bus system with SSCB – LLG fault

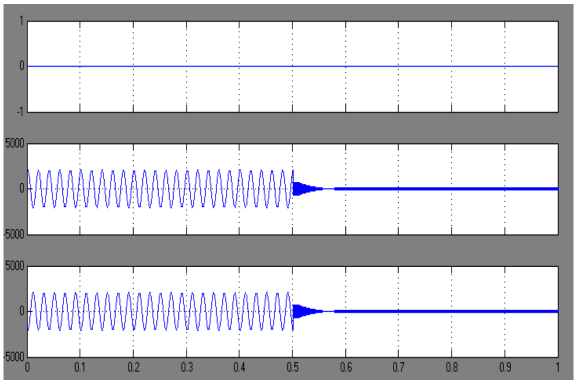

Fig. 4g Line voltage waveforms of ab, bc & ac - LLG fault

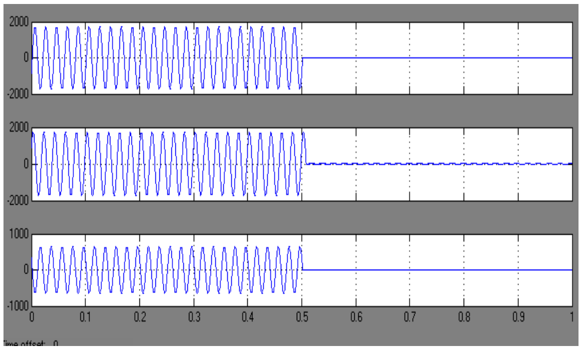

Fig. 4h Line Current waveforms of a, b, c – LLG fault

V. CONCLUSION

The fault analysis of the power system with three phase SSCB is done using Matlab Simulink. The circuit models are developed successfully using the blocks of Simulink. The simulation results for healthy condition, LL fault and LGG fault are presented. The results indicate that SSCB is capable of isolating the faulty section. The simulation results are in line with the predictions.

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A.Kalai Murugan was born in 1977. He received B.E. in electrical and electronics engineering from Madras University, Chennai, India in 1999 and M.E. degree in power systems from Annamalai University, Chidambaram, India in 2004. Now he is doing Ph.D. at Sathyabama University, Chennai, India. He is a member of IEEE and ISTE. His area of interests are power system protection, power electronics, control systems.

Dr.R.Raja Prabu was born in 1967. He received B.E. and M.E. in degrees in electrical engineering and power system engineering in 1988 and 1990 respectively from Annamalai University, Chidambaram, India. He received Ph.D. degree in high voltage engineering from College of Engineering, Guindy, Anna University, Chennai, India. Currently he is working as professor and head in the department of electrical and electronics engineering , B.S.Abdur Rahman University, Chennai, India. He is a Member of IEEE , CIGRE and I.S.T.E. His research area includes outdoor insulation, digital protection, and high voltage application in life science, power quality and Nano-dielectrics. He is a Chartered Engineer. He has been awarded various fellowships by AICTE, DST, CSIR and TNSCST. He has got more than 25 Research Publication to his credit. He has visited USA, UAE, Japan, China, Thailand, Singapore, Malaysia and Srilanka for Research and Official purposes.