Design and Analysis of Z-Source Inductor Based Circuit Breaker for DC Applications

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***Abstract* — In this paper we are implementing a z-source inductor based circuit breaker for DC application. Therefore, in order to overcome the power conversion steps and the micro grid with the renewable energy sources which is utilized for the dc power systems. According to the system components there are various source load with the power conversion which is readily available. therefore, the main limitation will be interrupting a current which does not have a zero crossing will sustain an arc. According to the paper we are implementing a new type of dc circuit breaker. Z-source networks provide an efficient means of power conversion between source and load in a wide range of electric power conversion application. It Works as a buck-boost inverter. And it is also utilized for a short conduction path which lies between the breakers and loads along with the mutual coupling to automatically and rapidly switch OFF in response to a fault. According to the proposed breaker we also utilized the crowbar type switch at the output so that it can be used as a dc switch. By using simulation result we can analysis the proposed topology by using a new dc switch which has been included.**

***Keywords*— circuit breaker, z-source, mutually coupled inductor, power transmission, thyristor, fault location and protection.**

I. INTRODUCTION

In coming days DC power generation has a great scope for utilization of electrical power to DC applications such as medium voltage DC power generation, home appliances, electric ships and etc., this DC circuit breaker is for protection purpose during fault condition. A circuit breaker is switch which automatically operates at fault condition to protect the electrical circuit hence it is also known as a protective device. When a fault is detected it interrupt the current which is its main function. Unlike fuse a circuit breaker can be reset manually or automatically and it can be replaceable. Hence these circuit breakers as used for different ranges like small appliances to large appliances. As we know that we are having only ac circuit breakers because in ac we are facing so many faults, but in dc we cannot face such faults we may face only short circuit are open circuit faults but both the faults cause damage to either source or load. So to overcome this problem we are introducing a new type circuit breaker with Z-Source.

By using Z-Source we can reduce the fault during time and as here this Z-Source acts as buck-boost converter which increase or decrease the magnitude of the power. During fault condition like short circuit voltage becomes zero and the output current increases this excess increase of current may damage either load or source. As in other DC circuit breakers like mechanical and solid breakers the excess amount of output current will be wasted. So by using Z-Source this current will be stored in inductor during fault condition and after clearing the fault the stored current will be added to the source current and goes to the load hence the Z-Source function is similar to that of Buck-Boost Converter.

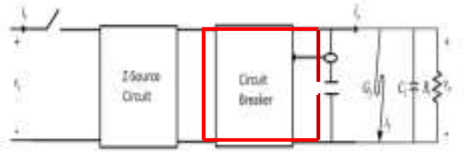

Fig (1) Circuit Breaker with Z-Source creating a short through path

As shown in the fig (1) which shows a Z-Source dc circuit breaker connected between load and a source. Hence the source current can be observed for fault detection. We are connecting a Capacitor in series with a sensor and it is parallel to the Circuit breaker which is helpful to detect the transient currents and sensor senses the fault, gives signals to the sensor. Hence here creates a short through path for faults and In capacitor an impulse current is created and this fault detects immediately and switch OFF the signal. This short through path is very helpful to sense the fault early and Z-source response during fault time is faster.

II. IDEAL DC CIRCUIT BREAKER

In this paper we are discussing about a dc circuit breaker which is for protection purpose for this the block diagram of dc circuit breaker is shown in the Fig (2)

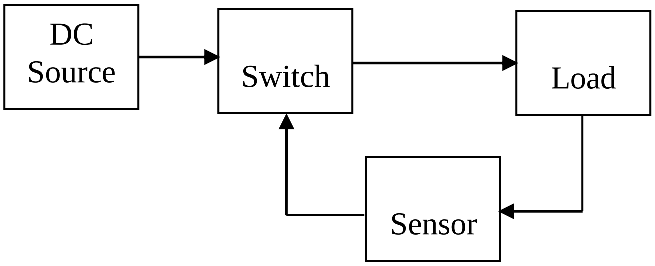

Fig (2) Block Diagram for DC Circuit Breaker

As we all know that whenever there will be change in load there will be variation in current so during this change in load the circuit breaker should not operate for this the Simulink block diagram and results are shown below.

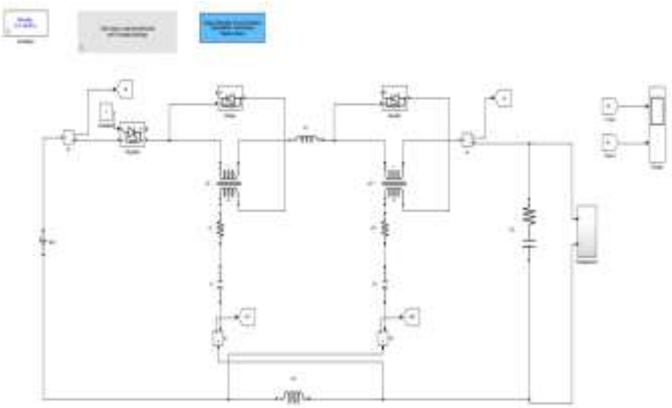

Fig (3) Simulink Circuit for Step Change in Load

The above Fig (3) shows the Simulink circuit for step change in load. In normal condition the current from source flows to the load. In this Simulink circuit consists of a Thyristor which acts as a Circuit Breaker and a mutually coupled inductor is works as a transformer the main function of this coupled inductor is the current flows through the primary side will be same on secondary side similarly whenever there will be change in current in one coil and there will be a change in other coil because they are magnetically coupled. Here the leg after source is nothing but Z-Source and an inductor is placed after this Z-Source for transmission purpose. The turn's ratio of the mutually coupled inductor is N_1/N_2. This turn's ratio can also be set as a step change in load is not a fault.

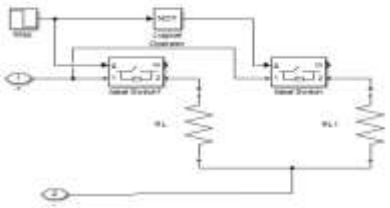

Fig (4) Sub-Circuit for Load Variation

The above Fig (4) shows the sub-circuit of load variation.

TABLE 1

PARAMETERS FOR THE TEST

V_{dc} = 100V	R = 0.2Ω	C = 100μF	N_1 = 70	N_2 = 24
L_1 = 10mH	L_2 = 10mH	R_{L1} = 50Ω	R_{L2} = 16.7Ω	C_L = 1μf

III. ANALYSIS

During step change in load the circuit breaker should not operate for this we are analysing as the ratio of turns for the transformer component should be as designed below and to know which type of change in load may cause to switch off the breaker. From the Fig (3) neglecting the transformer magnetizing current we get,

$$i_s = i_o - (N_2/N_1)i_c \qquad \text{equ (1)}$$

At normal Steady- State Condition the capacitor current will be zero at that time the source current will be equal to load current. Now consider there will be change in load this cause a sudden change in load current which is represented by capacitor current will be change, that is

$$\Delta i_c \approx \Delta i_o \qquad \text{equ (2)}$$

From transformer action,

$$\Delta i_s \approx -(N_2/N_1)\Delta i_c \approx -(N_2/N_1)\Delta i_o \qquad \text{equ (3)}$$

Initially the output current is,

$$i_s = I_o \qquad \text{equ (4)}$$

The output current is changed then the source current will be

$$i_s = I_o - (N_2/N_1)\Delta i_o \qquad \text{equ (5)}$$

If the change in current meets the above condition, then the source current and SCR current will goes to zero.

$$\Delta i_o > (N_2/N_1)I_o \qquad \text{equ (6)}$$

From equation (6), it is clear that the amount of change in output current that will result to switch OFF the breaker. This can also be used for selection of turn's ratio for the breaker to not switch OFF during load transients.

From Fig (4) initially the load will be 50ohms for 0.5msec as a step signal is given to the both the loads and a not gate is connected to the 2nd load. For 0.5msec the step signal 1 will activate the 50ohms load to be considered and after 0.5msec the step signal goes to zero by using not gate at the 2nd load the step signal goes to 1 and the 16.7ohms (2nd load) will activate and 50ohms will disconnect as the step signal given is 0.

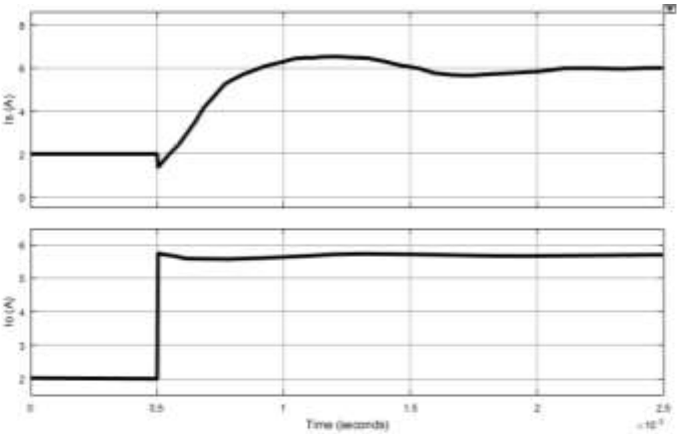

Fig (5) Source Current & Load Current Response During Change in Load

Detailed Simulation for Change in Load:

From Table 1 the source voltage given is 100V, and consider the load is purely resistive. The Fig (5) shows the Source and Output current when there is a change in load from 50 Ω to 16.7 Ω. Initially for 50 Ω the output current will be 2A after 0.5msec the load is changed to 16.7 Ω for this there will be a change in current then circuit breaker should not open in this condition which refers to the equation (6). After this change in load the output current changes from 2A to 6A. So a step in capacitor current which flows back to the source current causing it to dip, but not equals to zero. As I_o = 2A and from Table 1 the turns ratio gives the change in output current is $\Delta i_o > 5.83$A would cause the breaker to switch OFF. From this the output current step from 2 to 5.9A without switch OFF the breaker. Therefore, the SCR is in close position and the source current reaches to 6.2 A and settle down at 6A.

IV. FAULT CONDITION FOR IDEAL DC CIRCUIT BREAKER

Here we are creating a fault as short circuit by connection a switch parallel to the load

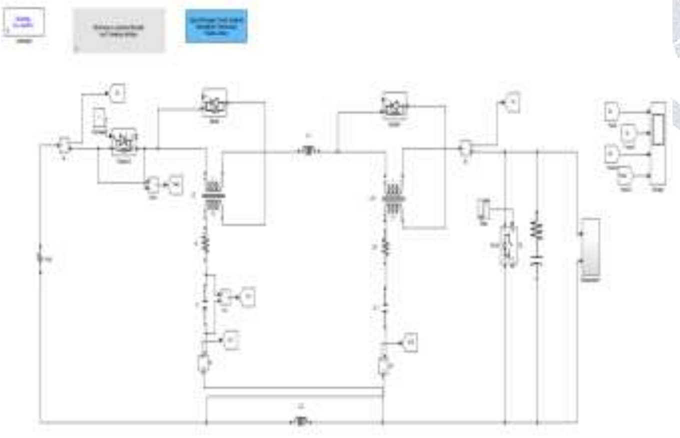

Fig (6) Simulink Circuit for Fault condition

The above Fig (6) shows the fault condition Simulink Circuit, for this the source voltage is 100V and the load resistance is 16.7 Ω. At this load we are creating a short circuit. The characteristics of Source current, Load current, Capacitor voltage and SCR across voltage are shown below.

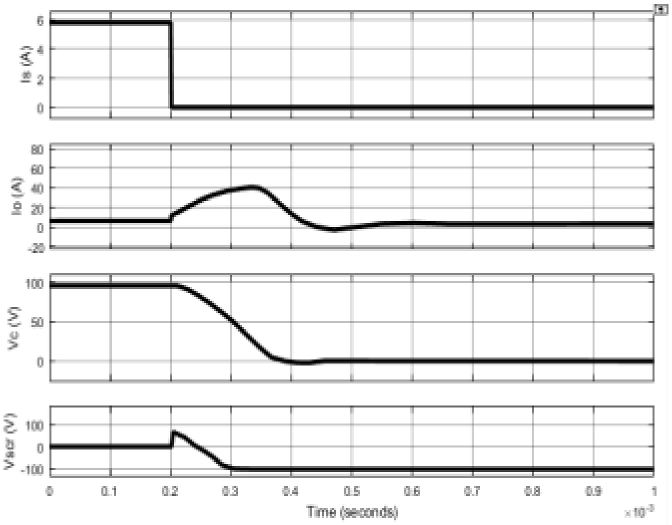

Fig (7) Simulink Response During Fault Condition

The above Fig (7) shows the response of fault condition initially the circuit breaker is in close position up to 0.2msec. After 0.2msec the switch across the load closes and creates a short circuit fault then the output current starts rising the current reflected in transformer causes the source current to directly go to zero in microseconds. When the SCR opens then the output current does not goes to zero as the capacitor starts discharging during this fault condition. After SCR switch opens initially SCR across voltage will be positive and after some time it goes to negative and its magnitude is equal to the source voltage, then the diode switches ON for stopping the response.

Hence after 0.2ms when the short circuit occurs the source voltage goes to zero since the SCR opens, and there will be a output voltage of 40A since capacitor starts discharging and the SCR across voltage starts increasing and goes to negative value.

V. PRACTICAL CONSIDERATION

In this case we are checking that how our dc circuit breaker may operate practically for power system, and a medium voltage design will be carried out for this type of breakers. Topology modifications, effect of transformer leakage inductance, effect of source impedance, and rate of fault inception will be considered.

Topology modifications

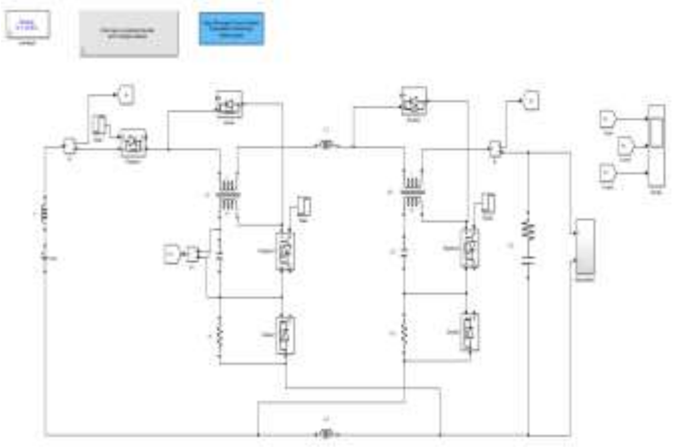

Fig (8) Modified DC switch for Power System

The above Fig (8) shows the practical consideration DC Circuit Breaker for a medium-voltage dc (MVDC) system. Two modifications have been done for the ideal dc breaker. First, the RC impedance in the previous topic has been replaced with a pure capacitor. For this in addition a charging resistance R_c with a diode had been placed in series. The placing of charging resistance at that point is to charge the capacitor. Initially the Source side SCR switch S_1 is closed. This causes the capacitor to charge through transformer and the charging resistor. We can set the charging time by using time constant formed by C and R_c. Initial surge current of capacitor is limited by charging resistor. A diode in parallel to the charging resistor is bypassed during the fault condition and the breakers respond as previously discussed.

The second modification a SCR switch S_2 is connected to this breaker. By adding this external switch gives an important feature to the breaker and it is used as a dc switch. When S_1 is in close position capacitor will be in charging condition and after 60msec S_2 will be triggered and discharges the capacitor through the secondary winding causing the Circuit breaker to switch OFF. Therefore, the breaker can be switch OFF by triggering switch S_2. We have to observe that this added switch has the same effect as crow baring the output as suggested. By connecting this S_2 switch a short through path is created between S_2 and capacitor hence either load or source do not get damaged.

Medium voltage:

This MVDC system has a source voltage of V_{dc} = 1000v and a power of 100KW when R_L = 10ohms. And the source side inductance of L_s = 10µH. The design of the circuit breaker will be considered by selecting the number of turns, turns ratio and other parameters.

TABLE 2

PARAMETERS OF THE PRACTICALLY DESIGNED BREAKER

V_{dc} = 1000V	R = 100Ω	C = 100µF	N_1 = 70	N_2 = 24
L = 10mH	L_1 = 10mH	L_2 = 10mH	R_L = 10Ω	C_L = 1µf

From Table 2 Breaker capacitance is 100µF, and the charging resistance is set to be 100ohms. Based on source voltage and charging resistance the capacitor charging current reaches up to 10A this is quite reasonable and the time constant will be based on this capacitor (C) and Charging resistance (R_c).

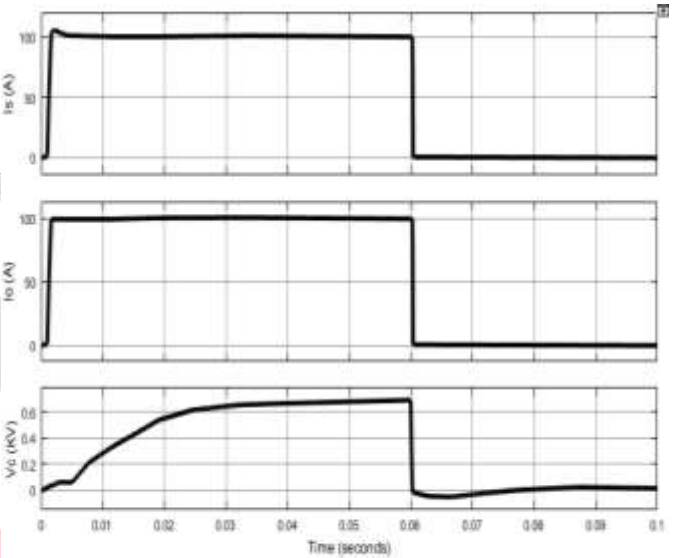

Fig (9) Simulink Response of Switching Capability

The above Fig (9) shows the switching operation of the practically considered circuit breaker. Initially S_1 is triggered and S_1 Is in close position in this period the capacitor starts charging through R_c. Here the time constant is 10msec hence the capacitor charges up to 50msec, at this point the breaker supports a load of 100KW. At 60msec the switch S_2 is triggered, causes capacitor to discharge through the transformer secondary and creating the breaker to switch OFF that is S_1 opens. Thus this added SCR cut-off the load by creating a short through path between this added SCR and capacitor. The Simulink response during this switching operation is shown in Fig (9).

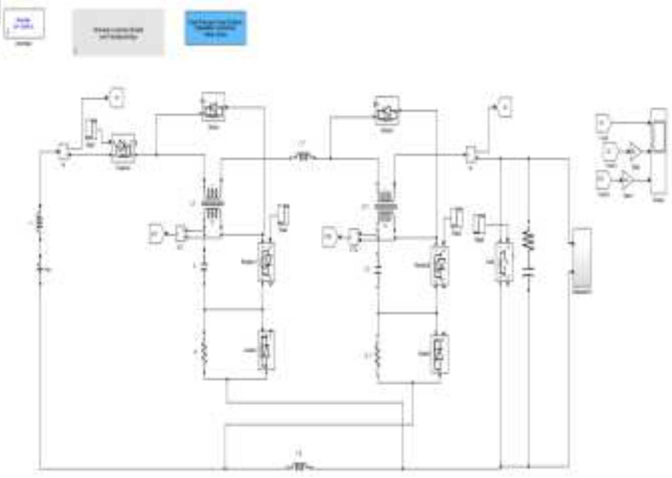

Fig (10) Simulink for practically designed breaker for Fault Handling

The above Fig (10) shows the Simulink Circuit for fault condition by connecting switch across the load. By giving the step signal to this ideal switch which cause the switch to close and create a short circuit fault and respective characteristics are shown below.

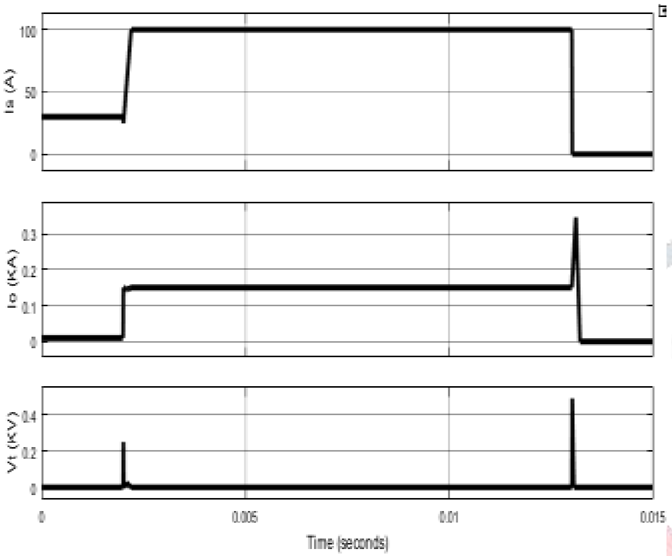

Fig (11) Simulink Response for Fault Handling

The above Fig (11) shows the Simulink response for Fault condition. At starting the breaker supports a 30KW load when the load is suddenly increased to 100KW. For this change in load the breaker does not switch OFF. This could be because of equation (6) using the turns ratio. And also the voltage across the transformer is about to 250V spikes. This measurement of this voltage will be useful to differentiate between a change in load and a fault. And from Fig (11) at the end of the simulation the fault is created and for this the output current surges cause the breaker to switch OFF and the source current will goes zero. At this point of fault creation, the voltage across the transformer goes to 460V. Hence this voltage V_t is useful to identify the fault. And a control signal, which is measuring of V_t may be helpful for removing the signal to S_1 for autonomous operation.

VI. CONCLUSION

As dc sources and dc micro grids become more prevalent, a solution is sought for dc switches and circuit breakers. Traditional methods relied on oversized ac breakers, hybrid breakers, and solid-state breakers. The dc switch proposed in this project is a variation on the solid-state breaker, but has the added feature that it can automatically switch OFF in response to faults. By using Z-source for this type of circuit breaker we can reduce the fault duration and the amplitude of output current & voltage will be increased or decreased since this Z-source function is similar to Buck-Boost Converter. Furthermore, there the turn's ratio in the circuit's transformer allows the designer to determine the amount of transient current that will be identified as a fault; as opposed to a step change in load. Analysis and design demonstrate the proposed breaker's response to a step change in load and to a fault. The breaker compares favourably to recent designs in that it has a common ground between source and load, is invariant to step changes in load, and does not produce ringing resonance in the source current.

VI. REFERENCES

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