THE TECHNIQUE OF STATIC SWITCHING WITH IGBT TRANSISTORS ON THE DC CIRCUIT BREAKERS

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REZUMAT. Deconectarea intreruptoarelor de tensiune continua este o problema tehnica dificila, datorita faptului ca aceste tipuri de intreruptoare trebuie sa intrerupa valoarea nominala a curentului, spre deosebire de intreruptoarele de curent alternativ, care pot fi deconectate la trecerea prin zero a curentului. Corelat cu preocuparile actuale in domeniu, lucrarea propune o variant care utilizeaza un contactor static cu tranzistoare IGBT. Se prezinta rezultatele simularilor in Mediul de Putere Blockset MATLAB, pentru un model experimental.

Cuvinte cheie: intreruptoare de tensiune continua, contactor static, blockset Matlab.

ABSTRACT. DC circuit breakers switch-off is a difficult technical matter mainly for the fact that this kind of breakers must interrupt current rated value, as opposed to AC. breakers that can be interrupted at current zero passage. Correlative to existent pursuits in this field, this paper propose a new approach using solid state circuit breaker based on IGBT transistors. Results for an experimental model simulated in Power Blockset Matlab are presented.

Keywords: DC circuit breakers, static switching, blokset Matlab.

1. INTRODUCTION

Commutation devices AEC represent the largest class of electrical devices with both „switch-on" and „switch-off "functions in electrical circuits for normal or fault operation. Commutation for „switch-on" but specially for „switch-off " is joined ussualy by firing and blow-out of commutation arc. For „switch-on" operation electric arc can have adverse effects if contacts closing speed is to low. Electric arc effect for „switch-off " operation consists mostly by thermic loads on contacts and components from blow-out chamber but also dielectric loads due to commutation overvoltages appeared after arc's blow-out called „recovery transient voltage".

Design for DC circuit breakers must consider aspects generated by electric arc appearance in „switch-off" operation, especially for short-circuit, aspected presented follow-up:

- arc voltage progression in time, for a certain current form, must determine a maximum arc power ;
- for short-circuit operation is necessary to reduce tripping time by using ultrafast triggers;
- assurance of a convenient form for limited current.

It is preferable that the decision of Joule integral to be made by decreasing current peak value and not release time t_d. A reduced value of release time involves a high value for L(di/dt) at $t=t_d$, resulting high over-voltages. A reduced value of limited current and time t_d relatively appreciable can be obtained by means of arc voltage with adequate form. This must increase fast and then to remain on values that not exceed supply voltage. Therefore ultrafast limiting breakers must be optimized according equipment's kinematics and electric arc evolution in "switch-off "operation for short-circuit. A solution for improving ultrafast breakers performances is ultrafast Thomson trigger.

2. DC SWITCHING METHODS

Methods known for breaking a DC. circuit : reverse voltage generation method, divergent current fluctuation method and reverse current infusion method are based on creating a 0 point. Figure 1, [2] present specific waveforms for current and voltage during a break in DC for each method.

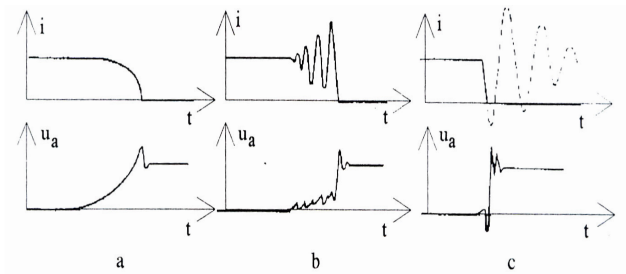

Fig. 1. Specific waveform for breaking a DC current a- reverse voltage generation method; b- divergent current fluctuation; -reverse current injection method.

Reverse voltage generation method reduces the current to zero by creating an arc voltage higher than supply voltage same as low voltage breakers. Applying this method for the DC high voltage transport systems (HVDC) it is complicated due to high values of arc voltage and energy that must be dissipated. A part from energy is dissipated, for most of the applications, commuting the current through a resistor and/or capacitor and a part in electric arc. This method is called "current commuting method".

The divergent current oscilation method creates point zero by increasing the amplitude of a current harmonic of high frequency. This method use negative characteristic of electric arc, figure 2, that creates an ascending current of oscillation in the circuit compound by electric arc, capacitor C and inductance L. A small increase of arc voltage lead to current increase in the capacitor. This leads to adequate decrease of current through arc inducing an additional increase of voltage due to arc negative characteristic. Balance analysis shows that, if arc time constant T_a is negative critical value critical T_c [3] is:

$$T_a < T_c = -\frac{1}{2}\cdot r\cdot C + \sqrt{\frac{1}{4}\cdot r^2\cdot C^2 - \frac{r}{R_a}\cdot L\cdot C} \quad (1)$$

In this equation where R_a is arc resistance in operation stable point and if arc dynamic resistance is negative then oscillatory current will grow in amplitude. Oil, air, sulphur hexafluoride circuit breakers can be used in this case for commutation but only modified to minimize effect from parallel capacitor. This method is part of current commutation category methods.

The inverse current injection method creates zero point by overlapping a reverse high frequency current over direct current by discharging a loaded capacitor. AC conventional circuit breakers can be used in this case however auxiliary circuit configuration is complicated comparative to other methods.

Interlinked modern supply networks need current devices and circuit breakers with high performances. Three requirements must be fulfilled:

- the possibility to deliver current in conduction free of excessive losses;
- fast passing from conduction state to blocked state in case of fault;
- high safety level to closing to support overvoltage.

For DC networks such as railway traffic circuit breaker must interrupt fault current by generating reverse voltage [4]. Furthermore energy must be dissipated on blocking due to electric arc appearance.

Classic circuit breakers have low contact resistance in closed circuit and operate galvanic interruption in open circuit. Electric arc appearance lead to contacts depreciation therefore this type of breakers have short lifetime and high maintenance costs.

Power solid state breakers provide fast, no arc interruption, high safety in operation, requiring low maintenance. Disadvantage for solid state type is high losses due to low thermal capacity. of semiconductor devices. Thereby high transient currents are not allowed even if efficient cooling device is installed (cooler).

Incorporating of mechanical circuit breakers and solid state circuit breakers allow transport in DC. with fast interruption without electric arc. To preserve the advantage of solid state interruption an ultrafast breaker is needed.

In the last two decades many solutions for solving this problem were proposed. Among these solutions can be mentioned hybrid thyristor breaker, GTO thyristors or IGBT thyristors [4], having new performance characteristics and opening new perspectives for new hybrid commutation techniques.

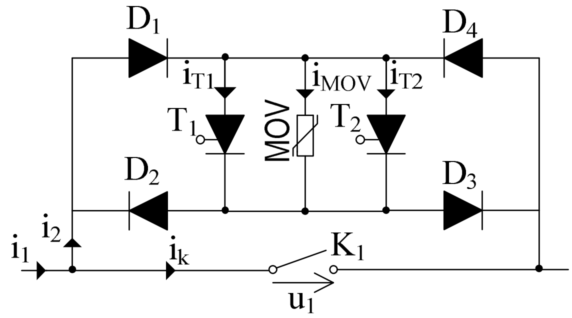

Fig. 2. Static switch with IGCT thyristors.

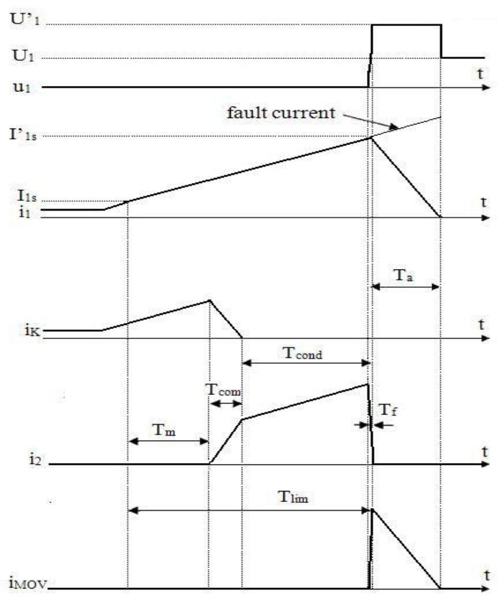

Fig. 3. Time-current-voltage diagrams for the switch with IGCT thyristors

Based on these considerations in [4] is proposed a new hybrid circuit comprising a mechanical switch and a static cell bidirectional with two thyristors IGCT connected in parallel, a convertor with four diodes and a metal oxide varistor (MOV), as shown in figure 2. The scheme allows the use of diode bridge breaker, both in DC and worldwide AC.

Nominal current in stationary mode is switch on/off by a mechanical contact. For a short-circuit situation current flowing direction is controlled through IGCT thyristors. Contacts detachment is produced after a period, release time T_m, as in figure 3. Voltage drop is reduced by current flow through power electronic devices.

After a time T_{cond}, when the distance between the contacts is sufficient IGCT interrupt the fault current, after receiving the lock signal. Available energy in circuit is absorbed by the MOV, which acts as a voltage limiter. Short-circuit time T_{lim} is limited to a value less than 300 ms [4].

3. IGBT TRANSISTOR BREAKER

By-pass circuit, figure 4, for short-circuit current limiting through K_1 contact consists in one H bridge having following components: IGBT transistors T_1, T_2, T_3, T_4, reverse current diodes D_1, D_2, D_3, D_4 and resonant load with inductance L_a=0,1 H and capacity C_a=60 μF.

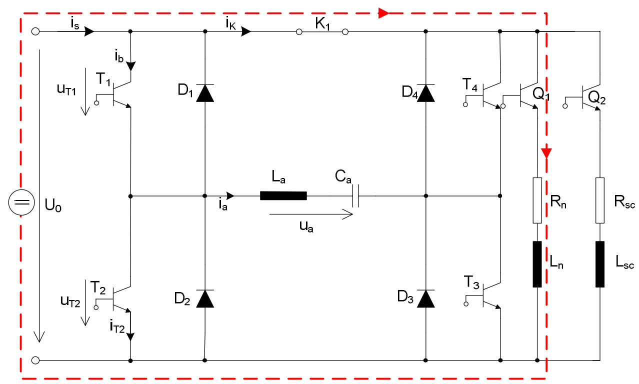

Fig. 4. Bypass circuit with H bridging.

Indicated values inductance L_a and capacitor C_a are values used for experimental model where for normal operation we have inductance L_n and resistance R_n and for short-circuit operation inductance L_{sc} and resistance R_{sc}. These two load circuits are connected through IGBT transistors Q_1 and Q_2 and the ratio between short-circuit and nominal values for current is 10.

When short-circuit appears current is commuted by commanding transistor Q_2, as shown in figure 5.

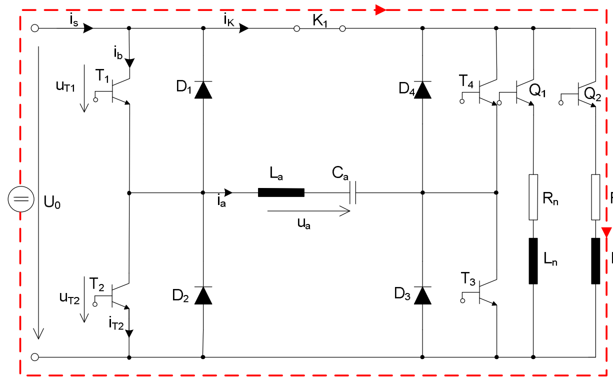

Fig. 5 Current flow in short circuit mode.

Further, the transistor T_1 and T_3 command is started the process of oscillation of resonant circuit L_aC_a as shown in figure 6.

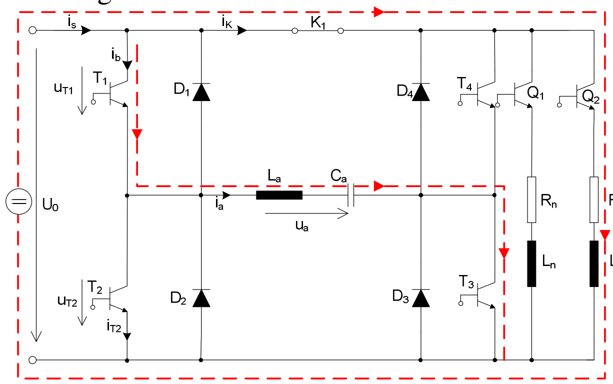

Fig. 6. Triggering the oscillation process.

It is known that on the trigger of the oscillation process for a resonant series circuit, the C_a capacitor must be charged from an outside source. This is because if at startup T_1 and T_3 transistors are being commanded , the load will close through T_1, L_a, C_a and T_3 having zero baseline, which cancels the phase difference existing in stationary regime. For this reason, when T_2 and T_4 transistors are being commanded, the necessary reactive power for switching is not provided, which leads to short circuit in the switch.

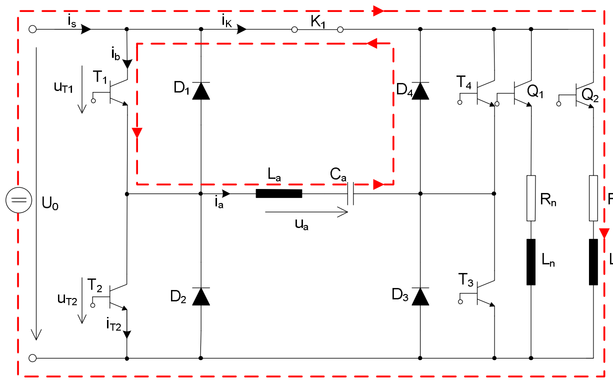

Fig. 7. Current flow on the blocking of the T3 transistors

When transistor Q_3 is blocking the current through L_aC_a group will close through the D_4 reverse current diode, being injected into reverse on contact K_1 of the electromechanical circuit breaker. It is the moment for the injection of the reverse current and is preferable for this to happen when the current through the oscillating circuit Laca has maximum value. Further, due to the open contact K_1, load current will close by the $R_{sc}L_{sc}$ load impedance, diode 4, resonant circuit L_aC_a and transistor T_1, which is blocking, preferably, when the current through the oscillating L_aC_a circuit is canceled.

4. THE SIMULATION OF THE IGBT SWITCH

The interconnections of the electrical circuit components and electromechanical devices such as motors and generators are common in electric power systems, which are basically non-linear equipments. Although in some special cases can be treated as a linear system, these cases are limited to a very small area of applications. Specialists working in this area are continuously concerned to improve the overall performance of the system by solving different design requirements. To increase efficiency and requirements which have increased significantly in recent years, power systems design engineers are forced to use sophisticated control systems and power electronic devices. Moreover, because the system is often highly nonlinear, the only way to solve a reduced cost is computer simulation.

Hydroelectric, turboelectric or using diesel generators power generation, is not the only use for MATLAB power system blockset. A common attribute of this tool is the use of power electronics and control systems to achieve desired objectives. Power system blockset was designed to provide a potential tool that allows designers to quickly and easily build models that simulate power systems in different ways. The power systems blockset is using Simulink [5, 6.7] as a medium to allow a model to be built, to simply use specific procedures. Not only that the circuit topology, can be quickly developed, but the circuit analysis may involve interactions with mechanical, thermal or other areas. This is because all electrical simulation parts interact with the extended modeling in Simulink library.

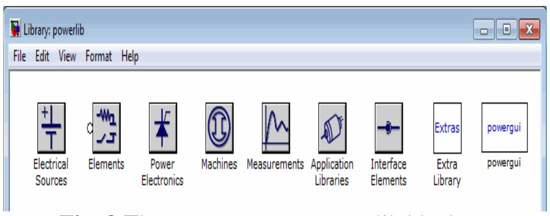

Fig. 8. The power systems powerlib blockset.

From MATLAB, Simulink uses as a calculation engine, the effective MATLAB toolbox, which can also be used by the designer. The power systems blockset allows users to build and simulate their own electrical circuits that contain linear or nonlinear elements.

Graphical user interface makes use of Simulink to connect various components of the power supply. These are classified and grouped in a special library called powerlib as shown in figure 8.

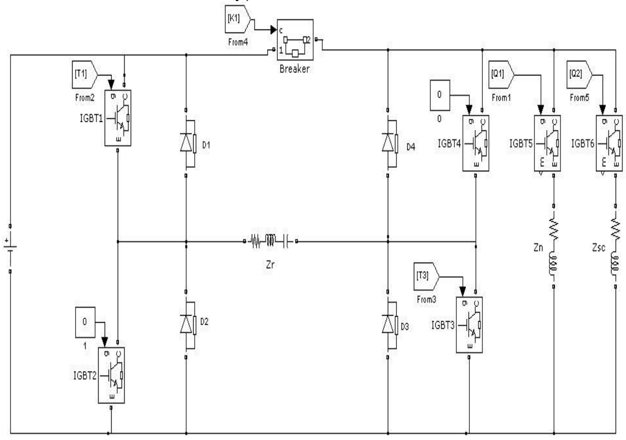

Fig. 9. The blockset powerlib of the circuit

To make the simulation of the Figure 4-7 circuits , the authors have used a DC voltage source, a static contact with IGBT transistors, a series resonant circuit as the load of the static contactor, a contact of a power circuit breaker, and two loads of the circuit breaker, one for normal operation, one for short circuit regime. Also, using control instruments for measurement of size, can be done simply by sliding a measuring tape to the desired position ,thereby, connecting the measured signals. Further it is illustrated the construction model for the analyzed scheme. Figure 9 shows a complete system with its models of Power System Blockset, including measurement function.

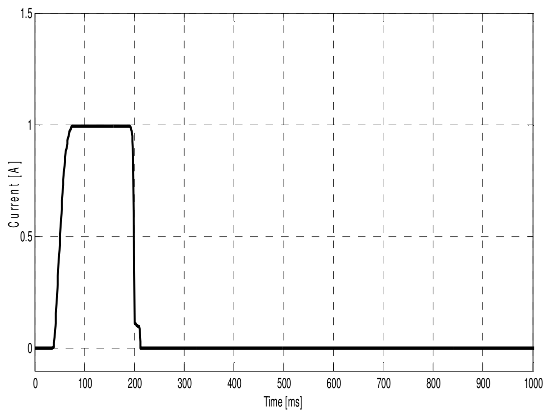

Fig. 10. Current through the L_nR_n load under normal operating

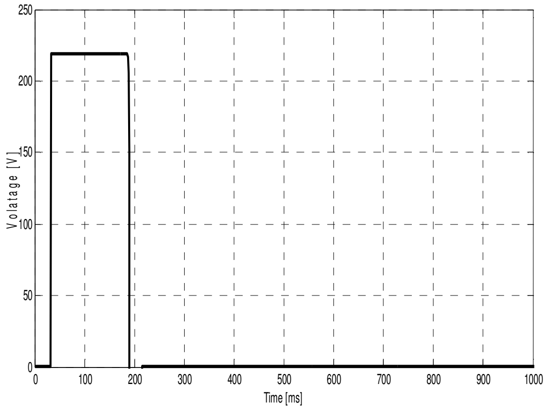

Fig.11. The voltage on the L_nR_n load in normal operation.

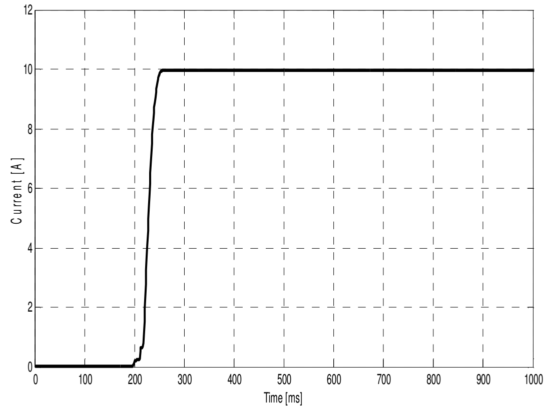

Fig. 12. Current through $L_{sc}R_{sc}$ load in the short-circuit mode, with static contactor offline.

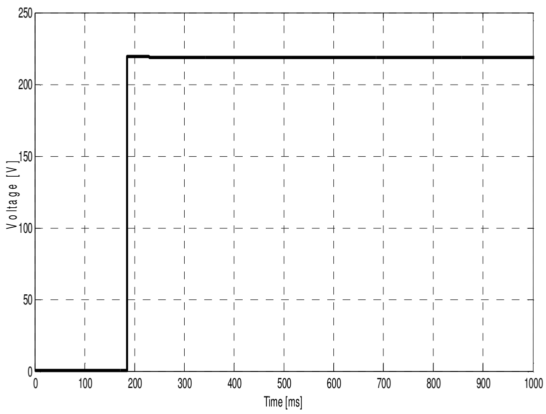

Fig. 13. Voltage on the $L_{sc}R_{sc}$ load in short circuit mode, with static contactor offline.

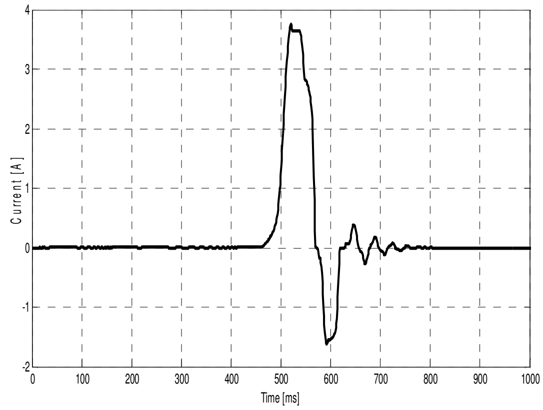

Fig. 14. Current through the $L_{sc}R_{sc}$ load in the short-circuit mode, with static contactor connected.

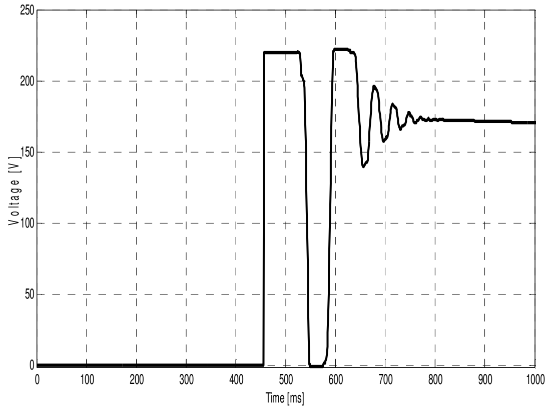

Fig. 15. Voltage on the $L_{sc}R_{sc}$ load in short circuit mode, with static contactor connected.

Simulation results for current and load voltage in normal operation and short circuit regime are presented in Figures 10-15.

5. CONCLUSIONS

✓ The solution proposed by the authors, by introducing a bypass loop with static contactor and IGBT transistors in parallel with the contact of the electromechanical circuit breaker, is feasible in practical terms, by confirming results from Matlab simulation.

✓ The model to be physically realized in the laboratory, has by similarity, in the current a reduction factor of 1:1000.

✓ To be developed in future researches on the use of static contactor high voltage bypass (220 kV), with thyristors, since high blocking voltage capability of these devices and higher safety in overload and short circuit operation.

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