POSSIBILITIES OF IMPROVEMENT OF MONITORING AND DIAGNOSTIC PROCESS OF POWER ELECTRONIC DEVICES

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In the present article are analyzed the possible break-down situations in the internal electric circuits of power rectifier convertors. The main task is a theoretical report of the developing processes during the occurance of internal short circuits under a failure of one or several valves and their influence upon the rest of them. The available possibilities for an optimal defence and the methods of their registrating and measuring are considered. They are applied in the digital complex introduced in the laboratory LAMAR of UCTM designed for research and control of the working process of power electronic devices. The complex is an adaptive system, which adjust the working regime towards the changes of the charges. The main ways for reducing the heat influence of the break down current through the undamaged valves are defined. The suggested classification is suitable for optimization of the working regimes for the devices of this type. The accomplished comparative evaluation of the examined variants can be used for working out methods for an effective defence for rectifier convertors.

Keywords: Power converters, Power Semiconductor, Digital complex, break – down process.

1. INTRODUCTION

The established use of silicon valves at power converters predetermine their sensitivity toward overwork- short circuits (s.c.) and overvoltages as well as the inability for recovery after thermal or electric failure. Some of the main problems are shown in [1], but they are not analyzed in details and don't carry the necessary information for the converters. There is a need for a precise formulating of the problems and their decision with the help of the modern digital systems. From the practice there is an interesting situation when there is a failure in one or more than one of the valves of the bridge. The occurrence of outer s.c. is given an account in the process of planning and is not a point in the present article.

2. THEORETICAL PLAN OF THE BREAK-DOWN CURRENTS AT A VALVE FAILURE

The scheme shown at fig. 1 is represented in generalized type. LT and RT are the total inductance and active resistance for each of the phases of the AC, executed to the secondary coil of the transformer. The next points are admitted when a break - down occurs with the purpose of facilitating the equations:

- The three - phase net is symmetrical and the voltages are sinusoidal and unchangeable in amplitude.
- All devices keep conductance with the exception of the damaged ones.
- The system of control doesn't read the failure.

- The defense chains are neglected because of overloading.

The most unfavourable break - down regime is described, which is exactly the maximal value of the voltage of the source and the minimal angle of regulation.
If we have a break-down in B5 valve at the moment of commutation from it to B1 at the situation of equal voltage in phases A and C. There occurs a path of two-phase s.c. between A and C through B1 and the failed valve. This case seems to be the worst from a point of view of the duration of the break-down current.

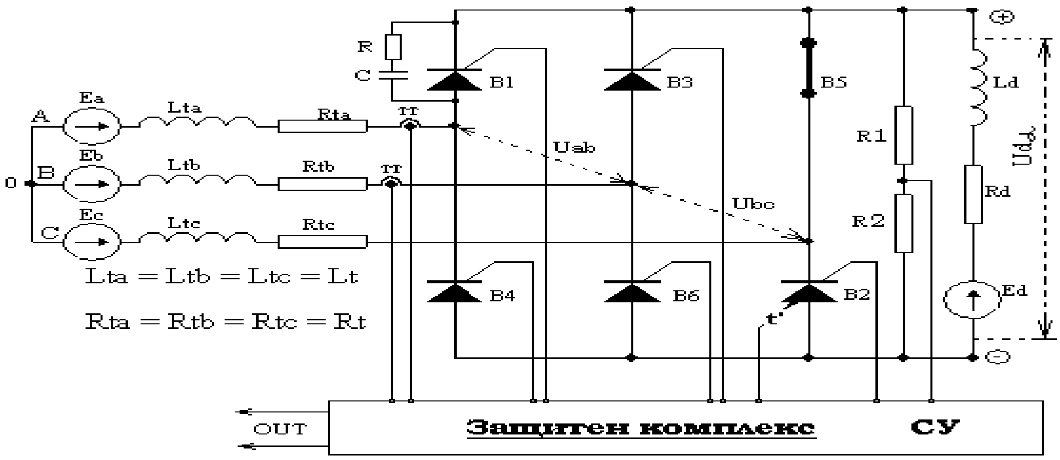

Fig.1. A three phase bridge rectifier with a failed element.

At the analyses we can neglect the influence of the load [3], [4], and those with great inductance don't change the amplitude of the break - down current through the devices [5]. From fig. 1 we can work out the subordination for the equation of the transitional process:

(1) $$e_A - e_C = i_{B1}R_T + L_T\frac{di_{B1}}{dt} + i_{B5}R_T + L_T\frac{di_{B5}}{dt}$$

Hawing in mind that iB1=iB5 (the net is symmetrical) and eA - eC = √3Umφ sinωt, we can go to the equation of the break-down current:

(2) $$i_{B1} = i_{B5} = \frac{\sqrt{3}}{2}\left[\sin(\omega t - \varphi_T) + \sin\varphi_T e^{-\frac{R_T}{\omega L_T}\omega t}\right]$$

The equation is correct till the moment t = π/2ω, after that the voltage of phase B becomes positive.B3 switches on and generates three phase s.c. The transient process in this interval can be described by the equations:

(3) $$e_A - e_C = i_{B1}R_T + L_T\frac{di_{B1}}{dt} + i_{B5}R_T + L_T\frac{di_{B5}}{dt}$$

(4) $$e_B - e_C = i_{B3}R_T + L_T\frac{di_{B3}}{dt} + i_{B5}R_T + L_T\frac{di_{B5}}{dt}$$

(5) $$i_{B5} = i_{B1} + i_{B3}$$

While reading of the boundary conditions and dividing the variable quantities the equations for the currents through the valves look like this:

(6)
$$i_{B1} = \sin(\omega t + \frac{\pi}{6} - \varphi_T) + \left[I_{B11} - \sin(\frac{2\pi}{3} - \varphi_T) \right] e^{-\frac{R_T}{\omega L_T}(\omega t - \frac{\pi}{2})}$$

(7)
$$i_{B3} = \sin(\omega t - \frac{\pi}{2} - \varphi_T) + \sin\varphi_T e^{-\frac{R_T}{\omega L_T}(\omega t - \frac{\pi}{2})}$$

(8)
$$i_{B5} = \sin(\omega t - \frac{\pi}{6} - \varphi_T) + \left[I_{B51} - \sin(\frac{\pi}{3} - \varphi_T) \right] e^{-\frac{R_T}{\omega L_T}(\omega t - \frac{\pi}{2})}$$

- where IB11 and IB51 are currents in B1 and B5 at the end of the first interval.
The second interval of the break – down process continues till the moment of the current falls in B1 till zero. After that we have to phase s.c. again, but between B and C. This is the third interval for which the transient regime will be described by equation (7). Because iB3 = iB5, having an account the initial conditions we achieve:

(9)
$$i_{B3} = i_{B5} = \frac{\sqrt{3}}{2} \left[\sin(\omega t - \frac{3}{\pi} - \varphi_T) - \sin(\frac{\pi}{6} + \gamma - \varphi_T).e^{-\frac{R_T}{\omega.L_T}(\omega t - \frac{\pi}{2} - \gamma)} \right] + + I_{B52}.e^{\frac{R_T}{\omega.L_T}(\omega t - \frac{\pi}{2})}$$

- where γ is the duration of the second interval, IB52 is the current in B5 till the end of the second interval.

The third interval will end when the current in B3 goes to zero and the two - phase s.c. goes to three - phase at the moment of equation of the voltage in phase A and C. In the first case the current through B3 goes to zero for less than 2π/ω, the break - down process will stop and B5 will let through the current in straight direction. At the moment of equation of the voltage in phases A and C the whole break - down process will repeat again. At the second case, when the current through B3 doesn't manage to go to zero at the moment of equation of the voltage in A and C, the s.c. becomes three phase and the current through the chain of the failed valve will be determined by the reading initial values. Those subjections are used as a base for the realization of the digital complex for control of rectifier converters [6], which schematic of connections is shown in fig.1.

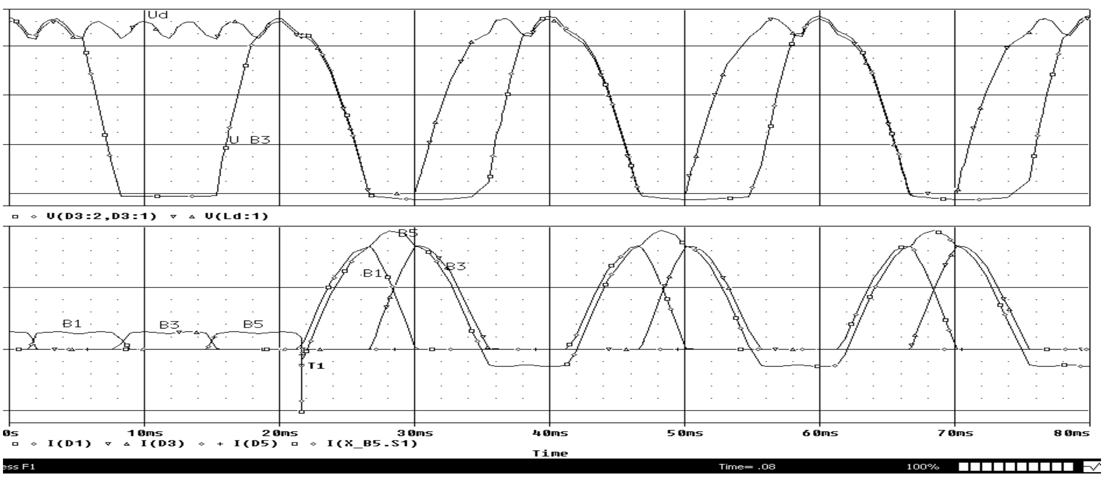

Fig.2.Simulation results of current in the cathode group.

The graphical subordinations at the computer simulations of the examined schematic are given in fig.2. On the first scope are shown the upright output voltage Ud and the voltage of one of the valves - B3. The reduction of the efficient valve of Ud is used for determining of the break - down process in the system for control. The second scope shows the currents in the chain. The moment of failure of the thyristor B5 is shown as T1. In this case B5 is in the cathode group and so the alternated short circuit is only with the devices of the group. This can be seen from the simulation shown on fig.3, on the first scope, which is for the currents through the thyristor in the anode group.

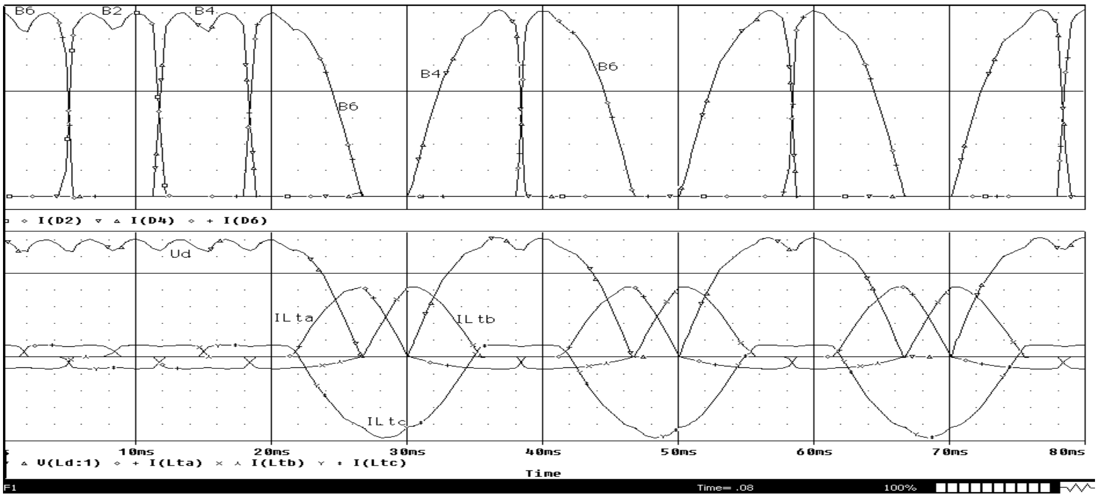

Fig 3.Simulation results of currents in the anode group.

There can be seen almost repeated rise of the current over admissible valves through the undamaged devices. It is restricted mainly by the summarized inductance Lt and the active resistance Rt of the secondary coil of the transformer. This is why it is necessary the break - down process to be stopped for a time no longer than 1 period, to avoid a failure in the undamaged valves as a result of overheating.

3. TYPES OF DEFENSES USED IN PRACTICE

As it was seen in the upper part of the article the heaviest failure in the converter seems to be in inner s.c. together with a valve break - down during the commutation of the current from this device to the next one (fig.2). Till the moment of ceasing of the break - down current, in some way or another, in this case we achieve the described periodical alternation of two phase and three phase regime of s.c., in the group (anode or cathode) with the damaged valve. As much as the thermal influence of the break - down current seems to be the main fact which leads to failure of the valves, the devices for defense must restrict the continuance and the amplitude of this current at such a level that that the thermal equivalent of the device for defense to be less than the admissible thermal equivalent of the defense device. [8]:

(10)
$$\int_0^t i^2 dt < (i^2 t)_{\text{доп}}$$

- where t is the time of work of the break-down current till its total disappearing [s].

i – the moment value of the break - down current [A].

(i2t)max. – index for defense of the device [A2s].

The screened index of the device is given for intervals from 3 to 10 mS, but more accurate results can be achieved when the maximum allowed temperature of the transition and the constructive peculiarities of the cooler is marked.

The contactors can not be used as defended devices for semiconductor valves because of the great self time for good team work. The automatic contactors are examined as defended devices, the fuses and scheme variants with additional commutation elements are examined.

- The used automatic contactors (a.c.) are from different types. But because of the long time for good team work they don't allow defense for the valves without additional measures. Its own time for switching off (t0), which marks the start of the current limiting of the automatic contactor from series A3000 of Semikron [9], reaches till 40 mS, from series BA – till 50 mS, and the total time for switching of is much more. For the time t0 the break – down current in the circuit reaches its amplitude value and as a sequence there is no current limiting. The amplitude value of the break – down current I depends from the state of the circuit and can exceed the fixed value of the current in the three phase s.c. – Im.

(11) $$I_m = \frac{\sqrt{2}.U_\Phi}{\sqrt{(\omega L_T)^2 + R_T^2}}$$

There are several ways for reducing the thermal influence of the break - down current through the undamaged valves with automatic contactors:

1. Reducing its own time for switching off the a.c. by the influence if remote switch. At the automats from the series A3000, this allows the achievement of times like t0 = 10 ÷ 15ms. But in this way the scheme of the converter becomes too complicated because at least in two phases of the power supply there must be provided current sensors (fig.1), as well as some additional elements for supply and control.
2. Reducing of the current amplitude of the three phase s.c., which is provided by network inductors at the entrance of the converters. The suggested ones have inductive resistance which doesn't allow reducing of the amplitude of the break - down current till a safe value.
3. Leading in a selective defense, which ensures turn off of train of control pulses till the moment of the next commutation. Therefore a transition is necessary from normal diode rectifier to transistor one with a system for phase regulation.
4. An addition of additional switching elements to ensure the occlusion of the undamaged thyristors before the end of the half - period.

- None of these methods are not efficient enough when used separately. A good defence of the undamaged valves can be done only when the described methods are used together in complex. Of course this means an increase of the size and price of the rectifier because of the complicated scheme decision.

4. CONCLUSION

From the information given above about the developing process and on the base of the statistical data for the failures gathered during the monitoring of the system, semiconductors are most pliable to damages provoked by thermal overloading. A failure of one of the elements by all means leads to a break - down of the others in the group. When projecting of systems for defense it is necessary the possible the break - down regimes in the inner chains to be predicted in relation with the parameters of the rectifier valves. The use of digital systems for prediction of failure of the elements in some of their parameters is a hopeful base for increase of the reliability of the rectifier converters. But the measures must be considered with the price range of the device and sometimes it could be undue when working with low powers.

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