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ANALYSIS OF MODES AND DIAGNOSTICS OF POWER KEYS OF CONTROL SYSTEMS OF ASYNCHRONOUS DRIVES OF ELECTRIC LOCOMOTIVES OF ALTERNATING CURRENT

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Annotation. The article presents the results of the analysis of the technical condition of IGBT power switches used in control systems of modern AC electric locomotives under operating voltage when driving under various actions of overcurrent, voltage, overheating and short circuits leading to their failure.

Keywords. Electric locomotive, control system, alternating current, diagnostics, power key.

Relevance. Modern electric locomotives are one of the elements of the railway transport infrastructure. Its stability, traffic safety and the cost of transportation largely depend on the system of their organization of operational modes of maintenance and repair installed on diagnostics [1,5,7].

One of the important elements that ensure the level of safe, uninterrupted movement and reliability of the control system is semiconductor power switches based on IGBT transistors [2,3,8]. High speeds of passenger and cargo transportation, a high level of overcurrent, voltage, overheating and short circuits lead to false triggering and failure of the control system.

In these conditions, an urgent task is research aimed at ensuring energy saving, increasing the efficiency and power of electric locomotives and traction network, including on lines with increased speeds, taking into account the operation of the asynchronous AC electric drives system in harsh climatic conditions of the region in traction and regenerative braking modes on the railways of the Republic of Uzbekistan. This problem should be solved first of all by analyzing the modes and diagnosing the power keys of the control systems of asynchronous electric locomotive drives. Since the protection and elimination of emergency modes of the power key, which is one of the main functional elements of the control device of electric locomotives, the reduction of the resource and its failure can be caused by various reasons: electromagnetic and thermal action, interacting in most cases simultaneously.

The formulation of the question and the purpose of this article is the issues of diagnosing power switches based on IGBT transistors from various types of accidents, for example from overcurrent, voltage, overheating and short circuit.

Analysis of the technical condition of power switches on IGBT transistors installed on 98 AC locomotives with asynchronous drive carried out during 2012-2022, according to the depot “O'zbekiston”, showed 576 failures and damages.

The presence of such a significant number of IGBT failures is of particular concern, because the high rate of development of such failures reduces the accuracy of assessing the residual resource of the electric locomotive control system and determining the technical condition of the electric locomotive becomes necessary to correctly interpret the detected damage. Based on the analysis of the existing reasons for the failure of IGBT installed in the control systems of a large number of more than 98 AC locomotives operated in “O'zbekiston temir yo'llari” as well as the existing reasons for other electric locomotives, it is necessary to develop a more generalized classification of them Fig.1.

One of the causes of IGBT damage is overcurrent caused by failures in the control algorithm, low rate of change of di/dt, depending on the inductance of the load and the control voltage and the failure of the key from saturation.

Another factor in IGBT failure is a voltage overload approaching the breakdown level. Overvoltage affects the power (collector-emitter; drain-source) and on the signal terminals (gate-emitter; gate-drain).

IGBT overload by current or voltage significantly increases the probability of failure of the entire system. Therefore, it is extremely important to determine the pre-failure states of power keys and replace potentially unreliable devices in a timely manner.

A large number of transistor failures are observed both with external and internal overvoltages. External overvoltage is caused due to the supply network. In practice, it is often observed, firstly, with a sharp dynamic braking of the electric drive or a failure in the control algorithm of the pulse rectifier.

Diagnosing the IGBT operating mode in the MATLAB Simulink system shows that overvoltage appears when the IGBT operating on an inductive load is locked:

$$\Delta U_{max}=L_K\, di_L/dt \qquad (1)$$

where L_K=1...100nH is the inductance of the parasitic circuits of the switching circuits; i_L is the deviation of the load current when the keys s_1 and s_2 are disconnected during the operation of the voltage inverter based on IGBT transistors.

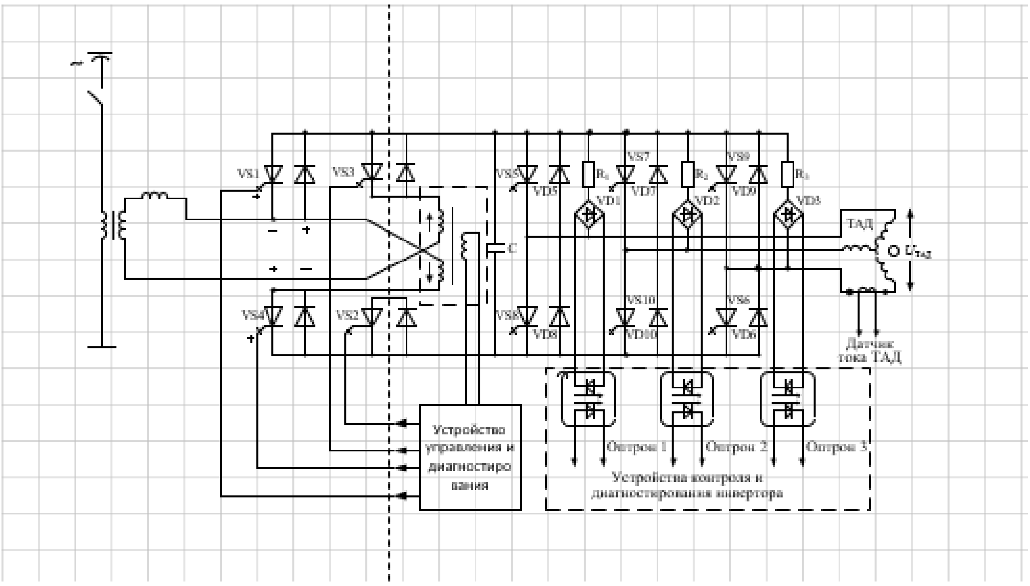

Fig.1. The basic diagnostic system of the asynchronous electric drive of electric locomotives of alternating current.

Overvoltages can occur in the short circuit mode (short circuit) due to the high dU/dt value. Due to the presence of Miller capacitances, i.e. capacitances C_ (z.k.) between the gate and the collector, between the gate and the emitter C_ (z.e.). According to the switching mode of the power switches, overvoltages can also be periodic (with a frequency of up to several kGn) and aperiodic.

Temperature has a considerable influence on the operating modes of IGBT. This is overheating due to an increase in the power dissipation caused by a large current or an error in the microprocessor control system, as well as a malfunction of the cooling system. For modern IGBTs, the limit value for their crystals is allowed T_{max}=+150...175 °C In addition, due to technological tolerances and malfunctions, the uniformity of heating of the semiconductor key is not ensured. This is one of the main tasks in power electronics. Its solution makes it possible to operate IGBT under increased loads [7].

Among the functional links of the traction asynchronous electric drive, the most vulnerable is the four-quadrant converter 4QS - these are two controlled bridges with two operational IGBT transistor modules. Counter-conduction diodes are connected to these modules in parallel. The process of switching power transistors and diodes can be divided into three phases: clocking, rectification and inverting.

Monitoring and diagnostics of 4QS is concentrated in compact modular control systems such as SIBCOS-C, made on the basis of microprocessor technology.

Long-term observations of the technical condition of the 4QS converter carried out by us according to the data presented by the depot “O'zbekiston” shows a large number of failures of IGBT transistors. The main reasons for failures are: a short circuit or an open circuit in the power circuit caused by a violation of the thermal regime of each of the two pairs of 4QS.

We propose an integrated device for diagnosing each arm of the 4QS, consisting of an additional transformer having three windings of ω_1,ω_2 and ω_3. The ends of the windings of ω_1 and ω_2 are connected, respectively, into the dissection of transistors VS_1, WS_2 and VS_3 and VS_4. As shown in Fig.2. and having a mutually opposite direction of magnetomotive forces (MDS). The output ends of the third IGBT winding are connected to the existing control and diagnostic system. If there is a short circuit or an IGBT power circuit break, then an assessment of the corresponding state is formed with its subsequent shutdown.

For thermal protection of IGBT and its diagnosis, thermoresistors with negative and most of all silicon resistors with a positive temperature coefficient are mainly used.

The measuring and converting system of thermal protection, diagnostics and monitoring IGBT converts the resistance of a silicon resistor into an analog voltage signal in the range of 0-15 V, with an error of more than 3%. The value of this voltage U_t is defined as:

U_t=-2+0.1t_code, (3)

where t_pod is the temperature of the ceramic substrate installed on the radiator

IGBT failures due to over-voltage. The development of the topology of power buses is the most important stage in the design of pulse converter devices. One of the most difficult problems is associated with the high rates of current change of modern electronic keys and the presence of parasitic inductors in switching circuits. Inverters must, under all operating conditions, ensure the absence of dangerous overvoltages, the ability to disable the power modules. The article is devoted to the peculiarities of calculating snubber capacitor circuits designed to limit switching voltage emissions.

When the IGBT is switched off, the collector voltage increases by ΔU=L_B (di_c)/dt relative to the potential of the V_DC power bus; where (di_c)/dt is the collector current decay rate. As a result, the collector-emitter signal U_CE=U_DC+ΔU can lead to an acceptable value and disable the transistor.

To reduce the Q-factor of the parasitic oscillatory circuit, a resistor is installed in series with the capacitor (Fig.4.b). This scheme is usually used in low-voltage high-current converters.

Diagram Fig.3.b is connected if necessary to limit the speed of the switching thyristor ... The snubber time constant is 5 s.–should be at least 3 times lower when the operating frequency R_S C_S <T_PR/3.

In the IGBT protection circuit according to the diagram Figure 4 v, the overvoltage capacitance C0 is selected from the condition for ensuring the permissible rate of change of the anode voltage:

C_0≥I_TM/(dU(dt))

where I_TM is the maximum anode current before switching; dU(dt)kr is the critical rate of rise of the anode voltage.

The resistance R is selected for the voltage to which the protective capacitor is charged:

U_0/I_T0 <R<t_n/〖3C〗 _0 , (4)

where U_0 is the voltage on the protective capacitor before switching on the IGBT; I_T0 is the permissible IGBT switching current. The diode is selected according to the voltage class corresponding to the power switch. This diode should be high-frequency with fast recovery and the minimum possible Qrr parameters.

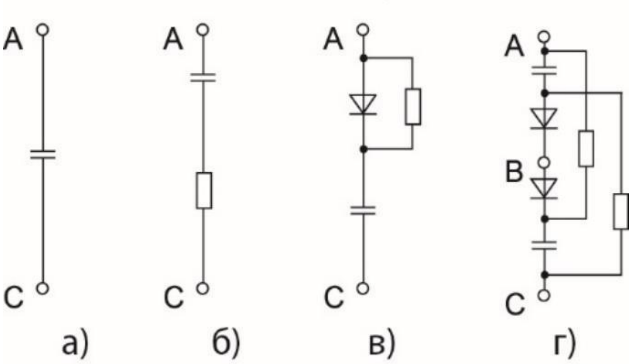

Fig.2. Schematic diagrams of IGBT surge protection dampers and their connection

After selecting a damping protective chain, the bursts of the same voltage 〖ΔU〗_1 and 〖ΔU〗_2 can be approximately calculated using the formulas:

ΔU_1=0.9I_TM (2 L_S2/t_GF +t_GE/〖3C〗_0), (5)

ΔU_2=E+I_TM (1/〖WC〗_0 - ωL_S2), (6)

where L_S2=12,5 NH parasitic inductance protective circuit; t_GF front of slad anode current IGBT; L_S1=18.2-20.0 NGN-parasitic inductance of the power bus; ω=2πf – circular switching frequency; E – anode voltage IGBT.

The scattering power in the protective circuit resistor is defined as:

P_0=0.5C_0 V_0 f, (7)

where f is the IGBT switching frequency.

Conclusion

A wide range of current and voltage changes due to the load of the asynchronous electric drive system, high-speed movement of the electric rolling stock, respectively, lead to an increase in the rate of rise of current and voltage di/dt and dU/dt, as well as the presence of Miller capacitances between the gate and collector, gate-emitter capacitance and inductance of switching circuits reaching Lk≈10mkGn, cause the appearance of threshold values of currents and overvoltages that lead to an IGBT break and short circuit.

Another factor of IGBT failures is its overheating at a temperature of t=125-150 ° C. The main reason for overheating is the high current value of the power switches, as well as the long reaction time of the thermal sensors due to the high heat resistance of the radiator, which affects the thermal stability of the mode and increases the measurement error.

To improve the accuracy and thermal stability of current measurement, it is advisable to use induction current meters of the compensation type.

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