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Operating Mode Influence on Probability Characteristics of Electric Devices

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Abstract: The presented study set the repetition factors of contact resistance value for electrical devices according to the condition of their permissible overheating describing the technical status of the electrical switchgear. The functioning performance measures and the likelihood of working capacity preservation for low-voltage switching devices were determined depending on an operating mode.

Key words: Electric, power supply, model, converters, electric grid, devices

INTRODUCTION

During the tests of low-voltage electrical devices for electrical life period the number of cycles is determined that a device can withstand at some laboratory or regulatory mode. Typically, the necessary level of durability is determined also on the basis of practical experience and reflected in the norms and standards by certain types of devices. As a rule, the reliability level during a test period represented graphically for clarity, where the operation time can be estimated on the basis of a product operation practical experience.

MATERIALS AND METHODS

Technical condition evaluation of electrical switching devices: Typically, a new device is subjected to tests and thus the operation period equal to t_1 is simulated in some degree. During this period, a substantial part of devices experience the wear of contacts but arc-extinguishing devices, chambers, etc., may remain in a operational state. Obviously in order to determine the electrical life of such elements in a particular mode the need may appear to continue testing after the replacement of contacts, i.e., on the sites t_2, t_3, etc. (Fig. 1).

Devices shall installed on a test bench in a proper manner. The cross section, the material and the method of lead wire fastening must be such as recommended for any operation. The devices designed for the operation in shells shall be tested in their individual shells. Testing modes must meet the requirements set out in regulations.

The attention is usually drawn at the examination of initial and end pressing of contacts, the pressing of return springs (where they exist), the simultaneous touch of contacts, the purity of their processing and the correctness of galvanic coating. Since, the wear of contacts depends essentially on their temperature and

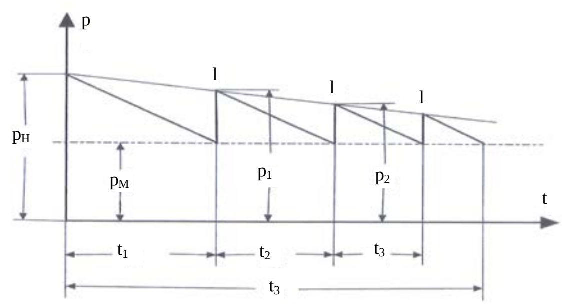

Fig. 1: The dependence of product reliability level on the time of operation: P_H: stable operation probability (reliability) of a new product; p_m: minimum acceptable level of reliability which requires repair; p_2, p_3, etc., a device reliability after the first, the second repair, etc.; t_1-a: device operation time before the first repair; t_2, t_3, etc., Device operating periods between repairs; $t_э$: operation time, after which repairs become too expensive

the temperature of parts which have a direct contact, These temperatures are measured and recorded during tests. In the process of electrical life testing the welded contacts or the overlaps between the poles or between the poles and the earthed parts shall be absent. The periodic cleaning of contacts and arc extinguishing chambers by the ways specified in a device maintenance manual is performed in necessary cases.

The evaluation of contact durability is performed usually by contact gap. A device is considered as passed the tests on the electrical life of contacts, if the contact gap remains in a given mode no >1/5 of the initial one (at the initial gap of 2.5 mm or more) and no >0.5 mm at the initial gap of 2.5 mm or less after a prescribed number of cycles production.

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During the study of contact durability one should measure the gap of contacts according to the control gap periodically. After an appropriate recalculation one should develop a dependence graph on gap loss within the function of performed test cycles. In most cases (except for running-in periods), this graph is a linear one, that allows you to use a very simple and a convenient value of contact wear, namely, the specific wear, expressed in millimeters per cycle. This value is calculated by the following expression:

$$i_к = \frac{\Pi_Н - \Pi_N}{T_р} \quad (1)$$

Where:

- i_K = The specific wear of contacts, expressed in millimeters, the gap losses per cycle
- $\Pi_Н$ = The gap of new unworn contacts
- Π_N = The gap of worn out contacts (after a certain number of cycles) (mm)
- T_P = The number of performed cycles, after which the measurement was performed

In some cases in order to compare different designs, it is necessary to express this figure in percentage, i.e.:

$$i_k(\%) = \frac{\Pi_Н - \Pi_N}{T_р \Pi} \cdot 100 = \frac{i_k}{\Pi} \cdot 100 \quad (2)$$

where, Π nominal gap of contacts, mm. During a repeated periodic tests of current production devices on the electrical life of contacts in the case of a repeating close match of wear rate (i.e., the specific wear) tests can be carried out up to the half of prescribed number of cycles with a subsequent extrapolation up to the total number of cycles.

One of the main test objectives is the need to ensure the unity of tests. The latter is achieved by using certified test equipment and tested measuring instruments, by the use of certification and verification means as well as the standards of product state test system, the standards of a state system ensuring the uniformity of measurement and other standards, specifications and certified test methods. Under certain special studies (for example, during the study of contact material transfer) the contact wear is determined during contact weight loss.

The main factor of mass transfer is the electric erosion of contacts which not only causes an intense wear of contacts defining a device wear substantially but can also cause very undesirable effects associated with metal-coating on insulating parts, thereby reducing their surface insulation resistance and causing the risk of an electrical breakdown.

The secondary factors of metal transfer can significantly impair the insulating properties of a device dielectric parts or, if the components of insulating materials are transferred, they can worsen the conditions of detachable contact connection contacting as well as the switching contacts of a main and an auxiliary circuit. The mass transfer in electric devices appears due to the following possible methods (Namitokov, 1985).

The transfer due to contact erosion. Until now, one can not consider it as a fully explained mechanism of this complex process, especially when it comes to quantitative characteristics. In high-power devices one should distinguish two classes of erosion phenomena basically: the first class is presented by phenomena that occur as the result of an electric arc; the second one are the phenomena occurring in the areas of the current contraction in contact transitions.

The substance transfer due to the indirect effects of the arc on the other parts of the device. the mass transfer to the parts of devices takes place not only due to the erosion of contacts but also from indirect exposure of an arc and plasma flows on them. The result of such impact is that material can be removed from a surface of some device parts (by evaporation, sputtering, dissociation) and to settle on the others. This process is relatively slow but it can’t manifest itself visibly at a large number of operating cycles, even at nominal currents.

The transfer of substance by the mechanical destruction of device parts. During an extended operation of unit coupled nodes (which may combine dissimilar metals and non-metals) the mechanical wear occurs by the movement of one part relative to another. The products of this deterioration are often inside the device, redistributing on its parts somehow. This is facilitated by the possibility of insulating material particle triboelectrification and the magnetization of the ferromagnetic particles. The deposition of these particles on the friction surfaces can have an abrasive effect, change the insulation properties and deteriorate contacting.

Diffusion and mechanical transfer. The diffusion transfer of one material to another is possible between the densely contiguous parts of a device. The diffusion transfer effect depends on the diffusion coefficient and the temperature at the boundary of parts. The diffusion transfer may be added by a purely mechanical transfer of one material to another in friction units, if these materials vary greatly by their physical and mechanical properties. Both types of mass transfer, although quantified slightly, can have a strong influence on the coefficient of friction and provide the phenomena of rubbing pair setting, the burrs on surfaces.

Chemical transfer of a matter. The metal parts of details made of different materials and alloys may form galvanic couples between them. In this case, at the presence of moisture and during the formation of chemical compounds under the influence of an arc, for example, the local areas of electrolytic conductivity may appear between the device parts(typically, on the surface of insulating materials separating the metal parts as moisture may condense on these surfaces).

Electrophoretic transfer. There is an electric field of a complex configuration, conditioned by the potential difference between the conductive elements and the possibility of insulating materials electrifying in an electric device.

However, there are always suspended electrically charged (or polarized) smallest particles as the result of mechanical wear erosion phenomena and the introduction of aerosol particles in a device and between its parts. Under the influence of an electric field, such particles will be moved and redistributed in the bulk and will be deposited on the device parts. Although these processes are relatively mild (compared with the above described ones) but in some cases they may cause insulation failure of arc overlapping between the device parts.

As we can see, the mass transfer processes in electrical devices have different nature as they are all connected with a variety of physical and chemical, mechanical, thermal and other factors.

Therefore, the quantitative evaluation of each of these factors requires a different approach. Even one of mass transfer manifestations associated with the electric erosion phenomena requires the study of a large complex of different techniques due to the variety of their forms. These phenomena can be characterized by the following indicators in relation to the electric devices:

The intensity of contact erosive destruction, usually determined by the change of contact gap; The transfer of material between the device parts. The transfer rate is judged by the visual changes of surfaces, immediately adjacent to the emission centers. Studies perform the calculation of elements by radioactive isotope method (traced atom method). This method is effective during the study of transfer between the rubbing parts of the device.

Degradation product analysis. If transfer products may be in any way removed from the parts on which they are deposited, then a lot of information is given by the analysis of their structure and composition. Knowing the ratio of vapor and liquid phases in the electrical erosion products it is not difficult to make an optimal choice of contact materials according to an operating mode (Belkin and Vedeshenkov, 1978). Material transfer dynamics. The direct product analysis is the most accurate one. In practice, they judge usually by the rate of contact gap change. In addition to the impact of known factors (material, operation mode, etc.) on the contact reliability, they described many cases of adverse effects and some specific work properties and conditions. For example, special lubricants are used sometimes to protect the contacts from oxidation, they accumulate dust that can disrupt contacting. Some silicone-based oils have a greater propensity for spreading and low volatility and the interaction with sparks during commutation leads to the development of SiO_2 which creates hardly removed insulating films on the contacts due to its glassy structure and firmness. The vapors of organic substances released from insulating materials are deposited and polymerized randomly on the contact surfaces. Rubber and ebonite emit sulfur and polyvinyl chloride emit chlorine which also develops a non-conductive oxide films on silver-containing contact surfaces, etc.

RESULTS AND DISCUSSION

Under these conditions, a significant impact on the reliability of contacting ceteris paribus is provided by the voltage at which contacts operate since conductive films make their way relatively easy at medium voltages (0, 3-0, 66 kV). N. Meyer recommends empirical formula for a rough estimation of contact violations, depending on main influencing factors

$$F = \frac{S^{0.8}}{V^2 R^{1.5}} \tag{3}$$

Where:

F = The number of contact violations
S = The number of on-off operating cycles
V = Operating voltage
R = The pressing of contacts

The occurrence of intermittent failures is particularly noticeable at voltages below 24 V. An effective known measure of contact reliability increase is the parallel turning on of contacts. The number of failures from two parallel-connected contacts F_P is determined by a certain number of n cycles:

$$F_P = \frac{F_k^2}{n} \tag{4}$$

where, F_K is the amount of one contact failures. Actually the assessments of contacting reliability concerning low-voltage devices is performed by voltage drop

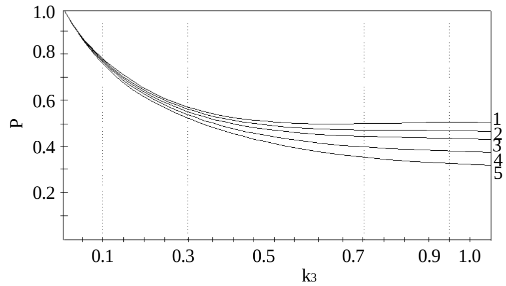

Fig. 2: The probabilities of low voltage switching device resistance keeping in the allowable range depending on load factor amount: KT contactor 6013; magnetic starter PML 1220; automatic switch AE 2040; packet switch VP 2-40; the switch BP 32-31

measuring on a tested contact during a test circuit switching and its comparison with a specified threshold value for each response. If the voltage drop on a tested contact exceeds the threshold value, it is considered a failure: a failure is considered after the accumulation of the allowable number of failures on a contact or a contact group.

The processes occurring during the operation of contact devices as was mentioned, at the apparent stability of conditions and modes are not always identical. For example, the contact erosion process in one cycle of the AC switch can be very different from the other, because they may be not identical by a phase at the moments of opening and closing in one and other cycles switched currents or contact and welding conditions, etc., may be different. Therefore, the researchers working in this field are well aware that it is not always possible to judge about the nature of processes occurring in devices according to the results of single tests. The analysis of such processes requires an adequate information on the events which have stochastic nature. The faults not eliminated promptly may also lead to a failure eventually. For example, the temperature rise on contacts above normal one as the result of a spring pressing weakening may take place in a circuit breaker at a prolonged passage of current without commutation. If this is not corrected resolved in the near future we can expect the welding of contacts and a switch failure.

Since, we consider the excess of contact connection certain critical value by resistance as a contact failure, at which there is an emergency defect requiring an immediate removal or the replacement of equipment, it is necessary to determine the probability of working capacity preservation concerning low-voltage switching devices, i.e., the probability of determined functions performance by the device. It is proposed to use the following condition for the evaluation of contact reliable operation

$$R_{KC} < R_{Kp} \quad (5)$$

Where:

R_{Kp} = Critical device resistance calculated according to the coefficients $K_{\Pi C}$

R_{KC} = The resistance of a switching device contact connections (Fedotov *et al*., 2005)

Assuming the law of contact resistance distribution as a normal one, let's determine the probability of a switching device resistance obtaining in determined ranges, using the expression (Koblenz, 1962):

$$p = \frac{1}{\sqrt{2\pi} I R_{kp}} \int_0^{R_{kp}} e^{\frac{-(R_k - \bar{R}_{kp})^2}{2I^2 R_k}} dR_k \quad (6)$$

Where:

I = Average mean square value of current, rel.un

R_{kp} = The critical resistance of the device in which an emergency defect takes place requiring an immediate removal or the replacement of equipment is calculated according to the coefficients

$K_{\Pi c}$ = Rel.un

R_K = The resistance of a switching device contact connection, rel.un.; The nominal current $I_{\text{ïï}}$ of a switching device, the contact connection resistance of a switching device until operating time are accepted as the basic values (Shevchenko and Gracheva, 2002)

The probabilities of switching device resistance keeping within the specified limits at load factor change are shown on Fig. 2.

CONCLUSION

They determined the contact resistance value repetition factors according to their permissible overheating term with respect to the nominal values characterizing the technical status of the electrical switchgear. Based on these multiplicities they defined the performance measures and the likelihood of working capacity preservation concerning low-voltage switching devices depending on operating modes.

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