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DETERMINATION OF OPTIMAL VALUE OF TESTING VOLTAGE FOR EFFICIENT CONTROL OF THE INSULATION

Electric physical process of electric machines insulation damages are analyzed for determination of optimal value of testing voltage and efficient control of insulation state. High voltage tests by rectified voltage at which dielectric losses are minimal and local heating during insulation test will be absent are suggested.

Key words: *insulation of electric machines, electric physical processes in the insulation, control of the state, minimal dielectric losses.*

Registration and analysis of insulation damages at electric power stations is carried out systematically by highly qualified operation staff. Electric and physical processes of insulation damage lead to purely electric mechanism of break – down, electric heat mechanism, ionization mechanism and their combination.

As it is seen from the results of the experiments, the values of break down voltages have a statistical dispersion and integral function of break-down probability $P_{pr}(U)$ is described by the normal distribution law [1]:

$$P_{pr}(U)=\frac{1}{\sigma\sqrt{2\pi}}\int_{-\infty}^{U} e^{-\frac{(U-\bar{U})^2}{2\sigma^2}}\,dU\ , \tag{1}$$

where σ – is distribution standard; $\bar{U}$ – is average value of break -down voltages.

Practically possible deviation of break-down voltage from $\bar{U}$ does not exceed $\pm 3\sigma$. Probability of such deviation value is estimated to be 0,0013 and the probability of $\pm 3\sigma$ deviation is estimated to be 0.023. That is why, for the characteristics of break-down voltage of the given form (aperiodic pulse, sinusoid, constant voltage) it is sufficient to known $\bar{U}$ and σ.

If 3σ rule is applied for insulation construction it is necessary to take into account the possibility of break-down voltage decrease to $\bar{U}-3\sigma$.

At constant high voltage ionization and electric thermal phenomena are weakly manifested, though, there appears new kind of insulation aging – chemical aging, i. e., electromagnetic phenomena that gradually lead to chemical regeneration of dielectric material, growth of conduction currents and finally to electric or thermal break-down.

Electrolysis emerges in dielectrics with the increased ionic conduction, for instance, in paper-oil insulation. Investigations of the action of the over -voltages of lighting and internal origin on the main insulation of electric machines and devices showed [2] that break-down voltage of faultless insulation is 2÷2,5 times higher than the residual voltage of surge arresters, that is why, these over-voltages are not dangerous.

In the process of operation the insulation is aging due to some slow processes such as general change of insulation structure under the impact of strong electric fields, temperatures that are higher than the class of dielectric heat resistance.

The action of the concentrators is especially negative: electric field strength, mechanical loads, heat losses. These concentrators create the emergence of local faults of the insulation that slowly increase.

Insulation of new electric machines and devices contains constructive drawbacks (erroneous construction), technological drawbacks (imperfect technologies) and poor performance of factory tests. We will start from the evaluation of high voltage tests efficiency of new electric motors main insulation.

Value of testing voltage of industrial frequency for motors of rated voltage $\mathrm{U}_{\mathrm{rat}} = 600$ V is:

$$U_{test.\mathrm{f}=50\Gamma 0} = 2\mathrm{U}_{\mathrm{rat}} + 1000 = 2{,}2\ \text{кV}.$$

As it is shown in [3] testing voltage of 2,2 kV enables to reveal only 45 % of through holes, whereas testing voltage of 1,5 kV – only 40 %, correspondingly.

These performance indices of through faults revealing by testing voltage of industrial frequency refer to only non-humid insulation. For the insulation in the state of operation humidity and contamination the efficiency of preventive tests will be higher. On the whole, the value of testing voltage of industrial frequency for such motors are not very efficient because they do not reveal considerable amount of even severe faults.

Analysis of the results of insulation tests, performed by megohmmeter, rated for 1000 V shows that only in 2÷3% of tests the resistance of the insulation with through faults is considerably reduced and in 98÷97% of cases the resistance remains unchanged.

Greater part of faults in dry insulation can not be revealed by 1000 V megohmmeter. The exceptions are insulation punctures, on their walls particles of sublimated metal or traces of carbon can be found.

Operation experience shows that if the value of testing voltage increases the amount of identified faults also increases, and faults rate of insulation damage decreases.

Calculation of insulation levels of electric machines and devices is based on admissible intensity of electric field that equals 2.0÷2.2 kV/mm. In real conditions main insulation of electric machine operates in conditions of nonuniform electric field. Analysis of the locations of insulation breakdown distribution shows that the ribs of the section are the most vulnerable, the amount of breakdowns is approximately 80 % of the total amount of breakdowns and 20 % are equally distributed between lateral, bottom and top edges.

It is explained by the greatest nonuniformity of electric field on the ribs. Nonuniformity coefficient in slop part of the winding is the largest on the ribs and depends on the ratio of corner radius r and the thickness of the insulation d. The value of corner radius of the ribs $r = 3 \div 5$ mm. If the ratio $r/d \leq 0.5$ the satisfactory value of nonuniformity ratio K_n ($r/d \geq 0.5$) < 1.5 is achieved. Then $d > \dfrac{r}{0.5} = \dfrac{3 \div 5}{0.5} = 6 \div 10$ mm. Proceeding from the thickness $d \geq 6 \div 10$ mm and admissible intensity $E_{adm} = 2.0 \div 2.2$ kV/mm, the value of testing voltage can be obtained

$$U_{test} = \frac{2.0 \div 2.2}{1.5} \cdot d = \frac{2.0 \div 2.2}{3} \cdot 2d = (0.67 \div 0.73) \cdot (12 \div 20) = 8 \div 14.6\ \text{kV}.$$

Another direction of increasing the performance of electric motors insulation tests $U_v = 600$ V is testing by the rectified voltage. In case of such voltage dielectric losses are minimal and dangerous local heating during insulation test does not occur.

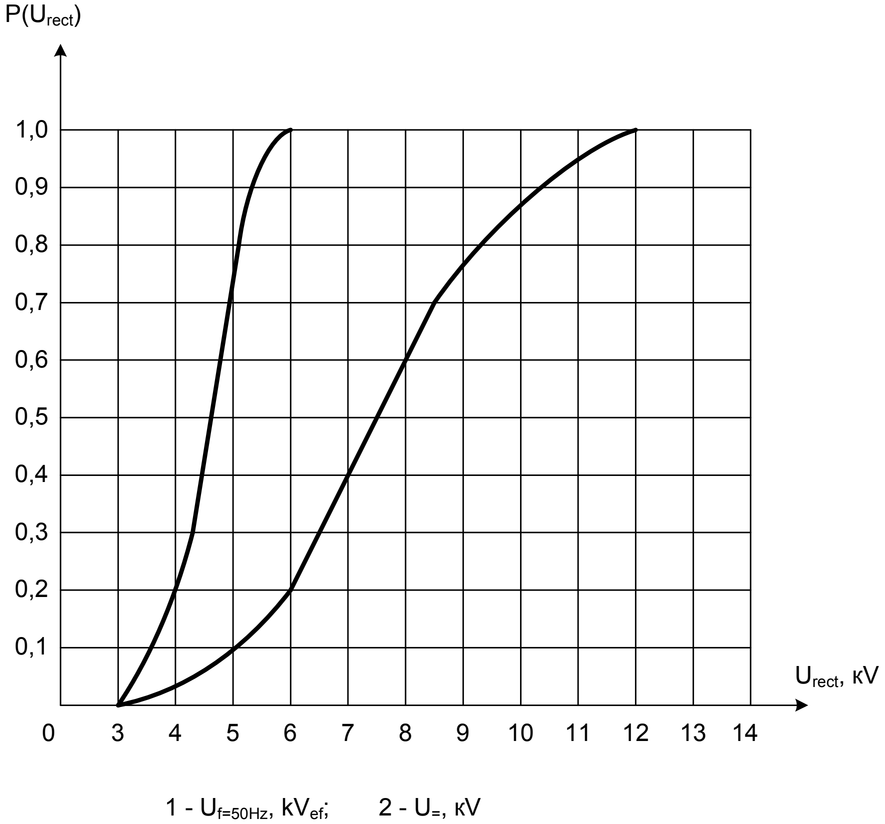

Fig. 1. Integral curves of electric breakdowns distributions of mica tape insulation of slot parts of electric motors by variable (1) and constant (2) voltage

It is seen from Fig. 1 that as a result of dielectric losses in the insulation at $U_{test.\mathrm{f=50Hz}}$ breakdown voltage $\bar{U}_{b.d.}$ in 1.73 times less, than at $U_{test.=}$ and correspondingly $\bar{U}_{b.d..=}$. That is why, the duration of testing voltage application $U_{test.f\mathrm{=50Hz}}$ should be limited in order to reduce the impact of insulation overheating on the result of tests.

At steady testing voltage break-down voltage at $P(U) = 0.5$ exceeds nominal voltage $7500/600 = 12.5$ times. In case of a.c. testing voltage break-down voltage at $P(U) = 0.5$ exceeds nominal voltage $4700\cdot 1.41/600 = 11$ times.

If arresters are available, the overvoltages are limited by their characteristics, and if arresters are missing – by the level of contact grid .

It is known that the level of contact grid insulation is determined by supporting and tension insulation suspensions. Length of source route on the surface of such suspensions depends on the area of pollution along the path and corresponding specific length of source route λ_{tf}. In Rules of electric installations arrangement λ_{ef} is given in efficient values of sinusoidal voltage, that is why, in case of direct current networks $\lambda_{ef} = \lambda_{ef\sim} \cdot \sqrt{2}$.

Thus for the networks of $U_{nom} = 600$ V for III zone of pollution $\lambda_{=} = 2.25\cdot 1.41$ cm/kV$_{\max}$ = 3.172 cm/kV$_{\max}$. Length of source route on the surface of the insulator in 600 V grid will equal

$$L_{s.r..} = U_{tom} \cdot 3.1725 = 5\kappa V \cdot 3.1725 = 15.8\,cm.$$

It is known [4], that the calculated level of insulation is determined from the equation

$$U_{cal} \geq (0.85 \div 0.9)\mathrm{U}_{\mathrm{test}} \cdot \sqrt{2} \cdot \mathrm{k}_{\mathrm{i}}\,, \qquad (2)$$

where U_{test} – is test voltage of industrial frequency, electric motor insulation is tested by this voltage after periodic restoration repairs, 2.1 kV$_{ef}$; k_i – is the coefficient of insulation pulse, that is taken for the equipment after preventive repair, it equals 1.1÷1.2.

$$U_{cal} \geq (0.85 \div 0.9) \cdot 2.1 \cdot \sqrt{2} \cdot (1.1 \div 1.2) = 3.2 \text{ kV}.$$

Recently, new electric devices--- overvoltages arresters, non-linear (OANL) are used instead of conventional valve-type arresters. Overvoltage arresters more deeply limit switching and lighting surges as compared with valve-type arresters. OANL – is a device, based on metal oxide varistors without spark gaps.

OLNL has two protective characteristics:

1. Lighting level of protection – residual voltage $U_{r.l..}$ in case of rated current I_r action.

2. Switching level of protection – the largest of residual voltages $U_{r.s..}$ in case of the action of switching pulses of current with rated amplitudes..

Overvoltages on frame insulation of traction electric motors

Atmospheric overvoltages, acting on frame insulation, are created by such type of lighting currents:

– Pulse of current with steep front (duration of the front 1μs, pulse duration 2÷20 μs);
– Pulse of current of large amplitude with the form 4/10 μs;
– Lighting pulse of current with the form 8/20 μs;
– Switching pulse of current with the form 30/60 μs;
– “Long” pulse of current of rectangular form, duration 2000÷4000 μs.

Losses of power at steady voltage

$$P_{=} = \frac{U_{test}^2}{R_V} \tag{3}$$

Losses of variable voltage are determined by the formula:

$$P_{\approx} = U_{test}^2 \cdot \omega \cdot C \cdot \text{tg}\delta \tag{4}$$

We determine how many times the losses differ:

$$\frac{P_{\approx}}{P_{=}} = \frac{U_{test}^2 \cdot \omega \cdot C \cdot \text{tg}\delta}{U_{rect}^2 / R_V} = \omega \cdot R_V \cdot C \cdot \text{tg}\delta \tag{5}$$

Between the capacitance C and the resistance of the insulation section there exists the relation:

$$R_V \cdot C = \varepsilon_0 \cdot \varepsilon \cdot \rho_V \tag{6}$$

We will substitute (4) in (3) and obtain the value $\frac{P_{\approx}}{P_{=}}$:

$$\frac{P_{\approx}}{P_{=}} = \omega \cdot \varepsilon_0 \cdot \varepsilon \cdot \rho_V \cdot tg\delta . \tag{7}$$

It is known that the product $\varepsilon_0 \cdot \varepsilon \cdot \text{tg}\delta = k_{\partial.в.}$ – is coefficient of dielectric losses, that is why

$$\frac{P_{\approx}}{P_{=}} = \omega \cdot \rho_V \cdot \mathrm{k}_{\mathrm{d.l..}} \tag{8}$$

We define $k_{d.l..}$ for such dielectrics:

Polystirol: $\varepsilon = 2.6 \div 2.8$; $\text{tg}\delta = 12 \cdot 10^{-3}$; $\rho_V = 10^{14} \div 10^{15}$ Ohm·m.

$k_{d.l/.} = \varepsilon_0 \cdot \varepsilon \cdot \text{tg}\delta = 8.854 \cdot 10^{-12} f/m \cdot 2.7 \cdot 12 \cdot 10^{-3}$

$$\rho_{\text{V}} \cdot k_{d.l.} = 5\cdot10^{14}\,Ohm/m\cdot 8.854\cdot10^{-12}\,f/m\cdot 2.7\cdot 12\cdot10^{-3} = 2390\cdot 12\cdot10^{-3} = 28.68$$

$$\omega = 2\pi\text{f} = 3.14\cdot 2\cdot 50 = 314\ \text{sec}^{-1}$$

$$\frac{P_{\approx}}{P_{=}} = 28.68\cdot 314 = 9000\,.$$

Mica: $\varepsilon = 6.1\div8.4$; $\text{tg}\delta = 12\cdot10^{-3}$; $\rho_V = 10^{13}\div10^{14}$ Ohm·m.

$$k_{d.l..} = 8.854\cdot10^{-12}\cdot(6.1\div8.4)\cdot 4\cdot10^{-4} = 240\cdot10^{-16} = 2.4\cdot10^{-14}$$

$$\frac{P_{\approx}}{P_{=}} = 2.4\cdot10^{-14}\cdot 314\cdot10^{14} = 753\,.$$

Polyethylene: $\varepsilon = 2.1\div2.4$; $\text{tg}\delta = (2\div3)\cdot10^{-4}$; $\rho_V = 10^{15}$ Ohm·m.

$$\varepsilon_0\cdot\varepsilon\cdot\rho_V\cdot\text{tg}\delta = 19480\,\text{sec}\ 2.5\cdot10^{-4} = 4.87\,;$$

$$\frac{P_{\approx}}{P_{=}} = 4.87\cdot 314 = 1530\,.$$

Glass: $\varepsilon = 3{,}75\div8{,}0$; $\rho_V = 10^{14}$ Ohm·m.

Porcelain: $\varepsilon = 6\div7$; $tg\delta = 0{,}03$; $\rho_V = 10^{15}$ Ohm·m.

Paper-based laminate: $\varepsilon = 5\div6$; $tg\delta = 10\cdot10^{-2}$; $\rho_V = 10^{6}\div10^{9}$ Ohm m.

Thus, testing of the insulation by variable voltage is dangerous for insulation as compared with constant voltage as a result of great losses, energy of which is spent for insulation heating. The probability of electric thermal mechanism of breakdown increases.

Conclusions

1. Level of main insulation of electric motors $U_{nom} = 600$ V is 12 times higher than nominal voltage.
2. During 12 – 15 years of operation this level decreases 1.5 times, i. e., 8 times higher than the nominal voltage.

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