Estimation of winding insulation resistance to the corona discharges

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Abstract. This article presents test results of enameled winding wires, characterizing an insulation electrical and mechanical strength. Standard and original test methods were used. Note that existing standard test methods do not estimate enamel insulation resistance to the electrical loads under winding operation of variable-speed drive. We show that estimation of wire corona resistance can be done by high frequency electrical impulse testing. Wire insulation plays the main role of reliability of insulation system.

1. Introduction
Widespread application of variable-frequency control (VFC) system of AC motors built on the base of pulse-width modulation (PWM) is the main development trend of automatic control system. Obvious advantages of VFC system applying go hand-in-hand with important disadvantages – detrimental effect on electrical insulation that could result in reducing sharply a winding lifetime – primarily, the turn insulation as the weakest winding unit. As a result, it acutely brings up an issue about testing methods and means of enamelled wire insulation, providing enough reliable estimate of its mechanical and electrical properties, as well as making assertion about applicability of one wire or another in variable-frequency drive (VFD) windings.

Currently, there are several methods normalized by different standards, specifications, etc. They make it possible to estimate the level of electrical and mechanical properties of enamel insulation. At the same time, the existing methods ignore aspects of winding operation at the VFC. It is known that PWM application causes sharp increase of electrical load level (overvoltage value is in excess of supply voltage value in 10 times; frequency – up to $10^{-4}$ s), leading to occurrence of partial discharges in winding [1, 2]. As a result, it raises a question about adequacy of existing test facilities for wires, being used in VSD windings [3 - 8].
2. Experimental results

This paper presents a done integrated research of electrical and mechanical properties for widely used winding wires by the existing standard methods. Mechanical properties were estimated by abrasion test, scratching an insulation by needle with ever-increasing load, and by calculation a number of wire insulation defects on unit length as-delivered condition and after winding on the metal rod. In addition, breakdown voltage of enamel insulation was determined as-delivered condition and after winding on the metal rod, equaling to double wire diameter. Obtained results are shown in Table 1 and indicate a satisfactory quality of all the test samples.

Table 1.

| Wire mark | Average (test) value of double needle moves (diameter 0.4mm) to breakdown /min. permissible | Breakdown voltage, kV /min. permissible value by specifications, kV | Number of insulation defects on unit length, mm⁻¹ | As-delivered condition | After mechanical stress |
|-----------|------------------------------------------------------------|---------------------------------------------------------------|---------------------------------|------------------------|------------------------|
| PET-200-1 | 275 / 30                                                   | 6.8 / 5.3                                                    | 0.00005                         | 0.0001                 |
| PET-155   | 230 / 20                                                   | 6.1 / 4.4                                                    | 0.00012                         | 0.00024                |
| PET-2      | 250 / 20                                                   | 8.2 / 5.1                                                    | 0.0001                          | 0.0002                 |
| PETD-180  | 203 / 70                                                   | 6.8 / 4.7                                                    | 0                               | 0.0001                 |
| PETD-2-K-180 | 393 / 70                                             | 8.3 / 4.5                                                    | 0                               | 0.0001                 |
| PEEA-155  | 33 / 20                                                   | 4.2 / 2.7                                                    | 0.0028                          | 0.0036                 |

Unfortunately, there are not enough domestic recommendations for estimating an enameled wire resistance to the corona discharges. This fact determined applying original methods for researching this issue. When performing the tests, the main idea is to place a test sample in the corresponding environment with surface (corona) discharges. Such conditions are obtained by using the electrode systems "wire-shot" (Fig. 1), "wire-plate" (Fig. 2). Taking into account the experience, the test voltage range can be from 4 to 5 kV. A lower voltage level provides surface discharges appearing; the top is not sufficient for immediate breakdown of the intact insulation. The criterion is the average time from a voltage input to a insulation breakdown.

Fig. 1 Test sell: a - 1 – bath; 2 – steel shot; 3 – a grounded wire; 4 – metal electrode; b - 1 – a grounded wire; 2 – copper plate.

The paper presents a number of the tests in the above mentioned electrode systems. The objects have been wire marks: PETD2-K-180, PETD-180, PET-155 and PETV-2. The samples showing the greatest time to breakdown (PETD2-K-180, PETD-180) have additionally been tested after the winding on a metal rod and the tension of 5% and 10%. The results are summarized in Histogram 1.
and 2. Thus, the wire PETD2-K-180 withstands better the electrical loads both in the as-delivery condition and after a mechanical impact.

In papers [9-12], a control-measuring system for the winding wire lifetime evaluation is proposed duplicating the conditions created by the frequency regulation system of an electric motor (temperature influence, frequency, voltage and rise time of pulses). In view of this, tests were conducted under the conditions of samples: an alternating voltage with the amplitude of 1200 V, frequency of 400 Hz with the quantization voltage frequency (modulation) of 5 kHz (the duration of the wave front), with the rate of pulse rise 4 ms and temperature corresponding to the heat resistance of enameled winding wires. The test samples are like a twisting wire with the operating zone of 125 mm.

Histograms 1 – Average time to insulation breakdown (as-delivered condition):
- a) electrode system “wire-shot”;
- b) electrode system “wire-plate”.

Histograms 2 – Average time to insulation breakdown (after mechanical stress):
- a) electrode system: «wire-shot», after the winding;
- b) electrode system: «wire-shot», after the tension.

The frequency of 400 Hz with the quantization voltage frequency (modulation) of 5 kHz (the duration of the wave front), with the rate of pulse rise 4 ms and temperature corresponding to the heat resistance of enameled winding wires. The test samples are like a twisting wire with the operating zone of 125 mm.
A corona resistance criterion is also the average time to an electrical insulation breakdown. Since the turn insulation system of AC windings is a complex of wire insulation and impregnation compound (IC), additional tests were carried out on high frequency test block by using a modern IC in the domestic market. These include impregnating varnish of KO-916K, impregnating compositions of KP-55-5 and KP-50. The results are shown in Histogram 3.

Histogram 3 shows that the PETD2-K-180 wire has the greatest corona resistance at the operating temperature. It enables to make recommendations for its use in the electric machines windings (in case of application of the system frequency control because of having the highest resistance to corona discharges). The wires having the thermal class F and wire PETD-180 are not much worth in size of the average time to the breakdown.

3. Conclusion

1. The obtained results clearly demonstrate the different degrees of enameled wires resistance to electrical loads.

   Among the tested wire marks, these two ones PETD-180 and PETD2-K-180 have the greatest time to a breakdown. The value of the average time to a breakdown of their enamel insulation is almost comparable in the delivery state. This is due to the fact that the insulation of these wires is a two-layer composition. The inner layer of the wire PETD-180 is made of a polyester enamel, external - of polyamide-imide enamel. The inner layer of PETD2-K-180 is made of a trihydroxyethylcyanurate enamel containing a silica nanoparticles at least 0.1% vol., and external – of polyamide-imide enamel. Such compositions provide the necessary corona resistance properties of the insulation.

2. It is necessary to carry out a more accurate estimation of the insulation stability to the surface discharges after a mechanical stress (tension, winding on a metal rod). The results show that the greatest resistance to corona discharges after the tension and winding have wire PETD2-K-180.

3. The average time value to the enamel insulation breakdown of samples on a copper plate is lower than in a steel shot. This is due to the fact that the large surface area of the pad electrode promotes an ozone concentration increase and thereby the destruction rate increase of an enamel film. A low value of the average time to an insulation breakdown was obtained as a result of the field inhomogeneity at the samples attaching point. However, the obtained results on a pad electrode show the different levels of enamel wire resistance to electrical discharges.
4. The final estimation of the corona resistance is possible after testing high-frequency electrical pulses. In this case, the sample is exposed to the complex loads under operating conditions: temperature, electric voltage, corona discharges.

5. Application of impregnation compounds does not provide corona resistance, and in several cases deteriorate properties of wire insulation. Thus, wire insulation plays the main role of reliability of insulation system.

6. Application of corona resistance materials when designing the VFD is compulsory condition. And it is necessary to choose materials carefully, not reducing properties of other ones. It is connected with the fact that an increase of the repetitive surge of electrical impulses, generated by the voltage source inverter PWM, the operating loads level is increased, accelerating the aging process of an insulating system. The electrical aging leads to premature wearing and an insulation breakdown.

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