

Determination of enamel insulation corona resistance by high-frequency modulated pulses

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Abstract. In the article test equipment is described for corona resistance testing of enameled winding wire samples. The primary element of equipment is generator producing test voltage with necessary waveform and magnitude according to the required PWM. Test conditions are accurately simulated by operational loads on a winding insulation (simultaneous impact of temperature and corona discharges). Obtained results of average time to breakdown show that the enamel insulation modified by silicon nanoparticles has a maximum corona resistance.

Keywords: enameled wire, corona resistance, winding, VFD, PWM, tests.

I. Introduction

Recent advances in the development field of power semiconductors and the method of pulse-width modulation allowed increasing significantly the frequency of switching operations (up to 20 kHz), minimizing power losses, and improving the performance of variable frequency drive [1]. However, increasing the switching speed reduced the rise time of the voltage pulses, which had a negative impact on the transition processes in the inverter – power cable – motor circuit. Impedance mismatches between the inverter, cable and motor excited wave processes in the cable and signal reflection phenomenon that resulted in overvoltages at the motor terminals [2–4]. Such electrical loads tightened operation conditions of VFD insulation system and, first of all, turn-to-turn insulation as the weakest element of the winding insulation. Corona discharges leading to accelerated aging of the insulation and further breakdown began appearing in voids and air gaps [5–7]. Currently, there are some standardized methods to determine the electrical, mechanical and thermal properties of the winding wire insulation. Unfortunately, there is no detailed information about any method to determine the enamel insulation resistance to the effect of corona discharges. In this regard, a reasonable choice of enameled wires for use in low-voltage machine windings with frequency regulation system is complicated. The aim of this work is to develop equipment for determining the enameled wire insulation resistance to the effect of operating loads in the VFD.



II. Theory

Total operational impacts causing aging of the insulation is varied and complex, but in many cases the main reason of aging is the high electric field. The main negative factors in the VFD resulting in overvoltage appearance in LV windings are:

- high slew rate (du/dt) – high rate of inverter output voltage rise has a negative impact on the cable insulation and its winding by small distances between inverter and motor.

- overvoltages at the motor terminals – it is the result of occurring wave phenomena being sometimes called "The long transmission line effect", "The reflected wave effect" or "The standing wave effect".

- additional losses in a motor and feeder – the higher harmonics of voltage and current lead to additional losses in feeder, motor core and winding, especially in the rotor "squirrel cage".

The destructive effect of surface discharges is a result of heating impact, charged particle bombardment (generally, electrons), the impact of chemically active products formed during the surface discharge effect, as well as impulse waves and radiation.

The effect of these factors causes erosion (destruction of the surface with material entrainment), as well as structural changes (degradation, cross-linking of the polymer chains). Erosion can be caused by the following reasons:

- a) oxidation of polymers by highly reactive radicals existing only in the discharge area;
- b) reactions of polymer microradicals formed under the influence of a discharge, with oxygen of gaseous atmosphere or another active material arisen as a result of the surface discharges;
- c) the dielectric surface bombardment by electrons and ions.

Ozone formation is typical of discharges in the air. Ozone is very corrosive, easily oxidize. In an enclosed space ozone formation is only a transitional phenomenon. Ozone oxidizes air nitrogen, after a while ozone disappears and nitrogen oxide stays. Various stable and unstable nitrogen bonds are formed by discharges in the void filled with air.

The mechanical and electrical insulation properties are sharply deteriorated because melting, emission, carbonization and chemical decomposition occurs in the field of surface discharges effect. Conductivity and lose factor of electrical insulating material increase because of rising the temperature that enhance the local heating.

Above factors have an effect together with increased temperature. Based on these conditions, tests of enameled wire must adequately reproduce the thermal and electrical loads on winding.

III. Test method

Sample is the standard twisted pair placed in heat chamber. Tests are carried out at a temperature of heat resistance class [7]. High-frequency electric loads are created on the twisted pair insulation using specially designed equipment (Figure 1). Criterion is the average time to insulation breakdown.

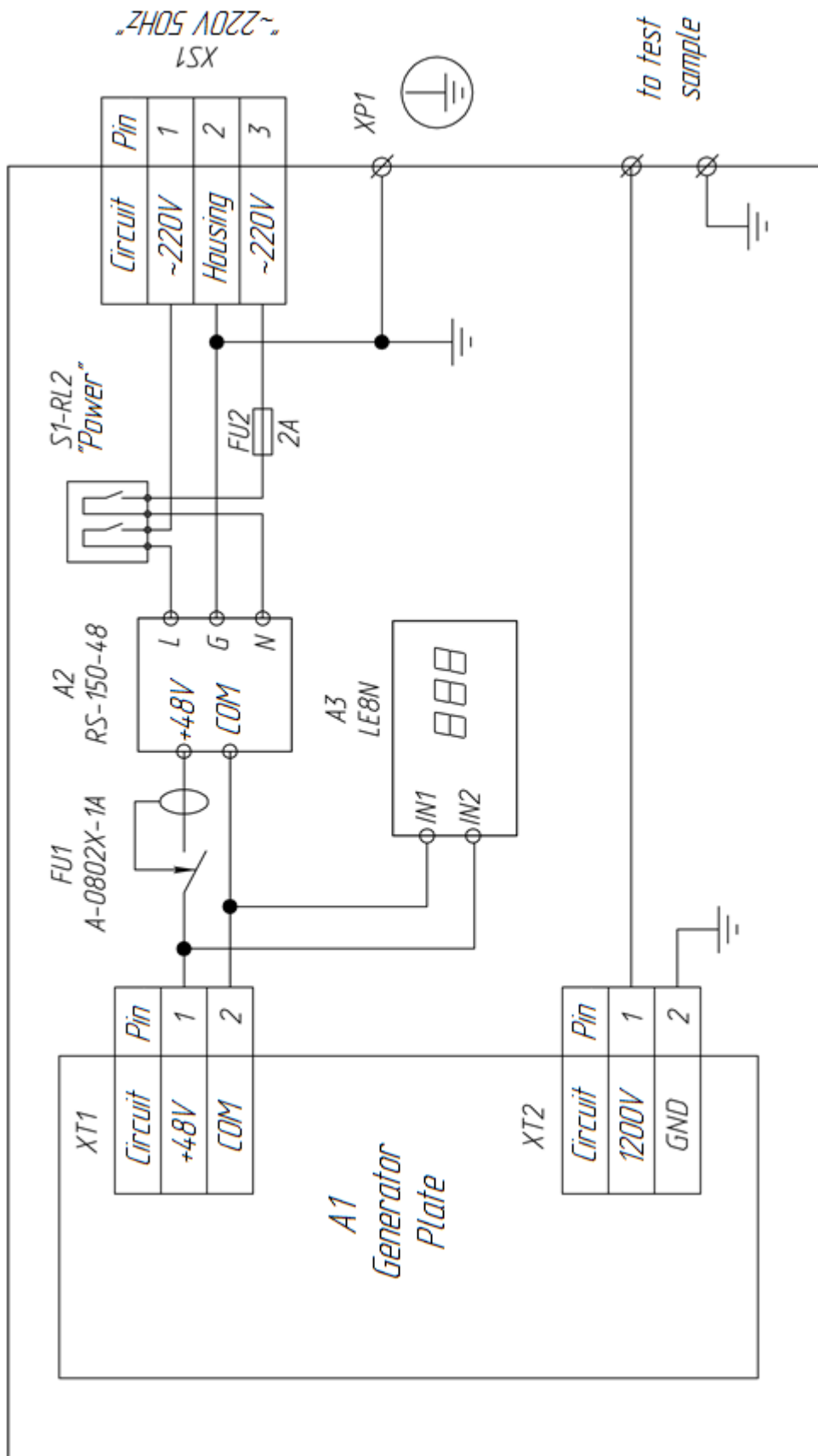


Figure 1. Schematic structure of equipment for test voltage generating, where A1 – generator plate, A2 – module power supply RS-150-48, A3 – accumulated hour meter LE8N, FU1 – circuit breaker assembly A0802X-1A, FU2 – amp fuse 2A, S1 – network commutator RL2.

Figure 1 shows equipment schematic structure forming the test voltage. Further, the operating principle of equipment is stated. Generator plate *A1* generates a pulse signal with amplitude $U_a = \pm 1200\text{ V}$ feeding the test sample in the heat chamber by the high-voltage wires. Generator plate is powered by the voltage $U_s = 48\text{ V}$ from module power supply *A2* through circuit breaker assembly *FUI*.

Accumulated counter timer *A3* is activated by synchronous power supply to the generator plate and test initiation. Time is calculated until control voltage of 48 V supplies the counter. The threshold level of circuit breaker is selected so that the input current is increased in the feed network by sample breakdown and circuit breaker *FUI* breaks the circuit. Tests are broken off and the accumulated counter timer *A3* stops counting. Equipment turn on / off is made by the *SI*. The equipment construction according to the current structure provides the simplest implementation.

Generator plate schematic is shown in Fig. 2. The scheme operational principle is stated below. A rectangular voltage formation with required PWM law is realized by the processor module *A1*. This solution is the most ideal for solving single tasks in the case of laboratory research. Module is powered by a galvanically isolated power supply *DA2*. Generated signals are transmitted to the following stages via photo coupler *DA1*. The galvanic isolation of the processor module allows providing the equipment resistance to interference. Driver *DA3* separates signals on two channels and enters a pause between control pulses of $0,4\text{ }\mu\text{s}$ by the power transistors. Drivers of control transistors *VT1* and *VT2* are implemented on chips *DA4* and *DA5* respectively. Switching circuits are identical and correspond to the standard ones recommended by manufacturer. Consider the example of driver work on the circuit *DA4*. Switching on is carried out by LED through a resistor *R1*. Chain *C10*, *R5*, *VD3* protects the transistor *VT1* against overcurrent, including short circuit. Resistor *R1* limits the switching speed of transistor and protects the output stage circuit *DA4* against overcurrent. Diode *VD1* and resistor *R7* provide protection of transistor gate against overvoltage and increase resistance to interference. Diode *VD5* provides a path flow of reverse current when the transistor *VT1* is off. The power stage is built by the scheme of circuit transformer with a common point. This scheme enables efficient operation of equipment at a low supply voltage. Transformer *T1* increases the test voltage up to $\pm 1200\text{ V}$, and provides galvanic isolation of equipment from high-voltage circuit. The output voltage is supplied to pins 3 and 4 of the connector *X1*. Supply voltage 48 V is supplied to the generator plate through the terminals 1 and 2 of connector *X1*.

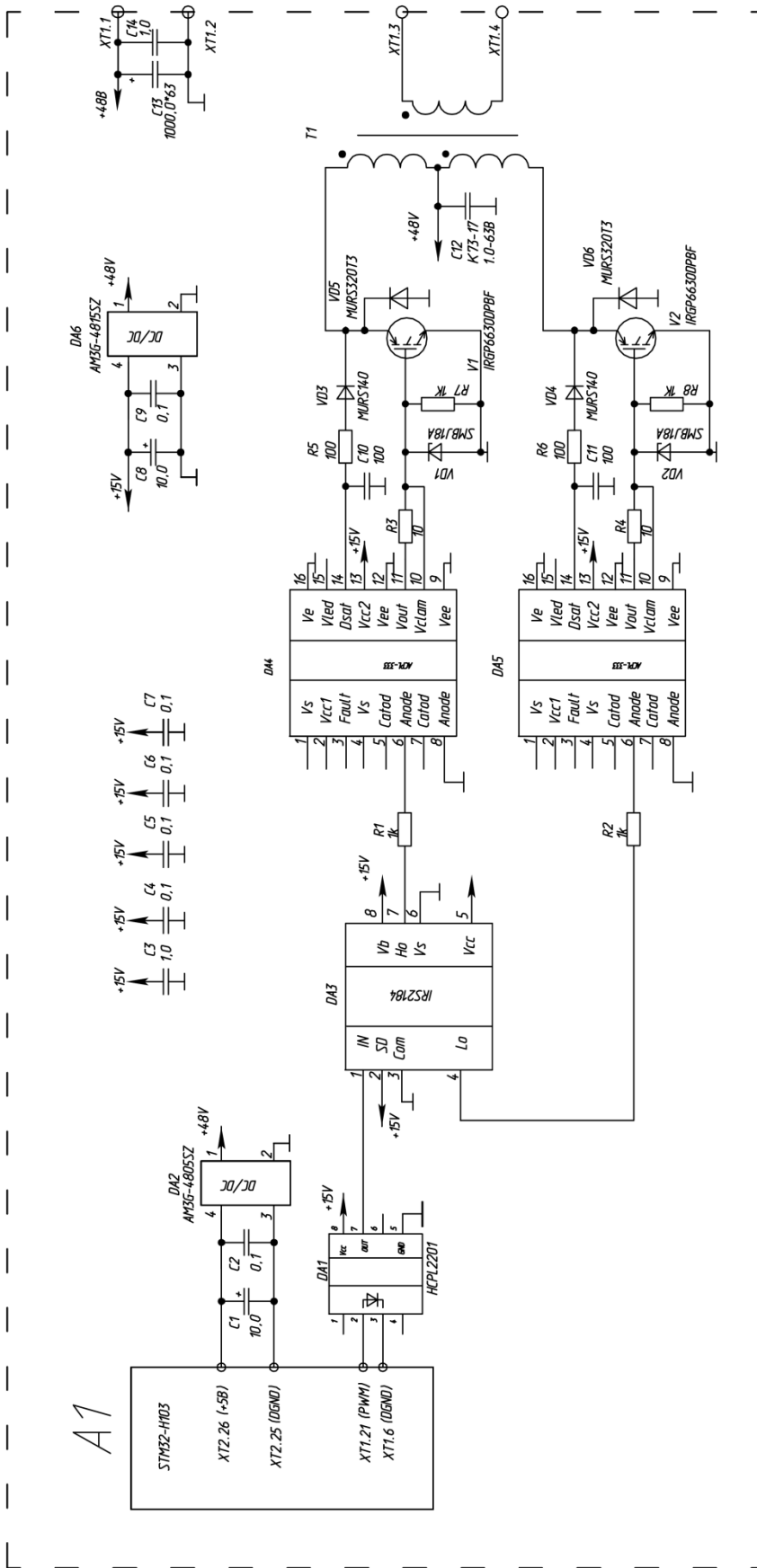


Figure 2. Generator plate schematic: A1 – processing module STM32-H103, DA1 – photo coupler HCPL2201, DA2 – modulate power supply AM3G-4805SZ, DA3 – driver IRS2184, DA4, DA5 – drivers ACPL-333, DA6 – modulate power supply AM3G-4815SZ, VD1, VD2 – protective diodes SMBJ18A, VT1, VT2 – transistors IRGP6630DPBF, VD3, VD4 – diodes MURS140, C1, C8 – tantalum capacitors TESAR CHIP 10uF x 10V type C 10%, C2-C7, C9-C11 – ceramic capacitors 1206-X7R- 50, C12, C14 – polymer film capacitors K73-17-1.0-63B, C13 – electrolytic capacitor ECAP 1000/63V 1625 105C SH, R1, R8 – CHIP resistors 1206 0.25 W 1%, T1 – voltage transformer MII2000HM- 4*K45× 28×8, w1= w2=105 wire windings PEV2-0.15, w3= 2800 wire windings PEV2-0.8.

IV. EXPERIMENTAL RESULTS

The general scheme of tests is shown in Figure 3.

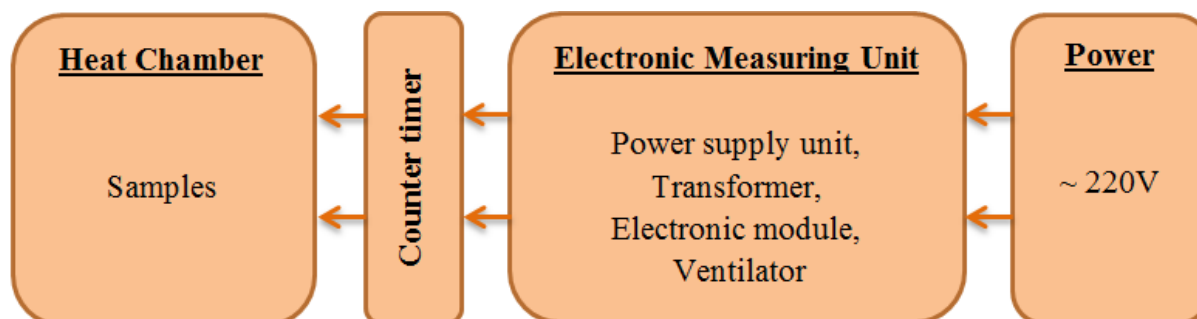


Figure 3. Block-scheme of high-voltage test equipment.

During the tests were obtained values of the mean time to breakdown samples wires with enamel isolation of various types. Samples were tested as in the initial state and after impregnation with impregnating materials. For each experiment was tested at least 20 samples. Summarized results are presented in Table 1.

Table 1. Determination of average time to wire twists breakdown by high voltage tests

Wire insulation type	Impregnating compound type	Average time to breakdown t_{br} , s
1 layer (inner) – 3-hydroxiethylcyanurate varnish, comprising at least 0.1 volume percent of silicon nanoparticles, 2 layer (outer) – polyamide imide varnish	Without IC	9509
	KO-916K	10664
	KP-50	14728
	KP -55-5	11412
1 layer (inner) – polyester varnish , 2 layer (outer) – polyamide imide varnish	Without IC	2009
	KO-916K	1286
	KP -50	1278
	KP -55-5	1192
Polyester varnish	Without IC	2337
	KO-916K	1085
	KP -50	1736
	KP -55-5	1812

V. Conclusion

1. Tests on the high voltage laboratory bench allow producing the whole range of operating loads, closest to the real operation of the VFD winding with PWM. In this case, temperature, electrical voltage, corona discharges influence on sample.
2. Developed equipment generates electrical impulses exciting appearance of stable corona discharge across the twisted part of the sample during the entire experiment. The value and shape of electrical impulses adequately reproduce overvoltages caused by the PWM operation: 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.
3. Wire with two-layer insulation modified by silicon nanoparticles has the greatest time to a breakdown. It is apparently associated with non-traditional mechanism of wire insulation destruction modified by nanoagents. In case of conventional wire aging, corona discharges cause material

destruction processes leading to the polymer chains break and the formation of free radicals and the volatile decomposition products. It results in relatively rapid insulation breakdown. But in the case of corona resistance wires, nanoparticles put into the enamel insulation have a strong interaction between the particles (bond strength) by the corona resistance development. Thus, it creates a kind of protective layer slowing the insulation breakdown during the material degradation.

References

- [1] Melfi M, Sung A M J, Bell S, Skibinski G L 1998 *Industry Applications, IEEE Transactions on* p 766 - 775
- [2] Stone G C, Culbert I M, Lloyd B A 2007 *Cement Industry Technical Conference Record, IEEE*, p 187 – 192
- [3] Bogh D, Coffee J, Stone G, Custodio J 2006 *Industry Applications, IEEE Transactions on* p 148 – 154
- [4] Fenger M, Campbell, S R, Pedersen J 2003 *Industry Applications Magazine, IEEE* p 22- 31
- [5] USSR copyright certificate №536443, МПК5 G01R31/00, published 25.11.1976
- [6] Pulse width modulation simulator for testing insulating materials. US Patent No. 6051980, Is-sued on April 18, 2000.
- [7] Leonov A P, Red'ko V V, Soldatenko E Yu 2014 *20th International Conference for Students and Young Scientists: Modern Techniques and Technologies (MTT'2014)*, Tomsk, Russia Vol. 66