Simulation of the aging process of insulating systems variable frequency drive

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Abstract. The paper deals with the intensity of the model in the electrical insulation variable frequency drive controlled at different temperatures and electric fields. It is shown that aging of insulation mechanism associated with the development of corona discharges caused by transients when the frequency adjustment. Laws aging of insulation can be described from the point of view of the theory of thermal destruction of dielectrics vibrations.

1. Introduction

The use of frequency converters (FC), in the structure using semiconductor switches, led to a new problem - sharp decrease in the life and the insulation of supply cables of the windings of electric machines. This is due to insulation failure caused by surge [1-2].

FC using a technology known as "Pulse width modulation" (PWM) is generated at the output of the necessary basic voltage and frequency. The inverter circuit "switching" transistors operating at high speed, producing a carrier frequency over which the useful basic voltage and frequency.

The output voltage of the autonomous voltage inverter (VSI) with PWM is a high-frequency sequence of rectangular pulses having different polarities and duration with the same amplitude DC input on the VSI. The high rate of rise of the voltage pulses is determined by the speed switching VSI power switches and by using different semiconductor devices is about 0.05 ... 0.1 ms.

Such a high speed has a negative impact on the flow of transients in the circuit VSI - power cable - squirrel-cage induction motor. Passage of pulse signal at a high speed causes a voltage rise in the cable wave processes, which give rise to surges in the cable line to the motor terminals [3].

In addition, the effect of the reflected mode caused by high-rise speed of tension (dU/dt) and length of the feeding cable, which works as the transferring line, affects. For example, for the class of inverters 3.3 kW speed voltage changes (dU / dt) can exceed 7500 (B / μsek). Due to the mismatch the wave resistance at different ends on the cable (the cable - the cable and the inverter - the motor) high-frequency part of the wave that reaches the motor windings and reflected back the source. As reflected peaks superimposed on the peaks of the waves coming, their values added, causing voltage surges. In operation, an increasing number of cable lines peaks "stacked" on each other, at the same time, resulting in a greater amount pulse voltage per unit time [4-5]. Having said that, there is the problem of determining actual values of voltages and taking into account their influence on the processes aging and deterioration the electrical insulation.

2. Experimental part

The problem of estimating the values of electric voltages solved in a graphical environment simulation MATLAB Simulink.

A general view a simulation model of the variable frequency drive, made in MATLAB Simulink and including FC based on a PWB (1), the cable line (2) and squirrel-cage induction motor (3), Fig. 1. When building simulation models take into account the wave parameters of cable lines: linear capacity C_x, inductance L_x and wave resistance Z_x.
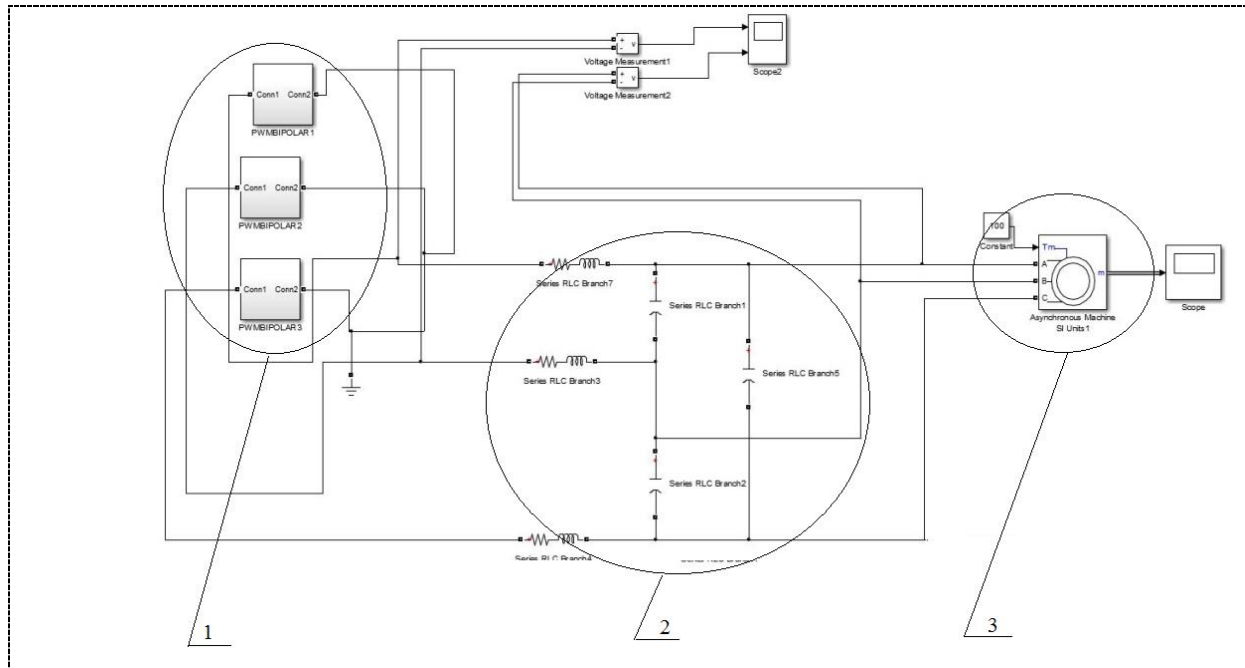

Figure 1. The simulation model of the variable frequency drive (VFD)
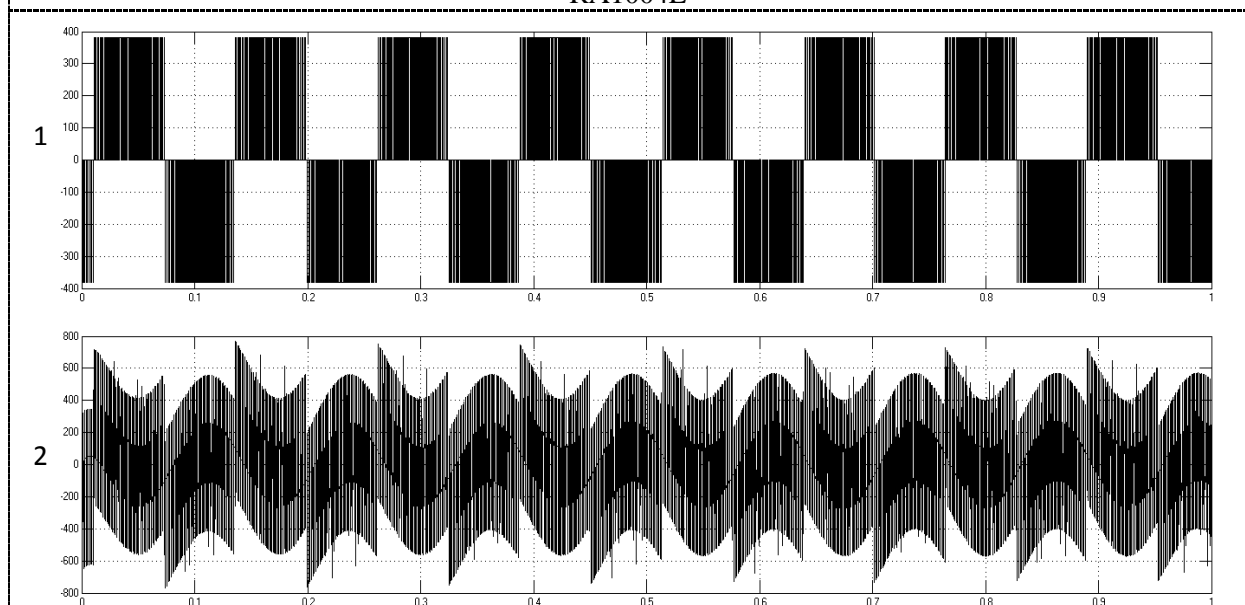1 - generator PWM pulse signals; 2 - cable line VVG 1x2,5; 3 - squirrel-cage induction motor series RA1004L

Figure 2. The nature of the voltage stress in the VFD 1 - effective value of line voltage generator after the pulse-pulse signals, 2 - the current value of the linear voltage after the cable line VVG 1x2,5

The simulation results allow to note:

1. In the absence of a sinusoidal filter is a sharp increase in the voltage amplitude on the cable line and motor terminals. This high level of stress in combination with high-frequency components of the PWM voltage pulses should definitely accelerate the electrothermal aging of insulation.

2. The supply voltage curve comprises high-frequency components that distort the voltage waveform (Fig. 6) and the resulting PWM operation, the effect of "reflected wave" and the high-frequency harmonics, belonging to the cable line from FC.

Definition of mean time to breakdown of the cable insulation

Subject to certain electric magnitudes of the stresses acting on the VFD element insulation, comparative tests were carried out cable samples under commercial frequency voltage and high-frequency modulated signal. The basis adopted by the procedure described in [6-8]. The results shown in Table 1.

Table 1. Temporal dependence before breakthrough on type of insulation and temperature

Type	Wire insulation	The mean time to breakdown (τ_{cp}), s.		
	Temperature, °C	180`°C	190°C	200°C
1	layer (inner) – polyester varnish , layer (outer) – polyamide imide varnish	3082,6	2642,2	2429,4
2	1 layer (inner) – 3-hydroxiethylcyanurate varnish, comprising at least 0,1 volume percent of silicon nanoparticles,2 layer (outer) – polyamide imide varnish	9692	5326	3441,4

The presence of corona discharges, as well as appropriate forms of electrical loads supplied signal characteristic for VFD confirmed glowing corona surface twists and waveform values, characteristic currents and voltages, removed from the sample (Fig. 3 a, b)

a)   b)

Figure 3. General view of the twist test and electrical load applied to the sample: a - glow corona discharge on the sample; b - waveform of current and voltage applied to the sample
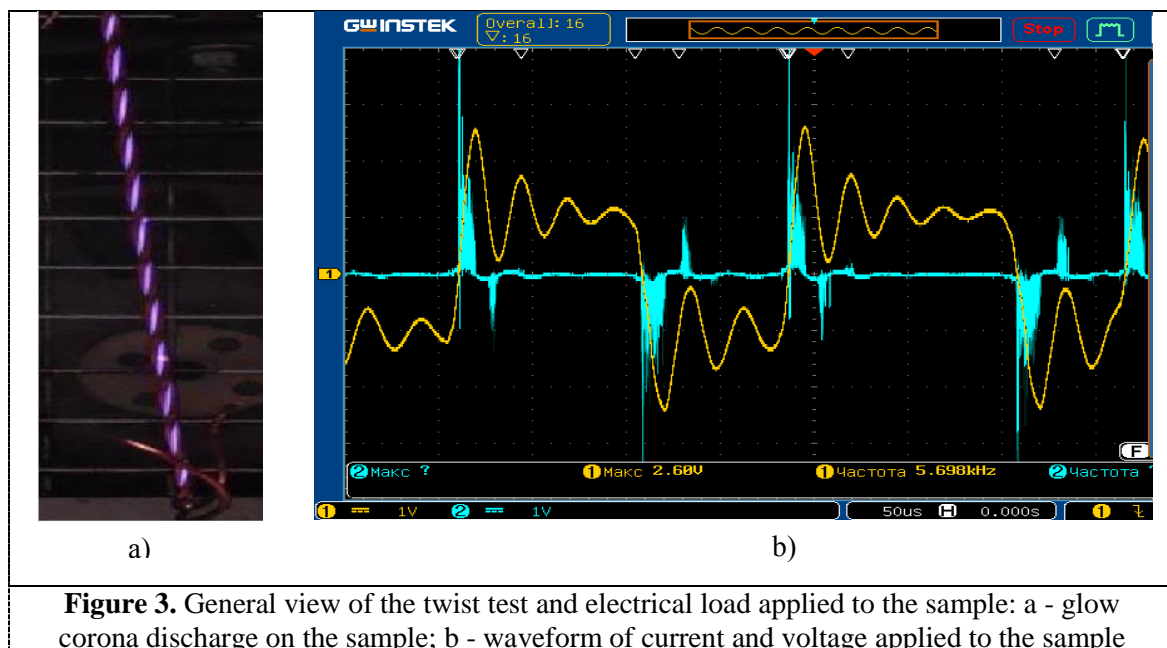
Table 1 shows that the greatest time to have a breakdown of the samples the wires with insulation type 1 with corona resistance enamel.

Explanation of the results can be discuss on the thermofluctuational destruction theory proposed Zhurkov. Based on the presentation of this theory in [9] it has shown that the basis of presentation breaks the chemical bonds of insulation is the failure mechanism when subjected to applied loads, which include temperature, electric field strength and frequency. In this model, the time until insulation breakdown can be determined:

$$\tau = \tau_0 e^{\frac{D \cdot \varphi(x)}{2KT}},$$

(1)

where: τ_0 – time constant, s; D – tear energy of chemical bonds, J; $\varphi(x)$ – function of acting loads (x), causing a decrease of potential energy barrier:
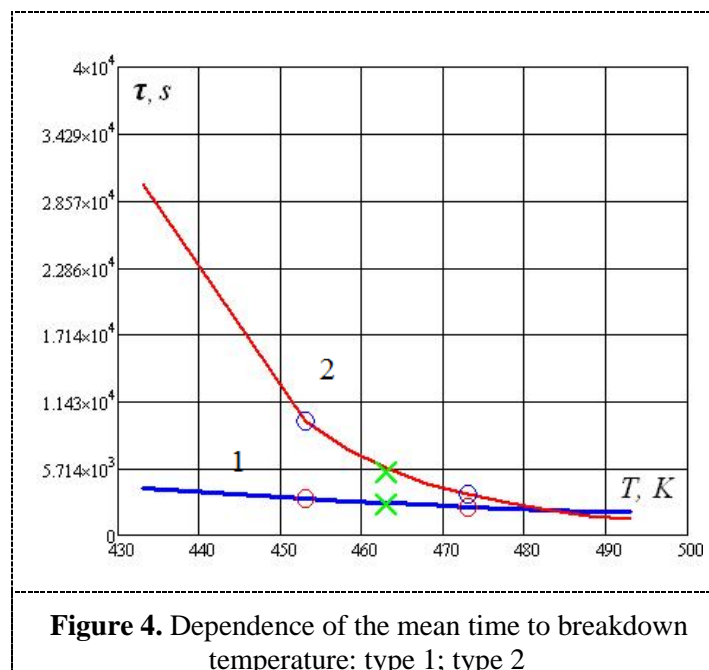
$$\varphi(x) = \sqrt{1-2x} - x\, ln\left[\frac{1}{x} + \frac{1}{x}\sqrt{1-2x} - 1\right],$$

(2)

$$x = \frac{1}{D}\sqrt{\left(Ae^{-bT}\beta\eta E\right)^2 + \left(\gamma\sigma\right)^2}.$$

(3)

A, γ - determined experimentally equation parameters (1); η - coefficient taking into account the increase of electric field strength by electrode shape; β - coefficient taking into account the increase of electric field strength by homogeneity of dielectric material structure; σ - mechanical load, [H/m]; E – strength of applied electric field, [V/m]; b - coefficient taking into account the change of material modulus of elasticity with temperature, 1/K.

To determine the parameters in the equation and the time to breakdown technique can be use as described in [10].

Results were obtain on basis of the calculations shown in Figure 4

Figure 4. Dependence of the mean time to breakdown temperature: type 1; type 2

As presented from Fig. 4, calculating the data according thermofluctuational theory are in good agreement with the experimental results shown in the graph in the form of points.

Conclusions

1. It shown that a mathematical model based on the thermofluctuational theory of destruction can used for explaining the mechanism of breakdown of polymer dielectrics.

2. The method of determining the equation parameters based on the preliminary insulation tests on breakdown at two temperatures of electrical aging are proposed and approved.

3. It is found that the calculated dependences of the time to breakdown based on thermofluctuational theory are good accordance with the experimental results and allow predict the time to breakdown of dielectrics taking into account various factors.

4. At calculating the time to breakdown, it is necessary to focus on the average values of equation parameters by the experimental data considering the inhomogeneity of electrical insulation and the statistical nature of impact loads.

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