



**HAL**  
open science

# AGING INVESTIGATION OF INVERTER-FED LOW VOLTAGE MOTOR WINDING INSULATION SUBJECTED TO HIGH DV/DT

Veronika Bolgova, Andrey Leonov, Stéphane Lefebvre, S Hlioui

► **To cite this version:**

Veronika Bolgova, Andrey Leonov, Stéphane Lefebvre, S Hlioui. AGING INVESTIGATION OF INVERTER-FED LOW VOLTAGE MOTOR WINDING INSULATION SUBJECTED TO HIGH DV/DT. XXVème Symposium sur les phénomènes électromagnétiques dans les circuits non linéaires (EPNC 2018), Jun 2018, Arras, France. hal-02363181

**HAL Id: hal-02363181**

**<https://hal.science/hal-02363181>**

Submitted on 14 Nov 2019

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# AGING INVESTIGATION OF INVERTER-FED LOW VOLTAGE MOTOR WINDING INSULATION SUBJECTED TO HIGH DV/DT

Veronika Bolgova<sup>1,2</sup>, Andrey Leonov<sup>2</sup>, Stéphane Lefebvre<sup>1</sup>, Sami Hloui<sup>1</sup>

<sup>1</sup>SATIE, CNRS UMR 8029, ENS Paris-Saclay,  
61 Avenue du Président Wilson 94235, Cachan, France, e-mail: veronika.bolgova@satie.ens-cachan.fr

<sup>2</sup>National Research Tomsk Polytechnic University,  
30 Lenin Avenue 634050, Tomsk, Russia, e-mail: leonov\_ap@tpu.ru

**Abstract** – The relevance of this paper determines by oncoming implementation of wide bandgap power semiconductors as SiC in inverters feeding motors. Hence, it is indispensable to investigate the influence of intensified electric stresses on winding insulation. In this regard, comparative corona resistance tests on pulse voltage with  $\mu$ s- and ns-level of rise/fall time were carried out. A novel specimen form for rectangular section wires is proposed. Considerations related to aging of dielectrics subjected to high dV/dt and high frequency pulse voltage are introduced.

## I. INTRODUCTION

During the service life electrical machines insulation system is subjected to various stresses, such electrical, thermal, mechanical, and environmental ones [1]. Their significance on dielectrics aging and deterioration process depends on electrical machine type, application, supply and control system. The thermal stress was the most recognized cause of low voltage electrical machines insulation deterioration and failure because the voltage magnitude and overvoltage were much lower than the breakdown one either the ionization start voltage, so there were no partial discharges (PD) [2, 3]. That was confirmed in case of sinusoidal 50-Hz AC supply voltage in [3].

In variable frequency drives based on voltage source inverters with pulse width modulation (PWM) repetitive surges due to voltage pulsed waveform with very straight rise/fall fronts and reflection phenomena [1, 2] lead to PD inception in motor winding insulation. It notably decreases the low voltage insulation service life.

The modern advances in semiconductors technology allow to create very powerful inverters using wide bandgap power semiconductors as SiC and GaN. Nevertheless, their higher switching speed and frequency range in comparison with silicon components lead to the raise of common mode currents and dV/dt with very fast rise/fall time (10-50 ns) [4]. The increasing electrical stress can drastically accelerate the motor insulation aging and failure.

Since the presence of PD in inverter-fed low voltage motors have been recognized, numerous studies were related to characterize PD, inception conditions and the influence of their presence on the insulation [5], or to detect insulation defects [6] and to develop insulation lifetime models depending on the applied stresses and their interaction [7].

Despite this, aging and deterioration process in insulation subjected to high dV/dt and high frequency repetitive pulses are not thoroughly investigated. In this article, results of enameled winding wires aging tests are presented and

discussed. The designed test benches make it possible to reproduce the severe stresses affecting to the winding insulation, adjusting voltage waveform parameters and temperature, in order to characterize the electrothermal aging and to highlight the influence of dV/dt and carrier frequency.

## II. TESTING METHOD

The proposed method is based on wires corona resistance test using a mean time to breakdown as an end-point criterion. The designed experimental benches allow to test enamelled wires for low voltage electric motor winding [8].

### A. Specimens

Specimens in form of twisted pairs (Fig.1, a) made of enamelled copper round section wires having 1 mm external diameter have been tested: two conventional wires and corona resistant one. A rectangular section (1 mm thickness and 3 mm width) enamelled copper wire (conventional) has been also tested. Specimens represented small coils made of two parallelly wound pieces of wire (Fig.1, b).



Fig.1. Specimens: a – twisted pair, b - coil

### B. Test benches

The both test benches represent pulse generators with climate chambers (allow heating during the test at temperature corresponding to wires thermal index, 180 °C) where specimens are installed (Fig.2).

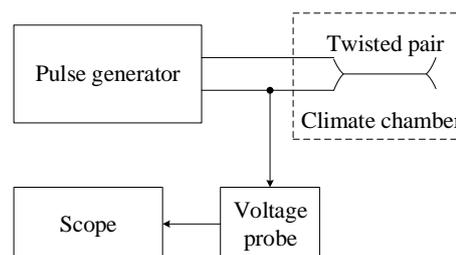


Fig.2. General scheme of test benches

The first test bench is made using Si IGBT transistors; generated signals parameters are: an alternating rectangular voltage with the steady-state amplitude equal to 1,2 kV, the frequency of 400 Hz, the carrier frequency of 5 kHz, the rise time equal to 4  $\mu$ s, and dV/dt equal to 0,3kV/ $\mu$ s (Fig.3, a).

Designed with SiC MOSFET transistors, the second test bench can generate adjustable pulse voltage waveforms with high dV/dt and steep rise front: rise time  $t_r \leq 50$  ns, 24 kV/ $\mu$ s for 1,2 kV voltage amplitude (Fig.3, b).

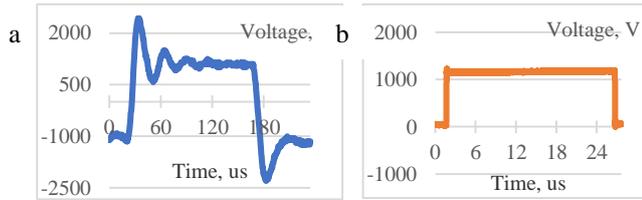


Fig.3 Voltage waveforms: a –  $\mu$ s-level pulses, b – ns-level pulses

### III. EXPERIMENTAL RESULTS

Two types of corona resistance test: at  $\mu$ s-level rise time pulses with low dV/dt, and at ns-level pulses with high dV/dt, were carried out.

TABLE I  
TEST CONDITIONS AND RESULTS

Test conditions			Experimental results				
Voltage, kV	Carrier frequency, kHz	Temperature, °C	Mean time to breakdown, min				
			1	2	3	4	
<i><math>\mu</math>s-level pulses</i>							
1,2	5	180	161,53	51,38	16,79	25,92	
<i>ns-level pulses</i>							
1	20	20		10,16	5,69	100,42	
1,2			> 420	5,57	1,60	14,24	
1,4			9,52	3,76	0,76	6,74	
1	50			11,23	2,31	0,70	13,05
1,2			5,78	1,87	0,29	7,73	
1,4			0,56	0,59	0,20	2,35	
1	20	180		130,27	4,65	0,61	26,37
1,2			64,82	3,93	0,23	19,89	
1,4			1,45	1,68	0,12	5,39	

In Table I: 1 corona resistant wire, 2 – conventional wire type 1, 3 – conventional wire type 2, 4 – conventional wire rectangular section.

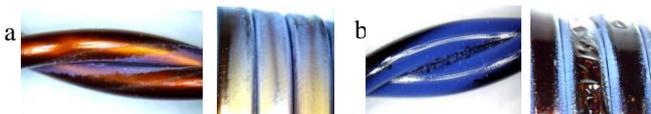


Fig.4 Specimens microscope views after electrothermal aging at 180 °C, 1,2 kV: a –  $\mu$ s-level pulses, b – ns-level pulses



Fig.5 Specimens microscope views after electrical aging at 20 °C, ns-level pulses: a – 1,4 kV, 20 kHz, b – 1,4 kV, 50 kHz

### VI. DISCUSSION

During the all tests the partial discharges in form of corona on wires surface were observed. Analysis of obtained experimental results and insulation destruction confirmed the significant influence of voltage and temperature interaction on insulation aging. Thus, in low voltage insulation subjected to sinusoidal 50 Hz, deterioration is mostly caused by thermal aging. At rectangular voltage pulses with  $\mu$ s-rise time electrical stress leads to PD inception degrading the insulation up to breakdown at defective or weakened area, then thermal stress accelerates the aging. Meanwhile, ns-rise time voltage high dV/dt pulses extremely speed up insulation aging and destruction. When such electrical stress reaches a critical value (1,4 kV, 50 kHz), the tested at ambient temperature specimens insulation is “burned” during just 30-50 s before the breakdown occurs.

Taking into account the drastic destruction in such short terms, dielectrics aging is considerably caused by dielectric losses fast rising and not only PD activity. The high dV/dt combined with high frequency lead to forced fast redistribution of electrical charge due to dipole and resonant polarization types in dielectric material.

### V. CONCLUSION

With regard to minimize the risk of unexpected motor failures it is indispensable to analyze comprehensively voltage waveform parameters influence, such rise/fall time, dV/dt, frequency, combined with thermal and other stresses.

### REFERENCES

- [1] Stone, Greg C., et al. *Electrical insulation for rotating machines: design, evaluation, aging, testing, and repair*. Vol. 21. John Wiley & Sons, 2004.
- [2] S. Grubic, J.M. Aller, B. Lu, T.G. Habetler. *A survey on testing and monitoring methods for stator insulation systems of low voltage induction machines focusing on turn insulation problems*. IEEE Transactions on Industrial Electronics, vol. 55, no. 12, 2008, pp. 4127–4136.
- [3] Derevyanko, V.I. *K metodu opredeleniya defektnosti obmotochnykh emal'-provodov, primenyayemykh v nizkovol'tnom elektrotekhnicheskoy oborudovanii* / V.I. Derevyanko, YU.P. Pokholkov // Tomsk: Izvestiya TPU. – 1974. – tom 282. – s. 56-60.
- [4] Narayanasamy, Balaji, et al. *Analysis and mitigation of reflected wave voltages and currents in WBG devices based motor drives*. Wide Bandgap Power Devices and Applications (WiPDA), 2016 IEEE 4th Workshop on. IEEE, 2016.
- [5] Wang, Peng, Gian Carlo Montanari, and Andrea Cavallini. *Partial Discharge phenomenology and induced aging behavior in rotating machines controlled by power electronics*. IEEE Transactions on Industrial Electronics 61.12 (2014): 7105-7112.
- [6] Ray, Susanta, and Debangshu Dey. *Characterization of stator turn to turn faults of induction motor using cross-correlation analysis based features*. Intelligent Control Power and Instrumentation (ICICPI), International Conference on. IEEE, 2016.
- [7] Salameh, F., Picot, A., Chabert, M., & Maussion, P. (2017). *Parametric and non-parametric models for lifespan modeling of insulation systems in electrical machines*. IEEE Transactions on Industry Applications.
- [8] Bolgova, Veronika, et al. *Development of testing methods for winding turn-to-turn insulation of low voltage motors fed by PWM converters*. Power Electronics and Applications (EPE'17 ECCE Europe), 2017 19th European Conference on. IEEE, 2017