Investigating the Effect of Waveform Characteristics on PDEV, PDIV and RPDIV for Glass Fibre Insulated Wire

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2022 International Conference on Electrical Machines (ICEM) | 978-1-6654-1432-6/22/$31.00 ©2022 IEEE | DOI: 10.1109/ICEM51905.2022.9910752

Abstract -- **The trends of partial discharge extinction voltage (PDEV), partial discharge inception voltage (PDIV) and repetitive partial discharge inception voltage (RPDIV) as a function of duty cycle, frequency, and rise time are experimentally investigated in this paper. The presented study is performed on a Glass fibre insulated wire (i.e., Type-II insulation), when it is excited/stressed with both positive and negative unipolar voltage impulses. The collected data are post-processed through a two-parameter Weibull distribution (i.e., shape/slope), while considerations are drawn and in-depth discussed. In particular, the focus is given to the differences between PDIV and PDEV values, RPDIV and PDIV values, as well as the dispersion level of the measurements. In addition, the voltage overshoot resulting from fast rise time plays the main role in determining the over-voltages with respect to PDIV and PD activity. Thus, the trend of this waveform characteristic as a function of rise time will also be discussed in the paper.**

Index Terms-- **electrical insulation, electric machines, partial discharges, pulse width modulation (PWM), reliability, variable speed drives**

I. Introduction

THE employment of power converters has been undoubtedly increased for the sake of better control and improvement of AC motors performance. This can affect the motor service reliability due to the supply waveform characteristics such as duty cycle, impulse voltage repetition frequency and fast rise time. Thus, understanding the impact of voltage waveform characteristics on insulation performance is crucial to guaranteeing insulation reliability [1], [2].

Since the cable characteristic impedance is generally lower than the surge impedance of the stator winding, over-voltages between 2-3 times the DC bus voltage can occur at the motor terminals during the surge flanks. Due to the partly inductive, partly capacitive nature of the winding, the over-voltages are applied to the initial turns [3], [4] increasing the electrical stress above the partial discharge (PD) inception field. Thus, PD activity will occur, which consists of localized discharges that do not bridge the insulation [5], but their permanent and continuous activity might result in premature failure and/or insulation breakdown.

In low voltage electrical machines, Type-I insulations (i.e., organic materials) are commonly used as winding insulating material. However, the PD activity triggered in Type-I insulation might shortly cause insulation breakdown [6]. Therefore, low voltage electrical machines are to be designed according to the PD-free criterion, i.e., the minimum PDIV is greater than the peak voltage across two adjacent turns [7]. Since the PD-free criterion cannot be kept throughout the insulation system life due to the inevitable aging (e.g., thermal aging), Type-II insulations (i.e., mixed organic-inorganic materials) might represent an alternative solution for mitigating the impact of PD in low voltage electrical machines and ensuring extended lifetime.

Type-II insulated wires, which are historically employed in medium voltage electrical machines, are PD resistant by nature, i.e., they can operate under the PD regime for a longer time span compared to Type-I insulated wires. In other words, the PD is considered an end-of-life criterion in Type-I insulated wires, while this concept does not stand for Type-II insulated wires. An example of Type-II insulated wire suitable for low voltage electrical machines is the Glass fibre insulated wire, which was selected for the present study.

The paper describes tests that were performed on Glass fibre insulated wire at room temperature in atmospheric pressure subjected to repetitive unipolar positive and negative impulse voltage waveforms featuring different waveform characteristics (i.e., duty cycle, frequency and rise time). The investigation aims at establishing experimentally-based empirical considerations on PD activity, which are applicable to Glass fibre insulated wire operating under repetitive unipolar (positive and negative) impulse voltage excitation. It is noteworthy to underline that the effect of extreme ambient conditions (e.g., high/low temperature, humidity, and partial vacuum) on PD inception is not addressed at such a preliminary stage of the study.

II. Measurement's Technology and Testing Conditions

A commercial variable pulse generator system (RUP6-18bip) was used to produce positive and negative unipolar waveform excitations. The RUP6-18bip allows for adjustment of the waveform's parameters, i.e., pulse width duration (duty cycle), frequency and rise time, to the desired values for the study.

PD was detected through an ultra-high frequency (UHF)

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antenna with 100 MHz–3 GHz bandwidth, which was designed to acquire electromagnetic emissions associated with the PD occurring in the specimens under test (i.e., polytetrafluoroethylene (PTFE)-wrapped pairs made of Glass fibre insulated wire). The antenna is connected to a frequency shifter and impulsive test synchronization module (ITSM) so that the signal can be processed through IEC 60270-compliant instrumentation (i.e., Techimp PD Base II). The acquisition system was endowed with digital noise rejection features along with a PD pattern recognition software [8]. The experimental setup employed for the investigation is schematized in Fig. 1.

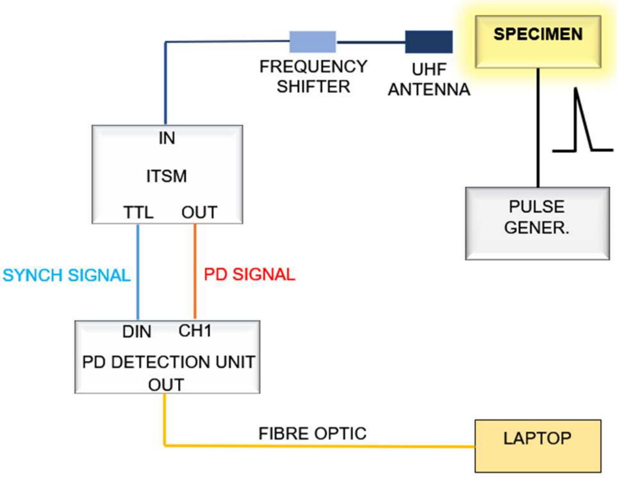
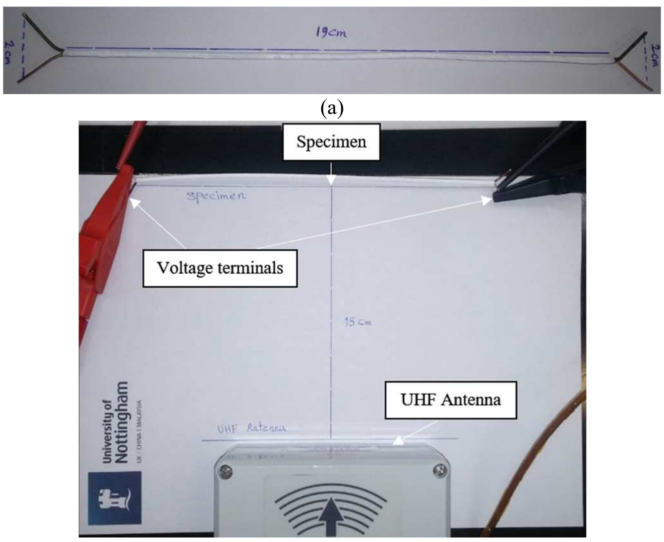


Fig. 1. Circuit and connections layout for PD measurements.

To make each specimen as shown in Fig. 2a, two adopted Glass fibre insulated wires (*2 Silix VSI manufactured by Von Roll*) with a diameter of 0.9 mm and a length of about 22 cm were wrapped thoroughly using PTFE tapes to be sure that there was a full contact between the surface of the two insulated wires. Thus, the PTFE tape has a purely mechanical function in the specimen assembly and does not play any electrical insulation role. Five samples were tested for every considered case study using the layout illustrated in Fig. 2b. The UHF antenna for PD detection was placed at 15 cm from the specimen under test.



(a)

(b)

Fig. 2. (a) Specimen geometry and (b) PD detection arrangement.

The PD measurements were performed at room temperature (21°C) and atmospheric pressure (1013 mbar). To measure PDIV, the voltage applied across the specimen's insulation was gradually increased from a value at which no PD can be detected. The voltage was raised in steps of 25 V with a duration of 30 seconds [4]. The step voltage of 25 V is chosen because represents a reasonable compromise between test duration and accuracy of the collected values. Moreover, there might be a significant (positive) error in the measured PDIV if the voltage increasing rate is too large [4]. When the PD with the repetition rate of at least two PD per minute was observed, the voltage was recorded as PDIV. The PDIV definition based on this PD repetition rate criteria makes the measured PDIV more meaningful and repeatable. Regarding PDEV, with the voltage steps of 25 V with a duration of one minute, the voltage was reduced. Once, the PD activity stopped, the applied voltage was recorded as PDEV. Finally, starting from the recorded voltage as PDIV, the voltage was increased in steps of 25 V with a duration of 30 seconds for each step, to reach RPDIV which is defined as the voltage level at which the probability of incepting a PD per voltage surge is equal to 50% [9]. For all the PDEV, PDIV and RPDIV measurements, both relevant DC and peak values were reported. The reason to consider the latter is that according to the PD-free criterion, i.e., the minimum PDIV must be greater than the peak voltage across the two adjacent turns under unipolar impulse voltage excitation [7]. In addition, reporting both DC and peak values will help to avoid any confusion which may come to the mind resulting from different reported trends in literature as a function of waveform characteristics where DC or peak value might be selected as a base for the PD measurements.

Using the measurement setup discussed in the previous section, three experimental test campaigns were carried out and for each of them, only one waveform parameter was varied, while the remaining two were kept unchanged. In the following subsection, the results collected during every test campaign are presented and discussed.

III. Experimental Results and Discussions

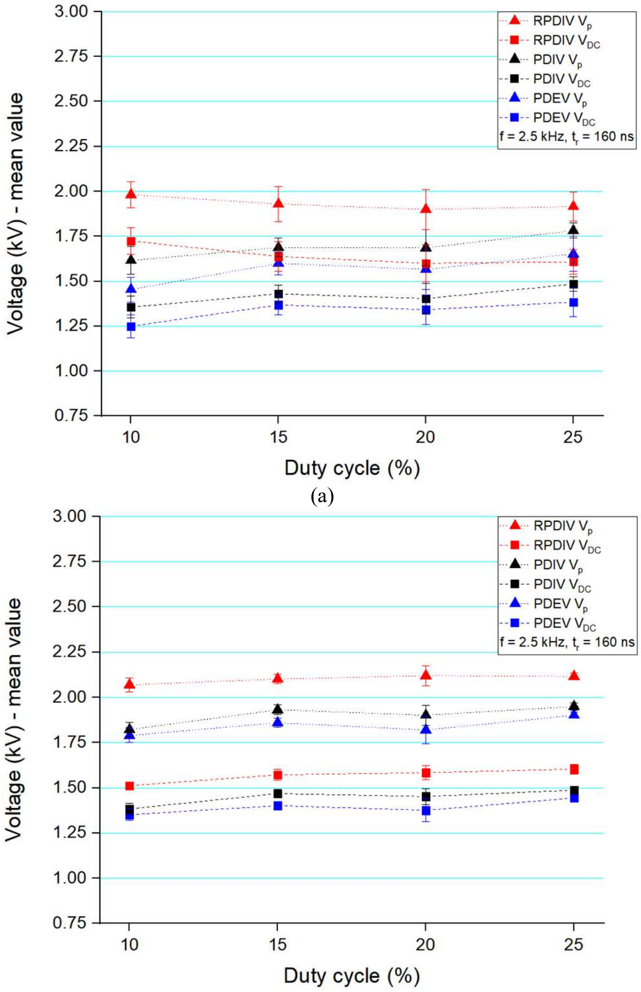
A. *Analysis of Duty Cycle*

The duty cycle is defined as the ratio of impulse voltage duration to the total period of the impulse (i.e., the reverse of impulse voltage repetition frequency) which is commonly expressed in percentage. The first experimental test campaign aims at evaluating the duty cycle effect of repetitive unipolar voltage waveforms on PDEV, PDIV and RPDIV. For this reason, four different impulse voltage width durations: 40 µs (duty cycle = 10%), 60 µs (duty cycle = 15%), 80 µs (duty cycle = 20%) and 100 µs (duty cycle = 25%) at constant impulse voltage repetition frequency (2.5 kHz) and rise time (160 ns) are considered. The measurement results for PDEV, PDIV and RPDIV are collected and reported as a function of the duty cycle in Fig. 3 for both positive and negative unipolar excitations.

As shown in Fig. 3, there is no significant variation in the measurement results. However, there is a slight increment of

PDEV, PDIV and RPDIV (both DC and peak value) with the increase of pulse width (duty cycle) except for RPDIV under positive unipolar excitation (Fig. 3a) where it decreases slightly with higher duty cycle values. The results for RPDIV under negative impulsive voltage are more stable with the increase of duty cycle compared with those under positive excitation.

The comparison between the measured PDIV values under positive and negative impulse voltage at the same duty shows that the DC values are comparable but the peak values under negative unipolar excitation are higher. The same holds for RPDIV except for the shortest impulse voltage duration (duty cycle 10%) where the measured DC value is higher for positive applied voltage while the peak values are almost the same.



(a)

(b)

Fig. 3. PDEV, PDIV and RPDIV as a function of duty cycle under unipolar (a) positive and (b) negative repetitive unipolar impulse voltage excitation.

The level of dispersion of the measured values can be evaluated by resorting to the shape/slope parameter of the Weibull distribution (β) where a higher β value verifies lower dispersion. This dispersion criterion as a function of the duty cycle is depicted in Fig. 4.

As described in Fig. 4, there is a lower value of β for the measured PDEV and PDIV (both DC and peak) when the duty cycle is the lowest confirming that those measured values under the lowest duty cycle are more dispersed than those under the highest duty cycle. This can be attributed to the higher impact of the firing electron delay when the duty cycle is the lowest. This is due to there are two conditions which must be met to start a PD: (1) the voltage should exceed the PDIV and (2) a free electron should be available [4]. The latter can be less satisfied when the duty cycle is the lowest considering the lowest value of β for the measured PDEV and PDIV values.

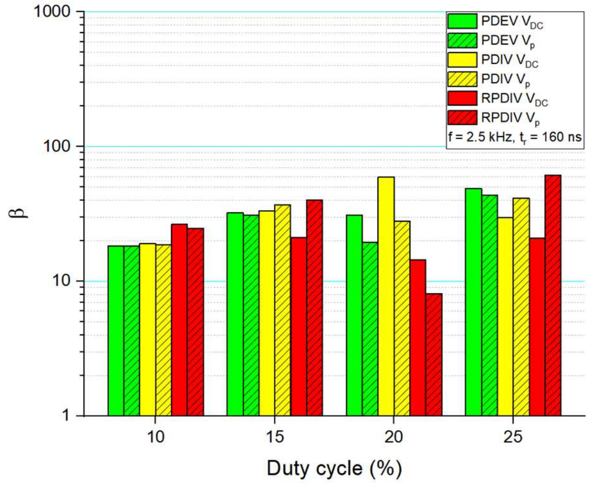


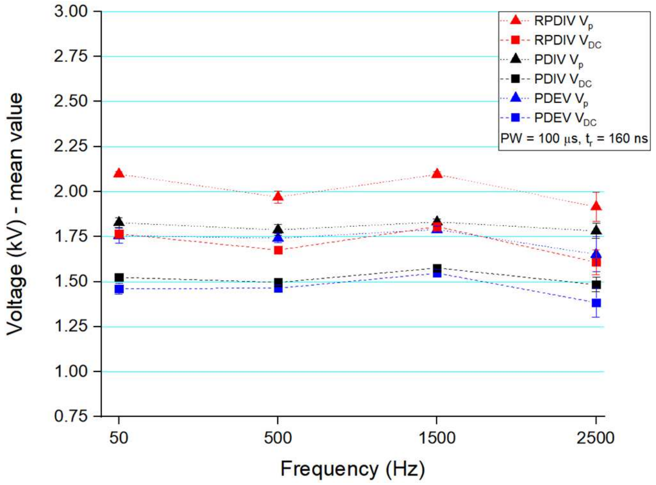
Fig. 4. The shape/slope parameter of the Weibull distribution as a function of duty cycle under negative unipolar impulse voltage excitation at PDEV, PDIV and RPDIV applied voltages.

B. Analysis of Impulse Voltage Repetition Frequency

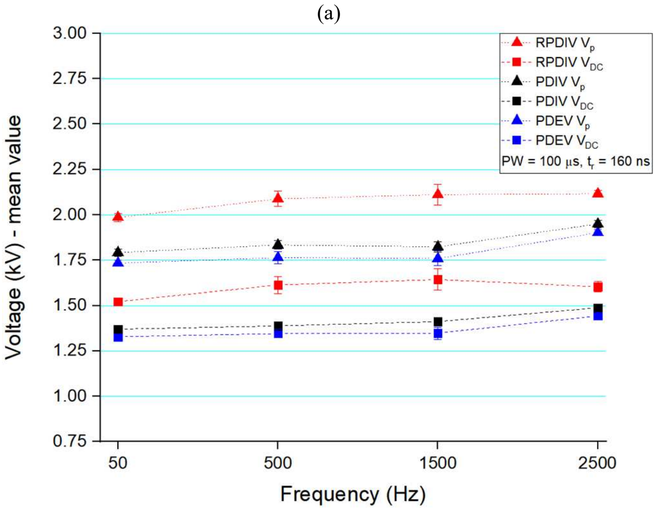
The purpose of the second experimental test campaign consists in analyzing how the frequency of the voltage excitation influences the PDEV, PDIV and RPDIV. Therefore, four different impulse voltage repetition frequencies: 50 Hz, 500 Hz, 1.5 kHz, and 2.5 kHz at constant voltage pulse width (PW) duration (100 μs) and rise time (160 ns) are used to stress the insulation across the two Glass fibre insulated wires. As in the previous case, the investigation is repeated for both unipolar positive and negative impulse voltage waveforms and the obtained results as a function of the frequency are depicted in Figs. 5a and 5b, respectively.

In Fig. 5a, the measured PDIV (both DC and peak values) remain almost constant under positive unipolar excitation. However, it increases slightly under 2.5 kHz when the polarity of the applied voltage is negative. Regarding the RPDIV, while the measurement results (both DC and peak values) show approximate stability under negative excitation, it decreases marginally at 2.5 kHz under positive unipolar excitation.

The comparison between positive and negative excitation at the same impulse voltage repetition frequency shows that the measured DC values (PDEV, PDIV and RPDIV) under positive applied voltage are higher while this difference is less evident when the impulse voltage repetition frequency is the highest (2.5 kHz). Comparing the measured peak values for PDEV and PDIV under positive and negative excitation at the same frequency shows that the peak values are almost the same for both polarities except for the highest impulse voltage repetition frequency (2.5 kHz) where the measured peak values are higher under negative excitation. In other words, the highest value of the voltage overshoot is attributed to the negative impulse voltage when the impulse voltage repetition frequency is the highest (2.5 kHz).



(a)



(b)

Fig. 5. PDEV, PDIV and RPDIV as a function of impulse voltage repetition frequency under unipolar (a) positive and (b) negative impulse voltage excitation.

The measurement results dispersion level under positive excitation as a function of impulse voltage repetition frequency based on the shape/slope parameter of the Weibull distribution is indicated in Fig. 6. Considering all the measured values, the highest dispersion (lower β) is observed under the highest impulse voltage repetition frequency (2.5 kHz).

It is noteworthy to mention that the difference between PDEV and PDIV based on the measured DC values remains almost constant reasonably with the change of impulse voltage repetition frequency. The reason for this is that since the considered PD repetition rate to record PDIV was constant under each impulse voltage repetition frequency (as defined already: at least two PD per minute), thus similar surface modification or change in charge depletion time constant resulting from PD repetition rate would be expected under different impulse voltage repetition frequencies.

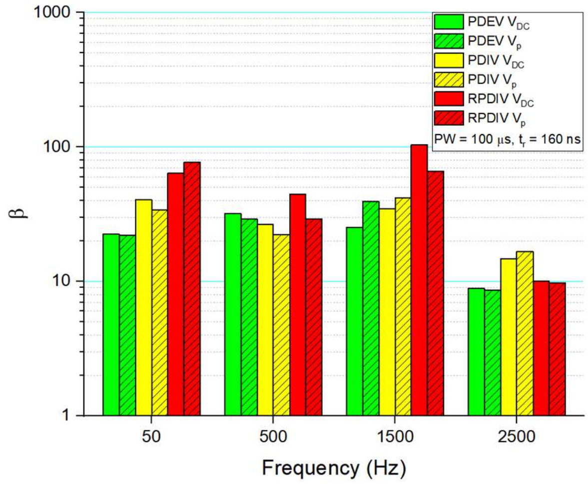


Fig. 6. The shape/slope parameter of the Weibull distribution as a function of impulse voltage repetition frequency under positive unipolar impulse voltage excitation at PDEV, PDIV and RPDIV applied voltages.

C. *Analysis of Rise Time*

If the maximum voltage variation during the switching operation is assumed to be ΔV_{max}, then the rise time is defined as the time for the voltage rise from 0.1 ΔV_{max} to 0.9 ΔV_{max} [10]. Considering this definition for the rise time, five different rise time values: 80 ns, 200 ns, 400 ns, 600 ns and 800 ns at constant impulse voltage width duration (100 μs) and impulse voltage repetition frequency (2.5 kHz) are selected for the third experimental tests campaign. This final test campaign has the intention of investigating the influence of the rise time on PDEV, PDIV and RPDIV when the Glass fibre insulation is exposed to unipolar positive and negative impulse voltage waveforms. For this test campaign, the measured PDEV, PDIV and RPDIV as a function of rise time are given in Fig. 7.

The measured DC values under both positive and negative excitations show an increasing trend for PDEV, PDIV and especially RPDIV with the increase of rise time. The lowest measured DC values under the fastest rise time can be attributed to the highest voltage overshoot that occurs when the rise time duration is the shortest. However, the measured peak values of PDIV and PDEV values are almost constant with the increase of rise time. This is more evident under negative applied voltage. The lowest measured RPDIV (both DC and peak values) under both positive and negative excitations is attributed to the fastest rise time (80 ns). The comparison of the results under positive and negative excitations shows that all the measured values at the same rise time are comparable for positive and negative excitations.

The measured overshoot under positive PDEV, PDIV and RPDIV applied voltages as a function of rise time are depicted in Fig. 8. The overshoot of the measured voltage across the specimen reduces with the increase of rise time under both positive and negative excitation. This decreasing trend is more considerable for lower rise time values (e.g., from 80 ns to 200 ns).

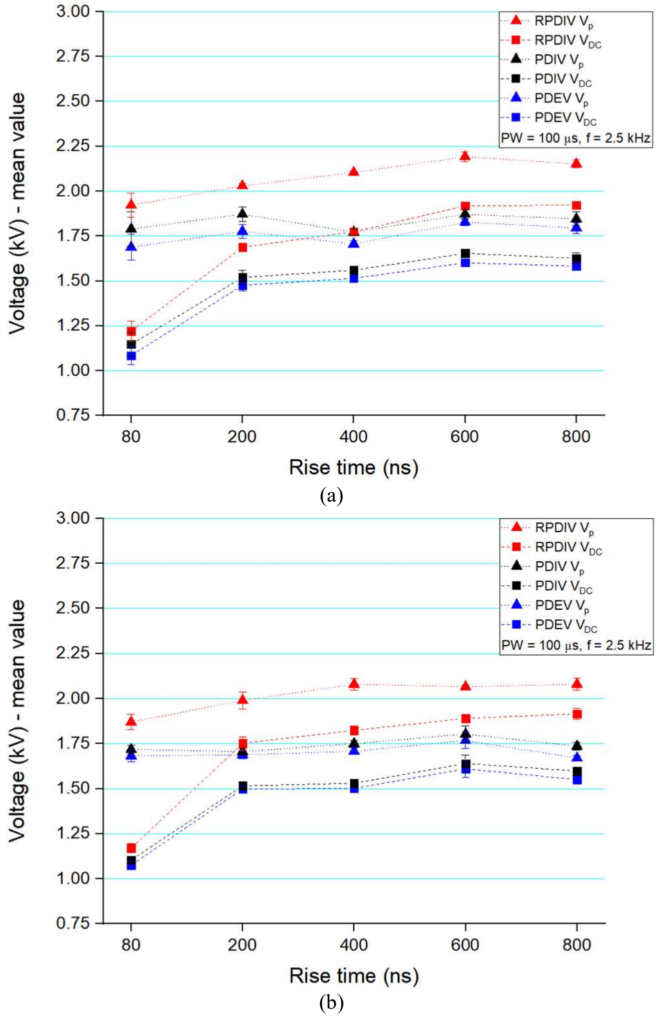


Fig. 7. PDEV, PDIV and RPDIV as a function of rise time under unipolar (a) positive and (b) negative impulse voltage excitation.

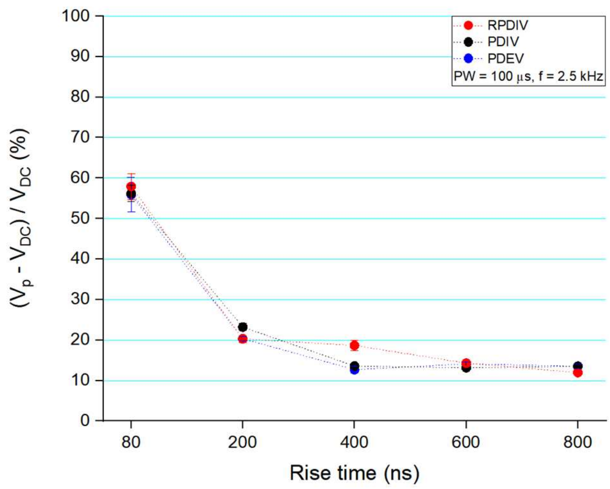


Fig. 8. The overshoot of measured voltage waveform as a function of rise time under unipolar positive impulse voltage excitation under RPDIV, PDIV and PDEV applied voltages.

The required over-voltage with respect to PDIV to provide RPDIV as a function of rise time is depicted in Fig. 9. This over-voltage based on the measured DC values increases uniformly with the increase of rise time. One plausible reason to measure the lower difference between PDIV and RPDIV could be higher voltage overshoot when the voltage slew rate is the fastest. This higher voltage overshoot can lead to reaching RPDIV with less count of the voltage increasing steps starting from PDIV. Thus, the magnitude of this over-voltage can be reduced at the shortest rise time. Higher dispersion in the measured RPDIV at the fastest rise time can be evidence for this claim (Fig. 10).

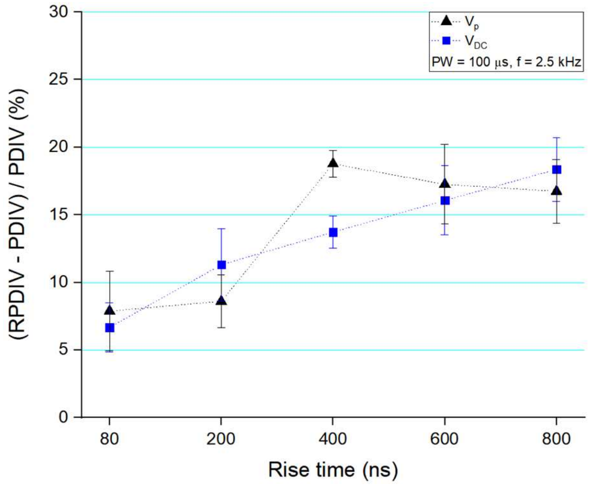


Fig. 9. The difference between RPDIV and PDIV as a function of rise time under unipolar positive impulse voltage excitation.

Another possibility for this lower overvoltage could be a higher rate of aging/damage when the voltage slew rate is the fastest. When the voltage applied across the specimen's insulation is higher than PDIV and the rise time is faster, both maximum PD charge amplitude and PD repetition rate are higher compared with those measured at longer rise time values under the same over-voltage respect to PDIV [11], [12]. Higher maximum PD charge amplitude is caused by the higher impact of the firing electron delay when the rise time is faster [13], while a higher PD repetition rate happens since the maximum electric field in the air gap can increase significantly because of higher voltage overshoot at the shortest rise time. Both higher PD charge magnitude and repetition rate can lead to higher aging/damage at the fastest rise time [11], [12]. This higher damage can lead to more reduction of charge depletion and recombination time constant when the rise time is faster. Consequently, the required over-voltage with respect to PDIV to trigger the minimum applied voltage at which PD occur with a repetition rate of one or more PD pulses for every two voltage impulses (i.e., RPDIV [14]) can be reduced when the rise time is faster as demonstrated in Fig. 9.

It is noteworthy to mention that the highest value of voltage decrease with respect to PDIV to extinguish PD (reach to PDEV) occurs at the fastest rise time (i.e., 80 ns). Considering other rise time values, this under-voltage remains almost constant. One possible reason for measuring the largest value of this under-voltage at the fastest rise time could be the considerable voltage overshoot which is observed at the shortest rise time. As a result, PDEV can be observed after a higher count of voltage decreasing steps to have the peak of the applied voltage lower enough than PDIV to extinguish the PD activity. Higher dispersion in the measured PDEV at the fastest rise time can justify this explanation (Fig. 10). Another explanation for this higher under-voltage can be more possibility of aging/damage rate caused by higher PD charge amplitude and repetition rate when the voltage slew rate is the fastest [11], [12]. Because of this higher damage, charge depletion and recombination in the discharge point can happen easier and faster. Thus, it is required to reduce the voltage more with respect to PDIV to extinguish the PD when the rise time is the shortest.

Overall, the analysis of rise time shows that the lowest measured DC values for PDEV, PDIV and RPDIV along with the highest voltage overshoot are attributed to the fastest rise time. While the measured peak values for PDEV and PDIV remain almost constant with an increase of rise time for both positive and negative excitations. All the measurement results under positive and negative impulse voltages are almost comparable. Finally, the highest under-voltage respect to PDIV to extinguish PD, the least over-voltage respect to PDIV to trigger RPDIV and the largest level of measurement results dispersion are observed when the rise time is the fastest.

In Fig. 10, the highest dispersion (lower β) of the measurement results is observed when the rise time is the shortest (80 ns).

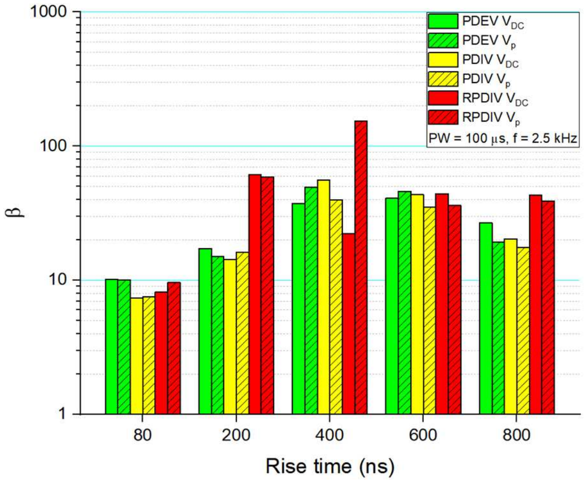


Fig. 10. The shape/slope parameter of the Weibull distribution as a function of rise time under positive unipolar impulse voltage excitation at PDEV, PDIV and RPDIV applied voltages.

IV. Conclusions

In this paper, the variations of PDEV, PDIV and RPDIV as a function of impulse voltage duration (duty cycle), impulse voltage repetition frequency, and rise time under positive and negative unipolar impulse voltage waveforms are presented and discussed for Glass fibre insulated wire.

Analysis of the duty cycle shows that the measured peak value for PDIV remains almost constant as a function of the duty cycle. For instance, it increases slightly from duty cycle 10% to 25%, only about 1.1 times under both positive and negative excitations. At the same duty cycle, there is a negligible higher measured peak value for PDIV under negative excitation compared to a positive one. For example, it is higher only about 1.1 times (at duty cycles 10% and 25%) for negative excitation. The least dispersion for the measured peak values of PDEV, PDIV and RPDIV is observed when the impulse voltage duration is the longest (the highest duty cycle).

The rate of variation of the measured peak values for RPDIV as a function of impulse voltage repetition frequency remains almost constant, especially under negative excitation. This finding is demonstrated by observing a higher (about twice) shape/slope parameter of Weibull distribution for negative excitation where it is about 21 and 39 under positive and negative excitations, respectively. At the same impulse voltage frequency, the measured peak values for RPDIV under positive and negative excitations are comparable. For instance, from positive to negative excitations, while it decreases just about 0.95 times at 50 Hz, it increases almost 1.1 times at 2.5 kHz. The highest dispersion of the measurement results (PDEV, PDIV and RPDIV) are observed under the highest frequency.

The analysis of rise time demonstrates that the maximum voltage overshoot under PDIV promotes at the fastest rise time (i.e., 80 ns) about four and six times higher than those at the longest rise time (i.e., 800 ns) for positive and negative excitations, respectively. This results in reducing the measured DC value for PDIV at the fastest rise time approximately 0.7 times under both positive and negative excitations compared to the longest rise time, while the peak value of PDIV remains almost constant for both positive and negative excitations. Under positive excitation and based on measured DC value, when the rise time becomes shorter from 800 ns to 80 ns, the required under-voltage respect to PDIV to extinguish PD increases about two times, while the over-voltage respect to PDIV to trigger RPDIV decreases almost 0.4 times. Finally, the level of measurement results dispersion (PDEV, PDIV and RPDIV) are promoted under the fastest rise time.

Finally, it is well known that industrial processes, including electrical drives, can reach temperatures higher than room temperature (21°C). An empirical model, such as that introduced in [4], can be developed to estimate the PDIV decrement level at a higher temperature as a function of the measured PDIV at the reference pressure and temperature.

V. Acknowledgement

This project has received funding from the Clean Sky 2 Joint Undertaking under the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 807081.

VI. References

[1] G. Stone, S. Campbell, and S. Tetreault, “Inverter-fed drives: which motor stators are at risk?,” *IEEE Industry Applications Magazine*, vol. 6, no. 5, pp. 17-22, Sept.-Oct. 2000.

[2] IEC 60034-18-42, Rotating electrical machines - Part 18-42: Qualification and acceptance tests for partial discharge resistant electrical insulation systems (Type II) used in rotating electrical machines fed from voltage converters, 2008.

[3] D. R. Meyer, A. Cavallini, L. Lusuardi, D. Barater, G. Pietrini, and A. Soldati, “Influence of impulse voltage repetition frequency on RPDIV in partial vacuum,” *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 25, no. 3, pp. 873-882, July 2018.

[4] L. Lusuardi, A. Rumi, A. Cavallini, D. Barater and S. Nuzzo, “Partial Discharge Phenomena in Electrical Machines for the More Electrical Aircraft. Part II: Impact of Reduced Pressures and Wide Bandgap Devices,” *IEEE Access*, vol. 9, pp. 27485-27495, Feb. 2021.
[5] *High-Voltage Test Techniques—Partial Discharge Measurements*, IEC Standard 60270, 2015.
[6] P. Giangrande, V. Madonna, S. Nuzzo and M. Galea, “Moving Toward a Reliability-Oriented Design Approach of Low-Voltage Electrical Machines by Including Insulation Thermal Aging Considerations,” *IEEE Transactions on Transportation Electrification*, vol. 6, no. 1, pp. 16-27, March 2020.
[7] M. Galea, P. Giangrande, V. Madonna and G. Buticchi, “Reliability-Oriented Design of Electrical Machines: The Design Process for Machines' Insulation Systems MUST Evolve,” *IEEE Industrial Electronics Magazine*, vol. 14, no. 1, pp. 20-28, March 2020.
[8] V. Madonna, P. Giangrande, W. Zhao, H. Zhang, C. Gerada, and M. Galea, “Electrical Machines for the More Electric Aircraft: Partial Discharges Investigation,” *IEEE Transactions on Industry Applications*, vol. 57, no. 2, pp. 1389-1398, March-April 2021.
[9] IEC 60034-18-41 ed. I, Rotating electrical machines - Part 18-41: Partial discharge free electrical insulation systems (Type I) used in rotating electrical machines fed from voltage converters – Qualification and quality control tests, 2014.
[10] N. Driendl, F. Pauli, and K. Hameyer, “Modeling of Partial Discharge Processes in Winding Insulation of Low-Voltage Electrical Machines Supplied by High du/dt Inverters,” *IECON 2019 - 45th Annual Conference of the IEEE Industrial Electronics Society*, Lisbon, Portugal, 2019, pp. 7102-7107.
[11] H. Naderiallaf, P. Seri, and G. C. Montanari, “Effect of voltage slew rate on partial discharge phenomenology during voltage transient in HVDC insulation: the case of polymeric cables.,” *IEEE Trans. Dielectr. Electr. Insul.*, July 2021.
[12] H. Naderiallaf, P. Giangrande and M. Galea, “A Contribution to Thermal Ageing Assessment of Glass Fibre Insulated Wire Based on Partial Discharges Activity,” *IEEE Access*, vol. 10, pp. 41186-41200, April 2022.
[13] A. Cavallini, “Reliability of low voltage inverter-fed motors: What have we learned, perspectives, open points,” *2017 International Symposium on Electrical Insulating Materials (ISEIM)*, Toyohashi, Japan, 2017, pp. 13-22.
[14] Cavallini, D. Fabiani and G. C. Montanari, “Power electronics and electrical insulation systems - Part 3: Diagnostic properties,” *IEEE Electrical Insulation Magazine*, vol. 26, no. 5, pp. 30-40, September-October 2010.

VII. BIOGRAPHIES

Hadi Naderiallaf was born in Mashhad, Iran, on April 16th, 1986. He received his M.Sc. and PhD degrees in electrical engineering (high voltage engineering) in 2012 and 2021 from the Leibniz University Hannover, Germany, and the University of Bologna, Italy, respectively. In 2019, he was a visiting scholar and PhD researcher at the Department of High Voltage Engineering at the Technical University of Berlin, Germany, for three months.

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Dr. Naderiallaf serves the scientific community as a reviewer for IEEE Transactions on Dielectrics and Electrical Insulation (IEEE-TDEI) and the journal of High Voltage co-published by the Institution of Engineering and Technology (IET).

Paolo Giangrande received the Bachelor’s (Hons.) and Master’s (Hons.) degrees in electrical engineering at the Politecnico of Bari in 2005 and 2008, respectively. He received his PhD in electrical engineering at the Politecnico of Bari in 2011. Since 2012, he was Research Fellow at the University of Nottingham (UK), within the Power Electronics, Machines and Control Group. In 2018, he was appointed Senior Research Fellow and he is currently head of the Accelerated Lifetime Testing Laboratory at the Institute of Aerospace Technology, Nottingham. His main research interests include sensorless control of AC electric drives, design and testing of electromechanical actuators for aerospace, thermal management of high-performance electric drives and lifetime modelling of electrical machines.

Dr. Giangrande constantly serves the scientific community as a reviewer for several journals and conferences. He is an IEEE Senior member since 2019 and he is currently Associate Editor for IEEE Transactions on Industrial Electronics, IEEE Transactions on Transportation Electrification, and IEEE Access.

Michael Galea received the Ph.D. degree in electrical machines design in 2013 from the University of Nottingham, Nottingham, UK. He was promoted to Full Professor of Electrical Machines and Drives with the University of Nottingham in 2019. Since 2021, Prof Galea is also affiliated with the Department of Industrial Electrical Power Conversion of the University of Malta. His main research interests include design and development of electrical machines and drives (classical and unconventional), reliability and lifetime degradation of electrical machines and the more electric aircraft.

Michael is a Fellow of the Royal Aeronautical Society and a Senior Member of the IEEE. Michael also serves an Associate Editor for the IEEE Transactions on Industrial Electronics and for the IET Electrical Systems in Transportation.