Effect of Switching Frequency on the breakdown of twisted pairs due to Power Electronic Converters

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Abstract **- Issues on the life of stator insulation in the Inverter fed drives have been a concern for researches over the last two decades. The high frequency switching pulses at the output waveform of the Power Electronic Converter (PECs) are the main cause for the enhanced stress on the winding thus causing premature insulation failure on the motors. In this work, the breakdown tests are conducted on twisted pair specimens prepared by enameled wires. The tests were performed by applying high voltage power frequency waveform and PWM output waveform obtained from high frequency switching for two different insulation thicknesses. The test results show the considerable decrement in the breakdown strength for both thicknesses stressed with PWM waveform compared to hv power frequency waveform.**

Keywords- Twisted pairs, enhanced stress, high frequency, insulation thickness.

I. INTRODUCTION

In industries the speed control of induction motor is achieved with the help of development in power electronic converters (PECs) which are very popular by the adjustable speed drive technology. This technology has paved way for dramatic changes in industrial control of motors. But the output waveform of the PECs using Sinusoidal Pulse Width Modulation technique has train of high frequency pulses due to the high frequency switching of MOSFETS/IGBTs. This high frequency switching makes the very high rate of rise of about few tens of kV/μs with a switching frequency of about 50 kHz[1]. Besides this, the impedance mismatch causes overshoots on the rising and trailing portion of the pulses [2-4]. These causes undue electric stress on the enamel insulation as the motor insulation is designed to operate with sinusoidal waveform. Now, the motor winding insulation experiences an enhanced stress thus reducing the life of insulation when stressed by this PWM output [5] which is observed by researchers is initiated by partial discharge activity besides other causes [6-9]. This may affect significantly the reliability of electric motor insulation system. In addition to that, the harmonics components generated in the system propagates towards supply network and non-sinusoidal voltage towards the load side. So the motor insulation must be designed in such a way that it can withstand the high stress caused by the PWM waveform and these highly distorted waveforms.

Life of motor insulation system, hence needs investigation and research is going on over the last two decades on various aspects. This work focuses on testing the winding primary insulation with two different enamel thicknesses made of modified polyester. Twisted pair specimen is used to investigate the winding insulation as it simulates the inter-turn insulation [5]. The breakdowns tests are performed with these twisted pairs. These specimens are subjected to stresses applied using high voltage power frequency sinusoidal waveform of 10 kV and PWM output to replicate enhanced high voltage high frequency stress. Test results showed that there is a considerable reduction in the life of insulation when stressed with PWM output with high switching frequency of both the thicknesses.

II. SAMPLE PREPARATION

As twisted pair resembles the inter-turn insulation to a greater extent, it is considered. It also resembles the narrow contact between the first and last turn of the input coils of a motor which normally experience a large potential difference between them.

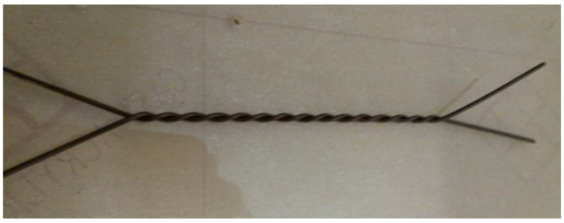


Fig 1. Twisted Pair Specimen

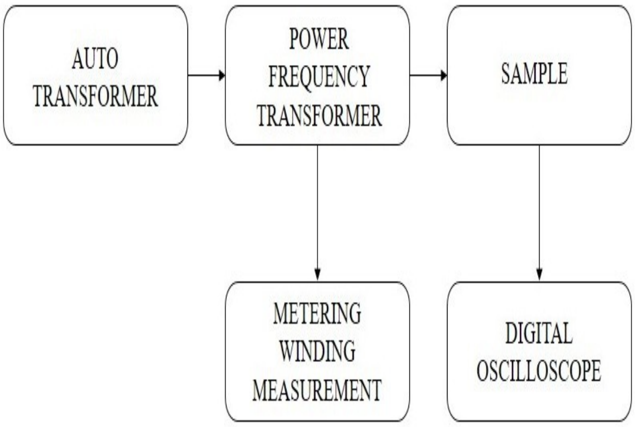
A twisted pair is composed by two enameled wires wound as a plait according to ASTM (1676-03) standards. As per the ASTM standards, the length of the twisted pair is 12cm and number of twisting are made according to gauge of the wires specified by the standards. The enamel insulation is modified polyester and thickness is 50 microns which is the primary coating which was readily available in the market. Over the primary insulation, secondary layer of different materials such as, epoxy resin (CY 230-1) with hardener (HY951), titanium oxide and alumina are coated with varying thickness. The epoxy resin of 13.5gm is mixed with 1gm of hardener (HY 951) is mixed in the ratio of 13.5:1 and that is used to coat samples. In order to coat the insulation the enameled wires are dipped in the salt water after some minutes it is dried and the mixture is coated over the primary insulation (modified polyester). The coated wires are kept in the oven at 60^0C to get it dried. One such twisted pair made in our laboratory is shown in fig 1.

III. EXPERIMENTAL SETUP

Tests are conducted over these twisted pairs with the experimental setup at high voltage power frequency of 50 Hz shown in figure 2 and PWM waveform with switching frequency of 20 kHz shown in figure 3.

A. Breakdown Voltage Test

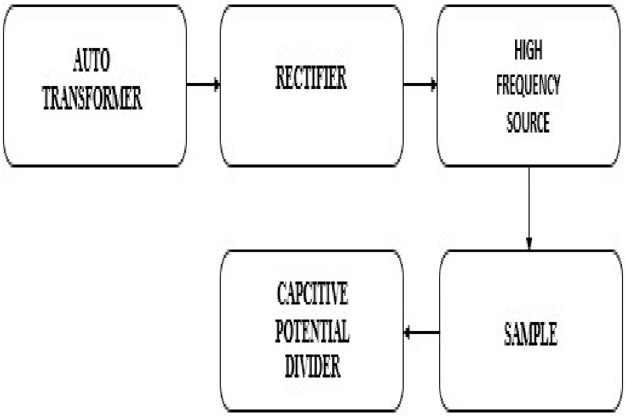
The voltage is gradually increased across the test sample at the rate of 0.5 kV/s. High voltage transformer used for this test is rated for 230 V/10 kV, 50 Hz. The ends of twisted pair are connected across the secondary of the transformer so that the enamel insulation between the twisted pair is stressed by the voltage applied. From this test the breakdown voltage



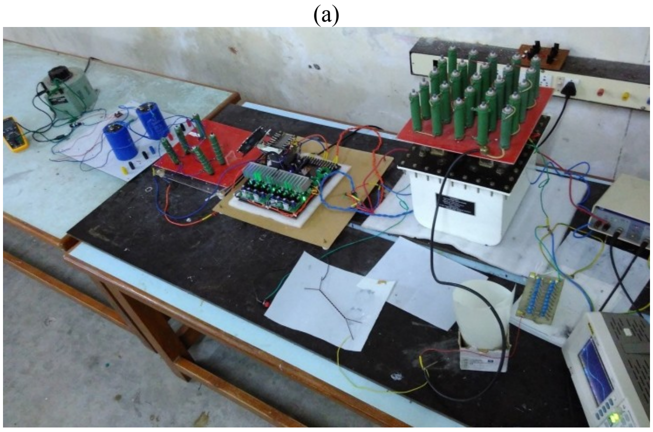
(a)

(b)

Fig 2 (a). The block diagram of HV Experimental Test setup and (b) Test facility



(a)



(b)

Fig 3 (a). The block diagram of PWM waveform Experimental Test setup and (b) Test facility

of twisted pair for 16 swg wire with 50 micron thickness and 100 micron thickness which are taken as a reference voltage are 7.7 kV and 9.44 kV respectively. Four to five samples are tested for each test and average voltage is taken.

B. Withstand Voltage Test

The test voltages applied for set of tests for 50 micron samples are 75%, 60%, 50% of reference voltage of 50 micron sample and corresponding reduced reference voltages of 100 micron sample. This test is done in order to check the withstand capability of insulation at reduced voltages.

IV. RESULTS AND DISCUSSION

A. Power Frequency Test:

The voltage at which the breakdown occurs is noted for secondary insulation coated for varying thicknesses over 50 micron sample and results are plotted in figure 4. It shows that Epoxy resin coated secondary insulation with varying thicknesses having better breakdown strength compared to alumina and titanium oxide. Among the three secondary coating, the TiO_2 nano composites show most improvement in the breakdown strength. Lower breakdown strength in filled coating can be attributed to partial discharge initiated at lower voltages and hence breakdown would have occurred earlier than plain epoxy coating.

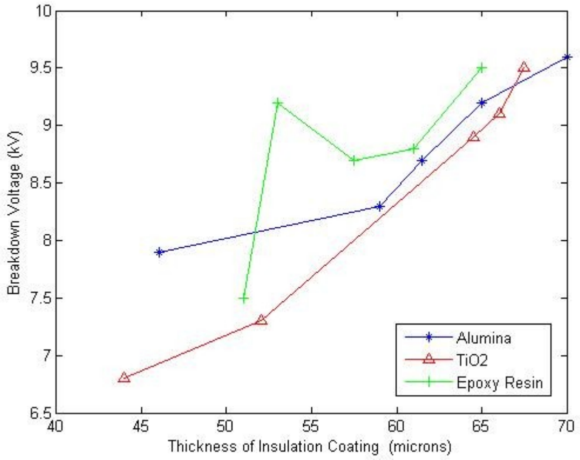


Fig 4. Variation of Breakdown Voltage over the thickness at power frequency

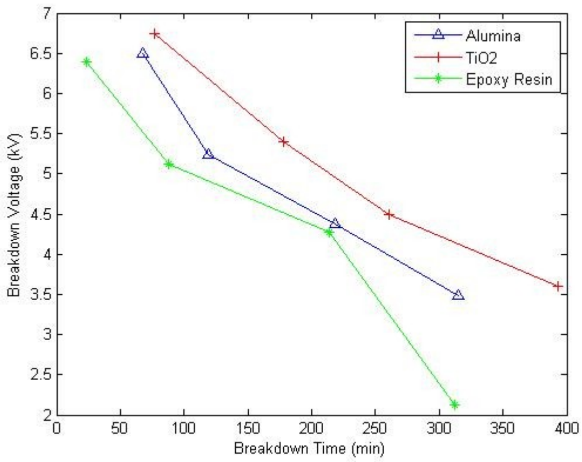


Fig 5. Variation of breakdown voltage stressed at reduced on Secondary Insulation at power frequency

Figure 5 shows that the time for breakdown of various twisted pair coated with the three materials on 100 micron thickness magnet wire. This show that titanium oxide taking more hours to breakdown compared to other materials and reduction is more or less linear. Moreover, the variation in breakdown time verses breakdown voltage shows a linear reduction with higher slope for Alumina and Epoxy coated, followed by linear drop in breakdown voltage in the case of alumina while the drop is varying in Epoxy coated samples.

B. High frequency test

Figure 6 show the improvement in breakdown voltage as the thickness of the samples were increased with the three materials stressed under high voltage power frequency. Epoxy resin coated as secondary insulation on 50 micron sample, has better breakdown strength compared to modified polyester obvious reasons. However, improvement in the breakdown strength is observed to be steep high for titanium oxide and alumina nano composite layer. Figure 7 shows that withstand voltage of various Nano filler materials. This show that titanium oxide taking more hours to breakdown compared to other filler materials.

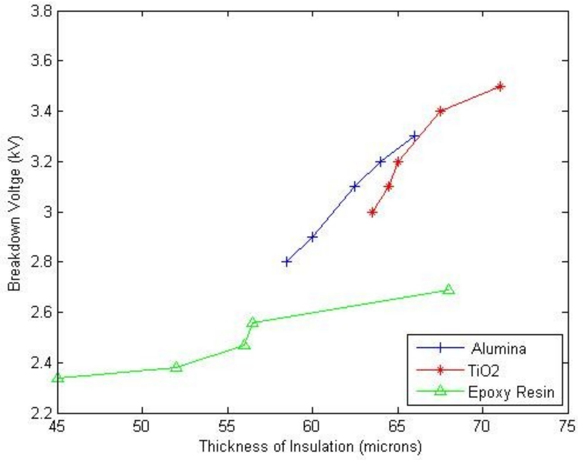


Fig 6. Variation of Breakdown Voltage over the thickness at hf PWM output

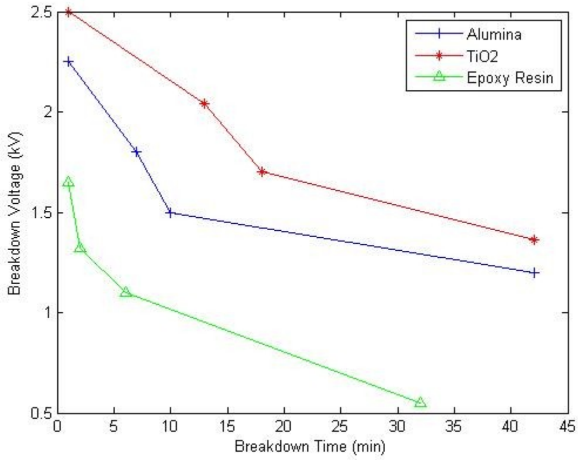


Fig 7. Variation of Withstand Voltage in Secondary Insulation at hf PWM output

Similar results can be observed from Guastavino et al [5] who has shown that the breakdown time for high frequency is less than reported here for almost the same voltage. The reason could be the switching frequency they have used is 2400 Hz, whereas the results produced here are obtained at 20 kHz and hence the breakdown time is much smaller in our case. Figure 7 shows the variation of breakdown voltage stressed at PWM waveform at high frequency switching of 20 kHz for 100 micron thickness material coated with all the three materials. This shows that the breakdown voltage is considerably reduced when stressed at 75 % of the corresponding reference voltage. Similar trend is observed for 60 % and 50 % of the reference voltage. Moreover the breakdown time is also found to be reduced sharply with high slope in all the three materials. After the critical time at 50 % of the reference voltage, the breakdown time decreases with much reduced slope when stressed with PWM waveform. This is not the case when stressed with high voltage power frequency. However in both figure 6 and 7, the linearity is lost. The reason for behavior of nano-composite behavior at high frequency is complex and is being studied.

V. CONCLUSION

Insulation degradation in electrical drives is due to various stress factors. The major stress factor considered in this study is the high frequency switching produced by the power electronic converters. It was very clear from the results that the twisted pair samples of both the thicknesses fed with the PWM waveforms shows earlier breakdown compared to the samples fed with power frequency waveforms. It is also observed that the increase in the breakdown voltage and withstand capability is almost linear for secondary layer with nano-composites than without for power frequency. The same is not true at PWM high frequency stress as linearity is absent through the overall profile observed in power frequency is also maintained here. Thus it can be concluded that the switching of power electronic converters leads to rapid degradation and the nano composite filler coating as a secondary layer improves the breakdown characteristics.

REFERENCES:

[1] R. J. Kerkman, D. Leggate, and G. L. Skibinski, Interaction of drive modulation and cable parameters on AC motor transients," *IEEE Trans. Ind. Appl.*, vol. 33, pp. 722–731, 1997.

[2] A.Cavalliani, D.Fabiani, and G.C.Montanari, "Power Electronics and Electrical Insulation Systems – Part 1: Phenomenology Overview", IEEE Electrical Insulation Magazine., vol.26 pp.6-14, May/June 2010

[3] A.Cavalliani, D.Fabiani, and G.C.Montanari, "Power Electronics and Electrical Insulation Systems – Part 2: Phenomenology Overview", IEEE Electrical Insulation Magazine., vol.26 pp.33-39, July/August 2010

[4] A.Cavalliani, D.Fabiani, and G.C.Montanari, "Power Electronics and Electrical Insulation Systems – Part 3: Phenomenology Overview", IEEE Electrical Insulation Magazine., vol.26 pp.30-40, September/October 2010

[5] Francesco Gustavino, Andrea dardano, "Life Tests on Twisted Pairs in Presence of Partial Discharges: Influence of the Voltage Waveform", IEEE Transactions on Dielectrics and Electrical Insulation Vol.19 pp.45-52, No. 1; February 2012

[6] D. Fabiani, G. C. Montanari, A. Cavallini and G. Mazzanti,"Relation Between Space Charge Accumulation and Partial Discharge Activity EnameledWires Under PWM-like Voltage Waveforms", IEEE Transactions on Dielectrics and Electrical Insulation Vol. 11, No. 3 pp 393-405; June 2004.

[7] F. Guastavino, G. Coletti, A. Ratto and E. Torello, "Electrical Ageing Test on Conventional and Nanocomposite Enamels: PD Patterns Analysis", IEEE Electrical Insulation Conference, Montreal, QC, Canada, May 31 - June 3, pp.101-103, 2009.

[8] T. G. Arora M. V. Aware and D. R. Tutakne, "Effect of Pulse Width Modulated Voltage on Induction Motor Insulation", IEEE Transaction,pp. 42-53,.Vol.10,2011

[9] H. Fabian, S. Hartmann and A. Hamidi, "Analysis of Insulation Failure Modes in High Power IGBT Modules",IEEETransaction,pp. 799-805, Vol 2,2005