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Influence of square waveform on life of twisted pairs due to power electronic converters

Narasimha Rao S* and Elanseralathan K*

Issues in the life of stator winding of electrical motors fed by inverter drives have been concerned about researchers over the last two decades for obtaining adjustable speeds.The Power Electronic Converters produces a square waveform (duty cycle, 50%) with fast rising pulses due to the high switching frequency of IGBT's, causes premature failure of motor winding insulation. The Life of such motor insulation is tested using twisted pair samples which are prepared using enamel wires.The enamel coating is of Modified Polyester (Class-F insulation) with different makes have the same thickness of 40 microns and Polyester-imide (Class-H insulation) thickness of 40 microns are the two primary insulation tested in this work and the results are compared. The breakdown test was performed with high voltage power frequency sinusoidal waveform and high frequency square waveform of different frequency levels of 5 kHz to 30 kHz. The test results show that breakdown strength of Class F insulation is more than that of Class H insulation.

Keywords: *Twisted pairs, switching frequency,primary insulation, breakdown, square wave form.*

1.0 INTRODUCTION

The use of inverter fed drive technology has been paved away for dramatic changes in industrial control of motors to achieve adjustable speeds with the help of Power Electronic Converters. The PEC's produces high frequency pulses due to the high switching frequency of IGBT's and generates harmonic distortions towards the supply network side and load side and switching rates produced by these converters generate voltage overshoots which in turn lead to the premature failure of motor winding insulation in both low voltage (less than 1 kV) and medium voltage (2.3 kV to 4.16 kV) motors [1-3]. The over voltages would appear at the terminals of the phase to phase and turn to turn insulation of motor winding traveling towards the load end can rise up to double the magnitude due to reflection and resonance phenomenon due to impedance mismatching between the inverter, cable and motor. These stresses are the responsible for leading to breakdown of motor insulation [4-8]. Further increasing of fast Power Electronic switching devices produces highly nonuniform voltage distribution among the turns and results in higher voltage stress in the first few turns of the coil, which is higher than the stress caused by a sinusoidal waveform [9-13].These over voltages exceeds the partial discharge inception voltage due to this PD activity and makes the life of enamel very short [14-15]. So it is noticed that one of the primary factors responsible for accelerated insulation degradation is the high switching frequency and the motor winding insulation must be designed in such way that it should withstand these high stresses. In our experimental study, the twisted pair specimen is used to investigate the life of the motor insulation.The work focuses here on testing two primary insulation of different

*Dept. of EEE Pondicherry Engineering College, Puducherry Puducherry, India.

makes (Apple, Atlas and RR Shramik) has same thickness made of Modified polyester (Class-F insulation, non- corona resistant material) and Polyester imide (Class-H insulation,non- corona resistant material). All the breakdown tests performed with twisted pair samples are prepared by enamel wires. Breakdown tests was conducted on two primary insulation with high voltage power frequency sinusoidal waveform and high switching frequency of asquare waveform with different frequency levels of 5 kHz to 30 kHz. The test results also show that breakdown strength of Apple Make is more than that of Atlas and RR Shramik. Apple and Atlas show almost same breakdown performance compared to RR Shramik with same thickness.The test results show that break down voltage of power frequency and high switching frequency of Class-F insulation is more than that of Class H insulation. Hence, earlier failure of breakdown voltage of Class H insulation for higher switching frequency levels as compared to Class F insulation. Moreover, as the switching frequency is increased the life of the motor insulation is reduced.

2.0 THE EXPERIMENTAL SET UP

Figure1 shows an auto-transformer, high voltage transformer 10 kV with power frequency was connected to the test specimen to measure the breakdown voltage and DSO observes the waveform. The twisted pair sample was connected across the high voltage transformer. Figure 2 shows that 220 V, 50 Hz source is fed to SMPS power supply. The frequency and duty cycle is controlled by using the SMPS power supply. An autotransformer is connected to rectifier circuit. This circuit consists of EMI filter, bridge rectifier and a capacitor, whose output is given to inverter driver and power supply. This drive generates the pulses fed to H- bridge IGBT inverter. The output of the inverter is stepped up by means of a ferrite core transformer for high frequency operation where the twisted pair is stressed. The peak voltage is measured by a digital oscilloscope through 1000:1 capacitance voltage dividers. Figure 4 shows experimental test set up for conducting breakdown tests.

2.1 Sample Preparation

The life test of motor insulation is performed with twisted pair's samples composed by two enamel wire wound as plait and prepared by according to ASTM D 1676-03 standards. This specimen resembles like a narrow contact between the first and last turns of the input coils of a motor with large voltage difference between the two coils.A 16 gauge (SWG) Class F insulation is insulated by single coated Modified Polyester enamelwith the same gauge and thickness of Class H insulation, insulated by single coated with Polyester-imide enamel (non-corona resistant material) were used for testing. As per standard the number oftwisting is required for this gauge is 6 and the length of twisted pair is (12±6) cm and the tension is maintained between the twisted pair is 1.35 Kg. This gauge wire is used for motor windings in between 1H.P to 25H.P and its rated current of 32A with voltage of 440V, the type employed in cooling fan motor, pump and blower.

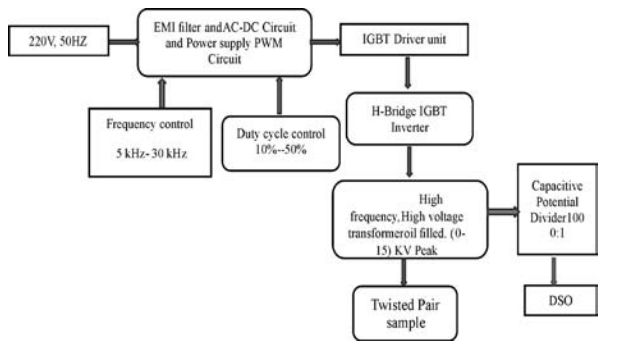

FIG.1. EXPERIMENTAL SET UP FOR HIGH VOLTAGE, POWER FREQUENCY

2.2 Test procedure

While performing the tests, care was taken that, the voltage was not applied both the ends of the same wire and the break down test was done by applying the voltage gradually till the total breakdown of a twisted pair of sample. During conducting the breakdown test, one end of the twisted pair is connected to the high voltage terminal and the other end connects ground terminal.While performing the break down test for Modified Polyester and polyester-imide enameled wires with high voltage power frequency sinusoidal waveformand square waveform of (duty cycle, 50%) high switching frequency variable of 5 kHz to 30 kHz was applied to the two primary insulations. After the voltage is applied, the appearance of initial spark is understood as insulation has failed and voltage at that point is noted which is reported here as breakdown voltage. Five samples per test were tested per each frequency and average breakdown voltage was determined.

3.0 RESULTS AND DISCUSSION

Table 1 show that the breakdown voltages for the modified polyester of the three different make and Polyester imide enamel. They are stressed with high voltage power frequency sinusoidal waveform and square waveform of high switching variable of 5 KHz to 30 KHz

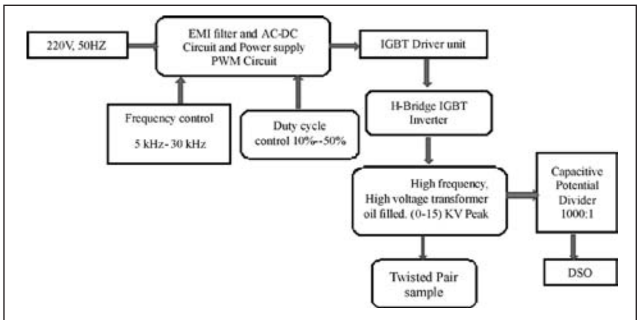

FIG. 2. SET UP FOR INVERTER WITH A SQUARE WAVEFORM OF HIGH VOLTAGE, HIGH SWITCHING FREQUENCY VARIABLE

TABLE 1
BREAKDOWN VOLTAGE OF MODIFIED POLYESTER AND POLYESTER IMIDE

Frequency	Modified Polyester			Polyester imide
	Apple	Atlas	RR Shramik	
50Hz	9.27	7.504	6.78	5.324
5kHz	5.11	3.98	2.92	2.7
10kHz	4.32	3.47	2.62	2.45
15kHz	3.93	3.02	2.33	2.22
20kHz	3.87	2.68	2.26	2.05
25kHz	3.56	2.48	2.12	2.0
30kHz	3.37	2.03	1.98	1.86

Figure 3 shows the comparison of breakdown voltage at power frequency and at high frequency square waveform for Modified Polyester and also for different material Polyester imide. It is observed from the graphs, the breakdown voltage of power frequency and high switching frequency variable of Modified Polyester is more than that of Polyester-imide. From the graph it can be observed that Apple make shows higher breakdown voltage compared to Atlas and RR Shramik. Polyester imide on the other hand shows lower breakdown strength compared to the entire modified polyester make and is close to RR Shramik make. This means that polyester imide coated enamelinsulation shows very poor breakdown strength at power frequency and squared wave form of high switching frequency compared to Modified Polyester enamel with the same thickness. The similar work was reported by the Guastavino *et al* [16]. They have used 2.4 kHz as a switching frequency and the reduction in breakdown voltage is less than the reduction reported here, which is due to higher switching frequency stress of 5 kHz to 30 kHz. Moreover, the two different and distinct slopes are observed, a high slope upto 5 kHz and a lower slope from 5 kHz to higher frequency up to 30 kHz. The reason for this faster degradation upto 5 kHz and a relatively slower degradation from 5 kHz to 30 kHz is being explored.Figure 5 to 7 shows the change in shape of the square waveform when the frequency is increased from 5 kHz to 25 kHz which may also influence the breakdown of the insulation. Investigations are going on to understand this aspect.

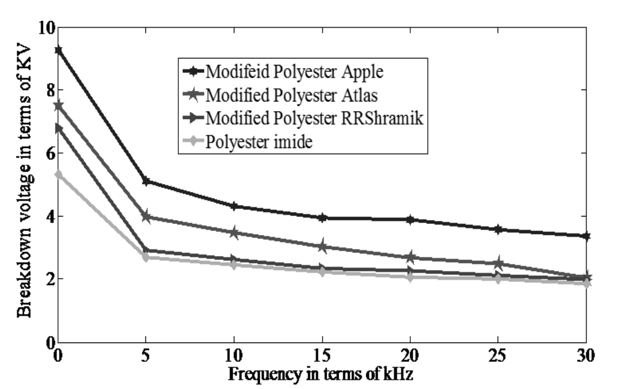

FIG. 3. COMPARISON FORBREAKDOWN VOLTAGE OF POWER FREQUENCY AND HIGH SWITCHING FREQUENCIESOF MODIFIED POLYESTER AND POLYESTER IMIDE

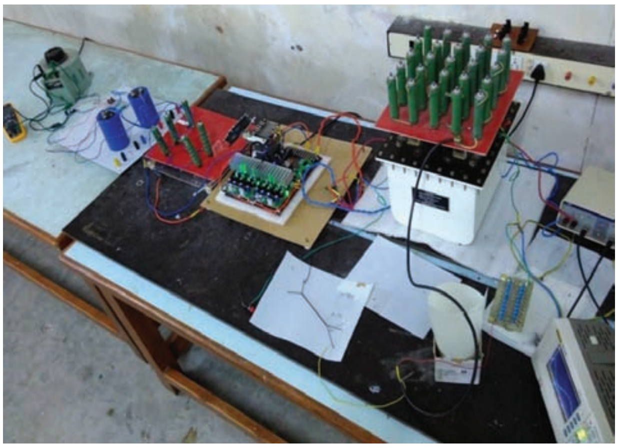

FIG. 4. EXPERIMENTALTEST SETUP PHOTO USED FOR BREAKDOWN TESTS

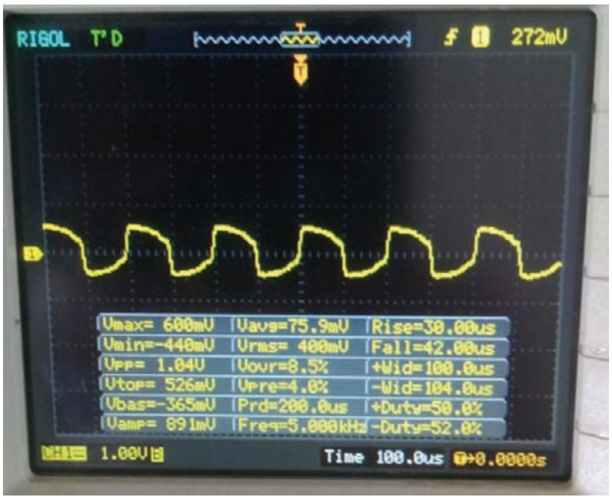

FIG. 5. SQUARED OUTPUT WITH SWITCHING FREQUENCY OF 5 KHZ SHOWN IN DIGITAL OSCILLOSCOPE

FIG. 6. SQUARED OUTPUT WITH HIGH SWITCHING FREQUENCY OF 10 KHZ SHOWN IN DIGITAL OSCILLOSCOPE

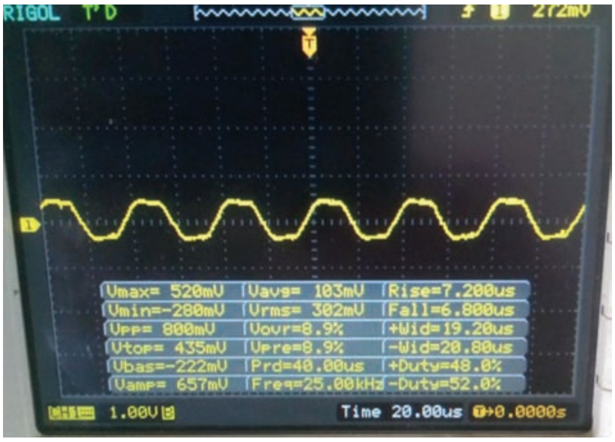

FIG. 7. SQUARED OUTPUT WITH HIGH SWITCHING FREQUENCY OF 25 KHZ SHOWN IN DIGITAL OSCILLOSCOPE

4.0 CONCLUSIONS

Insulation reliability problems are caused by PECs, in which high switching frequency is major stress factor, which rapidly reduces the life of the motor insulation. In our work, it is observed that the Power frequency breakdown voltage with sinusoidal waveform and high frequency squared waveform reduces the lifetime of both Modified Polyester and Polyester imide. BD voltage of Modified Polyester is more than that of Polyester imideand breakdown profile of Apple make is more than that of Atlas and RR Shramik make. Thus, it is concluded that as the switching frequency is increased the life of the motor winding insulation is reduced. However, even this insulation fails when subjected to Adjustable speed drives. Efforts are being made to coat the motor winding with new type of inorganic materials, which are corona resistant to withstand the undue stress produced by the high frequency switching of Power Electronic Converters.

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