AN INVESTIGATION OF SPACE CHARGES ACCUMULATED WITHIN THE INSULATION AND ADJUSTABLE SPEED DRIVES PULSES

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Abstract: The application of power electronic devices with electrical machines can cause premature failure of their insulation due to accumulated space charges within the insulations. In this paper, the effects of space charges on distortion of electric fields are investigated in a 2-D model of form-wound winding in the slot of stator. To calculate the transition effects of space charges and overshoots of pulses on electric fields, COMSOL Multiphysics software have been employed in quasi-statics transient analysis mode. The results for the effects of overshoots of pulses on insulation and the variations of electric fields with different amount of space charges are also presented. It was revealed that an increase in voltage overshoot amplitude and decrease in rise time of pulses can result in enhancement of electric field distribution on the edges which can lead to early aging of insulation.

1 INTRODUCTION

The application of power electronic devices with electric machines has been growing in recent years. With advances on the technology of these devices, switching has become faster and thereupon with decreasing of switching time, the energy efficiency has increased. But the worth to mention point is the role of these devices on the lifetime of insulations of electrical machines. Recent researches have shown that the lifetime of insulations in these machines is less than the conventional machines with no converters on their drives [1-4].

The cause of rapid aging of insulations with power electronic devices is the factors that result in differences between those pulses created with adjustable speed drives (ASD) and normal frequency ac waveforms. The differences are resulted from three major features [5]:

1- Very fast rise time of pulses

2- The voltage overshoot that occurs on each pulse (sometimes it reaches about one and a half times of peak voltage)

3- Very high repetition rate of these pulses (about 10 KHz)

A demonstration of these features of pulses is presented in fig.1.

There are two types of insulation aging due to using of ASDs: electrical aging and thermal aging. Among the features of above mentioned pulses, the most common reason of thermal aging can be related to the very high repetition rate of these pulses. The high switching frequency of converters can cause more heating on windings and as a result, the strength of insulation decreases [7,8].

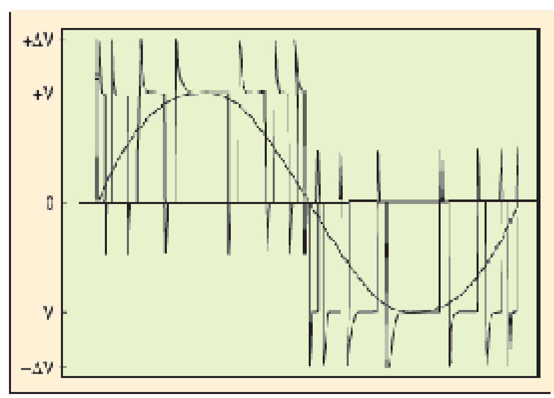

Fig. 1. Typical voltage wave format PWM-controlled motor terminals (non-ideal pulses)[6]

Two factors can cause electrical aging of insulation: partial discharges (PDs) and space charges [9].

In this paper, the behaviour of insulation material subjected to non-ideal generated pulses as well as ideal PWM pulses is investigated and compared. Furthermore, by considering the changes in the amount of accumulated space charges for different rise times of pulses [10]. We have investigated the distribution of electric field for different amounts of space charges. The calculation of electric fields is performed with Finite Element Method (FEM) in COMSOL Multiphysics software environment. In our simulations the distortion of electric fields in presence of space charges is considered as a factor that can cause accelerated aging of insulation.

2 ACCUMULATION OF SPACE CHARGES WITHIN THE INSULATION

With applying voltage on windings, polarization occurs within the insulation. Material is being polarized with different relaxation times that are dependent on the type of polarization [11]. In machines that use ASDs, created pulses with too fast rise time produce high frequency harmonic components within windings.

Because of high repetition rate of pulses and also high frequency harmonic components generated by fast rise time pulses, material doesn't have enough time to react to these changes. So it can not completely polarize or depolarize. As a result of this, space charges are accumulated within the material after a short time.

These accumulated charges cannot move within the insulation easily and they are trapped in some material traps, so they cannot create conduction in insulation. However in presence of these charges, electric field intensity can be distorted. This perturbation of electric fields can increase the stress upon the insulation. In these circumstances, electric field cannot be calculated by using Laplace's equation (equation 1).

$$\nabla^2 V = 0 \tag{1}$$

where: V = voltage in volt (V)

In order to calculate electric field in presence of space charges, Poisson's equation (equation 2) should be used.

$$\nabla^2 V = \rho \tag{2}$$

where: V = voltage in volt (V)

ρ = space charge density (C/m^3)

Previous researches have shown that space charges are often accumulated beside the electrodes (fig. 2) [12]. In this paper, we have assumed the same way of space charge accumulation near the electrodes.

3 MODELLING AND SIMULATIONS

In order to calculate the electric fields, form-wound winding with groundwall insulation within a slot of stator is modelled in the COMSOL Multiphysics software 2-D environment. Finite Element Method is employed for structure analysis. To study the transient effects of applied pulses by ASDs, the quasi-electric transient analysis mode in COMSOL Multiphysics software is utilized.

The model of the simulated structure is presented in fig. 3. In this figure, the cross section of a form-wound winding which is inserted in a slot of stator with groundwall insulation is shown. Component "1" is the conductor and its material is considered as copper.

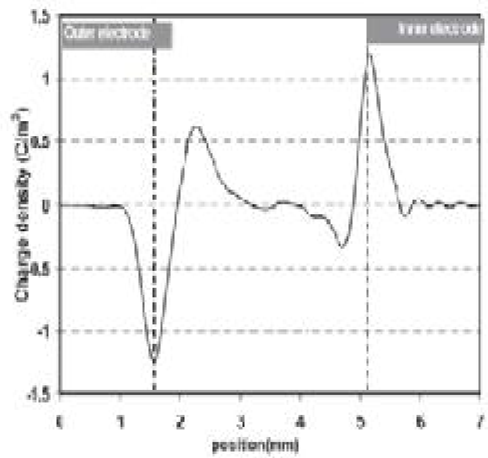

Fig. 2. Space charge accumulation across the insulations between two electrodes [12]

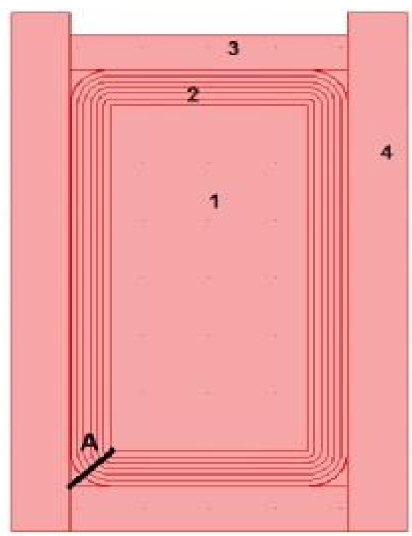

Fig. 3.The Model used in simulations

Component "2" is Groundwall insulation and component "3" is wedge. The material for components "2" and "3" is considered to be polyamide and epoxy, respectively. Component "4" is the core of stator. Since form-wound winding is used in high voltage machines, the thickness of Groundwall insulation is considered to be about 5 mm [13].

As mentioned before, space charges within the insulation is accumulated near the electrodes. In our simulations, we used the one cycle wave with different amplitudes of overshoots. This waveform is shown in fig. 4. The amplitude of these voltages is 20 kV, but different waveforms with different overshoots and rise time values were considered in each simulation. For each value of rise time, the amount of accumulated space charges is different.

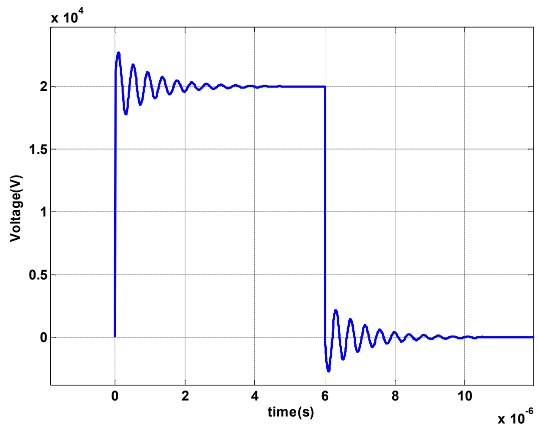

Fig. 4. Applied voltage waveform to the model

The amount of accumulated space charges for our simulations was defined according to the [9] and it was considered to vary from 0.003 (c/m^3) to 0.08 (c/m^3).

4 SIMULATIONS RESULTS

The distribution of electric fields in our model is presented in fig. 5.

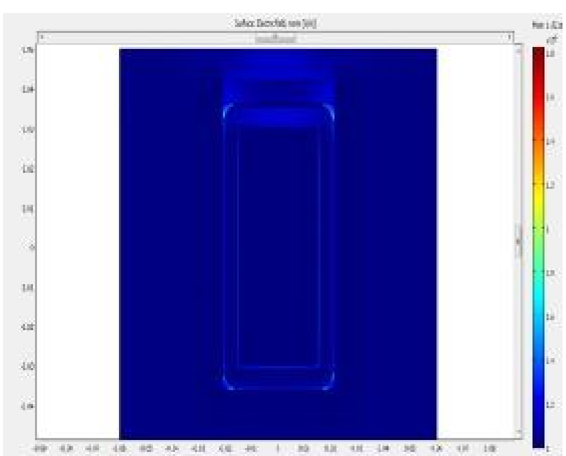

Fig. 5. Distribution of electric field across the insulation

The effect of different amounts of pulse overshoots in absence of space charges is depicted in fig. 6. In this figure, vertical axis represents the electric field along the line A in fig. 3, and horizontal axis represents the distance from the edge of the conductor. The amplitude of voltage overshoots can be about 1.5 times greater than ideal PWM-like pulses. As it can be seen in fig. 6, these overshoots can increase electric fields especially in edge locations. This enhancement of electric fields can increase the stress on the insulation and therefore can accelerate aging process.

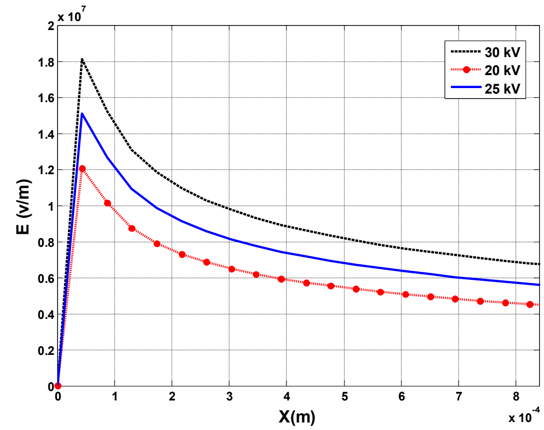

Fig. 6. Electric field vs. the distance from the edge of conductor

The effects of space charges on distortion of electric fields with a certain voltage level are depicted in fig. 7. In this figure, vertical axis represents maximum of electric field and horizontal axis represents accumulated space charges within the insulation. It can be inferred from this figure that with enhancement of accumulated space charges within the insulation, electric fields will increase.

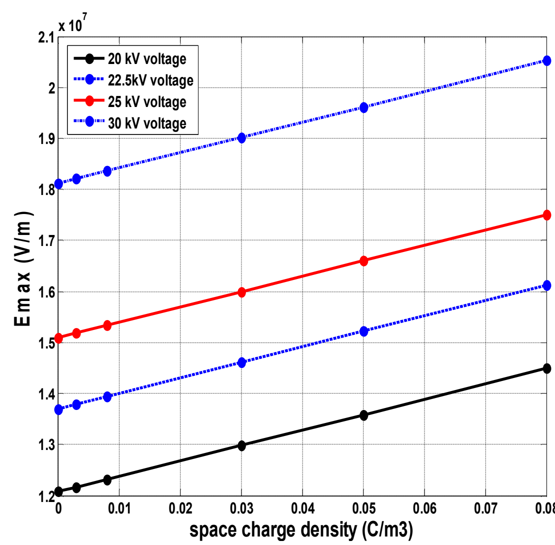

Fig. 7 Maximum of electric field vs. space charge density at different voltages

The effect of increasing the voltage from zero to the peak amplitude of voltage overshoots for different amounts of space charges is presented in fig. 8. It should be mentioned that even at low voltages, presence of space charges can cause considerable enhancement on electric fields.

As we know, with increasing the electric field, the stress on insulation becomes larger and as a result of this increased stress, different occurrences can happen, such as more accumulation of space charges due to changes in atomic structure of material and in much worse conditions PD can occur. These conditions can cause early aging of the insulation which can result in premature failure.

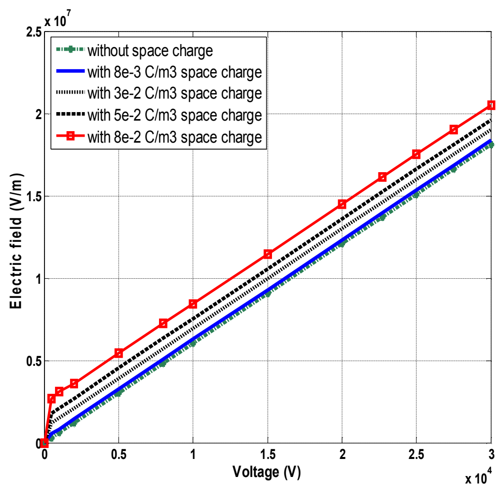

Fig. 8. Electric field vs. voltage for different amounts of space charges.

5 CONCLUSION

Power electronic devices used in ASDs have an important role on premature failure of electrical machines insulations. The effects of space charges as one of the factors in rapid aging of these machines, is presented in this paper. Furthermore, we showed that the increase in space charges density will result in electric fields enhancement within winding's insulation. This increased stress, can cause more accumulation of space charges and even PD occurrence. These effects will result in rapid aging and premature failure of insulations.

6 ACKNOWLEDGMENTS

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7 REFERENCES

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