3D Modeling of Polymer Nanocomposite under High Voltage

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Abstract

Nanoparticle has been proven as a good improver of dielectric properties in electrical insulations. In this research, both 2D and 3D models of polypropylene Nanocomposites made of polypropylene matrix and incorporating various Nanoparticles within polymer matrix have been built and simulated. The purpose is to simulate dielectric properties such as electric field, voltage contours internal to the Nanocomposites and analyze them. Also, effect of percolation limit to influenced dielectric property and electric field behavior has been analyzed.

Indexing Terms: **Nanoparticle, dielectric, electric field, permittivity**

1. INTRODUCTION

Polypropylene is widely used in power industry as insulation [1]. When polypropylene is used in power apparatus, under the application of high voltage, the insulation suffers from various issues such as internal materials degradation, space charges, partial discharges, electrical treeing, insulation breakdown etc[2]. Space charges distorts applied electric field, and when maximizes it introduce complex partial discharges inside [3] and outside the insulating materials. Nanoparticle can solve these issues to some extent [4].

The objective is to investigate dielectric properties of Nanocomposites by building 3D model for simulation purpose, apply boundary conditions, perform simulation and obtain results. The obtained simulation results can be utilized to explain real experimental results [5][6][7] obtained from application of high voltage to dielectric nanocomposites.

2. SAMPLES AND PROCEDURE

Isotactic Polypropylene films with organic natural Nanoparticles were used in multiphysics simulation. The thicknesses of the nanofillled microfilm were 135µm. The diameter of Nanoparticle was less than 100nm. Two copper electrodes were used to apply high voltage and ground respectively. Second system plane-plane electrodes are also used including same Nanocomposite ((0%, 1% and 4%) sample.

Figure 1 shows the model that was used in our simulation. A Rod-Plane electrode system was used to apply electrical stress to the samples. Rectangular samples of length 60 millimeters were perfectly attached to the ground electrode. The Rod-electrode was secured to the top of the Nanocomposite sample and a clearance of 2mm between Rod-electrode tip and sample surface was maintained by a dielectric barrier. The diameter of the Rod electrode was 15mm and radius of the tip was 7.5mm.

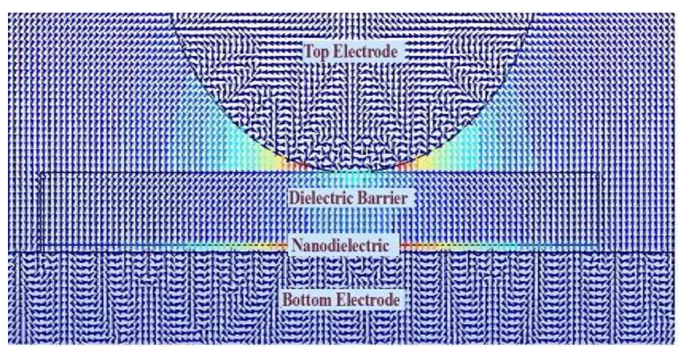

Figure 1: Electric-field arrow in nanofilled polypropylene

The second set up which is with a plane-plane electrode system having same thin polypropylene film filled with Nanoparticles have been used. Here the thin sample is the films incorporating Nanoparticles. Figure 2(b) shows a transparent view of nanoparticle distribution within sample.

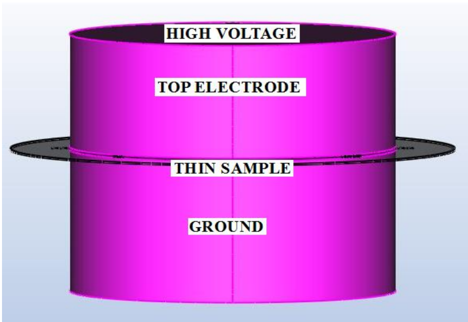

Figure 2(a). 3D Model of Nanocomposite in plane-plane copper electrode system

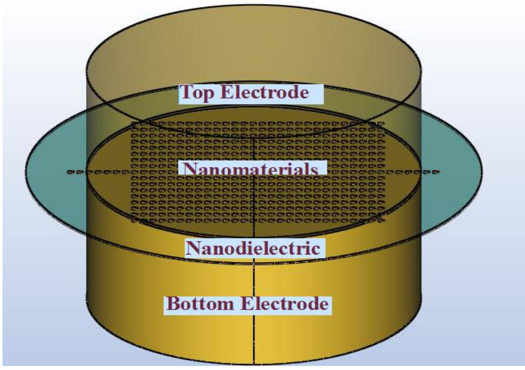

Figure 2(b). Transparent view of the nanoparticle filled (4%) sample

3. SIMULATION, RESULT AND ANALYSIS

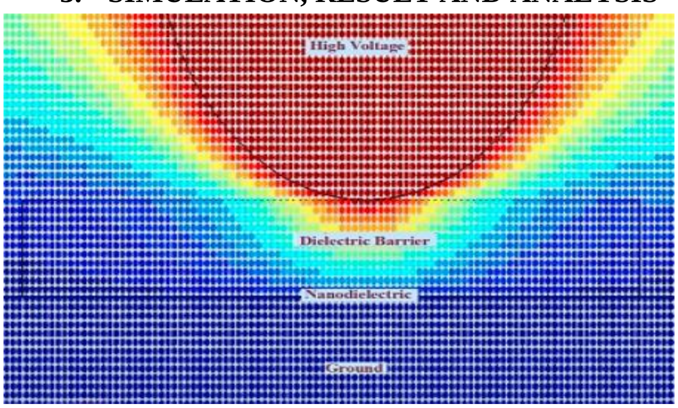

Figure 3(a). Voltage Scatter under Applied Voltage

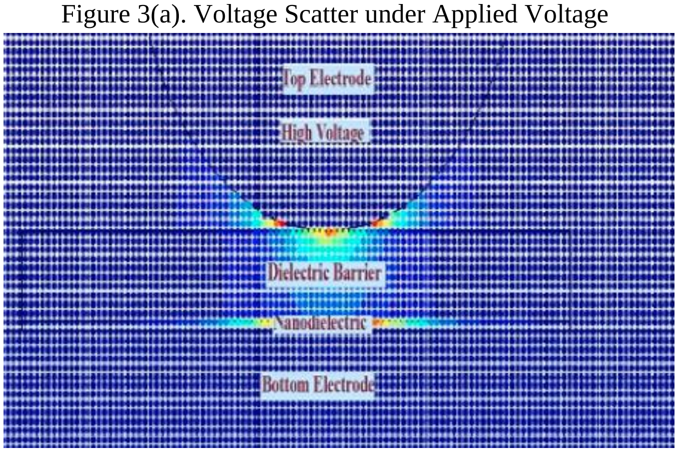

Figure 3(b). Electric Field Density under Applied Voltage

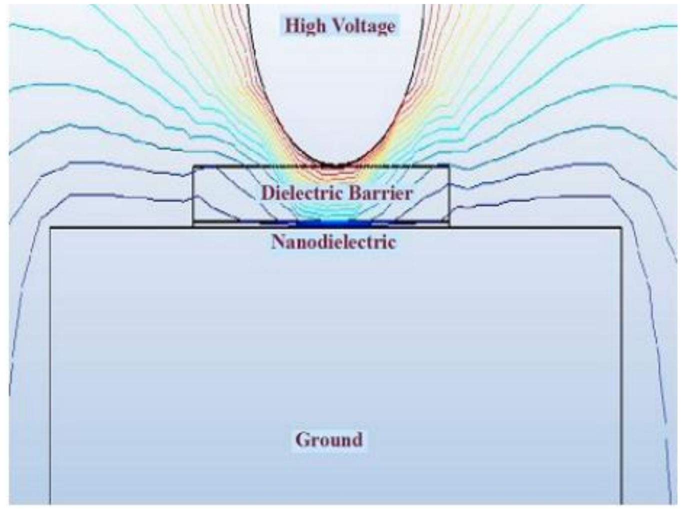

Figure 3(c). Voltage Contour under Applied Voltage

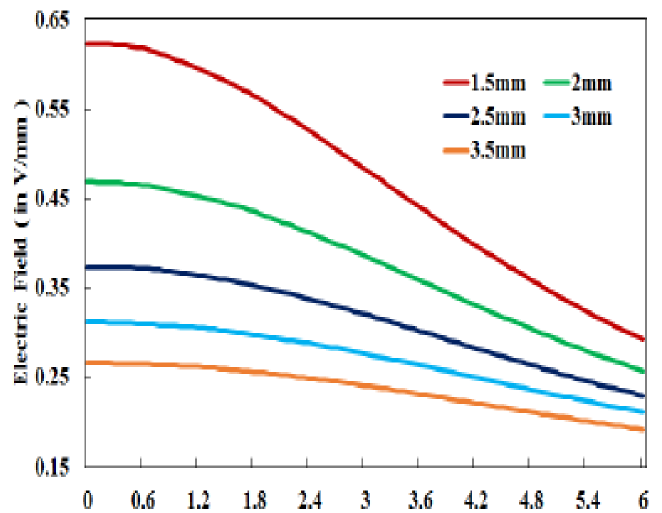

Figure 4. Electric Field simulation for various thickness of dielectric barrier or distance from rod tip (of top electrode) to sample surface

Dielectric used in areas of insulation suffers from some issues when high voltages are applied to them. Because of the generation of space charge due to applied high voltage, electric field distortion happens inside the sample [8]. To reduce this filed distortion nanoparticle can be used [9]. Nanoparticle has higher permittivity (>50) than the dielectric such as polypropylene (2.2) itself [10][11]. So, nanoparticle can sustain more electrical stress than the base material which can be used in high voltage application [6][12]. Here, simulation of electric field of nanofillled dielectric polypropylene subjected to applied voltage for variation in dielectric barrier is done. Next simulation of sample with nanoparticle concentration has been done.

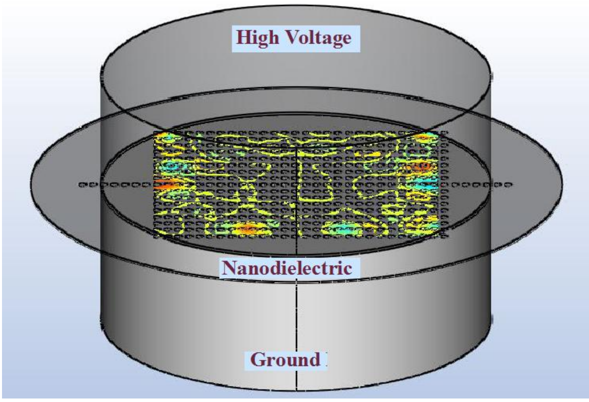

Figure 5(a). Voltage Contour in plane-plane electrode system with nanofillled (4%) dielectric

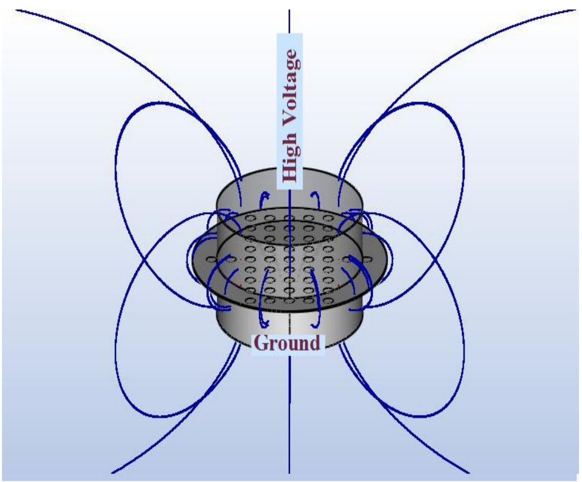

Figure 5(b): Electric Field streamline in Nanofillled (1%) sample

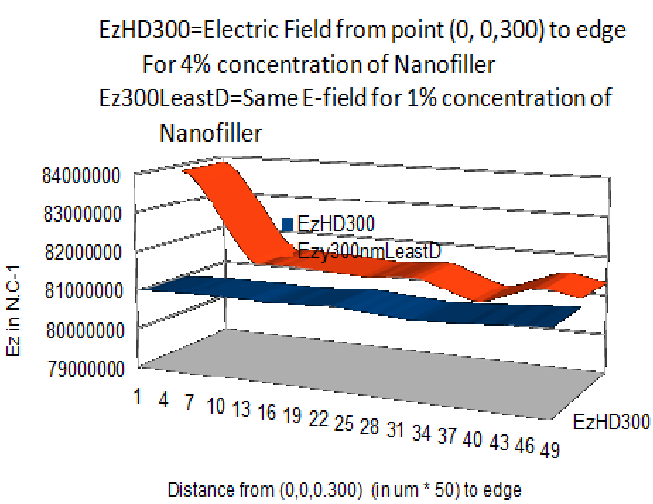

Figure 6. Electric Field for nanoparticle concentration of 1% and 4%

Here, high voltage was applied from top electrode to the nanofillled sample and variation in output electric field within the sample for different concentration of nanoparticle has been observed. Results indicate that for 4% concentration the electric field becomes lower. This can be attributing to the fact that more nanoparticles with higher permittivity can absorb more electrical stress. However, concentration higher than 6% is not used because it its above the percolation limit, where nanoparticle cannot improve dielectric properties under high voltage. Above percolation limit nanoparticle interface zone overlapped and loose effectiveness to trap charge.

4. PHYSICAL MECHANISM TO PREVENT ELECTRICAL STRESS

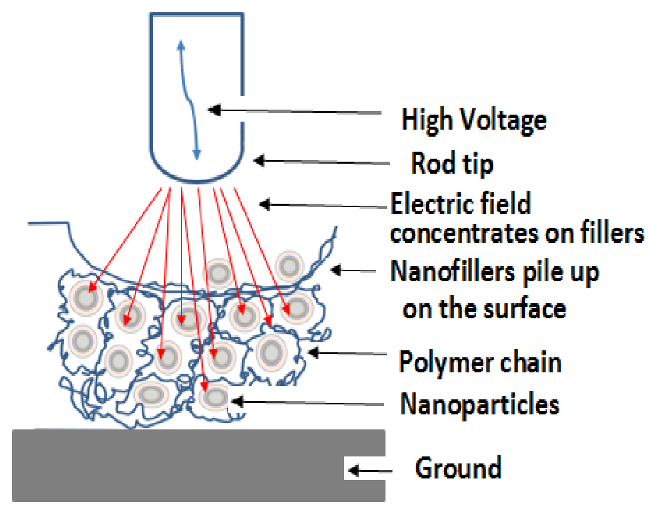

Figure 7: Mechanism of discharge resistance and reduction in electric field at the surface and internal to the surface

There are several physical mechanisms that happen inside and at the surface of nanofillled sample that play important roles to reduce surface discharges and local electric field [2][4][6]. In 3D nanoparticle filled polypropylene, 3D nanosegmentation occurs internally. This nanoscale interface zones can trap charges and prevent charge penetration[13]. This in turn reduce surface local electric field from electrode rod tip to sample and from sample center to the edge of the sample [7]. When applied electrical stress is too high, nanofillers can get out of internal portion of the sample and pile up on the surface. These particles gathered and work against extreme electrical stress and reduce localized field distortion at the surface and internal nanodielectric region of the sample.

5. CONCLUSIONS

- 2D and 3D models of nanocomposites under high voltage have been built
- Boundary conditions were applied as top electrode voltage=any HV, ground=0V.
- Various electrical properties such as voltage contour, electric field density, voltage scatter, electric field contour have been simulated.
- Results of electric field simulation have been obtained and analyzed with respect to dielectric barrier from rod tip to sample surface and also for various concentration of nanoparticle.
- Analysis of results has been performed.

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