

Lossless and Efficient Transmission of Electrical Energy using Nanotechnology

G K Naveen Kumar¹, Akanksha Thakur², Renu Yadav³
 Dept. of Electrical Engineering^{1,2,3}
 National Institute of Technology^{1,2,3}
 Kurukshetra, India^{1,2,3}

Abstract— In this paper various probabilities and wide applications of nanotechnology in power engineering were investigated. On one side new materials required for conductors and on the other side new coatings for electrical insulators were taken into consideration. For high voltage insulation systems used in electrical engineering, the aim is to extend the lifetime, to minimize the life cycle costs, to decrease the size or weight, to reduce the maintenance expenses, and to raise the efficiency. The practical application of nanotechnology in conductors include functional filler material called carbon nano tubes. These nano tubes have high electrical conductivity and it approaches very close to the conductivity properties of a good conductor material. In insulators nanocoating were applied on the ceramic surface and the stability test for long term duration was conducted under a humid and thermal cycling procedure under natural climatic conditions. For long term stability purpose the contact angle can be observed by optical measuring instruments in defined time intervals.

Keywords-Conductors, Ethylene propylene rubber(EPR), Leakagecurrent(LC), Insulators, Room Temperature Vulcanised (RTV)SILICONE, SWNT

I. INTRODUCTION

In wide areas nanotechnology is already present and the preceding connection can clearly be assumed. The areas where nano technology is presently and widely used are in the field of medics, biomedical and electronics. Now it sounds like fortuitous to implement nanotechnology in power engineering. Power engineering where thousands of Megawatts of Power and Volts have involved a technology of miniaturization of elements shows a drastic change with its implementation. The does of this technology include the following:

- Improvement of metallic conductivity (By reducing losses).
- Improvement of insulators (By rising electrical insulation, mechanical stability, thermal load behavior resistance).
- Miniaturizing of design, higher reliability.
- Improvement of electromagnetic compatibility (EMC).
- Long duration improvement of efficiency and prolonging life time period.

A new nano conductor with ultra-low resistivity at a reasonable cost will have an extremely wide impact on present day electrical technology. Conduction losses can be drastically decreased and metals with high environmental impact can be replaced by metals that are more environmentally friendly[1].

II. ELECTRICAL CONDUCTORS

An electrical conductor is a material that allows the general movement of an electrical current because the material consists of charged particles (usually electrons) which move in the presence of an electrical potential difference. The degree to which a material allows efficient movement (low resistivity) of electricity without loss of charge or increase in heat indicates its conductivity. All metals are conductors, though not all are efficient enough for functional use. Some common electrical conductors include:

- Copper – the common material due to its conductivity balance.
- Silver - a better conductor than copper, but expensive to use.
- Aluminum – Potentially dangerous gives certain imperfections in wiring.
- Gold – more expensive for usage.
- Iron - too heavy for practicality.

Each material has its own unique resistivity and cost, which are the two main factors determining use.

The fundamental properties of conventional ohmic conductors and ballistic conductors may differ. In an ohmic conductor, the conductance G can be written as:

$$G = \sigma A/L \quad (1)$$

where σ is the conductivity of the material, A is the area and L is the length of the conductor. In general a conductor has an ohmic behaviour if its dimensions are larger than certain characteristic lengths like the mean free path, l_{mf} , the phase-relaxation length, l_{ph} , and the de Broglie wavelength, l_{dB} . The mean free path, l_{mf} , is the average distance an electron is travelling before it has lost all of its original momentum. The conductivity of a sample is proportional to the mean free path, i.e. the longer the mean free path the higher the conductivity for a material.

The relation can be defined as:

$$\sigma = (ns l_{mf} / m^* v_f) \times q^2 \quad (2)$$

where q is the electron charge, ns the density of conduction electrons, v_f the Fermi velocity and m^* is the effective mass. At room temperature the mean free path of Cu is approximately 40 nm. It is found, both theoretically and experimentally, that as the length of a conductor approaches zero, the conductance approaches a large value, but not infinity. This type of conductor is referred to as a ballistic

conductor. If the conductor has a length much less than the mean free path of the electron all losses occur at the contacts. Recently, H. Dai's group at Stanford University have proven that single-walled carbon nanotubes (SWNTs) can be ballistic conductors. The best way is to use high-quality SWNTs, produced by a chemical vapour deposition(CVD) method and carefully contacted with Ti contacts.

III. ELECTRICAL INSULATOR

Electrical insulators, or dielectrics, are non conducting materials that can withstand electrical current passage. Insulators support and protect conductors so that current freely flows through the conductor. These protective insulator materials help to prevent electrical shock or sparks.

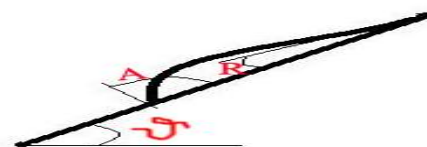
Dielectric materials comprises of substances with energy particles or electrons, that are compressed each other by chemical process. Electrical voltage to pass through these materials is highly impossible. Some insulators that are having higher thresholds for electrical voltage than others are called high voltage insulators[7].

Glass, porcelain, mica, and ceramic, can withstand the high ranges of electrical current. Along with rubber, plastics has a lower threshold voltage than porcelain and glass, because of their loose electron composition.

A. Hydrophobic Properties of Insulator Surfaces

In nanotechnology products there was a material to enhance the hydrophobic behaviour of surfaces. Hydrophobicity of a surface indicates the ability of the surface in repelling water and is indicated by its contact angle. Hydrophobic surface has contact angle more than 90° while hydrophilic less than 90° . Normally used ceramic outdoor insulators are associated with corona discharges, flashovers and leakage current due to humidity, rainfall along with dust, industrial pollution, salt fog or sand storms accelerate the ageing of the porcelain surface[5,10]. The less leakage current and best flashover behavior of an insulator shows a better hydrophobic surface of the insulator, which some of the polymer insulators have. When compared to polymer surfaces the ceramic insulators show a poor hydrophobic characteristics [6]. For this reason Nano Technology goes with a silicone rubber coating of the ceramic surface for getting succeeded. In this process the long term stability of nanocoated ceramic insulators were examined.

For hydrophobic properties of insulator surfaces the contact angle is the determining parameter. In accordance to IEC Standard 62073, for an inclined surface the dynamic contact angle consists of an advancing and a receding angle as shown in Fig.3 The static contact angle was not considered for these process because the insulator caps normally have minimum inclination of 15° .



θR ...Receding Contact Angle
θA ...Advancing Contact Angle

Figure 3. Dynamic contact angle measurement

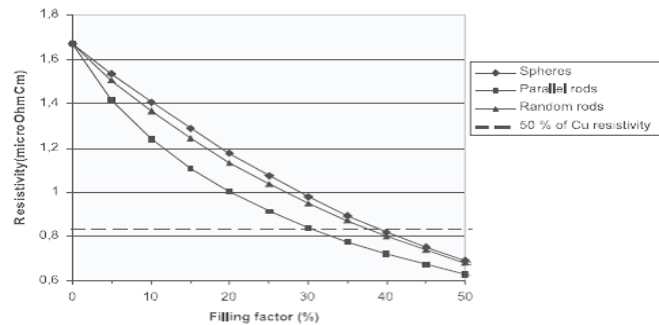


Figure 1. Calculated resistivity in a composite of SWNTs and Cu. The resistivity is shown as a function of SWNT filling[2].

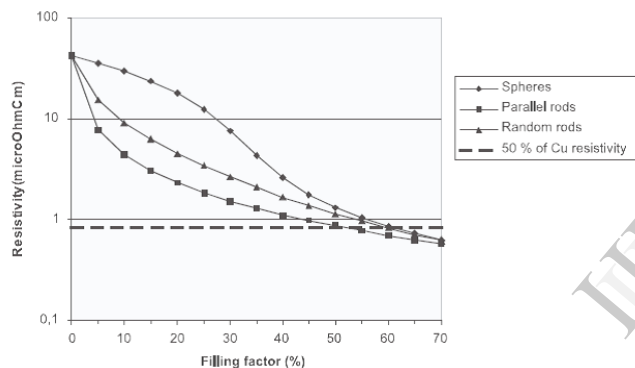


Figure 2. Calculated resistivity in a composite of SWNTs and Ti. The resistivity is shown as a function of SWNT filling[2].

The ultra-low resistivity property is possible for carbon nano tubes(CNT) because they have an electron mean free path magnitude several order times longer than metals like Ag and Cu . This ensures that a system with parallel-connected nano tubes can have a room-temperature resistivity far less the resistivity of normally used metal conductors like Al, Ag, and Cu,. These affords the reduction of ohmic losses at metallic conductors using Carbon Nano Tubes (CNT)[1,2]. In Fig.1 and Fig. 2 a ultra-low-resistivity material based on a single walled carbon nanotube (SWNT) filling was represented. In a simple and effective model it can be shown that resistivity of 50% lowers than the actual resistivity of Cu is achievable at room temperature and the obtained resistivity from a composite of copper and CNT. This phenomena is possible because of single-walled carbon nanotubes[1]. If the ohmic resistance <50% could be reduced, that much percentage of conductivity can be improved. Thus, the power losses could be reduced and the efficiency of cables can be improved.

B. Contact Angle Measurements Of Insulator Surfaces

From the beginning of this process the receding and advancing contact angle was observed up to the end. By using digital camera the contact angle was observed and pictures were evaluated using graphical software. The contact angle determination is shown in Fig.4.

With different size of water drops beginning from 1 μl up to 100 μl in steps of 5 μl this measuring procedure has been done. The results of advancing and receding contact angles have been recorded. The water drops were inserted with a pipette where the drop size can be adjusted continuously between 1 and 200 μl . By introducing the equal water drop size two or more times the measuring results were verified with previous values.

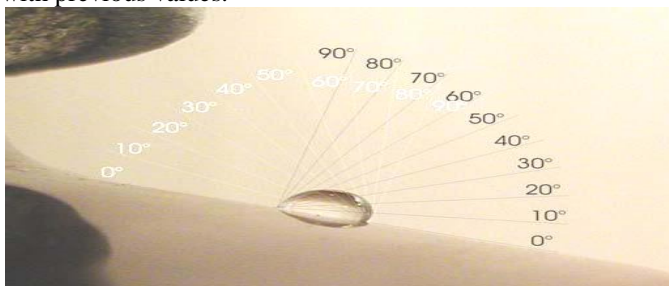


Figure.4 Contact Angle Determination

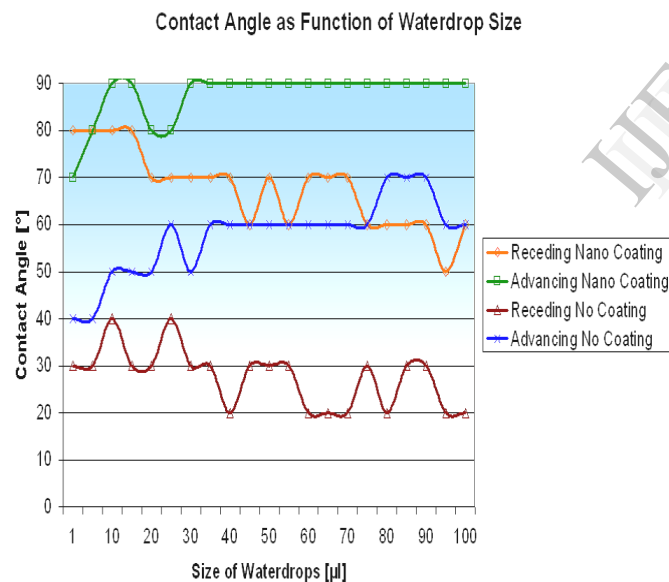


Figure 5. Contact angle characteristic of nanocoated and non coated ceramic surfaces

The contact angles determination with respect to water drop size were shown in Fig.5. The light degrading characteristic for bigger water drop volume was shown under receding contact angle where as the nanocoated insulator advancing contact angle was almost constant at 90° for any of water drop sizes.[5].

The contact angle is almost constant over the whole test period for coated type.

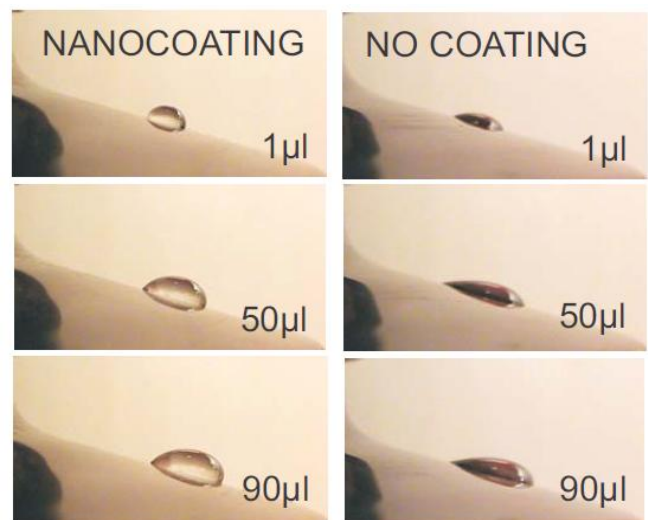


Figure 6. Interfacial tension for different water drop sizes[3,5]

Between the coated and the non coated ceramic surface a huge difference in the hydrophobic characteristic was observed. Fig.6 states the difference of the interfacial tension of non coated and coated insulators for different water drop sizes. It is clearly visible to see that the contact angles of nano coated were much higher than that of an untreated surface on the right side[3,5].

IV. EFFECT OF WATER DROPLETS & FILMS ON THE PRACTICAL OUTDOOR INSULATORS

Presence of water droplets over the insulator surface enhances the electric field intensity and leads to electrical breakdown. Water droplets/films lead to the breakdown of the insulator even under the absence of actual contaminants. Effect of deterioration of the hydrophobicity is investigated through placing multiple droplets/films on the sheath and shed regions of practical insulator configurations [5].



Figure 7. High Voltage insulator of 138KV where 'a' represents the shed region and 'b' represents the sheath region [5].

A. A. Sheath Configuration

Insulator wettability and hence hydrophobicity of insulator surface are instrumental in controlling the shape of the water droplet. Since the shape of water droplet affects redistribution of electric stress, this aspect has been investigated varying the contact angle and verifying the pattern of Emax w.r.t contact angle. The two commonly used materials namely SIR and Porcelain have been used in our calculations. For both materials it has been noticed that Emax is a function of contact angle. It can be observed in Fig.8, that for lower values of contact angles (10°.to 30°.) as signified by materials that have substantially lost hydrophobicity, the intensification of E-field is relatively low since the water film produces a resistive

grading effect. At moderate contact angles (30° to 90°) the stress values are relatively higher. Beyond 90° the stress concentration steadily reduces. This is because at higher contact angles that indicate fresh and unaged insulator surface, the triple point is engulfed by the equipotential water surface leading to a lower stress concentration. Hence it is most desirable to have a contact angle above 90 deg. below which the insulator is more vulnerable to wet flashover[8].

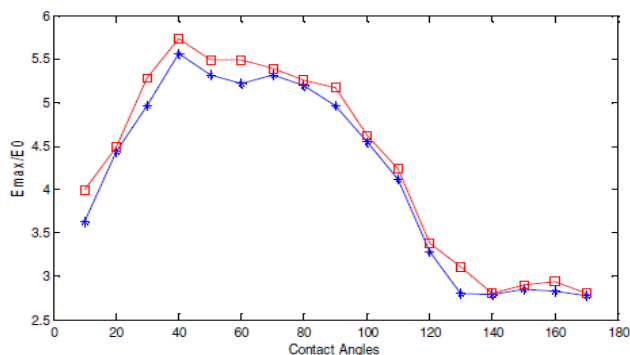


Figure 8. Variation of normalized maximum electric field values with respect to the contact angle for sheath configuration. Square points are for porcelain and Asterisk points are for Silicone Rubber. E0 is the average E-Field and Emax is the maximum E-Field[5].

B. Shed Configuration

The water particles will be deposited on the shed region due to rain, fog, dew, snow etc. The particles can also occur due to condensation on the underside of the shed caused by temperature gradient. Results of simulations as shown in Fig.9 indicate that when hydrophobicity of material is low (contact angle 10 deg. to 50 deg.) the maximum stresses occur at the triple point, whereas at a comparatively better hydrophobicity (contact angle 60 deg. to 170 deg.) level the stresses occur at the top most tip of the droplet. The trend is similar in both SIR and porcelain although the stress values in porcelain are higher than those in SIR mainly because the relative dielectric constant of porcelain is larger than that of SIR[5].

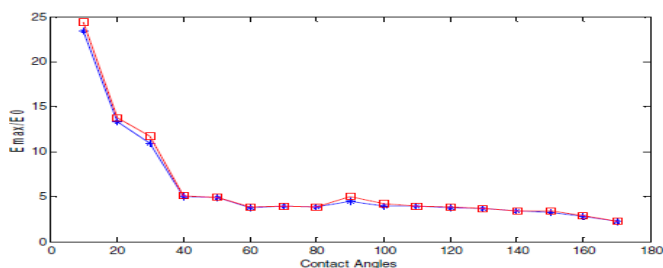


Figure 9. Variation of normalized maximum electric field values with respect to the contact angle for shed configuration. Square points are for porcelain and Asterisk points are for Silicone Rubber. E0 is the average E-Field and Emax is the maximum E-Field[5]

V. RTV SILICONE RUBBER NANO FILLER COATING ON OUTDOOR INSULATOR

CERAMIC insulators are now routinely used for new construction as well as replacement of conventional polymer insulators for overhead lines by many utilities. Besides the advantages of lighter weight, higher vandalism resistance, and ease of handling when compared to ceramic insulators, nonceramic insulators have an additional merit which is improved flashover performance under contaminated conditions. The latter advantage is due to the smaller diameter than a ceramic insulator and an external surface that resists water filming initially. Of the two classes of materials used widely for nonceramic insulators, namely silicone rubber and ethylene propylene rubber (EPR, other material families are also in use for HV outdoor insulation), the ability to resist water filming, commonly referred to as HYDROPHOBICITY, is more apparent for the silicone rubber family. Due to this beneficial property silicone rubber (room temperature vulcanizing, Room Temperature Vulcanised/RTV) is also used as a protective coating for ceramic insulators, especially in stations, in order to improve the contamination performance of ceramic insulators[3,4,10].



Figure 10. Pictures of non coated [left] and RTV coated [right] samples[4,11]

However, with the accumulation of airborne contamination, ageing, corona activity and surface discharges, the materials can be expected to lose their initial hydrophobicity to varying degrees. Flashover of outdoor insulators is a complicated phenomenon and is even more so for non ceramic insulators due to the possible interaction of the arc with the dynamic polymer weather shed material. It has been well reported via some laboratory tests that the flashover voltage of silicone rubber insulators is higher than that of EPR coated insulators, if the insulator details are the same. Also the reduction in the flashover voltage of EPR insulators with time of aging is more than that for silicone rubber[7,10].

The difference in leakage current flowing through the insulator surface can be observed for noncoated RTV silicon rubber and coated one for different kaoline salt pollution having some amount of conductivity as shown in Fig.11 and Fig.12[4].

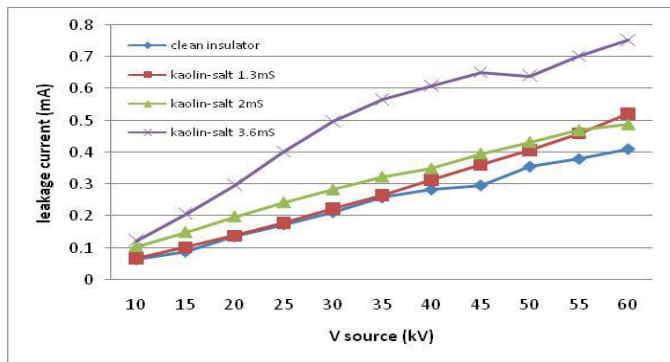


Figure 11. Leakage Current (LC)magnitude as function of applied voltage for insulators with various kaolin-salt pollution and clean type for uncoated surface[4,11].

On applied voltage 10 kV, it can be seen that clean sample and kaolin-salt samples have LC magnitude almost the same. As the applied voltage goes on increasing, the LC magnitude of clean sample lower than that of kaolin sample. LC is affected based on the amounts of salt applied. Higher LC magnitude due to increase in kaolin salt pollution. At 60 kV, the lowest LC magnitude flowed on clean sample and at 3.6 mS the highest LC magnitude flowed on insulator polluted with kaolin-salt pollution and the large amounts of kaolin-salt pollution increases the surface conductivity of an insulator. It can also be concluded from Fig.12 that as a function of applied voltage the LC magnitude of an insulator with larger amount of pollution has greater gradient compared to non polluted type[4,11].

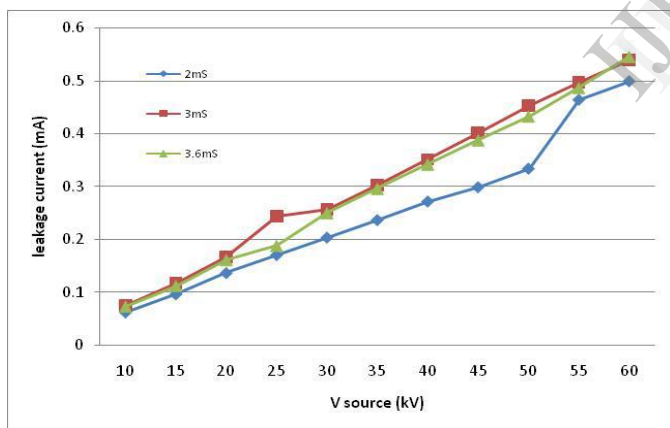


Figure 12. Leakage Current magnitude as function of applied voltage for insulators with various kaolin-salt pollution a for RTV silicone Rubber coated surface[4,11]

Fig.12 shows LC magnitude variation with respect to applied voltage and it is almost equal for kaolin polluted insulators under kaolin salt fog with conductivity of 2, 3, and 3.6 mS. It can be seen that the magnitude of LC didn't affected by salt fog conductivity since the magnitude of LC under various salt fog conductivity was almost the same. Compared to the LC magnitude under salt fog, the LC magnitude under clean fog was almost equal[4,9].

No	Water Droplet Profile	Contact angle (deg.)
a		100 - 110
b		95 - 100
c		105 - 110
d		105 - 115
e		100 - 105

Figure 13. Typical photographs of water droplets 50 μ L on (a) clean insulator, (b) Insulator polluted with kaolin pollution, (c) Insulator polluted with kaolin-salt pollution at 1.3 mS, (d) Insulator polluted with kaolin-salt pollution at 2mS, and (e) Insulator polluted with kaolin-salt pollution at 3.6mS[4].

RTV silicone rubber coating improves hydrophobicity and the surface smoothness. The results also shows that for various artificial polluted conditions the contact angle of RTV silicone rubber coated insulator are still more than 90°. These indicated that RTV silicone rubber coated insulator can maintain its hydrophobicity under various polluted condition[4,11]. RTV silicone rubber coating suppressed the magnitude of leakage current, the harmonic content of leakage current and increased the flashover voltage under various artificially - simulated pollution. The low Leakage Current corresponds to high surface resistance which indicates high quality of insulator. These results indicate that RTV silicone rubber coating improves the performance of ceramic outdoor insulator to overcome pollution effect. RTV silicone rubber coated insulator is suitable to be placed on seashore and other environment with tropical climate[10,11].

VI. TEST OBJECTS & TEST RESULTS

Polymer insulators with silicone rubber weather sheds show excellent flashover voltage characteristics under contaminated and wet conditions owing to surface hydrophobicity. But due to organic material of weather sheds, long-term ageing deterioration of the results of different test showed that a porcelain long-rod insulator coated with silicone rubber was less deteriorated compared with a transmission line polymer insulator coated with the same silicone rubber.

A. Accelerated Ageing Test

After 380 cycles of accelerated ageing test, specimen insulator surface were observed. Any significant deterioration was not found on any specimens. But black contaminant was deposited on the energized end shed surface of the transmission line polymer insulator as shown in Fig.14 (a), which is considered to be caused by partial discharges. Actually continuous partial discharges were observed as shown in Fig.14 (b) after 200 cycles. The contaminant could be, however, wiped off easily[6].

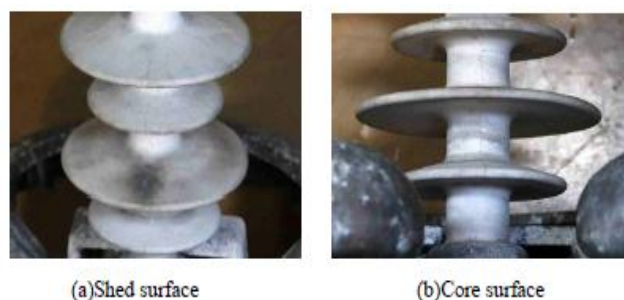


Figure 14. Appearance of transmission line polymer insulator after 380 cycles of ageing test[6].

B. Partial Discharge Inception Voltage Test

In the case of the transmission line polymer insulator with 26mm of core diameter, continuous partial discharges were observed along the core surface. In the case of the other specimens, corona discharges were observed at the tips of water drops. But the magnitudes of leakage currents of these streamer corona discharges were very small, and they occurred only intermittently. Partial discharge inception voltage test results are shown in TABLE I. In the case of the transmission line polymer insulator partial discharges started at the very low voltage of 40-kV. But in the case of the other specimen insulators, partial discharges started at much higher voltages and only streamer corona discharges[6].

TABLE I. Partial Discharge Inception Voltage Test Results[6]

Specimen	Partial Discharge Inception Voltage, kV
Transmission Line Polymer Insulator	40
Polymer SP Insulator	100
Polymer Bushing Shell	60
Porcelain Aero-shed Long-rod Insulator	60
Porcelain Normal-shed Long-rod Insulator	110

All above stated tests were applied for the same ceramic/porcelain insulator type. Out of eight insulators used in the test program, Nanocoating was applied to six of them were in a climate chamber with relative air humidity between +93% and 50% and a test program with temperature differences between +60°C and -20 °C . During a half year period of time almost 70 to 80 ageing cycles to be happened. These insulators were exposed to outdoor climate of -10°C and +25°C, with natural pollution. The evaporation process under heating and freezing of the air humidity under cooling at the insulator surface showed in accelerated ageing procedure.

VII. CONCLUSIONS

In power transmission the influence of nano fillers for insulating materials, the coating for hydrophobic surfaces and achieving a ultra low resistivity conductor were discussed. The hydrophobic properties of non coated and nano coated ceramic insulators were tested under different test conditions. A difference in measured contact angles of 30° in average was observed between the uncoated and the coated surfaces. This value matches well with contact angle measurements of polymer surfaces recently published. The nano coating shows no degradation after more than 70 to 80 ageing cycles. The application of the nano surface on insulators is quite easy and it can be done at installed and new insulators also. By Using Nano technology we have numerous advantages when compared to a non coated material. In addition to that the conductor of ultra-low resistivity cannot be realized by present technology but nanotechnology gives us hope to find new ways of getting the loss free electric conduction.

REFERENCES

- Changxin Chen a, Liyue Liu a, Yang Lu a, Eric Siu-Wai Kong a, Yafei Zhang a, Xinjun Sheng b, Han Ding b, "A method for creating reliable and low-resistance contacts between carbon nanotubes and microelectrodes" *Vol. 1, 27 August 2006.*
- O. Hjortstam, P.Isberg, S.S.Oderholm, H. Dai,"Can we achieve ultra-low resistivity in carbon nanotube-based metal composites?", *Appl. Phys. A 78, 1175–1179 (2004).*
- S.Ganga, G.R.Viswanath, R.S.Shivakumara Aradhya "IMPROVED PERFORMANCE OF SILICONE RUBBER INSULATION WITH NANO FILLERS" *IEEE 10th International Conference on the Properties and Applications of Dielectric Materials July 2012,Bangalore.*
- Suwarno and Fari Pratomosiwi "Application of RTV Silicone Rubber Coating for Improving Performances of Ceramic Outdoor Insulator under Polluted Condition" *IEEE Transactions Vol.1, No.6, pp.982-990,2009.*
- Bhargavi Sarang, Prathap Basappa, Vishnu Lakdawala, "Effect of Water droplets and Water films on the Electrical Performance of Practical Outdoor Insulators" *IEEE Transactions on Dielectrics and Electrical Performance Vol.15,February 2010.*
- Taeko Tanahashi, Syoichi Ishikawa,Masahito Imai,Tomoyasu Sasaki, Hiroyuki Shinokubo, Ryosuke Matsuoka,Masayoshi Suzuki, Masanori Isozaki, "Effect of Insulator Configuration on Ageing Deterioration of Polymer Insulators" *Electrical Insulation Conference June 2011.*
- Qi Wang and George Chen and Abdulsalam S. Alghamdi, "Influence of Nanofillers on Electrical Characteristics of Epoxy Resins Insulation" *IEEE Transactions Vol.34,2010.*
- S.Venkataraman, R.S. Gorur, "Extending the applicability of insulator flashover models by regression analysis", *IEEE Transactions on Dielectrics and Electrical Insulation , Vol.14, No.2, pp.368-374, 2006.*
- D.L. Williams, A. Haddad, A.R. Rowlands, H.M. Young and R.T.Waters, "Formation and characterization of dry bands in clean fog on polluted insulators", *IEEE Transactions on Dielectrics and Electrical Insulation, Vol.6, pp.724-731, 1999.*
- Cherney E A, and R S Gorur. "RTV Silicone Rubber Coatings for Outdoor Insulator." *IEEE Transactions on Dielectrics and Electrical Insulation,Vol.1, pp. 481-487.*
- Fari Pratomosiwia ,Suwarno "Performance Improvement of the Ceramic Outdoor Insulators Located at Highly Polluted Environment Using Room Temperature Vulcanized Silicone Rubber Coating" *International Journal on Electrical Engineering and Informatics - Volume 2, Number 1, 2010.*