Influence of Air Microcavities on Electrical Field Distribution, Electromechanical Pressure and Dielectric Losses in High Voltage Cable Insulation

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***Abstract*—The origin of electrical discharges in high voltage cables insulation probably can be attributed to many causes such as: overvoltage and the presence of impurities which have been introduced into the insulation during the manufacturing step. These impurities may lead to electrical field increasing thus to the formation of partial discharges. The purpose of this work is to determine the effect comes from cavities presented in Cross-linked Polyethylene (XLPE) on the electrical field, temperature and electromechanical pressure distribution into and around the cavity. The calculation of these constraints is performed by the resolution of LAPLACE equation using Finite Difference Method (FDM).**

Keywords— Electrical discharges, Crosslinked Polyethylene (XLPE), Finite Difference Method (FDM), Air Microcavities.

I. INTRODUCTION

The chemically cross linked polyethylene PRC is the most used material in the industry of electric cables (high voltage). However, the crosslinking processes applied to polyethylene to obtain the PRC all lead to the formation of microcavities within the material [1,4]. The sizes of these defects vary from 1μm to 20μm and they are concentrated in the part located at three quarter of the thickness of the cable insulation starting from the core [2]. The heterogeneity of the dielectric medium that presents the portion containing the microcavities leads to the distortion in the lines of electric field in the vicinity of these defects. When the intensity of the electric field inside the microcavities reaches the dielectric strength of the gas, a partial electric discharge arises. The magnitude of these distortions depends on the permittivities of the two environments, the shape of the microcavity and its position relative to the cable core [3,6]. In the industry, cable breakdown tests are necessary, however during their manufacturing, it is difficult to avoid the penetration of foreign particles within the insulation (defects), and we can hardly realize such case to study the influence of these particles.

The size of the fault, its nature (permittivity) and its position in the cable insulation as well as the effects of the electromechanical pressure and the temperature, considerably influence the behavior of the insulation of the cable and thus limiting its lifetime. The purpose of this article is based on the study of the effect of the presence of an air cavity, its position and size on the distribution of the electric field, the electromechanical pressure and the dielectric losses in an insulator. PRC type used in the insulation of medium voltage cables (18/30kv) manufactured by ENICAB-Biskra. This cable has the characteristics listed in Table I:

TABLE I. CHARACTERISTIC OF THE CABLE

Cable Features	Value for PRC
Type	185mm², Al, 30 / 50kV
Ray of the core	7 .65mm
Thickness of the semi-layer conductor on the core	1.0mm
Thickness of the insulation	11.3mm, PRC
Thickness of the semi-layer conductive on the insulation	1.2mm
Metal screen made of copper wire	0.8mm
PVC protective sheath	5.3mm
Dielectric loss factor	4.10-3
Electrical conductivity	10-12 (Ω.cm) -1
Thermal conductivity	0.286 W / m. ° C
Volume heat	2.08 J / cm3. ° C

II. INFLUENCE OF MICROCAVITIES ON THE DISTRIBUTION OF THE ELECTRIC FIELD

The effects of a permittivity cavity ε_2 on a host dielectric of ε_1 permittivity are first evaluated in terms of potential perturbation [5-10]. We will determine for the case of a spherical cavity the expressions of the potential and the electric field in the insulating medium and in the cavity. Assuming that the density of free charges ρ in the host dielectric is small enough to be neglected, the Poisson equation describing the potential in both media is reduced to the Laplace equation such that:

$$\nabla^2 V = 0 \qquad (1)$$

Given the cylindrical shape of the cable, the lines of the electric field are radial and divergent, on the other hand the dimensions of the cavity are quite small in front of the thickness of the insulation [11-18]. Given the symmetry of the system at turn of the cable axis (Z), the equation (1) can be expressed by the following form:

$$\frac{\partial}{\partial r}\left(\frac{r^2 \partial V}{\partial r}\right)+\frac{1}{\sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial V}{\partial\theta}\right)=0 \tag{2}$$

The general solution of (2) is of the form $V(r,\theta)=f(r)g(\theta)$

With $f(r)\sum_n A_n r^n$ and $g(\theta)=P_n(\cos\theta)$ or P_n is the Legendre polynomial. This solution is valid in both environments. The expression of the potential for the case of a spherical cavity is of the form:

$$V_i=\left(A_i+\frac{B_i}{r^2}\right)\cos\theta \tag{3}$$

The index i takes the values 1 or 2 respectively corresponding to the insulator and the cavity. The integration constants A_i, B_i are determined by the boundary conditions. The expressions of the potential in the insulator and in the spherical cavity are obtained as follows:

$$V_1=E_0\left(r+\frac{\varepsilon_1-\varepsilon_2}{2\varepsilon_1-\varepsilon_2}.\frac{r_2^3}{r^2}\right)\cos\theta \tag{4}$$

$$V_2=E_0\frac{3\varepsilon_1}{2\varepsilon_1+\varepsilon_2}r\cos\theta \tag{5}$$

$$E_2=\frac{\partial V_2}{\partial x}=E_0\frac{3\varepsilon_1}{2\varepsilon_1+\varepsilon_2} \tag{6}$$

Or :

r_2 : Is the radius of the cavity.

r :Is the position of a given point in the insulation relative to the center of the cavity.

It is noted that the potential V_2 inside the cavity depends on E_0 ($r\cos\theta$), Knowing that:

$$E_0=\frac{V_1}{r_i}=\frac{\ln\left(\frac{R_t}{r_i}\right)}{\ln\left(\frac{R_t}{r_c}\right)} \tag{7}$$

Where V_1 is the conductor voltage, R_t is the outer radius of the cable, r_c is the radius of the conductive core and r_i is a given radial position.

It follows that the intensity of the proportional E_2 field at E_0 depends on the values of the permittivities ε_1 and ε_2 of the two environments [4].

A. Approximation of the electrical potential at each node

Generally, when dealing with a problem with two environments, it is better to use the finite difference method, especially if the two environments have a symmetry and a fairly simple geometry. This method consists in replacing the continuous medium, in which the equation to be studied is applicable at all points by a set of points to which the discretized equation applies (Fig.1) [6-10]. For such reason this method has been chosen to be used in this article.

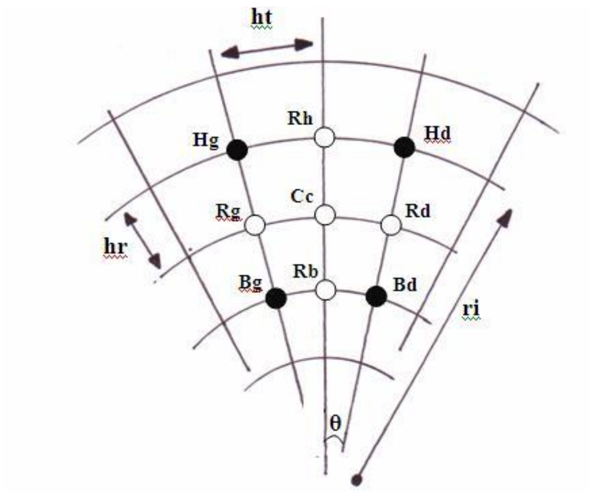

Fig. 1. Discritization of the cavity

The equation of the potential obtained by the series development of TAYLOR:

$$V(i,j)=\frac{r_i^2.h_t^2.h_r^2}{2.\left(r_i^2.h_t^2.h_r^2\right)}.\left[\begin{array}{l}\frac{1}{r_i^2.h_t^2}V(i,j+1)+\frac{(2.r_i+h_r)}{2.r_i.h_r^2}V(i+1,j)+\\ \frac{1}{r_i^2.h_t^2}V(i,j-1)+\frac{2.(r_i+h_r)}{2.r_i.h_r^2}V(i-1,j)\end{array}\right] \tag{8}$$

This formula is applicable for each node in both environments [7, 8]

B. Approximation of the electric field in each node

Since the electric field is deduced by calculation of the potential gradient, it is given by:

$$\vec{E}=\begin{cases}gradV=-\frac{\partial V}{\partial r}.\vec{e}r-\frac{1}{r}.\frac{\partial V}{\partial\theta}.\vec{e}\,\theta\\ E_r.\vec{e}r+E_\theta.\vec{e}\,\theta\end{cases} \tag{9}$$

Thus, electric field module will be:

$$E=\sqrt{E_r^2+E_\theta^2} \tag{10}$$

However, the radial Er and tangential Eθ components of the electric field will be written as follows:

$$E=\begin{cases}E_r(i,j)=\frac{1}{2h_r}\left[V(i+1,j)-V(i-1,j)\right]\\ E_\theta(i,j)=\frac{1}{2h_t\,r_i}\left[V(i,j+1)-V(i,j-1)\right]\end{cases} \tag{11}$$

The module in each point will be given by:

$$E(i,j)=\sqrt{E_r^2(i,j)+E_\theta^2(i,j)} \tag{12}$$

C. *Approximation of electrostatic pressure and dielectric losses*

The electromechanical pressure and the dielectric losses are connected directly to the electric field by the following expressions [19-21]

$$P(i, j) = \frac{1}{2} \varepsilon_0 \, \varepsilon_r \, E^2(i, j) \tag{13}$$

$$P_{diel}(i, j) = \omega \varepsilon_0 \, \varepsilon_r tg\delta \, E^2(i, j) + \sigma E^2(i, j) \tag{14}$$

P *(i, j)*: is the electromechanical pressure [N/m²] in the point *(i, j)*

P_{diel} *(i, j)*: is the dielectric loss [W/m^3] in the point *(i, j)*

III. RESULTS AND INTERPRETATIONS

A. *Influence of air cavity on electric field distribution*

In Fig. 02 we have presented the radial distribution of the electric field according to the radius of the cable. This distribution is marked by increased distortion at the cavity-insulator interface, which can be explained by the accumulation of polarization charges that strengthens the field inside the cavity and limits it in the insulator. This distortion quickly recovers over a distance of about three times the diameter of the cavity. It is found that the distribution of the electric field which passes through the center of the cavity and on the walls follows the same pace with values much higher than the center of the cavity.

Fig.3 show the values of the electric field according to the position of a 1µm radius of cavity. The field in the cavity center has a value of 6 kV/mm, it decreases depending the position of the cavity and reaches a value of 3kV/mm in a cavity near the sheath. In Fig.4 we presented the values of the electric field in terms of the radius of a cavity located at a distance of 8.65mm from the conductive core. Note that the electric field in the center of the cavity is proportional to its radius.

B. *Influence of the air cavity on the electromechanical pressure distribution*

We elaborate in Fig.5 the electromechanical pressure in accordance with the radius of the cable.The electromechanical pressure in the center of the cavity is more intense than in the homogeneous case because of the permittivity changing, and on the other hand the electromechanical pressure in the walls of the cavity is greater than in the cavity center because of the accumulation of the charges on the walls of the cavity, which exerts an additional pressure on its walls.

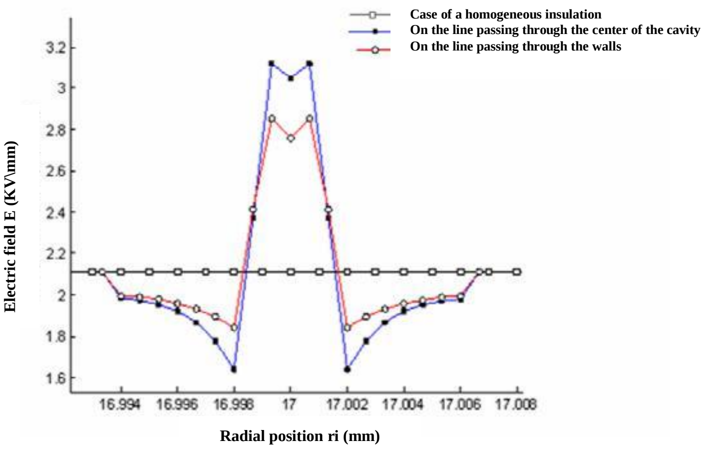

Fig. 2. Distribution of electric field under the influence of a cavity located 17 mm from the center of the conductive core.

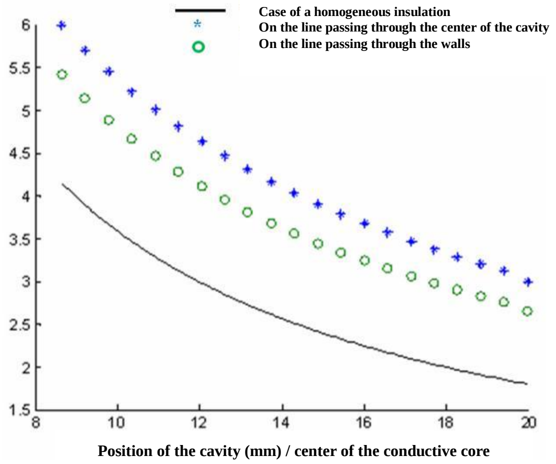

Fig. 3. Electric field inside the cavity according to its position

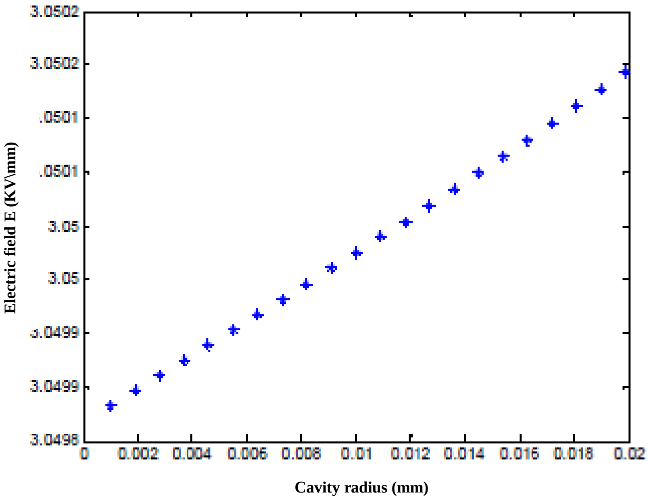

Fig. 4. Electric field inside the cavity according to its radius

It is noted in fig. 6 that the electromechanical pressure is greater in the case of a cavity close to the conducting core, and each time the distance between the core and the cavity is enlarged the electromechanical pressure decreases, since the Electromechanical pressure is proportional to the electric field. It can be seen in fig. 7 that the electromechanical pressure increases as the radius of the cavity increases because of the charges in the walls which are in a very large quantity as the size of the cavity increases.

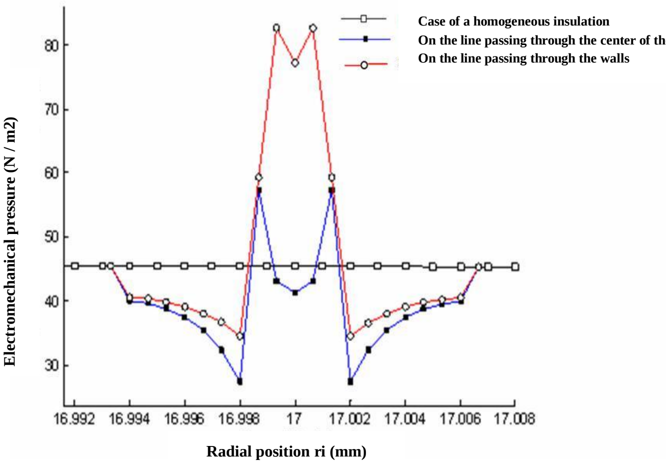

Fig. 5. Distribution of the electromechanical pressure under the influence of a cavity located 17 mm from the center of the conductive core

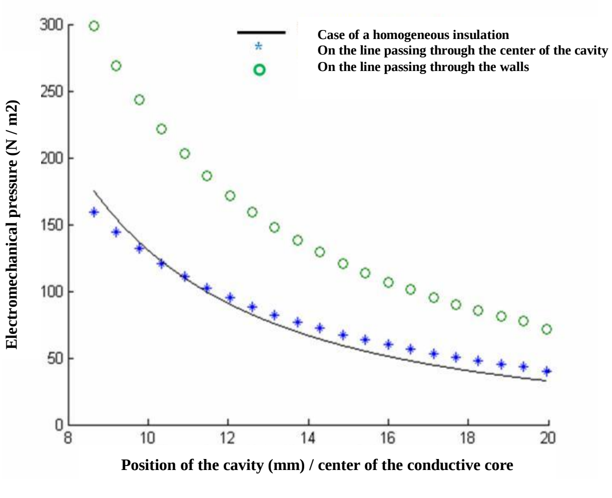

Fig. 6. Influence the position of the cavity on the electromechanical pressure

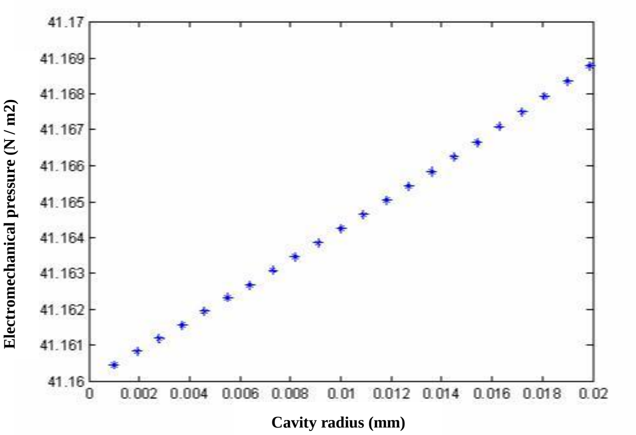

Fig. 7. Influence of cavity radius on electromechanical pressure

C. *Influence of the air cavity on the dielectric loss distribution*

We have shown in Fig. 8 the distribution of dielectric losses according to the radial position. It is noted that the dielectric losses on the line passing through the walls of the cavity are very important as the line passing through the center of the cavity. In Fig.9 we present the distribution of the dielectric losses within the position of the cavity, it is found that the dielectric losses rises to an important stage in the case of a cavity (1µm) close to the conductive core, and drops each time the cavity approaches the outer sheath. Fig. 10 shows the dielectric losses depending the radius of the cavity, a linear increase is observed because of the charges in the walls, which are in a very large quantity as the size of the cavity increases.

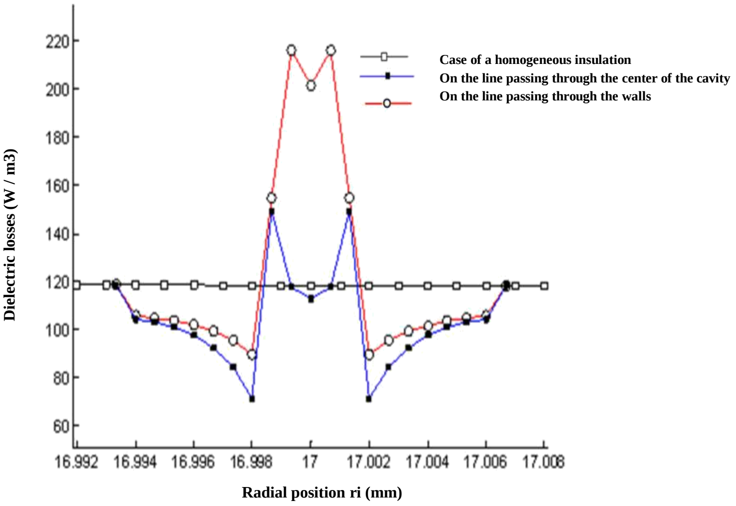

Fig. 8. Distribution of dielectric losses under the influence of a cavity located at 17 mm center of the conductive core

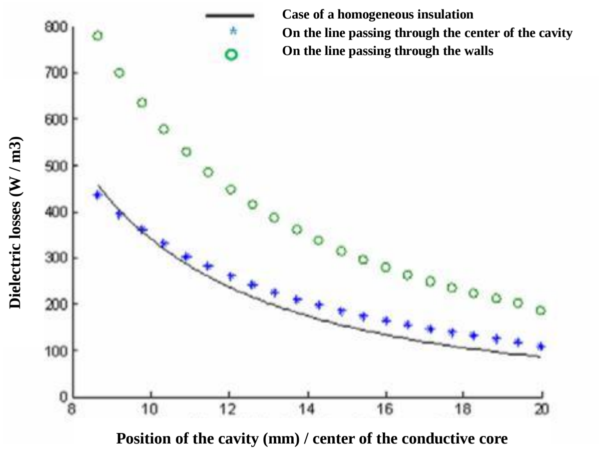

Fig. 9. Influence of the position of the cavity on the distribution of dielectric losses

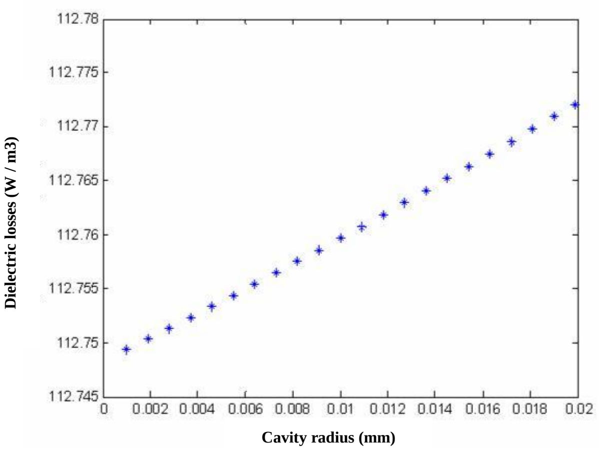

Fig. 10. Influence of the radius of the cavity on the distribution of dielectric losses

IV. CONCLUSION

The main goal of this work is the study of the behavior of insulators used in unipolar high voltage (HV) cables in the presence of cavities. We found that defects disturb the electric field within the insulation and strongly depend on their positions and sizes. This field disturbance causes a dielectric losses increasing within the insulator and leads to the acceleration of the degradation thereof. This disturbance does not exceed a certain zone called zone of influence, this allowed us to reduce the size of the calculation procedure, and reduce the execution time.

REFERENCES

[1] KS Harisha, N Gouthami, V Harshitha, C Madhu, " Partial DischargeAnalysis of a Solid DielectricUsing MATLAB Simulink ,"international journal of innovative research in electrical, electronics, instrumentation and control engineering Vol. 4, Issue 6, June 2016

[2] B Ramachandra, HC Manohara, " PD Analysis in CylindricalVoidWith Respect To Geometry of the Void ," International Journal of InnovativeResearch in Electrical, Electronics, Instrumentation and Control Engineering Vol. 4, Issue 10, October 2016.

[3] DM Srinivasa, BN Harish, KS Harisha , " AnalysisStudy on Partial Discharge Magnitudes to the Parallel and Perpendicular Axis of a CylindricalCavity ," International Journal of Engineering Trends and Technology (IJETT) – Volume-45 Number7 -March 2017.

[4] Keshav Gupta, N.K.Yadav ,P.K.Rattewal , " partial discharge within a spherical cavity in solid dielectric material," International Research Journal of Engineering and Technology (IRJET) Volume: 02 Issue: 08 | Nov-2015

[5] S. Karmakar and A. Sabat , " Simulation of Partial Discharge in High Voltage Power Equipment ," International Journal onElectrical Engineering and Informatics,", vol. 3, nov. 2, 2011.

[6] M. Hadjadj, B. Mokhtari and D. Mahi , " prediction of the physical parameters change inside aspherical cavity located in a material xlpe of a medium voltage cable by non-stationary modelling ," Journal of Electrical Engineering 14(1):184-190 · March 2014

[7] Y. Z. Arief, W. A. Izzati, Z. Adzis, " Modeling of Partial DischargeMechanisms in Solid DielectricMaterial,"International Journal of Engineering and InnovativeTechnology (IJEIT) Volume 1, Issue 4, April 2012

[8] Pragati Sharma, Arti Bhanddakkar« Simulation Model of Partial Discharge in Power Equipment International ," Journal of Electrical and Electronics Research Vol. 3, Issue 1, pp: (149-155), 2015.

[9] H. T. Manani, 2 K. K. Dudani , "Analysis of partial discharge signal by FDTD technique,"International Journal of Advance Engineering and ResearchDevelopment (IJAERD) Volume 1,Issue 3, 2014,

[10] Taimur Khan, Adnan Haleem, "A Novel Method for InsulationTesting of High Voltage Electrical Equipment ," International Journal of Engineering Works Vol. 5, Issue 2, PP. 32-36, February 2018

[11] CS Kumar, B Ramachandra , " Comparison of PD Activity in Cylindrical and CubicalVoidusing MATLAB Simulink ," International Journal of InnovativeResearch in Electrical, Electronics, Instrumentation and Control EngineeringVol. 4, Issue 10, October 2016

[12] H. A. Illias, Z. H. Lee, A. H. A. Bakar, H. Mokhlis, "Distribution of electricfield in medium voltage cablejoint geometry ,"2012 IEEE International Conference on Condition Monitoring and Diagnosis23-27 September 2012, Bali, Indonesia.

[13] H. Illias, G. Chen and P. L. Lewin, "Modeling of partial discharge activity in spherical cavities within a dielectricmaterial," in IEEE ElectricalInsulation Magazine, 27, 2011, pp. 38-45.

[14] H. A. Illias, G. Chen, P. L. Lewin, "Partial dischargewithin a spherical cavity in a dielectricmaterial as a function of cavity size and material temperature," in IET Science, Measurement and Technology, 6, 2012, pp. 52-62.

[15] Shailendra Kumar Agarawal Love Kumar Mittal HumairaJafri, "Simulation of Partial Discharge in High Voltage PowerEquipment,"International Journal of Electronics, Electrical and Computational System IJEECS Volume 6, Issue 8August 2017

[16] G Callender, P Rapisarda , "Investigating the dependence of partial discharge activity on applied field structure," IEEE ElectricalInsulation 2016 .

[17] SZ Dabbak, HA Illias, BC Ang , “Effect of surface discharges on different polymer dielectric materials under high field stress ,” IEEE Transactions on 2017

[18] Ö Altay, Ö Kalenderli, A Merev , “ Preliminary partial discharge measurements with a computer aided partial discharge detection system,”ELECO 2009 .

[19] Jna bhandakkar , “ analysis and simulation of partial discharge for different insulation material,” International Journal of Innovation in Engineering , 2017.

[21] T Tanmaneeprasert, PL Lewin , “Analysis of degradationmechanisms of silicone insulation containing a spherical cavity using partial dischargedetection ,”Conference (EIC), 2017 .

[20] H Illias, G Chen, PL Lewin , “Modeling of partial dischargeactivity in sphericalcavitieswithin a dielectricmaterial ,” IEEE ElectricalInsulation , 2011 .