Nanocomposites for Electrical Power Applications

المـركبـات النـانـوية لـتـطبـيـقات القوى الـكهـربائـية

Speakers

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Part (1)

- Nanofluids for power transformers
- Heat transfer coefficient measurements
- Breakdown measurements
- Dielectric constant measurements
- Stability

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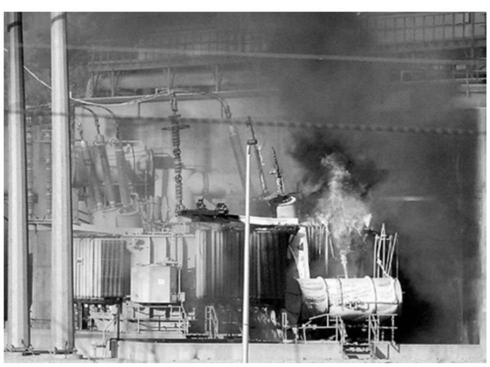
Electrical power (what do we need?)

Catastrophic failure



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Part (1)

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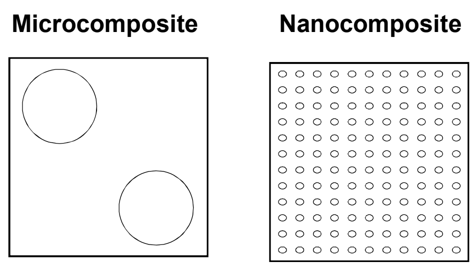
What is Nanomaterials (Nanocomposites) ?



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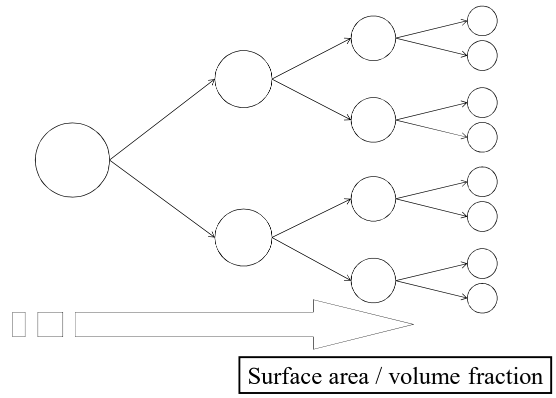
What is Nanomaterials (Nanocomposites) ?



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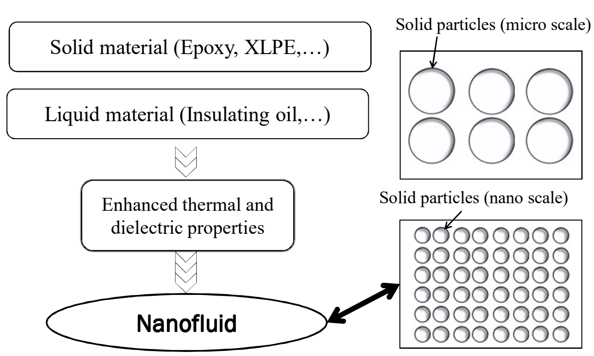
Nanofluid composition :



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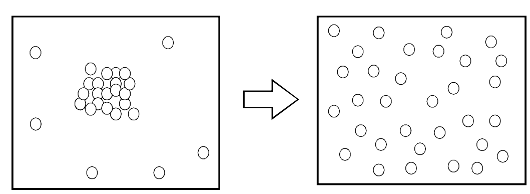
Dispersion of nanoparticles :



Physical processes → **Ultrasonic homogenizer**

Chemical processes → **Chemical additives**

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➢ Part (1)

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- Stability

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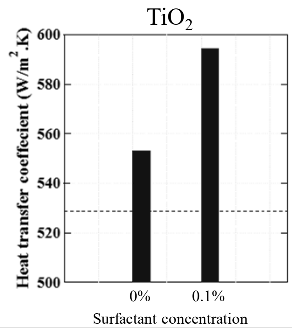
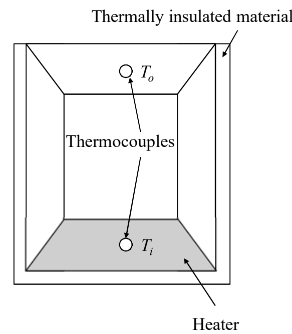
Heat transfer coefficient :

$$h = \frac{q}{(T_i - T_o)}$$





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➢ Part (1)

- Nanofluids for power transformers
- Heat transfer coefficient measurements
- Breakdown measurements
- Dielectric constant measurements
- Stability

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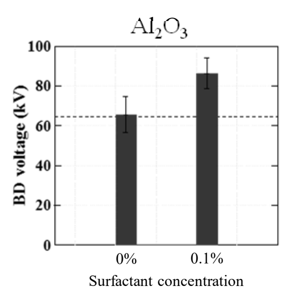
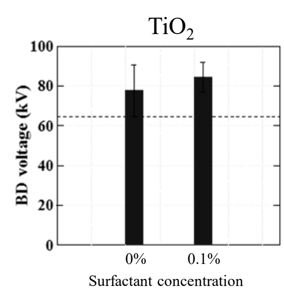
Breakdown results :





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Breakdown mechanism :

Nanoparticle itself

- Electronegativity
- Band gap structure

Interfacial region

- Double layer thickness
- Ability to trap electron

Band gap: Al_2O_3 8.8 eV and TiO_2 3.0 eV

Electronegativity of a compound:
simple average or geometric mean
Approximately the same for Al_2O_3 and TiO_2

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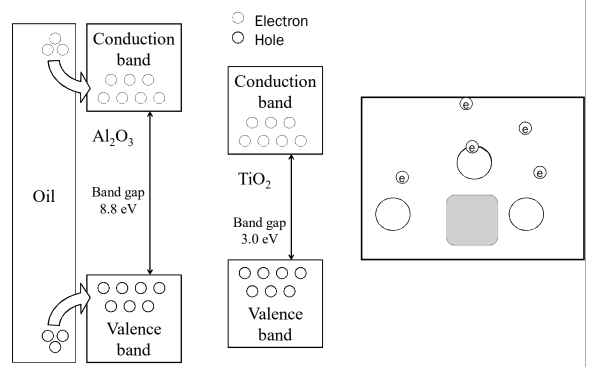
The role of nanoparticle in breakdown :



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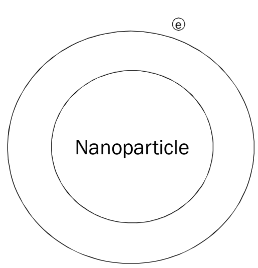
The role of interface in breakdown :



The benefits from this extended significantly under aging conditions

When transformer exposed to overheating conditions the oil suffer from aging

The main by-products are acids

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The role of interface in breakdown :

Aging test

Aging was carried out for 3 days at 120 °C

Equivalent for three years in service

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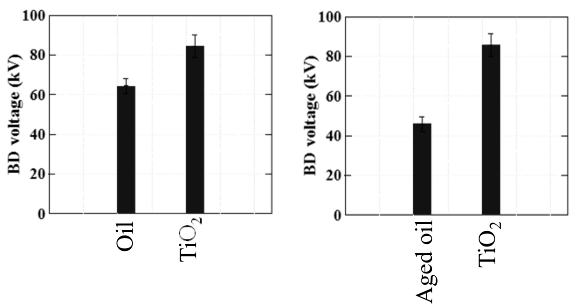
The role of interface in breakdown :



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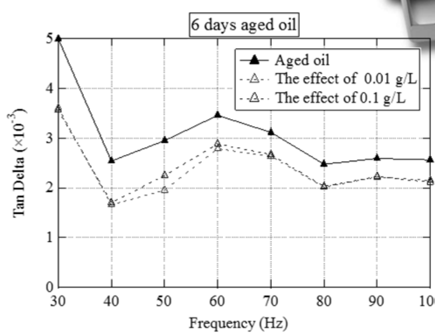
Dielectric constant :



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- **Part (1)**

  - Nanofluids for power transformers
  - Heat transfer coefficient measurements
  - Breakdown measurements
  - Dielectric constant measurements
  - Stability

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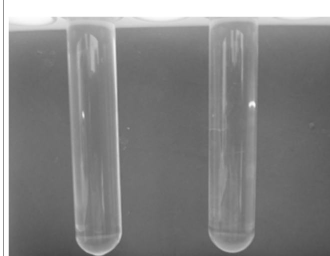
Stability measurement :



UV-Vis spectroscopy

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Stability measurement :

0.1…	0.545

Stability is the main challenge that need to be faced for actual application of nanofluids

- Separation of large sized nanoparticles
- Use of core shell nanoparticles
- Surface functionalization of nanoparticles

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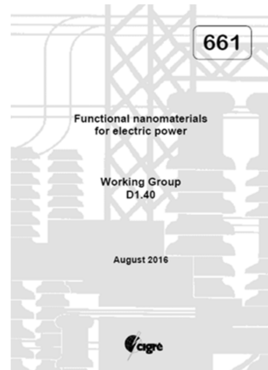
Part (2)

Polymer nanocomposite Applications:

1) Cables insulation
2) Capacitors insulation
3) OHTL insulator
4) Transformer pressboard paper
5) Motors winding insulation
6) Sub/St. equipment's



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1) Cables insulation

1.1) PVC

1.2) Polyethylene

Title of my PhD thesis :

“ Application of Nanoparticles for Improving the Performance of Insulating Materials of Underground Cables ”

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Thesis outlines:

- Objectives
- Background
- Experimental Processes
- Results & Discussion
- Conclusions
- List of publications
- Acknowledgements

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Objectives

- Improvement the Dielectric, Mechanical and Thermal Properties of PVC and LDPE, as the most common used power cable insulation, by inserting chemically modified TiO_2 & SiO_2 nanoparticles (with different coupling agents).
- Design new insulation systems for power cables that:
  - ✓ can withstand higher voltage levels (BDS).
  - ✓ have lower charging current (permittivity).
  - ✓ have reduced dielectric losses.
  - ✓ have high partial discharge resistance.
  - ✓ have good mechanical performance.
  - ✓ have high thermal stability.

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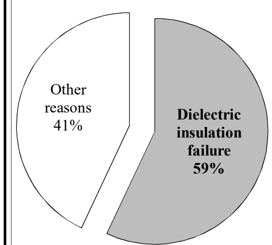
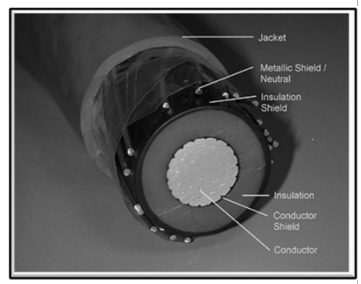
Background

Pie chart of underground cable failures





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Background

- **The history of insulation type of cables :**
  1) Paper-insulated cables (1954)
  2) oil-impregnated cables (early of 1960)
  3) Gas-filled and compressed-gas-insulated cables (1972)
  4) Polymer-insulated cables (1975 : 1985)
     - 4.1) PVC
     - 4.2) Polyethylene
  5) Composite & microcomposite-insulated cables (1994)
  6) Polymer nanocomposites – insulated cables (2002)

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Background

Polymer Nanocomposites

- **Composite:** combination of two or more constituent materials with significant different physical or chemical properties.
- **Polymer composites:** inorganic particles homogeneously dispersed into organic polymeric matrix.
- **Polymer nanocomposites:** the dispersed inorganic particles are in nanometer scale (not exceed 100 nm)

⇨ **Unique combination of properties:** good electrical, thermal, and mechanical properties

Is that easy????

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Background

- **Challenges: Nanoparticles should be highly dispersed within the base polymer (no agglomeration).**
- **How: By physical modification (Ultra-sonication & Mech. sterring) and chemical functionalization of nanoparticles using suitable coupling agent in order to render their surfaces hydrophobic to be compatible with the common organic polymers.**
- **Benefits: Good interaction between the two materials, strong interfacial area, and improvements in properties such as dielectric properties.**

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Experimental process

Functionalization of TiO_2 and SiO_2 nanoparticles Preparation of PVC and LDPE nanocomposites

Characterization of PVC and LDPE nanocomposites using FT-IR and FE-SEM

Measurements of ε_r, tan δ, σ and AC-BDS & DC-BDS and its simulation using COMSOL

Measurement of PDs activity using PRPDA with online SysMux program (physical mechanisms)

Measurement of mechanical properties, such as elongation, tensile strength, and Young's modulus

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Experimental process

❖Materials :

- **Compound PVC pellets provided by EGYPLAST, El-Sewedy Electric Co., Egypt.**
- **Commercial LDPE pellets with code (FT5230) provided by Borealis Co., Italy.**
- **Nanoparticles: TiO_2 nanopowder (21 nm). Also, SiO_2 nanopowder (10:20 nm).**
- **Methanesulfonic acid for surface activation of nanoparticles.**
- **Coupling agents: tris (2-methoxyethoxy) silane called "vinyl silane", and Gamma-amino propyl-triethoxy silane called "amino silane".**
- **Solvents: Cyclo-hexanone, Para-xylene, Toluene, and Isopropanol alcohol.**

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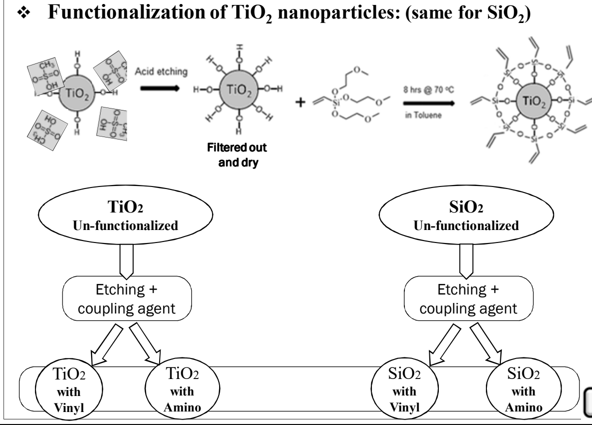
Experimental process

❖ **Functionalization of TiO_2 nanoparticles: (same for SiO_2)**



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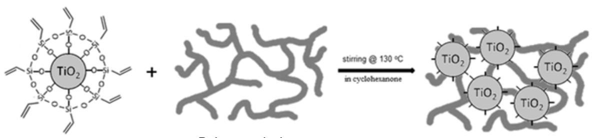
Experimental process

❖ **Preparation of PVC nanocomposites: (same for LDPE)**

➢ **Solution casting method**

Functionalized Nanoparticle → Cyclo-hexanone + Ultra sonicator →
PVC pellets → Cyclo-hexanone + Mech. stirrer →
Mech. Stirrer + Thinky mixer → Petri dish + room Temp. 48 h + vacuum 24 h



The choice of the coupling agent is based on the value of its surface tension, and it should be close to that of nanoparticle and polymer.

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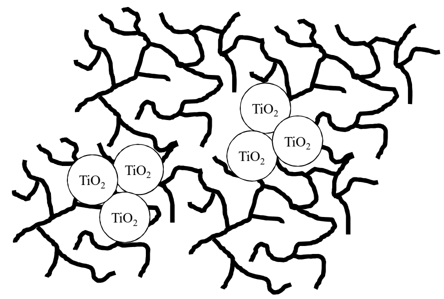
Experimental process

❖ **Effect of functionalization on dispersion behavior**



Without functionalization

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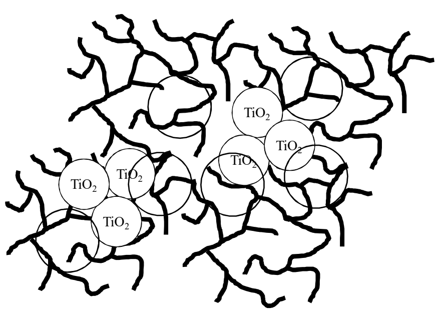
Experimental process

❖ **Effect of functionalization on dispersion behavior**



With functionalization

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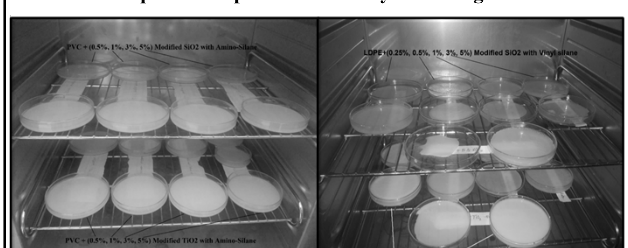
Experimental process

➢ **Preparation using melt blending method (Industrial)**

Industrial method discussed in details as seen in Videos No. 1 & 2

➢ **Nanocomposite samples after directly annealing :**



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Experimental process

❖ **Characterization of the prepared samples:**

1- Using FE-SEM to verify the dispersion of nanoparticles within PVC matrix.

The model type of **FE-SEM is Quanta FEG-250 (FEI-Inc.)** that operated at 10:30 kV, and with carbon fibers used to coat the fractured surfaces.

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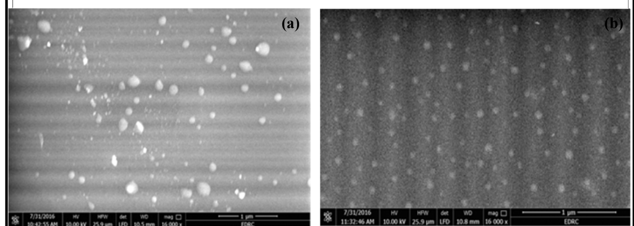
Experimental process



FE-SEM micrographs of PVC/ TiO_2 nanocomposites with; (a) 3% un-functionalized, (b) 3% vinyl-silane.

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Experimental process

➢ **Relative permittivity, dielectric loss and conductivity :**

→ Using LCR meter Agilent E4980A
→ **Range of frequencies:** 20 Hz → 2 MHz
→ **Supply signal test voltage:** 1 V → 20 V

Test standard : ASTM (D150−11)

→**This device can help in the following measurements**:

1- Dielectric constant
2- Dissipation factor (Tan Delta)
3- Electrical Conductivity

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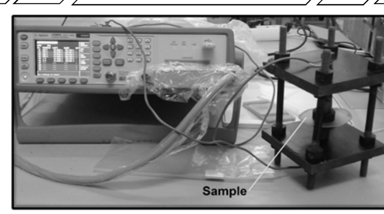
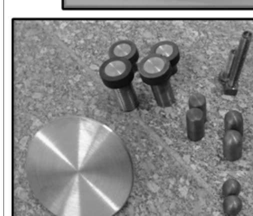
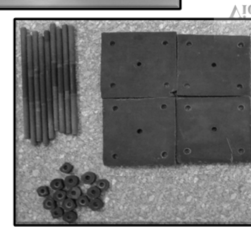
Experimental process



Measuring test discussed in details as seen in Video No. 3





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Experimental process

❖ **AC & DC breakdown strength :**

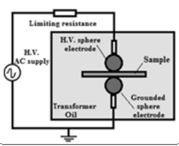
1) Sphere–Sphere field
2) Sphere–Plate field

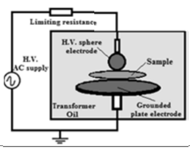
Test standard : ASTM (D149−09)

Measuring test discussed in details as seen in Videos No. 4 and 5

➢ **Components:**

- AC high voltage supply (100 kV) with serial No. WBS 5.8/100 – High Volt Co., Germany.
- DC high voltage supply (50 kV) with serial EL – Glassman HV Inc., Sweden.
- Sphere and plate diameters of 2 and 10 cm.
- Silicon oil to eliminate the flashover on sample surface.





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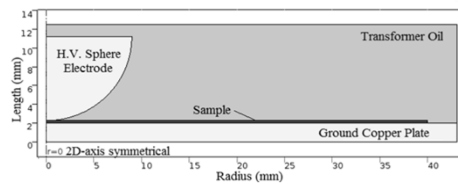
Experimental process

❖ **Simulations of breakdown strength :**

➢ using COMSOL Multiphysics 5.1, as a commercial software that resolve the electrostatic field based on the finite element method (FEM)

➢ Three input parameters for model are:

1) The measured rms values of breakdown voltage.
2) The relative permittivity of sample.
3) The thickness of sample.



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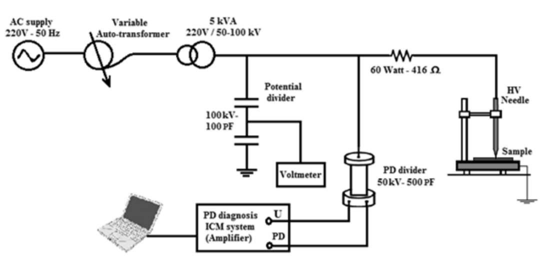
Experimental process

❖ Partial discharge measurements :

Needle-plane electrodes with the help of phase resolved PD analyzer (PRPDA) with ICM online system called SysMux 4.38 software was used to monitor and record the PD values.

Test standard : IEC– 60270



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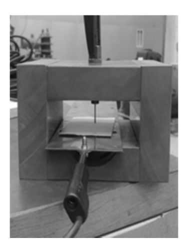
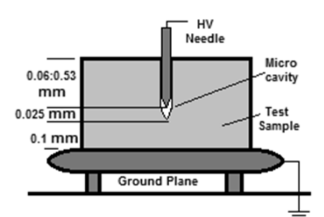
Experimental process

❖ Creation of Micro-cavity :

Suitable stainless steel needle of 1.5 mm diameter with tip radius of 10 μm was used as the HV electrode. The needle was inserted inside sample then moved back by 0.025 mm in order to create an air filled cavity.

Micro-distance determined by Dial indicator





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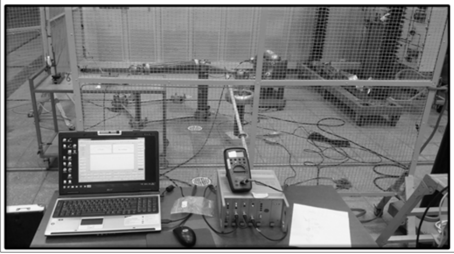
Experimental process

❖ **Output statistical parameters of PD analysis for nanocomposites:**

1) Average discharge magnitude (Q_{IEC}).
2) Inception voltage (U_i).
3) Extinction voltage (U_e).
4) PD generation rate for each half cycle (pps).

Measuring test discussed in details as seen in Videos No. 6 and 7



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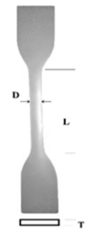
Experimental process

❖ Mechanical Measurements :

Obtaining **Stress–Strain** Curve using tensile tester device, **Elongation**, **Tensile strength**, and **Young's modulus**.



dumbbell-shaped specimens

Test standard : ASTM (D882-12)

(Tensor Check Profile, Gibitre instruments: model No. TCC 2009054)

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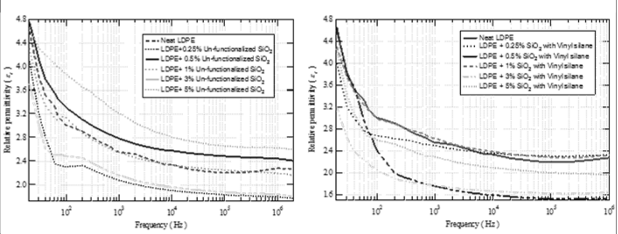
Results & Discussion

➢ **Relative permittivity (ε_r) for LDPE :**



✓ **LDPE/3% Vinyl-functionalized SiO_2 nanocomposite has lower ε_r than both neat LDPE and LDPE/un-functionalized SiO_2 nanocomposites.**

✓ **ε_r decreases by about 34.3% from the neat LDPE at 50 Hz.**

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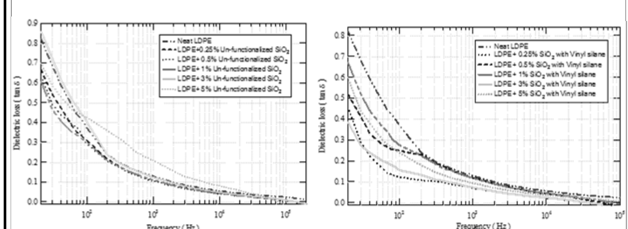
Results & Discussion

➢ **Dielectric loss (*tan δ*) for LDPE :**



✓ **LDPE/3% vinyl-functionalized SiO_2 nanocomposite has the lowest value of losses compared to both neat LDPE and LDPE/un-functionalized SiO_2 nanocomposites.**

✓ ***tan δ* decreases by about 58.7% from the neat LDPE at 50 Hz.**

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Results & Discussion

- AC-BDS in case of sphere-sphere field for LDPE :

LDPE/SiO_2 Un-functionalized

Loading fraction (wt.%)	Average values of measured BDV (kV)	Samples thickness (mm)	AC-BDS at Tip of sphere (kV/mm)
0	27.81	0.35	79.46
0.25	44.15	0.63	70.08
0.5	23.38	0.31	75.42
1	26.27	0.28	93.82
3	23.35	0.25	93.4
5	30.87	0.45	68.6

LDPE/SiO_2 Vinyl-functionalized

Loading fraction (wt.%)	Average values of measured BDV (kV)	Samples thickness (mm)	AC-BDS at Tip of sphere (kV/mm)
0	27.81	0.35	79.46
0.25	30.04	0.31	96.90
0.5	34.97	0.45	77.71
1	28.84	0.3	96.14
3	25.61	0.25	102.44
5	42.92	0.6	71.54

✓ **AC-BDS increases by about 29 % for 3 wt% of vinyl-functionalized SiO_2 from the neat LDPE.**

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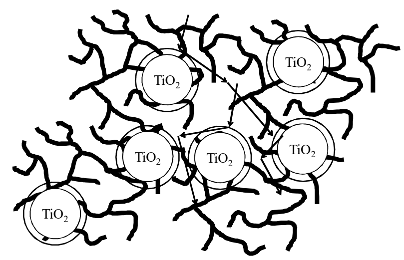
Results & Discussion

❖ **Effect of functionalization on breakdown strength :**



With functionalization

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Results & Discussion

- DC-BDS in case of sphere-sphere field for LDPE :

LDPE/SiO_2 Un-functionalized

Loading fraction (wt.%)	Average values of measured BDV (kV)	Samples thickness (mm)	DC-BDS at Tip of sphere (kV/mm)
0	41.57	0.35	118.77
0.25	62.31	0.63	98.9
0.5	32.11	0.31	103.58
1	34.97	0.28	124.89
3	30.72	0.25	122.88
5	44.31	0.45	98.47

LDPE/SiO_2 Vinyl-functionalized

Loading fraction (wt.%)	Average values of measured BDV (kV)	Samples thickness (mm)	DC-BDS at Tip of sphere (kV/mm)
0	41.57	0.35	118.77
0.25	33.15	0.31	106.93
0.5	45.96	0.45	102.14
1	39.63	0.3	132.1
3	37.22	0.25	148.88
5	60.18	0.6	100.3

✓ Measured DC-BDS enhancement with **25.5 %** for 3 wt % of vinyl-functionalized SiO_2 from the neat PVC. This enhancement motivates the usage of HVDC cables.

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Results & Discussion

- **Partial discharge types :**

Surface discharge (erosion)

Internal discharge

Corona

Treeing (series of internal discharge)

- Fewer studies on internal and corona discharge tests for polymeric insulation materials nanocomposites of cables were performed.

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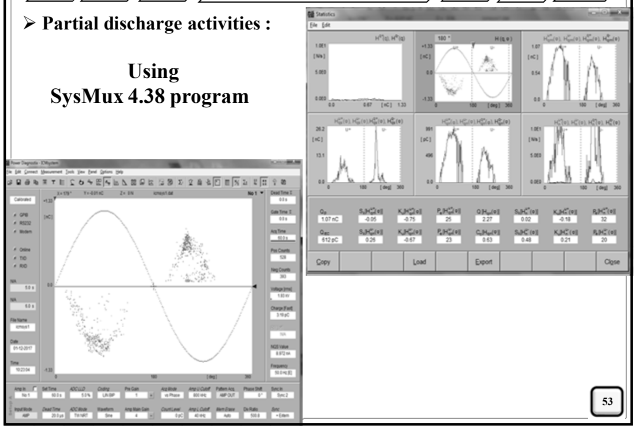
Results & Discussion

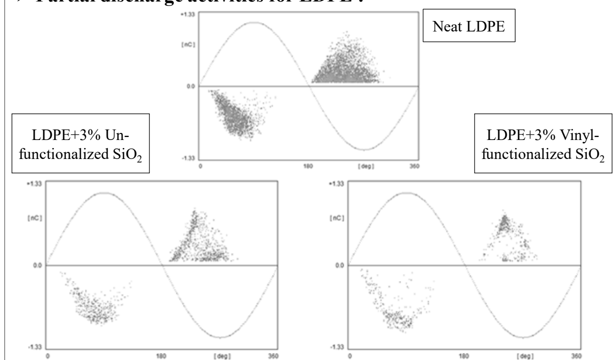
➤ **Partial discharge activities :**

Using SysMux 4.38 program



Results & Discussion

➤ **Partial discharge activities for LDPE :**



Distribution of charges inside the different LDPE/SiO_2 nanocomposite samples

Results & Discussion

➤ **Partial discharge activities for LDPE :**

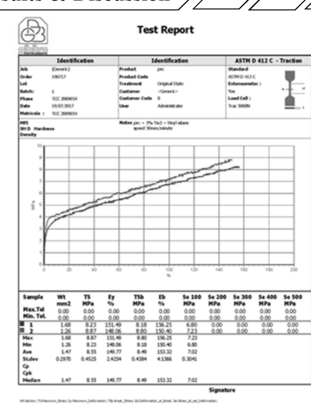
Name of sample	U_i (kV)	Q_{IEC} (pC)	U_e (kV)	Max. pulses in positive cycle (pps^+)	Max. pulses in negative cycle (pps^-)
Neat LDPE	2	827	1.4	235	275
LDPE+3% Un-functionalized SiO_2	2.55	731	1.6	145	164
LDPE+3% SiO_2 with vinyl silane	2.65	589	1.9	150	172

The optimal PD parameters achieved in sample LDPE/3wt% vinyl-functionalized SiO_2 that the $\mathbf{U_i}$, and $\mathbf{U_e}$ enhanced with **32.5 %** and **35.7 %** respectively, however the $\mathbf{Q_{IEC}}$ is reduced with **40.4 %** compared with neat LDPE values.

Results & Discussion

➤ **Mechanical results :**

Output sheet of Stress-Strain curve from **Tensor Check Profile**



Results & Discussion

➤ **Mechanical results for LDPE :**

Name of sample	Young's Modulus (MPa)	Elongation (%)	Tensile Strength (MPa)
Neat LDPE	188	1310	6.15
LDPE/3% un-functionalized SiO_2	238	892	7.62
LDPE/3% vinyl-functionalized SiO_2	313	930	8.32

The modulus of elasticity and tensile strength of the LDPE/3% vinyl-functionalized SiO_2 are enhanced by about 66.5 % and 35.5 % over that of the neat LDPE, respectively. However, the elongation is decreased by 29 %.

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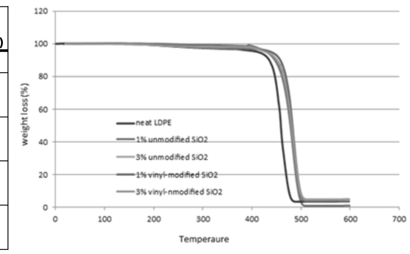
Results & Discussion

➤ **Thermal results for LDPE :**

Sample	Onset temperature (°C)
Neat LDPE	447
LDPE + 1% Un-SiO2	457
LDPE + 3% Un-SiO2	458
LDPE+1% Vinyl-SiO2	458
LDPE+3% Vinyl-SiO2	451



➤ Thermal gravimetric analysis **(TGA);** using SDT-Q600 TA instrument. Samples were analyzed in platinum pans over the temperature range of **25-600 °C** at a heating rate of **20 °C/min** to determine the thermal stability and thermal degradation Temp.

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Conclusions

1) the samples prepared by solution method have enhancements in all properties much better than the other samples that were prepared by melt blending method.

2) Functionalization process provides a strong interaction between polymer and nanoparticles represented in (hydrogen bonds or van der Waals forces or chemical covalent or ionic bonding) that results in lessen the surface energy of nanoparticles to be compatible with polymeric materials (non-polar, good dispersion).

3) The most suitable coupling agents in the enhancement of dielectric and mechanical properties is the vinyl silane over the amino silane, specially in high weight fraction of nanoparticles within the PVC or LDPE matrix. This is because the chain length of amino silane is much longer than that of vinyl silane. Also, due to the incompatibility between the surface tension of polymeric materials and amino silane that weakness the interfacial area between them.

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Conclusions

4) The enhancement in all properties in LDPE chains is much better than PVC chains for the same nanoparticles type, size, shape and weight fraction. This is because the compound PVC contain plasticizers, stabilizers, and other additives that may weakness the chemical bonds between the polymer chains and nanoparticles.

5) the values of AC-BDS at sphere-sphere field is higher than those in sphere-plate field. Also, DC-BDS is higher than that in AC-BDS, which encouragement the use of HVDC cables in wide range application.

6) Ui , Ue are higher in nanocomposite samples than neat one. This is because, the presence of nanoparticles behave as trapping grid against the movement of electrons and also inter-filler distance between nanoparticles are reduced.

7) The modulus of elasticity and tensile strength of the PVC or LDPE/functionalized nanocomposites are enhanced over that of the neat samples, respectively. However, the elongation is slightly decreased. Also, the thermal stability and thermal degradation are improved in functionalized nanocomposite samples.

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List of Publications

1) Nagat M. K. Abdel-Gawad, Adel Z. El Dein, Diaa-Eldin A. Mansour, Hanaa M. Ahmed and M. M. F. Darwish, "Effect of functionalized TiO_2 nanoparticles on dielectric properties of PVC nanocomposites used in electrical insulating cables", IEEE 18th International Middle East Power Systems Conference **(MEPCON'16),** Helwan University, Cairo, Egypt, pp. 693–698, December 2016.

2) Nagat M. K. Abdel-Gawad, Adel Z. El Dein, Diaa-Eldin A. Mansour, Hanaa M. Ahmed, M. M. F. Darwish and M. Lehtonen, "Experimental measurements of partial discharge activity within LDPE/TiO_2 nanocomposites", IEEE 19th International Middle East Power Systems Conference **(MEPCON'17),** Menoufia University, Cairo, Egypt, pp. 811–816, December 2017.

3) Nagat M. K. Abdel-Gawad, Adel Z. El Dein, Diaa-Eldin A. Mansour, Hanaa M. Ahmed and M. M. F. Darwish, "Influence of coupling agent on dielectric and mechanical properties of PVC/TiO_2 nanocomposites", 4th International Conference on Energy Engineering **(ICEE-4),** Aswan, Egypt, December 2017.

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List of Publications

4) Nagat M. K. Abdel-Gawad, Adel Z. El Dein, Diaa-Eldin A. Mansour, Hanaa M. Ahmed, M. M. F. Darwish and M. Lehtonen, "Multiple enhancement of PVC cable insulation using functionalized SiO_2 nanoparticles based nanocomposites", Electric Power Systems Research **(EPSR),** Elsevier, Vol. 163, pp. 612-625, 2018.

5) Nagat M. K. Abdel-Gawad, Adel Z. El Dein, Diaa-Eldin A. Mansour, Hanaa M. Ahmed, M. M. F. Darwish and M. Lehtonen, "Enhancement of dielectric and mechanical properties of polyvinyl chloride nanocomposites using functionalized TiO_2 nanoparticles", IEEE Transactions on Dielectrics and Electrical Insulation **(IEEE-TDEI),** Vol. 24, No. 6, pp. 3490-3499, 2017.

6) Nagat M. K. Abdel-Gawad, Adel Z. El Dein, Diaa-Eldin A. Mansour, Hanaa M. Ahmed, M. M. F. Darwish and M. Lehtonen, "Development of industrial scale PVC nanocomposites with comprehensive enhancement in dielectric properties", **Accepted** in IET Science, Measurement, and Technology **(IET-SMT).**

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List of Publications

7) Nagat M. K. Abdel-Gawad, Adel Z. El Dein, Diaa-Eldin A. Mansour, Hanaa M. Ahmed, M. M. F. Darwish and M. Lehtonen, "Impact of nanoparticle functionalization on partial discharge activity within PVC/SiO_2 nanocomposites", 2nd IEEE International Conference on Dielectrics **(ICD2018)**, Budapest, Hungary, July 2018.

8) Nagat M. K. Abdel-Gawad, Adel Z. El Dein, Elsayed Y. Elkady, Diaa-Eldin A. Mansour, Hanaa M. Ahmed and M. M. F. Darwish, "Dielectric Response of PVC and LDPE Nanocomposites upon Functionalization of their Containing Nanoparticles", IEEE 20th International Middle East Power Systems Conference **(MEPCON'18),** Cairo University, Cairo, Egypt, December 2018.

9) Diaa-Eldin A. Mansour, Nagat M. K. Abdel-Gawad, Adel Z. El Dein, Hanaa M. Ahmed and M. M. F. Darwish, "Recent advances in polymer nanocomposites based on polyethylene and polyvinylchloride", **Under publication** in Polymers Journal **(Elsevier).**

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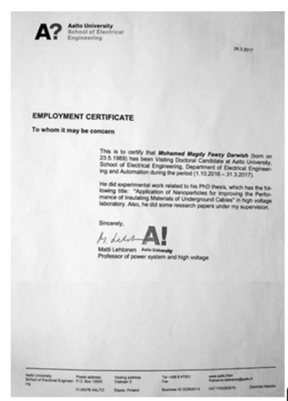
Aalto University
School of Electrical Engineering

28.3.2017

EMPLOYMENT CERTIFICATE

To whom it may be concern

This is to certify that ***Mohamed Magdy Fawzy Darwish*** (born on 23.5.1989) has been Visiting Doctoral Candidate at Aalto University, School of Electrical Engineering, Department of Electrical Engineering and Automation during the period (1.10.2016 – 31.3.2017).

He did experimental work related to his PhD thesis, which has the following title: "Application of Nanoparticles for Improving the Performance of Insulating Materials of Underground Cables" in high voltage laboratory. Also, he did some research papers under my supervision.

Sincerely,

Matti Lehtonen
Professor of power system and high voltage

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2) Eng. Ehab Ahmed
Eng. Khaled Abdelgawad
(SEDCO–ELSEWEDY Co.)

ELSEWEDY SEDCO

إفادة

تفيد شركة السويدي سيدكو للصناعات الكهربية بأن السيد

د.م/ محمد مجدي فوزي درويش

المدرس بقسم الهندسة الكهربائية بكلية الهندسة بشبرا جامعة بنها

قد تلقا تدريب على بعض أجهزة المعمل الكيميائي داخل شركتنا ,وقد قام بأجراء بعض التركيبات التجريبية واختبار عينات عزل للكابلات الأرضية الخاصة برسالة الدكتوراه الخاصة به لدى معمل الكيمياء على جهاز الشد والاستطالة بشركتنا .

وكان عنوان الرسالة

"Application of Nanoparticles for Improving the Performance of Insulating Materials of Underground Cables"

يعتمد

مدير الإدارة

م/ أيهاب احمد

01/04/2018

Egyptian Company for Advanced Industries (Elsewedy - Sedco)

Cables Accessories

65

Thank You Very Much

for your attention

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