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INFLUENCES OF NANOPARTICLES ON DIELECTRIC FLUID TRANSFORMERS: A REVIEW

Shylaja G K*
Lecturer, Dept. of Electrical & Electronics Engineering. Govt. Polytechnic Joida-581186
shy.shylajagk@gmail.com

Anusha Naik
Lecturer, Dept. of ECE, Govt. Residential Women's Polytechnic, Shimoga- 577205.
anaik035@gmail.com

Rehan Ahmed Shaikh
PG Student, Dept. of Mechanical Engineering. Brunel University London.
rehangoa@gmail.com

Mubarakbanu N Sawar
Lecturer, Dept. of Civil Engineering. BCN Polytechnic Laxmeshwar - 582116
mubaraksawar@gmail.com

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Abstract: *Applications of nanoscience & nanotechnology have produced advanced materials & demonstrated impressive development in a number of industrial domains. Many technological advancements & research & development initiatives involving nanotechnology concepts are underway these days in an effort to ace the performance & dependability of traditional materials. The electrical sector has been benefited from these nanotechnology initiatives by seeking applications for its various apparatuses, such as electrical transformers, which are regarded as one of essential parts of the electrical grid. This paper presents an extensive assessment of the literature on the uses of nanotechnology principles for transformers, with a focus on studies pertaining to dielectric fluids, monitoring systems, solid or outdoor insulators & many other components. The most recent research on the use of nanomaterials in transformer applications has been examined and documented. Furthermore, prospects for further investigation*

Keywords: Nanoparticles, Dielectric, Transformers, Insulating Martials, fluids, Esters

Introduction

Electrical transformers is one of the most vital apparatuses of the network that yields & circulates electricity, as any failure or malfunction in these components can reduce system reliability & result in power supply interruptions [1, 2.]. As transformers are essentially static devices that induce mutual coupling between circuits by means of one or additional connected windings, with or without a core of magnetic content [3]. They also consist of a range of interior building materials, primarily polymers and metals. In case of oil-immersed transformers, fluids insulating with thermal properties as well as dielectric properties are been utilized, while in dry-cast transformers, all of the internal components are encapsulated in a polymeric resin. Electrical transformers have not undergone major operational or functional changes in more than a century; nevertheless, manufacturers have made a substantial advancement in the fields of design-related R & D work, hence an effort to deliver high-value products with increased efficiency in terms of capacity & dependability. However, some research & advancements have concentrated on both the introduction of novel materials & the improvement of conventional materials. But given are some of the principles of the materials physics, it is evident that the conventional ingredients are operating at their limits due to their microstructure, which in many situations, it has already attained. Since advanced materials & nanoscience & nano technology have been emerged in recent decades to revolutionize material science, many manufacturers of electrical transformer have made an effort to look into new innovation & new technology that will initiatives as one of alternatives to gain a challenging edge against industrial competitors. The potential uses of nanostructured materials in biology, electronics, medicine, engineering, & various other fields has led to a great deal of research on the subject in recent years. There is a lot more of curiosity in nanomaterials because some studies have revealed that the addition of nanoparticles can significantly change a material's performance. Examples of these include increased ductility, wear resistance, mechanical resistance, hardness, magnetic properties dielectric & thermal capacity, etc. [4].

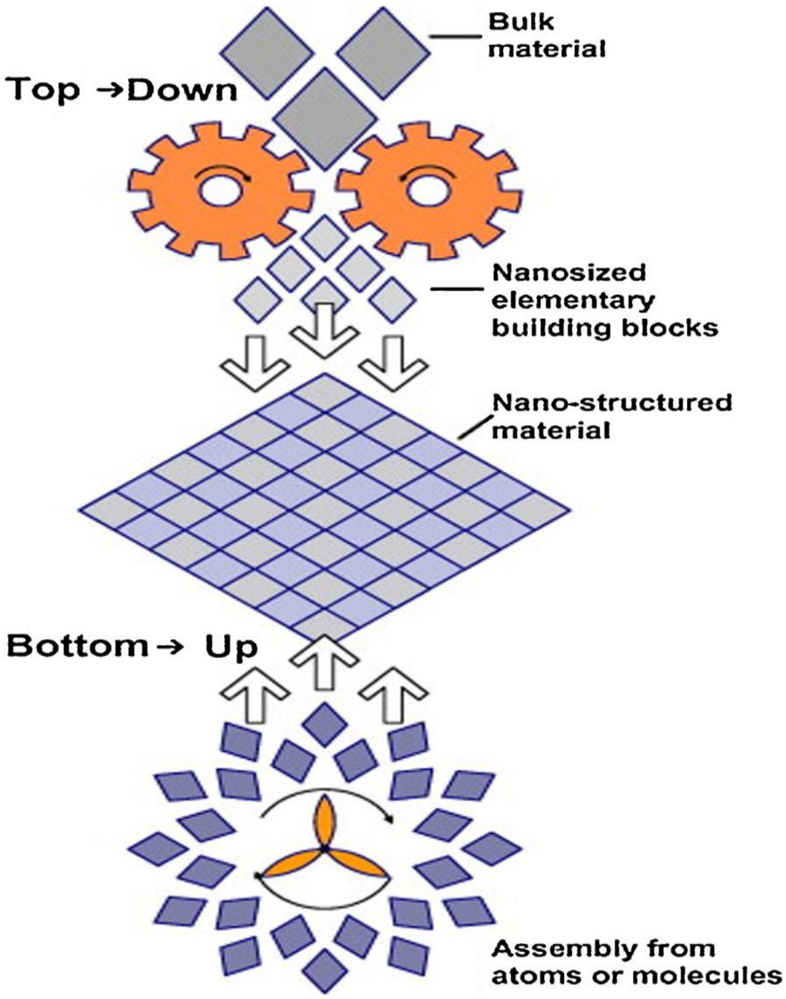

Fig. 1. Diagrammatic illustration of several methods for the creation and assembly of nanostructures. With permission from ref [16]

Both the development of novel materials for electrical transformers & the improvement of existing materials can be accomplished with the help of nanotechnology (fig. 1). Hence this paper focuses on research on nanomaterials for transformers & their advantages over conventional materials while offering a cutting-edge literature outcomes of applications of nanotechnology in electrical transformers. This work includes references to nanotechnology approaches for monitoring & diagnosis (M&D) systems, dielectric fluids, solid insulation, outdoor insulators, & other interior materials. Lastly, a broad summary of potential nanotechnology substitutes for the upcoming generations of electrical transformers is included.

2.0 Types of Nanotechnology alternatives for Transformers

1. Nano fluids-based di-electric fluid transformers,
2. Nano-technology Alternatives for Electrical Transformer in Solid-insulations,
3. Nano technology Concepts for Porcelain-Insulators,
4. Nano-technology Applications in Monitoring & Diagnosis M&D of Transformers,
5. Other Nano-applications in Electrical transformers.

1.1. Nano fluids-based dielectric fluid transformer

With time, a variety of dielectric fluids have been utilized in oil-immersed transformers. [5]. silicone oils, synthetic esters & Mineral oils & natural esters, are the most often utilized insulating liquids globally, despite the fact that power transformers have a variety of uses. This industry has historically utilized mineral oil, or petroleum-based fluid. It is the most commonly used dielectric fluid because of its greater resistance to oxidation, low in viscosity, simplicity of supply, & affordability. It's low biological solubility & low saturation of moisture & also low fire points & flash-points, & are some of its drawbacks. Conversely, natural esters that are easily biodegradable have become more popular as dielectric fluids in current years. Additionally, these are have excellent qualities including high fire, moisture saturation, & flash points, & a slowing down of paper deterioration. On the other hand, oxidative instability and high viscosity are some of its drawbacks. Another kind of dielectric fluid is silicone oil. Its positive attributes include higher viscosity even at higher temperatures, very low biodegradability & poor lubrication. On the other hand, silicone oil has high absorption of gas under partial discharges, high thermal, high-fire & flash-points & also oxidation stability. Ultimately, the favorable attributes of synthetic esters include higher moisture saturation, higher breakdown of strength, flash-points &, high-fire, high biodegradability, oxidation stability & good capacity to lubricate. The primary drawback of synthetic esters is their exorbitant expense, which consequently restricts their application [5]. Table 1 presents these dielectric fluids' properties in comparison [15] .

Li et al. investigated the dielectric capacities of magnetite nanoparticle-containing natural ester (NE)-based nano fluids in 2012 [6]. Comparing nano-Fe_{3O4} to NE fluid, it was discovered that the latter boosted the impulse lighting break down voltage by up to 12%. The dielectric performance of TiO2 nanoparticle additions (less than 100 nm in dia) in MO was studied by

Mansour et al. [7]. The breakdown of the voltage in MO is increased by up to double when using nano-TiO2 compared to conventional fluid, according to the results. In a related study, *Pugazhendhi* found that adding nano-TiO2 (0.005 wt %) to MO enhances its AC breakdown voltage by 31%. This rise is explained by the nano filler's high relative permittivity [8]. Conversely, *You Zhou et al.* examined the electric properties of press-board that had been coated with oil, by nano fluids of TiO2. It is discovered that when compared to pure oil impregnated pressboard, nanofluid-impregnated pressboard showed much greater partial discharge inception voltage (66%) in addition to significantly higher AC & DC voltage breakdown ranging (from 6-12%). Similarly, when transformer cellulose paper is soaked with TiO2-nanofluids as opposed to pure oil-saturated paper [9].

R. Liao etl, al. discovered that the dielectric voltage breakdown of the papers increases by 20% [10]. *Jin et al.* produced and assessed various silica nano fluids based on dielectric MO [11]. The hydrophilic properties of SiO2 nanoparticles allowed silica nano fluids (0.02 wt %) to increase the AC breakdown strength by 27.4% when compared to ordinary MO. Conversely, silica nanoparticles barely affect thermal conductivity & MO's viscosity. Parallel research was carried out in 2015 by *Rafic et al.*, who discovered that since SiO2 nanoparticles produce a huge digit of traps to catch electrons, nanosilicon (10 wt% –20 wt%) which improves the breakdown voltage of about (6.7%) of MO. [12].

With the usage of MO, *Fontes & etl*, associates produced diamond nanoparticles and multi-walled carbon nanotube (MWCNT) nanofluids [13]. As the concentration of nanoparticles rose, it was found that heat conductivity increased while viscosity & the AC dielectric breakdown decreased. A method for creating MO-based functionalized nano diamonds (0.120 wt%; 4 nm to 8 nm) with superior thermal conductivity & good stability of roughly 14.5% above MO was proposed by ***Shukla et al.*** Furthermore, when compared to NE base fluid, BN of about 0.1 wt%, based NE-nano fluids exhibit better performance in transfer of heat & AC breakdown voltage of (34%).[14]. The behavior of the di-electric MO augmented with magnetite nanoparticles in terms of illumination impulse breakdown has been studied by ***Nazari et al.*** The results demonstrated that due to its electric & magnetic properties, Fe3O4-based nanofluid has a higher dielectric capacity than conventional mineral oil. [27].

Table. 1. Characteristic performance analysis of various Easters for nano fluids .From ref [15]

Ref ,Author & Year	Base Fluid content	Nano particle & its Concentrations	Remarks
Lietal. Et.al.,in 2012,[28].	Natural-ester.	Fe3O4	12% of increment in the lightning of impulse voltage than that of base oil
B.X.Du et al.in 2015.[26].	Natural-ester.	Boron-nitride 0.10wt%	NE based NF possesses 34% of hike in AC voltage breakdown than that of NE-base oil
Usama et al in 2019, [29].	Synthetic-Esters of MIDEl-7131.	Fe3O4 Al2O3 & SiO_2 Each at a concentrations of (0.05, 0.20, 0.30 & 0.40) g/L	At 0.4 g/l (50 nm) highest AC BDV of 88.67 kV for Fe3O4 based NF At 0.050 g/l (13 nm) highest AC BDV of 80.830 kV for Al2O3 based NF.
Thomas.et al in 2018, [30].	Synthetic-Ester of MIDE-7131.	CaCu3Ti4O12 [CCTO]. 0.0010,0.0025, 0.005,0.01 & 0.050) % of Volume	<0.01% was as an optimum concentrations for the improved performances. Highest of AC BDV, LI voltage & PDIV of about 41.60 kV, 17.30kV & 34.950kV respectively. Hence thermal conductivity improvement & flash-point. Reduced di-electric loss

Du et al. (2015). Reported the first instance of a novel kind of "nano-modified" (NE) fluid & containing "Boron nitride" (BN) nanoparticles [26]. In comparison to NE base fluid, they discovered that BN of about (0.1 wt %) based NE-nano fluids shows better heat transfer performances & an AC breakdown voltage (34%). The impulse lighting breakdown behavior of di-electric MO enhanced with "magnetite" nanoparticles was recently explored via ***Nazari et al.*** [27]. The magnetic & electric properties of the nano-particles are what allow Fe3O4-

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based nano fluid to have a greater dielectric capacity than traditional mineral oil, according to the results as shown in (fig 2)[16,17,18]..

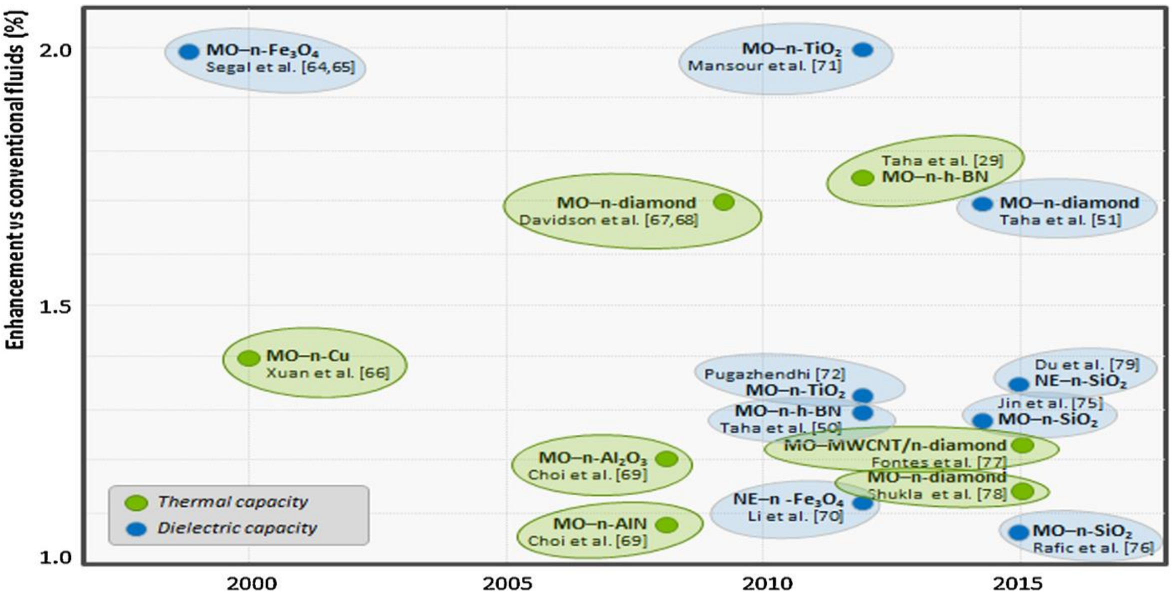

Fig. 2. Dielectric & thermal enhancement of nano-fluids in contrast with that of conventional fluids for electric transformers. From, ref [16, 17, 18].

2.2. Nano technology alternatives for electrical transformer solid-insulation

Electrical transformers require a solid insulating material since it expressively affects the machinery's lifespan [2]. Within the electric transformer industry, it is well known that a transformer's lifespan is essentially equal to the lifespan of its paper insulation.

A significant amount of material based on cellulose, such as laminated papers, blocks of higher density, pressboard, & etc., may be found in an ordinary oil-filled power transformer. Sometimes, like in large substation units, these have many tons of solid insulation. Cellulose has historically been the foundation for the material of insulation used in electrical transformer windings [20–21]. A polymer solution of some units of glucose is joined to one another in a unique way is called cellulose. The terms "kraft paper" & "kraft board" refer to the electrical grading paper & pressboard, which are primarily composed of wood pulp that has undergone the "kraft chemical process".42% cellulose, 28% lignin, and 27% hemicellulose are the typical composition [20]. Because it is inexpensive, readily available, & performs quite well, Kraft insulation is the recommended choice for oil-filled transformers. Including improved cellulose pulp, thermal upgrading, optimum fiber length, merging paper of cellulose with that of synthetic material, & synthetic fiber I,e, (materials of non-cellulose content) in order to create novel, higher-performance in solid insulation for electric transformers [22]. The usage of cutting-edge of the materials or even ideas from nanotechnology has recently been suggested as a way for the improvement of the thermal, mechanical, & electrical, performances of transformers solid insulation. ***Liao et al.*** investigated the impact of 500 nm-diameter SiO_2 hollow spherical powders on the end characteristics of kraft pulps in 2012 [23].

It's been found that, by the additions of particles of SiO2 to various mineral oils increases the breakdown voltage over untreated kraft models by 15% [15]. *Yuan et al.* modified the kraft paper with montmorillonite (MMT) nanoparticles of clay to create a new insulation of cellulose-based for electrical transformers [24]. Compared to regular kraft paper, kraft-montmorillonite insulation had a greater breakdown electrical strength (13%) (Fig. 3). Conversely, as the amount of MMT nano-clay increased, the tensile-strength of the nano-paper dropped.

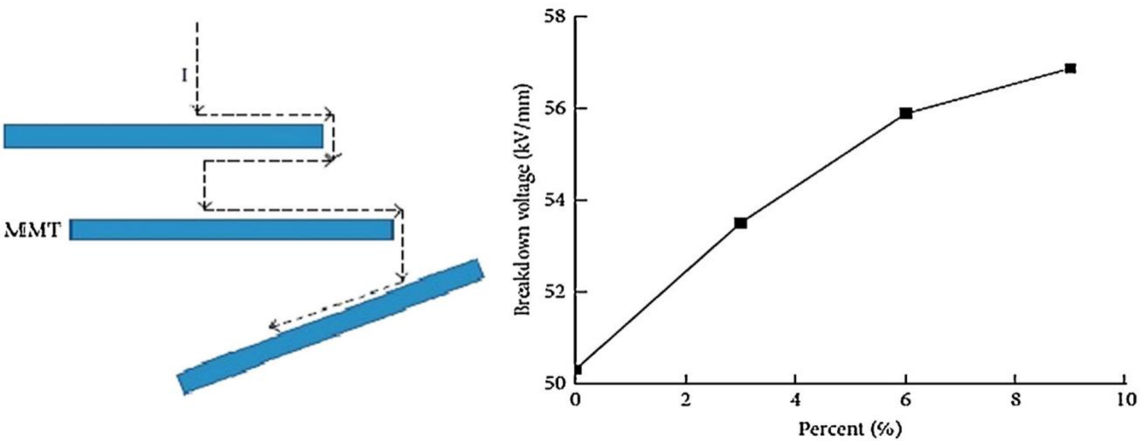

Fig.3. Impact of MMT concentration on voltage breakdown in kraft nano-clay insulation submerged in oil. From reference, [25].

These days, by the use of nanotechnology to electric transformers material insulating is a relatively one of new area of research that is being developed. Consequently, additional studies on the modification of cellulose usage alternate nanoparticles as well as nano- cellulose evaluation & characterization at the proto type lab size are anticipated. And hence by the addition of new nano new-cellulose material of insulating are anticipated [19].

It is strongly advised to provide alternative liquid insulation for improved equipment & power utilities in order to improve the state of liquid insulation. Ester-based nano fluids have been drawn a huge of attention from scientists & researchers in recent decades as a possible replacement for traditional MO. Ester oil's dispersed nanoparticles support better behavior and characteristics than base oil. This work offers a thorough assessment of the literature on the many kinds of nanomaterials, the creation of nano fluids, & **table 2.** Shows the effects of these materials on electrical, chemical, & physical properties.

Table .2.Characteristic performance analysis of various nano fluids. From ref [15]

Author, Years, [Ref no].	**Base - fluid Content**	**Nano particle & its Concentration**	**Remarks**
R. Madavan. Et,al. [30]. 2017.	Sunflower Rapeseed Mineral oil	SiO2Fe3O4ZnO (0.050% - 0.250% w/w) & with(0.005% w/w), of increments	Fe-3O4 based NF recorded the excellent voltage breakdown, viscosity, flash- point & fire-point.
J.Lietal.2012,[28]	Rapeseed mineral oil	Fe3O4 20nm	31%increment in the AC BDV
Mohammed, et,al 2019, [29].	Palm oil	Fe3O4 & TiO2 0.01g/L&1.0g/L	1). Improvement in di-electric strength seems for both NF based oil. 2). At lower concentrations there will reduced & no of partial discharge occurrence appears for TiO_2 based palm oil.

Conclusion

Applications of nanotechnology are anticipated to improve insulation systems with the increased di-electric strength in the electrical power systems while having a negligible environmental impact. This research covers the distinctive performance of natural and synthetic esters oils, as well as MO based on nano fluids. Yet, the viscosity & thermal conductivity of MO are barely affected by silica nanoparticles. It's been noticed that difficult for researchers to deal with nanofluids as an alternatives to liquid insulation in case of high voltage transformers because of stability of nanoparticles caused by agglomeration. Additionally, nano fluids improve the liquid insulation's performance qualities, which lowers the incidental failures in transformers. Despite the several important features that have been highlighted, there are still a number of barriers that stand in the way of progress. In order to enhance or improve the characteristics of nano fluids, it is important to take into consideration the type, size, volume concentration, preparation method, and surfactants of the nanoparticles, as discussed above. Furthermore, the thermal characteristics of nanofluids deteriorate due to the aggregation of nanoparticles. Therefore, there is still room for research projects to address the problems mentioned above.

References:

L. Lundgaard, W. hansen, D. Linhjell, T.J. painter, & etl. Aging of oil-impregnated paper in power transformers, IEEE Trans. Power Deliv. 19 (2004), 230–239.

J.H. Harlow," Electric Power Transformer Engineering", in CRC Press, year -2004.

John J. winders, "Power Transformers Principles & Applications", 1st ed., Marcel Dekker Inc., New York.2002.

AIRI/Nano-tech IT, Roadmaps at 2015. On "Nano technology applications in the Sectors of: materials, health & medical systems, energy, Nano road map Synthesis" Report (2006).

Mehmet karatas &Yunus bicen, Nanoparticles for next-generation transformer insulating fluids: " review Renewable & Sustainable Energy Reviews" Volume 167, October 2022, 112645.

J. Li, R. Liao, L. Yang, & etl, "Investigation of natural ester based liquid dielectrics & nano-fluids", Int. Confr. High Volt. Eng. Appl. (2012),, 16–21.

D.-E. mansour, E.G. atiya, R.M. Khattab, & A.M. Azmy, "Effect of titania nano particles on the dielectric properties of transformer oil-based nano fluids", in IEEE Conf. Electric. Insulator dielectric Phenom. (2012),295:298.

S.C. Pugazhendhi, & etl,: "Experimental evaluation on dielectric & thermal Characteristics of nano filler added transformer oil", IEEE Conf. on High Volt. Engg. Applications. (2012), 207:210.

Y. Zhou, Y. zhong, M. Chen, S. zhang, Y. Du, Y. Lv, C. Li, & T. Liu, "Effect of nano particles on electrical characteristics of transformer oil-based nano fluids impregnated pressboard",@ IEEE Int. Symptoms on Electric. Insulator. (2012), 650:653.

R. Liao, C. Lv, L. Yang, Y. zhang, W. Wu, C. Tang, 'The insulation properties of Oil-impregnated insulation paper reinforced with nano-TiO2', J. Nano mater.Hindawi (2013).

.H. Jin, T. andritsch, I.A. T sekmes, R. kochetov, P.H.F. Morshuis, J.J. Smit, Properties of mineral oil based silica nano fluids", IEEE Trans. Di-electric. Electric. Insulator. 21 (2014), 1100–1108.

M. Rafiq, D. khan, M. Ali, "Dielectric properties of transformer oil based silica Nano fluids", Power Gen. Syst. Renew. Energy Technol. (2015), 1–3.

D.H. Fontes, G. Ribatski, E.P. bandarra, & etl, "Experimental evaluation of thermal conuctivity, viscosity & breakdown voltage AC of nano fluids of carbon nano tubes & diamond in transformer oil", Diamond Relat. Mater. 58 (2015), 115–121.

G. Shukla, H. aiyer, "Thermal conductivity enhancement of transformer oil by using functionalized nanodiamonds", IEEE Trans. Dielectric. Electric. Insulator. 22 (2015), 2185–:2190.

Mariappan Yamuna, Rengaraj Madavan "A comprehensive review on nanotechnology for enhancement in performance of transformer liquid insulation," Materials Today: Proceedings on 11 April 2021. https://doi.org/10.1016/j.matpr.2021.04.128

J. Taha-Tijerina, G. Gao, M. Rohde ,T.N. Narayanan, D. Tsentalovich, M. Pasquali, & P. Ajayan, Electrically insulating thermal nano-oils using 2D fillers, ACS Nano 6 (2012), 1214–1220.

J. Taha-Tijerina, T.N. Narayanan, J.E. Contreras, J. Rodriguez, P.M. Ajayan, "Enhanced dielectric performance of nano boron nitride impregnated cellulosic insulations", ASME Proc. Micro- Nano-Syst. Eng. Package 10 (2015), V010T13A031, 6 pages.

J. Taha-Tijerina,, C.S. Tiwary, K. Lozano, T.N. Narayanan M. Chipara, P.M. Ajayan, "Nanodiamond-based thermal fluids", ACS Application, Mater Interfaces 6 (2014), 4778:4785.

F. Sanchez, K. Sobolev, "Nanotechnology in concrete—a review", Constr. Build. Mater. 24 (2010), 2060–2071.

T.A. prevost, T.V. O Ommen, "Cellulose insulation in oil-filled power Transformers": part I-history & development, IEEE Electric. Insulator. Mag. 22 (2006), 28–35.

A.M. Emsley, M. Ali, X. Xiao, R.J. Heywood "Degradation of cellulosic insulation in power transformers". Part 2: formation of furan products in insulating oil, IEEE Proc.—Sci. Meas. Technol. 147 (2000), 110–114.

T.V. Oommen, T.A. Prevost, "Cellulose insulation in oil-filled power Transformers": part II-maintaining insulation integrity and life, IEEE Electric. Insulator. Mag. 22 (2006), 5–14.

R. chandrashekar, S. chaudhari, P. bajpai, R. Mehta, "Developments in Insulating Paper for Power Transformers", http://www.academia.edu/6851508/ Developments in Insulating Paper for power transformers.

R. Liao, F. zhang, L. yang, T. Liu, C. Tang, Y. Yuan, Preparation & electrical Properties of insulation paper composed of SiO2 hollow spheres, Energies 5 (2012), 2943:2951.

Y. yuan, R. liao, A novel nano modified cellulose insulation paper for power Transformer, J. Nanomater. Hindawi in (2014), 1–6.

B.X. Du, J. Li, X.Y. Tao, X.L. Li, "Effects of BN nanoparticles on thermal Conductivity & breakdown strength of vegetable oil", IEEE 11th Int. Conf. on the Prop. & Appl. of Dielectric. Mater. (2015), 476–479.

M. Nazari, H. Hosseini, M.H. rasoulifard, "Dielectric breakdown strength of Magnetic nanofluid based on insulation oil" after impulse test, J. Magn. Magn. Mater. 399 (2016),1:4.

J. Lietal, R. liao, L. yang, "Investigation of natural ester based liquid dielectrics & nano fluids, Int. Conf. High Volt. Eng. Appl. (2012), 16:21.

Wei Yao, Peng sun, Wei wang, Muhamad ali, Mehmood & Zhengyong Huang, ''Effect of h-BN & Fe3O4 nano particles on streamer propagation & dissipation in vegetable oil based nano fluids", AIP Adv. 9 (2019).

R. Madavan, Sujatha Balaraman, Investigation on "effects of different types of nanoparticles on critical parameters of nano-liquid insulation systems", J. Mol. Liq. 230 (2017), 437:444.