Classical methods cannot explain electrical breakdown of Nanofluids in Transformers

Quantum mechanics is shown to explain the higher positive breakdown voltage and lower streamer velocities found in nanofluid transformer oils.

Aug. 4, 2009 - *PRLog* -- Background
It is generally thought that conductive particulate added to transformer oil lowers breakdown strength. Classical field theory shows sharp particulate surfaces produce high local electrical fields that initiate lower breakdown than for pure oils. It follows therefore if the particulate is comprised of submicron nanoparticles (NPs) breakdown should be lower than for pure oil.

Contrarily, experiments over a decade ago on oil cooled transformers showed nanofluids comprising NPs of magnetite (Iron Oxide) added to transformer oils increased and not decreased the positive breakdown voltage above that for pure oil. However, the main purpose of the testing was to determine if thermal cooling in transformers would be improved by NPs because at that time nanofluids in other applications showed significant increases in conductivity for insignificantly small volume fractions of NPs. Indeed, it was even thought long-standing mixing rules had to be revised for nanofluids.

In 2008, quantum mechanics (QM) was shown to explain the enhanced heat transfer in nanofluids without violating mixing rules. See www.nanoqed.org at “Nanofluid Thermal Conductivity”, 2008. Unlike classical heat transfer, QM restricts the heat capacity and specific heat to vanishing small levels. What this means is NPs are precluded from conserving absorbed electromagnetic (EM) radiation by an increase in temperature, which for nanofluids absent Joule heat from electron collisions is limited to the thermal kT energy of colliding oil molecules. The kT energy is low-frequency EM radiation in the infrared (IR) beyond 100 microns. Here, k is Boltzmann’s constant and T absolute temperature. By the theory of QED induced heat transfer, the low-frequency kT energy is frequency up-converted by QED to the confinement frequency of the NPs only to be emitted as EM radiation, usually at the VUV and beyond. QED stands for quantum electrodynamics and VUV for vacuum ultraviolet. In 2009, the nanofluid analysis was updated. Ibid, “Nanofluid Update”, Paper and Presentation, 2009.

With QED induced heat transfer, the VUV emitted from the NPs penetrates the oil far more than the IR absorbed at NP surfaces. The NPs therefore locally absorb IR while emitting VUV that is absorbed in the distant surrounding, i.e., heat is transferred over a greater distance because of the NPs than in oil without NPs. Depending on the absorption spectrum of the oil, the QED induced heat transfer may be significant, e.g., for liquid water, VUV penetration is of order a few meters while in the IR the penetration is a few tens of microns.

Comparisons of Classical and QM Methods
Recently, classical methods were used to explain the decade-old transformer data showing higher positive breakdown voltage and smaller streamer velocities for magnetite NPs in transformer oils. See Ibid, “Classical Methods in Analysis of Nanofluids in Transformers,” 2009. Computation of electrical field lines in the NP and oil is presented, but the underlying physics of nanofluids is lacking as described in the following comparisons between classical and QM methods.

1. NPs as Electron Scavengers. Field lines are presented to explain how electrons are scavenged by NPs located at the streamer tip and converted to slow moving negatively charged NPs, thereby hindering molecular ionization allowing propagation without breakdown. But NPs can only hinder streamer propagation if located at the streamer tip, but field lines may be located anywhere in the liquid and not necessarily terminated by a NP at the streamer tip. Absent NPs at the streamer tip there is no hindering of

molecular ionization with breakdown occurring as for pure oil. Obviously, another mechanism is required to explain the higher breakdown strength observed for NPs in transformer oils.

2. QM Mechanism. One such mechanism is QED induced heat transfer. Compared to classical methods, QED induced heat transfer treats the fast electron scavenging by NPs as a source of low frequency Joule heat that cannot be conserved by an increase in temperature. Instead, the Joule heat is frequency up-converted by QED to the VUV or higher confinement frequency of the NPs and promptly emitted as an EM wave that penetrates the oil. Unlike the pure oil where the fast electrons cause collisional ionization at a single oil molecule, the NPs convert the fast electrons to a VUV radiation field that is distributed uniformly throughout the oil. The VUV liberates electrons from many oil molecules, thereby reducing the tendency for positive streamers to form and increasing breakdown strength over a wide region.

3. Molecular Ionization. Classically, streamer propagation with NPs is claimed to depend on molecular ionization in the same manner as for pure oil. QED induced heat transfer differs in that the NPs produce VUV radiation that although distributed to enhance breakdown still ionizes oil molecules. In pure oil, the fast electrons by collisional ionization directly fragment the oil molecules.

4. NP Charging. Charging dynamics is claimed to occur as electrons are captured and converted to slow moving negatively charged NPs. QED instead converts absorbed fast electrons in the NPs to VUV radiation that readily removes electrons from the metal based magnetite leaving the NPs with a positive and not a negative charge.

5. Free Radicals. By classical theory, conductive NPs are claimed to enhance breakdown and lower streamer velocities, but only for fast transients. Free radicals are produced in the oil from QED induced VUV radiation that leads to future breakdown. It is therefore possible that adding magnetite NPs to pure oil actually makes the breakdown worse at longer times than for pure oil.

Conclusions
The conclusion that conductive NPs improve the breakdown strength of transformer oils “flies in the face” of experimental evidence. The classical explanation of how this occurs presupposes a NP is present at the streamer tip to scavenge fast electrons and produce a slow moving negative charge, thereby neutralizing the formation of positive streamers. But this is impossible because the NPs would have to present at every conceivable streamer tip that forms for scavenging to take place.

In contrast, QM treats the NP scavenging of fast electrons as a source of Joule heat that is conserved by the emission of VUV radiation. Unlike the fast electrons that induce collisional ionization at a single oil molecule, the VUV is distributed uniformly in the oil so that many molecules are irradiated and by the photoelectric effect electrons are liberated throughout the oil. In effect, the NPs induce the formation of a bath of electrons thereby reducing the tendency for positive streamers to form anywhere in the oil. Positive breakdown strength is therefore increased and attendant streamer velocities are reduced.

However, the NP induced VUV radiation leaves positive charged molecular oil fragments that produce free radicals that subsequently initiate breakdown. Indeed, the question may be asked whether adding NPs to pure oil is actually worse than using pure oil alone. Indeed, the converse is more likely. If NPs present in pure or used oils can be removed, it is likely that breakdown in transformer oils can be reduced. Long term testing is necessary to assess the benefits of NPs in transformer oils.

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About QED induced Radiation: Classically, thermal EM radiation conserves heat by an increase in temperature. But at the nanoscale, temperature increases are forbidden by quantum mechanics. QED radiation explains how heat is conserved by the emission of nonthermal EM radiation.

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Industry	Science, Research, Technology
Tags	Quantum Mechanics, Nanofluids, Electrical Breakdown, Transformers
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