Part Ⅰ: Technical proposal

Problem Posing

Transmission and distribution transformers form a critical, highly loaded and expensive part of the electricity generation and distribution network. Electric transformers rely on the high dielectric strength and cooling properties of insulating oil to achieve normal operation. The potential consequences of transformer failure can be quite damaging; and dielectric insulation problems blamed for 75% of high voltage transformer failures. It is therefore important to improve insulating properties of transformer oil.

A particularly novel work aiming to enhance transformer oil's insulating characteristic is development of dielectric nanofluids (NFs) by suspending nanoparticles in transformer oil. Recently, much effort has been focused on preparing magnetic NFs by suspending magnetite nanoparticles into the transformer oil and testing their insulating and thermal property. It has been shown that ac breakdown strength can be increased up to 1.1 times when the moisture content was 10 ppm. Furthermore, the positive impulse breakdown voltage of magnetic nanofluids was improved up to 2 times that of the base oil [1]. However, Kopwansky et al have found that the dispersibility of magnetic nanoparticles is greatly influenced by orientation of external magnetic field. In magnetic field H||E the magnetic particles aggregation led to the formation of the bridge across the gap between the electrodes, which lowered the dielectric breakdown voltage [2].

Based on simulating the propagation of streamer, a model of electron scavenging by conductive nanoparticles is proposed by Markus Zahn to explain the cause of the decrease in positive streamer velocity and higher breakdown strength in magnetic NFs stressed by positive impulse voltage [3]. It is believed that the magnetite nanoparticles in NFs can capture free fast electrons required for streamer development and convert these fast electrons to slower negative charged particles, because the relaxation time constant of the conductive magnetite nanoparticles is much faster than the microsecond time scale of streamer development in transformer oil. However, Chiesa et al have demonstrated that a kind of conductive nanoparticles with a short relaxation time constant (1.1×10^{-12} s) fails to increase the breakdown strength of transformer oil [4]. The model of electron scavenging by conductive nanoparticle, judged by the relaxation time constant fails to explain these phenomena. Thus, there is still more

work to do for exploring the modification mechanism of nanoparticles on insulating properties of transformer oil.

The instability of magnetic nanoparticles under magnetic field prohibits the widespread use of nanofluid in transformer. We developed a new type of nanofluids by suspending TiO_2 semiconductive nanoparticles into transformer oil (SNFs). It is found that AC and positive impulse breakdown voltages of nanofluids are increased by 19% and 24%, respectively, compared to pure oil. It is interesting to notice that the positive impulse breakdown time of nanofluids is prolonged by as much as 53% compared to that of the pure oil, indicating a slower streamer velocity in nanofluids [5]. Thermally stimulated current method (TSC) and pulse electroacoustic technique (PEA) have been used to measure charge trap and transportation characteristics of pure oils and nanofluids. It is found uniform charge distribution and high charge decay rate could be attributed to high shallow trap density in SNFs created by semiconductive nanoparticles. It could be believed that shallow traps are associated with charge hopping transport process in the sample and the fast electrons created at high field in the SNFs can be captured by the shallow traps and released rapidly from these shallow traps. Rapid transfer of charge carriers in the shallower traps results in their larger mobility in SNFs than transformer oil in high field, which significantly mitigate the accumulation of space charge and electric field distortion.

In sum, it is unable to interpret the improvement, caused by all kinds of conductive nanoparticles or semiconductive nanoparticles, by using the model of electron scavenging. Therefore, it is necessary to investigate why the magnetite nanoparticles can improve the electrical strength of transformer oil, the electron scavenging theory, shallow traps theory or both of them? Is there electron scavenging process in SNFs? Which kind of the properties that nanoparticles should have can give rise to the improvement in nano-modified transformer oil? These questions are what we will discuss in this project, which are helpful to develop high performance nano-modified transformer oil for special purposes and promote the use of nanofluid in transformer in the near future.

Research Approaches

In the case of nanoparticles, the surface area in contact with the oil is dramatically increased and creates large interaction zones formed at the internal interfaces. In the interaction zone, the nanoparticle has a surface charge (due to the differences in Fermi level between the nanoparticles and oil), that creates a Stern layer

surrounded by a diffuse Gouy–Chapman layer. This Gouy–Chapman–Stern layer induces altered local charge adsorption and distribution in the vicinity of the nanoparticles. Hence, to investigate the electron scavenging ability of different kinds of nanoparticles (magnetite and semiconductive nanoparticle), electrophoresis measurements will be carried out to investigate the Zeta potential which can represent the change of charge adsorption and distribution at nanoparticles-liquid interface. In the experiments, the liquid sample cell is placed between two gilding electrodes under variable dc voltage which can give rise to different concentration of free electrons. If the Zeta potential changes regularly with different applied voltage, it means electron scavenging ability of this kind of nanoparticle.

In addition, to investigate the trap characteristic and charge transport process in transformer oil before and after nano-modified, thermally stimulated current method (TSC) and pulse electroacoustic technique (PEA) will be used. The details have been given before in [5].

Compared with the results of above experiments, we will get more insight into the colloid system and advance some explanation for the improvement of electrical strength caused by different kinds of nanoparticles.

Based on the scientific research abilities I have gained, intensive researches should be conducted reliable, efficient and most importantly, economically viable. This is why I am here writing this statement to show you that I am worth being chosen.

[1] V. Segal, A. Hjortsberg, A. Rabinovich, D. Nattrass and K. Raj, “AC (60 Hz) and impulse breakdown strength of a colloidal fluid based on transformer oil and magnetite nanoparticles”, IEEE Int’l. Sympos. Electr. Insul. Arlington, VA, USA, pp. 619-622, 1998.

[2] P. Kopcansky, L.Tomco, K.Marton, M.Koneracka, I.Potocova and M. Timko, “The DC dielectric breakdown strength of magnetic fluids based on transformer oil”, J. Magnetism and Magnetic Materials, pp. 415–418, 2005.

[3] J. G. Hwang, O'Sullivan, M. Zahn, O. Hjortstam, L.A.A. Pettersson and R. Liu, “Modeling of Streamer Propagation in Transformer Oil- Based Nanofluids”, IEEE Conf. Electr. Insul. Dielectr. Phenomena (CEIDP), pp. 61-366, 2008.

[4] M. Chiesa and S. K. Das, “Experimental investigation of the dielectric and cooling performance of colloidal suspensions in insulating media”, Colloids and Surfaces A: Physicochem. Eng. Aspects, Vol. 335, pp. 88-97, 2009.

[5] Y.F.Du, Y.Zh.Lv, C.R.Li, et al., “Effect of electron shallow trap on breakdown performance of transformer oil-based nanofluids”, Journal of Applied Physics, 110, 104104, 2011.

Resources needed to accomplish the target:

1. Different chemical reagent and apparatus used to composite new kinds of nanoparticles.
2. To achieve the measurement of electron scavenging process, we need to establish an experimental installation based on principle of electrophoresis.
3. To investigate the trap characteristic and charge transport process, we need modified thermally stimulated current method (TSC) and pulse electroacoustic technique (PEA) equipments.

Applicant: Du Yuefan

Part Ⅱ: A letter of nomination/recommendation from the student's research director

Du Yuefan is in his Ph. D. program. As the supervisor of Mr. Du, I am very pleased to monitor the progress of the student’s work during the award period. I will greatly appreciate it if he could be awarded the Graduate Student Fellowship.

Sincerely yours,
Prof. Li Chengrong

Part Ⅲ: A letter from the student's Department Head / Chair

As the dean in department of Electrical and Electronic Engineering, North China Electric Power University, a leading university in China, I am very pleased to take this opportunity to recommend one of my favorite students to 2012 DEIS Graduate Fellowships award.

In 2004, Mr. Du was an undergraduate student in department of Electrical and Electronic Engineering. He is active and passionate about answering class questions. Mr. Du is bright, energetic and enthusiastic boy who loves speaking out his own ideas. He never escapes from those points of which he is skeptical. Apart from that, he often puts forward his ideas upon questions and exchanges all of his innovate ideas with teachers. Ranking 2nd among undergraduate students in his major, he was enrolled by the graduate school in 2008, exempt from admission exam. He is now a Ph. D. in the High Voltage Technology and Insulation program.

During the period of his graduate study, he did a great job in required and related researches in the field of insulation material. His intelligence was shown through a series of his experiments to solve engineering project and science exploration. His work also clearly showed his ability to run a team effectively in positive ways.

I believe Mr. Du’s industriousness, passion and dedication will make him an ideal candidate you are seeking for your program, so I highly recommend his without any hesitation to you. And I will greatly appreciate it if he could be awarded the Graduate Student Fellowship.

Sincerely yours,
Prof. Li Geng-yin

Part Ⅳ: Summary of research contributions and publication

1. Participate in multiple researches in the field of nano-modified transformer oil, including the National Natural Science Foundation of China under Contract No.51077050, projects of State Grid Corporation of China and TBEA Shenyang Transformer Group Co., Ltd..
2. Yuefan Du, Yuzhen Lv, Chengrong Li, et al., Effect of electron shallow trap on breakdown performance of transformer oil-based nanofluids, Journal of Applied Physics,2011,110, 104104 .
3. Yuefan Du, Yuzhen Lv, Chengrong Li, et al., Effect of nanoparticles on charge transport in nanofluid-impregnated pressboard, Journal of Applied Physics,2012,111, 124322 .
4. Yuefan Du, Yuzhen Lv, Chengrong Li, Mutian Chen, Jianquan Zhou, Xiaoxin Li, You Zhou, Effect of Semiconductive Nanoparticles on the Insulating Performances of Transformer Oil, IEEE Transactions on Dielectrics and Electrical Insulation, 2012,19(3),770-776
5. Yuefan Du, Yuzhen Lv, Chengrong Li, Mutian Chen, Jianquan Zhou and Xiaoxin Li, Insulating property and mechanism of semiconducting nanoparticles modified transformer oils, Proceedings of the Chinese Society of Electrical Engineering,2012,32(10),177-182
6. Du Yue-fan, Lv Yu-zhen, Zhou Jian-quan, Chen Mu-tian, Li Xiao-xin, Li Cheng-rong, Effect of Ageing on Insulating Property of Mineral Oil-based TiO_2 Nanofluids, 2011 IEEE International Conference on Dielectric Liquids (ICDL), USA, 10.1109/ICDL.2011.6015444.
7. Du Yue-fan, Lv Yu-zhen, Zhou Jian-quan, Li Xiao-xin and Li Cheng-rong, Breakdown properties of transformer oil-based TiO_2 nanofluid, 2010 Annual Report Conference on Electrical Insulation and Dielectric Phenomena, 10.1109/CEIDP.2010.5724082
8. Yuefan Du, Yuzhen Lv, Chengrong Li, et al., Effect of water adsorption at nanoparticle-oil interface on charge transport in high humidity transformer oil-based nanofluid, Colloids and Surfaces A: Physicochemical and Engineering Aspects (under revision process)

Part Ⅴ: Visa issue

Visa issues are not an impediment for me to report the activity to DEIS-sponsored conferences or participate to next CEIDP.