# Effect of Titanium Oxide on Dissipation Factor for the Insulation of Transformer Oil

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***Abstract*—***In most cases, The electrical insulation of the transformer oil is exposed to different internal problems, such as short circuit , over voltage, over load, over excitation and etcetera. The insulation of transformer is sever decreased into minimum value, that is unacceptable. This requires some treatments of oil liquid ,such as refining or replacing the old oil, which is a very expensive process. In this paper, The old oil is enhanced with nanoparticles (NPs) for reusing in the power transformer again. The NPs enhance the insulation, physical and chemical properties of transformer oil. The breakdown voltage(BDV) and the dissipation factor (DF) are tested for old oil and after addition the NPs according to IEC standard methods. The NPs are many types, Titanium oxide (TiO2) is one of them, which is used in this research. NPs reduce the effect of moisture as it absorb and form hydroxyl groups around. Also, reduce the effect of dissolved carbonate in oil without harmful effects. A comparative study is conducted to identify the effects of using NPs in transformer oil to ensure their effect on electrical insulation, Also to be used again. The results show that adding small amount of TiO2 to transformer oil improves its breakdown strength as well as dissipation factor.*

***Keywords*—**Nanoparticles; dissipation factor test; breakdown voltage test and Titanium oxide.

## I. Introduction

Electrical transformer is used to transmission and distribution the electrical power. It is an important electrical equipment, so it is a spirit of the system because it converts voltage and current with stability of power and frequency. The lifespan of transformer is very important that be ranged from 35 to 40 years. Electrical faults are reduced the lifespan and low the level of electrical insulation [1-4]. The insulation test of the transformer is important, It is entering the service or not.

Due to the regular operation of the transformer, thermal stresses are exposed. This heat causes severe risk. The oil penetrates between the windings to transfer the heat. There are several ways to transfer heat either; pregnancy, conduction or radiation. Therefore, fans, pumps and radiators are used to expel heat from the transformer body. The normal operating temperature of the transformer should not exceed 60 ° C. If the heat increases, the transformer will become aged [2].

The transformer oils are used to isolate, cool the coils, extinguish any electrical arc, Prevent the occurrence of chemical processes such as oxidation and give an indication of the internal state; in order to determine its faults in the transformer. Many tests are operated dissolved gas analysis, break down voltage, chemical test, screen tests, furan test and water content. Therefore, if there is a problem in the oil, the treatment must be either by replacing or refining oil and both methods are very expensive [5-7]. Transformer oil is derived from petroleum derivatives, so replacing it is expensive because the transformer may contain tens of tons.

The refining process costs about 70% less than the replacement. The refining process requires several cycles, reduces moisture and acidity then, the transformer can recover again. The refining process is inefficient if there is an internal problem with the transformer. The large number of refining processes lead to the erosion of paper Cellulosic. So many of the transformers after the refining processes are not valid for operation. Refining machines and spare parts have a high price that be increased the process of difficulty. So a new technique is needed to cure this problem.

Nanotechnology is a scientific revolution in the fields of engineering, medical and scientific. It is based on the substitution of the atom material, which produces a new material completely different from the original material has new physical and chemical properties. These materials of NPs are the most commonly used. It is cheaper, more stable and easy to prepare than other metal elementary substance.

Previous studies are pointed to the importance of using nanotechnology to improve the properties of transformer oil. Therefore, nanoparticles have been used to improve the age of limitation of the transformer and can extend its lifespan to double for paper [4]. It is also used in improving electrical insulation, dissolving gases, improving chemical properties and improving viscosity properties [9]. The NPS of the transformer oil have become as important as the medication for its diseases. it was found the kinds of NPs ($Fe_3O_4$, CuO, ZnO, $Al_2O_3$ and $TiO_2$) can increase both positive and negative breakdown voltages under switching impulse voltage [10-15]. Cadmium sulfide and hexagonal crystal structure are added to transformer oil to improve its dielectric and thermal properties, as well as an increase in the breakdown strength by about 81% in comparison to the base transformer oil for paper [16]. the effect of different nanoparticle material types on the DC and AC breakdown voltages of transformer oil nanofluid has been demonstrated, The effect of the external electric field on the charge type (i.e. positive or negative) has been also presented in paper [17]. Huge works for NPs have been deployed to improve the properties of transformer oil.

From this view, this research aims to improve dissipation factor of the transformer using NPs. In this paper, The TiO2

is used. The paper is organized as follows. First, the old oil is processed by adding nanoparticles materials and then shedding ultrasonic waves and infrared ray on this oil. Second, the breakdown voltage test is performed to ensure that the values are improved after the addition of the nanoparticles and then a mini model of the power transformers is immersed in this oil that will be used. Third, the dissipation factor is tested. Finally, the proposed mechanisms are obtained. The results are discussed between new oil , old oil and nano oil.

## II. Experiment Method and Test

### A. Nanofluid Sample Preparation

Mineral oils are petroleum derivatives, so it contains Hydrocarbons components, which are carbon and hydrogen compounds. These oils are used in electrical transformers, separation and conduction equipment and capacitors. The properties of oil are high viscosity, high electrical strength, high oxidation resistance, have the ability to absorb heat. Shell Diala of transformer oil is many kinds; B,C,D,Dx and F. Shell diala oil D is used in this experiment, That is Conformed to specification IEC 296. This oil is highly refined include a density is 895 kg/ m3. at 20 °C, a viscosity is 12 at 40 °C, a flashpoint is 135 °C, pour point is -40 °C, a breakdown voltage after treatment is 70 kv and a dielectric dissipation factor is 0.005.

The new oil is used as a basis for comparing the results between the nano oil and the old oil that is used. The old oil is taken from the tap changer of the power transformer That, rated power is 40 MVA and the voltage ratio is 66/22 KV, The sample is 2 liters. Nano oil is prepared by using TiO2, It is added into the old oil. TiO2 is obtained from (Alpha Chemika) company as a powder with a particle size below 100 nm , a purity 99.5% and a relative density of 4.26 g/ $cm^3$. Quantity of titanium oxide is very important, so it is weighed with a sensitive balance of high accuracy. Then the nanoparticles are mixed with the old oil. The mixing machine rotates at low speed to prevent bubbles and gases in the oil. This process takes 20 minutes after, it is stopped. However, the nanoparticles are not fully soluble in oil. This is because the titanium oxide particles are solid materials that are only dispersed at high frequencies. So, the ultrasound is dissolved titanium oxide in oil.

Ultrasound called the audio frequencies exceeding 20 kHz. Ultrasonic waves are a high-frequency wave that the human ear cannot hear. For example, these waves can remove brain tumors and break up kidney stones. At some frequencies, these waves can generate enough energy to weld some metals. In this experiment, The frequency is used at 65 kHz and the waves are concentrated on oil for two hours. So, nanoparticles were melted into the oil.

Despite the benefits of ultrasound, it caused the appearance of moisture and dissolved gases in the oil. To treat these problems, thermal energy must be used. Heat is transmitted by conduction, pregnancy or radiation. In this experiment, The infrared is used for heating the oil, because it distributes the heat on all the atoms of the sample evenly, so complete removal of moisture and full saturation of oil with added NPS.

Infrared radiation is an electromagnetic radiation that comes after visible radiation and before the microwave. The source of infrared radiation must be characterized by a non-fluctuation of the ray and its stability. Philips lamp is used with rated power 250 watt and 230 volt. It has double reflector system to concentrate the rays on the oil. The radiation was given for two hours, with a five minute break every 20 minutes. The oil temperature ranges between (50 - 55 ° C). The oil temperature should not exceed 60 ° C because this increase causes oil aging, which affects the life of the transformer. That is shown from this equation[2]:

$$t_f = t_k * 2^{(\frac{T_k - 60}{7})} \quad (1)$$

Where, $T_k$ refers to the accelerated aging temperature, $t_f$ indicates the equivalent time and $t_k$ shows the aging period under accelerated. It is indicated the aging rate doubles approximately for every 7 °C increase in temperature above 60°C. The steps of preparation the nano oil are summarized as follow in Fig 1.

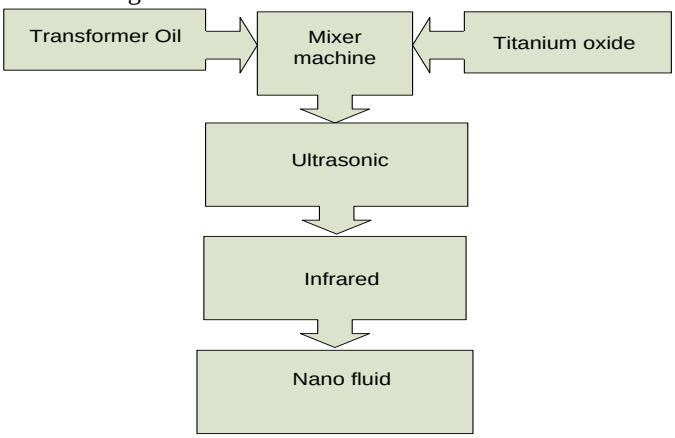


Fig. 1: The Nano fluid preparation steps.

### B. Breakdown Voltage Tests

The BDV is measured ability of oil to withstand electrical stress without collapse. The AC breakdown The oil is put in the clean vessel and the gap will be 2.5 mm between the electrodes, now slowly rising voltage is applied between the electrodes. The rate of rise voltage is generally controlled at 2 KV/s and observed the voltage at which sparking starts between the electrodes. The tester gives six values of breakdown were performed. The average value was used as AC breakdown voltage. This test is useful for detecting the presence of insoluble pollutants in oil. such as; moisture, sediment and particulate matter, as it reduces the isolation of oil.

In this search, (BAUR) oil tester model (DPA 75C) is used. The oil breaker contains a magnetic stirrer to stir the sample after each operation. If the magnetic stirrer is not used, the electrons are deposited after each test on the electrodes. Thereby increasing negative charges between electrons. Therefore, the values of breaking oil insulation are incorrect Because the values are raised. The test is done for pure oil, old oil, oil after ultrasonic treatment and nano-oil. Results are compared discussed.

### C. The Dissipation Factor Test Methods

The DF is called tan(δ) test. This test shows the leakage of current in oil. The dissipation factor device was used in this experiment is (BIDDle). It has two units one of them for control and other for injected the power, the rated of voltage injected 10 kV, apparent power 1 KVA and current 0.1 A. The angle between the voltage and current are measured through the insulation. appendix A is shown, The specifications of the transformer that is used in this research.

If the angle between the voltage and current is (θ) that shown in fig.2, therefore the completed angle is (δ) that very small value. Whenever small tan(δ) was better insulation and increased is bad insulation. The typical tan(δ) value shall not

exceed 0.5% at 20 ° C. The capacitor shall be measured to confirm the quality of oil insulation of the windings.

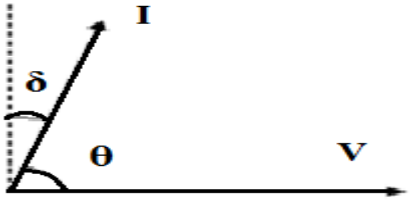


Fig. 2: The angle between voltage and current.

The transformer tank is filled with new oil at first and then tested the DF. After that, it is replaced the new with old oil and nano oil. The procedures of DF test are connected the high voltage cable to the primary side and sensor cable to the low side and tested in these sequence; for measuring (CHG+CHL), for measuring (CHG) and for measuring (CHL).The connection of test in fig.3.

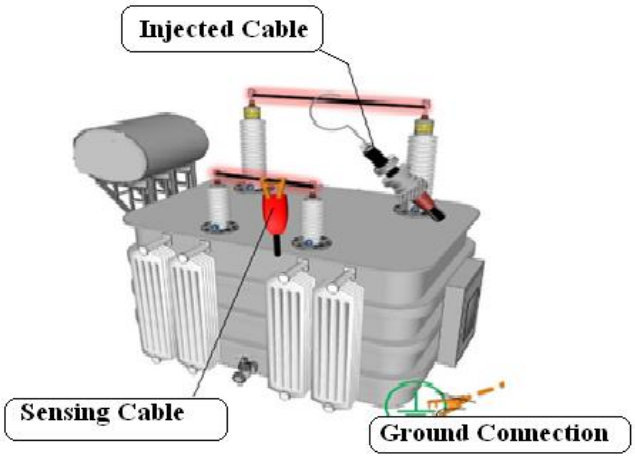


Fig. 3: The injected from HV side.

After that the test will be returned but the injected cable will be at LV side and the sensing at HV side. That be shown in fig. 4.

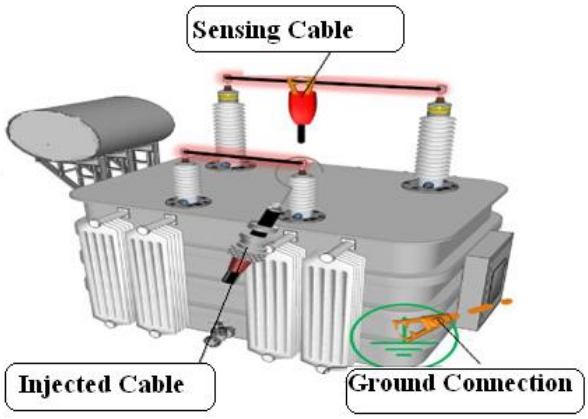


Fig. 4: The injected from LV side.

The purpose of this test is to ensure the quality of internal insulation between windings and ground. The ground of the transformer expresses the iron heart and the transformer tank. This insulation shall be between low voltage side and ground connection, the insulation between high voltage and low voltage sides and the insulation between high voltage side and ground connection.

## III. Experiment Result

### A. Breakdown Voltage Measurement

Initially, the amount of titanium oxide is determined. So the BDV test is done for new oil. Six readings of new oil were taken at room temperature, the average value was 56 kv. Then, TiO2 is added to the new oil with small values, in milligrams per liter. The added values are 0.02, 0.04, 0.06, 0.08, 0.1, 0.12 and 0.14 g / L. At each value, ultrasonic and infrared treatments are performed and the BDV is tested.the results are shown in fig 5.

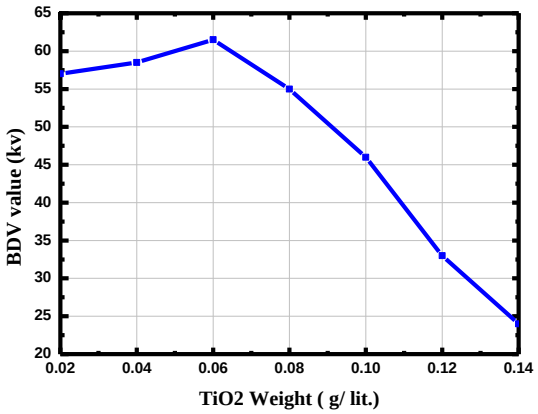


Fig. 5: The amount of $TiO_2$ nanoparticles in BDV test.

Figure 5 shows the relationship between the amount of ($TiO_2$) and BDV value. At first, the relationship is positive and then changes to be inverse. the amount 0.06 (g/l) of $TiO_2$ gives the maximum value of BDV that 61.5 KV for this test. Increasing the titanium oxide particles above that caused a change in the properties of the oil. Viscosity and BDV value are decreased Substantially. So 0.06 g / L of titanium oxide is added to the old oil, to improve the insulation properties. The values of BDV for new oil ,old oil and nano oil are illustrated in fig 6.

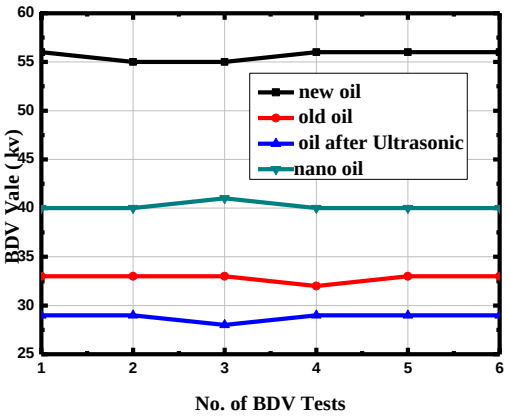


Fig. 6: The BDV measurement for oils.

From the Figure 5, the average values of oils are as follows: new oil is 56 kv, old oil is 33 kv, oil after ultrasonic 29 kv and nano oil is 40 kv. Oil after ultrasonic treatment is decreased the value. This is due to gaps, moisture and bubbles caused by the process. Infrared absorbs foreign matter with organic compounds, that can affect the movement of rotational and vibratory molecules. In the field of organic chemistry is needed short wavelength radiation, which ranges between (30 - 50 cm), leading to high concentration of frequency between (3 - 400 GHz). Therefore, in this research, when using infrared radiation with oil temperature control not to exceed 60 ° C, the

BDV was increased from 33kv into 40 kv. The percentage of enhancement can be calculated according to this equation[19]:

Where, $BD_{nf}$ is the BDV of nano oil and $BD_{oil}$ is the BDV of base oil. The improvement rate is 21%. This corresponds to the values in previous research [2,8,19].

### B. Dissipation Factor Measurement

The DF test is essential test in the power transformer. This test ensures the lifespan of overall insulation system of an electrical power transformer. The results of DF are shown in table 1.

Table 1: DF test of the oils.

| Injected side | Test volt (v) | Measures | Tanδ % | | |
|---|---|---|---|---|---|
| | | | New oil | Old oil | Nano oil |
| HV side injected | 500 | CHL | 0.22 | 0.48 | 0.3 |
| | 500 | CHL+ CHG | 0.28 | 0.65 | 0.35 |
| | 500 | CHG | 0.25 | 0.45 | 0.29 |
| LV side injected | 100 | CHL | 0.12 | 0.15 | 0.12 |
| | 100 | CHL+ CHG | 0.11 | 0.15 | 0.12 |
| | 100 | CHG | 0.11 | 0.16 | 0.12 |

From this table The values of Tan(δ) test as follow; new oil is 0.28,old oil is 0.65 and nano oil is 0.35. In the practical life and according to the MPIS ( maintenance procedure information system) and IEC:60247 standard, If the DF test is exceeded 0.5 % the transformer is disconnected from the service, Several oil refining cycles are performed. After that, all site-specific tests are done, As well as chemical tests and dissolved gases. If the results are less than the allowed, transformer does not enter the service. After that, an internal detector is made to the transformer. Where, team test are logged through maintenance slots.

The results of DF are enhanced. By Using titanium oxide particles, the values are 0.35 and are within the permissible limits. Effect of applied voltage test on the DF is very important, therefore, it is illustrated in Fig 7.

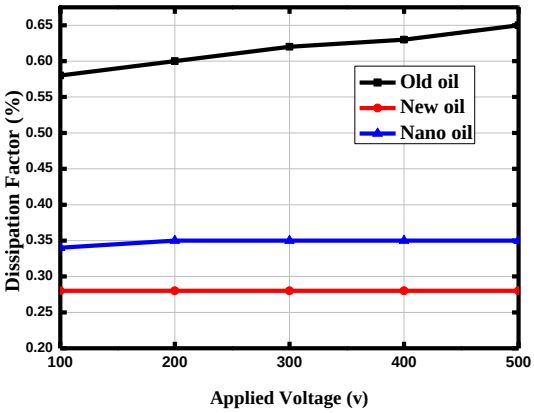


Fig. 7: Relationship between the DF % and applied voltage.

The relationship between the applied voltage and DB is illustreted high stability of the DF in the new oil, as well as in nano oil. DF of the old oil is oscillated in values. This indicates that many atoms of carbon have become semi-conductive, thus affecting insulation. The stability of the nano oil is showen. Transformer oils contain structures of carbon and hydrogen, are systematically correlated that shown in fig. 8.

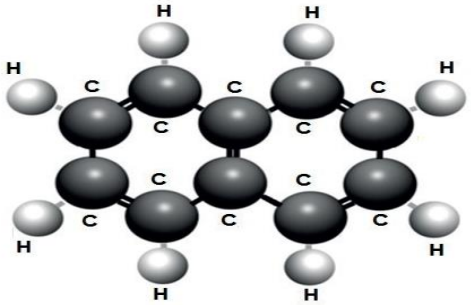


Fig. 8: The structure of transformer oil.

When an electric arc occurs inside the oil, The oil is extinguished the spark, But with frequent recurrence it is decomposited. Carbon atoms appear in oil individually and noticeably. Carbon is a non-metallic substance, Quad parity. Carbon is associated with other elements to be organic compounds. Also found in the inorganic image in carbon dioxide $co_2$. Carbon of semiconductors, in the normal state is an insulator and when the heat increases the insulation is broken. From (MPIS) instructions, the maintenance of high voltage equipment must not exceed the steps of the tap changer 5000 steps without maintenance or five years, Whichever comes first. Serious maintenance of the tap changer is done by removing it, cleaning the contact points, then returning it and testing the transformer before entering the service. This process in practice is difficult , Sometimes the transformer is damaged due to errors in the maintenance process.

In this research, the sample was taken from the oil of the voltage changer to be practical, So that oil is at the worst conditions. So the BDV was 33kv and after treatment it became 40kv. The basic idea, when attaching a carbon atom with titanium oxide while providing electromagnetic radiation, There is a stirring and interdependence between them, This reaction produces $co_2$ [20] that shown in equation 3. Fig. 9 shows, Infra-red radiation causes adhesion of carbon atoms to the outer surface of titanium oxide.

$$TiO_2 + C \rightarrow Ti + CO_2 \quad (3)$$

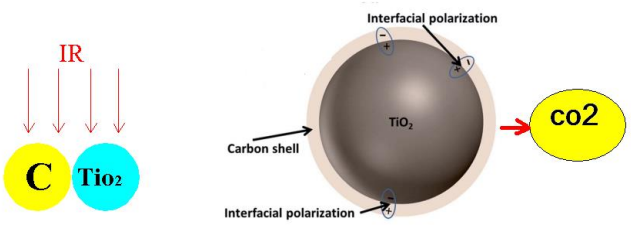


Fig. 9: The effect of IR on carbon and titanium oxide.

From standards IEC 60567 for dissolved gas, the increase in carbon dioxide is not harmful to oil, Allowable 2500 ppm for alarm value and 4000 for trip value. The results are leaded to use this nanoparticles in the electrical field. There is no doubt that using nanotechnology is much better than not using it.

## IV. Conclusion

The paper demonstrated the utility of using nanoparticles to enhance the properties of the transformer and improve its efficiency. A model of a transformer similar to power

transformers was made in power grids. Experiments were performed using pure oil and nano-oil. The main conclusions were summarized as follows:

1) The weight of nanoparticles is important and dangerous, so be careful while preparing the oil because the nanometer excess amount reduces the electrical insulation of the transformer and further deterioration.

2) AC breakdown voltage of nanoparticles was higher than pure oil. Also, the dissipation factor is improved.

3) Nanoparticles are enhanced the properties of transformer oil, reduce maintenance risk, Provision of oil change or refining costs and the long life of transformer will be increased also.

## Appendix

Table 4: The specification of the transformer.

| no. | discriminative | Value |
|---|---|---|
| 1 | No. of phase | Single phase |
| 2 | Rated of power | 500 VA |
| 3 | Voltage on primary | 220 volts |
| 4 | Voltage on secondary | 12 volts |
| 5 | Current on primary | 2.27 Amps |
| 6 | Cooling transformer | ONAN |
| 7 | Frequency | 50 HZ |
| 8 | Mfg. year | 2016 |

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