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Department of Electrical Engineering

THESIS

Presented for obtaining the degree of ACADEMIC MASTER

In: ELECTROTECHNIQUE

Specialty: Electrical Networks

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Subject

REAL TIME TRANSFORMER OIL MONITORING

Publicly defended on 00/00/2021, in front of the jury composed of:

Dr.Talal GUIA Framer

Dr. Examiner

Dr. Examiner

Dr. Examiner

Dedications

We thank Allah Almighty for him and his help in completing this research.

To the one who gave me everything he had so that I could fulfill his hopes to him, to the one who pushed me forward in order to attain the desired, to the one who watched over my education with great sacrifices, to my first school in life, my dear Father to my heart, may Allah prolong his life;

To the one who gave her heartfelt pleasure all the tender and tenderness, to the one who was patient with everything, the one who took care of me and was my support in adversity, and her claim to me for success, she followed me step by step in my work, to whom I was relieved whenever I remembered her smile in my face the source of tenderness my Mother The dearest angel in the heart and the eye, which I wished to be present with us, may Allah have mercy on her, and he brought her into his spaciousness;

To them I dedicate this humble work to bring in their hearts something of happiness to my Brother and Sisters who have shared with me the burden of life.

Saadeddine

Dedications

We thank Allah Almighty for him and his help in completing this research.

To the one who gave me everything he had so that I could fulfill his hopes to him, to the one who pushed me forward in order to attain the desired, to the one who watched over my education with great sacrifices, to my first school in life, my dear Father to my heart, may Allah prolong his life;

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To them I dedicate this humble work to bring into their hearts something of happiness to my Brothers and Sisters who have shared with me the burden of life.

Abdelrahmen

Thanks

We would like to first of all thank God the Almighty for the will, the health and the patience, which he has given us during all these long years.

We are pleased to take these few lines, so few in number, to thank the people who supported us during our brief.

In a special way, we would like to warmly thank Mr. T. GUIA for the honor he did us by agreeing to supervise us, for his precious guidance, his encouragement, the time he devoted to us throughout of this project and for allowing us to carry out our work in excellent conditions, his support and professionalism made it possible to carry out the work in our memory.

We would also like to thank a jury for examining and discussing the graduation memory, and we are honored by their acceptance of this assignment.

Résumé

Notre travail porte sur l'étude du comportement de l'huile de transformateur, sous tension alternative à une fréquence industrielle de 50 Hz, dans un système d'électrodes sphère à sphère à distance constante.

L'huile usagée appelée Borak 22 a été étudiée sous de nombreux facteurs tels que la tension appliquée, la tension équivalente dans l'isolation de l'air et la valeur du courant de fuite.

Les résultats des tests sont vérifiés pour les changements de tension de claquage et de courant électrique. Une condition caractérisant la détérioration de l'huile après chaque panne est également indiquée.

Mots clés : Huile de transformateur- tension de claquage- *la température- courant de fuite***.**

ملخص

يتعلق عملنا بدراسة سلوك زيت المحولات، تحت الجهد المتناوب بتردد صناعي 50 هرتز، في نظام من أقطاب كرة إلى كرة على مسافة ثابتة .

تمت دراسة الزيت المستخدم المسمى Borak 22 تحت لعديد من العوامل مثل الجهد المطبق والجهد المكافئ في عزل الهواء وقيمة تيار التسرب .

يتم فحص نتائج الاختبار لمعرفة التغيرات في جهد الانهيار والتيار الكهربائي. كما يتم عرض حالة التي تميز تدهور الزيت بعد كل انهيار .

الكلمات المفتاحية زيت المحولات - جهد الانهيار - درجة الحرارة - تيار التسرب

Abstract

Our work relates to the study of the behavior of transformer oil, under AC voltage at an industrial frequency of 50 Hz, in a sphere-to-sphere electrode system at a constant distance.

The used oil called Borak 22 has been studied under many factors such as applied voltage, equivalent voltage in air insulation and leakage current value.

The test results are checked for changes in breakdown voltage and electric current. A condition characterizing the deterioration of the oil after each breakdown is also shown.

Keywords: Transformer oil - breakdown voltage - temperature - leakage current.

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General Introduction

Electrical transformers play a major role in the distribution and transmission of electricity. They regularly suffer from technical failures and can explode. When such damage occurs, people's lives are in danger and the financial consequences for power companies are considerable.

These accidents are favored by the steady increase in electricity consumption. In fact, production is increasing by 2% per year in the world and by 5.8% in Algeria. This development represents an overload for old transformers, especially since most of them are over 30 years old. This causes their premature degradation.

The human and financial losses caused by transformer explosions emphasize the need to find preventive methods to reduce these losses without causing unnecessary shutdown of installations. These methods must be effective enough to enable action to be taken before the accident occurs.

Liquid dielectrics used as insulating oils are one of the most important elements in a transformer. It requires regular monitoring and maintenance in order to guarantee good insulation and good cooling. Monitoring the oil condition of a transformer in service is an effective preventive measure. It can also provide information on the internal state of the active part.

In our work, we are interested in liquid dielectrics for transformers and more precisely in mineral oils, and in increasing the dielectric strength of oils used in transformers without affecting the size of the latter. This is the reason why studies and research, focusing on insulating oils and, more generally, on liquid dielectrics, are, to this day, a topical subject.

It is with this in mind that we have attempted, on our scale and by the means which have been made available to us, to carry out a study on the influence of insulating barriers on the behavior of mineral insulating oil. industrial application. Our choice fell on a transformer oil, used by SONELGAZ (Algerian Electricity and Gas Company) and commercially called "Borak 22".

This manuscript has four distinct chapters:

- ► We start with the first chapter that deals with electrical voltage transformers, where it explains their characteristics, components, function and importance in protecting the permanence of electric power transmission in the national transmission network.

- ► The second chapter deals with different oils used on an industrial scale. We are interested in insulating mineral oil for transformers, because it is the most common in the electrical insulation industry. To this end, we emphasize the presentation of its various characteristics, namely: electrical, physical and chemical. We also cite the factors favoring oil spoilage in service. Finally, we discuss all the processes allowing the regeneration of used mineral oils.

- ► The third chapter talks about the different breakdown mechanisms of liquid dielectrics. We recall the factors influencing dielectric strength of liquids.

- ► The fourth chapter was devoted to describing the experimental techniques that were performed, and presenting and discussing all the experimental results that were obtained in the high voltage laboratory of the University of El-oued HammaLakhdar.

Chapter I

General information about power transformers

The transformer plays an important role in the transport and distribution of electrical energy. It allows electrical energy to be transported over long distances, it then allows its distribution to industries and homes.

This first chapter first introduces the context in which the power transformers. Their operating principles, their different types and their main elements will be presented.

1. Power transformers

1.1. DESCRIPTION

A power transformer is a static device with two or more windings which, by electromagnetic induction, transforms one system of alternating voltage and current into another system of voltage and current of generally different values at the same frequency in order to transmit the electric power 'standard (IEC 60076-1, 2000). "Transformers are reversible and allow either the raising or lowering of the voltage; hence the possibility of choosing the best voltage for the production, transmission, distribution, use of electrical energy, and to easily switch from one to the other. »An electrical transformer therefore makes it possible to transmit electrical power in alternating current (AC) from the power plant to its end user with a minimum of losses, at different voltage levels. The transformer is the element of the network which allows the passage from one given alternating voltage to another: it is an AC / AC converter at a fixed frequency, that of the network.[1]

1.2. PRINCIPLE OF WORKING

The primary winding is subjected to a sinusoidal voltage. It is therefore traversed by a sinusoidal current and gives rise through the magnetic circuit to a sinusoidal flux. This flow then generates an electromotive force induced in the primary winding and in the secondary winding. At the level of the terminals of the secondary, then appears sinusoidal voltage whose frequency is the same as that of the voltage applied to the primary, but whose amplitude is different.

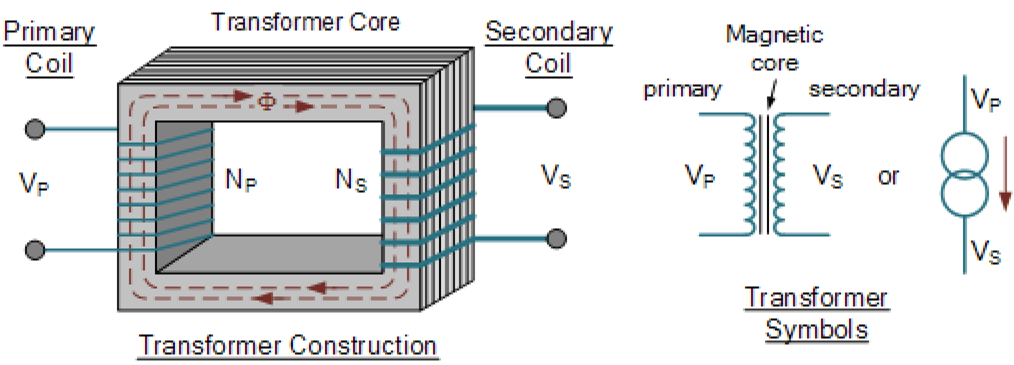


Figure 1.1: Operating principle of the transformer

The behavior of the transformer can then be apprehended by the diagram deferred on (Figure1.1).

1.3. CONSTITUTION

The majority of power transformers are of three-phase construction, and its main components are shown in (figure 1.2):

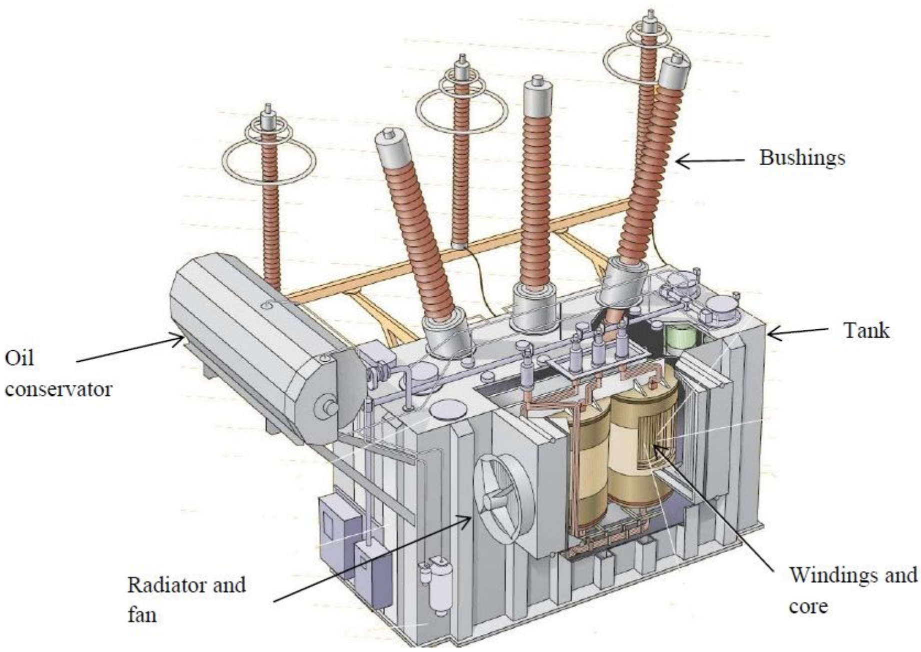


Figure 1.2:Cross section of a power transformer

This figure shows the following elements[2, 3, 4]:

- The low and high voltage bushings which can be isolated respectively by porcelain and paper impregnated with oil or epoxy resin. They allow the transit of power. Some are submerged, especially for very high voltages, others are dry.
- The tank made of steel sheets. The walls of the tank are, depending on the model, finned or rigid radiators equipped with removable radiators connected by a shut-off valve. The structure and the assembly welds can be reinforced if good vacuum resistance is required.
- The magnetic core made up of grain oriented silicon steel sheets. The stacking and assembly of the sheets must be carried out in such a way that the

transformer has the best possible performance from an electro dynamic, electrical and acoustic point of view.

- The windings (strip or round, or flat copper or aluminum) are mounted on the core. The forms of windings, the sections and the number of turns are conditioned by the constraints to be mastered in electrical, thermal and mechanical terms. Each coil is fitted with cooling channels to ensure oil circulation and heat exchange.
- The oil conservator (metal tank (usually steel) is located on top of the transformer. It acts as an expansion vessel for the oil. Variations in oil temperature imply variations in volume. The conservator allows the oil level to vary without affecting the pressure in the transformer, nor uncovering (exposing) the active parts. In some cases, a flexible bag is present in the conservator; oil to come into contact with the ambient air Some transformers are fitted with a dryer to limit the water content of the air entering the conservator.
- On-load or off-load changers.
- Dielectric fluid (mineral, synthetic or vegetable oils).
- Solid insulators (cellulose-based papers, tapes, varnishes, epoxy resins, cardboard, wood, etc.).

1.4. ROLE AND FIELD OF APPLICATION

Three-phase transformers are present in different places in electrical networks to adapt the effective values of the voltages to the desirable levels. In a simplified way,electrical energy is produced in power plants at medium voltages. Transport to long distance requires high voltages in order to limit Joule losses and reduce the sizing of conductors.

The use requires low or medium voltages. So step-up transformers are necessary at the start, and step-down transformers are essential at the end of the consumers.[5]

1.5. DIFFERENT TYPES OF TRANSFORMERS

There are different types of transformer, we are interested here, in the study of power transformers for three-phase electrical networks. These transformers are of greatest interest in the development of network interconnection.

To differentiate between transformers, there are several types of classifications namely:

1.5.1. CLASSIFICATION ACCORDING TO THE TYPE OF CONSTRUCTION

From the construction point of view, two main technologies are distinguished, namely column transformers and armored transformers.[5]

1.5.1.1. COLUMN TRANSFORMER (CORE TYPE)

The column transformer consists of two concentric windings per phase. These windings are mounted on a ferromagnetic core which closes at its ends via yokes generally of circular sections in order to ensure good channeling of the magnetic flux. In this technology, it is the windings that surround the magnetic circuit (Figure 1.3)[5].

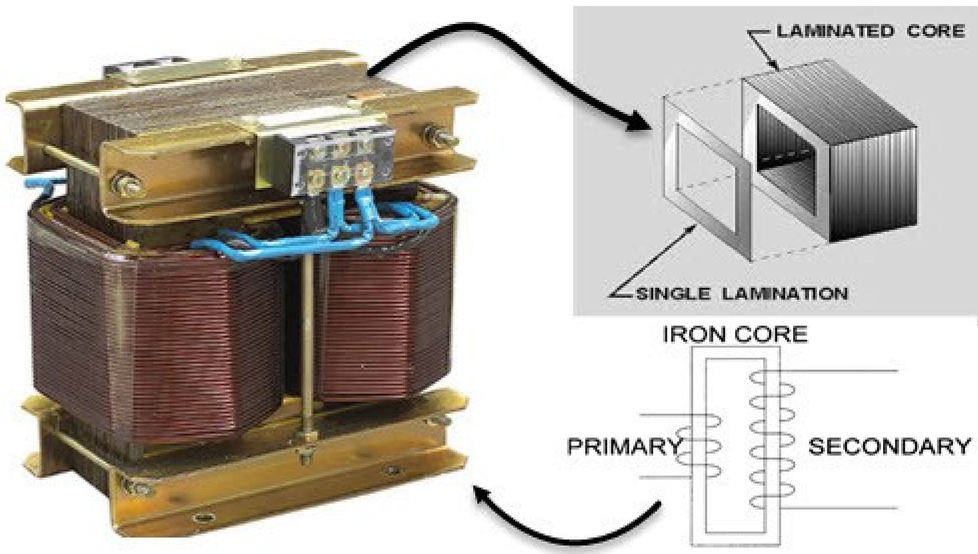


Figure 1.1:Column transformer (Core type)

1.5.1.2. ARMORED TRANSFORMER (SHELL TYPE)

In this technology, the magnetic circuit surrounds the windings formed by rectangular coils with a horizontal axis, of rectangular section made up of sheets laid flat. The tank secures the magnetic circuit and windings as shown in (figure 1.4).

These transformers are used in transmission and distribution networks where transient over voltages are frequent. In this environment, they must guard against the harmful effects of these over voltages on the windings. For this, screens are used in order to reduce the stresses linked to the electric fields in the windings. [5]

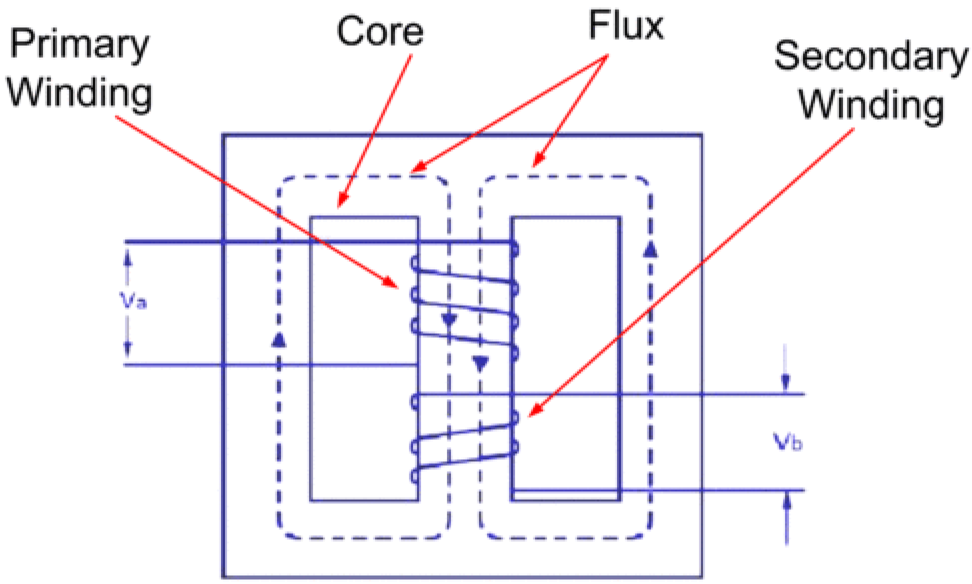


Figure 1.2:Armored transformer (Shell type)

1.5.2. *CLASSIFICATION ACCORDING TO THE FIELD OF APPLICATION*

From the point of view of their applications, ordinary phase transformers (single-phase, two-phase, and three-phase), grouped in three or five columns fall into three categories:

- Transformers for large networks and large power plants, their power varies from 100 to 400 MVA.
- Transformers for distribution networks which supply medium voltage lines, their power varies from 5 to 30 MVA.
- Distribution transformers intended to supply low voltage (380 or 220V) eclectic energy users, their power varies from 5 to 1000 KVA. [5]

1.5.3. *CLASSIFICATION ACCORDING TO THE TYPE OF COOLING*

Depending on the type of cooling, a distinction is made between: oil-fired transformers and dry-type transformers. [5]

1.5.3.1. OIL TRANSFORMER

To prevent the harmful action of air on the insulation of the coils and improve the cooling the transformer, the magnetic core with the windings is placed in a tank filled with mineral oil. Despite these advantageous properties, transformer oil has two main drawbacks: it is flammable and its vapor forms an explosive mixture with air under certain conditions. In addition to its role as a dielectric liquid reservoir, the tank

ensures the mechanical maintenance of the magnetic circuit and the windings. The construction of the generally oval shaped tank is linked to the thermal calculation of the transformer. The cooling of the transformer is all the more difficult to achieve the greater the power of the transformer. The tank is lined with magnetic shunts, of which there are two types:

- Magnetic shunts formed by a stack of magnetic sheets similar to the core and which channels the leakage flow.
- The more economical non-magnetic shunts, made of copper or aluminum plate having the role of repelling the leakage flow. [5]

1.5.3.2. DRY TRANSFORMERS

Transformers immersed in liquid mineral oil or silicone are more suitable for higher powers and high voltage levels, but present risks of leakage, fire and pollution of the environment. This made room for transformers with dry technology, with coated (impregnated) windings. The electrical insulation system is replaced by a resin (epoxy) and air. Resins have been developed to withstand the electrical tensions and the mechanical and thermal stresses that appear

in a transformer in service. The favorable aspect is its non-flammable and light behavior. This type of transformer is the most suitable for the distribution of electricity with a high degree of safety [Esl-2010].[5]

2. Lifespan of a Transformer

The lifespan of a transformer is known to be around 30 to 40 years. The best efficiency of a transformer in regular and continuous service, operating in a properly ventilated room, is between 60 and 80% of its nominal load.

If it operates in an irregular regime, it is exposed to:

- Thermal and electrical constraints
- Poor mixing and circulation of the mass of the dielectric A hydration, condensation and deposits (a drop in temperature promotes moisture

impregnation of paper / cardboard insulation) and the passage of dissolved water into free water).

If it is operating overloaded, it is exposed to:

- Lower yield
- Thermal and electrical constraints
- Accelerated degradation of the dielectric fluid
- Abnormal heating of the insulators (solid insulation)
- Premature aging of cellulose components.

3. The Insulation of a Transformer

In a transformer, insulation is provided by a solid dielectric complex (paper or cardboard) and liquid dielectric (insulating oil).

We call active parts of a transformer, the windings and their insulation (paper or cardboard). In the active part of a transformer, between the elements brought to different electrical potentials, insulation is provided by insulators in two states:

- **Liquid:** mineral oil, chlorinated hydrogen carbide (pyralene)
- **Solid:** organic (paper, synthetic resin, varnish)

These insulators carbonize at a low temperature, hence the need to carefully monitor the insulating characteristics in order to reduce the risks. It is carried out by extrapolation of the characteristics of the oil.

4. Transformer monitoring

The maintenance of transformers meets the standards in force and in particular specified in publications IEC 60.422 [6]. In addition to these maintenances, a crucial point remains to be resolved and the following questions arise:

- Are the transformers currently in a perfect state of reliability?
- Are they not exposed to a risk of breakdown?
- Are the dielectric oils in transformers not altered?

The fault-free operation of power, voltage or current transformers, circuit breakers and disconnectors largely depends on the dielectric qualities of the insulating oils.

5. Dielectrics

A material is dielectric if it does not contain an electric charge capable of moving macroscopically. It is essential in all electrical equipment. Its performance must increase according to the electrical stress to which it is subjected. Its electrical rigidity should be as much as the applied voltage is. The dielectrics used in high voltage belong to the following three main categories [7]:

- Gaseous insulators: air, certain electronegative gases (SF6, N2, etc.)
- Solid insulators: synthetic materials (PVC, mica, paper, etc.)
- Liquid insulators: the wide range of dielectric oils (mineral, etc.)

5.1. PHYSICAL PHENOMENA IN DIELECTRIC MEDIA

The electrons present in a dielectric medium cannot, by definition, move over great distances. On the other hand, they can present movements of very small amplitude on our scale, but which can be at the origin of many phenomena. These movements are often oscillatory movements around the nucleus: the electron cloud can be deformed and thus create an electrostatic dipole. The same goes for the global displacement of atoms within the material (they also create dipoles) [8].

5.2. QUANTITIES AND CHARACTERISTICS OF DIELECTRIC MEDIA

Dielectric materials are characterized in particular by:

- their dielectric strength
- their dielectric permittivity ε
- their tangent delta loss angle

5.3. SOME COMMON DIELECTRIC MEDIA

Solid:

- Glass, used to make high voltage line insulators
- Ceramic, widely used for HVB equipment in electrical substations
- Most plastics, in particular polyethylene in its cross linked form (XLPE) and PVC, both used for cables
- Polypropylene, used in particular in HTA or HTB capacitors
- Mica, which is hardly used anymore in the electrical engineering industry
- Bakelite, formerly widely used for low voltage electrical equipment
- Teflon, used for some parts of high voltage circuit breakers.

Gaseous:

- The air
- Sulfur hexafluoride
- Nitrogen.

Liquids:

- Pyralene, formerly used in transformers, but which is tending to disappear because of its risks.
- Mineral oil, which replaced pyralene in transformers
- Pure water. If ordinary water is conductive, perfectly pure water is a very good insulator. The difficulty of keeping very pure water makes any industrial use difficult.

5.4. USES OF DIELECTRICS:

Dielectrics are good electrical and thermal insulators, and are therefore used to sheath electrical cables to avoid contact with other cables or people. So they are useful in capacitors. In the very simple case of the flat capacitor, the plates can be brought together without risk of contact or breakdown. Dielectric layers are thus inserted in industrial capacitors, which makes it possible to increase the capacitance while reducing the bulk [8]. On the other hand, if it is subjected to a sufficiently powerful electric field, any substance will ionize and become conductive.

6. *Conclusion*

Power transformers are complex devices, which must withstand numerous and strong constraints, of various kinds, during their life cycle. In addition, in the current context, transformers will be subject to increasingly severe constraints, for several more years a priori. Although their reliability is quite good, transformers remain critical elements of any electrical network. It is therefore very important to be able to choose the most efficient insulators, in order to optimize the use of the equipment itself, and above all to guarantee the significant transmission of electrical energy which passes through itself.

Chapter II

Insulating mineral oils for transformers

The electrical industry makes extensive use of insulating oils. Indeed, the latter contribute to the development of very diverse electrical equipment: transformers, capacitors, cables and circuit breakers etc. The nominal voltages in these devices range from a few hundred volts to a thousand kilovolts.

Dielectric oils are classified according to their origin as mineral oils, vegetable oils and synthetic oils. Mineral oils are natural products obtained directly by refining crude petroleum and are the most common in the electrical insulation industry due to their low cost price. These oils, used as solid insulation impregnates or as fillers for electrical equipment, have two main functions: electrical insulation and heat transfer.

Mineral insulating oils can be subjected to several stresses: electrical, thermal, chemical, etc. Despite the advantages they present, these dielectrics deteriorate progressively under the combined or separate action of these

constraints. Analysis of the performance of the oil in service can be assessed by diagnosing the various physicochemical and dielectric characteristics. These tell us about the degree of deterioration of the oil.

1. Different categories of insulating oils

There are three classes of oils used on an industrial scale [10]:

1.1. SYNTHETIC OILS

Synthetic liquids are used when particular properties are required (fire resistance, resistance to partial discharges, negative gassing, etc.). These synthetic products were differentiated by their type of chemical structures.

1.1.1. HALOGENATED HYDROCARBONS

The need to reduce the risk of fire in electrical equipment is at the origin of the synthesis of halogenated hydrocarbons. The electrical engineering industry has mainly used chlorinated products which had the advantage of not giving off flammable or explosive gases under partial discharges or in an electrical breakdown. The principle is to replace part of the hydrogen atoms in the molecule with atoms of chlorine. Under ionization or electric arc, HCI molecules are formed instead of hydrogen gas.

The first industrial production of polychlorinated biphenyls (PCBs) dates back to 1929. They are referred to generically as Askarel. They were mainly used in transformers for their resistance to fire and in capacitors (for their resistance to partial discharges) until their persistence in the environment led to their progressive ban in all countries [9].

1.1.2. AROMATIC AND ALIPHATIC HYDROCARBONS

They are characterized by a strong gaseous absorption capacity under ionization (the alkyl benzenes), used in high voltage cables and in particular for filling capacitive dividers. Polybutenes used primarily in “mass impregnated” cables are characterized by high viscosity [9].

1.1.3. ESTERS

There are several types of ester in electrical engineering. Phthalates have been used since the beginning of the questioning of PCBs, for the impregnation of low and medium voltage capacitors, currently only dioctylphthalate (DOP) is still used for the impregnation of low voltage capacitors. Tetra esters are used for filling "fire resistant" distribution transformers, their high fire point (> 300 ° C) being the primary characteristic of these products [9].

1.1.4. SILICONE OILS

The most commonly used silicone oils are dim ethyl polysiloxanes. They come in the form of non-toxic liquids having the consistency of an oil, characterized by the following properties [11]:

- Their viscosity can range from 10 to 100 centistokes. This varies much less with temperature than that of mineral oils or chlorinated biphenyls.
- Their freezing point is exceptionally low (-60 ° C).
- Their good thermal stability (operating temperature up to 200 ° C).

Due to their high price, silicone oils are used in the insulation of small equipment working at high temperatures.

The disadvantage of dim ethyl siloxanes is that their dielectric strength decreases considerably following dielectric breakdown, and the presence of an arc gives off a large amount of gas [11].

1.2. OILS OF VEGETABLE ORIGIN

Vegetable oils were among the first insulating liquids used in the manufacture of electrical devices. There is a wide variety of vegetable oils. Only castor oil has been used for many years. It is used for the impregnation of energy storage capacitors.

They are generally not very toxic and biodegradable. These qualities are due in particular to a low resistance to oxidation and hydrolysis. These two characteristics, which are favorable for the ecotoxicological aspect, represent a significant draw back for electro technical applications. Moreover, their dielectric strength is not very high. For these reasons, vegetable oils are used relatively little (mainly in certain types of capacitors for direct current), although their use in transformers has been proposed recently [10].

1.3. MINERAL OILS

1.3.1. ORIGIN

These are natural products obtained from the fractional distillation of selected crude oil, then subjected to extensive refining. Their chemical composition is extremely complicated (several thousand different molecules) of hydrocarbons,sulfur, oxygen, nitrogen and trace organ metallic compounds [10].

To obtain dielectric grade mineral oils, crude oil must be refined by a process that usually includes distillation, followed by dew axing, solvent extraction, and catalytic hydrogenation [12].

The oils thus obtained are no polar dielectrics, the relative permittivity of which remains close to 2.2 in a wide frequency and temperature range.

1.3.2. PRESENTATION OF MINERAL OILS

An insulating or dielectric mineral oil is an oil that has low electrical conductivity due to a low charge density. It is mainly composed [13]:

- A so-called base oil (or a mixture of base oils) obtained according to traditional crude oil refining processes.
- Chemical compounds called additives, in very variable content, which make it possible to reach the specifications for the use of finished oils.

The composition of a mineral oil generally reflects that of the original distillate. Base oils in electrical engineering spread to three major classes of chemical trends. They are defined by their paraffinic carbon (CP), naphthenic carbon (Cn) and aromatic carbon (Ca) content.

1.3.2.1. PARAFFINIC TENDENCY

In this type of oil, the paraffinic tendency or the presence of paraffinic hydrocarbons predominates. These hydrocarbons are complex molecules with a saturated structure and a straight chain branched or not, but not cyclic.

The characteristics of this family of oils rich in paraffinic hydrocarbons are:

- A low density for a given viscosity.
- A relatively small variation in viscosity as a function of temperature.
- Low volatility for a given viscosity.
- Low solvent power [14].

1.3.2.2. NAPHTHENIC TREND

It is an oil rich in naphthenic hydrocarbons, that is to say, there is the presence of cyclic hydrocarbons with saturated bonds. The physical and chemical characteristics of these hydrocarbons are reflected in particular by:

- A relatively high density for a given viscosity

- Rather rapid variations in viscosity as a function of temperature.
- Greater volatility than the corresponding paraffinic functions of the same viscosity.
- A relatively high solvent power.

This type of hydrocarbon contains the most desirable properties for lubricating oils.

1.3.2.3. AROMATIC TREND

very high density, a very low viscosity index, a very low resistance to oxidation, a very low aniline point (is a very high solvent power) and ease of emulsion with water. The use of these hydrocarbons in the manufacture of oils is very limited due to their alterability. They are easily oxidized and cause the formation of resinous or asphaltic deposits accompanied by corrosive derivatives. The manufacture of lubricating, insulating or other finished oils is driven by trends in base oils [14].

The aniline point of oil, which is defined as the minimum temperature at which equal volumes of oil and aniline are miscible in any proportion, measures the solvent power of the oil. Its vapor is related to the aromatic hydrocarbon content of the oil, but is also influenced by other chemical factors: branching, instauration and molecular weight.

1.3.2.4. CHOICE OF BASE OILS

The choice of base oils is determined by:

- Has the desired chemical nature of the oil: paraffinic, naphthenic or aromatic.
- The physical and chemical characteristics that we want to give to the finished oil: viscosity, density, viscosity index, resistance to oxidation, etc.

Obtaining a finished oil capable of meeting the requirements of various usage constraints requires the use of a number of additives. The latter, which are of paramount importance in the mineral insulating oil industry, are chemicals incorporated in small quantities into the base oil, to improve certain properties such as the viscosity index, the antioxidant power which can delay the action of oxygen on the oil in service, the point of flow, etc ...

1.3.3. CHARACTERISTICS OF MINERAL INSULATING OILS

The properties of liquids are generally divided into physical, chemical and electrical properties. However, some properties belong to either of these divisions indiscriminately. The chemical properties relating to electrical applications being limited, and the electrical properties being predominant. The division is made into electrical characteristics, study characteristics, service characteristics and other characteristics [15].

1.3.3.1. Electrical Specifications

The electrical characteristics of liquids in general depend on their formulation (composition, molecular constitution, etc.), and their conditions of use in packaging (filtration, dehydration, etc.). We cite: permittivity, conductivity, dielectric loss factor and dielectric strength.

a. Permittivity

This is an electrical characteristic related to the formation of the liquid, it depends mainly on its chemical structure. For a dielectric oil, the permittivity defines the possibility of releasing charges under the action of an electric field [12]. It results from the phenomena of electronic and atomic polarization.

The relative permittivity ε of a product is defined as the ratio between the capacity of a capacitor filled with this product and the capacity of the same empty capacitor [10].

$$\varepsilon_r = {}^{C_p}/_{C_0} \quad \text{(II.1)}$$

The relative permittivity of hydrocarbons is low and close to 2. The presence of heteroatom's (oxygen, chlorine, etc.), by creating dipoles of high intensity, gives molecules a high permittivity.

The relative permittivity decreases with the temperature and the frequency of the current. However, for polar and viscous products, below a certain temperature, there is a sudden drop in permittivity due to immobilization of the dipoles [10].

b. Conductivity and dielectric loss factor

Any dielectric subjected to a direct or alternating voltage is always the site of electrical losses which result in a more or less significant heating of the liquid. The main cause of these losses is obviously the presence of current flowing through the liquid. This current characterizing the electrical conductivity of the fluid is the result of the displacement of existing free charges (positive and negative), under the effect of the electric field [16].

At low fields, conduction generally presents an ohmic character. At high fields, the conduction of insulators loses its ohmic character. Several theories account for high currents depending on whether or not they are contaminated with impurities [12].

In practice, to better characterize a dielectric from the point of view of losses, it is usual to use the tangent of the loss angle tg(δ)which is the complementary angle of the phase shift between the applied voltage and the current which results when the dielectric consists exclusively of the insulating material. This characteristic is an increasing function of the temperature and depends on the voltage [15].

Since many insulating liquids have dipoles in their molecular structures, orientation polarization is of particular importance. Indeed, it is the major cause of losses by polarization and responsible for the frequency dependence of ε and tg(δ) [17].

c. Dielectric strength

Power-frequency dielectric strength is the maximum value of the electric field that can be applied to oil without discharge [12]. Like conductivity, dielectric strength at power frequency is a conditioning characteristic of the liquid, but also of its formulation.

In industry, it is conventionally maximized by the effective voltage necessary to cause, under standardized conditions, the breakdown of a volume of liquid between two electrodes whose shape, distance and nature are specified, hence its name. "Breakdown voltage" [16].

1.3.3.2. STUDY CHARACTERISTICS

a. Density and coefficient of volume expansion

The density ρ_θ expressed in kilograms per cubic meter, is the ratio of a mass m of the liquid to its volume v, measured at temperature θ. It is determined at 20 ° C, and decreases with increasing temperature [15].

The density is obtained at 20 ° C by the following formula:

$$\rho_{20} = \rho_\theta[1 + \alpha_v(\theta - 20)] \quad \text{(II.2)}$$

α_v : mean coefficient of volume expansion of the liquid in the vicinity of the temperatureθ.

$\alpha_v$is defined by:

$\alpha_v \Delta\theta = \Delta v / v$ (II.3)
and can be determined from two values ρ_{01} and ρ_{02} of the density ($\rho_{01} > \rho_{02}$) by:

$\alpha_v = (\rho_{01} - \rho_{02}) / \rho_{02}\ \Delta\theta$(II.4)

Density is an intrinsic characteristic of a product. It depends on the chemical composition. Thus, paraffinic mineral oils have a lower density than naphthenic oils [19].

The coefficient of volume expansion α_v defines the variation in density as a function of temperature [9].

b. Specific heat capacity at constant pressure

For mineral oils, the specific heat capacity at constant pressure increases with temperature and decreases with density according to the following relation [9, 10]:

$c_p = (1684 - 3.39\ \theta)\sqrt{\rho_{15}}\left[J/Kg.K\right]$ (II.5)
with ρ_{15}: density at 15 ° C.

At 20 ° C, the thermal capacity varies from 1000 to 2300 J / (kg.K).

c. Thermal conductivity

Measured in Watts per Kelvin meter, it expresses the flowing heat flow, in steady state under the effect of a thermal gradient between two isotherms of the liquid. It decreases as the temperature and density increase. The average value is

$$\lambda = 0{,}14 W/(m.K)$$ [9, 15].

d. Viscosity

Viscosity and its variation with temperature are parameters of primary importance for heat transfer. Indeed, the more viscous the liquid, the more difficult it is to circulate it in the device, to cool the hot active parts [10].

The viscosity of a fluid reflects the forces that oppose the molecules of this fluid to a force tending to move them. It is therefore the resistance to movement that all fluids manifest. The viscosity index expresses the variation in viscosity as a function of temperature. Transformer oils have a very low index; which allows easier circulation, therefore more efficient cooling.

e. Pour point

The use of outdoor electrical equipment requires knowing the viscosity of liquids at low temperatures corresponding to operation in winter (-25 ° C) or in extreme climatic conditions (-60 ° C).

The liquids used generally freeze at temperatures that can range to -60 ° C (polybutenes, silicone oils), to - 30 ° C (mineral oil), not to mention synthetic liquids with a high pour point (+ 9 ° C). for chlorobiphenyls), and non-migrating cable oils with pour points of 80 to 100 ° C [18].

The pour point is defined as the lowest temperature at which a liquid can flow when cooled under set conditions. When a liquid is cooled, it acquires a certain on-freezing consistency, corresponding to the solid state of a pure substance at a fixed temperature. This consistency is linked to the molecular mass, to the composition of the liquid as a mixture of different molecules (isomers and additives) [18].

Lower pour point oils are obtained from naphthenic cuts.

1.3.3.3. SERVICE FEATURES

a. Solubility of gases

All gases dissolve more or less in mineral oil, as they do in liquids. The largest value of the volume of gas that can be dissolved to saturation is called the solubility coefficient S. This coefficient is defined as the ratio of the volume of dissolved gas to the volume of oil and is expressed as a percentage hundred.

b. Water solubility

The electrical properties of liquids are affected by their water content. The latter depends on the temperature and partial pressure of water in the atmosphere above the liquid. The solubility of water in oil depends on the chemical composition of the oil. It grows with the concentration of aromatic hydrocarbons. In the case of aged oil, the degradation products increase the amount of water it can hold [15].

c. Acidity and color

In new oils, there is no presence of mineral acids, but that of organic acids.

The acidity of new oil is very low. It is in the range of 0.02 to 0.03 mg of KOH / g of oil. In the early stages of oxidation, it increases to reach, after a certain service time, a value where it remains constant. This stability is explained by the precipitating deposits [19].

Color is an intrinsic property of new oil. It has a relationship with the hydrocarbons that make up oil. It helps assess the quality of new oils and is an effective way to monitor the acidity of oils in service. It also provides information on the aging of the oil, as it becomes darker with age [20].

d. Oxidation stability

Oxidation is a set of complex and slow reactions in which hydrocarbons react with dissolved oxygen. The rate of oxidation reactions increases with temperature and oxygen concentration. The consequences of oil oxidation on insulation are [18]:

- Poor heat dissipation due to increased viscosity;
- An increase in dielectric losses and conductivity;
- Corrosion of metal parts;
- Faster degradation of cellulose insulation.

e. Thermal stability

Thermal stability generally relates to materials in association with oil. However, knowing the behavior of oil alone is of interest, in the case of non-winding hotspots. Oxygen plays a major role in the thermal decomposition of oils, for temperatures of 175 ° C to 235 ° C [21].

f. Electrical stability at partial discharges

Under the action of an intense electric field and via partial discharges in gas occlusions which form or which exist beforehand, liquids decompose to form gases. Electrical stability, referred to as Gassing, is evaluated by the Gassing coefficient G. Two methods indicate, depending on the test conditions, whether liquid insulators are absorbers or emitters of gas. The gassing behavior of liquid insulation is particularly dependent on its chemical composition, but variations in certain test parameters can dramatically alter the results. These two methods differ in their test conditions. G_A expressed in cubic millimeters per minute is positive or negative depending on whether there is emission or absorption of gas. In the case of an electric arc, and therefore very high temperatures (over 2000 ° C), there are no liquids that can resist. The nature of the gases formed and their relative proportions make it possible to characterize the severity of the stress [22].

1.3.3.4. WORK SECURITY

The safety of use of insulating liquids concerns the risks of fires and explosions, of which they could be the cause of the health of individuals and the risks for the environment. The fire danger is based on flammability characteristics (flash point, fire point, auto ignition temperature) and certain combustion characteristics (oxygen index, amount of heat released). The danger of explosion is linked to the nature of the gases produced by the decomposition of liquids under electric arcs and hot spots, with hydrogen, methane and acetylene being the main gases concerned.

a. Flash point and fire point

The gradual heating of a liquid causes the release of vapors along its vapor pressure curve, whether it is a pure substance or a mixture. As soon as the concentration of these vapors in the atmosphere above the liquid becomes sufficient to form a flammable mixture, they burn on the approach of a flame. The corresponding temperature is called the flash point of the liquid [15].

By continuing the heating, experience shows that permanent combustion is established in the presence of a flame from a certain temperature which corresponds to the fire point of the liquid. Non-flammable liquids have no fire point.

b. Auto-ignition temperature

The auto-ignition temperature of a liquid is the minimum temperature at which instantaneous combustion occurs, it can be higher than the flash point. This temperature corresponds to the behavior of a liquid in a fire, while the fire point characterizes operating thermal limits (for example, 105 ° C for paper-oil insulation) [15].

c. Combustion characteristics

The fire point distinguishes flammable liquids and non-flammable liquids, a simple situation when the electrical construction only had mineral oils and Askarels. The ban on Askarels and the introduction of replacement fluids poses the flammability problem in new terms. These replacement liquids have a high fire point (> 300 ° C) which can reduce the risk of fire, but, although said to be not very flammable, they nonetheless burn and their behavior in materials caught in a fire poses problem. To answer this question, the combustion characteristics (limiting oxygen index, thermal combustion capacity, release of fumes) are now considered, further associated with the corrosiveness of the combustion products and their toxicity [10].

1.3.4. USED MINERAL INSULATING OILS

1.3.4.1. DEFINITION

Used oil is conventionally defined as being oil which no longer fulfills all the roles assigned to it; It is therefore an oil which has lost some of these qualities or characteristics due to its use. The deterioration of oil in service results not only from the degradation of some additives improving its characteristics, but also from the presence of contaminants of external origin to the oil.

1.3.4.2. ALTERATION OF OILS IN SERVICE

In service, oil regardless of its quality and stability, whether inhibited or not, eventually oxidizes and deteriorates. Keeping the spoiled oil in operation can be a potential hazard. The deterioration of the oil results in the oxidation of the latter and an increased acidity.

1.3.4.3. FACTORS FAVORING THE DETERIORATION OF INSULATING MINERAL OIL

Contaminants in used mineral insulating oil can be divided into three broad classes.

a. Volatile products

The most common volatile products of oils in service are:

- Water: the presence of water in oil can have various origins. It can arise from the condensation of atmospheric air and chemical oxidation reactions. Indeed, in contact with a humid atmosphere, the oil becomes charged with moisture in an equal proportion with respect to saturation and the oxidation reaction is [12]:

$$C_nH_{2n+2} + \frac{3}{2}O_2 \rightarrow C_nH_{2n}O_2 + H_2O$$

  Water can be in dissolved or free form. Its solubility depends on the temperature, it increases with the latter. Oil saturated with water can lead to the formation of small droplets due to fluctuations in the oil temperature. These very fine droplets can lead to water-oil emulsions [18].

- Air: the solubility of gases in oil depends on the pressure of the gas phase. Air bubbles can present a hazard to paper-oil insulation [18].
- Dissolved gas: The different categories of dissolved gas come from the decomposition of oil. Gases in the form of CO, CO2, H2, O2 and C2H4 can be

released under the effect of an intense electric field, causing the appearance of partial discharges and the formation of new degradation products [23].

Mineral oils contain a number of gases, one of which is oxygen, which causes the oil to oxidize faster the higher the temperature is. This oxidation leads to the formation of acid products and in a subsequent phase, solid deposits, partly soluble in the oil, but which increase its viscosity and can be deposited on the insulations with which the oil is in contact. Oxidation products are always peroxides, highly unstable products that initiate true chain reactions, often referred to as "autocatalytic oxidation" [23].

b. Products insoluble in insulating mineral oil

Insoluble products come from the oxidation of oil, degradation of insulating paper (carbon), mechanical wear (metal, metal oxides) and ambient air (dust). In service, insoluble products are carried away by the circulating oil and eventually settle on the walls of the circulation channels and on the conductors. Due to their very low conductivity, they slow down heat exchange between the oil and the various components to be cooled, while at this point causing excessive heating. The removal of these insoluble products is, in general, less problematic than the volatile and soluble products [23].

c. Products soluble in insulating mineral oil

Soluble products correspond to the whole family of bodies formed by oxidation, reactive products, both acidic and non-acidic, resins and asphalts [18].

d. Factor favoring gas formation

In an appliance with oil in the insulation, the presence of excessively hot spots, partial discharges or an electric arc will result in the decomposition of the oil and the formation of gas. These gases, in part dissolve in the oil and in part emerge from it, to come together either in certain points of the device, or as is often the case in accessories specially designed to collect them. The nature of the gases formed, their relative proportions, the rate of gas evolution vary with the nature and intensity of the defect that gives rise to them and on the other hand with the constitution of the deteriorated insulation. Analysis of evolved or dissolved gases can therefore, to some extent, be used to characterize the fault and its severity.

- **Partial discharges**

The gases formed by partial discharges in oil contain very large proportions of hydrogen and small amounts of hydrocarbons [19].

❖ **The electric arc**

The gases formed by the presence of an electric arc in oil contain mainly hydrogen, methane, ethylene and acetylene. In the case of a small arc, the composition is similar to that of partial discharge gases, i.e. hydrogen predominates: when the intensity of the arc increases, the mixture is depleted in hydrogen and enriches in hydrocarbons (methane, ethylene, acetylene) [19].

❖ **The heat**

The thermal decomposition of oil leads to the formation of hydrogen and hydrocarbon gases at the same time as it releases dissolved air [19].

1.3.4.4. REMINDERS ON THE REGENERATION OF USED MINERAL INSULATING OILS

Regeneration is a set of processes allowing the production from a charge of used oil, one or more base oils. Recycling used oil saves the need to consume new amounts of new oil. Therefore, regeneration is presented as another form of energy saving and environmental pollution control.

❖ **General principle of regeneration**

Successive operations to obtain a high quality product constitute a new form of used oil refining. This cycle usually includes successive phases in the following order [14]:

- decantation, the purpose of which is to remove solid bodies, large impurities and free water.
- The separation of impurities suspended in the oil. This operation is currently the most difficult phase of regeneration. Indeed, the very fine particles which are in suspension in the oil remain insensitive compared to the old sediment precipitation processes by breaking the colloidal suspension or by electrolyte such as sodium silicate.
- Dehydration which aims to remove water by heating to a temperature of 150 ° C. You can also use a desiccant namely $CaCl_2$.
- The acid treatment leads to the flocculation of the carbonaceous suspensions and the sulfonation of the oxidized products, but without this resulting in an attack on the oil itself. This treatment is carried out on oil heated to a temperature of around 30 ° C to which is added 4% by volume of 90-92% sulfuric acid H2SO4. These products are mixed either beforehand or directly in a conical bottom settling tank. The acid sludge is precipitated at the bottom of the tank and separated from the purified oil. The purified oil will be subject

to further processing. These treatments allow the reduction of metal contents from additives and mechanical wear to a few PPM (parts per million) in the reclaimed oil.

- Neutralization of the oil occurs after the acid treatment. This is because purified oil still contains acids of different kinds, especially sulfonic and small particles of sulfuric acid. The purpose of neutralization is to convert the acid residues in the purified oil into salts. For this purpose, soda and lime carbonate at 1% by weight are generally used.
- The passage to the earth is an operation which is carried out in a conical tank equipped with an agitator. It directly precedes the mixing of the oil with the activated soil. After neutralization, the oil is mixed with 1 to 10% of activated earth for 15 to 20 minutes, at a temperature varying between 80 and 100 ° C. Finally, the mixed oil is filtered through filter presses. This treatment improves their qualities by discoloration and elimination of easily oxidizable products.

2. Conclusion

Assessed in terms of risk, the need to monitor transformers in service is of prime importance. The most powerful current techniques for evaluating the condition of a transformer are based on the physico-chemical analysis of the various properties of oil. Indeed, to ensure the continuity of operation of the device, the insulating oil must have the following qualities [24]:

- High dielectric strength.
- Thermal stability over a wide temperature range.
- High purity, resulting in homogeneity and good reproducibility of dielectric strength.
- Non-polar, which leads to low species dissociation and leads to low contamination.
- Non-toxic and biodegradable, and therefore complies with the current law on environmental protection.
- High aromaticity index, which gives it good gassing properties.

Chapter III

Breakdown of liquid dielectrics

Liquid insulators are of great importance in high voltage technology because they play a dual role: insulation and cooling. We owe their integration as a dielectric in 1887 by G. Westinghouse. Hydrocarbon oils are currently the most widely used in the power transformer industry [28].

They have good dielectric strength (several times greater than that of gases), very low permittivity and dielectric losses. However, their main drawback is their flammability, not to mention other public health concerns of PCBs (polychlorinated biphenyls) [29].

Studies on the mechanism of conduction and breakdown in liquids have developed considerably in recent decades, as these processes are of great importance in many contemporary fields of physics, chemistry, electrical engineering and engineering. radiobiology. These studies are closely related to other very important fields, such as plasma physics, semiconductors, physics and technology of resistance of materials to electrical breakdown, etc ... [30].

The breakdown of liquid insulation is fundamentally different from that of gases and solids. In technically pure oils, breakdown is mainly due to the presence of impurities, the phenomenon of aging, or even space charge [31].

1. Breakdown of insulating liquids

The breakdown of liquid dielectrics is fundamentally different from that of gases and solids, and the study of their dielectric breakdown is very complex because it involves fundamental laws of matter.

The knowledge acquired, especially over the last three decades, has not made it possible to establish a unified theory capable of explaining the breakdown phenomenon of liquid media, the best known of which are: the electronic breakdown mechanism, based on a cumulative process of ionizations and collisions between electrons and liquid molecules, the breakdown mechanism where the gas phase acts as a detonator and the breakdown mechanism due to the establishment of a particle bridge between the electrodes [25].

A distinction is generally made between electronic breakdown and thermal breakdown, while noting that the distinction is not necessarily obvious because electronic breakdown always leads to local destruction of the material by thermal fusion and vice versa. Thermal breakdown is mainly the consequence of an injection and / or conduction phenomenon of an electronic nature [26].

These two processes are the main mechanisms that can be presented with regard to the breakdown of liquid dielectrics. The third may be due to the presence of impurities of various kinds suspended in the liquid dielectric. This last mechanism is the closest to that concerning transformer oils subjected to various constraints in operation, more particularly to electrical aging and thermal aging in the presence of impurities of different kinds [25].

1.1. ELECTRONIC MECHANISM

The first works proposed to adopt the results obtained in gases, to explain the breakdown in liquid dielectrics. They hypothesized that a-type ionization mechanisms based on electronic vibrations and free electrons, or electronic emissions and multiplications, were involved in the breakdown of liquid dielectrics [32].

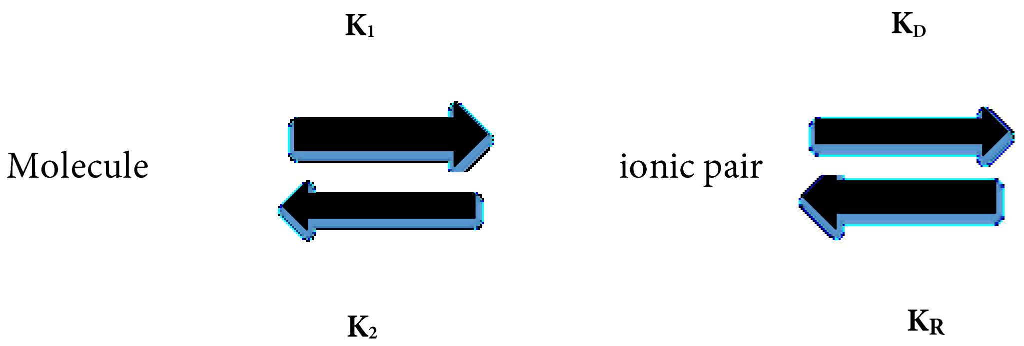
The process of electron multiplication was originally proposed by Townsend, to describe the arcing phenomena in gases. This process is a consequence of the acceleration of one or more electrons by the field, over a distance equal to the mean free path. The energy gain acquired by these charges allows ionization, following collisions, of one or more molecules [33].

Knowledge of fluid conduction improved when polar fluids such as nitrobenzene were studied. The chemical aspect of conduction phenomena and its relation to electrochemistry were then the first to be understood. Later the concepts of electrochemical kinetics were successfully applied to polar and non-polar liquids.

The electrical conduction of liquids could be fully understood from the moment when measurements of the distribution of the electric field between the electrodes were made at different instants under voltage. We were then able to know the origin of the charge carriers and their speed of movement.

The charge carriers are created within the liquid (creation in volume) or at the electrodes. In terms of volume, the appearance of new carriers is due to a reaction that can be schematized as follows:

A neutral molecule dissociates into free ions (mono-valent) according to the following process:



The stage of formation of the ionic pair depends on the more or less complex chemical process.

The rate constants K_1 and K_2, independent of the electric field, cannot be calculated using a simple model. On the other hand, the formation of the pairs of ions resulting from the Colombian interactions K_R and dissociation K_D of two charges of opposite sign in electrostatic interaction can be calculated.

The application of an electric field in the liquid changes the interaction energies between the ions in the liquid. The exact kinetic field theory on pair dissociation is due to Onsager. It predicts that K_D varies with the absolute value of the field while K_R is independent of the field [33].

Charge carriers can also be created at the electrodes, either by discharging ions from the liquid onto the electrodes, or by creating new ions. The ion discharge causes the formation in the liquid, of a space charge of opposite sign (heterogeneous) at the neighboring electrode, while the injection is accompanied by a space charge of the same sign (homocharge). The exchange of charges at the electrode can therefore be characterized by measuring the electric field near the electrodes [34].

Discharging the ions is not a problem, neither theoretical because it always seems to happen, nor practical because it removes the ions from the solution. On the other hand, the injection, which is responsible for the very rapid increase in the conduction of liquids at high fields, depends a lot on the liquid-electrode system.

Several ion creation mechanisms can be considered [34]:

- Injection of electrons by the cathode and capture of electrons: liquids are not sufficiently pure under their conditions of use, so that their conduction is electronic and the electrons are immediately trapped by electron acceptor compounds ($O2$,….).
- Ionization of the liquid.
- Electrochemical reaction.

The formation of electronic avalanches in a liquid, which can lead to breakdown (as in gases) has been very controversial. Several arguments are against such an assumption. In most liquids:

- The mean free path lm is probably of the order of intermolecular dimensions (a few tens of manometers), therefore much less than that of an electron in a gas at atmospheric pressure.
- A pressure of a few bars has a remarkable effect on the appearance of streamers, especially since such pressures are incapable of acting on the mean free path of electrons in almost incompressible liquids.

1.2. BREAKDOWN MECHANISM INVOLVING A GAS PHASE

In ultra pure liquid and in point-plane geometry, under direct voltage, it has been observed that from a certain voltage threshold, gas bubbles form in the vicinity of the point, then are violently driven towards the plane. . This gaseous phase would result either from the vaporization and nucleation of the bubbles, or from cavitation [35]. Some authors assume that gas cavities exist a priori and only consider the propagation of these cavities [27].

1.2.1. *ORIGIN OF PARTICLES*

From the point of view of their origin, small particles present in transformers can be classified into three categories [27]:

- Particles initially present in the tank filling oil.
- Particles which then appear in the oil from the elements of the transformer, such as windings, magnetic circuits and other solid parts and which were found fixed on them during assembly operations.
- Particles appearing during service.

The particles in new oil are very fine and are not removed by filtering and rinsing operations. These can be impurities in the crude oil itself or impurities that may have been introduced during refining operations.

Particles introduced during manufacturing and assembly operations include cellulose fibers, resin particles, metal (steel, aluminum, copper) and dust.

1.2.2. *PARTICLE CONTENT*

Based on a quantitative analysis of particles collected by filtering transformer oil, 94% were combustible (that is, made from cellulose fibers), with the remainder being materials or dust. During service, the content of particulates, such as cellulose, metal and resin fibers, is likely to increase slowly as a result of metal aging and wear due to the forced circulation of oil for cooling. In addition, in the event of an abnormal situation, such as local heating or the existence of partial discharges, the content of carbon particles tends to increase.

1.2.3. *ROLE OF PARTICLES IN BREAKDOWN*

The presence of impurities in insulating liquids leads to local strengthening of the electric field. The deformation of the field depends on several parameters such as:

- Forms, dimensions, permittivity and conductivity of impurities.
- Concentration of impurities between the electrodes.
- Intervals and shapes of electrodes.

Values of the free charges existing at the surface of the particles.

1.2.3.1. INSULATING PARTICLES

The insulating particles, having the permittivity greater than that of the liquid, would be attracted by the action of the electric field to the regions of strong field and would form bridges between the electrodes. The rupture, in this case, would be the result either of the heating produced by the Joule effect in the bridge which is more conductive than the liquid, or by the great local intensity of the field which appears just before the completion of the bridge [33] .

1.2.3.2. CONDUCTIVE PARTICLES

Conductive particles can easily charge on contact with one electrode and carry their charge to the other electrode. When the distance between the particle and the electrode with the opposite sign is very small, the field is so high that a micro-discharge initiating between the particle and the electrode would trigger the rupture.

Dielectric breakdown is generally preceded by impulse phenomena called "pre distruptives" or "pre-plating".

1.3. LONG DISCHARGES IN LIQUIDS

In a liquid, intervals of a few centimeters are considered long intervals. The mechanism of evolution of discharges for such intervals is similar in general characteristics to that observed in air for intervals of the order of a few meters. This mechanism is called as in gas: streamer leader mechanism [35].

The study of the mechanisms of streamers has continued to develop. Much work has focused on the progression of streamers in divergent geometries. It is generally accepted that whatever the geometry and the polarity of the electrodes, the breakdown is preceded by a pre-layering phase which can itself be split into two:

- A generation phase where phenomena of various kinds (electrical, optical, hydraulic, etc.) can appear simultaneously or successively, characterized by a so-called generation time tg, during which appears in the vicinity of an electrode, a disturbance in the form tree called "streamer" in the English formulation.

- A propagation phase during which the previously created disturbance develops. This phase has been by far the most studied and is characterized by a so-called propagation time tp.

Streamers are characterized by their refractive index which is different from that of liquid. They produce currents and emit light, just as their propagation is accompanied by shock waves regardless of their speed.

2. *Factors influencing the dielectric strength of liquids*

2.1. ELECTRO-GEOMETRIC PARAMETERS

The increase in the inter electrode distance leads to an increase in the breakdown voltage . In addition, the dielectric strength of the liquid decreases with in creasinginter-electrode distance. In a non-uniform field, when the applied voltage exceeds a certain level, a density of energy in the form of pulses is injected from the roughness of the tip. The radius of curvature of the tip plays a role Important on the nature and duration of pre disruptive phenomena, the smaller this radius, the greater the intensity of the electric field obtained.

2.2. HYDROSTATIC PRESSURE

It has long been known that hydrostatic pressure has a considerable effect on the breakdown voltage of liquid dielectrics; the higher the pressure is increased [33].

2.3. TEMPERATURE

As the temperature increases, the dielectric strength of the oil decreases. At elevated temperatures, the conditions for thermoelectric ignition improve [33].

2.4. VOLTAGE

The voltage rise time, its polarity, its duration and its amplitude greatly affect the propagation speed and the shape of the streamer. For voltage levels slightly above the generation threshold voltage, several authors confirm the appearance of gas bubbles in the vicinity of the tip electrode [33].

2.5. HUMIDITY

The presence of a little moisture in the liquid considerably decreases the dielectric strength of the latter (Figure 3). Oil saturated with water can lead to the formation of small droplets, due to fluctuations in the oil temperature. These very fine droplets can lead to water-oil emulsions [36].

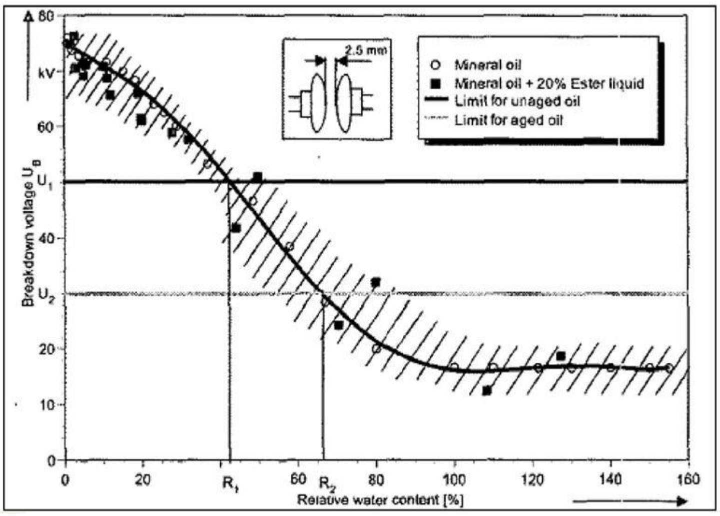


Figure 3: Breakdown voltage as a function of the relative water content in mineral oil and in a solution composed of mineral oil with 20% liquid ester.

3. Conclusion

Failures in electrical equipment are due, to a very large extent, to electrical breakdown or breakdown of insulation. We thus designate the final stage of a succession of irreversible processes where any dielectric liquid is suddenly crossed by an electric arc. The various works and studies carried out on the breakdown of liquid dielectrics have made it possible to accumulate a very large amount of information. However, the fundamental processes leading to breakdown are still poorly understood. This is largely due to the fact that knowledge of the physical properties of the liquid state is even less developed, than in gases and solids.

Chapter IV

Experimental techniques and results

This chapter will be devoted to experimental work conducted in the high-level laboratory of high voltage stress in University of El-oued.

The tests were carried out with the aim of studying the parameters experimentally to influence the breakdown voltage of Borak 22 oil under 50 Hz sinusoidal alternating voltage, several effect parameters will be dealt which are; The effect of the electric tension level and the determination of the voltage value in three successive collapses of oil and the study of the values of the leakage current after each collapse, and this is in the case of constant geometry of the electrodes, their nature, and the electrode distance.

- *First, we introduce the device used for the various tests conducted.*
- *Second, we analyze the obtained values of the leakage current before and after several successive collapses.*
- *Finally, we present the various results obtained followed by conclusions.*

1. Experimental devices

For the measurement of the breakdown voltage, we used a device shown schematically in the figure (Figure 4.1). The latter comprises the following elements:

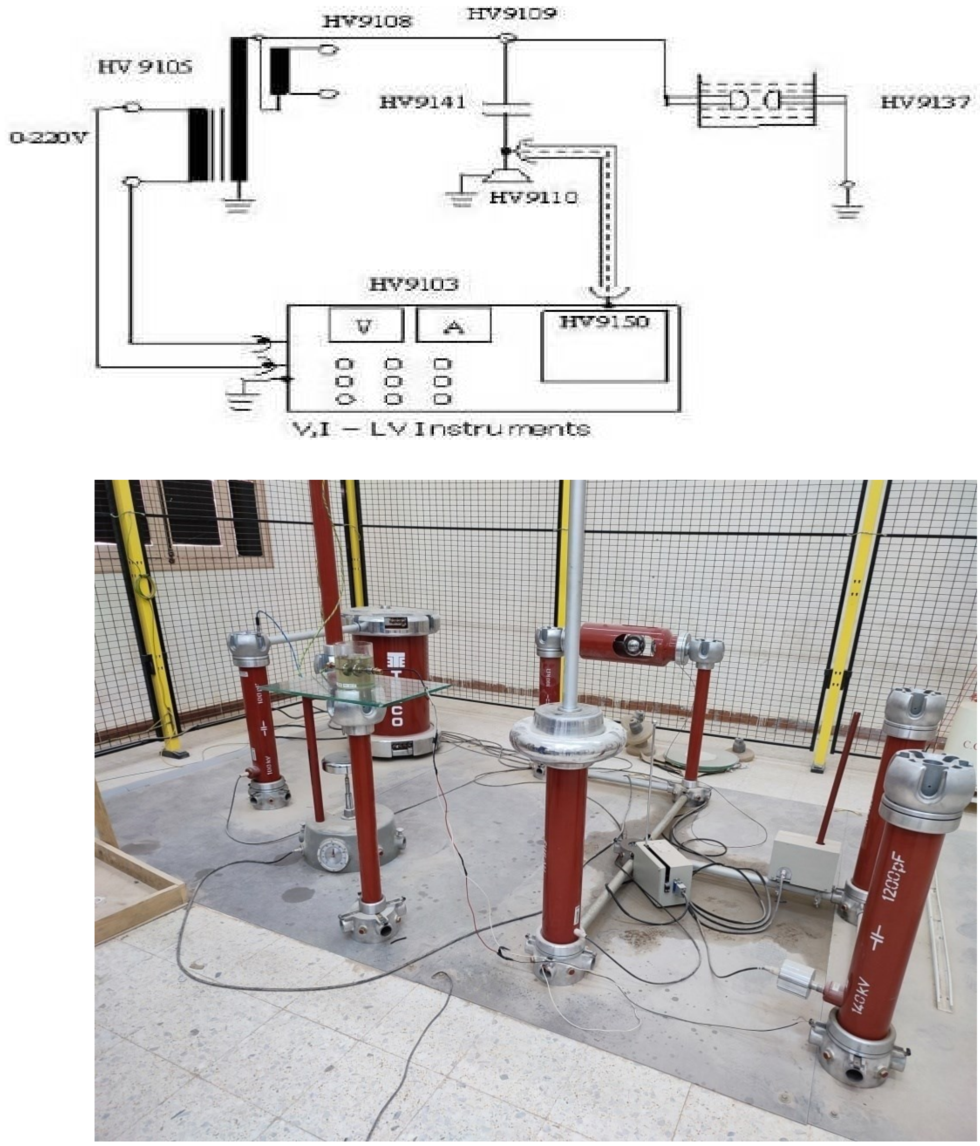


Figure 4.1: test circuit and devices table

HV test transformer	HV9105	1
Control panel	HV9103	1
Measurement capacity	HV9141	1
AC voltmeter	HV9150	1
Rod conductor	HV9108	1
Cup conductor	HV9109	1
Earth connection	HV9110	1
Test tank	HV9137	1

1.1. CONTROL PANEL

It is the one of the important integral part to drive the breakdown voltage of the air using the method of the standard sphere deviation. The control panel consists of all measuring instruments including security, switching control such as voltmeter, ammeter, circuit breaker, alarm etc. , which is shown in (Figure 4.2). The main function of the control panel is to control all the equipment under test.

Figure 4.2:Control panel

By changing the button the applied voltage of the voltage regulator is changed on the test objects. In this experiment, the gap distance between the spheres is changing from the control panel by controlling the speed of the motor connected to the gearbox of the moving sphere electrode. During the experiment, the breakdown voltage at the particular spacing distance between the spherical electrodes are displayed in the control panel.

1.2. CIRCUIT BREAKER

A circuit breaker is an automatically controlled electrical switch intended to protect an electrical circuit against damage caused by an overload or a short-circuit. The main function of the circuit breaker is to identify faults in the circuit and isolate it. In high voltage circuits faults mainly occur symmetrical faults, asymmetric faults and earth faults. Once a fault is detected and the contacts in the circuit breaker should open to interrupting the circuit, mechanically stored energy contained in the circuit breaker is used to separate the contacts and, although some of the energy required can be obtained from the fault current itself. The circuit breaker contacts must carry the load current without excessive heating, and must also withstand the heat of the arc produced when the circuit is broken. Contacts are made of copper or copper alloys, silver alloys, and other materials. The service life of the contacts is limited by erosion due to the interruption of the arc. Miniature and high voltage circuit breakers have replaceable contacts. When a current is interrupted, an arc is generated. This arc must be contained cooled and extinguished in a controlled manner, so that the gap between the contacts can still bring voltage in the power circuit. Therefore, once the fault condition has been cleared, the contacts must be closed again to restore power to the interrupted circuit. Circuit breakers come in various sizes, from small devices that protect an individual home appliance to large switchgear designed to protect high voltage power circuit industries. These high voltage circuit breakers improve system stability and availability.

1.3. HIGH VOLTAGE TRANSFORMER

A transformer is a static device. It transfers electrical energy from one circuit to another circuit through the inductively coupled conductors of the transformer coils. A varying current in the primary winding creates a varying magnetic flux in the transformer core and therefore a varying magnetic field across the secondary winding.

This variable magnetic field induces a variable electromotive force (EMF) in the secondary winding. This effect is called mutual induction. In this high voltage step-up transformer arrangement having the nominal power of 15 kVA, 400V / 100kV is used which is shown in (Figure 4.3) As the voltage increases, the current decreases in the same proportion.

Figure 4.3:High voltage transformer

2. Insulating Oil Testing

High voltage power transformers contain quantities of insulating oil for insulation and cooling. The good dielectric properties of the insulating oil are therefore an important prerequisite for a perfect insulation of these transformers. Since the breaking strength of an insulating oil depends significantly on its composition, its preparation conditions and determination is an important part of high voltage testing of transformers. In IEC60296 valid for insulating oils, a minimum quality is prescribed for new or used oils under exactly specified test procedures. The complete test program covers, viscosity, breakdown voltage, dielectric dissipation factor and specific volume resistivity. The breakdown voltage shall be measured using a standard test cell in alternating voltages at supply frequency. The spherical caps with spacing s = 2.5 mm, should be chosen as electrodes. The test voltage should be increased from zero at a rate of approximately 2 kV / s until breakdown. Six decomposition experiments should be performed for every 2nd to 6th measurement cannot be less than certain minimum values. These values are 60 kV for new oils in transformers and instrument transformers and up to 30 kV for switchgear; Lower values are authorized for equipment in service.

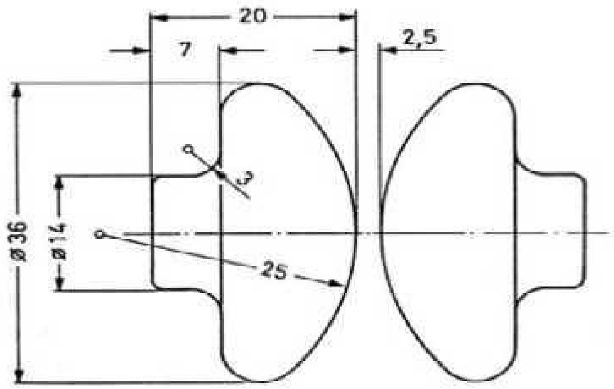


Figure 4.4:Breakdown voltage measurement electrodes for insulating oils

Figure 4.5:Cylindrical glass container

For Insulating Oil Degradation Test a circuit as shown in (Figure 4.5) must be configured. An oil sample is taken from the transformer to be tested. The oil to be studied should be poured slowly into the test vessel, avoiding the formation of air bubbles (by allowing it to run along a glass rod), then left to stand for about 10 min before voltage is applied. The voltage must be cut off at the instant of breakdown. An interval of about 2 minutes should be maintained after each discharge and the interval between the electrodes waved with fresh oil by carefully passing a stirrer through the gap.

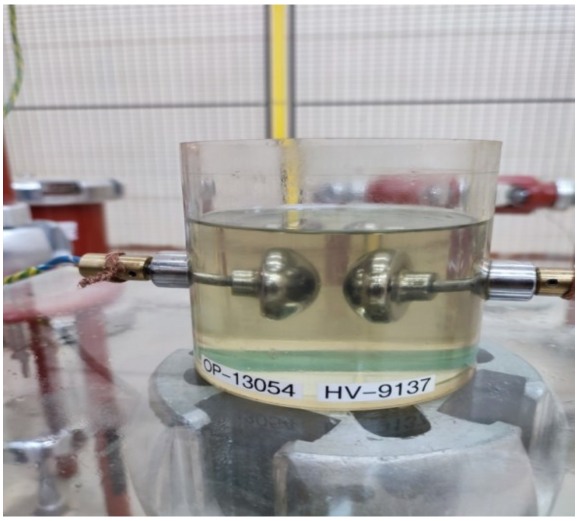
3. *Properties of Borak 22*

Electrical properties	**Unit of measure**	**New oil standard requirement**	**Standard**	**Measured value**
Slap tension after meal	KV	>70	CEI 156	38,8-72
Dielectric dissipation factor at 90°C tgδ		≤ 5,00 E-03	CEI 247	0,87 E-03
Physical properties				
Aspect		Clear and free form solid matter	CEI 296	Limpid
Kinematic viscosity at 40 °C	mm^2/s	< 11	ISO 3104	6,940
Flash point	°C	>130	ISO 2719	137
Density		<8,95 E-01	ISO 12185	8,57 E-01
Chemical properties				
Acidity index	Mg KOH/g	<3,00 E-2	CEI 296	(2,00-5,8) E-02
Water content	ppm	<30	CEI 814	
Color index	ppm	<02	ASTM D 1500	< 0,5
Refractive index				1,474

Figure 4.6: The characteristics of Borak 22 insulating oil

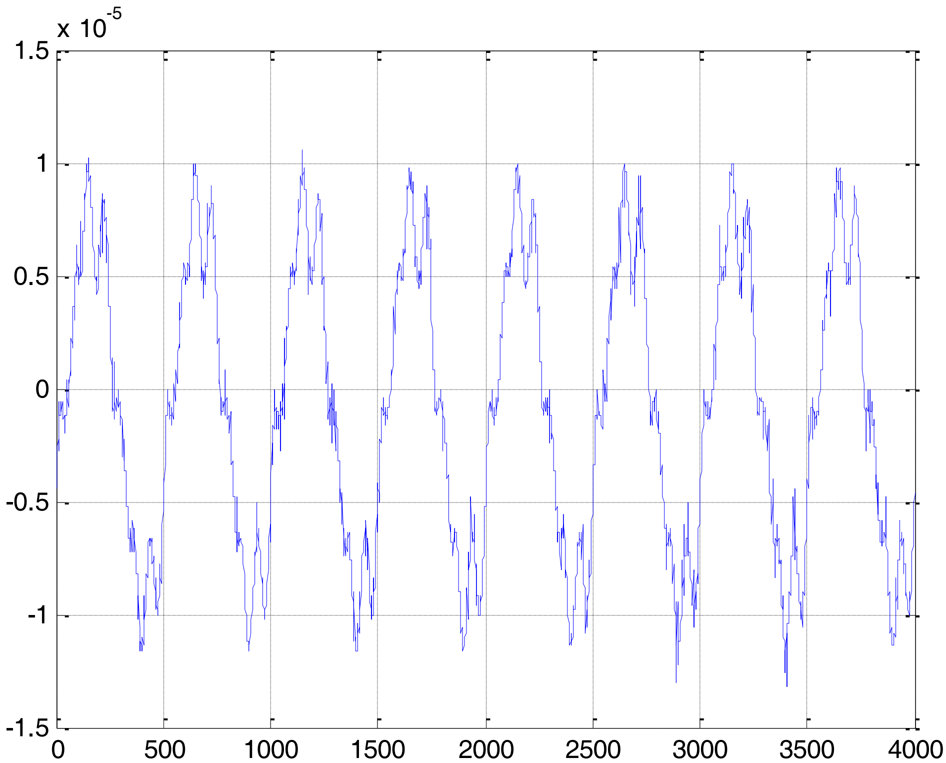
4. Leakage current

4.1. LEAKAGE CURRENT IN TEST WITHOUT BREAKDOWN

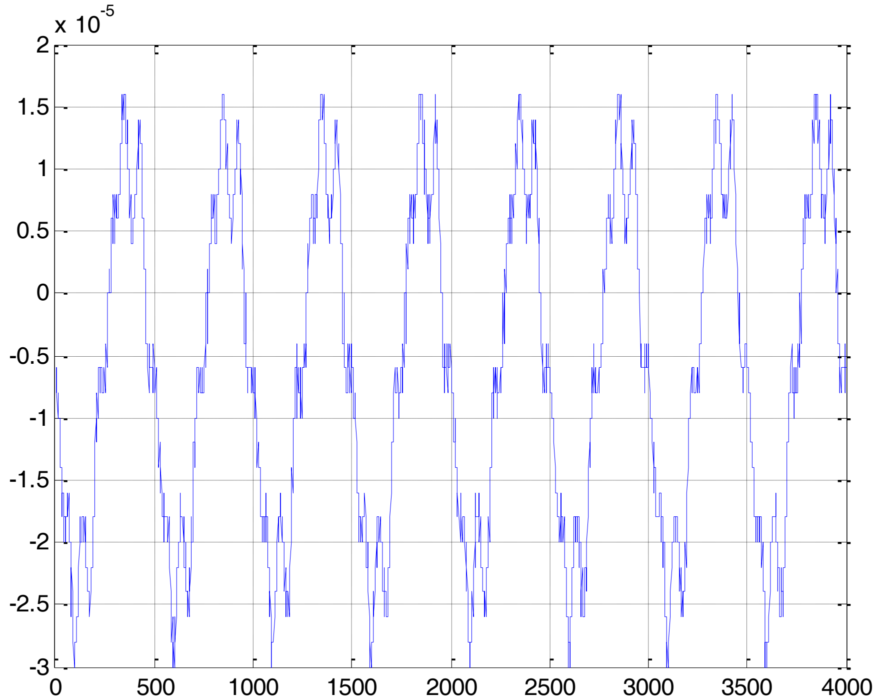


Before breakdown

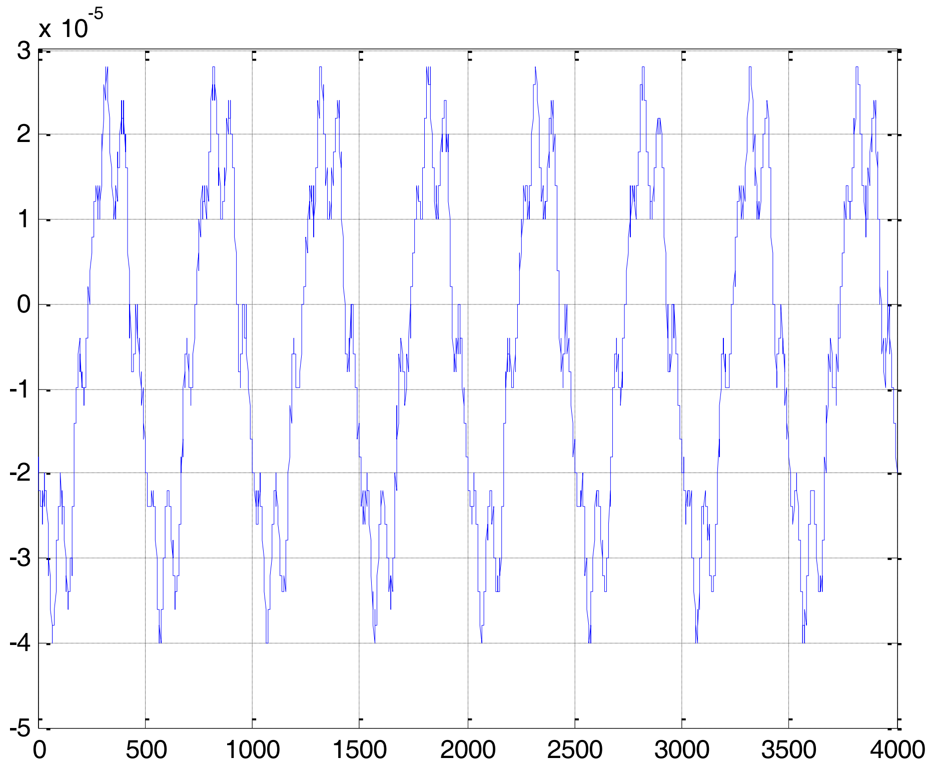
- ✓ **In case 5kv**



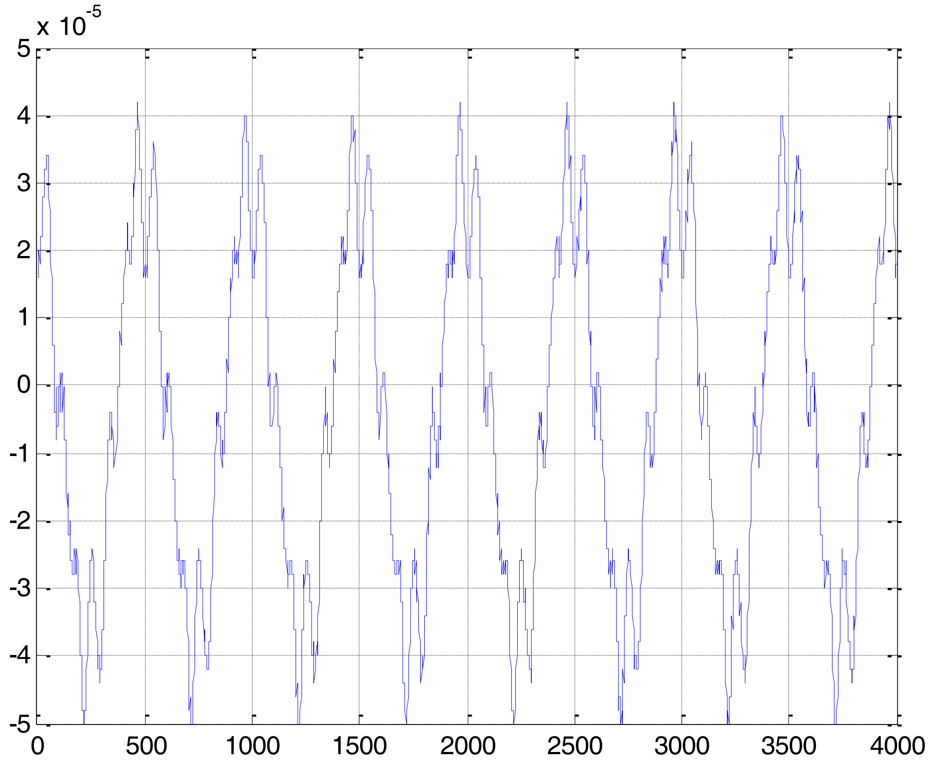
✓ **In case 10 KV**



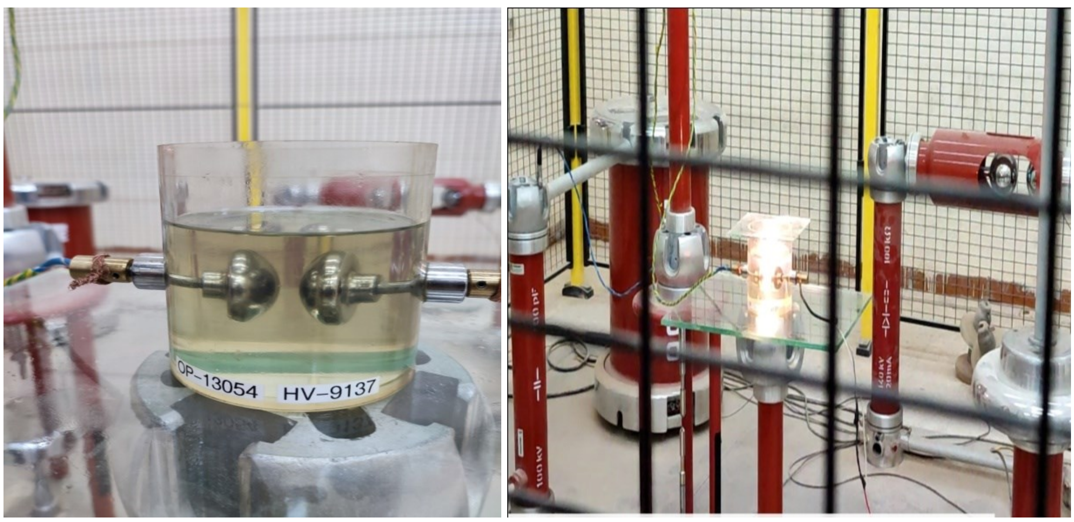
✓ **In case 15kv**



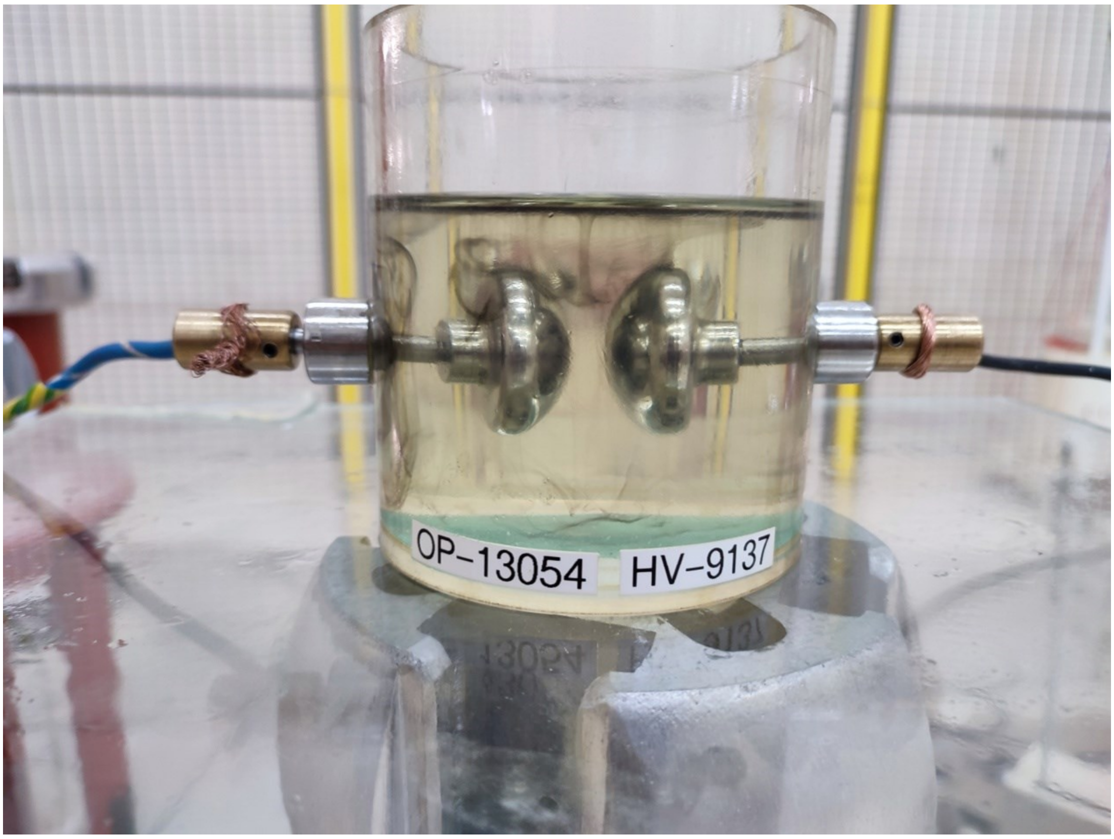
- ✓ **In case 20kv**



4.2. LEAKAGE CURRENT IN TEST WITH 1 BREAKDOWN

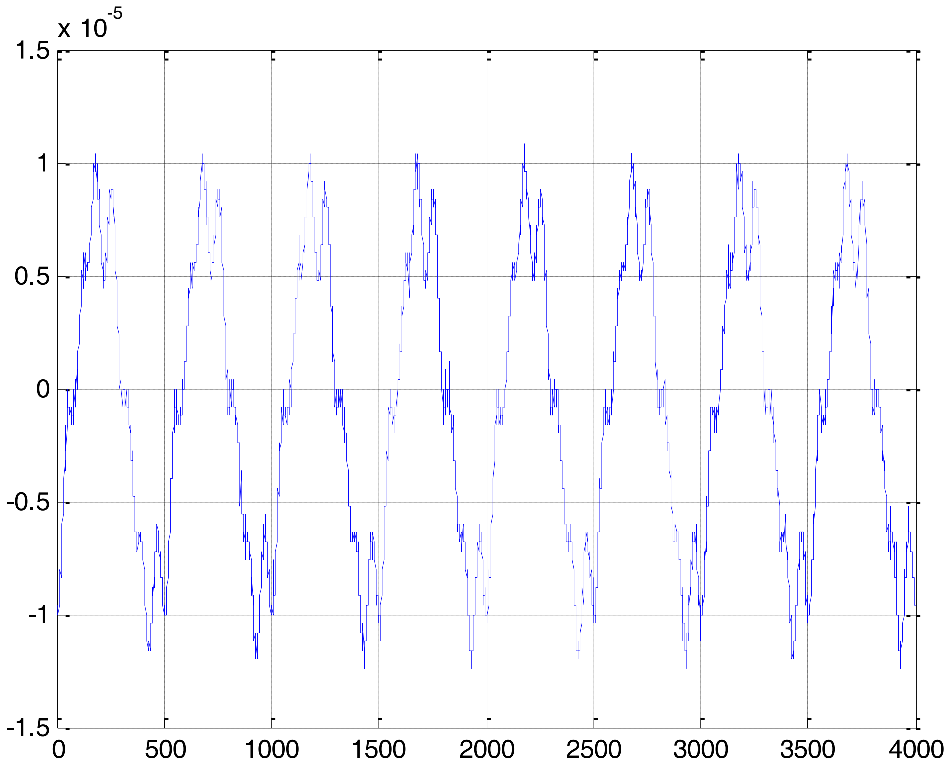


a. Before breakdown   b. In breakdown

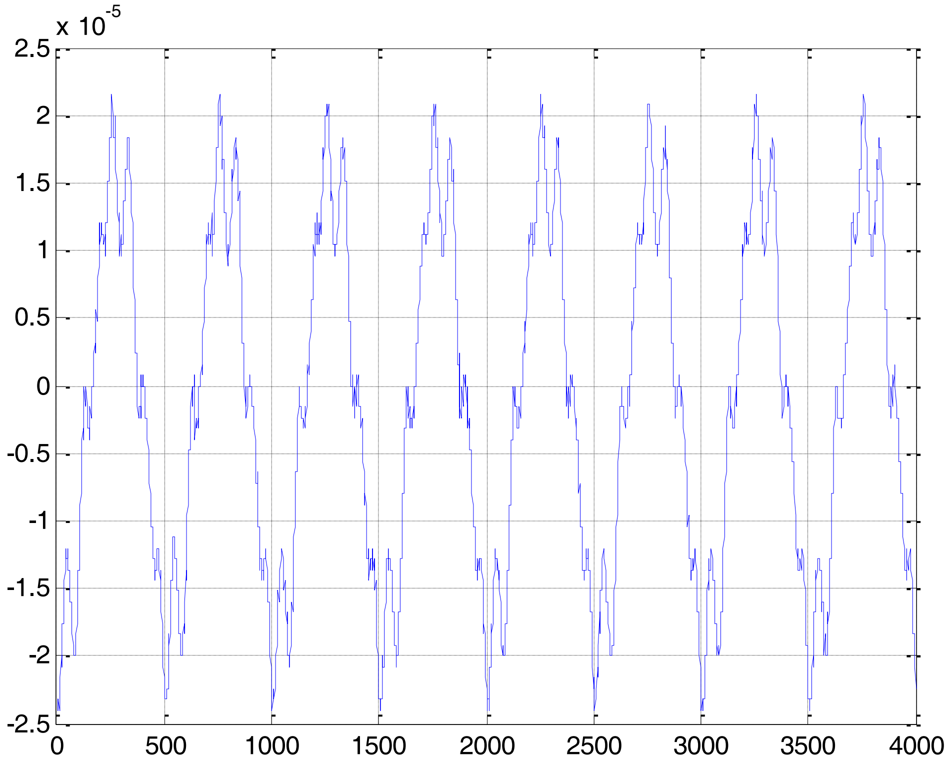


c. After breakdown

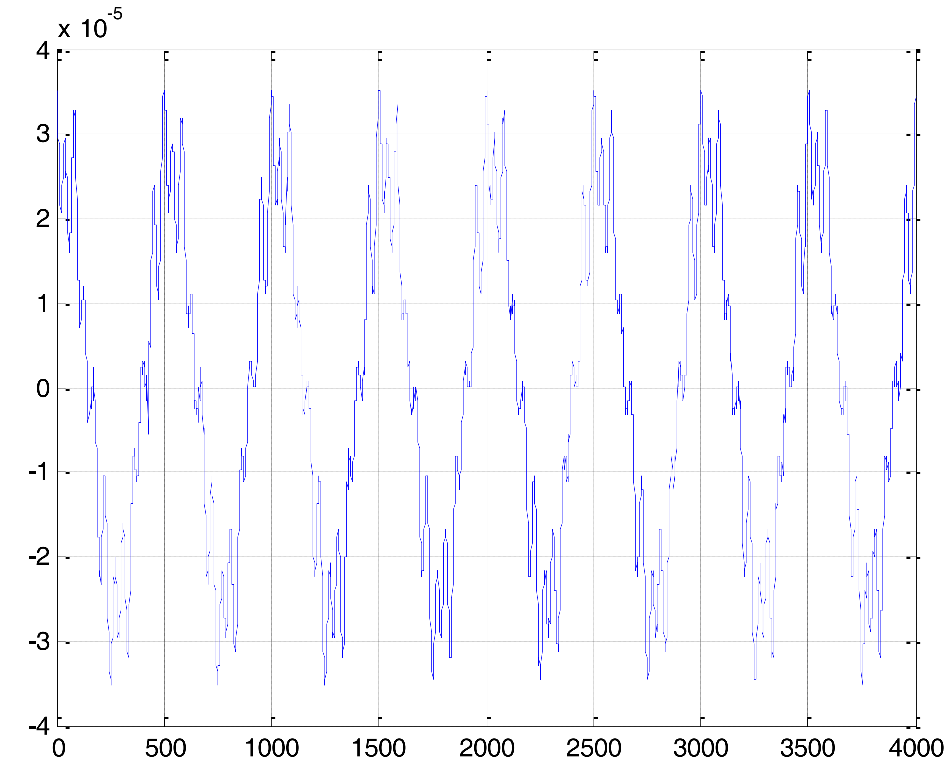
✓ **In case 5kv**



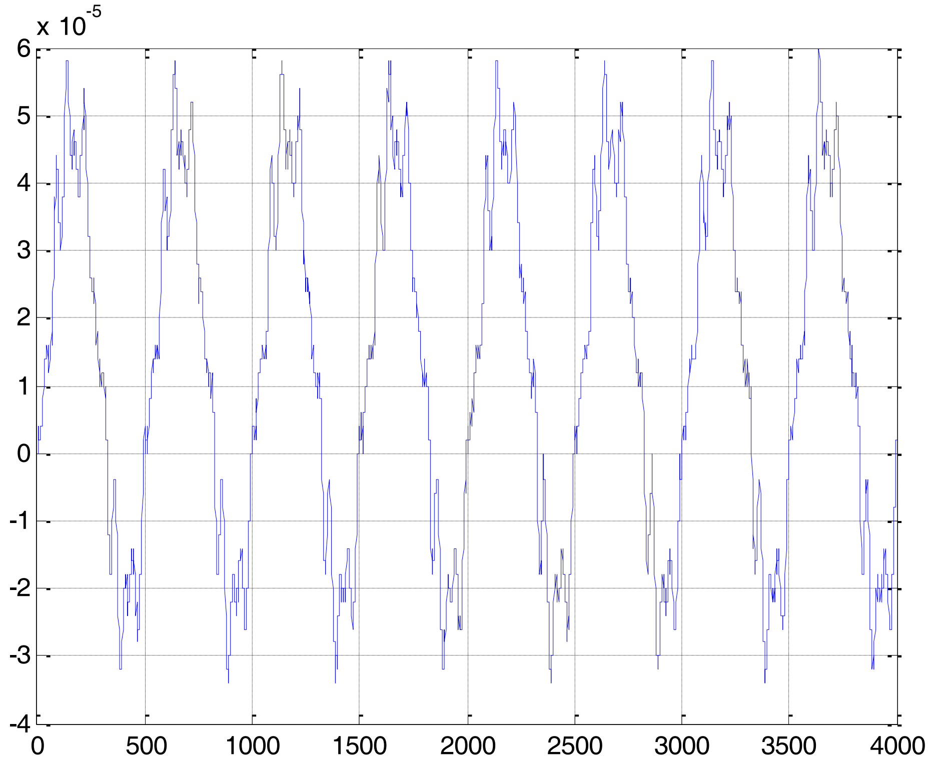
✓ **In case 10kv**



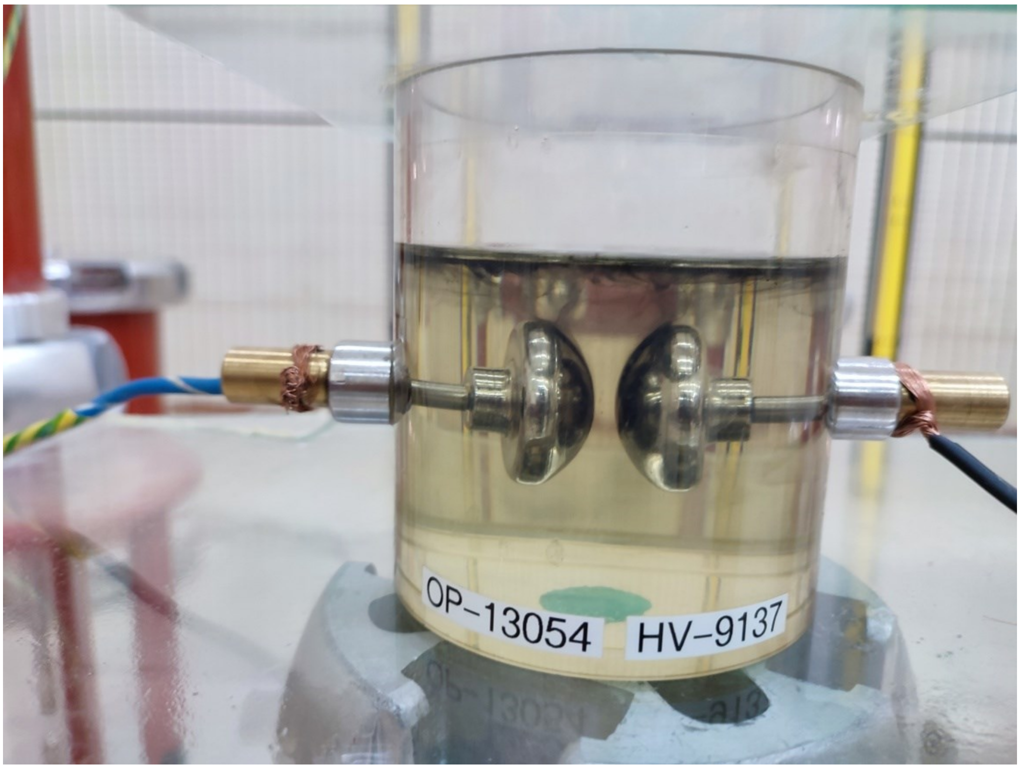
✓ **In case 15kv**



✓ **In case 20kv**

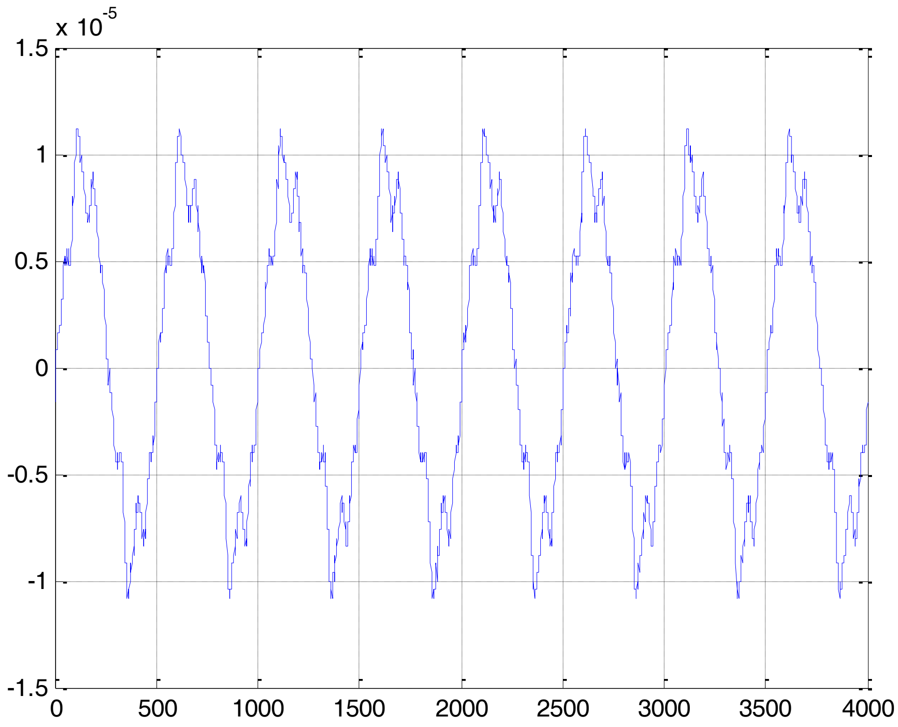


4.3. LEAKAGE CURRENT IN TEST WITH 2 BREAKDOWNS

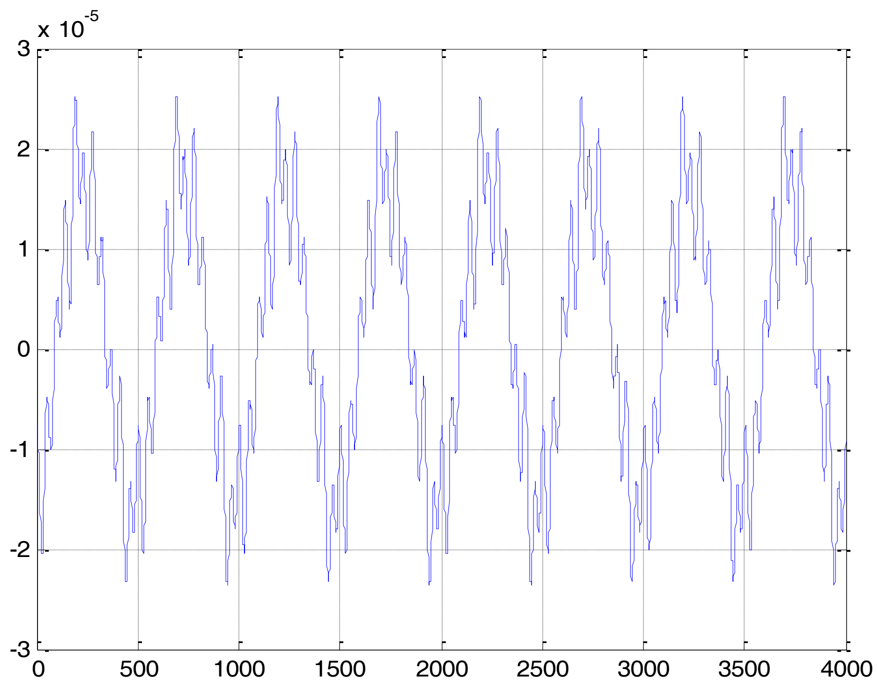


After second breakdown

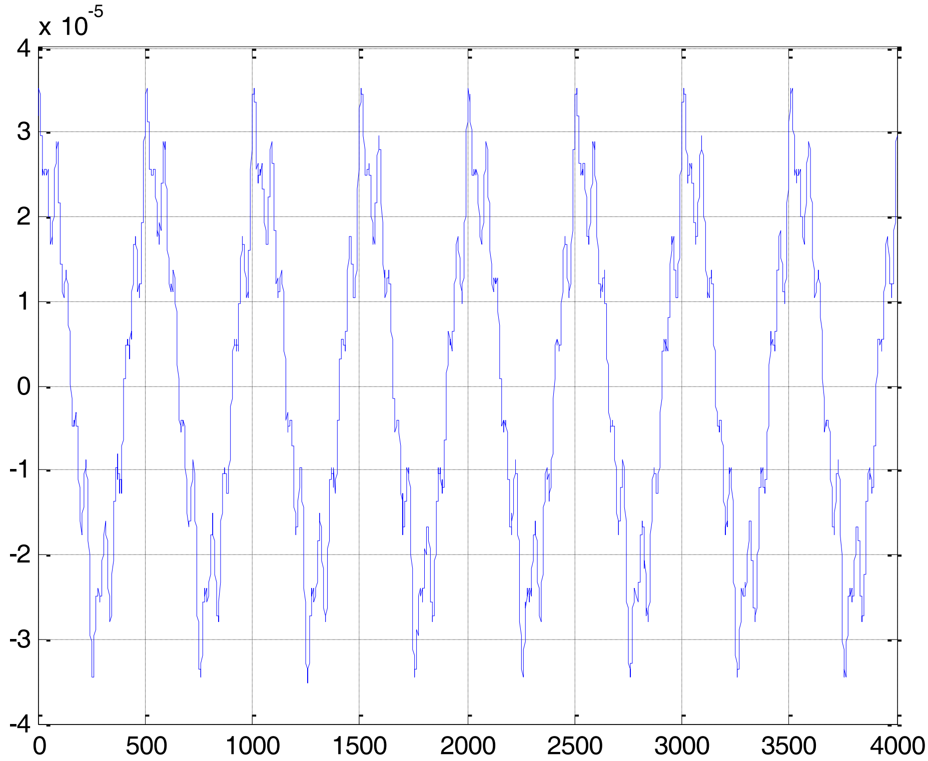
- ✓ **In case 5kv**



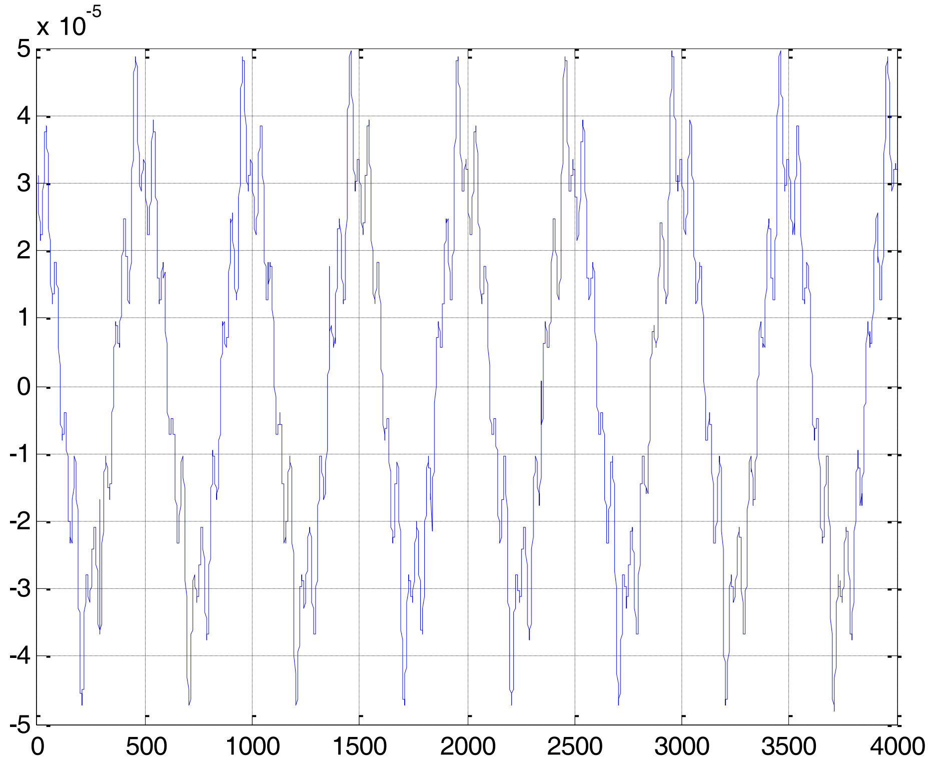
- ✓ **In case 10kv**



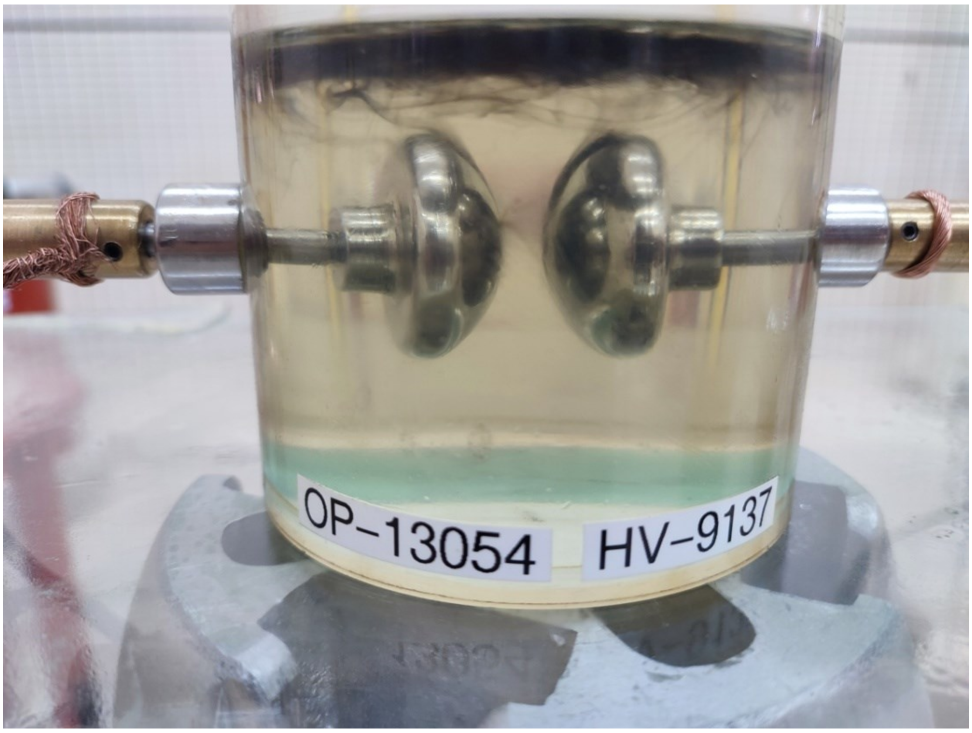
- ✓ **In case 15kv**



- ✓ **In case 20kv**

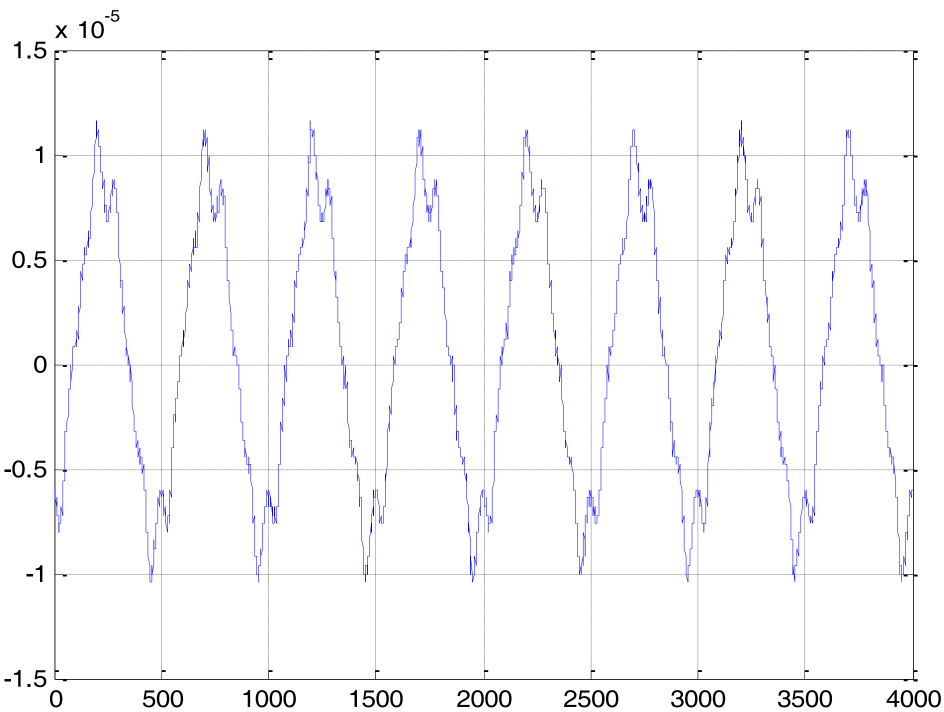


4.4. LEAKAGE CURRENT IN TEST WITH 3 BREAKDOWNS

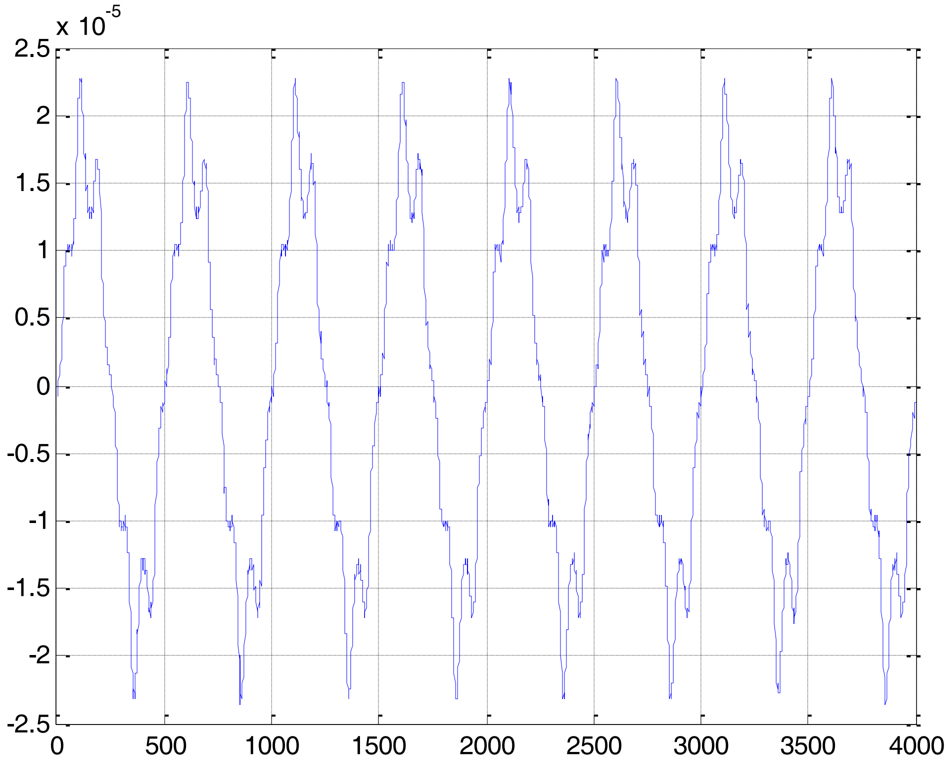


After third breakdown

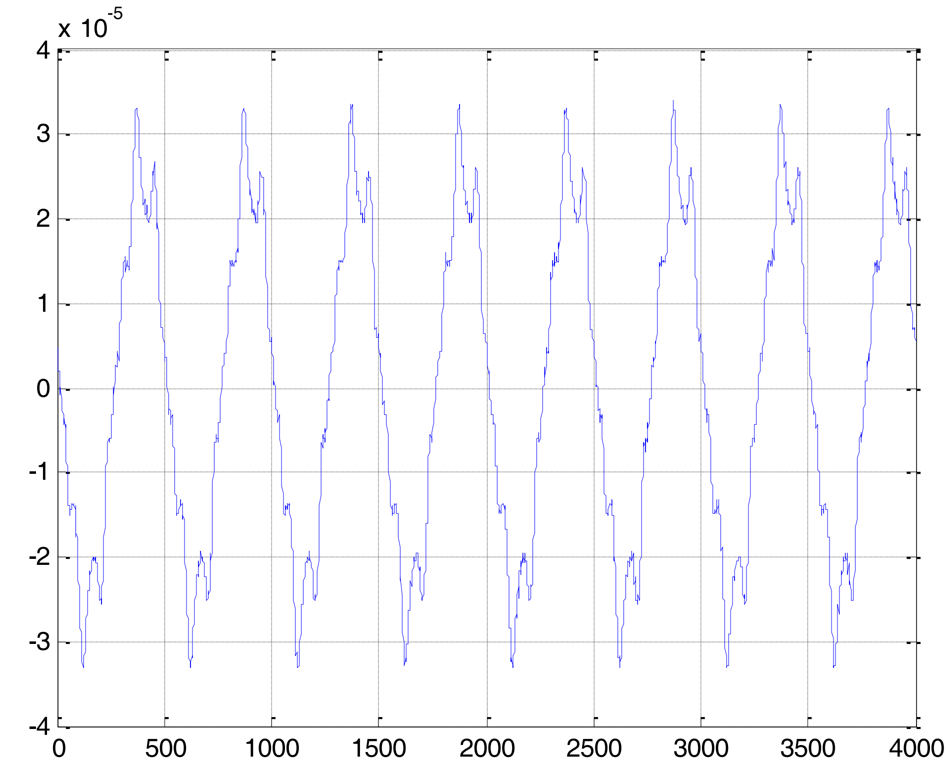
✓ **In case 5kv**



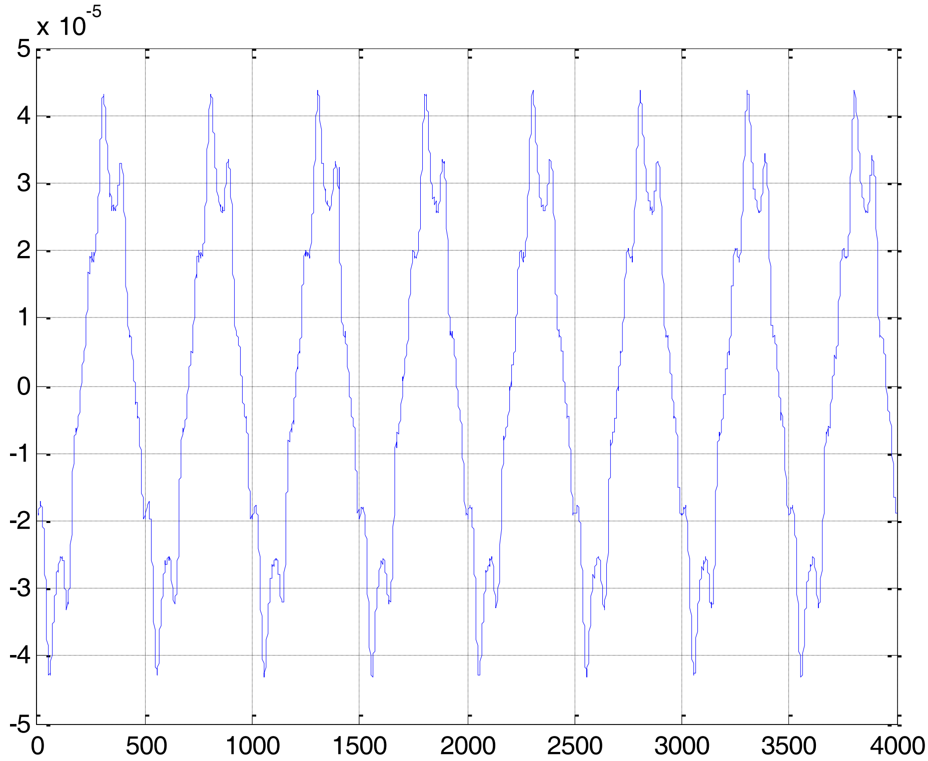
✓ **In case 10kv**



✓ **In case 15kv**



- ✓ **In case 20kv**



5. Some results

	Before the Breakdown	First Breakdown	Second Breakdown	third Breakdown
Break down voltage test (KV)	/	61,37	47,97	47,78
Lab pressure (Hpa)	1006	1006	1006	1006
Lab moisture (%)	34	34	34	34

Oil temperature before breakdown (C°)	28,6	28,6	29,8	30,9
Oil temperature after breakdown (C°)	28,6	28,8	30,0	31,2
Lab temperature (C°)	28,3	28,6	30	30,6
Equivalent distance from the air (cm)	/	1,3	1,1	1,0
Equivalent breakdown voltage in the air (kv)	/	20	20	20

Figure 4.7:Experiment results

6. conclusion

Through the experiments that we carried out in the laboratory, we conclude that the insulation of this oil and its life span is negatively affected by many factors that lead to a current leakage, including:

- The number of electrical breakdowns that the oil is exposed to during its service life in the electrical transformer
- Tension force applied to the oil

Conclusion General

A transformer is a stationary electromagnetic induction device intended to convert a system of variable quantities into another system of generally different currents and voltages but of the same frequency. The transformer is the basic component of the electrical network.

Through this bibliographic research, we theoretically presented the components, role, necessity and importance of the transformer in the transmission electrical network. We also gained knowledge about insulating oils in general and mineral transformer oil in particular, and deepened our understanding of the mechanisms that lead to the breakdown of liquid insulating materials.

Our study is first and foremost a contribution to understanding the dielectric behavior of mineral oil in point-to-plane engineering under AC voltage (50 Hz).

The oil studied in this work is an insulator that retains good physical and electrical properties despite the large number of malfunctions it suffers from.

From the various experimental results collected, the following main conclusions emerge:

- *The influence of climatic and atmospheric factors on the condition and insulation of the oil where it lead the combination of electrical breakdowns and an increase in temperature leads to a faster dielectric deterioration and a faster oil life.*
- *The value of the leaking current is affected by changing the value of the tension applied to the insulating oil, as it increases with increasing tension and decreases with its decrease, meaning that they are proportional to each other.*

- *The insulation of oil is affected by the electrical breakdowns applied to it, as the greater the number of breakdowns, the lower the insulation, the higher the value of the leakage current and the oil temperature , and the oil color changes after each breakdown*
- *The dielectric of oil is three times better than that of air, and the value of the applied tension is affected by the distance between the electrodes, their shape, size and the material they are made of..*

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