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# Programming code using the Duval method for diagnosing power transformers and direct way

Programação de código usando o método Duval para diagnóstico de transformadores de potência

Código de programación por medio del método de Duval para el diagnóstico de transformadores de potencia

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## ABSTRACT

A transformer is a piece of equipment of great value in a public or private power substation in that it allows power to be supplied to the production processes. Thus, as it is used, the equipment is exposed to different environmental conditions such as level of contamination, salinity. , height, humidity, among others, as well as energy demand and quality, causing different types of electrical and thermal stress inside. That is why the objective of this study is to implement a programming code using the Duval method for the diagnosis of power transformers. For this, programming based on the supervised learning algorithm is used as a methodology to process the gas concentration levels contained in the dielectric oil obtained from the analysis of dissolved gases and for its interpretation the Duval method is used, which is presented in IEEE C57.104™-2019 standard. The designed code individually processes the dissolved gas analysis reports as well as large quantities of reports from the same transformer or from different ones, allowing the comparison of historical data of the equipment or equipment and the evaluation of its status according to the electrical stress to which it is subjected.

**Keywords:** Code, Diagnostic, Duval, Faults, Transformer.

## RESUMO

Um transformador é um equipamento de grande valor em uma subestação de energia pública ou privada, pois permite o fornecimento de energia aos processos produtivos e, portanto, à medida que é utilizado, o equipamento fica exposto a diferentes condições ambientais, como nível de contaminação. , salinidade. , altura, umidade, entre outros, bem como demanda e qualidade de energia, causando diversos tipos de estresse elétrico e térmico em seu interior. Por isso o objetivo deste estudo é implementar um código de programação utilizando o método Duval para diagnóstico de transformadores de potência. Para isso, utiliza-se como metodologia a programação baseada no algoritmo de aprendizagem supervisionada para processar os níveis de concentração de gases contidos no óleo dielétrico obtido a partir da análise de gases dissolvidos e para sua interpretação utiliza-se o método Duval, que é apresentado na IEEE C57. Padrão 104™-2019. O código projetado processa individualmente os relatórios de análise de gases dissolvidos, bem como grandes quantidades de relatórios do mesmo transformador ou de diferentes, permitindo a comparação de dados históricos do equipamento ou equipamento e a avaliação do seu estado de acordo com o estresse elétrico ao qual está sujeito.

**Palavras-chave:** Código, Diagnóstico, Duval, Falhas, Transformador.

## RESUMEN

Un transformador es un equipo de gran valor en una subestación de potencia pública o privada en cuanto permiten la alimentación a los procesos de producción, es así que conforme su uso, los equipos se encuentran expuestos a diferentes condicientes del entorno como nivel de contaminación, salinidad, altura, humedad, entre otros, así como exigencia y calidad de energía, provocando distinto tipo de esfuerzo eléctrico y térmico en su interior. Es por ello que el objetivo de este estudio es implementar un código de programación por medio del método de Duval para el diagnóstico de transformadores de potencia. Para ello se emplea como metodología la programación basada en el algoritmo de aprendizaje supervisado para procesar los niveles de concentración de gas que se contienen en el aceite dieléctrico obtenidos del análisis de gases disueltos y para su interpretación se emplea el método Duval que se expone en la normativa IEEE C57.104™-2019. El código diseñado procesa individualmente los reportes de análisis de gases disueltos así como cantidades grandes de reportes de un mismo transformador o de distintos permitiendo la comparación de datos históricos del equipo o equipos y la evaluación de su estado según el esfuerzo eléctrico al que se someten.

**Palabras clave:** Código, Diagnóstico, Duval, Fallas, Transformador.

## INTRODUCTION

A preventive maintenance program is characterized by following a logical sequence from the detection of the problem, in which case it proceeds to study it, identify its causes and subsequently the timely and most efficient solution alternatives (Álvarez J., 2019). This translates as a process in which the following phases are identified: measurement, monitoring and monitoring of those physical variables that could impact the correct functioning of a piece of equipment, therefore the relationship of the physical variables is with wear or tear. machine conditions (Almanza & Pedroza, 2019).

Preventive maintenance merges systematic and predictive maintenance, it is defined as the execution of scheduled actions, according to prior planning, which aim to achieve a reduction in the occurrence of failures that will impact the trust and safety of a equipment so that it can fulfill its period of time considered as useful life and its operation is optimized (Álvarez et al., 2022). In this regard, among the advantages of having a preventive maintenance plan are the reduction in the frequency of stops, taking advantage of the intervention to make other arrangements or adjustments, reduction of maintenance activities seeking overloads or significant reduction in service, Damage is prevented from increasing and the risk to the security system is reduced.

Due to the above, the importance of avoiding such problems has been considered through preventive maintenance programs that carry out reliable diagnostic tests applied to the transformer, which seek to identify the problem before it becomes critical and in this way the problem is identified. can carry out the respective corrective measures (Zorilla et al., 2020). Therefore, to provide guarantees in the provision of preventive maintenance service, in a timely manner, the identification, attention and prevention of potential failures that may be found in the electrical system is required, fundamentally in the power transformers, since these would represent high costs, especially due to the unexpected stoppage of activities and unscheduled corrective processes (Villacrés et al., 2021).

Thus, among the components of the preventive maintenance scheme are primary tests, these allow the determination of the conditions of a power transformer in relation to its life time curve, this insofar as the objective of the process is to lengthen it. or ensure compliance. It is feasible to mention that the power transformer is exposed to constant operation so that it can provide the electrical energy service, so an internal failure would represent a great loss at an economic level, in addition to not supplying energy and requiring a compensation to users for the suspension or interruption of the service, given that the investment costs for maintenance and preservation correspond to the responsibility of the owners and/or operators of the network (Arteaga, 2018).

It is in this way that in the present investigation it is considered that predictive diagnosis is a very relevant technique used in power transformers immersed in oil, as it allows periodically analyzing the mechanical and electrical condition of the equipment due to its deterioration due to the conditions of the environment in which it operates and that cause it to corrode, rust or even cause oil leaks to occur in different parts. This affects the electrical conditions due to the switching overvoltage that occurs in the system or due to an unusual operation in the load, causing electric arcs inside the transformer that are extinguished by the dielectric oil, however this could cause waste and therefore deterioration in the coils that affects the electrical measurements and causes gases inside the equipment.

In this scenario, it has been identified that annually, the industrial sector, and specifically the electrical sector, grows, which implies that they incorporate numerous power transformers and therefore demand a plan for their maintenance, however, companies and professionals in the branch are not able to cover this need due to its size if it is carried out in a traditional system, hence the proposed objective for this work arises in implementing a programming code through the Duval method for the diagnosis of transformers of power.

### Types of maintenance

Until a few years ago, 3 types of maintenance were recognized: predictive, preventive and corrective, however, with current advances it has been possible to have a broader vision so that four types of maintenance are recognized, that is, detective is added. With this addition, it is possible to focus on comprehensive maintenance plans in order to guarantee that the equipment meets its lifespan and may even be longer (Pillado et al., 2022).

Predictive maintenance, also known as on-condition maintenance, consists of searching for signs or symptoms that allow a failure to be identified before it occurs; Preventive maintenance is carried out with the intention of reducing the probability of failure; Corrective maintenance is what is carried out once the failure has occurred, since in this case it is about repairing breakdowns. This typology is acceptable when the cost of prevention activities is greater than repair activities and when the possible failure does not produce adverse consequences on system safety or the environment; and detective maintenance, also called fault finding, functional testing or FFI (Failure Finding Interval), consists of testing protective devices under controlled conditions (Pillado et al., 2022).

### Power transformer

It is a passive static electromagnetic device that works based on Faraday's Law of Induction by converting the voltage and power level from one value to another that, since it does not have moving parts, does not require as much frequency of maintenance maneuvers, but Attention must be paid to the fact that, in most cases, failures in transformers are not spontaneous, but rather develop progressively, leaving in their wake a series of events or intermediate events, which allows, through several types of diagnosis, the possible causes can be determined (Núñez et al., 2023).

One of the most important elements of a transformer is the insulation, which is composed of two types of insulating material: solid and liquid. The solid material used as insulator is cellulose or paper that covers the high and low voltage windings, while the liquid insulator is oil, which also has cooling as its main function. Under abnormal conditions, a thermal failure may occur, which can occur due to prolonged overloads of the transformer, external failures caused by poor system power, or deficiency in the equipment's cooling system. To detect the origin of these problems, thermography or analysis of gases dissolved in the oil is used (Núñez et al., 2023).

**Electrical tests**

Another of the main events that generates the operating output of a transformer are ground faults, which are generated by failures in the bushings or loss of dielectric strength associated with overloads that initiate electric arcs towards the grounded parts of the transformer. (Zorilla et al., 2020). The following tests have traditionally been used to diagnose the condition of a transformer:

- SFRA test.
- Power factor.
- Insulation resistance.
- Excitation current test.
- Transformation ratio test.
- Winding resistance test.
- Leakage reactance or short circuit current tests.
- Thermography.

**Insulating oil testing**

They evaluate the physical and chemical properties of the oil, as well as the appearance of gases inside the equipment, since the three main components subject to deterioration and contamination are the paper used for the insulation of the conductors, the cardboard that is used for the insulation main and for the supports of the windings and the dielectric oil, it is also necessary to take into account the contamination produced by oil leaks due to the deterioration of the gaskets or due to poorly executed maintenance maneuvers leaving points out of adjustment. With the deterioration of the insulating materials, different types of gases are formed that are diluted in the insulating oil and that can show the presence of a failure inside the transformer (Foros & Istad, 2020).

Factors that affect insulation are humidity, oxygen, heat, vibration, surges and high electrical stresses due to internal failures. 90% of the deterioration of cellulose is of thermal origin, the thermal degradation of the insulation is a function of time, temperature and how dry the insulation is. High temperatures cause accelerated aging of the cellulose used as insulation, reducing its mechanical and electrical rigidity, producing depolymerization or destruction of the paper; Other effects due to high temperatures are the generation of water, acidic materials and gases ($CO_2$, CO). There is evidence that shows that, if a transformer is overloaded with temperatures above 140ºC at the hottest point, gas bubbles will form, which decrease the dielectric strength of the insulation (Foros & Istad, 2020).

**Dissolved Gas Analysis (DGA)**

There are several techniques to analyze gases in the process of maintenance and diagnosis of breakdowns in power transformers in operation, among them, the analysis of dissolved gases. DGA is a popular method for diagnosing and interpreting different types of power transformer faults; To refine interpretations in the diagnosis process, techniques such as expert systems and data analysis using artificial neural networks are currently available. The use of analysis of gases dissolved in insulating oil to detect failures in transformers is based on the physical phenomenon of breakdown, both in the molecules of insulating oils and cellulose insulation, when subjected to excessive thermal and electrical stresses. , producing complex compounds and volatile gases (Jian et al., 2020).

Typical gases generated by some failures in power transformers are: Hydrogen ($H_2$), Oxygen ($O_2$), Nitrogen ($N_2$), Methane ($CH_4$) Carbon monoxide (CO), Ethane ($C_2H_6$), Carbon dioxide ($CO_2$) , Ethylene ($C_2H_4$) and Acetylene ($C_2H_2$).

Hydrogen, Methane, Carbon Monoxide, Ethane, Ethylene and Acetylene are combustible gases. When gases are detected in sufficient quantity to assume the existence of a failure, it is necessary to know its severity; it is determined based on the growth rate per day of each particular gas, or the total gases dissolved in the oil. (Institute of Electrical and Electronics Engineers, 2019).

In 1978 Rogers observed that the concentration of each gas varies with the temperature of the breakdown, and introduced a new relationship between the concentrations of gases (Ethylene and Acetylene) that require a higher temperature to be generated. Furthermore, it proposes the use of three relationships between gases. The relationships involve the following gas pairs: acetylene/ethylene, methane/hydrogen, and ethylene/ethane. For its part, Doernenburg uses four gas ratios, namely: methane/hydrogen; acetylene/methane and ethane/acetylene for the purpose of diagnosing thermal decomposition, partial discharge or arcing. The value of the gases at first must exceed the concentration of L1 to determine if there is really a problem with the unit and then if there is sufficient generation of each gas for the relationship analysis that is applied (Institute of Electrical and Electronics Engineers, 2019).

**Duval Method**

For his part, Michel Duval proposed new versions of his classic triangle, using triangle 1 for mineral oil, triangle 2 for on-load tap changers, triangle 3 for non-mineral oils (natural or synthetic esters) and, finally, triangles 4 and 5 for low temperature breakdowns, where oil dispersion gasification may interfere with diagnosis. In the 1980s, Duval implemented his theory through the presence of six gases to classify states or breakdowns in transformers, where he highlights that H2 mixes faster than a metal (Fernández et al., 2021).

It is based on the concentrations of Methane, Ethane and Acetylene. For each gas, its proportion in the sum of the three gases is calculated. The application of a set of rules in which each pair of gas proportions is considered separately allows the detection of thermal, partial discharge or arcing problems. The use of the three gases used in this method has its origin in a device for monitoring gases dissolved in oil used at Hydro Quebec. The method developed by Duval proposes the use of three gases that represent, based on their concentrations, an increase in the energy or temperature content such that: Methane (CH4) for low energy or temperature failures, Ethylene (C2H4) for high temperature failures. and acetylene (C2H2) for temperature/very high energy/arc failures. On each side of the equilateral triangle, the relative percentages of these three gases are graphed (Fernández et al., 2021).

Duval triangles 4 and 5 are constructed and used in the same way as triangle 1 but using different gases and zones. Duval's triangle 4 method uses H2, CH4, and C2H6 and Duval's triangle 5 uses CH4, C2H4, and C2H6. Duval triangles 4 and 5 can be applied to learn more about thermal failure subtypes. When low energy or low temperature faults are identified using Duval triangle 1 with PD, T1 or T2 as faults more information can be obtained with Duval triangle 4. When very high temperature faults have been identified with Duval triangle 1 (T1 or T3), more information can be obtained using the Duval triangle 5 (Fernández, 2021).

**Support Vector Machine (SVM)**

It is a learning approach that implements the principle of structural risk minimization (SRM). Basically, SVM finds a hyperplane that maximizes the margin between two or several classes. SVM was originally designed by Vapnik in 1995 for binary classification. However, many apps have more than two categories. There are two ways to extend SVMs to multi-class problems: you can find related research, or build multiple binary classifiers. SVM is a classification algorithm that is based on supervised learning model. This algorithm maps the predictors onto an n-dimensional plane and discrimination between classes is identified using a hyperplane. A hyperplane is a plane that separates an n-dimensional space into two subspaces. When new data is provided to the algorithm, it identifies the data as a point in n-dimensional space. SVM strives to maximize the margin around the hyperplane. The margin is defined by vectors on each side of the hyperplane (Fernández, 2021).

## METHODS

In the research, the descriptive and explanatory methods were used, the first to describe and evaluate the Duval method in coherence with the regulations required for the preventive maintenance of power transformers, while the second helped make this methodology suitable for the proposed purposes. . For the development of the programming code it was necessary to identify the subsystems and essential aspects that are part of the power transformer, based on this it was identified, perceived and intervened regarding possible failures and the determination of the actions required for maintenance, depending on the conditions of the equipment. We also proceeded with the investigation of the operating conditions and previous preventive maintenance processes, their frequency in each part of the transformer in accordance with the technical specifications. Three fundamental aspects were considered: maintenance planning based on the manufacturer's instructions, generic maintenance protocol, prior diagnosis of failures.

For the development of the process of diagnosing failures in transformers, it was necessary to consider the Dissolved Gas Analysis or DGA technique that internally measures in the oil the concentration of particles per million or ppm of hydrogen (H2), Methane (CH4), Ethane ( C2H6), Ethylene (C2H4), Acetylene (C2H2), Carbon Monoxide (CO) and Carbon Dioxide (CO2), whose regular levels oscillate according to the concentration of Oxygen (O2) and Nitrogen (N2) (See Table 1).

**Table 1.** Percentage of gas concentration according to the O2/N2 coefficient and years in µL/L (ppm)

| Gas | $O_2/N_2$ Ratio ≤ 0.2<br>Transformative years | | | | $O_2/N_2$ Ratio > 0.2<br>Transformative years | | | |
|---|---|---|---|---|---|---|---|---|
| | UNK | 1-9 | 10-30 | >30 | UNK | 1-9 | 10-30 | >30 |
| $H_2$ | 80 | 75 | | 100 | 40 | | 40 | |
| $CH_4$ | 90 | 45 | 90 | 110 | 20 | | 20 | |
| $C_2H_6$ | 90 | 30 | 90 | 150 | 15 | | 15 | |
| $C_2H_4$ | 50 | 20 | 50 | 90 | 50 | 25 | | 60 |
| $C_2H_2$ | 1 | | 1 | | 2 | | 2 | |
| CO | 900 | | 900 | | 500 | | 500 | |
| $CO_2$ | 9000 | 5000 | 10000 | | 5000 | 3500 | | 5500 |

**Source**: Institute of Electrical and Electronics Engineers (2019)

If one or more gases were found in percentages other than those referred to in Table 1, it is assumed that the transformer would be exposed to more electrical, thermal or mechanical stress, which could cause a considerable reduction in its useful life. and fast. Given this, the Duval method is used in order to recognize the origin of the failure, this performs an analysis through three equilateral triangles on the relative concentration (between 0 to 100) of CH4, C2H4 and C2H2 for failures of electrical type, and H2 CH4 C2H6 and C2H4 in the case of faults with thermal origin with high and low intensity. Below are the formulas for calculating percentages for gases in Duval's triangle 1, 4 and 5.

Triangule 1

$$\%C_2H_2 = \frac{C_2H_2}{C_2H_2 + C_2H_4 + CH_4}$$

$$\%C_2H_4 = \frac{C_2H_4}{C_2H_2 + C_2H_4 + CH_4}$$

$$\%CH_4 = \frac{CH_4}{C_2H_2 + C_2H_4 + CH_4}$$

Triangle 4

$$\%H_2 = \frac{H_2}{H_2 + CH_4 + C_2H_6}$$

$$\%CH_4 = \frac{CH_4}{H_2 + CH_4 + C_2H_6}$$

$$\%C_2H_6 = \frac{C_2H_6}{H_2 + CH_4 + C_2H_6}$$

Triangle 5

$$\%CH_4 = \frac{CH_4}{CH_4 + C_2H_4 + C_2H_6}$$

$$\%C_2H_4 = \frac{C_2H_4}{CH_4 + C_2H_4 + C_2H_6}$$

$$\%C_2H_6 = \frac{C_2H_6}{CH_4 + C_2H_4 + C_2H_6}$$

## RESULTS

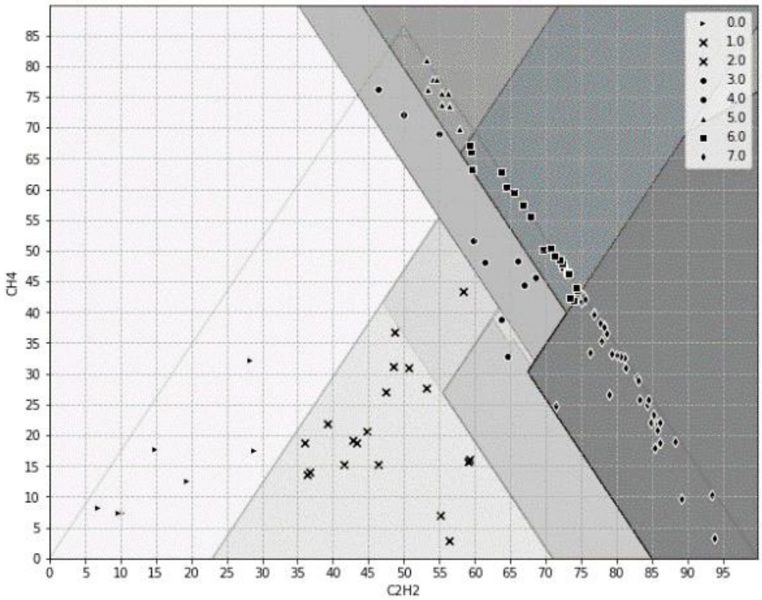
The results obtained from the failure type diagnosis were obtained, after having classified the test data, according to the type of predicted failure (see table 2), origin and the risk or severity they represent, and then made suggestions regarding actions. to follow regarding the maintenance of the power transformer. In the case of faults of term origin, these are classified by subtype through SVM2 and SVM3 (Support Vector Machines) using the specific areas in the Duval triangle 4 and 5 as appropriate.

**Table 2.** Diagnosis according to the SVM1 fault typology

| Abbreviation | Type of fault | Detail | Class |
|---|---|---|---|
| PD | Partial download | Corona discharge forming gas bubbles and possible formation of sludge on the insulating paper. | 8 |
| D1 | low energy discharge | Partial spark type discharge, produces holes, charred punctures in the paper. Low energy arc that induces carbonized drilling or carbon particles to form in the oil. They are caused by poor connection or power differences. | 0 |
| D2 | High energy discharge | Discharges in the paper or oil, flashovers that cause extensive damage to the paper or overgeneration of carbon particles in the oil that are produced by internal short circuits | 1 – 2 |
| DT | Thermal and electrical failures | Combination of thermal and electrical failures. | 3 – 4 |

**Source** : Institute of Electrical and Electronics Engineers (2019).

**Figure 1.** Fault classification results – SVM1.




**Note**: Prepared by the authors.

In the case of the classification of incipient faults in the transformer by means of SVM2, the limitations of the zones established in Duval's triangle 4 are used, in which 3 gases of the energy content or increasing temperature of the faults are used: Hydrogen for low energy partial discharge faults; Ethane for excessive heating failures with the presence or absence of degradation of the insulating paper and Methane for gasification or carbonization failures of the paper (See Table 3).

**Table 3.** Fault zone boundaries, triangle 4.

| Gas%/ Failure | $\%H_2$ | $\%CH_4$ | $\%C_2H_6$ |
|---|---|---|---|
| PD | - | ≥2 y <15 | <1 |
| S | ≥9<br>≥15<br>-<br>-<br>- | -<br>-<br><36<br><36 y ≥15<br><2 | ≥30 y <46<br>≥24 y <30<br>≥1 y <24<br><1<br><1 |
| O | <9 | - | ≥30 |
| C | -<br><15 | ≥36<br>- | ≥24<br>≥24 y <30 |
| ND | ≥9 | - | ≥46 |

**Source**: Institute of Electrical and Electronics Engineers (2019).

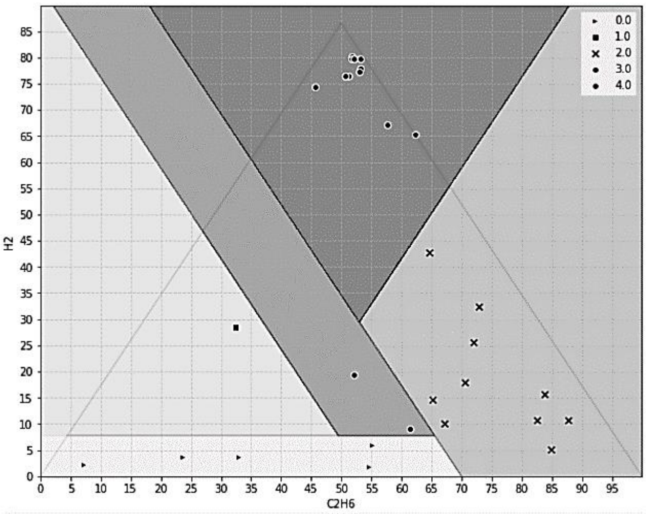
The failures analyzed in this process are of low and medium intensity thermal origin (See Table 4) while Figure 2 shows the results achieved after classifying the test data.

**Table 4.** Diagnosis according to the type of failure SVM2

| Abbreviation | Type of fault | Detail | Class |
|---|---|---|---|
| O | Low intensity thermal | Overheating <250°C without carbonization of paper. | 0 |
| ND | Not specified | Requires verification through electrical tests. | 1 |
| C | Medium intensity thermal | Possibility of carbonization of paper. | 2 |
| S | Low intensity thermal | Dispersed gasification at temperature <200°C | 3 – 4 |

**Source**: Institute of Electrical and Electronics Engineers (2019).

**Figure 2.** Fault classification results – SVM2.




**Note**: Prepared by the authors.

The classification of incipient failures of the power transformer through SVM3 required the limits in the zones set in Duval's triangle 5 (See Table 5), in which 3 gases of the energy content or increasing temperature of the failures; Ethane, which is generated due to heating oil or paper; Ethane for overheating failures whether with or without the presence of degradation of the insulating paper; and, Methane for gasification or carbonization failures of insulating paper.

**Table 5.** Fault zone boundaries, triangle 5.

| Gas%/ Failure | %$CH_4$ | %$C_2H_4$ | %$C_2H_6$ |
|---|---|---|---|
| PD | - | <1 | |
| O | -<br>-<br>- | ≥1 y <10<br><1<br><10 | ≥2 y <4<br><2<br>≥54 |
| S | - | <10 | ≥14 y <54 |
| T2 | - | ≥10 y <35 | <12 |
| T3 | -<br>-<br>-<br>- | ≥35<br>≥50<br>≥70<br>≥35 | <12<br>≥12 y <14<br>≥14<br>≥30 |
| C | -<br>- | ≥10 y <50<br>≥10 y <70 | ≥12 y <14<br>≥14 y <30 |
| ND | - | ≥10 y 35 | ≥30 |

**Source**: Institute of Electrical and Electronics Engineers (2019).

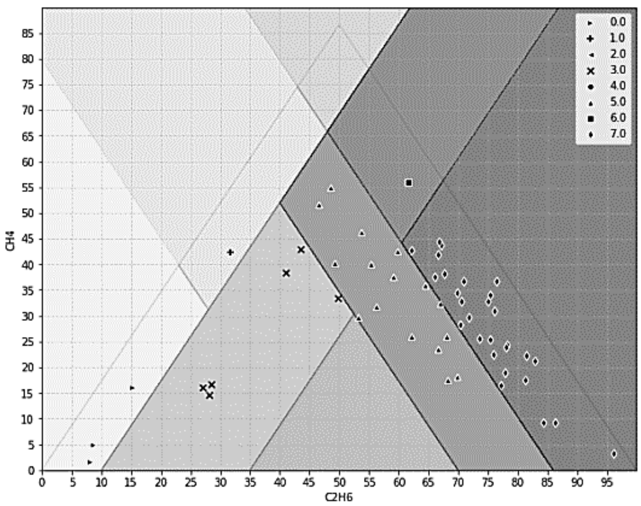
In Figure 3 you can see the results of SVM3 after classifying the test data according to the data predicted in Table 6 to carry out the type of failure, origin and severity in the analyzed power transformer. With SVM3 the code ends, examining all types of failures and subtypes of electrical and thermal origin inside the equipment.

**Table 6.** Diagnosis according to the SVM3 failure typology

| Abbreviation | Type of fault | Detail | Class |
|---|---|---|---|
| O | Low intensity thermal | Overheating <250°C without carbonization of paper | 0 – 2 |
| ND | Not specified | Requires verification through electrical tests. | 3 |
| C | Medium intensity thermal | Possibility of carbonization of paper | 5 |
| S | Low intensity thermal | Dispersed gasification at temperature <200°C | 1 |
| T2 | Medium intensity thermal | Between 300°C to 700°C, it requires verification by means of complementary electrical tests | 6 |
| T3 | High intensity thermal | Between 300°C to 700°C, requires verification by means of complementary electrical tests. | 4 – 7 |

Source: Institute of Electrical and Electronics Engineers (2019).

**Figure 3.** Fault classification results – SVM3.




Note: Prepared by the authors

In accordance with the analyzes carried out, it is possible to present the diagnosis according to the type of failure, its causes and consequences:

- Disruptive discharge: these correspond to electrical type discharges in which the current passes through the insulator as the amount of energy contained in the discharge varies and the recording damage to the equipment can be defined as high or low.
  - Low power discharge – D1: this occurs through the oil at points of different potential, low energy discharge between clamps; bushings and tank; high voltage and ground inside windings and on tank walls. Its origin is due to the detriment in dielectric strength, humidity and contamination, which accelerate the degradation of paper, oil or ceramics. This results in significant perforation of the paper, indentations in the surface of wood blocks, cardboard or winding spacers, and carbon particles in the oil.
  - High power discharge – D2: High energy arcing, short circuit: between low voltage and ground, connectors, winding, bushings and tank, copper bars and tank, windings and core, oil passages, turrets, bolts separated from the core and frame metal rings. It is caused by the detriment in dielectric strength, humidity and contamination, these are accelerators of the deterioration of paper and oil, also by atmospheric discharge. As a consequence, severe damage and carbonization of the paper is evident, the metal parts fuse and considerable formation of carbon particles occurs in the oil.
- Sudden gasification: corresponds to the generation of gas from insulating mineral oil heated to a relatively low temperature between 90°C and 200°C, without the influence of other materials derived from electrical devices or electrical stress. It is produced during refining, occasionally severe hydrotreatment and also through the application of additives. Derivative problems occur with DGA analysis.
- Low temperature failure (<300°C) T1: occurs due to overloading of the power transformer in emergent conditions, elements that can block the ducts through which the oil flows or due to inefficient cooling. As a consequence, a darkening of the insulating paper occurs.
- Medium temperature failure (300°C to 700°C) T2: caused by current flowing between clamps and holding bolts, clamps and laminations, ground wiring, defective cables or clamps on magnetic shields; contacts inside in an imperfect state or between the aluminum bars and the connections with bushings that produce hot spots. This results in loss of insulation between adjacent parallel conductors in the windings and carbonization of the insulating paper.
- High temperature failure (>700°C) T3: derived from excess current circulation in metallic areas, tank and core, causing a large core dispersion flux and short circuits in its laminations. This causes carbon particles to form in the oil, the metal becomes discolored (800°C) or the metal parts fuse (>1000°C). However, the results derived from electrical or thermal failures are similar and in operation, some could be a consequence of the others and, conversely, they are differentiated by the grooves that appear in the insulation as the only proof of the discharge or by the certain gases formed from one fault or another.

Now, to validate the proposed method that involves data processing, normalization, analysis and diagnosis through SVM 1, 2 and 3 trained in advance with historical figures from the DGA to obtain the current condition of the power transformers, They used values from dissolved gas studies from studies by Ganyun et al (2005), Sarma & Kalyani (2004) and Hung & Wang (2004), also considering the failure states in each case. The voltage and power levels of the transformer are not taken into account since the diagnosis methodology does not take these values into account and therefore the method can be applied to any transformer.

Once the general analysis of the data has been carried out in SVM1, separating the electrical and thermal faults, the latter are processed in SVM2 and SVM3 with the aim of obtaining the fault subtype to achieve a more precise diagnosis of the condition of the transformer. Through Google Colab, the data is recorded and the code that was designed for each of the vector machines is processed. This information is presented graphically and through summaries through the confusion matrix function.

**Figure 4.** Parameters of SVM.

```
[4] #Parametros de regulacion para SVM1
    C_1 = 1 #Regulacion 1 - valor 1
    clf_1 = svm.SVC(kernel='linear', C = C_1, decision_function_shape='ovo')
    modelo_SVM1 = clf_1.fit(TD1x_train,TD1y_train)

    h = 0.1 #Regulacion 2 - valor 0.1
    TD1_xx, TD1_yy = np.meshgrid(np.arange(0, 100, h),
                                 np.arange(0, 90, h))
    TD1_z = clf_1.predict(np.c_[TD1_xx.ravel(),
                                TD1_yy.ravel()]).reshape(TD1_xx.shape)
```

Note: Prepared by the authors.

Through the clf_score (x_test, y_test) function in each support vector machine, it is recorded that the precision results for the validation data have a confidence level greater than 90% for each SVM (See Table 7).

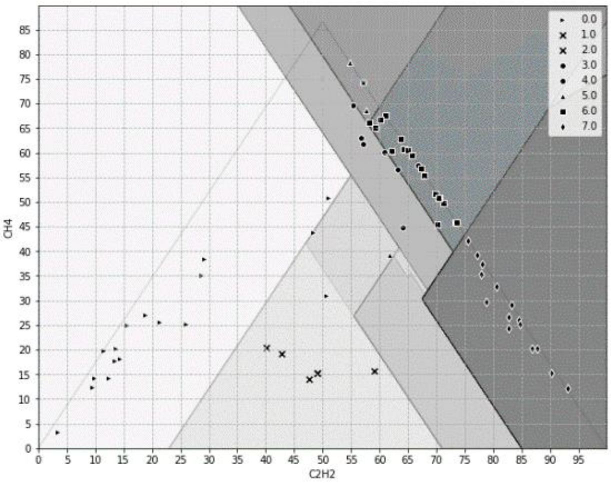
**Table 7.** SVM results 1, 2 y 3

| SVM | N° Class | N° Validation | % successes |
|---|---|---|---|
| 1 | 8 | 70 | 91.429% |
| 2 | 5 | 26 | 96.154% |
| 3 | 8 | 35 | 94.286% |

Note: Prepared by the authors.

The predicted failures and the results recorded from SVM1, SVM2 and SVM3 are evident in the figures 5, 6 y 7.

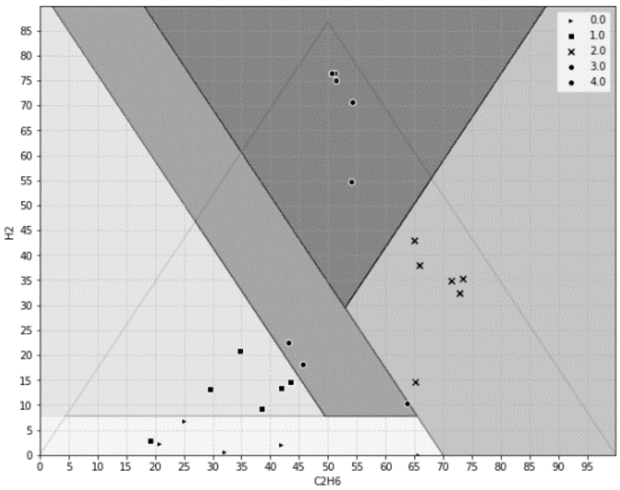
**Figure 5.** SVM1 Validation




Note: Prepared by the authors.

Figure 5 shows mainly the electrically originated faults for which the support vector machine has currently been programmed. It can be mentioned that in comparison with the values of the aforementioned studies, there is accuracy in the diagnosis.

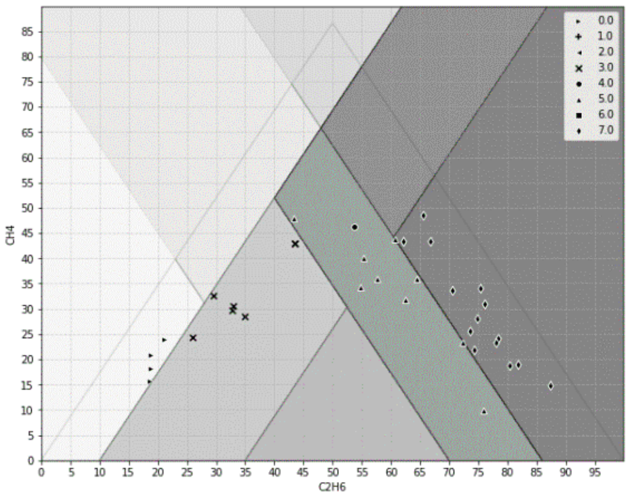
**Figure 6.** SVM2 Validation




Note: Prepared by the authors.

Figure 6 shows the thermal faults T1 and T2 for which the current support vector machine is programmed. The results of the actual diagnosis compared to those of the cited research denote accuracy.

**Figure 7.** SVM3 validation




Note: Prepared by the authors.

Figure 7 shows the results of SVM3 with the thermal faults T2 and T3 for which the support vector machine is currently programmed. The data denotes accuracy in relation to the referenced studies. Additionally, SVM2 and SVM3 reduce incorrect diagnoses in SVM1, which improves the reliability of the algorithm as a whole. It is possible to indicate that the greatest number of failures are found in DT corresponding to combined failures (electrical and thermal problems) for which we recommend carrying out additional electrical tests for diagnosis. In addition, SVM1 carries out a diagnosis at the origin of the potential failure, with 91.429% of the hits, thus the reliability of this first machine depends on the additional analysis with SVM2 and SVM3, therefore this value of hits is considered for comparison with other methods. such as De la Torre (2021) who uses a diagnosis through artificial neural networks in MATLAB with 82.81% correctness, this allows us to conclude that SVM has a better percentage of assertiveness.

## CONCLUSIONS

The implementation of a programming code through the Duval method for the diagnosis of power transformers has been designed in such a way that it individually processes the laboratory report of dissolved gas studies or large quantities of reports, and it can also be done independently. different power transformers allowing the historical progress of the equipment or the conditions between a variety of these to be compared according to the electrical efforts they make. Regarding the optimization of the programming code, a mathematical transformation was used that allowed a 33% reduction in the processing of the information obtained from the historical reports of the dissolved gas studies, resulting in a source of trust. for training, testing and validation phases of SVM and being able to obtain the current condition of the transformer as well as the origin of the fault with high percentages of successes for SVM 1, 2 and 3.

Finally, it is possible to indicate that the programming code allows easier processing of numerous readings that are obtained through sampling or online, this favors the reduction of the diagnosis time of the real condition of the power transformer and then proposes prevention actions that are necessary in the next maintenance of the equipment. This also represents savings in economic terms for companies and the conservation of the useful life of the equipment.

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| C. elaboration of figures and tables: | 33% | 33% | 33% |
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