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# Identification of critical variables in conventional transformers in distribution networks

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**Abstract.** Transformers are essential equipment to the operation of electrical power systems, a failure causes the lack of electricity supply to end-users, affecting the operating indicators of companies in the distribution sector. The investigation presents an identification of the faults in transformers through a fishbone diagram, an evaluation of the variables that cause the identified failure using the cross-impact matrix method and a proposal to improve the performance. The results will enable a plan to be developed for taking action with monitoring plans to avoid faults that could put the electrical asset at risk and achieve a better performance of the distribution network.

## 1. Introduction

The growth of cities requires the expansion of distribution systems to meet the growing demand for electricity [1]; one of the fundamental components are transformers, used to modify electrical voltage levels, reducing electrical losses and risks when it supplies electrical energy to the end-user [2].

The electricity service must be provided reliably to users, avoiding failures which may occur due to the malfunction of the electrical system or part of it [3]; for this purpose, standards NTC 2050 [4] and IEE C57. 12. 00-1987 [5] are established as requirements for the proper operation of distribution transformers in Colombia. Distribution systems have technical loss percentages of 15. 7% [6], due to oversized or overload of the circuit, resulting in an increase in the occurrence of faults and a decrease in the useful life of the equipment [7].

The costs associated with the maintenance and replacement of the transformer are high [8]; avoiding failures is a key factor for distribution companies, due to the impact on their service indicators. Knowing their causes allows companies to create preventive and corrective maintenance plans to extend the useful life of transformers. This study presents a characterization of failures presented in distribution transformers and the use of Cross Impacts Matrix-Multiplication Applied to a Classification (MICMAC) method, based on qualitative study between the variables identified in a fishbone diagram and their interactions, it allows us to identify key factors to the performance of the transformer, the results will allow to design monitoring plans to avoid faults that can put in risk the electrical asset and to achieve a better performance of the distribution network.



## 2. Methodology

The research begins with the parts of a transformer and the failures that they present during its operation; variables are identified which may be managed to the optimal performance of the transformer. The methodology is organized in three phases:

### 2.1. Identification phase

It involves the documentary review of failures in transformers and their components, the design of a fishbone diagram that relates the causes and effects, allowing the identification of variables that affect the performance of the electric asset.

### 2.2. Analytical phase

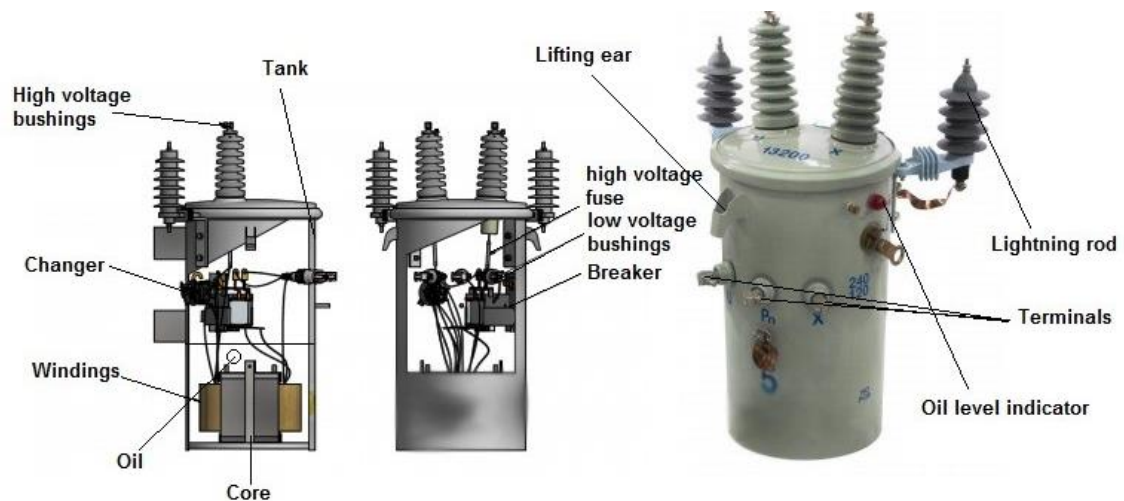
The identified variables and the cross-impact matrix method are used to identify the critical elements for the operation of the transformer; these variables are located in the conflict zone generated by the matrix.

### 2.3. Propositional phase

The variables located in the conflict zone of the structural analysis are identified, these variables are the strategic elements and their intervention will allow the adoption of strategies for the care of the transformers.

## 3. Parts of a distribution transformer

The transformer consists of two windings, one with high voltage and the other with low voltage, an iron core inside a tank full of dielectric oil; and bushings for high and low voltage, the latter allow the connection of the coil terminals to the medium and low voltage network [9]. Figure 1 shows a diagram of the distribution of the components:



**Figure 1.** Parts of a conventional distribution transformer. **Source:** [10]

## 4. Distribution transformers faults

### 4.1. Overvoltage in distribution transformers

An overvoltage is caused by an increase in the grid voltage; it can be induced by an atmospheric electric shock [11] or caused by a decrease in the impedance into the transformers, preventing voltage regulation [12].

4.2. *Ground fault*

This fault is caused by the poor condition of the bushings or loss of dielectric rigidity in the transformer components, causing overloads and electric arcs to the grounded parts of the transformer. A bushing is damaged by the presence of hot spots due to poor maintenance of operators, reduced internal insulation, presence of plants or animals and deformation of the bushing [13].

4.3. *Moisture in distribution transformers*

Moisture is always present in a conventional distribution transformer in an acceptable quantity and is specified on the transformer data sheet. The initial moisture comes from manufacturing and increases due to atmospheric humidity or the ageing of the cellulose in the insulating paper [14].

4.4. *Overload in distribution transformers*

This fault occurs when the nominal transformer power value is exceeded, due to the connection of an additional load, a wrong dimensioning in the supply demand or a bad design of the operating temperature [15].

4.5. *External short circuits*

This fault is related with the environment where the transformer is located, affected by environmental factors such as the short circuit by contact with a tree, animal or object, vandalism, failures in the end-users circuits and wind gusts that cause contact between distribution lines [9].

4.6. *Internal problems*

These failures occur due to lack of tightness and moisture presence, false contacts in the switch, output terminals broken, low oil level, factory defects or damage due to improper in transport and assembly handling [16].

5. Results

5.1. *Variables identification*

According to the described faults a fishbone diagram is made to relate the faults and their causes [17], in figure 2 the diagram can be observed.

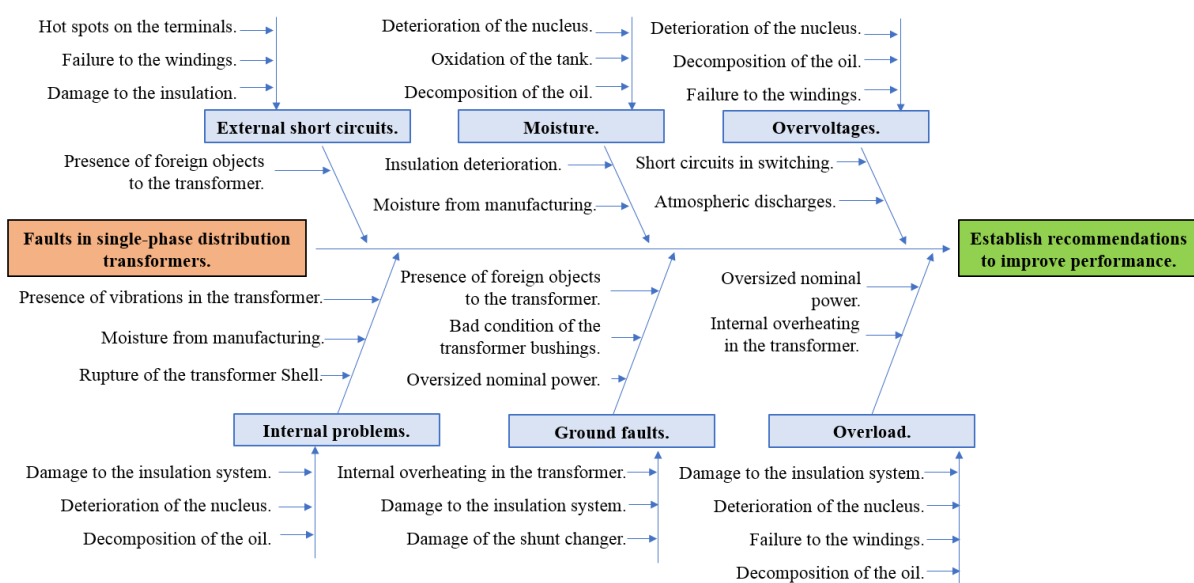


Figure 2. Fishbone diagram of faults in distribution transformers.

Figure 2 presents in a simplified way the relation of the causes and the effects due to the faults in the distribution transformers; table 1 lists ten (10) variables that affect the performance of these equipment, identified in Figure 2.

**Table 1.** Variables identified from the fishbone diagram.

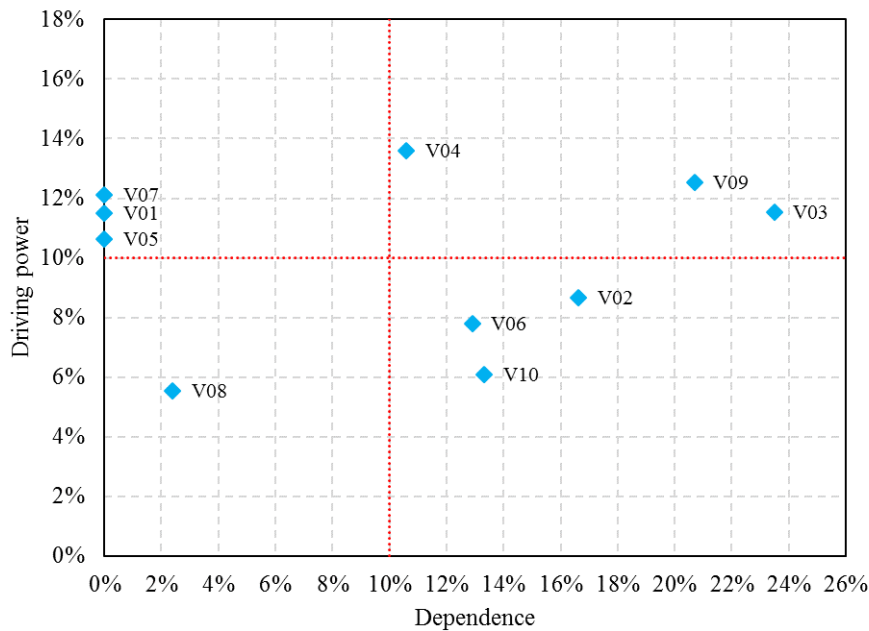
Code	Causal
V01	Presence of foreign objects in the transformer
V02	Rupture of the transformer shell
V03	Internal overheating in the transformer
V04	Oversized nominal power
V05	Atmospheric electrical discharges
V06	Short circuits due to faults in the switching
V07	Moisture from manufacturing
V08	Presence of vibrations in the transformer
V09	Insulation deterioration.
V10	Bad condition of transformer bushing

### 5.2. Structural analysis: Identification of key variables

The method of structural analysis is composed of three steps, the first is the identification of a set of variables that characterize the system; Table 1 shows the variables identified; In the second step, the interaction matrix is made with the identified variables, a group of participants collaborated to evaluate the degree of influence between them, the variables identified were valued from 0 to 5 taking into account the following relationship, (0) null, (1) very low, (2) low, (3) medium, (4) high and (5) very high; the degree of dependence and driving power was calculated. Table 02 and Figure 03 presents the result of the matrix interactions and dependence vs driving power diagram. Finally, the identification phase of the key variables, the variables located in the conflict zone are selected due to their high dependence and high driving power; because they have a significant influence on the others.

**Table 2.** Cross-impact matrix with the variables in table 1

	V01	V02	V03	V04	V05	V06	V07	V08	V09	V10
V01	0	1	2	0	0	1	0	2	4	2
V02	0	0	4	0	0	1	0	0	2	1
V03	0	1	0	3	0	1	0	0	4	1
V04	0	2	5	0	0	2	0	1	2	2
V05	0	1	2	1	0	3	0	2	1	2
V06	0	1	1	1	0	0	0	1	2	2
V07	0	5	1	0	0	1	0	0	4	1
V08	0	1	1	0	0	2	0	0	1	1
V09	0	5	4	1	0	1	0	0	0	2
V10	0	0	1	0	0	3	0	0	2	0



**Figure 3.** Driving power and dependence diagram.

Figure 03 shows variables V03 (Internal overheating in the transformer), V09 (Insulation deterioration) y V04 (Oversized nominal power) in the conflict zone; V03 and V09 are considered the critical variables to improve performance to decrease the failures occurrence due to its high driving power and dependence. The correct operation requires a proper use of transformers, do not oversize, check the internal overheating and the insulation; they can be affected by insulation failures caused by insulation gaskets damaged, moisture ingress conclude with the tank rupture due to oxidation.

### 5.3. Improve the operation of distribution transformers

The results presented the variables V03, V04 and V09 in the conflict zone, create plans for their care and prevention will help manage the care of the transformer affecting its useful life and optimal performance. The following are strategic to favor the control of these variables:

- ✓ Periodically check the installation area of the packages, keep the area free of sand or foreign particles from the outside.
- ✓ Verify the oil condition, by checking the color and condition or using the test dielectric breakdown voltage, in case of doubts; it is advisable to use accredited laboratories.
- ✓ Check the transformer paint and determine the degree of deterioration of the tank.
- ✓ Check the sealing of the transformer cover to prevent the entry of water.
- ✓ Evaluate the working conditions in front of the transformer data sheet, according to the connected load.

## 6. Conclusions

The work presented the components and faults of a transformer, a fishbone diagram was made in which the causes and effects of the failures were identified; allowing the identification and selection of ten variables that affect the operation of these equipment. The MICMAC method was used to identify critical variables, located in the conflict zone, and variables V03 (Internal overheating in the transformer) and V09 (Deterioration of the insulator) were the variables with the most influence.

The results suggest that preventive maintenances must be carried out, especially the checking of the external components of the transformer. It is suggested to check the system of isolation and

verification of the oil condition, and look for hot spots; avoid connecting loads higher than the demand supported by the transformer.

The care of distribution transformers will allow to have a safe and reliable operation, improving operational indicators such as SAIDI and SAIFI, indicators evaluated by the Superintendence of Public Services of Colombia; if these indicators have a bad rating, they will represent financial penalties for network operators.

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