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Article

Study of transformer network to comply with standards, electrical safety, and avoid failures due to Inrush current

Estudio de red de transformadores para cumplir normas, seguridad eléctrica, y evitar fallas por la corriente Inrush

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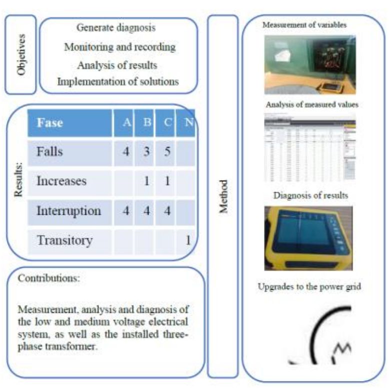
Abstract

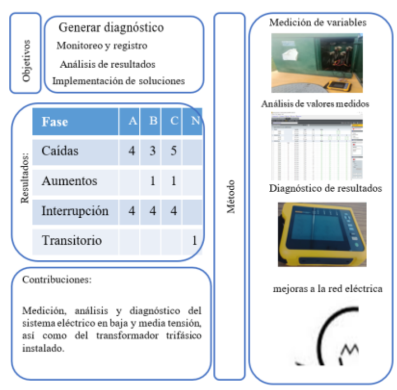
The challenges of energizing a transformer, in an electrical power system, are critical aspects, due to the magnitudes of the currents and the importance of the transformers. These currents cause system instability; current peaks, and transient voltages. The instabilities affect the transformer and the connected equipment. It is crucial to manage power timing to avoid load imbalances and interruptions. Energization planning and execution are essential to ensure transformer integrity and system stability. The objective is to study the process of energizing the network of six transformers, responsible for the energy supply of the National Technological Institute of Mexico IT of Tuxtla Gutierrez, to identify opportunities that guarantee electrical safety, comply with applicable regulations and minimize the adverse effects of inrush currents. A load survey was carried out on the distribution transformers. A one-line diagram was constructed. The behavior of the Electrical Power System was studied. Transient monitoring was carried out in the secondary circuits of the transformers. With these actions, opportunities were identified to mitigate failures, which translate into safety and energy savings.



Inrush current, distribution transformer, SEP protections

Resumen

Los desafíos de energizar un transformador, en un sistema de energía eléctrica, son aspectos críticos, debido a las magnitudes de las corrientes y a la importancia de los transformadores. Estas corrientes causan inestabilidad en el sistema; picos de corriente y tensiones transitorias. Las inestabilidades afectan al transformador y a los equipos conectados. Es crucial gestionar la sincronización de la energía para evitar desequilibrios de carga e interrupciones. La planificación y ejecución de la energización son esenciales para garantizar la integridad del transformador y la estabilidad del sistema. El objetivo es estudiar el proceso de energización de la red de seis transformadores, responsables del suministro de energía del Instituto Tecnológico Nacional de México IT de Tuxtla Gutiérrez, para identificar oportunidades que garanticen la seguridad eléctrica, cumplan con la normatividad aplicable y minimicen los efectos adversos de las corrientes de entrada. Se realizó un estudio de cargas en los transformadores de distribución. Se construyó un diagrama unifilar. Se estudió el comportamiento del sistema eléctrico de potencia. Se realizó una monitorización de transitorios en los circuitos secundarios de los transformadores. Con estas acciones, se identificaron oportunidades para mitigar fallas, que se traducen en seguridad y ahorro de energía.



Corriente de irrupción, transformador de distribución, protecciones SEP

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Introduction

This study deals with the study of an electrical power system of an underground distribution network in a ring configuration consisting of six pad-mounted transformers, responsible for the supply of electrical energy to the Tecnológico Nacional de México IT in Tuxtla Gutiérrez. The objective is to guarantee electrical safety, minimising potential risks for users and goods in the medium and low voltage installations, and to comply with the applicable regulations.

The main result is expected to establish the basis for designing a system with protections for energising the circuit of six transformers in no-load conditions, avoiding faults caused by transient inrush current.

At the Tecnológico Nacional de México IT in Tuxtla Gutiérrez, the MV supply network consists of six transformers in ring configuration, with different power; two 500 , two 300 , one 225 , and one 150 . Voltage ratios; (13.8 - 220 /127. Total system power; 1975.)

When a transformer is energised, a transient current, magnetising current during start-up, flows several cycles, until normal flux conditions are established. In a number of cases, this current transient is of little importance, provided that in the ferro-magnetic core of the transformer, the magnitude of the remaining flux is small, which is related to the phase angle of the voltage during transformer disconnection.

However, when in the ferro-magnetic core of the transformer, the remanent flux is high, it causes this start-up to momentarily affect the proper operation of the system, causing a current similar to the short-circuit current, circulating through the transformer primary.

In [Beder, 2021] they mitigate the inrush current of the system, due to the magnetisation of the core and the voltage that when energised is out of synchrony. The inrush current is up to 30 times the rated current of the transformer, and its magnitude is affected by factors such as residual flux, saturation flux and the angle of the energising voltage. Inrush currents have the potential to activate trip signals in protective relays, such as differential and overcurrent (O/C) relays, resulting in malfunctions.

In [Yang, 2020] they define that at the moment of switching on the supply voltage, an inrush current (inrush current) equivalent to a value between 5 and 10 times the rated current is generated inside the transformer. This inrush current represents a danger to the safe and stable operation of the electrical network. Such an inrush current of this magnitude causes malfunctioning of the protections and prevents the transformer from connecting to the mains. Harmonic signals, in inrush current, cause damage and malfunctioning of power electronic equipment.

In [Moradi, 2017] they state that the switching on of a power transformer creates an energising inrush current (EIC), which leads to a sympathetic inrush current (SIC) in adjacent in-service transformers (IT). The sympathetic inrush current changes the waveform and prolongs the duration of its EIC origin. The EIC voltage causes conditions similar to an internal short circuit when energising the transformer. Identifying the short-circuit fault current during EIC is a challenge for transformer differential protection. The SIC current induces an error in the earth fault protection of the adjacent transformer in service.

In [Moradi, 2017] they propose an equivalent circuit based on the DC component of the inrush current, which is efficient for identifying concurrent EIC and SIC. They derive predictive formulas for EIC and SIC based on this equivalent circuit. They identify the internal transformer fault during the inrush current, based on the comparison between the predicted and measured waveforms, which prevents the differential protection from failing and tripping.

They compare the SIC waveform with the measured waveform to prevent the ground fault protection of the CT transformer from tripping during the SIC inrush current. They verify, the proposed equivalent circuit and formulas using the results of the ETAP-EMTP simulation of a network, under different system conditions.

The inrush current increases the reactive power loss of the transformer, and causes the transformer in the adjacent zone to respond to the induced current in the secondary of the first transformer, causing malfunction in the overcurrent protection (50/51 or 67) and extending the scope of the power outage.

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Consequently, the problem of the deterioration of the safety and stability of the electrical power system, due to the influence of the inrush current in the transformer, and the tripping of the differential protection, is the subject of worldwide research.

In [Lu, 2024] they explain that; differential protection is used as the main protection of transformers, because of its fast action and high sensitivity; the inrush current is identified by the differential protection as fault current and causes malfunction. They comment that in an increasingly complex electrical system, existing methods have shortcomings and the discrimination rate is low, in the case of current transformer (CT) saturation and remanent magnetisation.

They obtain the waveform characteristics using the mathematical morphology gradient (MMG) operator. They then use the morphological pattern spectrum (MPS) to extract the differences between the inrush current and the fault current. Finally, they use the normalised spectrum value and the gradient criterion as input to the least squares support vector machine (LSSVM) to identify the inrush current and differentiate it from the fault current.

Development of headings and subheadings of the article with subsequent numbers

1. Introduction.

2. Methods.
2.1. Measurements and analysis.
2.2. Applicable Standards.
2.3. Underground systems.
2.4. Underground and Overhead Power Cables.
2.5. Differential protection.

3. Results.
3.1. Underground network.
3.2. Earthing systems.
3.3. Transformer protection.
3.4. Power analyser.
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4.1. Coordination of protections.
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4.5. Second harmonic.
4.6. Star-Star connection.
5. Conclusions.
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7. Abbreviations.

2. Methods

2.1 Measurements and Analysis

The electrical parameters are measured and analysed for a safety diagnosis, compliance with the applicable regulations, and to establish strategies to identify and mitigate inrush currents, with the aim of safeguarding users and assets. A study of the physical survey of the electrical power system was carried out to determine the characteristics of the installations, the types of existing protections and their functionality, the transformers and the loads fed by them. The electrical variables were measured The electrical variables were measured with an energy analyser; Fluke brand, model 1775, class A.

2.2 Applicable Regulations

The [NOM-001-SEDE-2012] helps electrical installations to be efficient and durable, reducing the likelihood of electrical failures and potential risks.

2.3 Underground Systems

The [CFE DCCSSUBT] specifies the types of systems applicable in underground installations, provides the regulations applicable to Medium Voltage installations.

2.4 Power Cables

The [NRF-024-CFE] specifies the types of conductors used in medium voltage installations, provides information for verification and diagnosis (single pole, 5kV to 35kV).

2.5 Differential Protection

The 87T detects faults within the transformer, including short circuits between turns, earth faults or faults between phases. The operation is based on the calculation of the difference between the input current and the output current of the transformer.

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In the relays the currents are adapted in magnitude and phase angle and the difference (differential current) is determined. If the differential current exceeds a predetermined limit value, the differential protection of the relay operates. The differential protection acts to disconnect the affected transformer from the rest of the system, minimising damage and preventing the fault from propagating.

3. Results

The main connection circuit of the supply network. It has a connection point with a concrete pole, a medium voltage main protection system of; 3 fuse cutouts, 3 current transformers and a lightning arrester system.

An overhead-underground transition. Provides the possibility of continuing the medium voltage circuit supply underground, with 1/0 gauge XLP power cable, with an interconnected earthing system and RMTA4 register.

3.1 Underground network

It leads to the first transformer (T1), 500 pedestal type, with a protection system, with lightning arrester 15, 200. The transformer is connected internally, in the wall, see figure 1, to a MV shunt in order to continue with the power supply to the next transformer (T2).

At the rear of the wall (M1), power is supplied to the three-phase transformer (T2) of 225, with a lightning arrester protection system in each of the phases. The output of the transformer primary (T2) is transmitted and connected to the MV branch circuit busbar (M2), see figure 2, which provides the possibility to feed the nearby transformers (T3) of 150 and (T4) of 300.

3.2 Earthing System

Accidents caused to people in industrial activities, or in the electrical field, have been caused by discharges through contact with metal parts. These accidents have been caused by the lack of an adequate earthing system. Therefore, there remains the risk of electric shock by contact and deficient protection of equipment against short circuits or earth faults.

It is planned to measure each of the systems of each transformer to verify the efficiency of the grounding system, and to propose a more efficient one if necessary.

Box 1

Figure 1
Wall M1 three-phase MV shunt to (T2)

3.3 Transformer Protection

The importance of having protections in transformers lies in the need to prevent damage from short circuits, overloads or ground faults, which compromise the integrity of the operation and assets. Optimal protection. For the protection system, it is proposed to use overcurrent relays (50/51), medium voltage cubicles and fuses for each transformer and for each feeder wall. 50/51 overcurrent relay. It is equipped with algorithms to reduce inrush current tripping by means of adjustable timing and harmonic blocking. Relay 50/51 is suitable for detecting overloads and short-circuits in transformers.

Relay 50 operates on instantaneous overcurrents, while relay 51 has an inverse time curve, set to protect against prolonged overloads. Both are essential to prevent transformer damage by quickly disconnecting the equipment in the event of an overload or short-circuit. The implementation of this solution aims to increase the reliability of the network and reduce outage time in case of faults.

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Box 2

Figure 2
225 three-phase transformer (T2) (kVA)

The implementation of a protection system requires careful planning. The steps for installation are; A) Coordination of Protections. A coordination study is necessary to determine the appropriate setting values for 50/51 relays and fuses. This allows the protections to operate selectively, avoiding unnecessary interruptions and limiting the affected area in case of failure. B) Configuration and testing.

The overcurrent relays (50/51) must be configured and tested according to the specific characteristics of each transformer. Initial testing includes checking the response to overload and short-circuit simulations to ensure that the system performs within the expected times and values.

3.4 Energy Analyser

Measurements were made with a Fluke power analyser, model 1527. The measurements were made for 7 days, starting on 24 October and ending on 31 October 2024. The variables that are within the limits of the applicable standards are: frequency, total harmonic voltage content, flicker, and unbalance.

Box 3

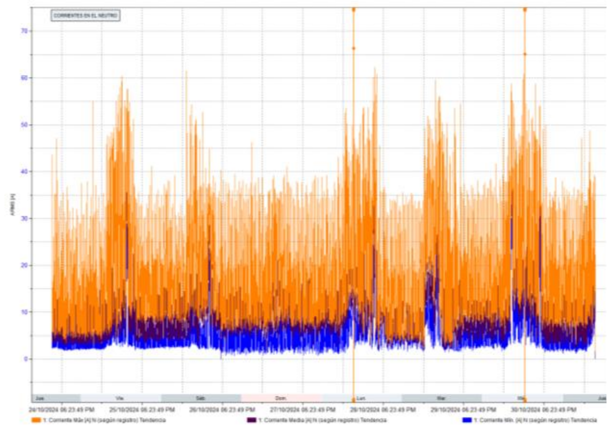

Figure 3
Maximum, average and minimum neutral current.

3.5 Power Quality Failures

There were 5 voltage drops, three of which were below 6 (V), with a duration of more than 5 (s). There was one overvoltage greater than 144 (V). There were four interruptions, with a duration of less than 180 (s). There were 141 power quality failure events, see table 1. Of the graphs provided by the energy analyser, the average current in phases is interesting, where a considerable current through the neutral is observed, see figure 3.

Box 4

Table 1
Summary of registered events

Event	Duration of voltage drop			
	Phase	Phase B	Phase C	Neutro
Fall	4	3	5	
Increase	0	1	1	
Interruption	4	4	4	
Shape deviation	27	26	18	
Changes	7	8	9	
Transient		0	0	1

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Box 5

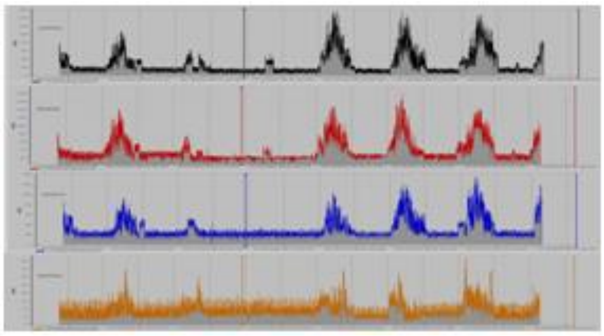

Figure 4
Average phase and neutral current

4. Discussion

4.1 Coordination of Protections

One of the aspects derived from the analysis of the physical infrastructure of the electrical installations (MV and LV) of the IT of Tuxtla Gutiérrez, is that it lacks a coordination of protections, which provides protection for the people who work there and the goods, in the face of the different possible faults.

4.2 Protection (87T)

There is no differential protection in the transformers. This protection detects and mitigates internal transformer faults due to short circuits between transformer phases, and acts immediately by disconnecting the affected equipment from the rest of the system. The disconnection minimises damage to other transformers and to the entire underground LV and MV electrical network that is connected.

4.3 Economic and Social Cost

If the system lacks the necessary protections and a medium voltage (MV) fault occurs, it causes interruptions to the electrical service within the institute's facilities (LV). If a transformer is damaged, it causes a power outage in a specific area, but it also causes an outage in some other area, due to the internal connection of the transformers in a ring, as they share the same power supply. A fault is a potential risk that damages people and equipment.

The proper use of transformer protection prevents electrical hazards and ensures a safe power supply. This impacts on the safety and well-being of the community and those who handle the power grid by avoiding risks associated with transformer failures.

4.4 Cost of Negligence

Damaged equipment results in power outages and economic repair costs (corrective maintenance).

4.5 Second Harmonic

For certain types of transformers the inrush current is made up of harmonics, the second harmonic being the one with the highest energy content, which is used to set the blocking of the differential protection at the moment of transformer energisation to avoid unwanted tripping.

4.6 Star-Star connection

In distribution systems star-star connection is used on the primary side of the transformer to minimise single-phase faults. In this connection the inrush current flows into the power system and causes significant voltage distortion in the secondary winding of the supply transformer.

5. Conclusions

5.1 Summary

A) A first analysis of the installations was made. It was checked that they have the characteristics and equipment indicated in the applicable regulations, for the correct operation of the electrical network. B) It was observed that there is a lack of a restorer (according to the installed load) to protect the overhead electrical system. C) A protection coordination system is being developed, through simulations, to mitigate the effects of the inrush current, without unduly activating the protections.

5.2 Recommendations

Following the analysis of the processes that take place in the equipment of the electrical installations of the Tuxtla IT, and the installed load of the different interconnected transformers, it is recommended to

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1) To have the necessary protections to mitigate faults, including inrush current, which is capable of triggering different protections. 2). It is recommended that through the differential protection, a block be programmed and at the moment of energising the transformers, the inrush current is identified and the protection is prevented from being activated. It is also recommended to design and implement a scheme for the coordination of protections. 3) Optimisation of efficiency and power quality is recommended.

Author contribution

Pérez-Lozano, Luis Alberto: Contribution in the idea of the project, as well as in the physical survey of the existing MV network, connection and disconnection of the metering equipment. Analysis of results.

Juan-Jímenez, Diana Alejandra: Analysis of equipment measurement results, knowledge of underground MV networks.

Herrera-Galicia, Rubén: Contribution to the project idea, as well as knowledge and mathematical analysis of the behaviour of the inrush current.

Sánchez-Alegría, Avisaí: His contribution is the simulation and analysis of the coordination of protections and the behaviour of medium voltage faults.

Availability of data and materials

The physical survey of the MV transformer installations and connections resulted in a single-line diagram that gives us a clear distribution of the equipment, which will also allow us to carry out the corresponding simulations to plan a protection system to protect the equipment, as well as to obtain a mathematical model to determine the scope of the transients in the system. The measurements obtained from the transformers have been very important due to the visualisation of possible faults, prevention of damage to the equipment and to propose improvements to the installations and operation of the equipment.

Funding

The project does not have any funding that would allow further scope and development.

Abbreviations

A	Amperaje.
BT	Low voltage
CT	Current Transformer.
CFE	Construction of
DCCSSUBT	Underground Systems
CFE	Federal Electricity Commission.
EIC	Energising Inrush Current
IT	Institute of Technology.
k VA	Kilo Volts Ampere.
kV	Kilo Volts.
M1	Wall one.
MMG	Mathematical Morphological Gradient.
MPS	Morphological pattern spectrum
MT	Medium Voltage.
NRF-024-CFE	Reference Standard 024
RMTA4	Medium Voltage Register in Arrollo type 4
S	Seconds.
SEP	1. Electrical Power Systems.
SIC	Sympathetic Inrush Current.
T1	Transformer one.
V	Volts.
XLP	Cross-linked Polyethylene Insulation.
87T	Protection System.

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