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Energy Efficiency Analysis of the Main Electrical Systems of the Latacunga General Hospital

Abstract: The present work consists of the analysis of the electrical energy efficiency of the main low voltage distribution transformers of the Hospital, through the application of an electrical energy audit; using parts of the ISO 50001 standards. For the development of this work, a field investigation is carried out, using a FLUKE 435-SII quality analyzer to measure the variables of the electrical system such as: voltages, currents, frequency, powers, harmonics. When evaluating the behavior of the electrical system comparing it with the ARCONEL standard, it is established that the potential problem is the presence of current harmonics in the network. As an alternative solution, the implementation of a 200 A four-wire three-phase multifunctional active filter for the distribution transformer of the new section and a 150 A three-phase active filter for the old section of the hospital is proposed. It compensates for harmonic currents, reactive power currents and phase imbalance currents.

Keywords: Hospital; efficiency; audit; quality; harmonics; power.

1. INTRODUCTION

Efficient and rational use of energy has become the topic of strategic development in various industries, which can improve competitiveness, reduce energy consumption, reduce carbon emissions, etc.

Ecuador does not have firm regulations that pressure large users of electrical energy to implement electrical energy efficiency programs. The industries that decide to adopt this type of initiatives do so to obtain their own economic benefits; many of the large electricity consumers are not interested in

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environmental protection issues and are not willing to invest in energy audits to improve their facilities, the incentive that drives to these users it is economical.

In the city of Latacunga, a Hospital Repowering work was carried out to meet demand needs. This work was built next to the old building. The new facilities consist of more sophisticated systems that promote the rational use of electrical resources, while the old facilities still consist of the previous equipment; no significant repowering has been carried out to resolve energy problems.

Hospitals are administrative and construction complexes that need to face new medical challenges, new technologies, they are complex plants ready to use and provide a wide variety of services. At the same time, there is probably no other area of the public service that has been viewed so critically by the population and that so urgently requires improvement in addition to efficiency.

This project seeks to improve the energy efficiency of the Latacunga general hospital while continuing to provide the care and comforts that patients and staff need, through an energy audit to propose viable strategies that allow adequate management of health resources. energy.

2. THEORETICAL FRAMEWORK

A. Energy and Environment

The topic of energy and its relationship with the environment has been the subject of study in recent years due to the growing concern about climate change and its effects on the planet. According to Hernández [1], "energy production and consumption is one of the main factors that contribute to greenhouse gas emissions" (p. 23). This has led to the search for alternative and sustainable energy sources that can reduce environmental impact. In this sense, González [2] points out that:

The transition to a low-carbon economy requires a fundamental change in the way we produce and consume energy. Renewable energies, such as solar and wind, offer a clean and sustainable alternative to fossil fuels, but their large-scale implementation still faces technical and economic challenges. (p. 45)

One of the main challenges is the intermittency of renewable sources, which makes it necessary to develop more efficient and affordable energy storage technologies. In this regard, Martínez [3] indicates that "advances in lithium-ion batteries and other storage technologies are allowing greater integration of renewable energies into the electrical grid" (p. 67).

In addition to renewable energy sources, energy efficiency also plays a crucial role in reducing environmental impact. As Rodríguez [4] states, "the implementation of energy efficiency measures in buildings, industries and transportation can significantly reduce energy consumption and greenhouse gas emissions" (p. 89). This implies the adoption of more efficient technologies, as well as changes in consumption and behavior patterns.

B. Energy management

Energy management has become a highly relevant topic in recent years due to the growing demand for energy and the need to optimize its use in an efficient and sustainable manner. According to Gómez [5], "energy management is a systematic process that seeks to improve the energy performance of an organization through the implementation of policies, objectives and action plans" (p. 12). This implies a comprehensive approach that covers everything from energy production to consumption.

One of the key aspects of energy management is energy efficiency, which refers to the reduction of energy consumption without affecting the quality of services or products. As Ramírez [6] points out:

Energy efficiency is a fundamental strategy for energy management, since it allows reducing operating costs, improving competitiveness and contributing to the mitigation of climate change. This is achieved through the implementation of technical measures, such as the modernization of equipment and systems, as well as changes in consumer habits and organizational culture. (p. 35)

Another important aspect of energy management is the integration of renewable energy sources. According to Torres [7], "the incorporation of renewable energies, such as solar and wind, into the energy matrix of organizations can significantly reduce dependence on fossil fuels and greenhouse gas emissions" (p. 58). However, this requires proper planning and investment in energy generation and storage technologies.

Furthermore, energy management involves the implementation of monitoring and control systems to optimize energy use in real time. As indicated by Vargas [8], "energy management systems based on information and communication technologies make it possible to collect and analyze energy consumption data in real time, which facilitates decision making and the identification of opportunities for improvement" (p. 81). This includes the use of sensors, smart meters and specialized software.

Energy management is a strategic and systematic approach to optimize energy use in organizations, reduce operating costs and contribute to environmental sustainability. This requires the implementation of energy efficiency measures, the integration of renewable energy sources and the use of real-time monitoring and control systems. Energy management is a challenge that demands the participation and commitment of all the actors involved, from senior management to employees and end users.

C. ISO 50001 management model

ISO 50001 is an international standard that provides a framework for establishing, implementing, maintaining and improving an energy management system (EnMS). According to Fernández [9], "ISO 50001 is based on the Plan-Do-Check-Act (PHVA) continuous improvement cycle and is integrated with other management systems, such as ISO 9001 and ISO 14001" (p. 18). The main objective of this standard is to help organizations improve their energy performance and reduce their costs and greenhouse gas emissions.

One of the key aspects of ISO 50001 is energy planning, which involves the identification and analysis of energy uses and consumption, as well as the definition of an energy baseline. As Gutiérrez [10] points out:

Energy planning is the starting point for the implementation of an EnMS based on ISO 50001. It consists of collecting and analyzing energy consumption data, identifying significant energy uses and establishing energy performance indicators (IDEn). Based on this information, energy objectives and goals are defined, as well as action plans to achieve them. (p. 42)

Another fundamental element of ISO 50001 is the implementation and operation of the EnMS, which includes the allocation of resources, competence and awareness of personnel, communication and documentation. According to Martínez [11], "the effective implementation of an EnMS requires the commitment and leadership of senior management, as well as the active participation of all the organization's staff" (p. 61). This involves defining roles and responsibilities, training and raising staff awareness, and managing documentation and records.

In addition, ISO 50001 establishes requirements for the verification and monitoring of energy performance, including measurement, analysis and evaluation. As Sánchez [12] indicates, "the regular monitoring and measurement of the IDEn allows organizations to evaluate the effectiveness of the actions implemented and detect opportunities for improvement" (p. 85). This is complemented by internal audits and management reviews to ensure compliance and continuous improvement of the EnMS.

The ISO 50001 management model provides a systematic and structured approach to energy management in organizations, with the aim of improving energy performance, reducing costs and mitigating environmental impact. Implementing an EnMS based on ISO 50001 requires energy planning, system implementation and operation, performance verification and monitoring, and continuous improvement. The adoption of this management model can contribute significantly to the sustainability and competitiveness of organizations in a context of growing concern about energy efficiency and climate change.

D. Power quality

Power quality has become a major issue in recent years due to the increasing use of sensitive electronic devices and the integration of renewable energy sources into the electrical grid. According to Rodríguez [13], "power quality refers to the characteristics of the electricity supplied, including the stability of voltage, frequency, waveform, and the absence of disturbances" (p. 23). Poor power quality can lead to equipment failure, lost productivity, and increased operating costs.

One of the key aspects of power quality is harmonic distortion, which occurs when non-linear loads, such as electronic equipment, inject harmonic currents into the power grid. As Gómez [14] points out:

Harmonic distortion can cause overheating of transformers, cables and motors, reducing their lifespan and efficiency. In addition, it can cause untimely tripping of switches and errors in measurement and control equipment. To mitigate these effects, it is necessary to implement active or passive filters, as well as carry out adequate sizing and selection of equipment. (p. 48)

Another factor that affects power quality is voltage fluctuations, known as flicker, which can be caused by variable loads, such as arc furnaces or motor starts. According to Torres (7), "flicker causes variations in the light intensity of the lamps, which can cause visual discomfort and fatigue in people" (p. 67). To mitigate this problem, static reactive power compensators or voltage regulators can be used.

In addition, power quality is affected by voltage sags (sags) and transient overvoltages (swells), which can be caused by network faults, load switching or atmospheric discharges. As Vargas [15] indicates, "sags and swells can cause the disconnection of sensitive loads, loss of data, and damage to equipment" (p. 91). To protect equipment, uninterruptible power supplies (UPS), surge suppressors, and line conditioners can be used.

E. Electrical power in three-phase electrical systems based on IEEE STD.1459-2010

A non-linear three-phase 4-wire electrical system with asymmetrical voltages and unbalanced currents corresponds to the most generic case presented in IEEE Std. 1459-2010. It includes electrical systems, whose voltages are asymmetric and distorted, and whose currents are unbalanced and distorted. Below is a summary of the equations used in the calculation of total, effective and non-fundamental powers. Equations that will be used to determine the power losses in the hospital transformers.

Fundamental effective voltage

It corresponds to the rms value of the fundamental positive sequence voltage, as explained in equation 1. Which will be one of the values measured by the network analyzer.

$$V_{e1}=V^{+}_{1} \tag{1}$$

Where:
V_{e1}: Fundamental effective voltage $[V]$.
V^{+}_{1}: Positive sequence fundamental voltage$[V]$.

Non-fundamental effective voltage

The non-fundamental effective voltage V_{eH} is made up of all harmonic voltage components and can be calculated from equation 2.

$$V_{eH} = \sqrt{\frac{1}{18}[3(V^2{}_{aH} + V^2{}_{bH} + V^2{}_{cH}) + (V^2{}_{abH} + V^2{}_{bcH} + V^2{}_{caH})]} \tag{2}$$

Where:
V_{eH}: Non-fundamental effective voltage $[V]$.
V_{aH},V_{bH} y V_{cH}: These are the phase-neutral harmonic and quadratic rms voltages measured at the pcc $[V]$.
V_{abH},V_{bcH} y V_{caH}: They are the harmonic and quadratic line-to-line rms voltages in the pcc $[V]$.

Effective voltage

The effective voltage V_e is made up of V_{e1} and V_{eH} according to equation 3.

$$V_e = \sqrt{V^2{}_{e1} + V^2{}_{eH}} \tag{3}$$

Where:
V_e: Effective voltage $[V]$.

Fundamental effective current

It corresponds to the rms value of the fundamental positive sequence current, as explained in equation 4. Which will be one of the values measured by the network analyzer.

$$I_{e1} = I^{+}{}_{1} \tag{4}$$

Where:
I_{e1}: Fundamental effective current $[A]$.
$I^{+}{}_{1}$: Positive sequence fundamental current $[A]$.

Effective current

The effective current Ie is made up of $Ie1$ and IeH according to equation 5.

$$I_e = \sqrt{I^2{}_{e1} + I^2{}_{eH}} \tag{5}$$

Where:
I_e: Effective current $[A]$.

Effective power

In theory, Se represents all the physical phenomena that can occur in the power system, including the losses in the neutral conductor in a three-phase four-wire system, also the unbalance phenomenon. It is obtained according to equation 16. This is one of the values that will be recorded in the network analyzer, with which the wasted harmonic power will be calculated.

$$S_e = 3.V_e.I_e \tag{6}$$

Decomposing the effective power into its components of fundamental effective power and non-fundamental effective powers, equation 17 is obtained.

$$S^2{}_e = 9(V^2{}_{e1} + V^2{}_{eH})(I^2{}_{e1} + I^2{}_{eH})$$
$$S^2{}_e = (3V_{e1}I_{e1})^2 + (3V_{e1}I_{eH})^2 + $$
$$+ (3V_{eH}I_{e1})^2 + (3V_{eH}I_{eH})^2 \tag{7}$$

Non-fundamental effective current

The non-fundamental effective current IeH is made up of all the harmonic current components. According to equation 8.

$$I_{eH} = \sqrt{\frac{1}{3}(I^2{}_{aH} + I^2{}_{bH} + I^2{}_{cH} + I^2{}_{nH})} \tag{8}$$

Where:
I_{eH}: Non-fundamental effective current $[A]$.
I_{aH}, I_{bH} e I_{cH}: They are the harmonic and quadratic rms currents per phase $[A]$.
I_{nH}: It is the harmonic and quadratic rms current of the neutral $[A]$.

The first term of equation 7 is S_{e1} corresponding to the fundamental effective power and the rest of the terms make up the non-fundamental apparent power S_{eN}, as shown in equation 9.

$$S^2{}_{e} = S^2{}_{e1} + S^2{}_{eN} \tag{9}$$

$$S^2{}_{eN} = (3V_{e1}I_{eH})^2 + (3V_{eH}I_{e1})^2 + (3V_{eH}I_{eH})^2 \tag{10}$$

The terms that appear in S_{eN} of equation 10 are defined in IEEE Std. 1459-2010. The first term is the power due to current distortion DeI (equation 11), it quantifies the electrical power phenomena caused by non-fundamental currents.

$$D^2{}_{eI} = (3V_{e1}I_{eH})^2 \tag{11}$$

The second term is the power due to harmonic voltage distortion D_{eV} (equation 12), quantifies the electrical power phenomena caused by non-fundamental voltages.

$$D^2{}_{eV} = (3V_{eH}I_{e1})^2 \tag{12}$$

The third term is the apparent harmonic power S_{eH} (equation 13), it quantifies the electrical power phenomena caused by non-fundamental voltages and current. It is composed of the active power.

$$S^2{}_{eH} = P^2{}_{H} + D^2{}_{eH} = (3V_{eH}I_{eH})^2 \tag{13}$$

P_H is an active power considered inefficient because it comes from an inefficient phenomenon and causes losses in the load and in the electrical power system.

3. MATERIALS AND METHODS

A. Kind of investigation

To achieve the objectives of the project, a field investigation is used, which allows the use of quality measurement and analysis instruments (network analyzer) in the transformers of the General Hospital of Latacunga, obtaining data on the behavior of the electrical system such as voltages. , currents, powers, harmonics, among other disturbances; in order to determine anomalies in the system that are causing energy waste.

B. Research Methods

The quantitative method is used, which allows the use of obtaining strategies (data collection and measurement instruments) and analysis of numerical information (regulations, numerical limits, established formulas, etc.).

To obtain the data, a FLUKE 435 SII network analyzer is used, data that will be analyzed through statistical procedures using formulas in accordance with the ARCERNNR 002-20 standard to determine the magnitudes that are not within the standard and proceed to the analysis of the respective corrections.

Formulas will be used to determine numerical values that size the alternative solution and the possible energy savings.

C. Data collection techniques

A general visit and a technical visit to the facilities are carried out to deduce how the electrical system works, define the operation and maintenance routines and identify any visible anomalies.

Constant meetings are required with maintenance personnel and personnel in charge of logistics and documentation, to keep interested parties informed; In the same meetings, it is required to know the existence of records, historical information, documents from previous audits, etc.

An analysis is carried out on the documented historical information, such as electrical diagrams, construction data of the facilities, inventories of the audited objects, quality dossier, etc.

With the network analyzer, the following magnitudes are measured for a period of 7 days, with data taken every 10 minutes:
• RMS values: phase-neutral voltages, phase-phase voltages, phase-neutral currents.
• Frequency
•voltage and current imbalance
• Powers: active, reactive, apparent, power factor, displacement favor.
• Energy consumed
• Voltage fluctuations: rapid voltage fluctuation (Pst, Pstmin, Plt).
• Harmonics: THD (voltage), TDD (current), harmonics from order 1 to order 50.
• Events: disturbances that degenerate the purity of the wave.

4. THE PROPOSAL

The General Hospital of Latacunga or Hermanas Páez General Hospital is located in the city of Latacunga, in the La Matrix parish, on Hermanas Páez and 2 de Mayo streets, at 2919 meters above sea level, with a temperature ranging between 10ºC and 22ºC. It consists of various buildings built over time.

Section 1 is the construction inaugurated in 1959, initially it had four specialties, so it is understood that it was not designed for a high increase in installed power, currently the consumption of this section is mostly for lighting and computer equipment. These sections 1 and 2 are associated with a connection, represented by a meter from the company ELEPCO S.A. Finally, section 3 is a one-story construction, which is used only by the administrative area, which has an independent meter.

Section 1, also called block A, is associated with transformer 2. This has the load installed in the old hospital building. Section 2, also called block B, is associated with transformer 1. It is connected to the load of the new hospital building, where most of the medical equipment is located.

A. Energy management according to ISO 50001

Each organization must implement energy management programs and designate a coordinator. However, due to the following barriers, it is not possible to fully embrace the standard.

The hospital does not have the necessary measurement equipment to monitor an energy management program such as a network analyzer, lux meter, etc. Each hospital employee plays a role and their respective activities according to their contract. When implementing an energy efficiency program, a great commitment is required on the part of the management staff and employees, which means that each of them would acquire more responsibilities, or Failing that, hire new personnel specialized in the area.

Low voltage electrical installations range from the output of the low voltage terminals of the transformers to each and every one of the outputs and specific loads. The low voltage system includes: main and secondary feeders and panels, interior and exterior lighting, power system (normal force, regulated force, force for special outputs).

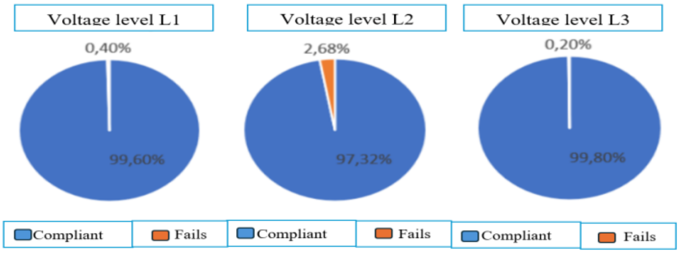

Figure 1. Percentage of recorded values that comply with ARCERNNR 002-20 with respect to T1 voltage level.

In general, Transformer 1 (T1) mostly complies with the ARCERNNR 002-20 standard, maintaining the voltage level within the permitted variation range. Slight nonconformities on line 2 should be monitored to ensure they do not become a significant problem. This analysis demonstrates the robustness of the T1 in providing a stable voltage supply, crucial for the effective operation of hospital electrical systems.

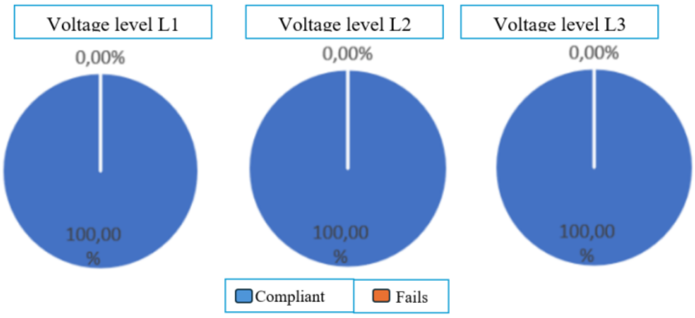

Figure 2. Percentage of recorded values that comply with ARCERNNR 002-20 with respect to T2 voltage level.

Figure 2 shows that 100% of the values recorded in the three lines of Transformer 2 (T2) do not exceed the 8% voltage level variation specified by the ARCERNNR 002-20 standard. This implies that all measured voltage values are within the permitted range, fully complying with regulatory standards. This high level of compliance indicates that Transformer 2 maintains excellent performance in terms of voltage stability, ensuring a constant quality of electrical power without significant fluctuations in the voltage level.

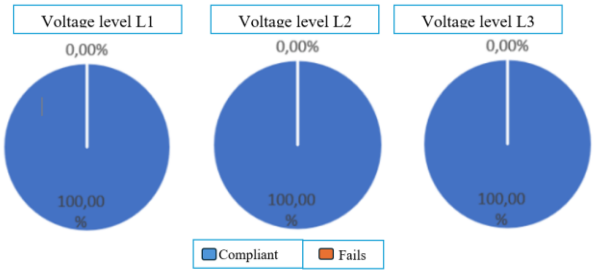

Figure 3. Percentage of recorded values that comply with ARCERNNR 002-20 with respect to T3 voltage level.

Figure 3 shows that 100% of the values recorded in the three lines of Transformer 3 (T3) do not exceed the 8% voltage level variation specified by the ARCERNNR 002-20 standard. This means that all measured values are within the permitted range, fully complying with regulatory standards. This high level of compliance suggests that T3 maintains excellent performance in terms of voltage stability, ensuring consistent electrical power quality without significant fluctuations in voltage level.

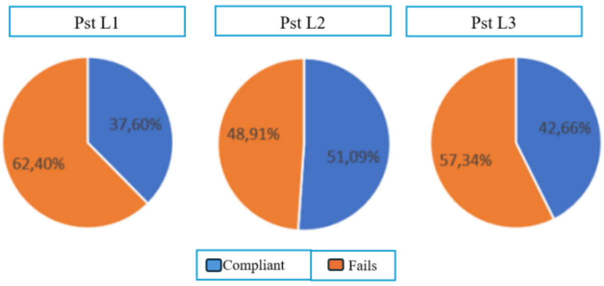

Figure 4. Percentage of recorded values that comply with ARCERNNR 002-20 with respect to T1 fast voltage disturbance.

Figure 4 reveals that the percentage compliance of the recorded values with respect to the fast voltage disturbance (Flicker) in Transformer 1 (T1) is less than 48.91% in the three lines. This indicates that more than 51.09% of the values exceed the limit allowed by the ARCERNNR 002-20 regulations, placing them outside the established range. The regulations indicate that at least 95% of the registered values must not exceed unity in the Flicker index. The high non-compliance rate at T1 suggests significant problems of rapid voltage fluctuation, affecting the quality of the power supplied and potentially causing discomfort or damage to connected electrical and electronic equipment.

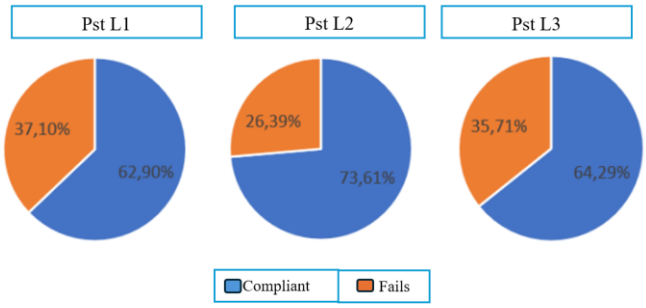

Figure 5. Percentage of recorded values that comply with ARCERNNR 002-20 with respect to T2 fast voltage disturbance.

Figure 5 shows that the percentage of compliance of the recorded values with respect to the fast voltage disturbance (flicker) in Transformer 2 (T2) is greater than 62.90% in the three lines. Despite this level of compliance, the transformer does not reach the parameter established by the standard, which requires that at least 95% of the recorded values do not exceed unity in the flicker index. This indicates that approximately 37.10% of the values do not comply with the allowed limits, suggesting that there is a significant presence of fast voltage disturbances. These fluctuations can affect the quality of electrical power and the efficient operation of equipment connected to the system.

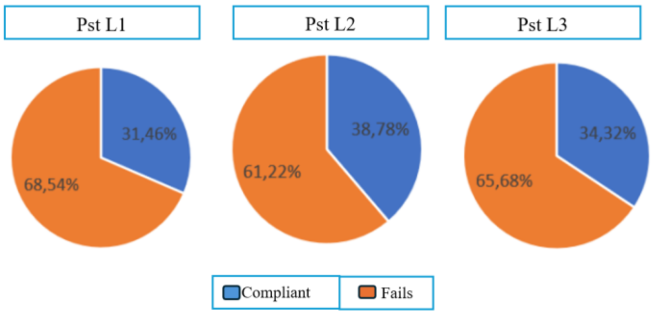

Figure 6. Percentage of recorded values that comply with ARCERNNR 002-20 with respect to T3 fast voltage disturbance.

Figure 6 shows that the percentage of recorded values that comply with the ARCERNNR 002-20 standard regarding fast voltage disturbance (flicker) in Transformer 3 (T3) is less than 38.78% in the three lines. This means that more than 61.22% of the values exceed the permitted limit, placing them outside the range established by the standard, which requires that at least 95% of the recorded values do not exceed one unit in the flicker index. This high percentage of non-compliance indicates that T3 faces serious problems with rapid voltage fluctuations, which can negatively impact the stability and efficiency of connected equipment. Additionally, because T3 is used exclusively for imaging, the loadings are not constant, which contributes to these significant variations.

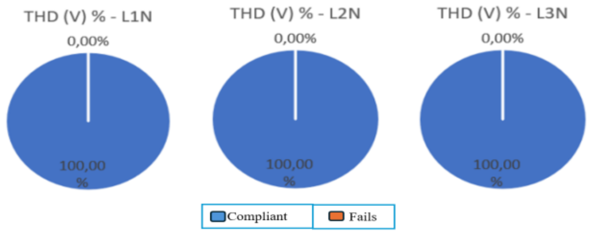

Figure 7. Percentage of recorded values that comply with ARCERNNR 002-20 with respect to T1 voltage harmonic distortion.

Figure 7 shows that 100% of the values recorded in the three lines of Transformer 1 (T1) present a voltage harmonic distortion of less than 8%, fully complying with the ARCERNNR 002-20 standard. This indicates that there is no recorded value that exceeds the allowable limit for voltage harmonic distortion, which is indicative of excellent performance of T1 in terms of power quality. T1's ability to maintain harmonic distortion within acceptable limits ensures the protection and efficiency of connected electrical and electronic equipment, minimizing risks of overheating and failure.

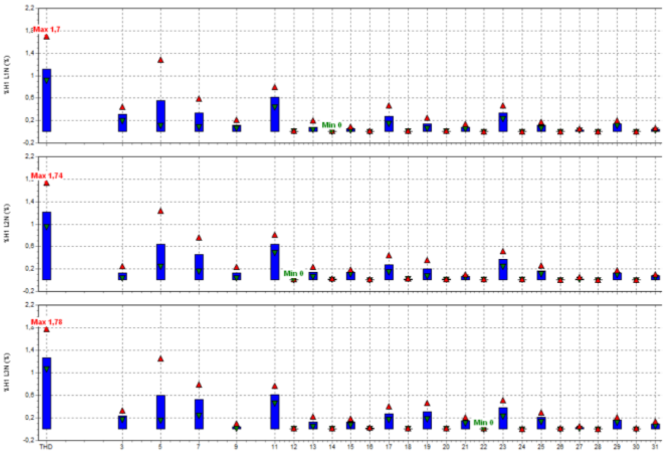

Figure 8. Voltage harmonic spectrum of T1.

Figure 8 shows the harmonic spectrum of Transformer 1 (T1) voltage from the third to the thirty-first harmonic. The voltage harmonic distortion values on all three lines remain below 1.4%. The most prominent harmonics are the fifth, seventh and eleventh, each of them with values less than 1%. This harmonic profile indicates that T1 operates within the limits established by the ARCERNNR 002-20 regulation, ensuring acceptable quality of electrical energy. The low presence of harmonics in the voltage minimizes the risk of adverse effects on electrical and electronic equipment, such as overheating or premature failure.

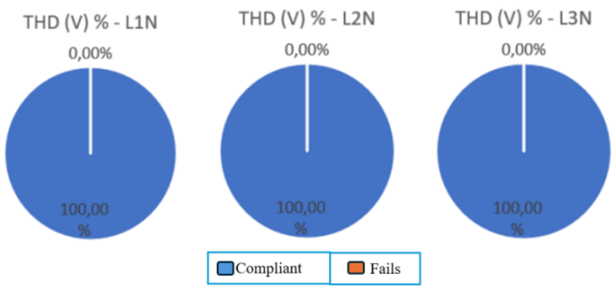

Figure 9. Percentage of recorded values that comply with ARCERNNR 002-20 with respect to T2 voltage harmonic distortion.

Figure 9 shows that 100% of the values recorded in the three lines of Transformer 2 (T2) present a voltage harmonic distortion of less than 8%, fully complying with the ARCERNNR 002-20 standard.

This indicates that all measured voltage values are within the allowed range, reflecting excellent stability of T2 in terms of voltage harmonic distortion. The ability to maintain low harmonic distortion is crucial to minimizing adverse effects on electrical and electronic equipment, such as overheating and reduced component life.

This level of compliance suggests that Transformer 2 operates efficiently and stably, guaranteeing high quality of electrical power. The absence of values outside the acceptable range implies that the T2 can drive the connected loads without significant harmonic distortion problems, which is beneficial for the continuous and reliable operation of systems that depend on this electrical supply.

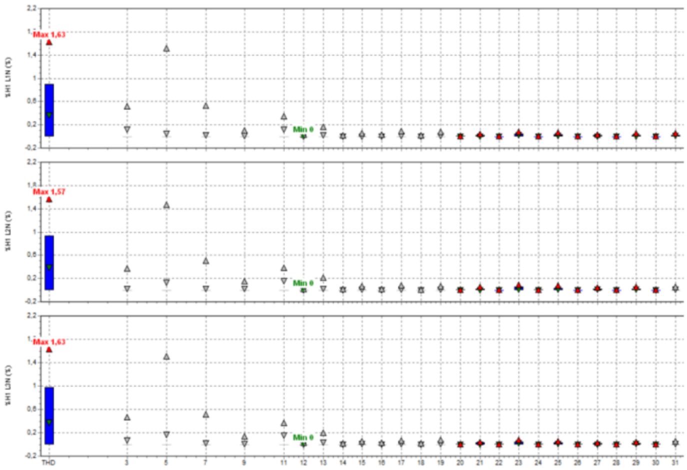

Figure 10. Voltage harmonic spectrum of T2.

Figure 10 shows the voltage harmonic spectrum of Transformer 2 (T2) for the individual harmonics from the third to the thirty-first harmonic. In this figure, the voltage harmonic distortion values are kept below 1% on all lines.

The most prominent harmonics are the third, fifth, seventh and eleventh, however, all of these are within the acceptable limit. The low presence of harmonics in the voltage indicates that T2 operates within the parameters established by the ARCERNNR 002-20 standard, ensuring adequate power quality.

The harmonic spectrum presented suggests that Transformer 2 is well designed and managed to minimize the effects of voltage harmonics, which is crucial for the protection of connected equipment. Keeping harmonic distortion below 1% is a positive indication of stability and efficiency in the power supply, as harmonics can cause overheating and failure of electrical and electronic equipment. Therefore, the good performance of T2 in terms of harmonic distortion contributes significantly to the reliability and durability of hospital electrical systems.

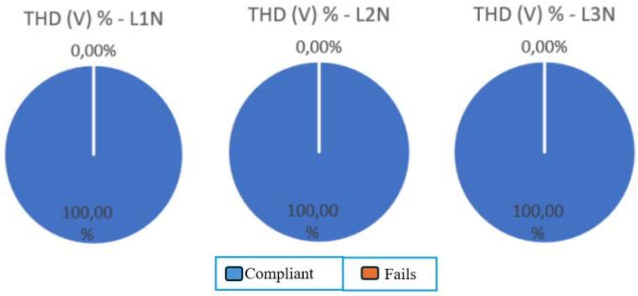

Figure 11. Percentage of recorded values that comply with ARCERNNR 002-20 with respect to T3 voltage harmonic distortion.

Figure 11 shows that 100% of the values recorded in the three lines of Transformer 3 (T3) present a harmonic voltage distortion of less than 8%, thus complying with the ARCERNNR 002-20 regulations. This high level of compliance indicates that all measured voltage values are within the allowable range, reflecting excellent stability of the T3 in terms of voltage harmonic distortion.

The ability to maintain low harmonic distortion is essential to minimize negative effects on electrical and electronic equipment, such as overheating and reduced component life.

100% compliance on all T3 lines suggests that the transformer is operating efficiently and stably, ensuring high quality of electrical power. This is especially important in a hospital environment, where reliable power supply is crucial for the operation of sensitive medical equipment.

Keeping harmonic distortion below 8% ensures that equipment connected to the T3 does not experience problems due to voltage harmonics, contributing to optimal performance and safe hospital operations.

The low voltage facilities operate at a voltage of 220/127 V. For the design of the elements and the low voltage system itself, it was considered that the building is intended to provide hospital services.

Load center type subboards are generally divided into subboards for normal force system, regulated force system, lighting system and air conditioning system.

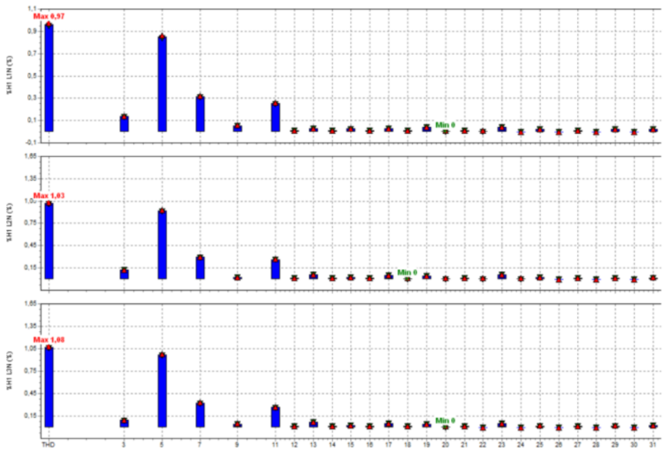

Figure 12. Voltage harmonic spectrum of T3.

Figure 12 shows the voltage harmonic spectrum of Transformer 3 (T3), spanning from the third to the thirty-first harmonic. In this figure, the voltage harmonic distortion values remain below 1.08% on all lines. The most prominent harmonics are the fifth, seventh and eleventh, although all of them remain within the acceptable limit.

The low presence of harmonics in the voltage indicates that T3 operates within the parameters established by the ARCERNNR 002-20 regulations, ensuring adequate power quality. This is crucial to minimize the adverse effects that harmonics can have on electrical and electronic equipment, such as overheating and reduced component life.

The harmonic spectrum presented suggests that Transformer 3 is well designed and managed to minimize the effects of voltage harmonics. Maintaining harmonic distortion below 1.08% is a positive indication of power supply stability and efficiency, as harmonics can cause significant problems in the operation of sensitive equipment. Therefore, the good performance of T3 in terms of harmonic distortion contributes significantly to the reliability and durability of hospital electrical systems.

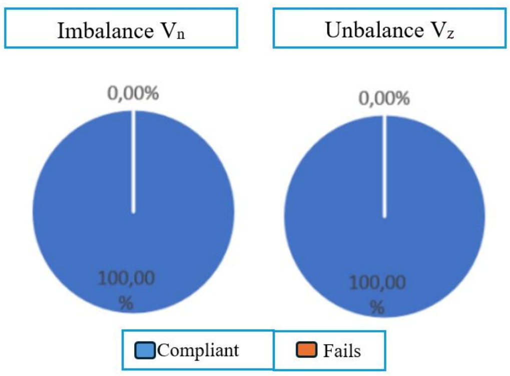

Figure 13. Percentage of recorded values that comply with ARCERNNR 002-20 with respect to T1 voltage imbalance.

Figure 13 shows that 100% of the values recorded in the three lines of Transformer 1 (T1) comply with the ARCERNNR 002-20 regulations regarding voltage imbalance. This implies that all measured voltage values remain within the acceptable variation limit of 2%, established by regulations. This high level of compliance indicates that the T1 provides a very stable power supply, minimizing fluctuations between phases and ensuring that voltage is distributed equally.

Full compliance with the regulations regarding voltage imbalance suggests that Transformer 1 is functioning optimally, without presenting imbalance problems that could affect the quality of the electrical supply. This performance is crucial in a hospital environment, where the accuracy and stability of the power supply is critical to the safe and efficient operation of sensitive medical equipment. The ability to maintain low voltage imbalance also contributes to the longevity of electrical equipment and the reduction of operational failures.

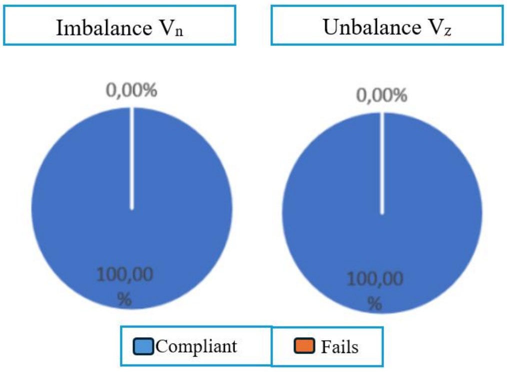

Figure 14. Percentage of recorded values that comply with ARCERNNR 002-20 with respect to T2 voltage imbalance.

Figure 14 shows that 100% of the values recorded in the three lines of Transformer 2 (T2) comply with the ARCERNNR 002-20 regulations in relation to voltage imbalance. This result means that all measured voltage values are within the acceptable variation limit of 2%, as established by the regulations. This level of compliance reflects the excellent stability of the T2 in terms of voltage distribution, which is essential to ensure a consistent and reliable power supply.

Full compliance with T2 with respect to voltage imbalance suggests that the transformer is operating efficiently and without phase imbalance problems. This stability is crucial in a hospital environment, where the precision and consistency of the power supply is essential for the safe operation of sensitive medical equipment. Additionally, maintaining a low voltage imbalance contributes to the longevity of electrical equipment, reducing the possibility of operational failures and improving system energy efficiency.

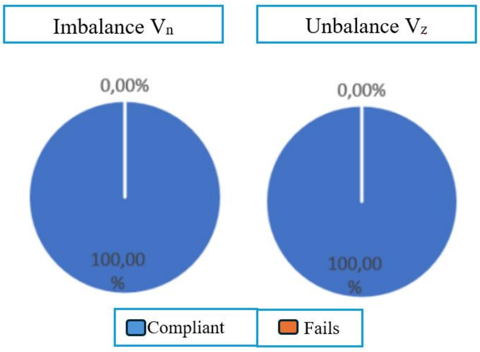

Figure 15. Percentage of recorded values that comply with ARCERNNR 002-20 with respect to T3 voltage imbalance.

Figure 15 shows that 100% of the values recorded in the three lines of Transformer 3 (T3) comply with the ARCERNNR 002-20 regulations in relation to voltage imbalance. This implies that all measured voltage values remain within the acceptable variation limit of 2%, established by regulations.

This high level of compliance indicates that the T3 provides a very stable power supply, minimizing fluctuations between phases and ensuring that voltage is distributed equally. The ability to maintain a low voltage imbalance is crucial for the protection and efficiency of connected electrical and electronic equipment, avoiding problems such as overheating and premature failure.

Full compliance with the regulations regarding voltage imbalance suggests that Transformer 3 is functioning optimally, without presenting imbalance problems that could affect the quality of the electrical supply. This performance is especially important in a hospital environment, where the accuracy and stability of the power supply is critical to the safe and efficient operation of sensitive medical equipment. T3's ability to maintain voltage imbalance within acceptable limits not only contributes to the reliability of the hospital's electrical system, but also improves energy efficiency and reduces long-term operating costs.

The main low voltage feeders leave the terminals of each transformer and feed the respective main distribution boards. The feeders are three-phase, 4 wires, nominal voltages 220/127 Volts.

The first 750 KVA transformer (transformer No.1) powers all the loads of the new building (Section B). From this transformer there is a low voltage connection to the automatic transfer panel 1. A connection from generator 1 also enters this panel, which has a stand-by power of 899 KVA. From the automatic transfer board 1 a connection comes out to the general board TPB. From this panel come the connections to the panels that feed the general loads of the hospital.

The second 750 KVA transformer (transformer No.2) will power all the loads of the old building (Section A) and machine room. A low voltage connection to the automatic transfer board 2 originates from this transformer.

A connection from generator 2 also enters this panel, which, similarly to the previous generator, has a stand-by power of 899 KVA.

From transfer board 2 a connection comes out to the TGA general board. From this panel come the connections to the panels to the panels of the old building, power house and certain point loads.

From the third transformer, 250 KVA (transformer No.3), a low voltage connection comes out to the TRX board which will exclusively power the loads of the X-ray, densitometer, mammograph and tomograph equipment.

The lighting system has been designed to offer adequate lighting levels according to the uses of each area. LED type luminaires were used for interior and exterior lighting of the building.

The type of luminaires to be installed is in accordance with the environments where they are located. For the parking area, stands, outdoor areas, machine house, generator room, gas house, electrical room, and in general, in places where there is no false or reticulated ceiling, hermetic superimposed LED-type luminaires are used.

For the rest of the interior areas, recessed luminaires are used, which depending on the area will be porthole type or 60x60cm luminaires.

In the operating room area, the luminaires for general lighting will be recessed. Additionally, ceiling lamps were installed in accordance with the respective regulations, in order to ensure an adequate level of lighting.

In consideration of the great importance of exterior lighting in a building, the installation of ornamental type posts with LED type luminaires, garden floor luminaires and LED reflectors has been planned.

B. *Measured data report*

To extract the recorded information, FLUKE's own software is needed, called Power Log, which allows you to view the data in the form of a table, trend line, percentages and statistics of the measurements taken.

The transformer nameplate data specifies that the voltage between line and line is 220V and between line and neutral is 127V. These voltage variations can cause damage to electrical equipment; it will be analyzed soon whether it complies with the parameters established by the standard. It is also observed that the voltage values do not vary significantly between one line and another, demonstrating that there is no load imbalance.

The transformer nameplate data specifies that the nominal current is 300A, however, it is observed that its magnitude visibly increases.

The value of the phase currents has an unstable behavior, probably due to the presence of harmonics that will be corroborated later through analysis; however, the most notable problem observed in the graph is the current that circulates in the neutral.

In a three-phase electrical system, the neutral current is the vector sum of the three line currents. If the system has perfect symmetry where its waves are 120º out of phase and with a balanced three-phase linear load, the neutral current is equal to zero. In reality, in a three-phase four-wire system, which is moderately balanced, the current flowing through the neutral is expected to be a maximum of 20% of the phase current.

The nominal frequency is 60Hz, the data shows a maximum reading of 60.128Hz and a minimum of 59.881Hz. Therefore, no failures are perceived in the system frequency.

Energy is directly proportional to power, therefore, it is understood that the highest energy recorded is found between midday hours and decreases during the night.

Rapid voltage disturbances, better known as flicker, are perceptible to the human eye in the form of flickering in the luminaires; these can cause damage to the equipment in addition to increasing fatigue.

Harmonics are voltage and current waves that alter the purity of the fundamental wave; odd-order harmonics are considered critical. especially the third harmonic. However, the harmonic graph shows high percentages at the fifth, seventh, and eleventh.

The voltage THD presents a distortion that approaches 2%, and the current THD presents a harmonic distortion of approximately 20%, being at first glance the biggest drawback of the system. Where Line 3 presents the greatest distortion.

The transformer nameplate data specifies that the voltage between line and line is 220V and between line and neutral is 127V. L3 and L31 present a greater voltage variation; it will be analyzed soon if it complies with the parameters established by the standard.

The voltage values recorded on the three lines are similar, load unbalance is ruled out. The transformer nameplate data specifies that the rated current is 300 A, however, a drastic current variation is observed.

In the same way as in transformer 1, current occurs in the neutral. Presenting a maximum reading of 152.9 A and a minimum reading of 51.9 A.

The nominal frequency is 60Hz, the data shows a maximum reading of 60.135Hz and a minimum of 59.821Hz. Therefore, no failures are perceived in the system frequency.

According to the power graphs of the three lines, the hours of highest demand recorded are between 11:00 am and 2:00 pm and the hours of lowest consumption are between 5:00 pm until the next day at 9:00 am.

In the same way as in transformer 1, the maximum apparent power consumed by transformer 2 is 213.27kVA, while its nominal value is 750kVA, which indicates that it is oversized, potentially causing losses in the core of the transformer.

The harmonic graph shows high percentages in the third harmonic. The voltage THD presents an average distortion of 1%, and the current THD presents a harmonic distortion of approximately 25%, which makes this data the critical problem of the system.

The transformer nameplate data specifies that the voltage between line and line is 220V and between line and neutral is 127V.

The nominal frequency is 60Hz, the data shows a maximum reading of 60.061Hz and a minimum of 59.928Hz. Therefore, no failures are perceived in the system frequency.

The harmonic graph shows high percentages in the fifth harmonic. The voltage THD has an average distortion of 1%, and the current THD has a harmonic distortion of approximately 40%.

C. Analysis

To determine the existing anomalies in the electrical system, 1008 data were collected for 7 days, every 10 minutes. Obtaining a large database, from which the calculations of each value have been carried out and the results compared with the ARCERNNR 002-20 standard, obtaining the following results.

Transformer 1

It is observed that 100% of the values recorded in lines 1 and 3 do not exceed 8% of voltage level variation, only line 2 presents 2.68% of recorded values that do not comply with the parameters. 95% or more of the recorded values do not vary more than 8% of the nominal voltage. Complies with the standard.

Transformer 2

It is observed that 100% of the values recorded in the three lines do not exceed 8% voltage level variation. 95% or more of the recorded values do not vary more than 8% of the nominal voltage. Complies with the standard.

Transformer 3

It is observed that 100% of the values recorded in the three lines do not exceed 8% voltage level variation. 95% or more of the values recorded in one day do not vary more than 8% of the nominal voltage.

To perform the calculation of Fast Voltage Disturbance (Flicker), equation 2 has been used. Applying it to the 1008 recorded data and determining the percentage of values that comply with the standard. According to this, 95% of the registered values or more must not exceed unity.

Harmonic voltage distortion

To calculate the maximum voltage harmonic distortion, the network analyzer has used equation 3, equation 4 and equation 5, automatically recording the data as a percentage. Applying it to the 1008 recorded data and determining the percentage of values that comply with the standard.

To plan possible solutions, the critical problems of the electrical system are first determined. In the analysis, the following problems were highlighted in the distribution transformers of the electrical system.

• Excessive rapid voltage fluctuation in the three transformers, does not comply with the ARCERNNR 002-20 standard.

• Presence of currents in the neutral in transformers 1 and 2.

• Presence of harmonics in the network, especially current harmonics, current harmonic distortion does not comply with the standard.

• Excess reactive power in the three transformers, maintaining the power factor above 0.92 allowed by the standard.

The maximum neutral current in transformer 1 is 119.2 A according to Table 16, and the current supported by the installed conductors is 2248 A, therefore, it is not necessary to increase the cable gauge, on the contrary, this It is sized for currents of 1968.2 A from the transformer secondary.

Transformer 2 has a cable of (3x6x500+6x500+6x350) mcm, which means that for the phases and the neutral there is an AWG 500 cable that supports a current of up to 358 A in buried duct and for ground there is an AWG 350 cable that supports a current of up to 281 A in buried duct.

To determine the energy saved per month, the power is multiplied by the number of hours it operates per month. According to the analysis of the daily consumption profile, there are approximately 8 hours that the hospital has the highest demand, obtaining 240 hours of highest demand in the month. Showing as a result the following energy values.

The energy savings of 6987kWh/month in transformer 1 and 3035kWh/month in transformer 2 were determined, based on the harmonic losses in the transformers, using the effective power values recorded by the network analyzer.

The total savings calculated is $651 per month, where the investment is recovered in 1 year and 3 months.

Based on the reactive power produced by the hospital, there is the possibility of paying a power factor penalty, making the acquisition of equipment to mitigate harmonics and reduce reactive power more urgent.

5. CONCLUSION

A specialized bibliographic research was carried out on management issues, electrical auditing and energy quality, to propose the appropriate management model for a public entity according to the recommendations of ISO 50001.

An electrical audit was carried out using ISO 50002 procedures, through an analysis of power quality in the hospital's distribution transformers, using a network analyzer provided by the Technical University of Cotopaxi, obtaining as a critical result the presence of harmonics. of current in transformers 1 in line 3 and transformer 2 in the three lines, with more than 20% harmonic current distortion. Obtaining a maximum harmonic current of 84.77 A in line 3 of transformer 1 and a maximum reactive current of 155.75 A in line 2 of transformer 1.

A 200 A three-phase four-wire active filter for transformer 1 and a 150 A three-phase four-wire active filter for transformer 2 were proposed as a possible solution, with the purpose of compensating for harmonic currents and reactive power, as well. balance the current between the phases of the transformers, with an acquisition, import and installation cost of $10,100.

6. ACKNOWLEDGMENT

The preferred spelling of the word “acknowledgment” in America is without an “e” after the “g.” Avoid the stilted expression “one of us (R. B. G.) thanks ...”. Instead, try “R. B. G. thanks...”. Put sponsor acknowledgments in the unnumbered footnote on the first page.

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