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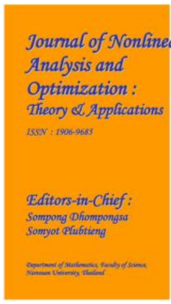

POWER QUALITY ANALYSIS AND ENERGY CONSUMPTION IN A TEXTILE INDUSTRY

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ABSTRACT

This study extensively explores power quality and energy usage dynamics in a textile factory. It meticulously analyzes disturbances like voltage dips, harmonics, and flickers in the electrical substation and production machinery. Emphasizing energy consumption and power factor in principal loads, the research identifies variable speed drives as a primary source of harmonic distortion, particularly the 5th harmonic. Despite occasional interruptions, the system exhibits overall stability. Variability in energy consumption is linked to production schedule fluctuations. The study reveals opportunities for power factor optimization through strategic capacitor bank implementation, indicating untapped efficiency potential. In conclusion, this work suggests further exploration, urging supplementary analyses to identify and capitalize on additional avenues for energy augmentation.

Keywords:
Power quality, energy efficiency, harmonics, voltage dips, textile industry

I. Introduction

The textile industry is vital in manufacturing weaving intricate fabrics that drape our lives in comfort and style. Within this bustling sector, the seamless operation of machinery and the unyielding demand for energy underscore the significance of power quality and consumption.This study embarks on a meticulous exploration into power quality and energy consumption within the textile industry. Titled "Analysis of Power Quality and Energy Consumption in a Textile Industry," this research endeavors to unravel the intricate interplay between power dynamics and energy utilization within this crucial industrial domain.

As the machinery hums to life, the power supply becomes the lifeblood, dictating the efficiency and reliability of production processes. However, the landscape is evolving. The surge in power electronics, coupled with the amplification of nonlinear loads, has ushered in a new era fraught with challenges to the pristine nature of power quality.

Simultaneously, the industry's evolution toward larger and more complex processes has escalated the energy demand, presenting a dual challenge of maintaining quality while ensuring sustainability. This analysis aims to delve into the heart of this conundrum, shedding light on the nuanced intricacies that govern power quality and energy consumption in textile manufacturing.By scrutinizing the electrical infrastructure, from its inception at the utility connection to the pivotal machinery orchestrating production, this study seeks to uncover the patterns and anomalies that define power quality. Through the lens of advanced monitoring tools and comprehensive assessments, this research unveils the underlying factors contributing to voltage fluctuations, harmonic distortions, and potential interruptions in power supply.

Moreover, the investigation extends beyond mere observation, venturing into energy consumption. Delving into the metrics of active power, reactive power, and overall power factors, this inquiry aims to decode the energy utilization patterns within the textile industry. Understanding how these consumption patterns interface with power quality is pivotal, offering insights and actionable pathways toward greater energy efficiency and sustained production efficacy.As the looms weave their intricate patterns, this analysis seeks to weave a narrative that not only dissects the present state of power dynamics within the textile industry but also envisages a roadmap toward an optimized, resilient, and sustainable future.

This research underscores the pivotal role of an unblemished power supply in the seamless operation of industrial facilities. A robust and dependable power source stands as the cornerstone, ensuring the efficiency and continuity of production systems. Yet, the pervasive integration of power electronics and nonlinear loads within factories has presented a growing challenge, often leading to the erosion of power quality.

Simultaneously, the burgeoning complexity of industrial processes has propelled a surge in energy consumption, delineating a pressing need to reconcile this escalating demand with sustainable practices. This thesis addresses these intricate issues through a comprehensive power quality audit and an in-depth energy assessment conducted at a prominent textile factory situated in India.By meticulously documenting the electrical system, spanning from the utility connection to the crux of the production machinery, this study aims to illuminate the intricate web of factors impacting power quality. Employing a sophisticated power analyzer deployed across multiple points, the research diligently monitors and analyzes various power quality disturbances, including voltage dips, harmonics, and flicker.Crucially, the assessment extends beyond mere identification, delving into the nuanced metrics of active power, reactive power, and the overarching power factor. These metrics serve as vital indicators, offering profound insights into the factory's energy performance.Understanding the intricacies of electricity consumption patterns within the machinery and comprehending their consequential impact on power quality forms the bedrock of this research. Such comprehension serves as a linchpin for pinpointing potential energy efficiency avenues and preemptively averting production losses arising from plausible disturbances.

Ali et al. (2023) proposed an intelligent hybrid energy system with fuel cell and batteries coupled to renewables for grid integration using microcontrollers to regulate components and smooth variability. Ali et al. (2021) conducted a systematic literature review on developments, challenges, and future directions in intelligent energy management systems using PRISMA analysis and VOSviewer visualization. AL-Jumaili et al. (2023) reviewed advancements in cloud computing for power optimization and battery management in renewable hybrid energy systems, identifying key concepts and recommendations.Ameur et al. (2023) developed a forecasting model for a home energy management system with hybrid PV/gravity energy storage, reducing energy use and costs.Andal& Jayapal (2022) designed an IoT-based intelligent controller for a PV/wind/battery system to manage power flows and optimize costs using ARDUINO microcontrollers.Asrol et al. (2023) presented a design for an intelligent decision support system to assess sustainability in supply chain management.

Ben Slama & Mahmoud (2023) proposed a deep learning model for home energy management using Q-learning to schedule appliances and storage for cost and comfort optimization. Cordeiro-Costas et al. (2023) applied deep learning for forecasting and reinforcement learning to manage building energy storage, validating improved efficiency.Deepanraj et al. (2022) presented an optimal deep learning-based model using BiLSTM and WGA optimization for short-term load forecasting in microgrids for sustainability. Gomes et al. (2023) developed an optimization model using mixed integer linear programming for community energy management to enable sharing within energy communities.Habib et al. (2023) proposed a risk-based energy management approach using stochastic optimization for intelligent parking lots with hydrogen storage and renewables. Huda et al. (2024) provided a comprehensive review on the role of intelligent systems and expert knowledge in transforming smart homes into sustainable smart cities.Kashiri et al. (2023) introduced a stochastic strategy using two-point estimate method and Honey Badger algorithm to optimize intelligent EV charging in parking lots.Liang et al. (2023) developed an IoT-based energy management system using data-driven forecasting and optimization for HVAC devices in a net-zero building. Nouri et al. (2024) designed an efficient V2G system with intelligent fuzzy logic-based management and ANN-PSO for optimal battery charging/discharging.

Ramani Bai et al. (2023) reviewed intelligent programming approaches applied in environment and waste management under uncertainty, identifying key methods, limitations and future research needs. Shaikh et al. (2013) developed a multi-objective optimization model using genetic algorithm to optimize energy consumption and comfort in building management systems.Smadi et al. (2024) proposed an artificially intelligent control system for energy management in PV systems.Tariq et al. (2023) presented a sustainability analysis framework assessing energy, economic, environmental and social impacts of integrating double-façade architecture and cooling systems in social houses. Uzair & Ali Abbas Kazmi (2023) pioneered a multi-criteria decision-making model to support the optimization of energy efficiency, costs and indoor environmental quality in buildings.Vignesh et al. (2023) implemented an adaptive neuro-fuzzy controller in biofuel hybrid electric vehicle for optimal battery charge sustaining using AECMS strategy.Wang et al. (2023) designed a green building system with biomass and solar for heating, cooling and electricity needs, achieving low emissions and costs. Wu et al. (2023) proposed a product-category oriented intelligent model using random forest algorithm for sustainable supplier selection criteria system construction.Zhao (2023) analyzed an industrial building energy management system using artificial intelligence for energy savings based on data collection and impulse prediction.ZOU et al. (2023) discussed the connotation and pathways for transitioning to a new green and intelligent energy system to meet sustainable development demands.

II. Materials and Methods

The monitoring and analysis of electricity quality and energy consumption within the textile industry demanded a suite of precise and sophisticated equipment. To meticulously capture and evaluate the nuanced parameters shaping power dynamics, the following state-of-the-art tools were employed:

This advanced apparatus served as the cornerstone in gauging and logging an array of crucial electricity quality metrics. Capable of measuring and recording voltage, current, harmonics, flicker, frequency, and more, three units of the Fluke 435 Series II were deployed simultaneously. Strategically positioned across distinct points within the installation, these analyzers provided comprehensive insights into the variegated aspects of power quality.

The Transformation Station (PT) is the company's installation responsible for converting electrical energy from Medium Voltage (MT) to Low Voltage (BT), involving composite voltages ranging from 15 kV to 400 V.

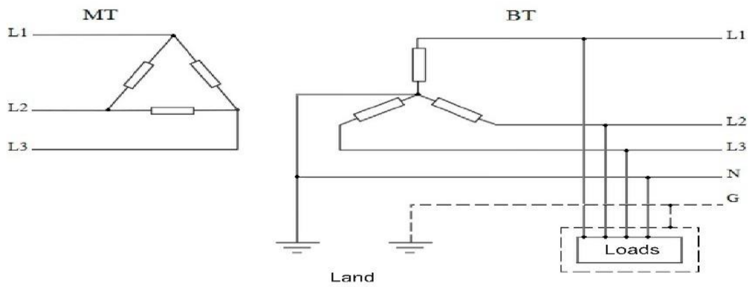

Figure.1 Neutral regime (TT) in PT installation.

The installation operates in a TT neutral regime (service earth and protective earth), utilizing this configuration across all transformers. Figure.1 illustrates the connection diagram, depicting the neutral connection to the service earth (N) and the bonding of metallic masses to the protective earth (G). This setup ensures the safety of individuals involved.

In this neutral regime, the appropriate protective devices are Differential Residual Current Protection Devices (DDR), designed to initiate interruption at the first sign of a fault. The purpose of neutral grounding is twofold: it limits voltage concerning the ground during operation and facilitates the proper functioning of protection devices.

A cell featuring a disconnector operates without cutting power (it does not open the circuit in case of a defect) and is positioned vertically upon arrival from Medium Voltage (MT) to the Transformation

Station (PT).

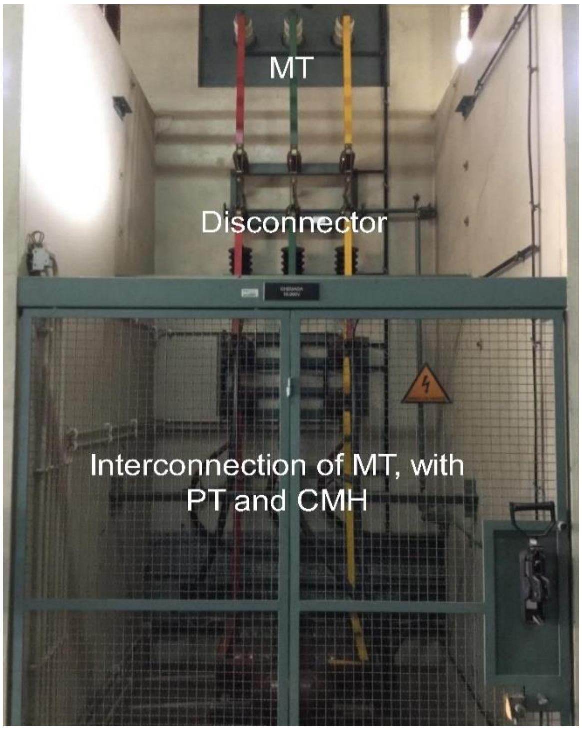

Figure.2 MT general outage cell.

The disconnector, highlighted in Figure2, is the interface linking the Medium Voltage network and the power supply of the entire transformation station, including the mini-hydro plant (CMH). The buses' red, green, and yellow colors denote the MT RST phases, respectively.

Harnessing the capabilities of the Fluke 1735 Power Logger, the energy consumption parameters were assessed with precision. This device meticulously measured and recorded active, reactive, and apparent power, alongside power factor assessments. The deployment of three units of this logger facilitated a comprehensive understanding of energy utilization patterns across the textile factory.

Critical in interfacing the current-carrying conductors with the monitoring apparatus, Current Transformers played an instrumental role. Employing CTs with ratios of 150/5 A and 300/5 A as per the specific requirements ensured accurate and calibrated measurements essential for the assessment process.

Shielded and adept at preventing external noise interference, specialized connection cables proved indispensable. These cables facilitated seamless connections, linking the monitoring equipment precisely to the current transformers or directly to the LV busbars. Their shielding capabilities ensured an environment conducive to precise data collection, free from external disturbances.

This ensemble of cutting-edge equipment, meticulously calibrated and strategically deployed, formed the bedrock of the comprehensive monitoring and analysis endeavors. Their collective prowess enabled the extraction of granular insights crucial in deciphering the intricate tapestry of electricity quality and energy consumption within the textile industry.

III. Experimental Setup and Procedure

The comprehensive evaluation within the textile factory relied heavily on the meticulous selection of monitoring locations strategically chosen to encompass pivotal stages of power transmission and utilization. These included scrutinizing the incoming medium voltage supply to the transformer substation to gauge baseline power characteristics, studying the low voltage buses of individual 1600 kVA transformers for localized assessments, and delving into high-power loads like stenter machines and the effluent treatment plant to understand energy consumption's impact on electricity quality.

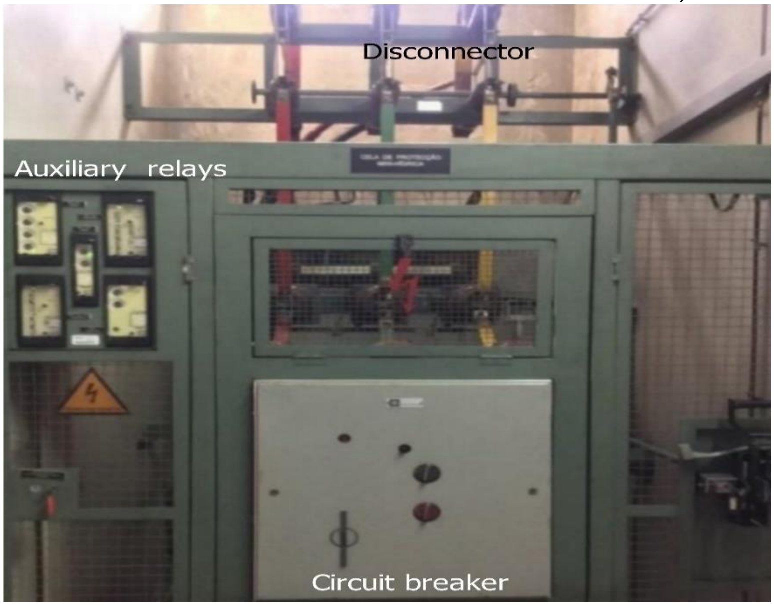

Figure.3 Interconnection and protection cell between the mini-hydro plant and the grid.

Figure 3 displays the interconnection and protection cell linking the mini-hydro plant to the grid. This setup is a crucial interface ensuring the seamless connection and secure operation between the mini-hydro plant's power generation system and the larger grid network. It typically incorporates protective devices, such as relays or circuit breakers, to safeguard both the mini-hydro plant and the grid from potential faults or disturbances. This configuration ensures efficient power transmission and enhances the reliability of electricity supply between the local mini-hydro system and the broader grid infrastructure.

Two monitoring durations were implemented to capture a holistic spectrum of data: continuous monitoring for a week at 10-minute intervals to observe transient fluctuations and spot measurements over three days at 5-minute intervals for in-depth analysis of engineering parameters such as harmonics, flicker, and power consumption. An extensive range of parameters was measured, including voltage, current, active/reactive/apparent power, power factor, frequency, flicker severity, voltage unbalance, harmonics, and total harmonic distortion.

The captured data underwent rigorous analysis employing specialized tools like Fluke Power Log Software and Excel. This analysis unveiled crucial insights into voltage regulation, load impact, deviations in electricity quality, harmonic contributions, and energy consumption patterns. The outcome was a thorough identification of installation issues and opportunities for energy efficiency improvements, culminating in a series of recommendations for enhancing the installation.

In conclusion, the meticulous selection of monitoring locations, detailed measurements, and advanced analytical tools provided a comprehensive understanding of the textile factory's electricity quality and energy performance. This assessment highlighted existing challenges and delineated a clear pathway toward augmenting operational efficiency and ensuring sustainable practices within the facility.

IV. Results and Discussion

The electrical distribution throughout the factory is carried out through a complex and enormous set of partial switchboards, with the loads connected to them being surveyed and updated in this work.

Figure.4 depicts the temporal progression of effective voltage values for L1N, L2N, L3N, and LNG (maximum and minimum half-cycle values) at T2. Over the monitored period, two short-term power outages occurred. The first outage was recorded around 5 pm on 11/17 (Saturday) and the second interruption occurred at approximately 1:20 am on 11/22 (Thursday).

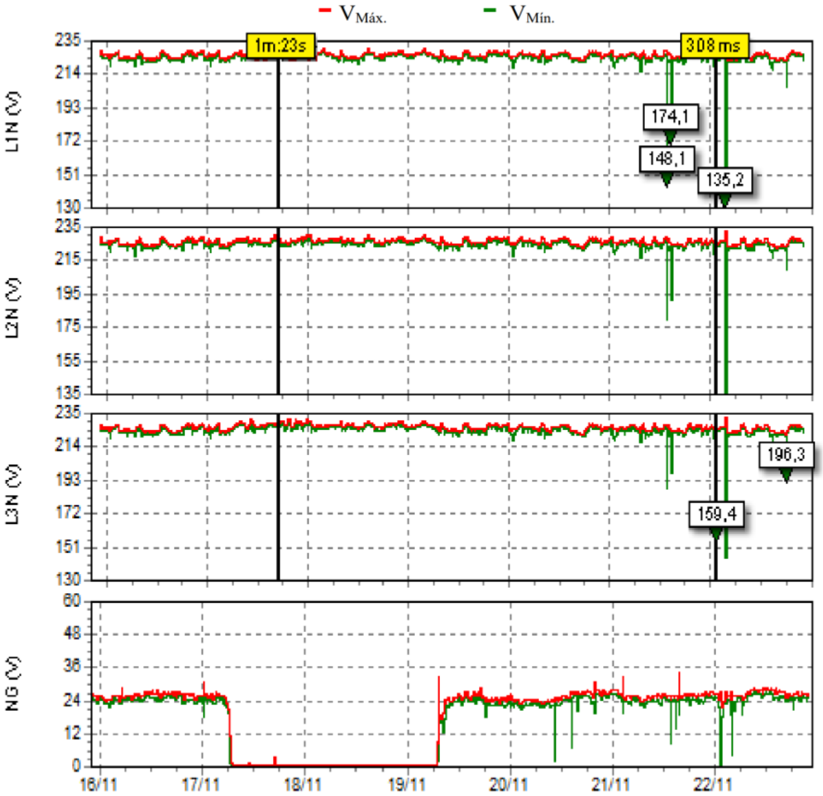

Figure. 4 Evolution of effective voltage values in T2.

The initial interruption resulted from a tree falling, which caused the MT lines to make contact during its removal. The subsequent interruption was due to meteorological conditions—a period of heavy rain and intense winds.

Figure5 shows the temporal evolution of the effective values of voltages L1N, L2N, L3N and LNG (maximum and minimum half-cycle values) at T3.

There is a voltage between neutral and ground (NG) of approximately 22 V over time, dropping to around 2 V, on average, during production shutdowns (weekends). The maximum and minimum values between phases and neutral were within the regulated limits until 10/28.

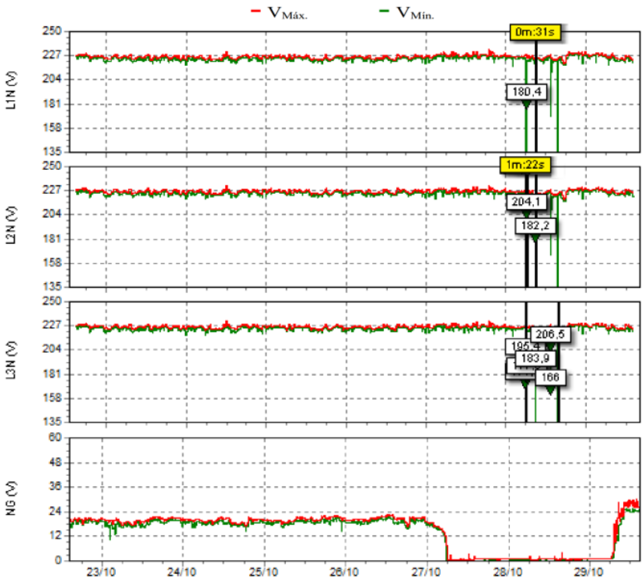

Figure. 5 Evolution of effective voltage values in T3.

On 10/28, a Sunday, there were short-term interruptions, with an interruption time of less than 2 minutes and some voltage dips, as seen in Figure6. The causes of the interruptions are once again related to phenomena meteorological conditions, such as thunderstorms and strong winds. The four recorded power outages lasted 1m:22 s, 1m:7 s, 46 s and 31 s.

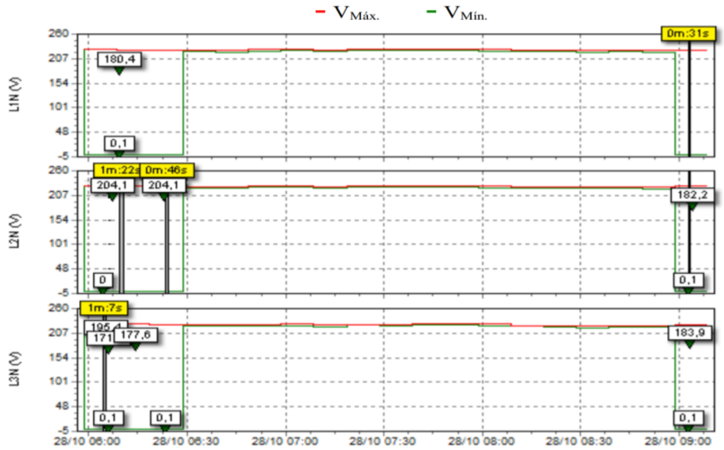

Figure. 6 Evolution of effective voltage values in T3, on 28-10.

Figure7 shows the records of the effective values of the currents L1, L2, L3 and N (maximum and minimum half-cycle values) in T2. An identical evolution can be seen in the three phases, with the maximum value reached being 1237 A in phase L3. On the neutral conductor, the maximum value recorded was 98 A, immediately following the interruption on 22/11.

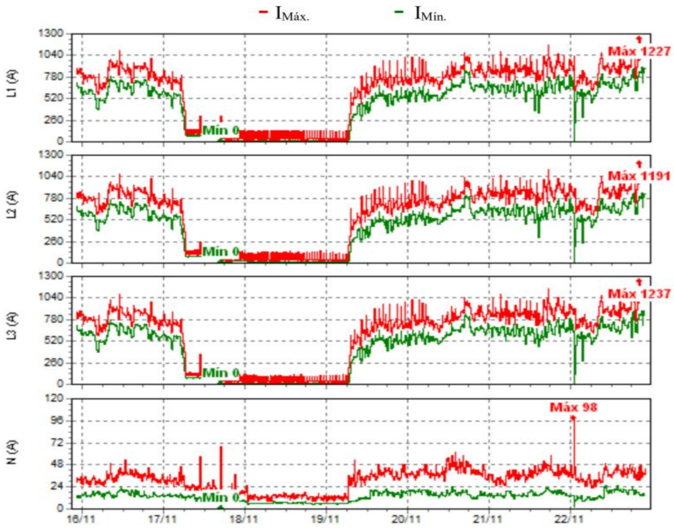

Figure.7 Evolution of the effective values of the currents in T2.

Figure8 shows the temporal evolution of the effective values of currents L1, L2, L3 and N in T3 (maximum and minimum half-cycle values).

The maximum values recorded were 1156 A, 1215 A and 1194 A for phases L1, L2 and L3, respectively. In the neutral conductor, the maximum value recorded was 92 A, corresponding to the power outages on 10/28.

The average voltage between neutral and earth (NG) throughout factory production measured around 25 V. In contrast, during the period without factory production (11/17 and 11/18), this average value reduced to about 1 V.Consistent with the operational principle of a TT neutral, the transformer neutral directly connects to the earth through independent electrodes. Consequently, the potential difference between neutral and ground typically remains low. It has been suggested that measurements be taken on both service and protection grounds to investigate the cause of the elevated voltage observed between neutral and earth.

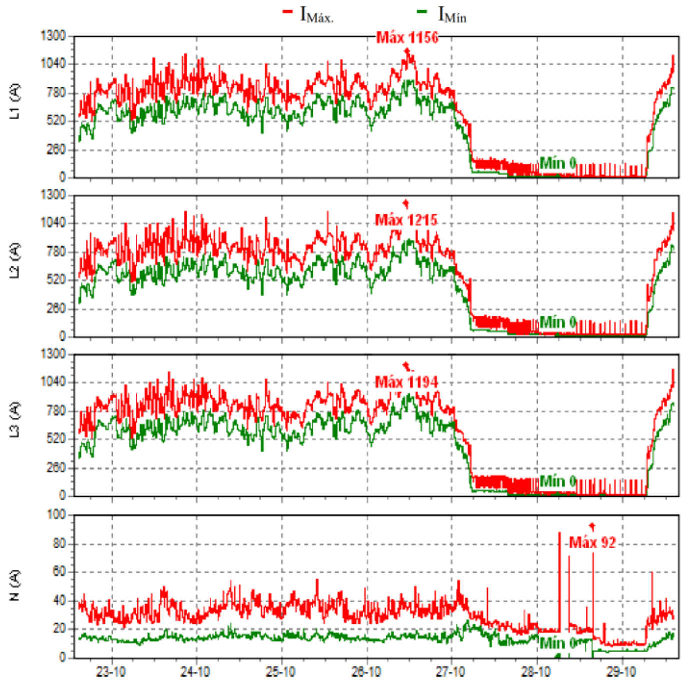

Figure.8 Evolution of effective current values in T3.

As seen throughout this chapter, electric motors are the highest installed power loads in the machines presented here. When powered by electronic speed variable frequency drives, a possible reduction in energy consumption and a reduction in motor starting current are evident. However, the distorted currents generated by the electronic converters considerably pollute the electrical network, thus increasing the distortion in the voltages. Since the WWTP was the only load analyzed here that does not have electronic speed drives for the motors, the THD in the current of the three phases was less than 10%, while in the other machines it was almost always higher than 30%. This fact is also quite clear from the current waveforms presented throughout this chapter for the different machines. It is concluded that the harmonic that contributed most to the THD of the current was the 5th order, for all loads. During the monitored periods, no critical events related to the continuity of service, frequency and flicker, voltage sags and swells were recorded. It was found that during the sampled time, the inverse component of the voltages did not exceed 2% of the corresponding direct component in the monitored loads, as stipulated by the standardization.

The high installed power in the factory shows that there is great potential for energy efficiency improvements. The periodic monitoring of currents in the main feeders of partial boards provides essential information to identify anomalies or opportunities for improvement. Monitoring the power quality parameters at the most critical points of the installation also allows detecting abnormalities, identifying their causes and defining mitigation measures.

Regarding power quality, it was found that the THD limits established by IEEE-519 were exceeded in some loads equipped with electronic speed drives. On average the 5th harmonic predominated in the current spectrum. Although there were no records of voltage events outside the established standards, it is important to continue monitoring to act preventively. The recorded voltage unbalance remained within the limits allowed by the regulations.

V. Conclusions

In this work, an audit was carried out to carry out a detailed analysis of the electrical installation of a textile company, to contribute to a greater efficiency and improvement of power quality.The analysis focused on characterizing the loads connected to the main partial boards spread over the factory, with special focus on the largest loads in terms of installed power. Measurements were also made at various points of common coupling to assess the most relevant power quality parameters.It was found that there are opportunities to improve energy efficiency by replacing older electric motors with more efficient ones, improving power factor correction and ensuring speed variation on large motors whenever the technological process allows it.Regarding power quality, although no critical events related to voltage disturbances were recorded, it was found that the current harmonic distortion exceeded the IEEE-519 limits at some points of common coupling, especially in variable speed drive applications. Continuous monitoring is, therefore essential to ensure early detection and mitigation of any anomalies. This work allowed to identify improvement opportunities, increase knowledge about the electrical installation and define an essential basis for efficient energy resource management. The factory now has more and better information to help decision making aimed at reducing energy costs and ensuring a quality power supply to equipment and processes.

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