American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-13, Issue-6, pp-64-78
www.ajer.org
Research Paper Open Access

Power quality analysis, case study with welding equipment

José Oliveira Dantas[1], Luiz Henrique Pereira da Silva[1], Ernesto Guevara Leal Maniçoba[2], Jacques Cousteau da Silva Borges[1*]

[1]Department of Industry, Instituto Federal do Rio Grande do Norte, Natal, Brazil
[2]Renewable Energy Technology Unit, Universidad Tecnológica del Uruguay, Durazno, Uruguay
**Corresponding Author*

ABSTRACT:*Power quality is a set of voltage, current and frequency parameters, which are established in laws and standards, and must be complied with by distribution companies and equipment suppliers. Historically, welding machines have always been known as power quality "villains", due to voltage sags and very low power factors. Currently, new "inverter" type machines have become popular. However, its use introduces other problems into the electrical grid, such as the various harmonics in the power system. This work details the use of three different machines, and measures their parameters using energy analyzer equipment, thus detailing the different effects and results of welding machines on the energy quality of an electrical network.*

KEYWORDS *Power quality, power analyzers, welding machines. harmonics.*

Date of Submission: 07-06-2024 Date of acceptance: 21-06-2024

I. INTRODUCTION

The objective of this work was to investigate how the use of different types of welding machines affected the quality of electrical energy available in the distribution board of an academic welding workshop, in accordance with the standards established by ANEEL Normative Resolution No. 956/2021, in Brazil.

The main reason for this investigation is that some modern welding machines work through the process of converting an alternating voltage profile to a continuous voltage profile. This process used in electronic equipment is known to cause several disturbances in the quality of electrical energy in the network to which they are connected.The accumulation of disturbances in a circuit significantly affects the functioning and useful life of devices and electrical infrastructure.

The analysis of quality parameters during the operation of these machines aims to confirm the impacts predicted in the technical literature, as well as to serve as guidance for future projects that aim to mitigate disturbances in energy quality.Next, the theoretical aspects directly related to the work developed will be addressed, detailing the main subjects of the study in question and based on the different approaches researched in the literature.

Electrical energy is supplied to the various consumers by an electrical voltage signal that propagates through a long and complex transmission network. The voltage profile (Fig. 1) used as a quality standard presents an alternating sinusoidal waveform, with a fixed frequency (f) and amplitude that varies depending on the type of service (LEÃO *et al* , 2014).

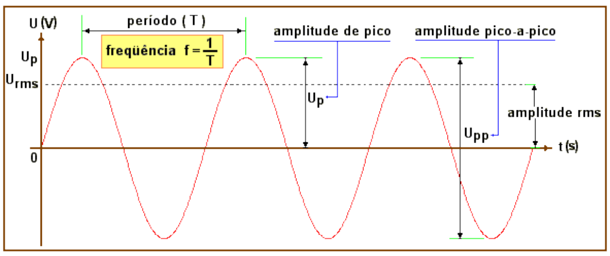


Fig. 1: Example of voltage profile. Source: FACOM, 2023.

In Brazil, for example, the electrical voltage profile available to residential consumers presents the form of a sinusoidal alternating wave, with a fixed frequency of 60 Hz and an effective voltage (rms amplitude) of 220 V or 117 V. Generating companies, transmitters and Electricity utilities work daily to maintain the energy signal within these standards. One of the reasons for this commitment is because electrical equipment is made to work exactly with the standardized electrical signal of our networks.

There are several power quality problems that can arise as deficiencies generated by poorly planned or poorly executed distribution. But quality problems also arise from the interaction of the supply system with the loads (LEÃO *et al* , 2014).

Loads, which are the electrical equipment we use, can be divided into two categories: linear loads and non-linear loads. Linear loads are those that, when fed by an undistorted sinusoidal voltage source (Fig. 1), will request an undistorted sinusoidal current wave from the network (LEÃO *et al* , 2014).

Non-linear loads are those that request a distorted current from the network, regardless of whether they are being fed by a distorted sinusoidal voltage source or not (LEÃO *et al* , 2014).

An example of a linear load are the electrical resistances found in toasters or electric showers. Examples of non-linear loads are the various electronic equipment that are used in homes, such as televisions, cell phones, computers, LED lamps, etc.

These electronic equipment work using a continuous electrical voltage signal and to obtain this signal they need to be powered by rectifier sources. These sources convert the alternating electrical signal from the network into a continuous signal and in this process they end up generating some disturbances that will be presented later.

The spread of residential and industrial electronic equipment (televisions, computers, LED lamps, cell phone chargers, frequency inverters, etc.) began to interfere with the quality of the electrical signal in a much more complex way by using electronic switching to rectify the power signal.Thus, Electrical Power Quality (QEE) is the condition of the electrical voltage and current that allows equipment, processes, installations and electrical systems to operate satisfactorily, without compromising performance (LEÃO *et al* , 2014) .

QEE currently constitutes a crucial factor for the competitiveness of practically all industrial and service sectors. In industrial installations that have critical loads, small interruptions generate large losses of data, raw materials and time (datacenters, pharmaceutical, food and process industries, assembly lines, telecommunications segment, etc.) causing considerable financial losses (SILVA *et al* , 2011).

To maintain the voltage level within certain acceptable operational limits, both at transmission and distribution levels, control and monitoring measures are necessary from both supervisory bodies and energy supplying concessionaires (OLESKOVICZ *et al* , 2007).

In Brazil, ANEEL Normative Resolution No. 956/2021 establishes the Electricity Distribution Procedures in the Brazilian National Electric System (PRODIST). It came into force on January 1, 2022 and its Module 8 deals with the Quality of Electricity Supply.

The disturbances associated with energy quality covered by this resolution are: steady-state voltage variations, power factor, harmonics, voltage unbalance, voltage fluctuations, frequency variation and short-term voltage variations.

Voltage variations in steady state refers to the comparison of the voltage value obtained by appropriate measurement, at the connection point, in relation to the voltage levels specified as adequate, precarious and critical (PRODIST – Module 8, 2021).For voltage values below 230 kV, voltage levels must be between 95% and 105% of the system's nominal operating voltage at the connection point. This means that the voltage at the input point for rms voltage values of 220 V must remain in the range of 209 V to 231 V.

Power factor is the measure that indicates how efficiently a load draws useful power from the supply network, defined by the ratio between active and apparent power (LEÃO *et al* , 2014)

For consumer units with voltage lower than 230 kV, the power factor at the connection point must be between 0.92 and 1.00 inductive, or 1.00 and 0.92 capacitive (PRODIST – Module 8, 2021) .

A distorted, deformed or non-sinusoidal periodic wave is the result of the superposition of a series of sinusoidal waves, which has a fundamental component and a set of waves, called “harmonics”, responsible for the greater or lesser degree of distortion of the distorted wave (LEÃO *et al* , 2014).

The total current harmonic distortion indicator must not exceed 10.0% of the fundamental wave in networks whose nominal voltage is less than 2.3 kV.

Voltage unbalance is the phenomenon characterized by any difference observed in the amplitudes between the three phase voltages of a given three-phase system (PRODIST – Module 8, 2021).

To evaluate the voltage unbalance, Equations 1 and 2 (PRODIST – Module 8, 2021) are used to find the Voltage Unbalance Factor (FD%).

$$FD\% = 100 * \sqrt{\frac{1-\sqrt{3-6\beta}}{1+\sqrt{3-6\beta}}}\,[\%] \qquad (1)$$

$$\beta = \frac{V_{ab}^4 + V_{bc}^4 + V_{ca}^4}{(V_{ab}^2 + V_{bc}^2 + V_{ca}^2)^2} \quad (2)$$

For consumer units with voltage lower than 230 kV, the FD% must be lower than 3.0%.Voltage fluctuation is a phenomenon characterized by the random, repetitive or sporadic variation of the effective or peak values of the instantaneous voltage (PRODIST – Module 8, 2021).

The distribution system and the generation facilities connected to it must, under normal operating conditions and in a permanent regime, operate within the frequency limits situated between 59.9 Hz and 60.1 Hz (PRODIST – Module 8, 2021).

Short-term voltage variations (VTCD) are significant deviations in the amplitude of the rms voltage value during a time interval of less than 3 minutes. For supplying electrical energy at an effective voltage of 220 V, they are classified into:Interruption: values below 22 V (below 10% of the effective voltage); Sinking: values between 22 V and 198 V (between 10% and 90% of the effective voltage); Elevation: values greater than 242V (above 110% of the effective voltage).

Table 1 lists some of the consequences when the network has or is affected by a quality problem.
An important condition to note is that the presence of harmonic distortions decreases the power factor, a low power factor generates voltage fluctuations, which will generate another problem and so on. In other words, the lack of care with any of these parameters triggers other quality problems, worsening the network situation.

Table 1: Consequences of the lack of quality in the electricity supply. Adapted from CAPELLI (2013).

Harmonic Distortions	*Low Power Factor*	Overvoltage
• Excessive heating of cables • Triggering of protective devices • Effective voltage drop • Decrease in power factor • Excess neutral current	• Limitation of transformer capacity • Voltage drops and fluctuations • Joule effect losses • Need to increase the diameter of the conductors	• Engine overheating • Burning of electronic boards • Activation of protection systems

The supply of electrical energy outside the permissible parameters can cause various damages, such as malfunction, burning, interruption of processes, among other anomalies (SILVA *et al* , 2011).

II. WELDING MACHINES

There are different models of welding machines available on the market. They vary according to the application, the type of material used, the voltage at the tip of the electrode, the magnitude of the current they are capable of conducting and the operating principle. In this work, three machines that are part of the equipment used in the academic welding laboratory were studied: the Smashweld 257 from the manufacturer ESAB, the PICCOLA 400T from the manufacturer BAMBOZZI and the MaxxiTIG 200P AC/DC from the manufacturer BALMER.

All of these machines have in their sources a step to convert the input current from alternating current to direct current (AC-DC). According to Senra (2013), AC-DC converters are among the main loads causing harmonics. Welding machines can then be characterized as disturbing sources of the electrical system, due to their non-linear loads and intermittent use behavior (SILVA et *al* , 2011).

Fig. 3: Smashweld 257 from manufacturer ESAB.

Table 2: Technical data of theSmashweld 257. Source: Adapted from ESAB.

Smashweld 257	
Tech. equipment development	Transformation/Rectification
Input Voltage	Three-phase 220V / 380V / 440V
Network frequency	50/60Hz
Output current/voltage range	30 - 250 A / 15.5 - 26.5 V

The Smashweld 257 (Fig. 3) is a semi-automatic set for MIG/MAG welding. The MIG/MAG fusion welding process uses the heat of an electric arc formed between a consumable metal electrode and the parts to be joined. Both the arc and the melting parts are protected against contamination of the atmosphere by a gas or a mixture of gases (Smashweld 257, User's Manual).

Fig. 4: PICCOLA 400T from the manufacturer BAMBOZZI .

Table 3: Technical data of the PICCOLA 400T. Source: Adapted from BAMBOZZI.

PICCOLA 400T	
Tech. equipment development	Transformation/Rectification
Input Voltage	Three-phase 220V / 380V / 440V
Network frequency	60Hz
Output current range	40 - 400 A
Arc voltage at 400 A	36V

The PICCOLA 400T (Fig. 4) is a three-phase welding machine for general applications. It has an arc current control that can be adjusted according to the material used. (PICCOLA 400T, User Manual).Unlike the other machines in the study, this one does not have any technology involving the injection of inert gas to protect the weld site from oxidation.

Fig. 5: MaxxiTIG 200P AC/DC from manufacturer BALMER . Source: BALMER.

Table 4: Technical data of the MaxxiTIG 200P AC/DC. Source: Adapted from BALMER.

MaxxiTIG 200P AC/DC		
Output Current Type	B.C	A.D
Tech. equipment development	Rectification/Inversion	Rectification/Inversion
Input Voltage	Single phase 220V	Single phase 220V
Network frequency	50/60Hz	50/60Hz
Output current/voltage range	10 - 200 A / 10.4 – 18V	5 A - 200 A / 10.2 – 18V

The MaxxiTIG 200P AC/DC (Fig. 5) uses TIG technology with an inverter source. TIG welding is an electric arc welding process between a non-consumable tungsten electrode and the fusion piece with gas shielding, to which a filler metal is added or not, normally in the form of a relatively thin wire. . The TIG process allows the welding of ferrous materials and their alloys, stainless steel, copper, brass, aluminum, etc. (MaxxiTIG 200P AC/DC, User Manual).

The Smashweld 257 and PICCOLA 400T have in their sources a stage consisting of an uncontrolled three-phase 6-pulse AC-DC converter, consisting of 6 diodes, identified in Fig. x by a rectifier bridge.The MaxxiTIG 200P AC/DC has one or two single-phase AC-DC conversion stages consisting of 4 uncontrolled diodes, depending on the chosen DC or AC output mode.

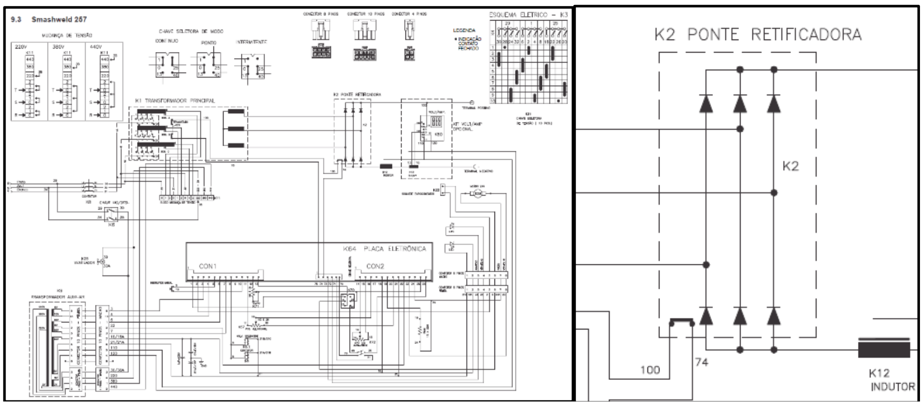


Fig. 6: Electrical diagram of the Smashweld 257, highlighting the diagram of an uncontrolled 6-pulse AC-DC converter . Source: ESAB.

Senra (2013) explains that in uncontrolled conversion processes, the converter diodes only conduct when the source voltage is greater than the capacitive filter voltage (first stage after rectification to guarantee a continuous voltage level at the output). This occurs for a short time and the current must be high to maintain the voltage across the load and still charge the capacitor.

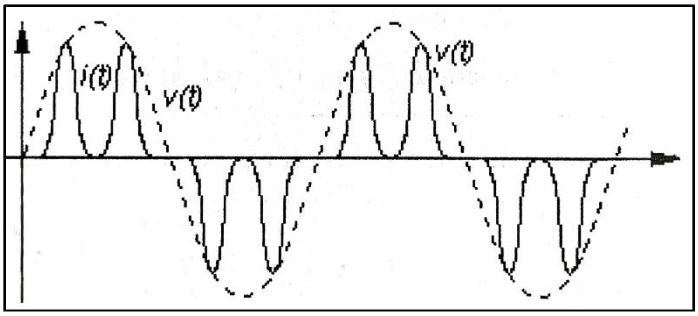


Fig. 7: Simulation of the current waveform (solid line) of a 6-pulse AC-DC converter fed by an unstrained voltage source (dashed line). Source: Adapted from SENRA, 2013.

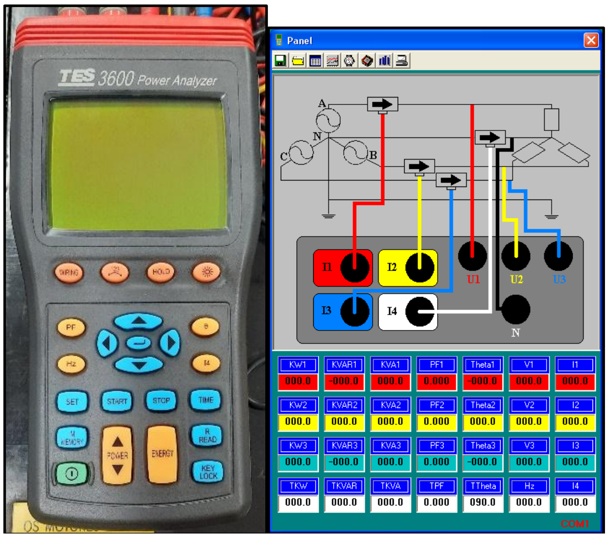
As a result, the current takes the form of a high pulse of short duration (Fig. 7). The presence of inductors at the rectifier input (mainly transformers) increases the current circulation time and this also affects its shape (SENRA, 2013).

III. MATERIAL AND METHODS

The quality of electrical energy is best assessed when multiple measurements are taken of the analyzed circuit. The reason for this is that some disturbances are only considered problems when they persist for a period.Therefore, to estimate the quality of electrical energy in the academic welding workshop, a device capable of creating a record of the values of various electrical quantities at fixed time intervals was used. The energy quality assessment was then carried out by comparing the equipment records with the standards defined by the ANEEL resolution.

The quality analyzer used in the experiment was the TES 3600 (Fig. 8a), from TES Electrical Electronic Corporation, capable of measuring electrical voltage (V), electrical current (A), active power (W), reactive power (VAR), power apparent (VA), power factor (PF), phase angle (Θ) and frequency (Hz).

A microcomputer connected to the analyzer (Fig. 11) ran the PwrAnalyzer V7.7 software (Fig. 9b), made available by the same company as the equipment, so that it was possible to monitor the quantities in real time and then extract the measured data.



a) b)

Fig. 8: Quality analyzer - a) TES 3600; b) PwrAnalyzer V7.7 software panel. Source: TES3600 Manual.

The measurements were carried out on the distribution board of the academic welding workshop (Fig. 10a) following the scheme in Fig. 10b for three-phase electrical circuits during a practical class (Fig. 9) that took place from 3:25 pm until 4:50 pm July 27, 2023.

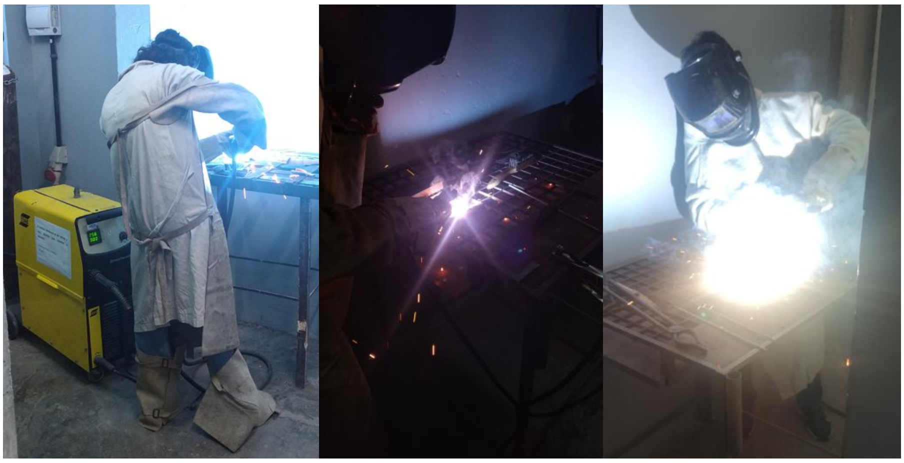


Fig. 9: Records of the practical welding class.

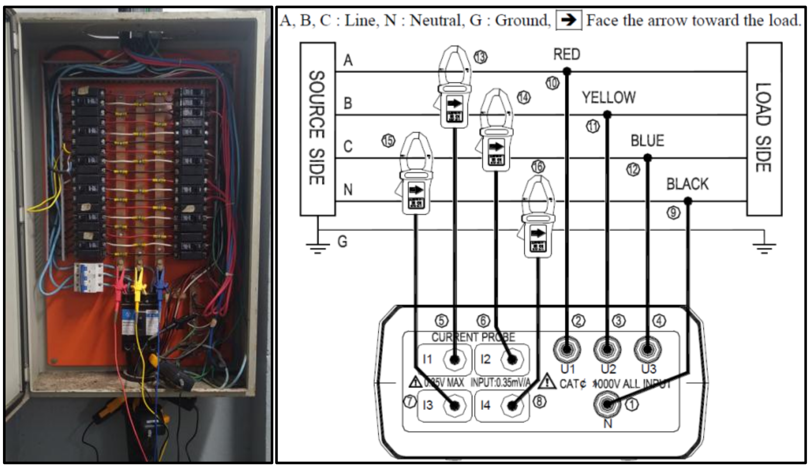


Fig. 10: Connection diagram - a) Connection of the equipment to the distribution board; b) Guide for connections. Sources: Author's own and TES3600 manual.

At the time of measurements, it is known that phase 1 powered a computer, an air conditioner, a notebook, ambient lighting and welding machines. Phases 2 and 3 were dedicated only to welding machines.In total, 3 sets of measurements were carried out. In the first and second measurements, the Smashweld 257 and MaxxiTIG 200P AC/DC machines were used. In the third measurement, only the PICCOLA 400T machine.

IV. RESULTS AND DISCUSSIONS

The objective of the work is to identify whether the quality of the energy distributed by the switchgear is disturbed by the use of welding machines. The data and analysis of each of the measurements will be presented below.It is important to highlight that in all measurements the frequency levels remained within the range of 59.9 and 60.1 Hz, in none of the measurements there was a voltage imbalance between the phases and no disturbances of the type of short-term voltage variation were observed. in the phases. Therefore, these topics will not be dealt with repetitively.

To analyze voltage fluctuations according to ANEEL standards, two continuous measurements are necessary, one lasting 10 minutes and the other lasting 2 hours. The data collected is not sufficient to carry out this analysis.It was noticed that the equipment uses the measured power values to calculate the power factor, that is, when there is no current being consumed the equipment records a power factor equal to 0. The graphs present all the recorded measurements, but for the analysis If the power factor is within the standards, measurements equal to 0 will be disregarded.

The equipment does not record harmonic current values, making it impossible to analyze the entire measurement period. However, the software allowed instantaneous extraction of the harmonic spectrum up to the 31st order, as well as the total harmonic distortion value of one phase at a time.

4.1 Measurement 1

The first measurement was carried out from 3:25:04 pm to 3:42:32 pm with an interval of 1 second for each data collection, totaling 1035 records. During the collection, two students practiced welding maneuvers, one using a three-phase Smashweld 257 and the other a single-phase MaxxiTIG 200P AC/DC connected to phase 3.
The data obtained is presented below:

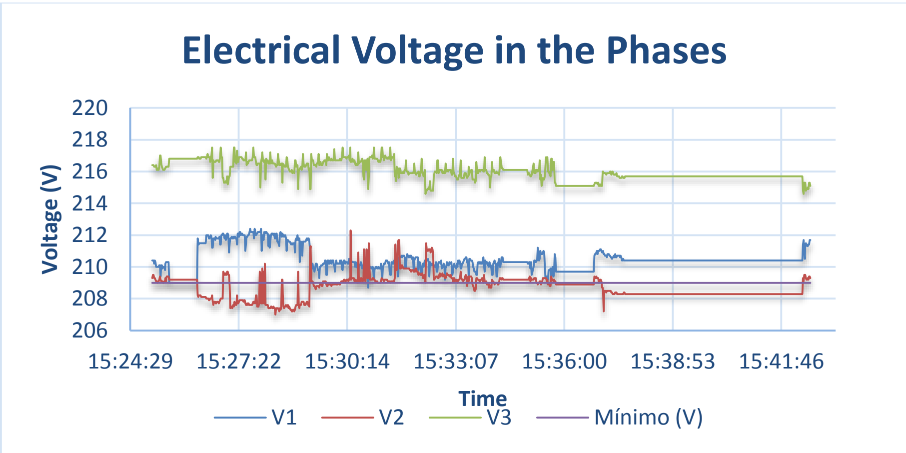


Fig. 12: History of voltage records from the first measurement.

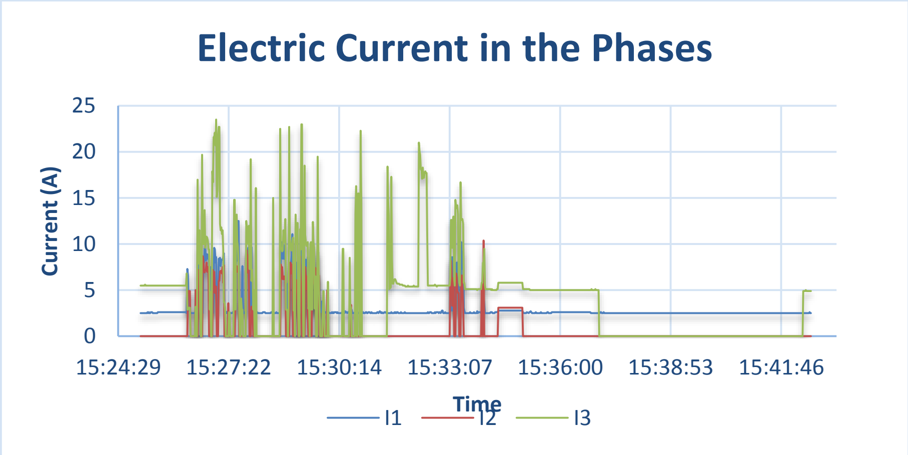


Fig. 13: History of current records from the first measurement.

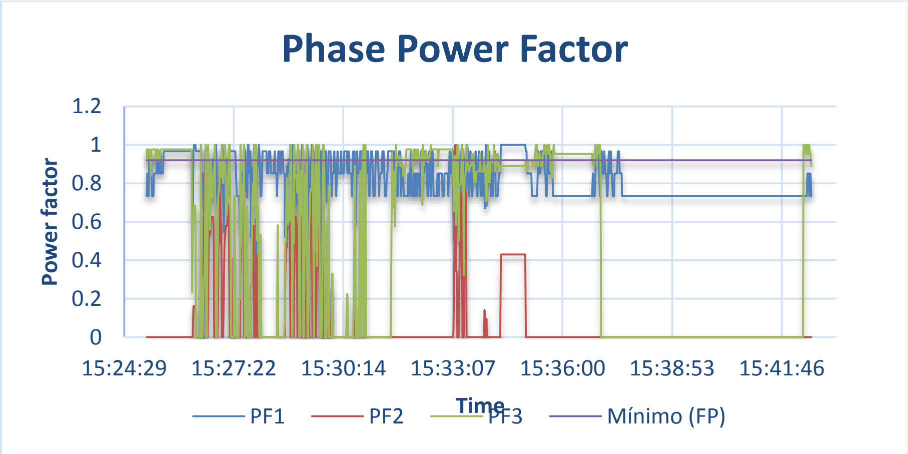


Fig. 14: History of power factor records from the first measurement.

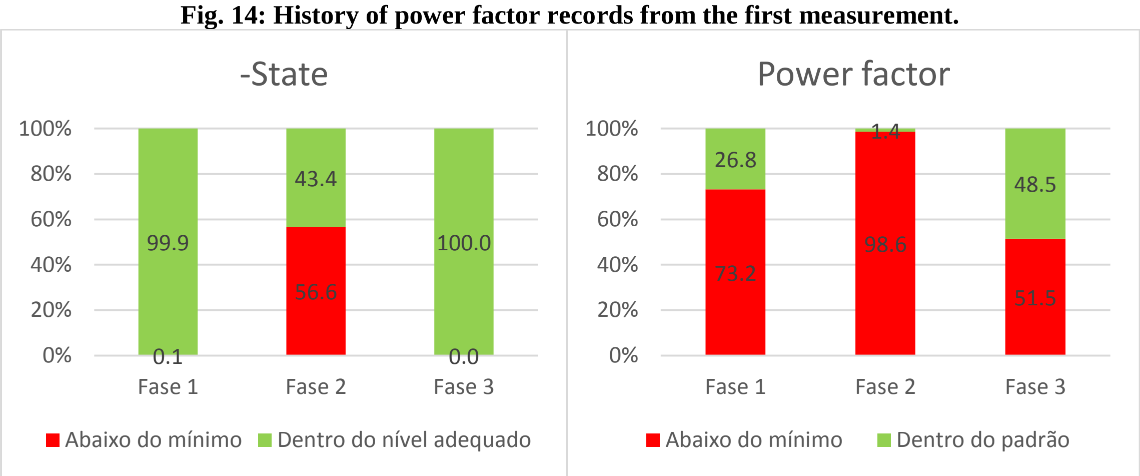


Fig. 15: Comparison with PRODIST parameters from the first measurement. Within the standard (green) and outside the standard (red) – a) Voltage in steady state; b) Power factor

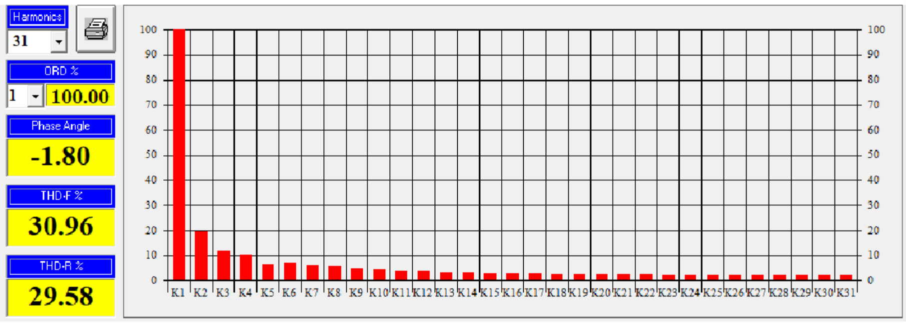


Fig. 16: Harmonic spectrum and total harmonic distortion rate of phase 1 during activation of the equipment in measurement 1.

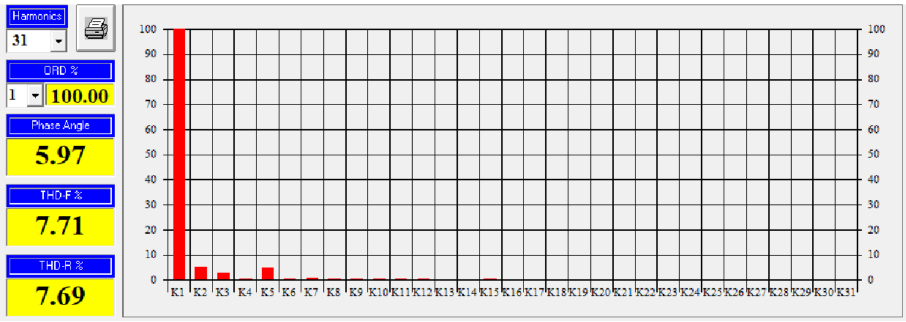


Fig. 17 Harmonic spectrum and total harmonic distortion rate of phase 2 during activation of equipment in measurement 1.

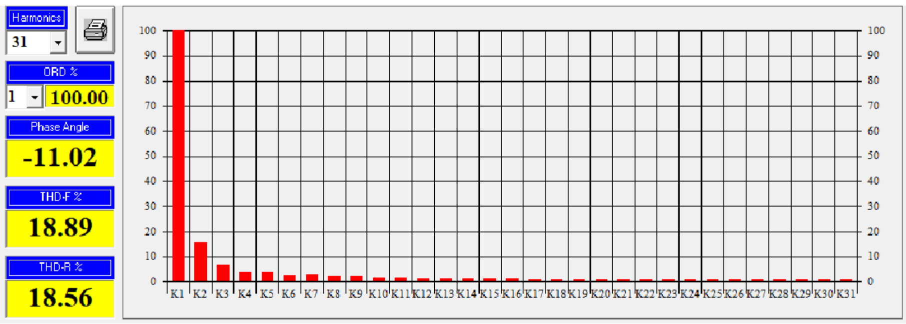


Fig. 18: Harmonic spectrum and total harmonic distortion rate of phase 3 during activation of the equipment in measurement 1.

The machine activation period is observed in Fig. 13 by current values above 2.6 A in phase 1 and values above 0 A in phases 2 and 3. A current value close to 2.6 A is observed in phase 1 due to the supply of energy to other equipment mentioned above.

As can be seen in Fig. 12, the electrical voltage in all phases fluctuates due to the use of machines. Phases 1 and 3 remain within the steady-state voltage levels considered adequate, unlike phase 2, which was below the appropriate level in 56.6% of the records (Fig. 15a). Some of these records occurred even when the welding machines were not activated, which may indicate the disturbance that other sectors cause in the workshop's distribution board.

Fig. 15b reveals how much the use of machines affects the network power factor. The power factor in phases 1, 2 and 3 were below the minimum in 73.2%, 98.6% and 54.5% of records, respectively.

It is notable that the equipment that worked connected to phase 1 slightly reduced the impact of the power factor, as did the MaxxiTIG 200P AC/DC connected to phase 3. The Smashweld 257 was the only machine that was fed from phase 2, revealing thus the low energy efficiency of the equipment.

Fig. 16 shows the harmonic spectrum of phase 1, which had other equipment in the sector connected, extracted during the activation of the welding machines. Phase 1 presents the highest total harmonic distortion rate, which is equal to 30.96%, well above the 10% standard limit. This must have occurred due to the concomitant use of air conditioning, computers, notebooks, welding machines and ambient lighting.

The total harmonic distortion rate of 7.71% in phase 2 that only fed the Smashweld 257 is within the limit (Fig. 17). The simultaneous use of the machines increases the total harmonic distortion rate in phase 3 to 18.89% (Fig. 18), confirming the generation of harmonic disturbances from the AC-DC converters.

4.2 Measurement 2

The second measurement was carried out from 16:00:56 to 16:18:24 with an interval of 1 second for each data collection, totaling 1033 records. During the collection, two students practiced welding maneuvers, again using the three-phase Smashweld 257 and the single-phase MaxxiTIG 200P AC/DC connected to phase 3.

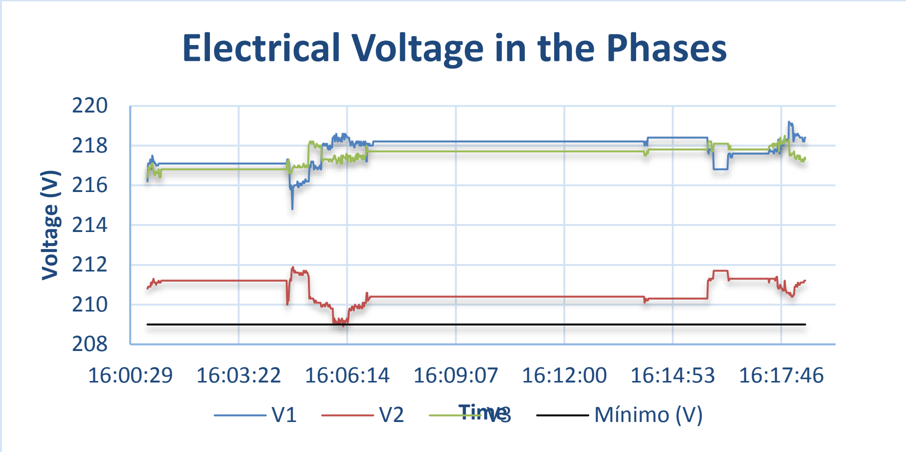


Fig. 19: History of voltage records from the second measurement.

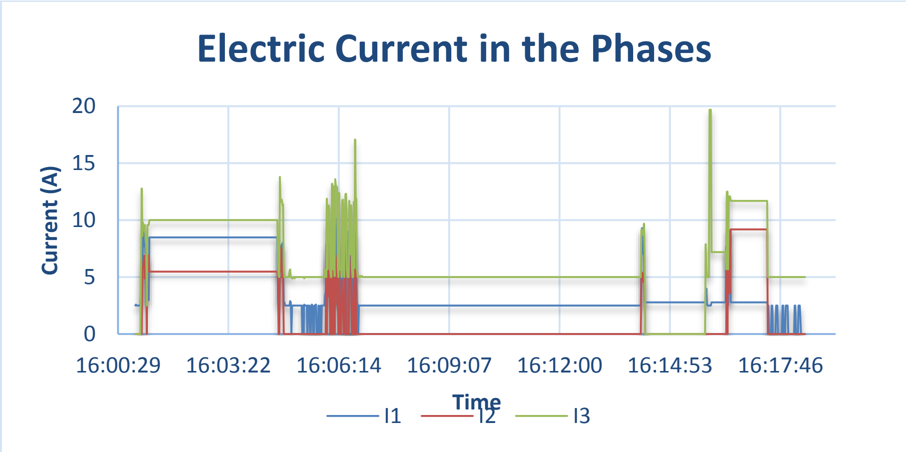


Fig. 20: History of current records from the second measurement.

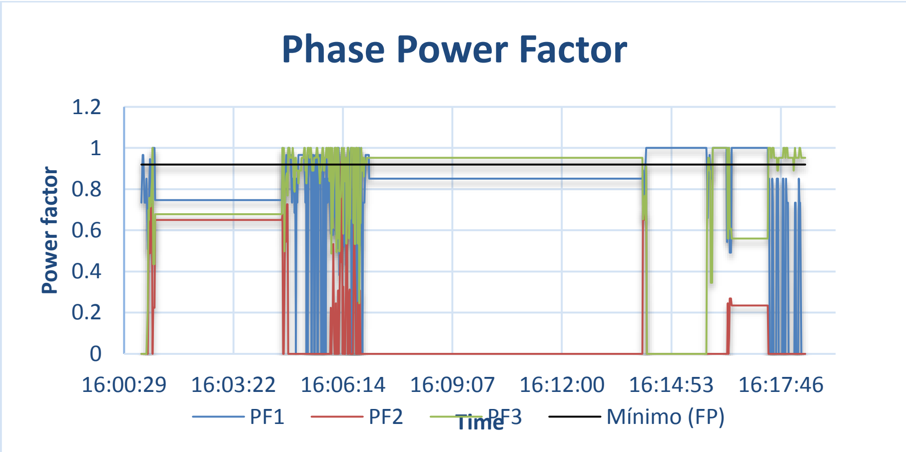
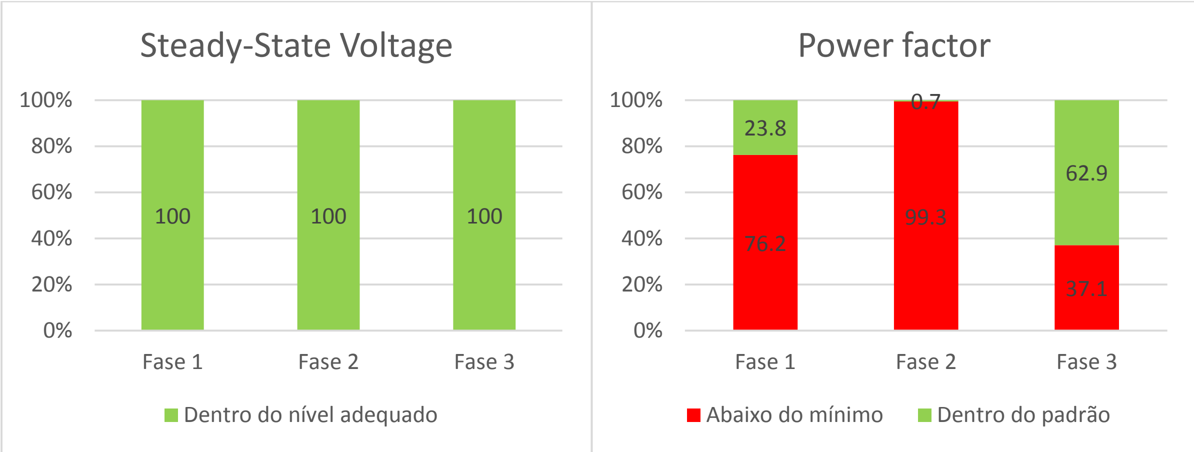


Fig. 21: History of power factor records from the second measurement.



a) b)

Fig. 22: Comparison with PRODIST parameters from the second measurement. Within the standard (green) and outside the standard (red) – a) Voltage in steady state; b) Power factor.

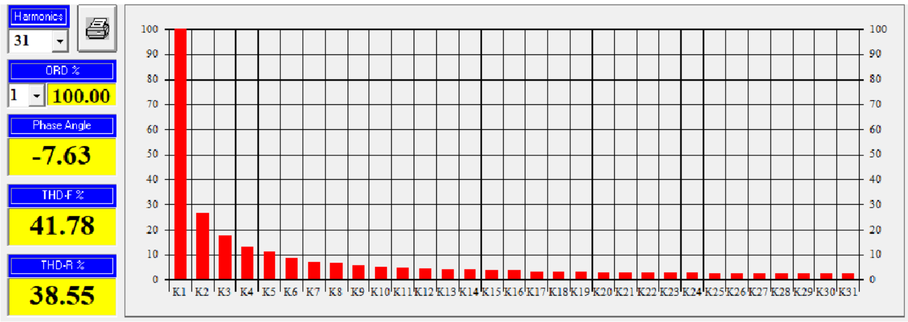


Fig. 23: Harmonic spectrum and total harmonic distortion rate of phase 1 during activation of the equipment in measurement 2.

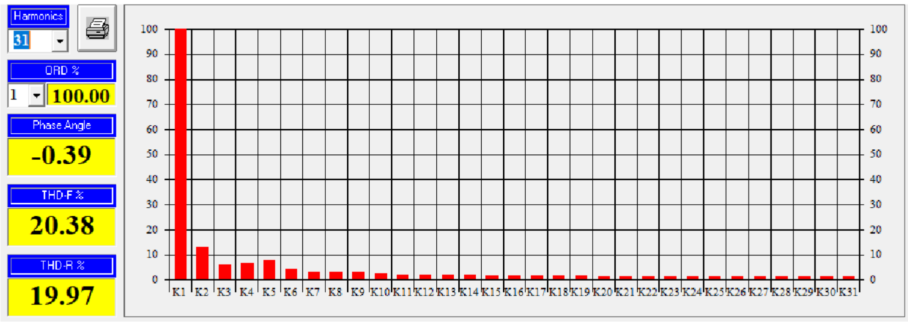


Fig. 24: Harmonic spectrum and total harmonic distortion rate of phase 2 during activation of the equipment in measurement 2.

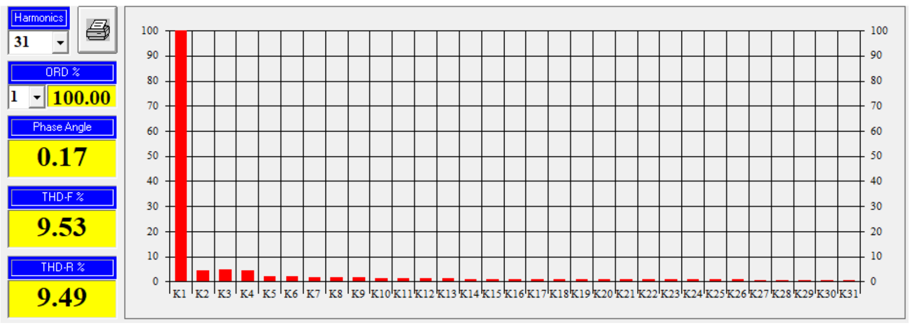


Fig. 25: Harmonic spectrum and total harmonic distortion rate of phase 3 during activation of the equipment in measurement 2.

As in measurement 1, the machine activation period is observed in Fig. 20 by current values above 2.6 A in phase 1 and values above 0 A in phases 2 and 3.The electrical voltage again suffers fluctuations in the phases (Fig. 19) due to the use of machines. This time all phases remain within the steady-state voltage levels considered appropriate (Fig. 22a), which strengthens the assumption of the disturbance that other sectors caused in the workshop's distribution board during measurement 1.

The power factor in the phases follows an almost identical behavior to that of measurement 1 (Fig. 22b), confirming the assumption of the influence of other equipment on the power factor of phase 1, the influence of the MaxiTIG 200P AC/DC on the power factor of the phase 3 and the low energy efficiency of Smashweld 257 revealed in phase 2.

Fig. 23 again shows the high total harmonic distortion rate of phase 1, which strengthens the assumption of the influence of other equipment connected to the phase.The total harmonic distortion rate in phase 2 was 20.38% (Fig. 24) and in phase 3 9.53% (Fig. 25), confirming once again the generation of harmonic disturbances from AC-DC converters, as they only supply power machines. solder.

4.3 Measurement 3

The third measurement was carried out from 16:33:55 to 16:50:01 with an interval of 1 second for each data collection, totaling 962 records. During collection, a teacher practiced welding maneuvers using the three-phase PICCOLA 400T machine.

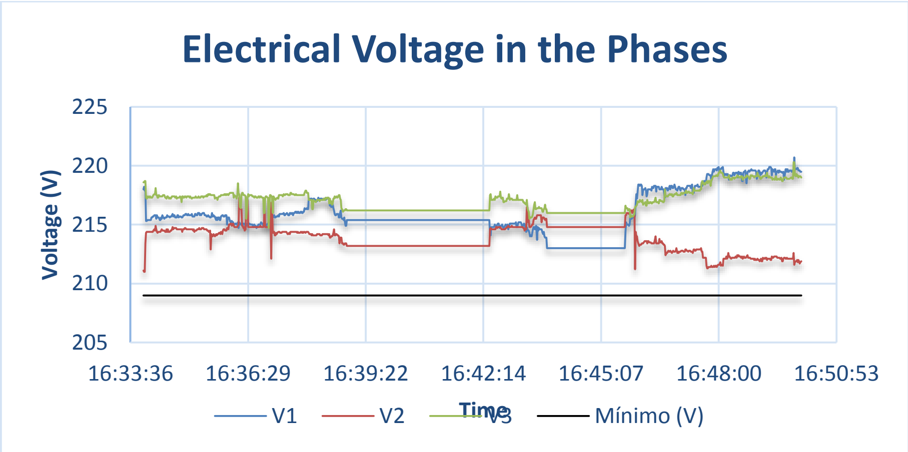


Fig. 26: History of voltage records from the third measurement.

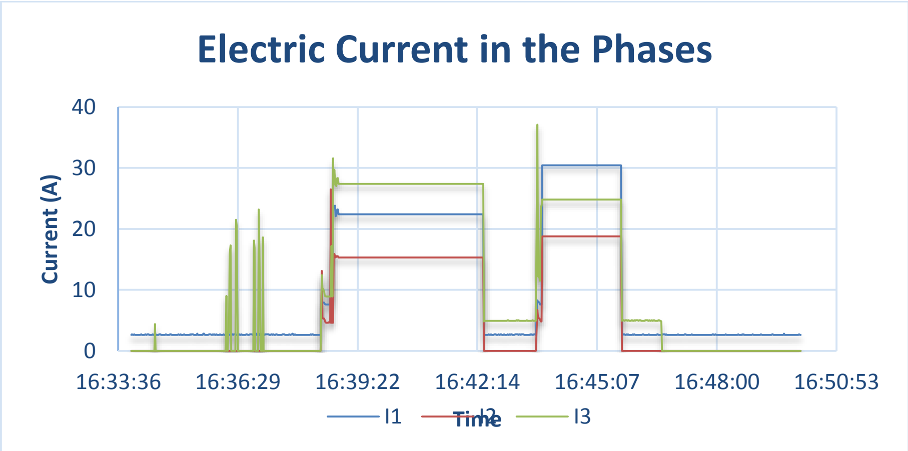


Fig. 27: History of current records from the third measurement.

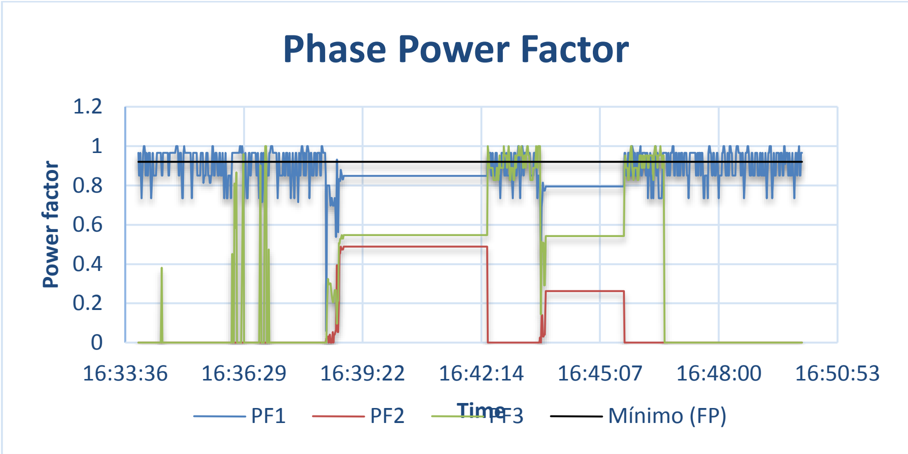


Fig. 28: History of power factor records from the third measurement.

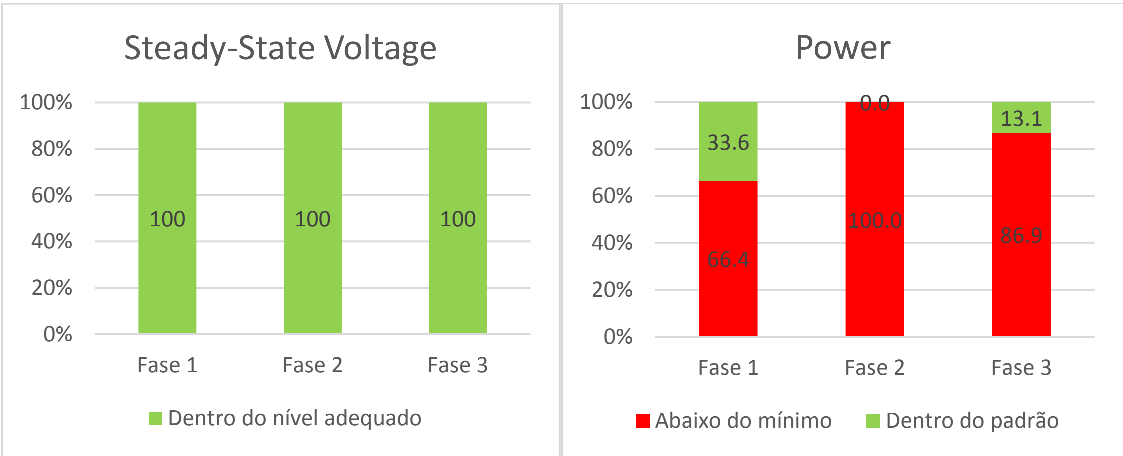


Fig. 29: Comparison with PRODIST parameters from the third measurement. Within the standard (green) and outside the standard (red) – a) Voltage in steady state; b) Power factor.

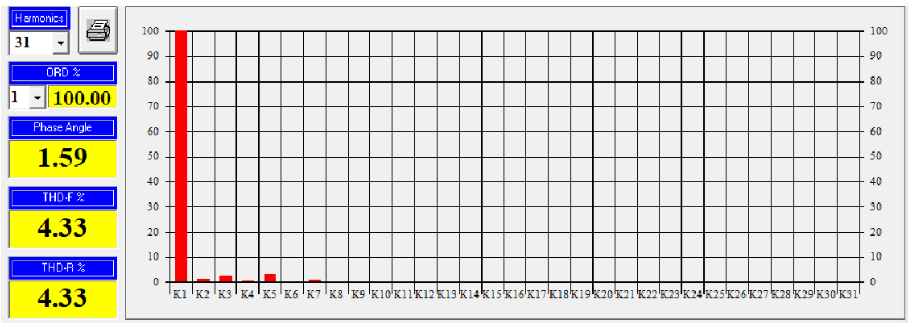


Fig. 30: Harmonic spectrum and total harmonic distortion rate of phase 1 during equipment activation in measurement 3.

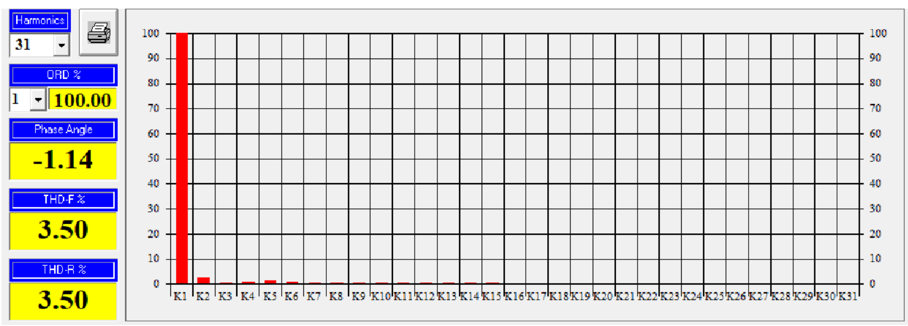


Fig. 31: Harmonic spectrum and total harmonic distortion rate of phase 2 during activation of the equipment in measurement 3.

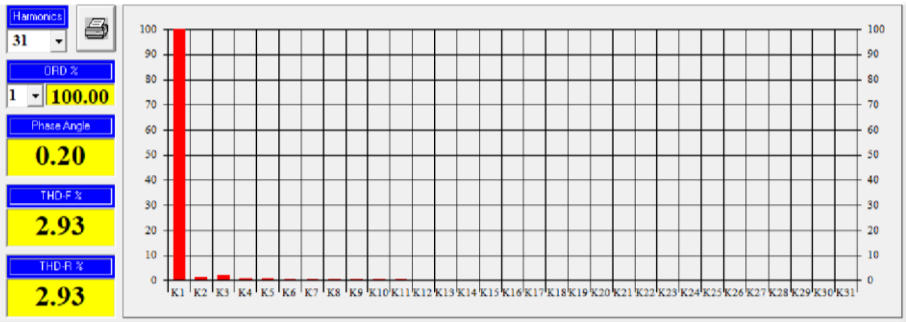


Fig. 32: Harmonic spectrum and total harmonic distortion rate of phase 3 during activation of the equipment in measurement 3.

As in measurements 1 and 2, the machine activation period is observed in Fig. 27 by current values above 2.6 A in phase 1 and values above 0 A in phases 2 and 3.Unlike what occurs in other measurements, activating the machine stabilizes the electrical voltage in all phases (Fig. 26), as if the machine became a fluctuation filter. As in measurement 2, all phases remain within the steady-state voltage levels considered appropriate (Fig. 28a), which strengthens the assumption of the disturbance that other sectors caused in the workshop's distribution board during measurement 1.

The power factor in phase 1 (Fig. 28b) follows a similar behavior to the other measurements, strengthening the assumption of the influence of other equipment on the phase power factor. The high rates of power factor values below the minimum in phases 2 and 3 that only powered the machine highlight the low energy efficiency of the PICCOLA 400T.

Fig. 30, Fig. 31 and Fig. 32 revealed that during activation the PICCOLA 400T produced a total harmonic distortion rate of approximately 3.5% in all phases, which despite being little corroborates the prediction of the generation of harmonics.

V. CONCLUSION

In all measurements, frequency levels remained within the range of 59.9 and 60.1 Hz, there was no record of voltage unbalance between the phases and no short-term voltage variation type disturbances were observed, which demonstrates a adequate electrical power supply for the workshop.

Analysis of the graphs reveals that activating the machines causes fluctuations in the voltage of the phases. In the first measurement, phase 2 voltage values were recorded below the limit considered appropriate for voltage variations in steady state. The normalization of this situation in the second and third measurements indicates that this disturbance in the phase 2 voltage level was caused by reasons external to the workshop.

The power factor of the phases is the variable most affected by the activation of the machines. High percentages of power factor values below the minimum established by the standard were recorded in all measurements. The Piccolo 400t and Smashweld 257 were perceived as low efficiency machines.

The analysis of the harmonic spectra extracted during the activation of the machines showed that other equipment connected to phase 1 generated harmonic disturbances. In all cases, the welding machines contributed to the presence of harmonic disturbances in the network, confirming the interference of the rectifiers of their sources in the quality of the electrical energy supply.

REFERENCES

[1]. OLESKOVICZ, M. et al. Estudo comparativo de ferramentas modernas de análise aplicadas à qualidade da energia elétrica. Março 2007 - Universidade de São Paulo, Escola de Engenharia de São Carlos, Laboratório de Sistemas de Energia Elétrica, São Carlos, São Paulo, Brasil.

[2]. SILVA, E. F. et al. Influência do Processo MIG/MAG na Qualidade da Energia Elétrica Fornecida pelas Concessionárias. XXXVII Congresso Nacional de Soldagem. Outubro 2011.

[3]. LEÃO, R.; SAMPAIO, R.; ANTUNES, F. Harmônicos em sistemas elétricos. – 1. Ed. – Rio de Janeiro: Elsevier, 2014.

[4]. CAPELLI, A. Energia elétrica: qualidade e eficiência para aplicações industriais. – 1. Ed. – São Paulo: Érica, 2013.

[5]. SENRA, R. Energia elétrica: medição, qualidade e eficiência. – 1. Ed. – São Paulo: Baraúna, 2013.

[6]. ANEEL. Procedimentos de Distribuição. Módulo 8 – Qualidade da Energia Elétrica. Dezembro, 2021.

[7]. BAMBOZZI. Piccolo 400t, Manual do usuário. Disponível em: <https://silo.tips/download/bambozzi-manual-de-instruoes-piccola-400t>; Acesso em: 24/06/2023.

[8]. BALMER. MaxxiTIG 200P AC/DC, Manual do usuário. Disponível em: <https://www.balmer.com.br/manuais>; Acesso em: 24/06/2023.

[9]. ESAB. Smashweld 257, Manual do usuário. Disponível em: <http://www.drmsoldas.com.br/upload/ecommerce/manuais/18102011045841.pdf>; Acesso em: 24/06/2023.

[10]. ITM. TES – 3600 INSTRUCTION MANUAL. Disponível em: <www.itm.com>; Acesso em: 24/06/2023.

[11]. NETTO, L, F. Sinais Elétricos: formas de onda. Disponível em: <https://www.facom.ufu.br/~jamil/eletronica/sinais_eletricos/sinais_eletricos.htm>; Acesso em: 24/06/2023.

[12]. TECHTUDO. Fórum Techtudo. Disponível em: <https://forum.techtudo.globo.com/perguntas/262250/aparelhos-110v-220v-ou-bivolt-como-descobrir-a-tensao-elétrica>; Acesso em: 21/07/2023.