Impact of welding equipment on power quality

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Received 5 August 2024; accepted 25 August 2024

Abstract In an industrial facility, many electrical consumers can affect the quality of electricity. Therefore, the freedom from interference sources of these devices and equipment can be crucial for quality and uninterrupted electricity supply. Electric welding equipment is also a possible source of interference. The electrical harmonic injections created by welding equipment into the electrical network can affect the operation of other consumers connected to the given distribution points and cause unjustified overheating and shutdowns of some network components. The aim of the research is to analyse the current harmonic injection of welding equipment of different types and modes of operation connected to the internal distribution network of the industrial facility. The effectiveness of the active harmonic filter built into the welding equipment was also examined in the paper. The results showed that the built-in active harmonic filter of the DC045 laser welding equipment was ineffective because the total harmonic distortion (THD) was about three times the 8% allowed by IEEE 519−2022 standard. The current harmonic injection of MIG 320 and MM403 type welding equipment was more than five times the permissible value of 5%. The current harmonic distortion of the PLAS140 type plasma-jet cutter equipment was below the 5% value allowed in the standard, thus it complied with it. Based on the measurement results, it can be concluded that the use of protection against harmonics is also necessary for welding equipment. Finally, proposals were made in the paper to reduce the effect of harmonics.

Key words electrical transients, harmonic distortion, electrical network disturbances, voltage breaks, total harmonic distortion (THD)

0 Introduction

Welding joins metal, plastic, and glass subassemblies made as separate structural elements with an insoluble bond. In the case of iron, blacksmith welding has been known for thousands of years since the Iron Age. However, the real development of welding began at the end of the 1 800 s, during the Industrial Revolution. Welding is a cohesive bond. One of the types of welding processes is electric arc welding. In the paper solid wire electrodes and neutral shielding gas arc welding equipment using this technology were analysed. Furthermore, CO_2 laser welding equipment using a solid-state laser and applying laser beam deep welding technology was analysed[1], and plasma jet cutting equipment using thermal cutting process technology was also examined[2]. During their operation, these devices affect the quality of electricity since they can inject electrical harmonics into the electrical network, affecting the operation of other consumers connected to the given distribution points. Therefore, analysing electrical networks is essential for the smooth operation of plants and uninterrupted electricity supply. The degree of distortions and the magnitude of harmonic injections are closely related to the welding physiological process and the non-linear physical characteristics of the arc plasma. Because in case of arc plasma, the flow of electrons from the cathode to the anode is not linear, in many cases it oscillates, therefore the current consumption required for welding will not be linear either. Due to the operation of the switching power supply units used in pulse welding equipment, the non-linear current consumption from the network further increases the harmonic injec-

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doi: 10.12073/j.cw.20240805024

tion. The tested DC045 type laser welding equipment is used in pulse mode, which increases harmonic pollution compared to continuous operation. The harmonics by DC045 type laser welding equipment inject into the electrical network can affect the operation of other consumers connected to the given common electrical distribution points and they can cause unjustified overheating and shutdowns at some components of the network. The magnitude of the harmonic distortions depends on the used welding technology and the distortion of the electrical network is closely related to welding processes. The various welding process parameters, such as pulse parameters, greatly influence the quality of the electricity, since the change over time of the current drawn by the welding machine and its linearity depend on them. The primary parameters of pulsed gas metal arc welding (GMAW) are peak current, background current, peak current duration, background current duration, pulse frequency, and duty cycle. It can be seen from the parameters that the current consumption during welding will certainly not be linear.

1 Formation of a distorted current sine wave

Electrical harmonics in the electrical network can have many negative consequences. Current and voltage sine wave distortions caused by non-linear loads and their possible consequences will not be discussed separately[3 − 10], but it will be shown that how such a distorted current sine wave occurs through an example. Fig. 1 shows the waveform of the phase current i_1 of the tested laser welding equipment, the 50 Hz waveform of the fundamental harmonic and the harmonic components of the current i_1. The waveform of current i_1 should have a regular sinusoidal shape for linear current consumption. Since the given equipment contains non-linear electronic components, i.e., its current consumption from the network is not constant over time, the change of the current taken within a period will not be an ideal sine wave. This can be seen in Fig. 1a.

This i_1 current waveform can be produced from the superposition of the fundamental sine (50 Hz) component and the sinusoidal harmonics. Current i_1 consists of a fundamental component with a frequency of 50 Hz and harmonics of different orders and amplitudes relative to the fundamental harmonic. Here, they were only represented up to the 9th (450 Hz) odd order, but this can be done up to hundreds of orders, so the supraharmonic (2 − 150 kHz) range can also be analysed[11]. The frequency range size depends on what the kind of data are required. These harmonics are sinusoidal voltages or currents whose frequency is a multiple of the mains frequency of 50 Hz.

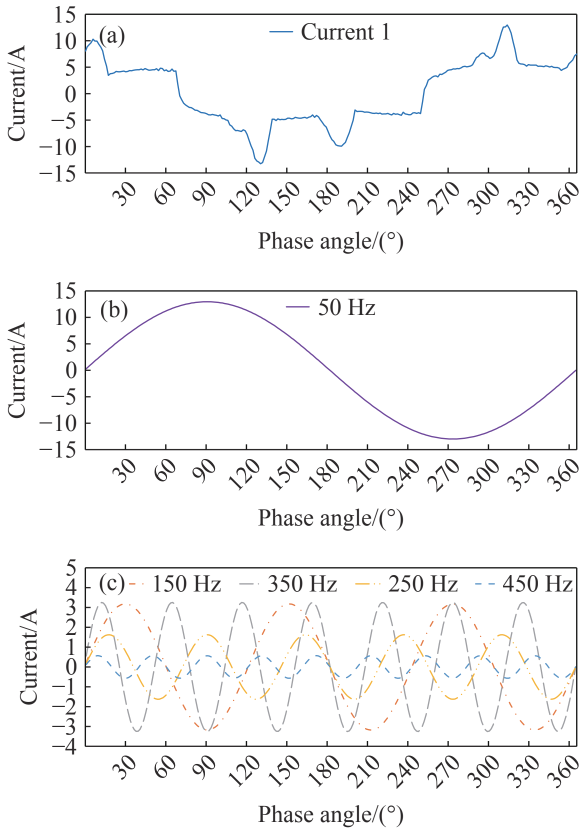

Fig. 1 Laser welding equipment distorted i_1 current waveform with fundamental and harmonic components based on own measurements (a) Current waveform (b) Current basic harmonic (c) Current harmonic

In the following, the quantities that can be used to evaluate the measurement results will be presented. The two most common distortion indicators are individual and total harmonic distortion, which are described by Eqs. (1) − (2). The first shows the ratio of the components present on the given harmonic number h compared to the fundamental harmonic. In contrast, the second compares the resulting overharmonic content of the signal to the fundamental harmonic. The two indicators can be determined analogously for both voltage and current.

$$D_{\mathrm{H}} = \frac{U_{\mathrm{h}}}{U_1} \tag{1}$$

$$THD_{\mathrm{U}} = \frac{\sqrt{\sum_{h=2}^{\infty} U_{\mathrm{h}}}}{U_1} \tag{2}$$

where U_{h} is the harmonic voltage of order h, U_1 is the fundamental harmonic voltage, D_{h} is the individual harmonic distortion, while THD_U is the total harmonic distortion. That is the term total harmonic distortion (THD) describes the effective sum of the voltages of all harmonic frequencies present relative to the fundamental harmonic.

The total current demand distortion (TDD) contained in the recommendation of the IEEE 519−2022 standard[12] gives the recommended maximum value of the total harmonic distortion (THD), which is the point of standard electrical network connection (point of common coupling, PCC) depends on the ratio of the short-circuit current (I_{SC}) and the load current (I_L) of the given device, these limit values are shown in Table 1.

Table 1 Recommended possible current distortion limits for systems rated 120 V through 69 kV by IEEE 519−2022 standard

I_{SC}/I_L	Individual harmonic order (h) (odd harmonics)[1,2] Maximum harmonic current distortion in percent of I_L					Total current demand distortion (%)
	$2 \leqslant h < 11$	$11 \leqslant h < 17$	$17 \leqslant h < 23$	$23 \leqslant h < 35$	$35 \leqslant h < 50$	
< 20 [3]	4.0	2.0	1.5	0.6	0.3	5.0
20−50	7.0	3.5	2.5	1.0	0.5	8.0
50−100	10.0	4.5	4.0	1.5	0.7	12.0
100−1 000	12.0	5.5	5.0	2.0	1.0	15.0
> 1 000	15.0	7.0	6.0	2.5	1.4	20.0

1. Even harmonics are limited to 25% of the odd harmonic limits above.
2. Current distortions that result in a DC offset, e.g., half-wave converters are not allowed.
3. All power generation equipment is limited to these values of current distortion, regardless of actual I_{SC}/I_L.

2 The purpose of network analysis

The analysis aims to investigate the distortions of the current and voltage sine waves of electric welding equipment, which are considered non-linear consumers due to the use of non-linear electronic components under real measurement conditions at the electrical connection points of the given equipment. The analyses were carried out on 06/2024 in an unnamed industrial facility. The equipment and devices measured were in use and in an unloaded state. The purpose of the measurements is to examine the current harmonic injection of the welding equipment in the standard electrical grid connection point (PCC). In this way, it is possible to determine to what extent the analysed welding equipment can be considered distorters of the electrical network sine wave signals and how much of a role they play in the possible deterioration of the quality of electricity. The measurements were performed with the PQA824 type network analyser of the HT manufacturer. The instrument was set according to the user guide prepared by Rapas Kft., while the recorded values were documented with the HT Italia Topview 2.2.2.3 software[13]. The measurement results were evaluated using our own processing, Fast Fourier Transform (FFT), and data transformation.

2.1 DC045 type laser welding equipment

Technical parameters of the DC045 type CO_2 laser welding equipment: output power 4 500 W, mains voltage 3 × 400 VAC ±10%, 50/60 Hz. Maximum current consumption 95 A. used in pulse mode. The mains analysis was carried out in the excited state of the equipment, under normal production conditions, when weld penetration was used. Fig. 2 shows the voltage-current waveform diagram for the laser welding equipment. The currents per phase were not precisely the same. Still, since the total harmonic distortion of the currents of each phase was almost the same, the most considerable i_2 current was only analysed in the paper. It can be seen that the neutral current is virtually zero and that all voltage and current waveforms are distorted. The measurement also showed how the harmonics distort the sinusoidal waveform of the current in case of the laser welding machine, which contains a significant amount of non-linear elements, semiconductors, coils and capacitors. These network analysis results also correspond to the literature descriptions of harmonic distortions.

Fig. 3 shows the harmonic current magnitude components of the distorted current waveform, i.e. the frequency spectrum of the measurement. The amplitudes of the harmonics relative to the fundamental can be read from the scale. The absorbed currents per phase were i_1 6 A, i_2 12.7 A, and i_3 9 A. This cannot be said to be symmetrical. However, in Fig. 2, one can also see that the current sine waveform is very distorted; in the case of the examined current i_2, the value of THD was 27.89%. The IEEE 519−2022 standard gives the recommended maximum value of the total harmonic distortion as the value of TDD. It was mentioned earlier, that TDD depends on the ratio of the short-circuit current of PCC and the load current of the given device. This ratio is now 630 A/27.89 A = 22.58; therefore, the permissible total current demand distortion according to

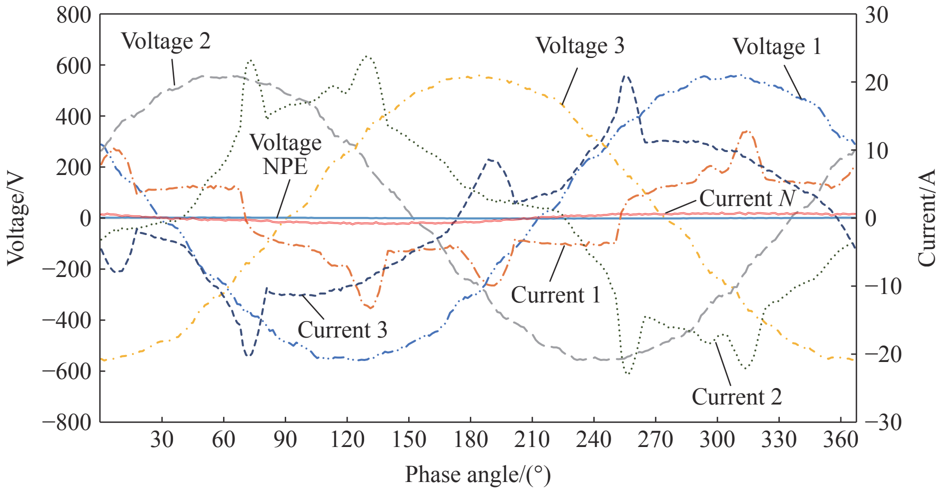

Fig. 2 Laser welding equipment distorted voltage and current waveforms

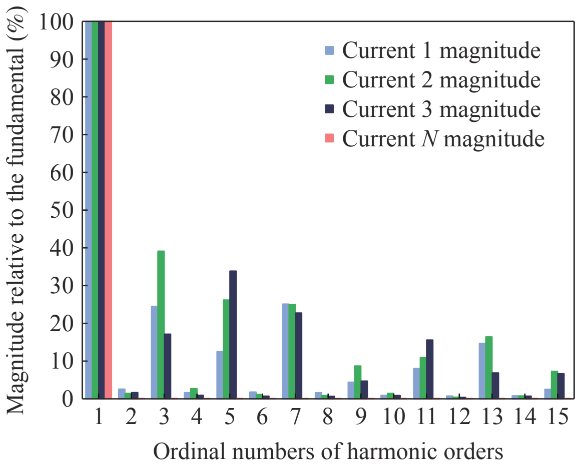

Fig. 3 Laser welding equipment harmonic current magnitude components of the distorted current waveform

Table 1, could be only 8%, so the defined THD 27.89% is more than three times the recommended maximum value, exceeding the limit value by 19.89%. However, it can also be determined from the measurement that according to Table 1, instead of the recommended 7% up to the 11th harmonic, in the case of the 3rd, 5th, 7th, 9th and 11th harmonics, the current distortion values are 39.12%, 26.19%, 24, 96%, 8.70% and 10.91%, which in some cases are multiples of the recommended limit value. From the 11th harmonic to the 17th harmonic, instead of the recommended 3.5%, the amplitudes are 16.43% for the 13th harmonic and 7.24% for the 15th harmonic. In the case of harmonic orders higher than these, the magnitude of the currents was already negligible, so they are not included in this analysis. The high degree of distortion of the current signals predicts that there may be emissions at higher frequencies, so we also examined the spectrum of the current above 2 kHz, the so-called supraharmonic range (2 − 150 kHz), which can be seen in Fig. 4. From the 40th order (2 kHz) to the 127th order (6.35 kHz), it approaches, and in many cases even exceeds, the amplitude of the permissible 3.5% fundamental harmonic. Therefore, in this case, it is important to protect devices sensitive to the presence of supraharmonics, such as IT and communication devices and cables. Based on the measurement results it can be assumed that the active harmonic filter is ineffective.

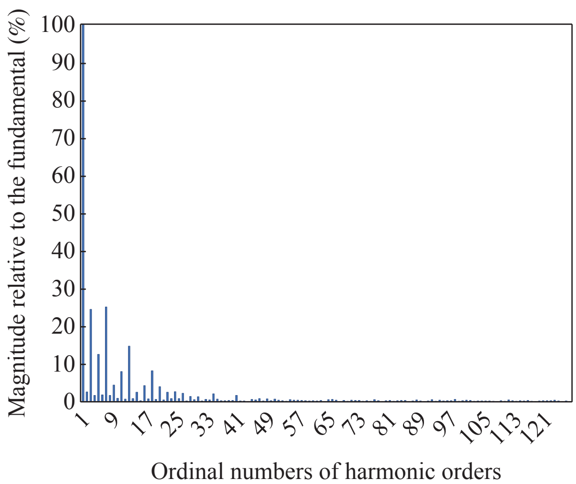

Fig. 4 Laser welding equipment supraharmonics current magnitude components of the distorted current waveform

2.2 MIG 320 type traditional transformer welding equipment

The voltage and current waveforms of another MIG 320 neutral gas arc welding equipment can be seen in Fig. 5.

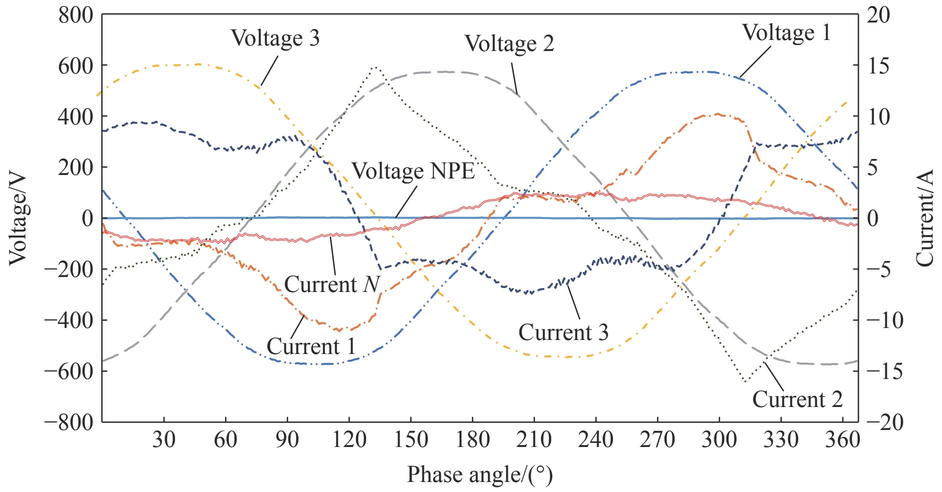

Fig. 5 MIG 320 type welding equipment distorted voltage and current waveforms

Technical parameters of the equipment: mains voltage 3 × 400 VAC ±10%, 50/60 Hz. The welding current for manual metal arc (MMA) welding is 70 − 300 A, while for metal inert gas (MIG) welding, 50 − 300 A. Maximum current consumption for MMA is 19 A, while for MIG, it is 18 A. According to the technical specification, an IGBT switching power transistor is used in the inverter to achieve a high switching frequency, which predicts that the harmonic injection resulting from the non-linear load will also be decisive here. In this case, the currents of each phase will be different thus THD of the currents also. The absorbed currents per phase varied between 5.8 A, 7.8 A and 6.2 A, so it cannot be symmetrical. Still, for reasons of scope, only the current i_2 was analysed because it was the most significant load current i_L, so the total current according to Table 1, the possible value of THD according to the standard can be the smallest here (this will be the most decisive during the evaluation). The network analysis was performed with the equipment under load, under normal conditions of use. In the case of the mentioned largest i_2, the value of THD of the current is 27.58%. The recommended maximum value of the total harmonic distortion of the recommendation according to the IEEE 519 − 2022 Standard for Harmonic Control in Electric Power Systems standard is determined by the ratio of I_{SC} to I_L, which in this case was 125 A/7.8 A = 16.02. According to Table 1, the permissible distortion could be only 5%, the exceeding of the limit value is thus 22.58%. The current of the neutral conductor is 0.9 A, which is negligible in this case, so i_N will not be analysed further.

Fig. 6 shows the spectrum of the phase currents of Fig. 5. In the figure, the numbers on the horizontal axis represent the n-th integer multiples of the harmonic orders, the fundamental frequency (50 Hz), while on the vertical axis one can see the amplitude related to the fundamental harmonic. It can be seen in the current spectrum that for the 3rd, 5th, 7th and 9th harmonics, the magnitude of harmonics is 34.25%, 9.36%, 7.08%, 5.2%, which in each case exceeds the maximum possible value of 4% up to the 11th harmonic recommended in the standard. From the 11th harmonic onwards, the magnitude of the harmonic orders was negligible, so it was not analysed. In summary, the magnitude of the harmonic distortions sometimes exceeds the level allowed in the standard, so it is necessary to filter them.

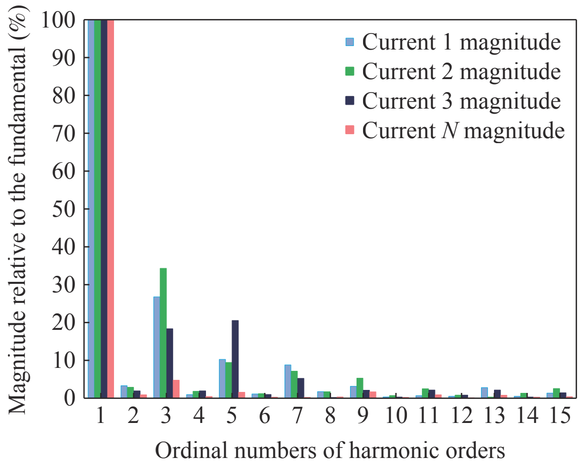

Fig. 6 MIG 320 type welding equipment harmonic current magnitude components of the distorted current waveform

2.3 MM403 type traditional transformer welding equipment

The voltage and current waveforms of another type, MM403 is a MIG neutral shielding gas arc welding equipment, can be seen in Fig. 7. Technical parameters of the

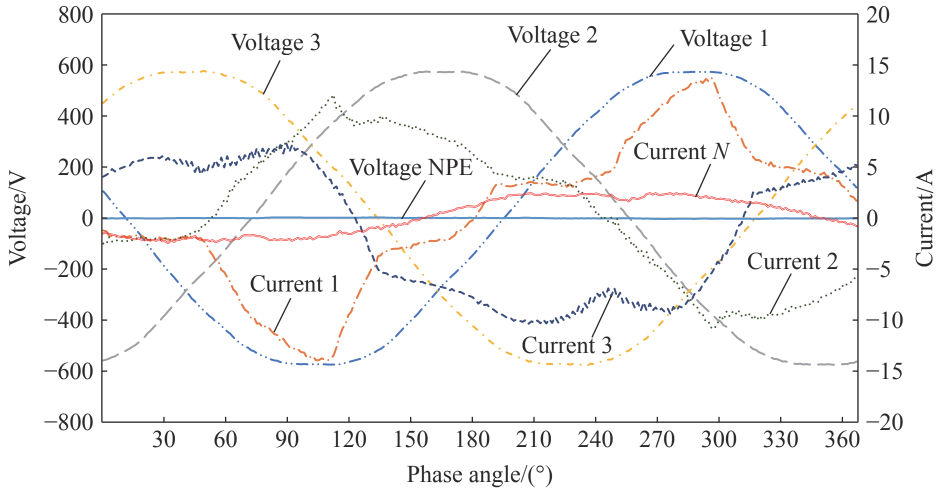

Fig. 7 MM403-type welding equipment distorted voltage and current waveforms

equipment: mains voltage 3 × 400 VAC ±10%, 50/60 Hz. Nominal mains power 17 kVA. The nominal welding current is 40 − 400 A. Due to the switched-mode power supply (SMPS) of the welding equipment, which acts as a non-linear consumer, the sine wave of the current is distorted. The magnitude of the harmonics of the harmonic injection is not constant, it also depends on the welding technology used. Therefore, the harmonic injection to the network also changes accordingly. The modulation of the welding voltage can have a significant effect on the distortion of the waveform of the currents. During the welding process, changes in voltage affect current, which can result in current waveform distortion. This distortion can cause various problems, such as poor welding quality or electrical equipment failure. It can be seen in Fig. 7 that there are no multiple zero crossings, but current also flows on the neutral conductor due to the asymmetric load, whose maximum value reaches 3.7 A, which is significant compared to the maximum phase current of 12.97 A, so care must be taken to ensure the correct cross-section of the neutral conductor at the connection point. In this case, only one phase current, i_1, was also analysed. The TDD value was also determined here. The value of THD of the current was 35.16% for the current i_1. According to the total current demand (TDD), the harmonic distortion is 125 A/7.1 A = 17.6. Still, according to Table 1, the permissible distortion could be only 5%, exceeding the limit value by more than five times, 30.16%.

Fig. 8 shows the frequency spectrum of the current of Fig. 7. The 3rd, 5th, and 7th harmonics (150 Hz, 250 Hz, 350 Hz) are very high, which may be due to the operating frequency of the frequency converter of the welding machine. According to Table 1, up to the 11th harmonic recommended in the standard, the maximum possible harmonic value per order could be 4%. In this case, the current

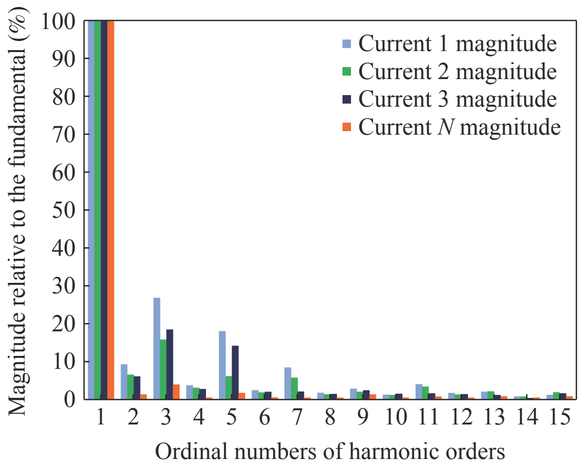

Fig. 8 MM403 type welding equipment harmonic current magnitude components of the distorted current waveform

amplitude values are only for the 3rd, 5th and 7th harmonics: 26.65%, 17.83% and 8.2%, thus reaching six times the recommended maximum value. From the 11th harmonic order up, the magnitude of the order is negligible for this device as well, so we did not analyse this here either. In summary, the magnitude of harmonic distortions at some frequencies is several times higher than the standard, so it is necessary to find a solution to filter out harmonics for this welding equipment as well.

2.4 PLAS 140 type plasma-jet cutter equipment

Fig. 9 shows the voltage-current waveform diagram of a PLAS 140 compressed air plasma jet cutting device. Technical parameters of the equipment: mains voltage 3 × 400 VAC ±10%, 50/60 Hz. Nominal mains power 49 kVA. Maximum current consumption 71 A. The nominal cutting current is 6 − 140 A. Material thickness that can be cut in

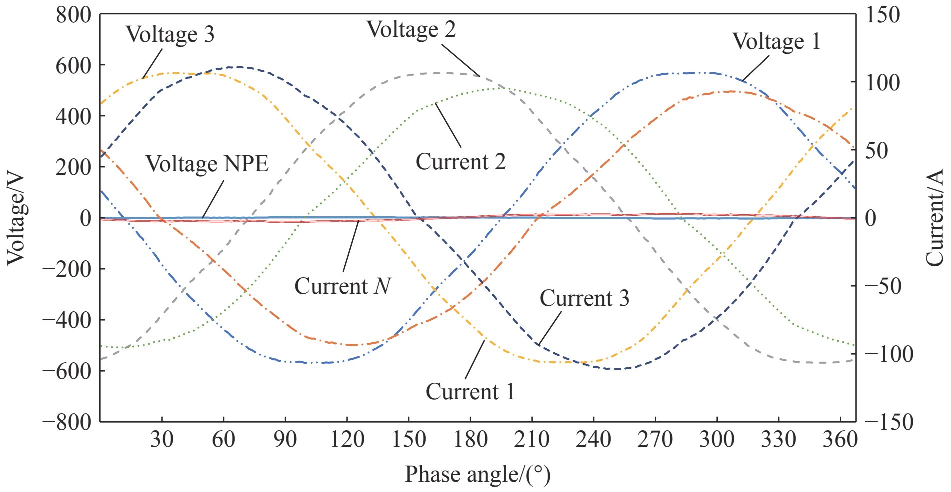

Fig. 9 PLAS140 plasma-jet cutter equipment distorted voltage and current waveforms

the case of steel is 45 mm. For reasons of scope, only current i_1 was analyzed. The current of the neutral conductor is considered to be zero, so it was not analysed. As one can see in the graph, the voltage and current waveforms underwent slight waveform distortion, so after the analysis, it can be expected to say that the equipment complies with the standard recommendation and has little or no effect on the current and voltage waveforms of the electrical network.

Fig. 10 shows the frequency spectrum of the measurement which represents the harmonic current magnitude components of the distorted current waveform. The amplitudes of the harmonics relative to the fundamental can be read from the scale. The current varied between 65 A and 78 A per phase, so it can be said to be symmetrical. However, in Fig. 9, one can also see that the current sine waveform is hardly distorted. Therefore, the value of the total harmonic distortion of the current is 3.49% for the i_2 current, which can be said to be very good. The IEEE 519−2022 standard gives the recommended maximum value of the total harmonic distortion with the harmonic distortion value according to the total current demand. The ratio is now 125 A/65.3 A = 1.91, therefore the permissible distortion can only be 5% according to Table 1, so the THD 3.49% is less than the recommended maximum value of 5%, and no limit value exceeded. If the compliance with the recommendations according to the individual harmonic orders is examined, one can see that according to Table 1, the magnitude of the amplitude related to the fundamental harmonic is below the recommended 4% up to the 11th overharmonic for each harmonic order. This is a very high-quality device from the point of view of harmonic injection.

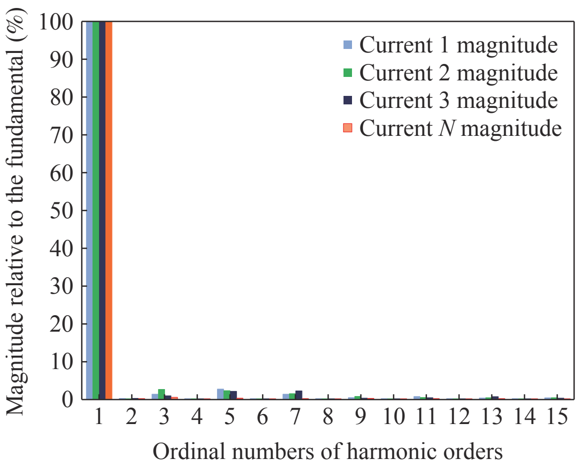

Fig. 10 PLAS140 plasma-jet cutter equipment harmonic current magnitude components of the distorted current waveform

3 Conclusions

The research aimed to investigate the current harmonic injection of welding equipment of different types and modes of operation connected to the internal electrical network of the industrial facility. During the measurements, total harmonic current distortion was measured and compared with the maximum possible total current demand harmonic distortion value given by the IEEE 519-2022 standard. This possible distortion value, expressed as a percentage, was created by the standard-setter considering the practical experience of how certain electrical networks can affect the sine wave shape of current and voltage in proportion to the load currents of individual consumers, and to what extent they can distort it. It has been clearly proven that if equipment with a lower load current was connected to an electrical connection point compared to its maximum current, the less they could influence the quality of the electrical current of the connection point and thus the voltage on it, from a harmonic injection point of view. It was shown that the PLAS140-type plasma jet-cutting equipment met the requirements of the standard in all respects and even exceeded them. This equipment will most likely not cause any problems with operating other equipment containing electronics connected to the same network. The harmonic injection of the MM403 neutral shielding gas arc welding equipment gave the worst result. The amount of total harmonic distortion was 35.16% instead of the possible 5%. This value was 27.89% for the DC045 type laser beam welding equipment, while it was 27.58% for the MIG 320 type neutral shielding gas arc welding equipment, which were multiples of the recommended permissible value. For this reason, possible operational problems are expected with other equipment connected to the same electrical connection point.

In order to avoid electrical network anomalies due to the harmonic injection of welding equipment and the failure of other equipment connected to the same distribution point, the following was recommended.

(1) In industrial facilities, welding equipment should be connected to high-current power outlets as far as possible, avoiding smaller power distributors (16 − 32 A) (630 − 800 A) to electric busbars, so the ratio of the PCC current and the load current of the welding equipment will be large, so the harmonics will have a much smaller effect on the distribution network and at the same time on the operation of other equipment connected to it.

(2) Since it has been proven that in some cases the harmonic filters installed by the manufacturer are not effective, it is therefore advisable to validate them before putting them into operation (information about the filters should be requested from the distributor).

(3) If the welding equipment to be purchased or the existing welding equipment does not have suitable filters, it is necessary to install them. Active harmonic filters are preferred, as they always filter the harmonics to the necessary and sufficient extent with compensation. One such power quality improvement technique is APLC (active network conditioning), which is a type of active filter that compensates for the distortions of the sinusoidal waveform of the power system.

(4) A possible solution can be also a central harmonic filter device connected to the direct feed point of the low-voltage (400 V) central electricity distribution system of the site. But based on practical experience, this is not recommended, as their efficiency is not adequate for small loads. The results of the related validation procedures will be published in a later paper.

(5) Due to their structure, the active filtering devices can implement several functions simultaneously, thus performing a complex, "power shaping" task instead of harmonic filtering. The potential excess power of the filter equipment can be used for reactive power compensation as well as load balancing.

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