International Journal of Innovation and Scientific Research
ISSN 2351-8014 Vol. 66 No. 1 Apr. 2023, pp. 34-41

http://www.ijisr.issr-journals.org/

Impact of harmonics on the power factor in an industrial network

Tangenyi Okito Marcien[1], Meni Babakidi Narcisse[1], and Kinyoka Kabalumuna God'El[2]

[1]Institut Supérieur de Techniques Appliquées de Kinshasa, Electronic section, Kinshasa, RD Congo

[2]Université Pédagogique Nationale, Faculty of Sciences, Department of Physics and Applied Sciences, Kinshasa, RD Congo

ABSTRACT: Today the power quality of industrial systems is a growing concern for electrical and electronics engineers. The main reason for deteriorating power quality is the high level of harmonics. Harmonics in industry are produced from many sources, primarily variable speed drives and rectified loads. The injection by non-linear loads of harmonic currents contributes significantly to the degradation of the power factor resulting in an increase in reactive power and apparent power. In this study, the analysis of harmonics will be presented in the brewing industry case of Bralima DR Congo using a PEL 103 meter. The measured THD values for voltage and current will be used to analyze their impact on the power factor. Some solutions are proposed for the reduction of harmonics and the correction of the power factor (PFC) at the same time in order to reduce the reactive and apparent powers and also to reduce the energy consumption impacting on the expenses due to the billing of electrical energy.

KEYWORDS: Harmonic analysis, power factor, voltage measurement, power quality, industries.

1 INTRODUCTION

The electrical energy mainly distributed by a three-phase system in the sinusoidal form makes it possible to supply the power necessary for the equipment and materials of electrical engineering. It is particularly the sinusoidal aspect of the original voltage that it is necessary to preserve, in order to preserve its essential qualities for the transmission of the useful power to the terminal equipment. When the voltage waveform is no longer sinusoidal, it is said to be harmonic distortion produced by nonlinear loads; disturbances then appear which generate malfunctions and overheating of the receivers and equipment connected to the same power supply network or harmonic pollution [1].

Harmonic pollution is a disturbance defined as a distortion of the waveform of a pure sinusoidal signal. On the electrical network, waveform disturbances are mainly due to the presence of non-linear loads. In terms of functions, the current and the voltage represent the waves or sinusoidal functions whose disturbance is manifest. Harmonics are sinusoidal signals whose frequencies are multiples by natural numbers (n) of the fundamental frequency [2].

Non-linear loads represent many industrial and domestic equipment, are distributed in many industrial sectors. These devices have an input system for converting energy in a given form into another form in line with the desired use. It is static converters which are implemented and which can be listed in four families [3]:

- AC-DC converters, this represents all the rectifiers,
- DC-DC converters, choppers and switching power supplies,
- DC-AC converters, voltage or current inverters,
- AC-AC converters, dimmers, frequency converters or cyclo-converters.

These polluting devices are classified according to their power and therefore the level of disturbance they cause.

For all of these polluting loads, an additional criterion must be taken into account, namely the utilization factor. Indeed, the quantification of the harmonic rate depends on the duration and simultaneity of the operation of these nonlinear loads.

It should be noted that there are also disturbances on harmonic orders that are not an integer multiple of the fundamental. These are called inter or infra harmonics. Interharmonics are sinusoidal components that are not whole frequencies of that of the fundamental

Our article analyzes and proposes some solutions for the reduction of harmonics and the correction of the power factor (PFC) in order to reduce the reactive and apparent powers impacting on the expenses due to the billing of electrical energy.

2 FOUNDATIONS

The electric wave (voltage or current) is a periodic function of period 2π, so it is, according to the Fourier series expansion, an infinite sum of terms [4].

$$f(t)=\sum_{n=0}^{\infty} a_n\cos(n\omega t)+b_n\sin(n\omega t) \tag{1}$$

$$\sum_{n=0}^{\infty} f_n\,(t)=a_0+a_1\cos(\omega t)+b_1\sin(\omega t)+\ldots+a_n\cos(n\omega t)+b_n\sin(n\omega t)$$

$$a_0=\frac{1}{2\pi}\int_0^{2\pi} f(t)dt \tag{2}$$

$$a_n=\frac{1}{\pi}\int_0^{2\pi} f(t)\cos(n\omega t)\,dt \tag{3}$$

$$b_n=\frac{1}{\pi}\int_0^{2\pi} f(t)\sin(n\omega t)\,dt \tag{4}$$

For an even function the coefficient b_n is zero just as for an odd function the coefficients a_0 and a_n are zero.

We know that the sum of 2 sinusoids with the same pulsation is a sinusoid with the same pulsation. So, let's write that:

$$a_n\cos(n\omega t)+b_n\sin(n\omega t)=C_n\sin(n\omega t+\varphi_n) \tag{5}$$

2.1 HARMONIC VOLTAGES AND CURRENTS

By definition, the effective value of a periodic current i (t) is:

$$I_{eff}=\sqrt{\frac{1}{T}\int_0^T i\,(t)^{\,2}}$$

After developing the instantaneous current, we conclude that:

$$I_{eff}=\sqrt{I_0^2+I_1^2+\sum_{n=2}^{+\infty} I_n^2} \tag{6}$$

$$V_{eff}=\sqrt{V_0^2+V_1^2+\sum_{n=2}^{+\infty} V_n^2} \tag{7}$$

2.1.1 EFFECTIVE VALUE OF HARMONICS

This is the effective value of all the harmonics:

$$I_H=\sum_{n=2}^{+\infty} I_n^2 \tag{8}$$

$$V_H=\sum_{n=2}^{+\infty} V_n^2 \tag{9}$$

2.1.2 HARMONICS DISTORSION RATE (THD)

Harmonic currents flowing through electrical system impedances cause harmonic voltage dips, observed as voltage harmonic distortion. One of the solutions intended to detect the presence of harmonics is the calculation of the THD, rate of harmonic distortion.

$$\mathrm{THD_V}=\frac{\sqrt{\sum_{n=2}^{+\infty} V_n^2}}{V_1} \tag{10}$$

$$\mathrm{THD_I}=\frac{\sqrt{\sum_{n=2}^{+\infty} I_n^2}}{I_1} \tag{11}$$

2.1.3 POWERS IN THE PRESENCE OF HARMONICS

The active power P consumed by the load is the average over a period of the instantaneous power [5-7]:

$$P=\frac{1}{T}*\int_0^T v(t)*i(t)dt$$

$$P=\frac{1}{T}\int_0^T\left[v_0+v_1\ \sin(\omega t+\varphi_1)\ +\ldots+\sum_{n=2}^{+\infty} v_n\sin(n\omega t+\varphi_n)\right]\left[i_0+i_1\ \sin(\omega t+\theta_1)\ +\ldots+\sum_{n=2}^{+\infty} i_n\sin(n\omega t+\theta_n)\right]dt$$

$$P=V_0I_0+V_1I_1\cos\varphi_1+\sum_{n=2}^{+\infty} v_n\, i_n \cos\varphi_n \tag{12}$$

The reactive power P

$$Q=V_1I_1\sin\varphi_1+\sum_{n=2}^{+\infty} v_n\, i_n \sin\varphi_n \tag{13}$$

The apparent power of the load is by definition:

$$S = V \times I \tag{14}$$

It is recalled that in the presence of harmonic the apparent power is composed of three terms of which we note the presence of the component D, resulting from the influence of the harmonic currents:

$$S^2 \neq P^2+Q^2$$

$$S^2 = P^2+Q^2+D^2$$

$$D^2=S^2-(P^2+Q^2) \tag{15}$$

2.1.4 POWER FACTOR EXPRESSION

The presence of harmonics adds a distorting power in the expression of the apparent power.

$$PF=\frac{P}{S}=\frac{V\,I_1\cos\varphi_1}{\sqrt{V^2{I^2}_1\cos^2\varphi_1+V^2{I^2}_1\sin^2\varphi_1+V^2{I^2}_1{\mathrm{THD_I}}^2}}$$

$$PF=\frac{\cos\varphi_1}{\sqrt{1+{\mathrm{THD_I}}^2}} \tag{16}$$

REMARK:

- When the current harmonic distortion rate (THDi) increases, the power factor decreases and the term.
- The term cos φ_1 is also called displacement factor (DPF: Displacement Power Factor).

3 Materials And Methods

3.1 Materials

To confirm our approach, we considered the following materials: linear loads (asynchronous motors: P=18 kW; U=400 /690 V; N=1800 rpm; f=50 Hz) associated with non-linear loads (variable speed drives) where we carried out measurements of the electrical parameters.

These recordings were made using a PEL 103 meter with the following characteristics:

- Ambient temperature 23±2°C;
- Relative humidity [45% RH; 75% RH];
- Voltage No DC component in the AC, no AC component in the DC (< 0.1 %);
- Current No DC component in the AC, no AC component in the DC (< 0.1%);
- Phase voltage [100 Vrms; 1000 Vrms] without DC (< 0.5%);
- Input voltage of current inputs (except AmpFlex® / MiniFlex®) [50 mV; 1.2 V] without DC (< 0.5%) for AC measurements, without AC (< 0.5%) for DC measurements;
- Network frequency 50 Hz ± 0.1 Hz and 60 Hz ± 0.1 Hz;
- Harmonics < 0.1%;
- Voltage unbalance 0%.

3.2 Methods

This section describes the measurements of the Bralima plant phase power system with non-linear load using the PEL103 meter. The Bralima plant used a load of approximately 3.13 MW and the operating load is 18 kW. It is powered from a 20 kV electrical network. The analysis was derived from measurements of THD current and voltage values due to the rectified load in the plant. The power analyzer can measure voltage sag, swell, unbalance, THD value of current, voltage and power as well.

4 Results

To understand the impact that harmonics can have on the power factor, a series of measurements were taken on a load group made up of asynchronous motors and variable speed drives.

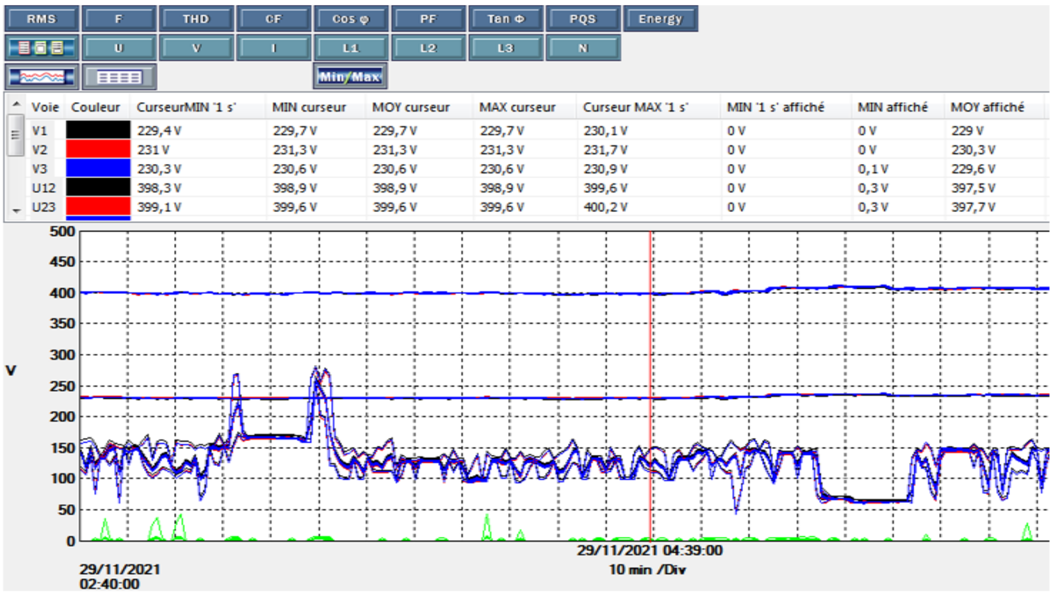

Fig. 1. Enregistrement de la tension de charge

From this figure (Fig.1) we can observe that despite the voltage variations, the average value has remained approximately that of the nominal operating voltage 230 V and 400 V.

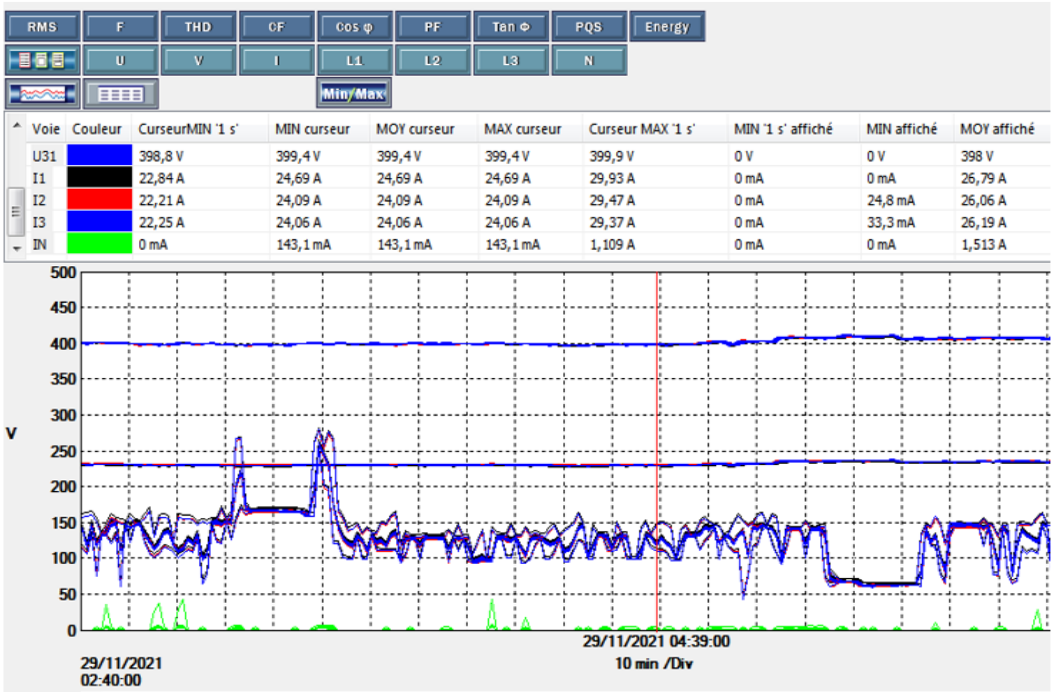

Fig. 2. Current of load taken as sample

The figure (Fig.2) shows that the load seems not to be purely balanced for the simple reason of the presence of a small current in the neutral.

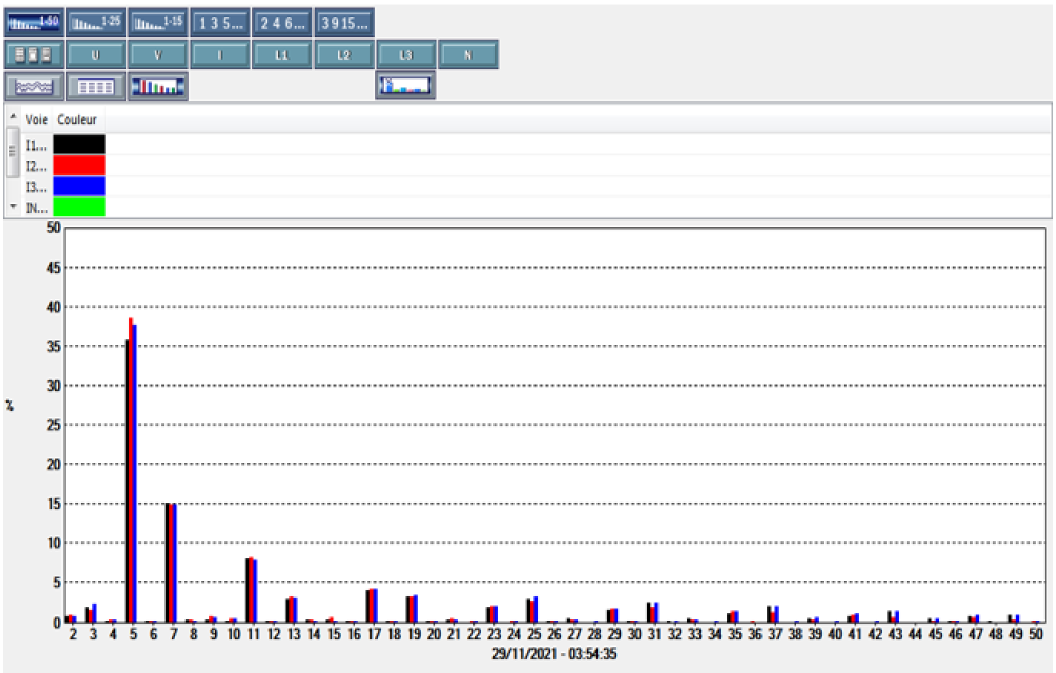

Fig. 3. Current harmonic spectrum of our sample load

The spectra presented in figure (Fig.3) indicate the predominance according to their percentages is that of harmonics of odd order not multiple of three.

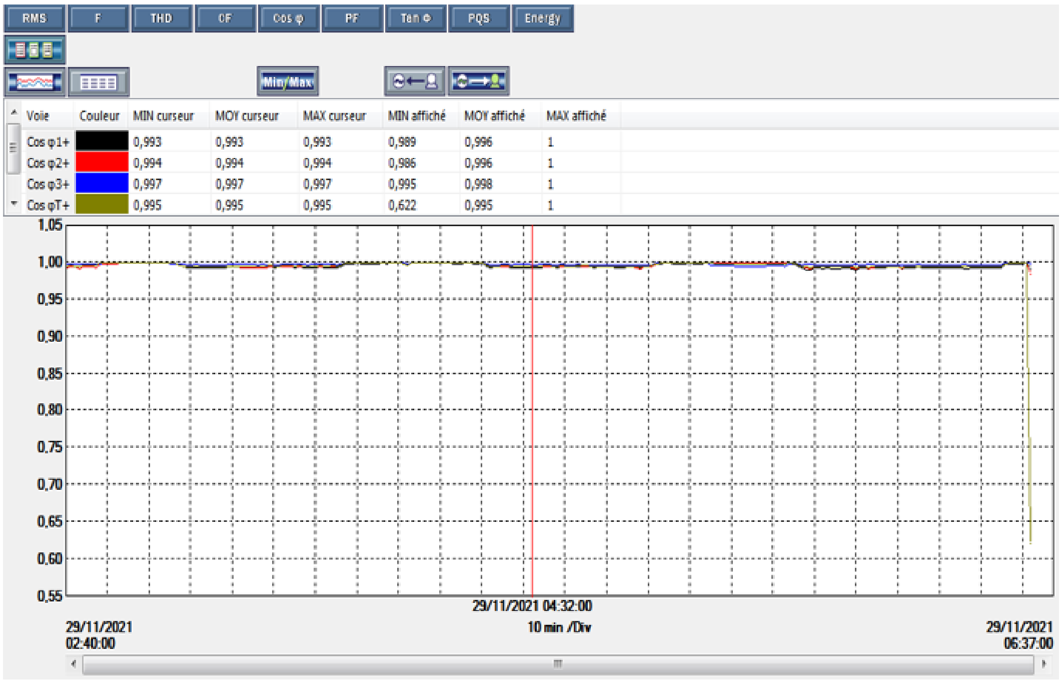

Fig. 4. ***Cosφ of our model load***

The **cos φ**presented by figure 44 is very good, it is 0.995. We recall that the **cos φ** in the harmonic domain no longer represents the power factor, the latter will be calculated by considering the current distortion rate of each phase.

In summary, the measurements gave us the following characteristics measured on the fundamental wave:

V_r=230 [V]

U=397.7 [V]

I=26.0 [A]

cos φ =0.995

P_T=16.25 [kW]

Q_T=1.159 [kVAr]

S_T=17.55 [kVA]

R_r=0.16[Ω]

L_r=0.16[μH]

The distortion rate per harmonic order after calculation considering the harmonics is:

$THD_{I_3}=3\%$

$THD_{I_5}=38\%$

$THD_{I_7}=16\%$

$THD_{I_{11}}=8\%$

$THD_{I_{13}}=3\%$

$THD_{I_{17}}=4\%$

$THD_{I_{19}}=3\%$

$THD_{I_{25}}=4\%$

Table 1. Value of currents per harmonic order.

Odd harmonics		Even harmonics	
Order	**Current (A)**	**Order**	**Current (A)**
3	0.78	2	overlooked
5	10.18	4	overlooked
7	4.286	6	overlooked
9	overlooked		
11	2.143		
13	0.78		
17	1.04		
19	0.78		
25	1.04		

The current I=26.0 A, read by the PEL 103 meter is not the total rms current due to the presence of harmonics induced by the non-linear load which is the asynchronous motor variable speed drive. The distortion rate of each harmonic order is synonymous with a current value added to the total effective value. This being so, we will calculate the harmonic currents of each harmonic.

5 ANALYSIS AND DISCUSSION

Expression (15) shows that adding the distorting power leads to a power factor described in equation (16). Logically the power factor is degraded, given that this distorting power is a component of the reactive power. The presence of harmonics in the power supply will cause the creation of harmonic couples in the machine. These harmonic torques are superimposed on the fundamental torque and increase the mechanical vibrations undergone by the machine, which will increase the mechanical fatigue of the engine more rapidly. Cables, transformers and electric motors are designed to operate in a harmonic-free network; their powers are calculated according to the effective current of the fundamental. In the presence of harmonics the effective current increases which leads to an overload.

The presence of harmonics on the network can disturb the power measurement and introduce errors into it. Electromechanical energy meters are composed of a magnetic circuit, a disc and coils [4]. The voltage and the current which will circulate in the device will produce a flux in the magnetic circuit, which will create a flux in the air gap of the circuit. This flow will generate eddy currents in the disc, and these currents will then create Laplace forces on this disc. These forces generate a torque which will spin the disk at a certain speed, thus giving the indication of power consumption.

Also, the presence of harmonics will, for the same power, increase the effective value of the current which circulates in the electric cables. As a first approximation, the losses present in a cable are the joule losses, which are proportional to the square of the rms value of the current. It is then easy to understand that the current harmonics will create additional losses in the electrical cables.

In general, the solutions envisaged refer to the standards are able to lower the harmonic impedances or even act on the structure of the installation such as IEC 61000-2-2.

The current I=26.0 [A] read by the meter is not the total rms current due to the presence of harmonics induced by the non-linear load which is the asynchronous motor speed controller. The distortion rate of each harmonic order is synonymous with a current value added to the total effective value. This effective value of the current in the presence of harmonic makes a difference of 7.46 [A] of the current value of the fundamental.

The increase in total apparent power is justified by taking into account the distorting component of harmonic currents. The power factor found is far different from the phase angle between current and voltage.

In order to limit the influence of a polluting load on the other loads connected to the network and at the same time to avoid the modification of the characteristics of the latter, the distributors of electrical energy have been led to issue recommendations. These recommendations concern the requirements at the point of connection of the user to the electrical network in order to:

- To spare the user of electrical energy the inconvenience caused by the presence of harmonics.
- To ensure the longevity and safety of the various equipment making up the network and those connected to it.

6 CONCLUSION

In this article, an analysis was presented on the distortion of harmonics in the Bralima plant due to non-linear loads, mainly variable speed drives and asynchronous motors. By taking measurements using the PEL 103 energy meter, it has been identified that the 5th and 7th harmonic orders are the most dominant in amplitude and are responsible for increasing THD levels. The results obtained with PEL 103 were used for the harmonic analysis of the entire installation. In an industrial network, the use of non-linear loads, in this case variable speed drives, generates harmonic currents which are superimposed on the value of the current of the fundamental with the consequence of modifying the electrical quantities. A power component called distorting power is added to the expression of the apparent power, which directly modifies the approach of the power factor which otherwise was translated by the phase angle between the current and the voltage.

ACKNOWLEDGMENTS

We have the obligation to fulfill a pleasant duty, that of thanking all the people who have contributed from far or near to the writing of this article.

REFERENCES

[1] Adamou, Mamane, et al. «Dépollution harmonique des réseaux électriques: Etude comparative des commandes, par Modulation de Largeur d'Impulsion et par Hystérésis, des filtres actifs shunts triphasés.» International Journal of Innovation and Applied Studies 28.2, 557-566, 2020.
[2] Bouacida, Farida, and Manel Zebiri. «Qualité de l'énergie electrique et norme IEEE-519.» 2009.
[3] Wang, Yayun, Zhimin Zhang, and Wenguang Yu. «Pricing equity-linked death benefits by complex Fourier series expansion in a regime-switching jump diffusion model.» Applied Mathematics and Computation 399, 126031, 2021.
[4] Luhtala, Roni, et al. «Online frequency response measurements of grid-connected systems in presence of grid harmonics and unbalance.» IEEE Transactions on Power Electronics 35.4 (2019): 3343-3347.
[5] Imam, Amir A., R. Sreerama Kumar, and Yusuf A. Al-Turki. «Modeling and simulation of a PI controlled shunt active power filter for power quality enhancement based on PQ theory.» Electronics 9.4, 637, 2020.
[6] DING, Keyan, et al. *Comparison of full-reference image quality models for optimization of image processing systems*. International Journal of Computer Vision, vol. 129, no 4, p. 1258-1281, 2021.
[7] Kebir, Ahmed Amine, Mouloud Ayad, and Saoudi Kamel. «Effects of harmonics and voltage unbalance on the behavior of a five-phase permanent magnet synchronous machine.» Archives of Electrical Engineering, 471-488, 2022.