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Quality analysis of electrical energy

Análisis de calidad de energía eléctrica

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Abstract

This study exposes the measurements of electrical parameters carried out with a power quality analyzer in a transformer. The first measurement taking into account a capacitor bank that was already installed and then taking it out of operation. It presents the results graphed in "Power Log" and analyzed with respect to the standards CFE-L00045, IEEE 519-1992 and the Regulatory Manual of Technical Requirements for the Connection of Load Centers. By disconnecting the capacitor bank, with the data records obtained from the measurement, it is possible to consider adding a harmonic filter that is presented as the proposal for improving the quality of electrical power, since it achieves an increase from 0.73 to 0.98 in the power factor without compromising the permissible values of harmonics in the system. The filter is calculated and simulated in "DigSILENT Power Factory" to demonstrate the feasibility of the proposal.

Harmonics, Power Factor, Quality

Resumen

Este estudio expone las mediciones de parámetros eléctricos realizadas con un analizador de calidad de la energía en un transformador. La First Measurement tomando en cuenta un banco de capacitores que ya se encontraba instalado y después sacando este de la operación. Se presentan los resultados graficados en “Power Log” y analizados con respecto a las Regs CFE-L00045, IEEE 519-1992 y el Manual Regulatorio de Requerimiento Técnicos para la Conexión de Centros de Carga. Al desconectar el banco de capacitores, con los registros obtenidos de la medición, es posible considerar añadir un filtro de armónicos que se presenta como la propuesta para la mejora de calidad de energía eléctrica, ya que se logra un aumento de 0.73 a 0.98 en el factor de potencia sin comprometer los valores permisibles de armónicos en el sistema. El filtro es calculado y simulado en “DigSILENT Power Factory” para demostrar la factibilidad de la propuesta.

Armónicos, Factor de Potencia, Calidad

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Introduction

The company specialized in the production of anti-refilling and aluminum closures has a focus on energy efficiency since most of its processes require electricity to function. The proposed aim for this project is to reduce the harmonics, concurrently increasing the power factor, which can interpret as a considerable reduction of the negative ecological impact and a financial improvement for the company.

In order to reduce the consumption of electrical energy, it has been proposed, to measure the electrical parameters and, based on the results obtained, propose the integration of a new component in the system, which will reduce the total cost of electrical energy consumed, and will have a trend close to the permissible values for the power factor which is one of the technical requirements applicable to consumer users in the IEEE 519-1992, CFE-L00045 and the Regulatory Manual of Technical Requirements for Center Connection of Load.

Background

The company specialized in the production of anti-refilling and aluminum closures has presented a power factor of 0.94pf. This parameter is an indicator on the utilization of energy, showing the relationship between the apparent power and the active power, the first being the required or demanded energy and the second, the energy that is really useful for the process. Despite the fact that the initially measured value of the power factor in the company is not low, it is not within the limits allowed by the Regulatory Manual of Technical Requirements for the Connection of Load Centers issued by the Energy Regulatory Commission, which indicates that this must be higher than or equal to 0.95pf (CRE, 2019). Failure to comply with this characteristic presents a penalty given by a formula proposed by the Federal Electricity Commission and is reflected in the receipt of this same company (CRE, 2019).

The problem that is presented nowadays arises from a previous situation in which the power factor was even lower, and the installation of a 160kVAr capacitor bank was implemented as the answer to the problem, however, as previously described, the results did not exempt the company from non-compliance with the requirement.

On the other hand, in the last years, there have been successful cases in various companies that provide service to the industry, which have achieve to increase the power factor by generating a bonus instead of a penalty.

Capacitor banks were installed in the company that produces and markets candy, managing to eliminate the penalty for the power factor (2020). The pet food development company was asked to connect a 620kVAr harmonic filter with the same objective (2019) and for the company dedicated to plastic extrusion and chrome plating, a capacitor bank was installed, achieving to increase the power factor to 0.98pf and mitigate the economic losses generated by the penalty (2019) (IEEE, 2012; Astudillo-Mora, 2016).

In all these reference cases, a constant was found which is the central point of this project, the previous analysis carried out on the quality of electrical energy. Carrying out the measurement of the electrical parameters allowed to know the relevant characteristics of the installed system, finding the problems to be solved and granting a personalized solution to each one of the cases presented.

Justification

When making a study of the quality of electrical energy, it is possible to know the state of the installation during its operation at the time of carrying out the measurements in a company. At the same time, the measurements provide information that, based on an analysis supported by regulations, stand out the following problems: a) Imbalances, b) low power factor, c) harmonics, d) current peaks, e) voltage drop.

The aforementioned situations result in considerable economic losses, such as additional charges in the payment of the receipt for penalties or fines depending on the applicable rate, loss of useful life or total loss of equipment installed in the plant, unscheduled shutdowns, stoppage of production lines, or even more alarming, accidents or human losses.

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On the other hand, by not having a good quality of electrical energy, consumption is higher, so generation must increase, and it pollutes mainly by thermal power plants that, through the burning of fossil fuels, produce CO_2, causing air pollution, by nuclear energy that causes radioactive waste from highly expensive treatments or by combined cycles that impact through combustion, in deposits, contamination of water, soil and ecosystems.

Topographic Analysis of the Network and Verification on the Point to be Evaluated

In order to carry out the corresponding operations to compare the results with the requirements described in the standards, it is necessary to obtain relevant data from the transformer which will be evaluated.

On the other hand, it is necessary to take into account the elements that are before and after the transformer, which is why the following single-line diagram is presented, showing the connection, the fuse, the transformer, the installed capacitor bank, the thermomagnetic switch and the electric board. The mentioned elements are in the same order from top to bottom in Figure 1.

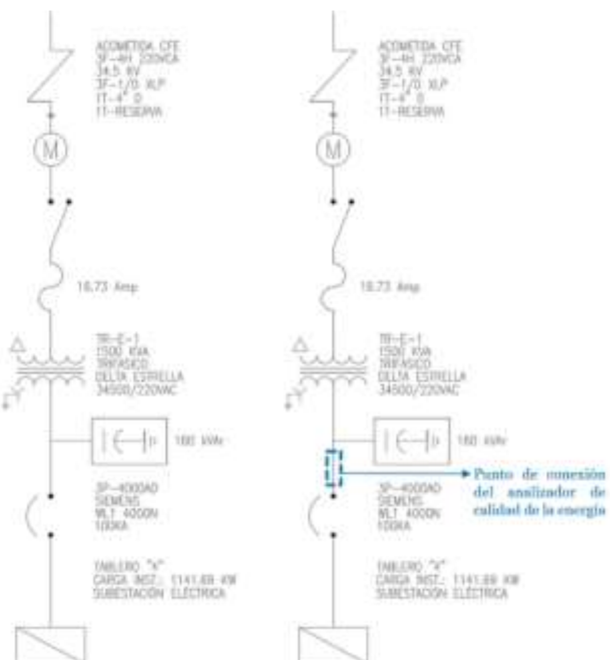

Figure 1 Single-line diagram of company's installation
Source: Own Elaboration

Measurement of Electrical Parameters in the Found System

By the time of carrying out the corresponding measurements, it was found that the system already had a capacitor bank that was intended to function as a solution to the low power factor, so the readings included this element. The following are the results:

Tension First Measurement

For voltage variations, the Regulatory Manual of Technical Requirements for the Connection of Load Centers is taken into account, where it is determined that these should not exceed ±5% with respect to the nominal voltage value. For this case the reference value is 220V (CRE, 2019). Table 1 shows the values obtained.

Ph	Tension (V)			Variation		Reg
	Min.	Rng.	Max.	Min.	Max.	
AB	217.57	224.65	226.44	1.1	2.9	Yes
BC	217.27	223.14	226.16	1.2	2.8	Yes
CA	217.78	224.48	226.63	1.0	3.0	Yes

Table 1 Verification of compliance of the regulation of tensión
Source: Own Elaboration

Current First Measurement

The occupancy percentage shows the breakdown by phases with respect to the total capacity. It is of high importance to have these values in order to not exceed them when increasing the installed load and moreover, to be able to verify that they are balanced (Ceballos, 2020), see Table 2.

Ph	Current (A)			Ocupation	
	Min.	Rng.	Max.	Min.	Max.
A	820	1,125	1,857	20.8	2.9
B	806	1,184	1,184	20.5	2.8
C	802	1,146	1,146	20.4	3.0

Table 2. Porcentage of current occupation respecto f the máximum capacity of the circuit (3,936A)
Source: Own Elaboration

The maximum occupancy percentage is 47.8% in Phase A, 50.2% in Phase B, 48.2% in Phase C, hence it is considered a good balance of Phases and there is a considerable percentage of occupancy left in case the user wants to increase the load (Ceballos, 2020).

ISSN 2523-2881

Frequency First Measurement

The frequency complies with the guidelines described in the Regulatory Manual of Technical Requirements for the Connection of Load Centers, since it mentions that the maximum permanent frequency must be 61Hz and a minimum of 59Hz, and in this case, its behavior is from 60.087Hz to 59.881Hz (CRE, 2019).

Energy Consumption First Measurement

The energy consumed (active power) is adequately higher than the lost energy (reactive power) and close to the apparent energy in the circuit (apparent power).

Table 3 shows the values obtained in the measurement, the active power that is the one used, the apparent power required for the operation of the system and the reactive power that is released in the use of energy. These values have a high relevance in the study because the relationship between them will reveal the value of the power factor, as well as other important parameters (Ceballos, 2020).

Power	Measured Values		
	Min.	Rng.	Max.
Apparent (KVA)	316	445.06	738
Active (kW)	290	412.87	700.2
Reactive (kVAr)	115.2	152.04	256.2

Table 3 Measured powers
Source: Own Elaboration

Power Factor First Measurement

We can observed that the average value is 0.83pf, however, for this parameter to be within the permissible limits, the value that is 95% of the time in the period must be taken into account, which is in this case 0.94pf (CRE, 2019).

Despite the fact that this value is considerably acceptable, it is not within the limits described in the Manual of Technical Requirements for the Connection of Load Centers that appears in the Network Code of the resolution of the Energy Regulatory Commission, since this mentions that it should be a value of 0.95pf (CRE, 2019).

Harmonic Dsitortion First Measurement

In relation to what is described in CFE L000-45 on the maximum limits of total harmonic distortion in voltage and individual harmonic component, there is no non-compliance with the regulation, see Table 4 and 5 (Blooming, 2006; IEEE, 1993; CFE, 2005).

Ph	THDV%	Limit	Reg
A	2.624	8%	Yes
B	2.416	8%	Yes
C	2.332	8%	Yes

Table 4 Verification of compliance of voltage total harmonic content per phase
Source: Own Elaboration

H order	Fundamental Value (%)			Limit	Reg
	A	B	C		
3°	0.168	0.119	0.148	6%	Yes
5°	0.995	0.961	0.936	6%	Yes
7°	1.472	1.383	1.486	6%	Yes
9°	0.151	0.165	0.189	6%	Yes
11°	1.589	1.313	1.097	6%	Yes

Table 5 Verification of compliance of voltage harmonic order per phase
Source: Own Elaboration

The CFE L000-45 standard is taken into account again to verify compliance with the values obtained, as described in the Table of maximum harmonic distortion allowed in current. Below are the results in which it is observed that there is a non-compliance of regulations, see Table 6 and 7 (Blooming, 2006; IEEE, 1993; CFE, 2005).

Ph	THDI%	Limit	Reg
A	10.183	5%	No
B	9.844	5%	No
C	8.446	5%	No

Table 6 Verification of compliance of current total harmonic content per phase
Source: Own Elaboration

H order	Fundamental value (%)			Limit	Reg
	A	B	C		
3°	0.506	0.666	0.683	4%	Yes
5°	2.159	2.143	2.195	4%	Yes
7°	3.608	3.279	3.331	4%	Yes
9°	0.558	0.442	0.735	4%	Yes
11°	8.101	7.620	6.069	2%	No

Table 7 Verification of compliance of current harmonic order per phase
Source: Own Elaboration

Article Journal Renewable Energy
December, 2023 Vol.7 No.19 1-11

Unbalance First Measurement

The CFE L000-45 standard mentions that the maximum voltage unbalance percentage allowed is 3%, which is why it is determined that the values comply with what is permissible (CFE, 2005).

In the CFE L000-45 standard it is mentioned that the maximum current unbalance percentage allowed is 5%, which is why it is determined that the values do not comply with what is permissible (CFE, 2005).

However, these values can be highly impacted when there is no load and in the points where it shows a higher imbalance there are no loads in operation, so the current imbalance percentage is not significant.

Summary of Results First Measurement

Tension. Phase imbalance does not exceed 3% allowed, so it is in safe operating conditions. The voltage regulation is within the standards.

Current. The maximum and minimum values are within the capacity of the circuit and current peaks that could trigger the electrical protections were not detected.

Power. The maximum power values are below 80% capacity of the transformer, which is why it is considered normal operation.

Power factor. It is below the established standards.

Harmonics. Within the readings carried out, the results show that the circuit is being affected by the presence of current harmonics.

With the summary of the results shown above, it is recommended to include a harmonic filter, however, since the system already has a capacitor bank, it is not possible to add it because it is not appropriate to place a correction element where one already exists, since that in each of the various brands that exist on the market, the behavior of the capacitor in micro farads varies, and even if it were of the same brand, if a filter or a capacitor is added, the inductance and capacitance would increase, making the calculation of these elements no longer correct due to the change in the characteristics of the circuit (Astudillo-Mora, 2016; IEEE, 2012).

This is why it is necessary to perform a second measurement by removing the bank of operation capacitors.

Second Measurement of Electrical Parameters with Capacitor Bank Out of Operation

Tension Second Measurement

For voltage variations, it is determined that they should not exceed ±5% with respect to the nominal value. For this case the reference value is 220V (CRE, 2019). The values obtained are shown below, see Table 8.

Ph	Tension (V)			Variation		Reg
	Min.	Rng.	Max.	Min.	Max.	
AB	215.07	222.33	231.16	2.2	5.1	Yes
BC	214.07	222.27	231.15	2.7	5.1	Yes
CA	215.25	222.51	231.24	2.1	5.1	Yes

Table 8 Verification of compliance of voltaje standard with a capacitor bank out of operation
Source: Own Elaboration

Current Second Measurement

The occupancy percentage shows a breakdown by Phases with respect to the total capacity, these current values can be seen in Table 9. It is of high importance to have these values in order to not exceed them when increasing the installed load and, moreover, to be able to verify that they are balanced (Ceballos, 2020).

Ph	Current (A)			Ocupation	
	Min.	Rng.	Max.	Min.	Max.
A	475	1,211	1,862	12.06	47.3
B	429	1,210	1,923	10.89	48.8
C	478	1,207	1,860	12.14	47.2

Table 9 Percentage of current occupation respect to the maximum capacity of the circuit (3,936A) with capacitor bank out of operation
Source: Own Elaboration

The maximum occupancy percentage is 47.3% in Phase A, 48.8% in Phase B, 47.2% in Phase C as shown, so it is considered a good balance of Phases and a considerable percentage of occupancy remains (Ceballos, 2020).

ISSN 2523-2881

Frequency Second Measurement

The frequency complies with the guidelines described, since it does not exceed the range of 61Hz to 59Hz, with 60.086Hz and 59.908Hz being the maximum and minimum respectively (CRE, 2019).

Energy Consumption Second Measurement

The energy consumed (active power) is adequately higher than the lost energy (reactive power) and close to the apparent energy in the circuit (apparent power), see Table 10.

Power	Measured Values		
	Min.	Rng.	Max.
Apparent (KVA)	184.2	463.04	705.3
Active (kW)	147.9	392.15	633.3
Reactive (kVAr)	103.8	152.04	360.9

Table 10 Measured powers with capacitor bank out of operation
Source: Own Elaboration

Power Factor Second Measurement

It is observed that the average value is 0.84, however, for this parameter to be within the permissible limits, the value that occurs 95% of the time in the period must be taken into account, which in this case is of 0.86 (CRE, 2019). This value is not within the limits described, since it is mentioned that it should be a value of 0.95 (CRE, 2019).

Harmonic Distortion Second Measurement

In relation to what is described in CFE L000-45 on the maximum limits of total harmonic distortion in voltage and individual harmonic component, the following results are presented, in which the percentage values of harmonic distortion are broken down, there is no non-compliance of the regulation (Blooming, 2006; IEEE, 1993; CFE, 2005), see Table 11 and Table 12.

Ph	THDV%	Limit	Reg
A	1.5	8%	Yes
B	1.532	8%	Yes
C	1.496	8%	Yes

Table 11 Verification of compliance of total voltage harmonics per phase with capacitor bank out of operation
Source: Own Elaboration

H order	Fundamental value (%)			Limit	Reg
	A	B	C		
3°	0.101	0.061	0.053	6%	Yes
5°	0.835	0.869	0.853	6%	Yes
7°	0.899	0.861	0.843	6%	Yes
9°	0.038	0.028	0.045	6%	Yes
11°	0.612	0.668	0.649	6%	Yes

Table 12. Verification of compliance by voltage harmonic order in each phase with capacitor bank out of operation
Source: Own Elaboration

The CFE L000-45 standard is taken into account again to verify compliance with the values obtained. The results are presented below in Tables 13 and 14, in which no non-compliance with regulations is observed (Blooming, 2006; IEEE, 1993; CFE, 2005).

Ph	THDI%	Limit	Reg
A	1.932	5%	Yes
B	1.958	5%	Yes
C	1.926	5%	Yes

Table 13 Verification of compliance of total current harmonics per phase with capacitor bank out of operation
Source: Own Elaboration

H order	Fundamental value (%)			Limit	Reg
	A	B	C		
3°	0.375	0.412	0.512	4%	Yes
5°	1.206	1.315	1.208	4%	Yes
7°	1.014	0.926	0.960	4%	Yes
9°	0.108	0.108	0.132	4%	Yes
11°	0.586	0.532	0.564	2%	Yes

Table 14. Verification of compliance by current harmonic order per phase with capacitor bank out of operation,
Source: Own Elaboration

Unbalance Second Measurement

In the CFE L000-45 standard it is mentioned that the maximum allowable percentage of unbalance in voltage is 3% and current is 5%, which is why it is determined that the measured values comply with what is permissible (CFE, 2005).

Summary of Results Second Measurement

Tension. Phase imbalance does not exceed 3% allowed, so it is in safe operating conditions. The voltage regulation is within the standards.

Current. The maximum and minimum values are within the capacity of the circuit and current peaks that could trigger the electrical protections were not detected.

Power. The maximum power values are below 80% capacity of the transformer, which is why it is considered normal operation.

Power factor. It is below the established standards.

Harmonics. Within the readings carried out, the results show that the circuit was being affected by the presence of current harmonics while the capacitor bank was in place, now that this element has been removed, the harmonics also decreased in such a way that they are within the established limits.

Solution Proposal for Non-Compliance with the Electrical Quality Regulations at the Installation

With the summary of the results shown above, it is observed that, having the capacitor bank connected, the circuit needs to add inductance since, due to the lack of this, the current harmonic content increased considerably. An element that adds inductance and capacitance at the same time is a harmonic filter, which is why it is considered an effective response to the problem (Astudillo-Mora, 2016).

For this case, an automatic passive filter is taken into account that is capable of providing a low impedance path for current harmonics and is made up of an RLC branch in series. The filter will be connected in parallel with the power system (Astudillo-Mora, 2016).

Harmonic Filter Calculation

Data:
Active power = 633,300W
Current power factor = 0.73pf
Desire power factor = 0.98pf
Tension Phase-Phase = 220V
Fundamental frequency = 60Hz
Apparent power = 705,300VA

The minimum value of the measured power factor is 0.73pf, to carry out the design it is proposed to raise this value up to 0.98pf with reference to the Regulatory Manual of Technical Requirements for the Connection of Load Centers where it is specified that the power factor of 0.95pf will be valid for 10 years, after which the requirement will be 0.97pf (CRE, 2019). The power in the capacitor for an 11th order filter is calculated below.

$$\emptyset 1 = cos^{-1}(FP1) = cos^{-1}(.73) = 43.11° \quad (1)$$

$$\emptyset 2 = cos^{-1}(FP2) = cos^{-1}(.98) = 11.47° \quad (2)$$

$$Qeff = P(tan\emptyset 1 - tan\emptyset 2) \quad (3)$$

$$Qeff = 633.3kW(\tan(43.11) - \tan(11.47)) = 464{,}317.102VAr \quad (4)$$

Corresponding to the IEEE 18-2012 standard, the capacitor bank must be selected with respect to the established values (IEEE, 2012). Taking this into account and the possible increase in installed loads, a 500,000VAr capacitor bank is established. The arrangement is made up of a 166.6kVAr capacitor per branch, making a total of 500kVAr triphasic. The remaining calculations are shown in the following formulas.

$$xfilter = \frac{Vnom^2}{VAr} = \frac{220^2}{166{,}66kVAr} = 0.2904\Omega \quad (5)$$

The tuning factor used is 0.95 to avoid resonance due to the impedance of the network or the load used.

Capacitive reactance calculation:

$$xcap = \frac{h^2}{h-1} \cdot xfilter = \frac{10.45^2}{10.45-1} \cdot 0.2904 = 3.35581\Omega \quad (6)$$

Angular frequency calculation:

$$W = 2\pi fh = 2\pi(60)(10.45) = 3.35581 \quad (7)$$

Capacitor calculation:

$$C_{farads} = \frac{1}{W \cdot xcap} = \frac{1}{3{,}939.5 \cdot 3.355} = 76.0941525\mu F \quad (8)$$

Inductive reactance calculation:

$$xL = \frac{xcap}{h^2} = \frac{0.0307301573}{10.45^2} = 0.03073\Omega \quad (9)$$

Inductor calculation:

$$L_{henries} = \frac{xL}{W} = \frac{0.03073}{3{,}939.5} = 0.0078mH \quad (10)$$

Resistence calculation:

$$R = \frac{x_L}{U} \equiv \frac{0.03073}{80} = 0.384126966m\Omega \quad (11)$$

ISSN 2523-2881

The characteristics for the harmonic filter are summarized in Table 15.

Conection	Star
Power per branch (VAr)	166,666.667
Tension (V)	220
Inductor L (mH)	0.00780040898
Capacitor C (F)	76.0941525
Resistence R (mΩ)	0.384126966

Table 15 Characteristics for the harmonic filter
Source: Own Elaboration

Harmonic Filter Simulation

To verify the veracity of these data, a model was made in DigSILENT Power Factory with the characteristics of the initial network where, when simulating the harmonic content, it provided values very similar to those obtained in the measurements (Astudillo-Mora, 2016), see Figure 2.

A 1500 kVA transformer was added to the elements, and together with the harmonics and the load, the simulation gave values of 633kW in active power, 360kVAr in reactive power, 728kVA in apparent power and 0.86pf in power factor. These values are highly similar to those obtained in the measurements actually carried out on the system.

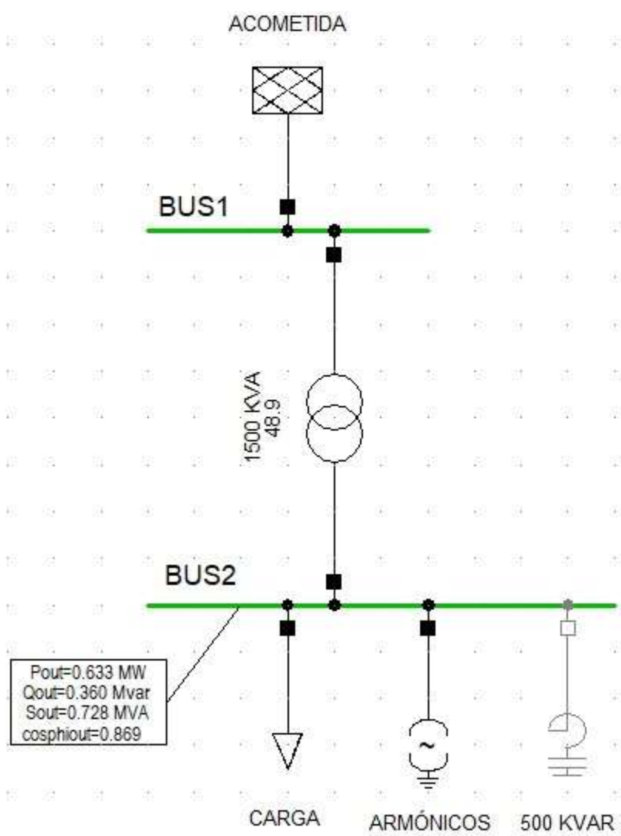

Figure 2 Diagram of the simulated system in DigSILENT Power Factory before applying the solution proposal
Source: Own Elaboration

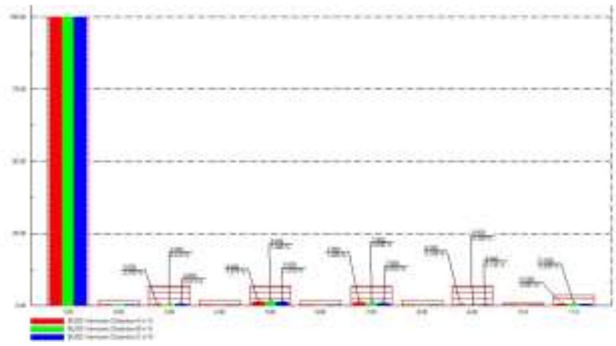

Figure 3 Simulated harmonic content in DigSILENT Power Factory before applying the proposed solution
Source: Own Elaboration

The closeness of the simulated harmonics that are observed in Figure 3, with respect to the values measured in the facilities, confirms that the software has the capacity to emulate the characteristics that the electrical system would generate in case of making any modification.

H order	Simulated harmonic content			Measured harmonic content		
	A	B	C	A	B	C
3°	0.38	0.41	0.51	0.38	0.41	0.51
5°	1.22	1.37	1.22	1.21	1.32	1.21
7°	1.03	0.94	0.97	1.01	0.93	0.96
9°	0.11	0.11	0.13	0.11	0.11	0.13
11°	0.59	0.54	0.56	0.59	0.53	0.56

Table 16 Comparison of the simulated and measured values
Source: Own Elaboration

The values taken for the measured harmonic content show a minimal variation in decimals of the simulated harmonic content values, this comparison is shown in Table 16. These were taken from the measurement made with the capacitor bank disconnected, therefore these are values that do not exceed the permissibe limit, however, it is necessary to analyze that, in the measurement made with the capacitor bank connected, the current harmonic of order 11 was highly affected.

Figure 4 shows the results that would be obtained in case of placing the harmonic filter sized at 500kVAr.

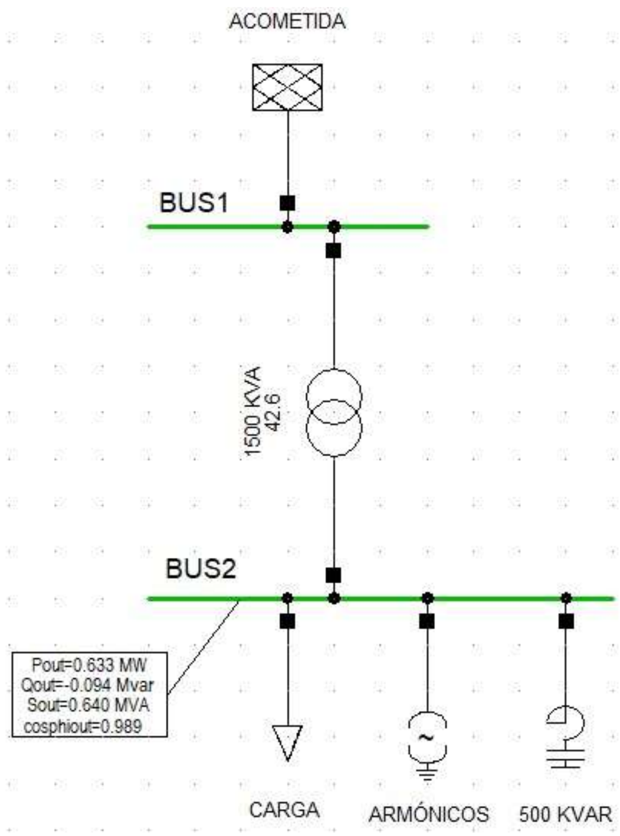

Figure 4 System diagram simulated in DigSILENT Power Factory with the harmonic filter activated
Source: Own Elaboration

It is observed that the active power in the system would be 633kW, the reactive power decreases from 360kVAr to 94kVAr, therefore the apparent power, in the same way, is affected by a decrease from 738kVA to 640kVA, and this effect causes the power factor that measures the effective use of electrical energy in the system increases to 0.98pf as expected.

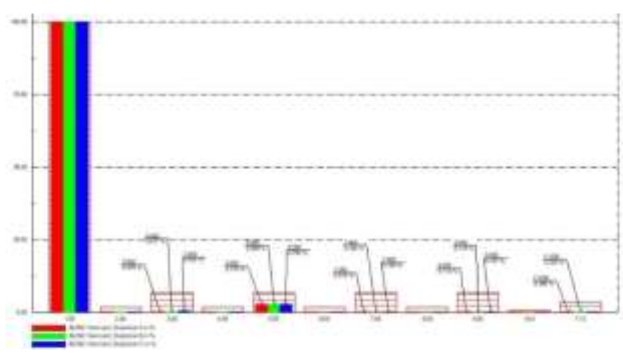

Figure 5 Simulated harmonic content in DigSILENT Power Factory with the harmonic filter activated
Source: Own Elaboration

The harmonics that are presented in Figure 5 are shown in Table 17. It is observed that these do not exceed the permissible limits in the regulations (Blooming, 2006; IEEE, 1993; CFE, 2005).

H order	Fundamental value (%)			Limit	Reg
	A	B	C		
3°	0.375	0.417	0.532	4%	Yes
5°	2.779	2.958	2.782	4%	Yes
7°	0.215	0.162	0.184	4%	Yes
9°	0.114	0.114	0.127	4%	Yes
11°	0.388	0.323	0.362	2%	Yes

Table 17. Verification of compliance with the standard by harmonic order with the harmonic filter activated
Source: Own Elaboration

Metodology

Considering the problem, it was evaluated that the best option to improve the quality of electrical energy is to first analyze the topography of the electrical system to determine the points where the parameter measurements will be made. In this way, it is possible to identify and specifically name those that are causing disturbances in the system, or are failing to comply with the applicable regulations in the case study.

To carry out the measurement, it is necessary to take readings for 7 continuous days as described in the CFE-L00045 standard with an electrical power quality analyzer regularly connected to the transformer or to the main distribution board, in this way it is possible to evaluate the general behavior of the electrical system of the company (CFE, 2005).

In this case, the system to be evaluated currently has a capacitor bank installed and in operation, however, the expected results were not obtained according to the regulations and technical requirements of electrical power quality, so the system is evaluated again disconnecting this element to know the behavior during its operation and thus be able to evaluate the parameters properly.

Once the measurements have been made and analyzed, we proceed to assess the resolution options for the diagnosed regulatory breaches by developing their respective simulation in the specialized software to verify the functionality of the proposal.

Results

The general objective has been covered in its entirety, because the breakdown of each of the electrical parameters shows that they have been analyzed and it is possible to determine a first state of the system.

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Having determined this state where there is a low power factor (CRE, 2019), shown in the summary of results with the capacitor bank disconnected, it is possible to issue a proposal that generates an improvement in energy quality, raising this value from 0.73pf to 0.98pf without increasing harmonic content. It is possible to observe this improvement in the model.

Conclusions

For this specific case study, it was necessary to place a new element, which is a 500kVAr automatic passive harmonic filter, which promotes an increase in the power factor and controls the percentages of harmonic content, keeping them below the levels allowed in the standards.

We can see the importance of first carrying out a power quality analysis since, without this, it would not have been possible to locate the problem that existed in the current harmonic content, and in general, in this analysis. It is possible to break down each of the parameters and visualize them in detail, finding the problem if there is one.

It is necessary to take into account that all the elements of an electrical installation must have a maintenance service annually to ensure that they continue to function satisfactory, which includes electrical evaluations, cleaning and readjustment of exhaustible resources or that deteriorate over time. In the same way, there must be a control where the loads to which the system is exposed are specified in order to be absolutely careful not to exceed the installed capacities.

Within the same recommendations, it is necessary to constantly update the single lines and load tables where it will be possible to observe the history of the changes that have been made in the electrical network, and in case of wanting to make a modification of any magnitude, have accessibility to those preceding states. On the other hand, this project reveals the importance of carrying out an energy quality analysis and, in turn, makes it impossible to make a proposal for a modification in the electrical network with the intention of improving quality without knowing a first state, since the effects can be counterproductive and cause the quality of electrical power to deteriorate.

In case of wanting to carry out an analysis of the quality of electrical energy, it is recommended to use the same procedure in question of prioritizing the analysis, however, the proposals for improvement will be conditioned to each of the cases found in the field, since which all vary in installed loads and individual system characteristics.

Carrying out this study covers a wide range of topics of importance in the behavior of energy. The power factor is not only a requirement that, if it is not met, generates an economic penalty, but it is a value which provides information about how much electrical energy is truly used, and how much is being lost, so that by its nature it causes pollution in the environment.

This analysis is responsible for pinpointing where energy is being wasted, where there are points where an immediate fix is required, and which of them present an area of opportunity in order to the energy does not continue to be wasted, and that which is generated is consumed efficiently.

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