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Energy Efficiency of a stones and minerals breaker plant in Campeche State to comply with the process Procedimiento de Evaluación de Conformidad (PEC) de la NOM-001- SEDE-2012

Eficiencia energética en una Quebradora de piedra y minerales en el Estado de Campeche para cumplir con el Procedimiento de Evaluación de Conformidad (PEC) de la NOM-001-SEDE-2012

LEZAMA-ZÁRRAGA, Francisco Román†*, SHIH, Meng Yen, CHAN-GONZALEZ, Jorge de Jesús and SALAZAR-UITZ, Ricardo Rubén

Universidad Autónoma de Campeche, Campus V, Predio s/n por Av. Humberto Lanz Cárdenas y Unidad Habitacional Ecológica Ambiental, Col. Ex-Hacienda Kala, CP 24085, San Francisco de Campeche, Cam., México.

ID 1st Author: *Francisco Román, Lezama-Zárraga* / **ORC ID:** 0000-0003-3397-7881, Researcher ID Thomson: U-1229-2018, **CVU CONACYT ID:** 205493

ID 1st Co-author: *Meng Yen, Shih* / **ORC ID:** 0000-0001-7475-6458, **CVU CONACYT ID:** 408617

ID 2nd Co-author: *Jorge de Jesús, Chan-Gonzalez* / **ORC ID:** 0000-0002-8638-1646, **CVU CONACYT ID:** 84196

ID 3rd Co-author: *Ricardo Rubén, Salazar-Uitz* / **ORC ID:** 0000-0003-2307-737X, **CVU CONACYT ID:** 416277

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Abstract

This article presents an energy efficiency study for a stone and mineral breaker plant that meets the requirements for the interconnection of a Load Center to the medium voltage distribution network of the National Electric System in accordance with the provisions of the Procedimiento de Evaluación de Conformidad (PEC) de la NOM-001-SEDE-2012. Through an energy diagnosis, the operating conditions of low-voltage electrical installations are evaluated, verifying the voltage and current levels, demand and consumption, in addition to monitoring the level of load imbalance in the three-phase system. In addition, it is visualized that conductors, conduits, protections and connected equipment are adequate to maintain said installations in safe and reliable conditions in such a way that when an electrical installation verification unit (UVIE) arrives, it provides the Load Center with the Verification Opinion of Electrical Installations signing in accordance and in which it certifies that it is complying with the applicable provisions of NOM-001-SEDE-2012, Instalaciones Eléctricas (utilización).

Energy diagnosis, Load center, Verification unit

Resumen

Este artículo presenta un estudio de eficiencia energética a una planta quebradora de piedras y minerales que cumpla los requisitos para la interconexión de un Centro de Carga a la red de distribución de media tensión del Sistema Eléctrico Nacional de acuerdo con lo establecido en el Procedimiento de Evaluación de Conformidad (PEC) de la NOM-001-SEDE-2012. A través de un diagnóstico energético se evalúa las condiciones operativas de las instalaciones eléctricas en baja tensión verificando los niveles de tensión y corriente, la demanda y el consumo, además del monitoreo del nivel de desbalance de cargas en el sistema trifásico. Además, se visualiza que conductores, canalizaciones, protecciones y equipos conectados sean los adecuados para mantener dichas instalaciones en condiciones de seguridad y confiabilidad de tal manera que cuando llegue una unidad verificadora de instalaciones eléctricas (UVIE) proporcione al Centro de Carga el Dictamen de Verificación de Instalaciones Eléctricas firmando de conformidad y en el que certifica que está cumpliendo con las disposiciones aplicables de la NOM-001-SEDE-2012, Instalaciones Eléctricas (utilización).

Diagnóstico energético, Centro de carga, Unidad verificadora

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† Researcher contributing as first author.

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Introduction

This article presents a study of energy efficiency through energy diagnosis as a requirement of the Conformity Assessment Procedure (PEC) of NOM-001-SEDE to a stone crushing company with an installed capacity of 110 kW in order to keep the electrical installations reliable and safe for the people who use them and for the connected equipment, thus distributing electrical energy efficiently. The Quebradora Plant is located in the town of Castamay, Campeche and bills at the GDMTO tariff.

According to the Regulation of the Electricity Industry Law, in its Art. 112, it says: "All electrical installations intended for the use of electrical energy must comply with the applicable Mexican Official Standards. The Ministry of Energy (SENER) may carry out inspections to verify compliance" (Cámara de Diputados, 2014). These inspections will be carried out by an authorised inspection body.

In order to comply with these regulations, the Conformity Assessment Procedure (PEC) of NOM-001-SEDE-2012 is applied, whose objective is to safeguard the safety of people and their property (Diario Oficial de la Federación, November 2017). The PEC in its numeral 7.2 for installations greater than 100 kW is required to comply with certain studies and documents, among which are.

1. The single-line diagram.

2. The ratio of loads.

3. List of materials.

4. Equipment used.

This documentation, which is integrated in an Electrical Project, must be ready to be handed over to the inspection body authorised by SENER called the Electrical Installation Verification Unit (UVIE). If during the inspection the UVIE finds any point of the electrical installation that does not comply with NOM-001-SEDE-2012, a Non-Conformity will be raised in the Conformity Assessment Act of the PEC, which must be corrected within a period agreed between the parties involved (designer and UVIE) and subsequently the UVIE will return to verify that the corrections have been complied with. If the electrical installation, called Load Centre, has already complied with the UVIE's requests, the UVIE evaluates it again with the Conformity Evaluation Act and issues the Electrical Installation Verification Report, signing in conformity and certifying that the Load Centre complies with the applicable provisions of the Mexican Official Standard NOM-001-SEDE-2012, Electrical Installations (use), so that it can be interconnected to the National Electrical System (National Energy Control Centre, 2018).

For Load Centres that are already interconnected to the SEN in Medium Voltage (between 13.8, 23 and 34.5 kV), they will also be visited by the UVIE and the same procedure explained in the previous paragraph will be applied. If there was any Non-Conformity of the PEC and it did not comply with the times and forms, it will be disconnected from the SEN and will be subject to a fine, and until it complies, it will be reconnected again.

Problem statement

The Load Centre has been interconnected to the SEN for 24 years, is a company dedicated to the crushing of stones and minerals and addresses the problem of the lack of documents to comply with numeral 7.2 of the PEC of the NOM-001-SEDE-2012. The aim is to solve the problem of the non-existence of the single-line diagram, the list of loads and the inventory of the equipment used in the Load Centre through the application of energy efficiency by carrying out an energy diagnosis. In addition to complying with the provisions of the PEC, this information collected and analysed is essential for compliance with the provisions of the Grid Code (DOF, 2020).

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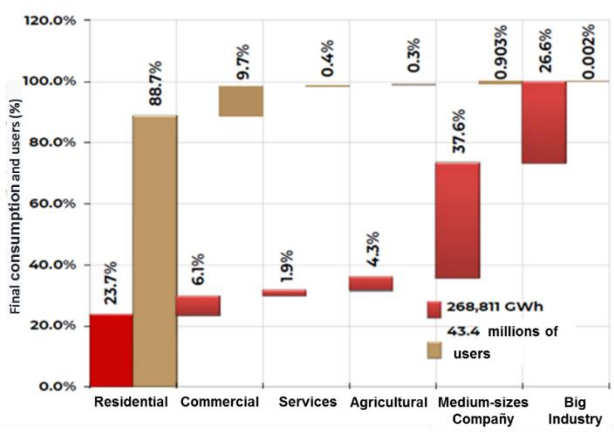
Theoretical framework

The disorganised and indiscriminate growth of the industrial sector causes a greater demand for electricity in the Load Centres to carry out their various activities and if there is no control over the conditions of the internal electrical installations of these Load Centres, interconnecting them to the SEN could cause failures with serious damage to their infrastructure and even collapse. To avoid these failures, the Electricity Legislation through the Energy Regulatory Commission (CRE) is responsible for issuing, monitoring and ensuring compliance with the regulatory framework on safety and reliability of the SEN.

Data from 2018 shows that the number of electricity users in Mexico reached 43.4 million, an increase of 2.7% compared to the number of users in the previous year. Graphic 1 illustrates six consumption sectors; among them, the medium and large industrial company sectors have high percentages of consumption: 37.6% and 26.6% respectively of a total of 266,811 GWh of electricity produced.



Graphic 1 Final consumption and number of users by sector
Source: PRODECEN 2019-33 of CENASE, 2018

The growth of the business and industrial sector has been disorderly, which has led to energy imbalances, higher demands, excessive consumption and often exceeds the capacity of electricity generation, so it is time to apply certain regulations or standards to maintain the operating conditions of the National Electricity System.

Such is the case of the Conformity Assessment Procedure of NOM-001-SEDE-2012 applied to low voltage electrical installations with substation and which also supports the provisions of the Grid Code that must be met at the point of interconnection at medium voltage (Official Gazette of the Federation, August 2016) which contain the criteria of efficiency, quality, reliability, continuity, safety and sustainability of the National Electric System.

Methodology

For this project, a methodology consisting of the following steps was used:

1. Preparation of tools, measurement equipment and personnel who will carry out the measurements and field survey.

2. Physical survey of the low voltage installations and the substation with the aid of the electrical plans and single-line diagram, identifying each of the conductors, conduits, protection, distribution boards, branch circuits and equipment.

3. Install the network analyser equipment to store the electrical parameters of interest to our study.

4. Analyse the information obtained from the survey and measurements with the help of spreadsheets and load tables to carry out phase balancing.

5. Define the proposals for improvement, through a report, and if there is opportunity to execute these proposals to compare with the previous conditions.

6. Compare current conditions against previous conditions to verify if the electrical installations are operating and being used efficiently.

This study will have the purpose of laying the foundations for other companies in the industrial sector to apply energy efficiency with energy diagnosis in order to keep their electrical installations safe and reliable, as well as to obtain economic benefits that will allow them to reinvest in the company.

Effect of unbalanced loads

The Breaking Plant is a 3F-4H electrical system. In this system, the neutral current is the vector sum of the three line currents, i.e. the sum of vectors IA, IB and IC. If the power system is balanced, with a symmetry of its vectors at 120º electrical and with a perfectly balanced three-phase linear load, the neutral current is equal to zero. In the opposite case, i.e. if the balanced three-phase electrical system has an unbalanced three-phase linear load, the neutral current is different from zero and this represents a serious danger to installations, people and equipment, such as:

- Overheating of the terminals and/or connection points of the conductors and power supplies to the different loads in the system.

- Protection schemes that may trip inappropriately.

- High current values through the neutral conductor irreversibly damage people.

- Reduced service life of conductors and equipment due to overheating.

- In the case of three-phase induction motors there is a decrease in efficiency.

- Increased energy consumption in all loads connected to the three-phase system.

An initial measurement is carried out during one week in April 2022 to analyse the information obtained and define the actions to be taken to make the system more efficient. For this purpose, a three-phase FLUKE model 430 Series II three-phase power and energy quality analyser was installed.

Load survey or census

From the load survey or census, the installed power is obtained, which is the sum of the power in kW of all the electrical equipment connected to the installation. The load census is presented in a load table, in which the % unbalance between the three phases is determined. Table 1 presents a general load chart of all the installed load and in which phase each load is connected.

According to NOM-001-SEDE-2012, the percentage of unbalance allowed between phases in a 3F-4H system should not exceed 5%. By applying equation (1),

$$\% \, Unbalance = \frac{kW_{Mayor} - kW_{Minor}}{kW_{Mayor}} * 100 \qquad (1)$$

It is verified that:

$$\% \text{ Unbalance} = \frac{38.342 \, kW - 34.726 \, kW}{38.342 \, kW} * 100 = \mathbf{9.43}$$

This is a higher percentage than allowed, so an analysis had to be carried out to reduce the % unbalance in the electrical system of the Breaker Plant.

Load	kW phase A	kW phase B	kW phase C	kW total
TAB 1, MARCH SQUARE D, MOD. JG250M81B, 460/318.94 V				
Squirrel-cage induction motor, three-phase, 460 V., 60 Hz, 100 HP (breaker)	24.866	24.866	24.866	74.6
Squirrel cage induction motor, three-phase, 460 V., 60 Hz, 20 HP (conveyor belt)	4.97	4.97	4.97	14,92
Squirrel cage induction motor, three-phase, 460 V., 60 Hz, 10 HP (screen)	2.49	2.49	2.49	7.46
Squirrel cage induction motor, 3-phase, 460 V., 60 Hz, 5 HP (positioning motor)	1.24	1.24	1.24	3.73
TAB 2, MARCH SQUARE D, QO312L125GRB, 220/127 V				
Lighting circuit C-1	1.672			1.672
(20 luminaires 2x38 W each)		1.672		1.672
Lighting circuit C-3	1.944			1.944
(20 luminaires 2x38W each)		1.944		1.944
Contact circuit C-2	0.58		0.58	0.58
(12 contacts of 162 W each)	0.58		0.58	0.58
Contact circuit C-	38.342	37.182	34.726	110.262
		Total installed power		110.262

Table 1 Total power installed in the electrical system of the crushing plant
Source: Prepared by the company

Next, a proposal is made to reduce the % unbalance by changing some single-phase loads to another phase. This proposal is shown in table 2 and it is verified that the percentage of unbalance obtained is reduced and is acceptable by NOM-001-SEDE-2012. This table shows the load changes through phase exchange that were performed; they are marked with orange cells.

According to table 2, for our 3F-4H system we have:

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$$\% \text{ Unbalance} = \frac{37.762\ kW - 36.090\ kW}{37.763\ kW} * 100 = \mathbf{4.42}$$

And this % unbalance is accepted by NOM-001-SEDE-2012.

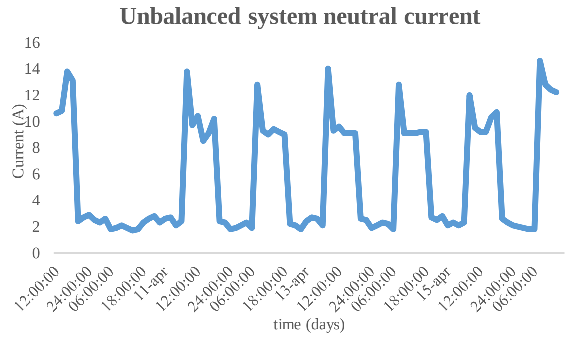
Load	kW phase A	kW phase B	kW phase C	kW total
TAB 1, MARCH SQUARE D, MOD. JG250M81B, 460/318.94 V				
Squirrel-cage induction motor, three-phase, 460 V., 60 Hz, 100 HP (breaker)	24.866	24.866	24.866	74.6
Squirrel cage induction motor, three-phase, 460 V., 60 Hz, 20 HP (conveyor belt)	4.97	4.97	4.97	14,92
Squirrel cage induction motor, three-phase, 460 V., 60 Hz, 10 HP (screen)	2.49	2.49	2.49	7.46
Squirrel cage induction motor, 3-phase, 460 V., 60 Hz, 5 HP (positioning motor)	1.24	1.24	1.24	3.73
TAB 2, MARCH SQUARE D, QO312L125GRB, 220/127 V				
Lighting circuit C-1 (20 luminaires of 2x38 W each)	1.672			1.672
Lighting circuit C-11 (20 luminaires of 2x38W each)			1.672	1.672
Contact circuit C-2 (12 contacts of 162 W each)	1.944			1.944
Contact circuit C-10 (12 contacts of 162W each)		1.944		1.944
Minisplit of 12,000 BTU C-57	0.58		0.58	0.58
12,000 BTU Minisplit C-46		0.58	0.58	0.58
Total kW per Phase	37.762	36.090	36.398	110.262
		Total installed power		**110.262**

Table 2 Total power installed in the electrical system of the Cracker Plant. The load changes in the phases are shown in orange
Source: Own elaboration

Current in the neutral

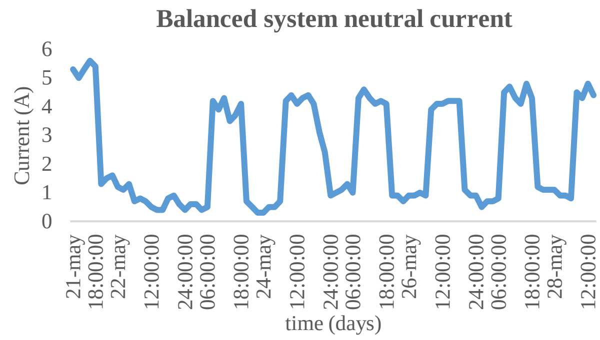
After the survey and measurements made with the network analyser during one week in April 2022, it is observed that the electrical installation 3F-4H is unbalanced. Graph 2 describes the major problem of having high current values in the neutral. At the beginning of each working day, all the motors are started up, giving rise to high current peaks of up to 14 A. and throughout the working day, it oscillates between 12 A. and 8 A. This figure is a reflection of what is shown in table 1 where the system has an unbalance of 9.43%.

This problem was solved by balancing the loads on the TAB 1 and TAB 2 distribution boards, reducing the unbalance to 4.42% and after this load balancing, other measurements were taken again during a week in May 2022.



Graphic 2 Current values in the electrical system when it is unbalanced at the Breaker Plant
Source: Own elaboration

Graphic 3 illustrates the benefits of balancing the electrical system, as the highest current peak is observed with a value of 5.6 A, and throughout the working day it oscillates around 4 A. These measurements are analysed and result in a significant reduction of the current in the neutral. This figure is a reflection of what is shown in table 2, where there is an unbalance in the system of 4.42%.



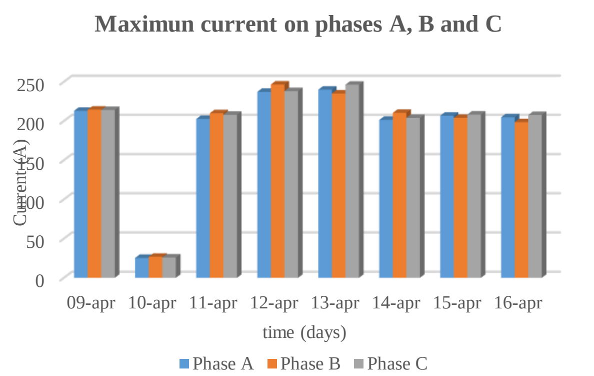
Graphic 3 Values of current in the electrical system when it is balanced in the Breaker Plant
Source: Own elaboration

In another section, it is shown that the reduction of the current in the neutral brings other benefits such as the reduction of electrical energy consumption, as well as eliminating overheating in conductors and equipment.

Correction of the anomalies found in the feeder circuit and its protection

The TAB 1 feeder circuit conductors physically installed are 3F+N of THHW 2/0 AWG gauge and according to table 310-15(b)(16) of NOM-001-SEDE-2012 we observe that they have a maximum ampacity of 195 Amperes at an operating temperature of 90° C and the grounding conductor is bare 8 AWG gauge. Due to the ambient temperature of 38° C, this conductor decreases its capacity to conduct current.

Graphic 4 shows that the maximum currents in each phase are above the ampacity of the THHW 2/0 AWG conductor, between 200 and 250 Amperes, so the installed conductor does not meet the ampacity criteria in accordance with the official Mexican standard NOM-001-SEDE-2012 and should be replaced by the appropriate gauge so that it does not overheat or reduce its useful life.



Graphic 4 Consumption by phase and total consumption during the days of measurement in the electrical system of the Breaker Plant when it is unbalanced
Source: Own elaboration

Similarly, the capacity of the 3P-250 A. main thermomagnetic circuit breaker is observed, which should be replaced by one of greater capacity due to the fact that the currents in each phase are reaching values of up to 246 A. and this can cause undesirable tripping of the circuit breaker.

Next, the calculations of the feeder circuit and main thermomagnetic circuit breaker are carried out.

From the physical survey, the measurements of the currents required by each equipment and branch circuit were obtained; these are shown in table 3.

We calculate the Icorrected, taking the following factors from table 310-15(b)(2)(a) of NOM-001-SEDE-2012, we obtain the F.C.T. = Correction factor for temperature = 0.91; we take a F.D. = Demand factor = 1.0 and the F.C.A. = Correction factor for grouping = 1.0 due to the fact that we only have 3 current-carrying conductors. Thus we apply these factors and we obtain

$$I_{corr} = \frac{I_{nom}(F.D.)}{(F.C.T.)(F.C.A.)} = \frac{245.9A(1)}{(0.91)(1)} = 270.91\ A$$

Load	Amps
Board 1	
Squirrel-cage induction motor, three-phase, 460 V., 60 Hz, 100 HP (breaker)	124
Squirrel cage induction motor, three-phase, 460 V., 60 Hz, 20 HP (conveyor belt)	27
Squirrel cage induction motor, three-phase, 460 V., 60 Hz, 10 HP (screen)	22
Motor de inducción jaula de ardilla, trifásico, 460 V., 60 Hz, de 5 HP (motor de posicionamiento)	7.6
Board 2	
Lighting circuit C-1 (20 luminaires of 2x38 W each)	13
Lighting circuit C-11 (20 luminaires of 2x38W each)	13
Contact circuit C-2 (12 contacts of 162 W each)	14
Contact circuit C-10 (12 contacts of 162W each)	14
12,000 BTU Mini Split C-57	5.8
12,000 BTU Mini Split C-46	5.5
Total current demand	**245.9**

Table 3 Maximum demand during the days of measurement in the electricity system of the Quebradora Plant
Source: Own elaboration

According to table 310-15(b)2(a) of NOM-001-SEDE-2012 on the ampacity of conductors, we have a feeder with an operating temperature of 90° C THHW gauge 250 MCM, with an ampacity of 290 Amperes and a cross section of 127 mm^2.

We verify that it complies with the voltage drop criterion, taking the distance from transformer T1 to the main ITM located in the TAB1 panel, which is 14 m. and we have:

$$\%e = \frac{2\sqrt{3}\ L\ I_{nom}}{s\ V_f} = \frac{2\sqrt{3}(14m.)(245.94\ A)}{(127\ mm^2)(480V)} = 0.195\% < 3\%$$

According to our calculation, the 250 MCM THHW conductor complies with NOM-001-SEDE-2012 for 3F+N in the feeder circuit of TAB 1.

We now proceed to calculate the protection of the TAB 1 feeder circuit.

A 3P-300 Amp thermomagnetic circuit breaker is required.

$$I_{protección} = 125\%\ I_{pcmotor\ mayor} + \Sigma I_{pcotros\ motores} + \Sigma I_{misceláneos}$$

$$I_{protección} = 1.25\ (124\ A) + 56.6A + 65.3A = 276.9\ A$$

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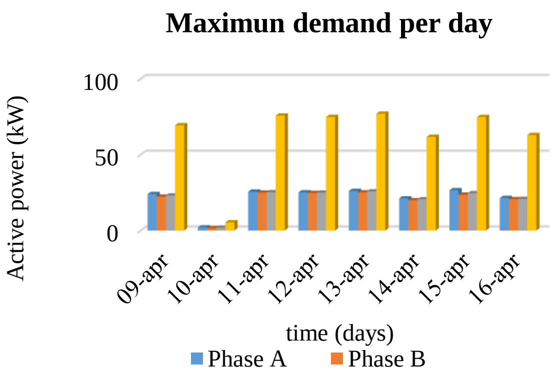
Having defined the protection of the TAB 1 feeder circuit, we now continue to select its earthing conductor, in accordance with table 250-122 of NOM-001-SEDE-2012, and the 4 AWG bare copper conductor is obtained.

Obsolete motor detection

In relation to table 3, the box marked with orange indicates that it was detected with the hook ammeter, that the 10 HP motor, which has more than 20 years of service, without maintenance and obsolete, consumes 22 amperes; this is a current greater than its current at full load with a value of 14 amperes, according to table 430-250 of NOM-001-SEDE-2012. A recommendation is made to replace it with a high efficiency motor.

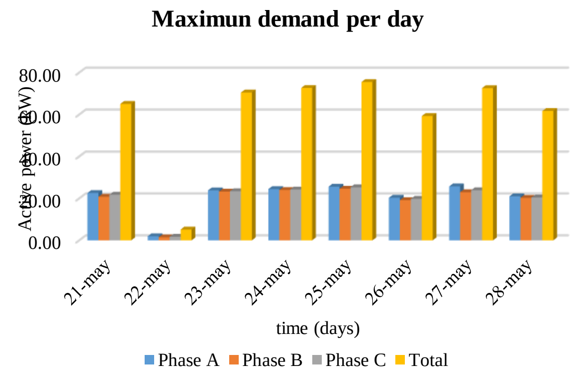
Analysis of demand (kW) and consumption (kWh)

Graphic 5 illustrates the maximum demand during the days of the initial measurement and shows the existing unbalance of the loads connected to each phase. The maximum demand on 11, 12, 13 and 15 April is close to 80 kW. The 10th of April is a Sunday and is a non-working day, and there is only demand for lighting.



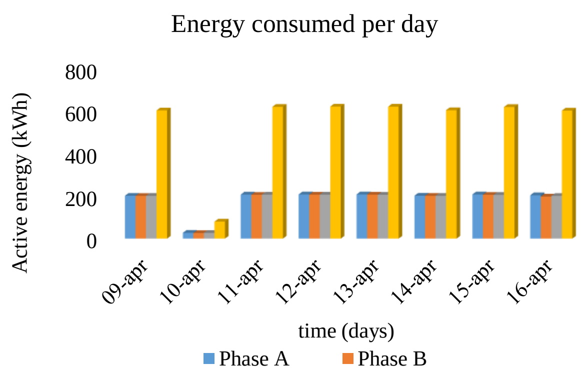
Graphic 5 Demand by phase and total demand of the Quebradora Plant during the measurement before load balancing
Source: Own elaboration

Similarly, Graphic 6 shows the measurement taken after the modifications to the feeder circuit and TAB 1 protection and the balancing of single-phase loads. It can be seen that with the modifications implemented, the total demand per day was reduced to values oscillating around 70 kW and the demand per phase is more uniform due to the balancing of loads in the three phases.



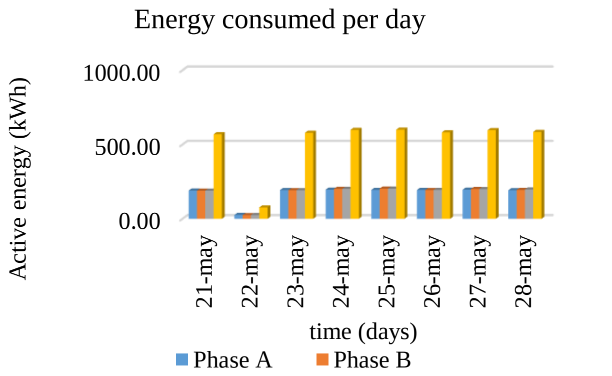
Graphic 6 Demand by phase and total demand of the Cracker Plant during the measurement after the modifications and load balancing
Source: Own elaboration

Analysing the maximum consumption per day obtained from the initial measurement, graph 7 shows a total value of over 600 kWh and a value per phase oscillating between 200 kWh. Furthermore, it can also be seen that there is an imbalance of consumption between the three phases. The 10th of April is a non-working day, so there is only consumption for lighting.



Graphic 7 Consumption by phase and total consumption of the Quebradora Plant during the measurement before load balancing
Source: Own elaboration

Graphic 8 shows a second measurement for the month of May 2022, after the modifications and load balancing. It can be seen that the total consumption per day was reduced to values below 600 kW and a value per phase below 200 kWh with a uniform profile.



Graphic 8 Total consumption and consumption per phase of the Quebradora during the measurement after the modifications
Source: Own elaboration

Single-line diagram

From the results obtained from the physical survey and the changes made to the TAB 1 feeder circuit and its protection, in addition to the load balancing in both panels, the actual single-line diagram was drawn up, as shown in figure 1, in accordance with the conductors, protections, channelling and equipment and loads installed.

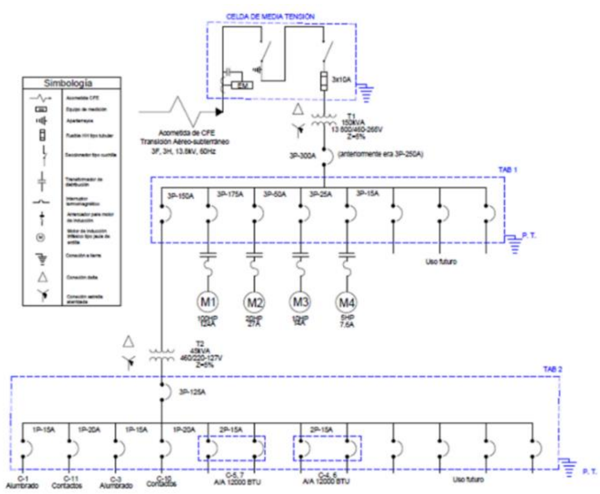


Figure 1 Updated single-line diagram
Source: Own elaboration

It is essential to keep the single-line diagram up to date and to have it at hand at all times for any revisions that may arise.

Acknowledgements

The authors are grateful for the support and effort of the Autonomous University of Campeche so that its researchers can disseminate the research projects being developed at this CIERMMI 2022 Congress.

Conclusions

The study developed in a stone and mineral crushing plant provides a methodology for the implementation of an energy efficiency study through energy diagnosis in companies in the industrial sector and thus comply with the Conformity Assessment Procedure (PEC) of NOM-001-SEDE-2012.

The single-line diagram, calculations and improvements made provided important and conclusive results that demonstrate the efficiency of the three-phase low-voltage system and the possibility that this model could be implemented in companies in the industrial sector.

As future work, its implementation in companies in the commercial and service sectors is recommended.

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