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Journal Electrical Engineering

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Support the international scientific community in its written production Science, Technology and Innovation in the Field of Engineering and Technology, in Subdisciplines Electromagnetism, electrical distribution sources, electrical engineering innovation, signal amplification, electric motor design, material science in power plants, management and distribution of electrical energies.

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Presentation of the content

As the first article we present, *Energy audit in an ice factory in the city of San Francisco de Campeche, Mexico*, by CHAN-GONZALEZ, Jorge J., SALAZAR-TORRES, Miguel, LANZ-GUTIÉRREZ DE VELASCO, Víctor and LEZAMA-ZÁRRAGA, Francisco, with affiliation at the Universidad Autónoma de Campeche, as the next article we present, *Decision management on optimal multi-objective maintenance of electrical distribution equipment*, by MOLINA-GARCÍA, Moisés, MELCHOR-HERNANDEZ, César L. and LÓPEZ-LEÓN, Ali, with adscription in the Instituto Tecnológico Superior de Huatusco, respectively, as next article we present, *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*, by LEZAMA-ZÁRRAGA, Francisco Román, SHIH, Meng Yen, CHAN-GONZALEZ, Jorge de Jesús and SALAZAR-UITZ, Ricardo Rubén, from the Universidad Autónoma de Campeche, as last article we present *Evaluation of a refrigerated container using photovoltaic solar energy for its implementation in the Mayan train*, by VALLE-HERNANDEZ, Julio, CANSECO-SANDOVAL, Karen, APARICIO-BURGOS José Esteban and TORRES-MENDOZA, Galilea, with affiliation at the Universidad Autónoma del Estado de Hidalgo.

Content

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Energy audit in an ice factory in the city of San Francisco de Campeche, Mexico

Análisis energético en una fábrica de hielo en la ciudad de San Francisco de Campeche, México

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Abstract

The cost of electricity represents a high percentage of the operating expenses of a company. It is important to establish strategies and operational policies for the efficient use of energy and consequently obtain economic savings. This paper presents a strategy aimed at the efficient use of electrical energy in the equipment installed in an ice factory in the city of Campeche, Mexico to reduce and control electricity demand, particularly during times of higher energy costs (peak hours). Optimize the operation of electrical equipment without affecting the production process, in such a way as to reduce operating costs and increase the company's profits. Some of the problems detected were: poor design of the plant and its electrical and control installations. Lack of maintenance (preventive, predictive and corrective). Lack of training of operating personnel. Poor prioritization of electrical loads and disconnection and reconnection times. Inadequate environmental conditions. On the other hand, it was found that it is cheaper to make 10 tons of ice with a 30-ton capacity machine than with a 20-ton one; the cost of energy per month is lower by a difference of $9,210.25 per month. It was also found that by placing thermal isolation in a flooded cooler, it has a decrease in its energy consumption by 56%.

Energy analysis, Energy Efficiency, Ice factory

Resumen

El costo de la energía eléctrica representa un porcentaje elevado dentro de los gastos de operación de una empresa. Es importante establecer estrategias y políticas operativas de uso eficiente de la energía y obtener como consecuencia ahorros económicos. Este trabajo presenta una estrategia encaminada al uso eficiente de energía eléctrica en los equipos instalados en una fábrica de hielo en la ciudad de Campeche, México; para reducir y controlar la demanda eléctrica, particularmente en el horario de mayor costo de energía (horario pico). Optimizar la operación de los equipos eléctricos sin afectar el proceso de producción, de tal manera que disminuyan los costos de operación y aumenten las utilidades de la empresa. Algunos de los problemas detectados fueron: mal diseño de la planta y sus instalaciones eléctricas y de control. Falta de mantenimiento (preventivo, predictivo y correctivo). Falta de capacitación del personal operativo. Mala priorización de cargas eléctricas y de los tiempos de desconexión y reconexión. Condiciones ambientales inadecuadas. Por otra parte, se comprobó que es más económico fabricar 10 toneladas de hielo con una máquina de 30 toneladas de capacidad que con una de 20 toneladas; el costo de energía al mes es menor en una diferencia de $9,210.25 mensuales. También se comprobó que, al colocar aislamiento térmico en un enfriador inundado, éste tenga una disminución en su consumo energético en un 56%.

Análisis energético, eficiencia energética, fábrica de hielo

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† Researcher contributing as first author.

Introduction

The Mexican state of Campeche is geographically located in the Yucatan Peninsula, Mexico, between parallels 17°49' and 20°51' north latitude; and between meridians 89°06' and 92°27' west; it has a warm humid climate with an annual average dry bulb temperature of 31 °C and a relative humidity of 70 to 86% throughout the year (Chatellier Lorentzen & McNeil, 2020)(INEGI, 2022). In terms of solar resources, irradiation (NREL, 2022) ranges from 5.5 to 6 kWh/(m2 day). The climatic conditions described above result in hot and humid conditions practically all year round. On the other hand, in recent years it has been observed that in the construction of public and private buildings as well as houses, no care has been taken to follow bioclimatic construction practices that help reduce the thermal gains to which they are subjected (Sandoya Mendoza, 2022). Similarly, no care has been taken to ensure that around new or old buildings there are abundant areas of wooded gardens that buffer or inhibit heat sources. Taking the above as a frame of reference, public and private buildings, as well as residential houses, annually have a high consumption of electricity for air conditioning and cooling, which is approximately 50-90% of total consumption (Víctor-Lanz, 2020). It is also notable that in hot-humid climates, the refrigeration machines in charge of air conditioning operate with less efficiency compared to hot-dry climates, up to 30% (Sierra, 2019) (HP Díaz-Hernández et al, 2019); mainly because to reach optimal operating temperatures, they first have to dehumidify the atmospheric air. As a consequence, energy consumption for cooling in hot-humid climates is higher than in hot-dry climates. The main strategy to be adopted to reduce the high cooling energy consumption is to achieve a substantial reduction of heat gains and to achieve energy efficiency. The energy audit is a fundamental tool for energy efficiency and savings (Osorio, 2013). It is useful both for analysis and diagnosis, whether in terms of tariffs or energy use and consumption, as well as for drawing up an orderly and structured proposal of practical measures to reduce operating costs and ensure profitability in the short, medium and long term. The objective was to gain a broad overview of energy use and consumption in order to identify strategies for efficient energy use.

The theoretical bases underpinning the methodology are: control and management of demand, electricity tariffs (analysis of the high demand tariff in hourly medium voltage, GDMTH); with emphasis on the applicable quotas and schedules, power factor and calculation of the insulation of the flooded cooler of the ice cube factory.

The following was carried out: analysis and diagnosis of energy consumption by means of a survey of electrical loads; collection of billing data; calculation of the average applicable quotas; energy costs at base, intermediate and peak times by production area; on-site measurement using a power quality analyser in electrical networks. With the previous work, it was possible to know the energy consumption of the factory, the necessary correction of the power factor, the optimal thermal insulation thickness for a flooded cooler (ice tube machines); all of the above to increase the production of the ice factory and make its energy performance more efficient by optimising the capacity of the installed equipment.

Justification

The main objective of this work is to provide a strategy aimed at the efficient use of electrical energy in the equipment currently installed in an ice factory in the city of San Francisco Campeche, Campeche, Mexico; to reduce and control the electrical demand of the company, particularly in the hours of highest energy cost (peak hours, from 7:00 to 19:00 hours) and optimise the operation of electrical equipment without affecting the production process, so as to reduce operating costs and increase the profits of the company. The cost of energy represents a high percentage of the operating expenses of any organisation (Castillo, 2014), which is why it is extremely important to establish strategies and operational policies to make efficient use of energy, without detriment to the thermal comfort of human beings (Benito, 2022), and to obtain economic savings as a result. In a study conducted by the Autonomous Universidad de Campeche for the Secretary of Economic Development of the state of Campeche in 2020 (Victor-Lanz, 2020), it indicates that at least 60% of electricity consumption in small and medium industries, homes, schools and universities, is due to cooling processes in any of its modalities.

Some of the problems detected in the demand control equipment, for which good results were not obtained, were due to the following reasons:

- Poor design of the plant and its electrical and control installations.
- Lack of maintenance (preventive, predictive and corrective).
- Lack of training of operating personnel.
- Deficient prioritisation of electrical load input and disconnection and reconnection times.
- Inadequate environmental conditions.

Objective

To conduct an energy audit in a company that manufactures ice in the city of San Francisco de Campeche, Mexico to identify the problems associated with high energy consumption; analyse them to find the best solutions to control and manage the energy demand for operating activities, optimising the use of the capacity of the installed equipment and reducing operating costs due to electricity consumption.

Hypothesis

By carrying out an energy audit in an ice factory, inefficient processes in the management of electrical energy can be identified and measures can be implemented to improve the efficiency of electrical consumption and, as a consequence, the respective economic savings.

Problem statement

The aim is to reduce energy consumption in an ice factory located in the city of San Francisco de Campeche, in the Mexican state of Campeche. Refrigeration processes require high values of energy to be carried out (Sierra, 2019). The environmental conditions at the site are important adverse factors during this process.

The location of the factory is geographically at 19.8129694º north latitude, and 90°.5904463 longitude (west), less than 50 meters from the coast with an average temperature of 31±0.1ºC and a relative humidity of 75±1%, also average (INEGI, 2022), 5 meters above sea level. It is desired to design and implement a comprehensive management system for the efficient use and respective saving of energy. To reduce energy consumption by means of a methodology that does not affect production levels. Determine potential savings. Reduce consumption during peak hours by shifting activities to base or intermediate hours. Decrease billable demand by implementing improvements. And finally, to reduce the amount of billing, through the implementation of the proposed methodology.

Description the ice factory

The company has been in operation since 1966. In the beginning it only produced industrial white ice bars. Eventually over the years it started to manufacture crystal ice bars and 5 kg bags of ice tubes, both suitable for human consumption. The company has been in operation for 56 years and throughout that time has gone through several stages of economic growth, infrastructure, installed load and consequently electricity consumption, to the point of becoming one of the largest companies in the refrigeration industry in the state of Campeche. The factory has a water tank for the production of 504 white ice bars, working 7 days a week, 24 hours a day. The ice production time is 24 hours, in 3 shifts of 8 hours. There are 168 bars per shift; with schedules from 6 am to 2 pm, from 2 pm to 10 pm and from 10 pm to 6 am. The freezing time for white ice is 18 hours. The company's ice is different from the rest of the city, because it melts in a longer time compared to the competition; for this reason not all the ice bars are extracted from the brine, as this way the cooling time of the ice bars is met, even though the production would be ready in 12 hours. The daily production is 504 white bars. Monthly production is 15,120 units. The company has a tube ice machine with the capacity to produce 168 bags of tube ice; working 7 days a week, 24 hours a day. The production time of tube ice is 24 hours in 3 shifts of 8 hours. A total of 1,680 bags are produced per shift and 5,040 bags of ice are produced per day. The monthly production of ice bags is 151,200 units.

Theoretical framework. Energy audit

The diagnosis of energy savings (DAE) or also called Energy Audits (AUDE) or Energy Diagnostics. It is the application of a set of techniques that makes it possible to determine the degree of efficiency with which the different energy systems that make up the entire energy process of a facility use the energy available to them. It also consists of the study of all forms and sources of energy. The objectives are to understand the current use of energy and to establish the processes necessary to achieve efficient use. It also provides information on the inappropriate use of energy. The diagnosis allows us to go into depth and find out the reasons why the consuming installation is in this situation and gives the best solutions to be implemented. Bad habits in the use of energy, inadequate controls, inattention to the energy issue, electrical equipment in poor condition or obsolete, among other factors affect the efficient use of energy in the industry. The profitability and relevance of each proposal is analysed, as well as the parameters that have the greatest impact and sensitivity, in order to monitor them in particular. This work was developed through the following sequential steps:

i. Compilation of available information: plans, single-line diagrams, electrical installation calculation memories, others.

ii. Carrying out on-site measurements of the necessary electrical variables. By means of a power quality analyser in electrical networks.

iii. Review and analysis of data, contrasting available information with direct measurements and with billing data from at least one year ago.

iv. Formulation and evaluation of efficiency and savings proposals.

v. Drafting and presentation of the audit report.

Peak demand

Peak demand is defined as the coexistence of loads in a time interval. The energy meter stores the reading corresponding to the maximum recorded value of demand (kW) in 15-minute intervals of the billing period. Electricity tariffs in Mexico for low and medium voltage over 25 kW contracted include, in addition to the consumption charge (kWh), a maximum demand charge (kW).

Demand management

Demand management and control are the activities necessary to optimise the use of the installed equipment. It consists of reducing or controlling the demand during a period of time, usually at the time of highest energy cost (peak hours), optimising the operation of electrical equipment without affecting the production process. The action of interrupting the operation of electrical loads that have a direct impact on billable demand, in order to reduce consumption levels; a change in consumption habits that leads to the establishment of operational strategies to make efficient use of energy and obtain economic savings as a consequence. The following benefits are obtained by establishing a change in electricity consumption habits:

For the client:

- Knowledge of the tariff structure among operational staff.

- Involvement of the personnel to know all the stages of the process.

- Growth of the energy saving culture in the company.

- Decrease in consumption during peak hours.

- Decrease in billable demand.

- Decrease in demand charges.

- Decrease in the consumption charge.

- Decrease in the amount of your invoicing.

- More competitive companies.

For the supplier:

- Reducing the demand requirement during peak hours, generating stability in the national electricity system.

- Reduction of losses due to overheating of equipment.

- Increase the useful life of equipment.

- Defer investment in infrastructure.

Proposed methodology for the analysis of photovoltaic electricity production.

The methodology presented in this work consisted of:

- To know the internal organisation of the ice factory: production and human resources.
- Obtaining electricity invoicing data for the years under study.
- Determine the historical consumption of electrical energy for at least two years, by means of invoicing.
- Carry out a detailed survey of existing electrical loads.
- Carry out an electrical energy analysis using tariffs applicable to the years under study, using the costs at base, intermediate and peak times in each production area.
- On-site measurement of electrical parameters with a network analyser, by production area.
- Consumption analysis by production area.
- Installation of capacitor banks for power factor correction.
- Installation of thermal insulation to equipment.

It should be noted that during the analysis process, hidden defects were found to control the loads, which were evaluated in order to eradicate them and significantly reduce the use of electrical energy. Peak demand was managed and controlled manually and with automatic devices. Staff coordinated the operation of equipment according to the production process in order to avoid unnecessary peak loads. It was limited in speed and accuracy by the human factor. Equipment operation was programmed by means of mechatronic devices in order to avoid peaks in demand. Regardless of the type of control used, the production process had to be perfectly known. It was advisable to start with a manual method of demand control before automating this process.

Analysis of the information and results obtained

Organisation of the company

The company currently has a total of 36 employees. The data are shown in table 1.

Post	Number of employees
Production	11
Maintenance	6
Driver and salesman	11
Administrative	4
Welder	1
Manager	3
Total	36

Table 1 Number of employees. Ice Factory in San Francisco de Campeche, Mexico
Source: Own elaboration

Energy consumption in the factory

Energy consumption is the amount of energy demanded by a given supply point during a time interval, called the billing period. This is invoiced by the commercialisation companies (Comisión Federal de Electricidad in this case); by applying a price per kilowatt hour (kWh), the amount of money paid by the company is determined. Tables 2, 3 and 4, as well as Figure 1, show the electricity consumption of the company and gave us an overview of the energy consumption in the billing years 2018 and 2019 in the Hielo factory.

	FIRST SEMESTER		
Months	2018	2019	Difference
January	78,360	90,912	12,552
February	92,712	84,864	7,848
March	108,888	115,248	6,360
April	109,392	119,976	10,584
May	118,200	148,296	30,096
June	110,208	133,224	23,016

Table 2 Comparative half-yearly electricity consumption (kWh), First Half Year (2018 - 2019)
Source: Own elaboration

	SECOND SEMESTER		
Months	2018	2019	Difference
July	130,032	124,152	5,880
August	144,888	141,168	3,720
September	130,800	138,888	8,088
October	137,736	134,112	3,624
November	101,328	105,384	4,056
December	114,576	123,048	8,472

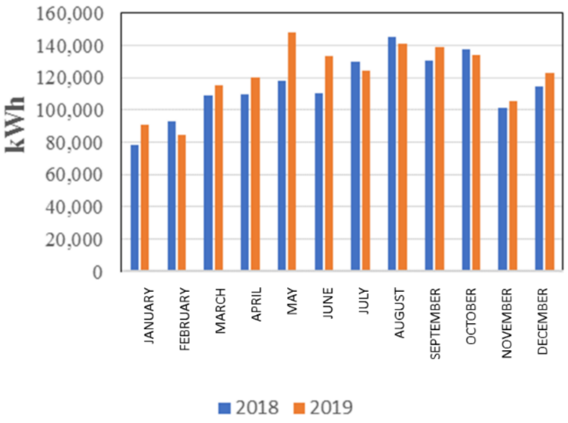
Table 3 Comparison of electricity consumption (kWh), half-yearly, second half-year (2018 - 2019).
Source: Own elaboration

First semester		Second semester	
2018	2019	2018	2019
102,960	115,420	126,560	127,792

Table 4 Average half-yearly electricity consumption in 2018 and 2019 kWh.
Source: Own elaboration

Load survey

The purpose of the load survey was to find out the installed power and working time of each piece of equipment, as well as to obtain an average monthly consumption and relate it to the factory's total energy consumption. To determine the power of each piece of equipment, the data on the nameplate were taken, or if they were not available, voltage and amperage measurements were taken. To determine the operating time of each piece of equipment, information was collected from the operators of each machine.



Graphic 1 Energy consumption (Kwh) in the ice factory in San Francisco de Campeche, Campeche, Mexico
Source: Own elaboration

The load survey was a very arduous job and generated an abundance of data, which is beyond the scope of this work. Tables 5, 6 and 7 show only some of the load surveys for illustrative purposes.

Building	Level	Area	Type	No of luminaires	Lamps per luminaire	Wattage W	Hours of use	kWh month
1	1	Ammonia tank and 2 compressors	LED	1	1	28	722.4	
1	1	Ammonia tank and 2 compressors	LED	1	1	9	722.4	6.50
1	1	Ammonia tank and 2 compressors	LED	1	1	9	722.4	6.50
1	1	Ammonia tank and 2 compressors	LED	1	1	9	722.4	6.50
1	1	Ammonia tank and 2 compressors	LED	1	1	9	722.4	6.50

Table 5 Lighting equipment load survey
Source: Own elaboration

Level	Area	Type AA	Capacity (BTU/h)	Power (W)	Hours of use per month	kWh per month
1	Office 1	Minisplit	12200	650	232	150.8
2	Office 2	Minisplit	12200	650	206	133.9

Table 6 Survey of air-conditioning equipment loads
Source: Own elaboration

Building	Level	Area	Miscellaneous	Power (W)	Hours of use per month	kW h per month
1	1	Bar production	Engine	1491.4	722.4	1077.3
1	1	Bar production	Engine	3730	722.4	2694.5
1	1	Bar production	Compressor	74600	722.4	53891.0
1	1	Bar production	Engine	118.55	722.4	808.0
1	1	Bar production	Engine	3730	722.4	2694.5
1	1	Bar production	Engine	560	722.4	404.5
1	1	Bar production	Engine	560	722.4	404.5
1	1	Bar production	Crane	2236	252.84	565.3

Table 7 Survey of loads for miscellaneous equipment
Source: Own elaboration

Electricity billing data for the years under study.

The study of the invoicing made it possible to verify the correct application of tariffs, and also to carry out a historical evaluation of consumption. It was possible to know the energy consumption in order to plan the management of the demand. The data on the invoicing sheet are as follows:

- Name: Ice Factory.
- Service number: 7898011101332.
- Connected Load: 259 kW.
- Meter Number: 7A8P00.
- Tariff: GDMTH.
- Contracted Demand: 250 kW.
- Route: 2450080-11-30HSB8-70101001.

	Maximum demand (kW)				
Month	Base	Inter	Tip	Billable	P. F.
Jan	147	151	146	151	0.81
Feb	145	157	148	157	0.82
Mar	233	242	150	242	0.82
Apr	24O	250	149	250	0.83
May	244	253	251	253	0.83
Jun	243	256	247	256	0.83
Jul	249	252	157	252	0.84
Aug	246	255	248	255	0.88
Sep	248	254	245	254	0.89
Oct	238	250	244	250	0.91
Nov	243	250	241	250	0.91
Dec	239	246	244	246	0.91

Table 8 Energy Demand Data (KW) in the 2019 Billing
Source: Own elaboration

Energy consumption (kWh) Billing					
Month	Base	Inter	Tip	Billing	Weights
Jan	30,072	48,888	11,952	90,912	$273,521
Feb	28,824	45,360	10,680	84,864	$258,576
Mar	40,680	62,664	11,904	115,248	$333,018
Apr	39,432	73,104	7,440	119,976	$340,936
May	49,872	90,384	8,040	148,296	$451,604
Jun	45,720	80,232	7,272	133,224	$420,406
Jul	42,072	75,984	6,096	124,152	$358,611
Aug	46,512	86,688	7,968	141,168	$428,042
Sep	51,312	79,968	7,608	138,888	$400,050
Oct	41,112	82,776	10,224	134,112	$388,584
Nov	35,304	56,664	13,416	105,384	$329,043
Dec	40,680	65,808	16,560	123,048	$365,174

Table 9 Energy Consumption Data (Kwh) in the 2019 Billing
Source: Own elaboration

Analysis of electricity energy through tariffs

For the Mexican Republic, the Ministry of Energy through the Federal Electricity Commission establishes and publishes (CFE, 2022) the average electricity tariffs applicable during a year. Table 10 presents the tariffs for Great Hourly Medium Voltage Medium Demand (GDMTH, broken down into base, intermediate and peak) applicable for the peninsular region (Yucatan peninsula).

Tariff	Description	Timetable	Charge	Unit	Average Annual
GDMTH	High demand in hourly medium voltage	-	Fixed	$/mes	512.44
		Base	Variable (Energy)	$/kWh	1.0993
		Intermediate	Variable (Energy)	$/kWh	1.8456
		Tip	Variable (Energy)	$/kWh	2.0585
		-	Distribution	$/kW	87.62
		-	Capacity	$/kW	346.75

Table 10 Electricity tariff (GDMTH) applicable in the Peninsular region, annual average during the time of study
Source: Own elaboration

Consumption analysis by production area

The installed load of each production area was in operation 24 hours a day, 7 days a week. After an analysis of the consumption and energy costs, a final summary is made, broken down (per day and per month), which is presented in table 11. It is worth mentioning that the offices, maintenance workshop, warehouse, external loading bay and external lighting are only in operation for 8 hours. On the other hand, the production of tubes and ice bars is based on an analysis of energy consumption and costs that is as realistic as possible, based on a detailed analysis of electrical loads.

Area	kWh/day	kWh/month	Cost
Bar ice	2,135.57	64,921.27	$ 104,011.87
Osmosis	68.33	2,077.32	$ 9,739.49
Water tanks	20.24	615.42	$ 1,978.44
Ice tubes	2,114.90	64,293.08	$ 98,726.47
Tubes ice bars backing	3.96	120.38	$ 1,778.01
Cold rooms	1,341.72	40,788.29	$ 65,562.84
Offices	61.38	1,866.01	$4,766.66
Maintenance workshop	34.02	1,034.21	$ 5,297.20
Loading bays	63.62	1,933.93	$ 12,025.92
Total	5,843.75	177,649.90	$ 303,886.91

Table 11 Energy consumption and costs in each production area according to the working time of the ice factory
Source: Own elaboration

Installation of capacitor banks

The capacitor is a passive electronic component. It is used to store electrical charge (in the form of an electric field). Capacitors play an important role in many electrical circuits to perform power factor correction, which by regulations of the Ministry of Energy must be equal or higher than 0.90 (Energy, 2016). The ice factory has three transformers; each of different capacity; they feed different electrical equipment which are mentioned below:

- Transformer 150 KVA. It powers: ice bar production compressor, ice bar mould filling tank pump, reverse osmosis equipment, compressor radiator, brine agitator, cooling tower and service area lighting.

- Transformer 125 KVA. Feeds: ice tube production compressor, ice tube machine, crushing machine, cooling tower, compressor radiator and production area lighting.

- Transformer 112 KVA. Feeds: back-up compressor for ice bars, back-up compressor for ice tubes, back-up ice tube machine, radiators for both compressors, cooling tower, condensing units for 3 cold rooms, crane for ice moulds, cistern pump, condenser blowers for the cold rooms, power supply for the warehouses, ice grinders and lighting for the cold rooms.

It is important to note that the company had two 20 kVA capacitor banks shown in figure 1, but for reasons of refurbishment prior to our work, they were disconnected from the 125 kVA and 150 kVA transformers. Using a Fluke 434-II/435-II/437-II/437-II (three-phase power and power quality analyser), figure 2, we were able to obtain the operation of the power supply system of each transformer, as well as the behaviour and the variables required to calculate the capacitor bank for the 112 kVA transformer.

Figure 1 20 KVA capacitor bank in the company Hielo San Bartolo
Source: Own elaboration

Figure 2 FLUKE model 430 Series II three-phase power and energy quality analyser, three-phase
Source: Own elaboration

Tables 12, 13 and 14 show the results obtained with the help of the electrical network analyser in each substation:

Area	kWh/day	kWh/month	Cost
Ice bars	2,135.57	64,921.27	$104,011.87
Osmosis	68.33	2,077.32	$ 9,739.49
Water tanks	20.24	615.42	$1,978.44
Ice tubes	2,114.90	64,293.08	$98,726.47
Tubes ice bars backing	3.96	120.38	$1,778.01
Cold rooms	1,341.72	40,788.29	$65,562.84
Offices	61.38	1,866.01	$4,766.66
Maintenance workshop	34.02	1,034.21	$5,297.20
Loading bays	63.62	1,933.93	$12,025.92
Total	5,843.75	177,649.90	$303,886.91

Table 12 Average data collected from the FLUKE brand network analyser, model 430 Series II. 125 KVA transformer
Source: Own elaboration

Data	L1	L2	L3	Unit
Voltage	130.2	131.6	129.8	V
Current	237.2	248.6	244.3	A
Active Power	26.8	28.9	28.5	kW
Apparent Power	29.5	31.2	30.0	kVA
Reactive Power	13.7	13.8	11.9	kVA
Active Power	26,824.9	28951	28460.4	kWh
PF	0.91	0.92	0.94	s/u

Table 13 Average data collected from the FLUKE brand network analyser, model 430 Series II. 150 KVA transformer
Source: Own elaboration

Data	L1	L2	L3	Unit
Voltage	130.3	131.8	131.4	V
Current	123.9	125.6	113.1	A
Active Power	12.7	13.6	13.3	kW
Apparent Power	16.0	15.8	15.4	kVA
Reactive Power	9.92	8.15	8.03	kVA
Active Power	1897.9	2123.	1827.	kWh
PF	0.82	0.89	0.88	s/u

Table 14 Average data collected from the FLUKE network analyser, model 430 Series II. 112.5 KVA transformer
Source: Own elaboration

Power factor correction

The power triangle is the best way to see and understand graphically the power factor (Cos φ) and its relationship with the powers present in an alternating current electrical circuit. Figure 3.

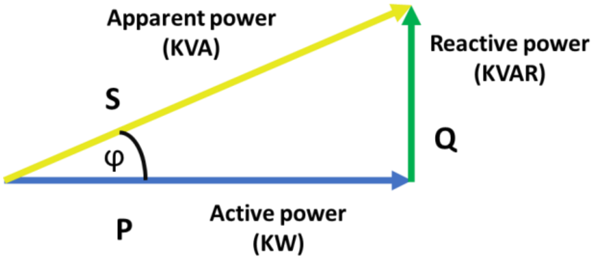


Figure 3 Electrical power triangle
Source: Own elaboration

The power factor is the ratio between the real working power and the total power consumed by the consumer connected to the alternating current electrical circuit. This ratio can be represented mathematically, with the formula 1 (Levy, 2020).

$$Cos\ \varphi = \frac{P}{S} \tag{1}$$

The calculation of the capacitor bank required to correct the power factor corresponding to the 112 kVA transformer is presented. It went from a value of 0.83 to 0.95, complying with the standard. The calculations are presented with equations 2 to 8 (Levy, 2020).

- Initial values

FP = 0.83, P1 = 40 kW.

Arc Cos (FP) = Arc Cos (0.83) = 33.9° (2)

$$Q_1 = P_1 tan(\varphi) = 40 * \tan(33.9) = 26.88\, kVAR \quad (3)$$

$$S_1 = {}^{P_1}/_{Cos\ \varphi_1} = {}^{40}/_{0.83} = 48.19\, kVA \quad (4)$$

- Final values

FP = 0.95, P1 = 40 kW.

Arc Cos (0.95) = 18.19° (5)

$$Q_2 = 40 * \tan(18.19°) = 13.14\, kVAR \quad (6)$$

$$S_1 == {}^{40}/_{0.95} = 42.11\, kVA \quad (7)$$

$$Q_{corre} = Q_1 - Q_2 = 26.87 - 13.14 = 13.73\, kVAR \quad (8)$$

From the above, a 13.72 kVAR capacitor bank was calculated; since no such capacity exists in the market, the installation of a 15 kVAR capacitor bank is recommended. Once the power factor was corrected, the penalty for low power factor became a bonus.

Thermal insulation to the flooded cooler

It is necessary to minimise energy losses due to heat gain in cooling and the thermal insulation acts as a barrier to this flow (Sierra, 2019). The flooded chiller in the factory, shown in figure 4, was not insulated. The flooded cooler is made of stainless steel, which has a thermal conductivity of 16.3 W/m ºC and a thickness of 0.05 m. The flooded cooler of the tube ice machine was insulated; it operates with ammonia refrigerant whose thermal conductivity is 0.55 W/m ºC.

Figure 4 Ice tube machine in the Hielo factory
Source: Own elaboration

ThermaSmartPRO thermal insulation was selected to insulate the flooded cooler because of the wide temperature range in which it operates, the excellent insulation value and the quick and easy installation. Table 15 shows the insulation properties, service temperature, thicknesses and lengths.

Thermal conductivity W/m °C
K = 0.38 at 40°C K = 0.36 at 23°C K = 0.34 at 0°C
Service temperature range
Maximum 95 ° C Minimum -80 ° C
Availabilities
Available in thickness: 7,5 mm - 10 mm - 13 mm - 19 mm - 25 mm -30 mm
Available in width: 50 cm - 60 cm - 100 cm - 120 cm

Table 15 Insulation properties, service temperature, thickness and length availabilities of ThermaSmartPRO insulation
Source: Own elaboration

It is required to know the heat transfer area. The area is the sum of the area of the lateral surface (AL) with the areas of the two bases (AB). Where r is the radius of the base and h is the height of the cylinder as shown in figure 5; the area of the cylinder is calculated as:

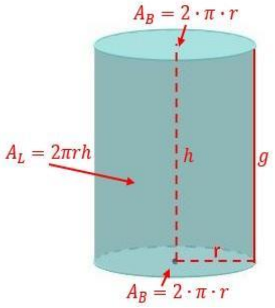


Figure 5 Heat transfer area of the flooded cylinder for ice tube manufacturing
Source: Own elaboration

The dimensions of the cooler are as follows: height of the cooler 3.17 m, height of the cutter 1 m, radius of the cooler and the cutter 0.596 m. Then the insulation area is defined as equation 9.

$$A = 2\pi r(r + h) = 2\pi(0.596)(0.596 + 4.17) = 17.85m^2 \quad (9)$$

For the selection of the ideal insulation thickness, the thickness that allows the least amount of heat transfer is chosen. Applying the following formula (HOLMAN, 2002):

$$r_{crit} = \frac{k}{h_{ext}} = \frac{0.034}{3} = 0.0113\, m = 11.3\, mm \quad (10)$$

Where:

k is the thermal conductivity in W/m ºC.

h_{ext} is the convective coefficient in W/m2 ºC.

From table 12, the ideal insulation thickness is 0.0113 m. The following comparison is presented by applying equation 11 and 12 (Holman, 2002):

$$Q = AU\Delta t \quad 11)$$

Where:

Q = Amount of heat transferred in Watts.

A = Area of the external wall surface (m^2).

U = Overall heat transfer coefficient W/m^2ºC.

Δt = Temperature difference in ºC.

$$U = \frac{1}{\frac{1}{h_{int}} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{1}{h_{ext}}} \quad (12)$$

With:

x = Thickness of the material.

k = Thermal conductivity of the material.

h_{int} = Indoor convective coefficient.

h_{ext} = Coefficient of external convection.

With the following data we calculate Q for the flooded cooler with and without insulation, supported by equations 10 and 11.

Area = 17.85 m^2

t1 = - 5°C.

t2 = 30°C.

h_int = 3 W/m2 ºC.

h_int = 10 W/m2 ºC.

k_1 stainless steel = 16.3 W/m2 ºC.

k_2 insulation = 0.034 W/m ºC.

x1 stainless steel thickness = 0.05 m.

x2 insulation thickness = 0.0113 m.

Flooded cooler without insulation: Q = 1,431.6 W

Flooded chiller with insulation: Q = 812.7 W

Proportionally the heat flux reduction for the flooded cooler is as follows:

$$Q = \frac{812.7\, W}{1{,}431.6\, W} = 0.56 = 56\%$$

Results

By establishing strategies to change electricity consumption habits, the following benefits were obtained:

- Training and knowledge of operational staff in the tariff structure of the Federal Electricity Commission (CFE).
- Involvement of administrative and operational staff to learn about all stages of the process, especially for joint decision-making.
- Exponential growth of the culture of saving throughout the organisation.
- Decrease in consumption during peak hours.
- Decrease in billable demand.
- Decrease of 20 to 30% in the amount of your total invoicing.
- More competitive company.

After correcting the power factors in the factory's transformers, an important change was noticed. It began to show a bonus in favour of the factory, whereas before the adjustments there were only penalties. The indicators shown below show the progression from January 2019 to February 2020. Table 16.

Months	Bonus (-) Penalty (+)	Power factor %
Jan 19	$ 13,287.41 (+)	81.40
Feb 19	$ 11,429.50 (+)	82.15
Mar 19	$ 13,245.71 (+)	82.89
Apr 19	$ 13,137.11 (+)	83.29
May 19	$ 15,940.23 (+)	83.75
Jun 19	$ 15,782.96 (+)	83.33
Jul 19	$ 11,577.04 (+)	84.20
Aug 19	$ 5470.08 (+)	87.62
Sep 19	$ 1306.41 (+)	89.37
Cct 19	$ -638.30 (-)	90.83
Nov 19	$ -1,355.31 (-)	91.76
Dec 19	$ -900.67 (-)	90.93
Jan 20	$ -1,826.05 (-)	93.34

Table 16 Power Factor Bonus and Penalty from January 2019 to February 2020
Source: Own elaboration

On the other hand, energy consumption by electrical equipment and production was obtained, the operating times of the electrical equipment, the magnitude of installed power and its relationship with billable consumption were known. The economic impact of the electrical equipment in each billing period and the electrical energy costs by production of tonnes of ice and working periods are presented. In the case of the 30-tonne ice machine, it produced 1.25 tonnes per hour, while the 20-tonne machine produced 0.83 tonnes per hour. It was required to produce 10 tonnes of ice per day. With a new operating scheme, the consumptions were compared; the 30-tonne machine worked 8 hours, while the 20-tonne machine worked 12 hours. The cost of energy to produce 10 tonnes of ice in each machine, based on the operating times of each machine, led us to conclude that the 30-tonne machine, despite consuming more electricity, has a lower monthly energy cost compared to the 20-tonne machine, with a difference of $9,210.25 per month; the result is presented in tables 17 and 18. In addition, given the way CFE bills, the fact of increasing electricity consumption is reflected in most of the billable items, affecting the final billing cost. Thus, the real difference in Mexican pesos between the operation of one machine and another is $16,464.37 per month.

Supply	$512.44	Fixed Charge	$512.44
Distribution	$4,530.35	Energy	$55,364.89
Transmission	$3,526.69	F.P	-$4,274.67
CENACE	$1,039.15	Subtotal	$51,602.66
Base	$18,897.23	VAT 16% VAT	$8,256.42
Intermediate	$7,760.21	Alum. Pub.	$20,675.67
Point	$0.00	Turnover	**$80,534.75**
ScnMEM	$719.41		
Capacity	$18,379.41		
SubTotal	$55,364.89		

Table 17 Invoicing, ice tube machine with a production capacity of 30 tonnes, producing 10 tonnes per day
Source: Own elaboration

Supply	$512.44	Fixed Charge	$512.44
Distribution	$5,384.31	Energy	$69,558.31
Transmission	$4,191.46	F.P	-$4,274.67
CENACE	$1,039.15	Subtotal	$65,796.08
Base	$16,303.78	VAT 16% VAT	$10,527.37
Intermediate	$19,563.91	Alum. Pub.	$20,675.67
Point	$0.00	Turnover	**$96,999.12**
ScnMEM	$719.41		
Capacity	$21,843.86		
Subtotal	$69,558.31		

Table 18 Invoicing, ice tube machine with a production capacity of 20 tonnes, producing 10 tonnes per day
Source: Own elaboration

Conclusions

This article presents an energy efficiency study of the facilities of an ice factory installed in the city of San Francisco de Campeche, Campeche, with the proposal to reduce its energy consumption (electricity) through a methodology that includes the determination of historical consumption of electricity for at least two years, the survey of existing electrical loads, obtaining data on electricity billing in the years of study, analysis of electricity using average rates applicable to the years of study using the costs in hours, analysis of consumption by production area, installation of capacitor banks. The methodology included obtaining electricity billing data for the years under study, analysis of electrical energy using average tariffs applicable to the years under study using hourly costs, analysis of consumption by production area, installation of capacitor banks for power factor correction and installation of thermal insulation for critical refrigeration equipment.

- A load survey was carried out to find out the installed power and working time of each piece of equipment, as well as to obtain an average monthly consumption and relate it to the factory's total energy consumption.

- Using a Fluke 434-II/435-II/437-II/437-II network analyser (three-phase energy and power quality analyser), the operation of the power supply system of each transformer and the entire electrical system was obtained, as well as the behaviour and the variables required to calculate the capacitor bank (15 kVAR) for a 112 KVA transformer.

- The economic impact of the electrical equipment in each billing period was determined to reduce energy consumption without compromising production.

- It was found that it is more economical to operate a 30-tonne capacity ice maker than a 20 tonne capacity ice maker. The 30-tonne machine, despite consuming more electricity, has a lower monthly energy cost compared to the 20-tonne machine, by a difference of $9,210.25 per month. The real difference between the operation of one machine and the other is $16,464.37 per month due to the way CFE bills.

- The placement of thermal insulation on the factory's flooded chiller allowed the heat energy of the refrigerant to be conserved in the system. With the insulated system, the reduction in energy consumption is reflected in a 56% reduction in energy consumption.

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Decision management on optimal multi-objective maintenance of electrical distribution equipment

Toma de decisiones en el mantenimiento óptimo multi-objetivo a equipos eléctricos de distribución

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Abstract

Maintenance objective in a power distribution equipment is to perform adequately its function, to guarantee the power energy supply in a reliable and security way. Companies have for its equipment overhaul interval maintenance scheduled, no matters its arrival times to failure. This article presents a proposal to help make optimal maintenance decisions, which must be given to a distribution equipment for its correct operation to guarantee its reliability. Based on its actually overhaul interval maintenance scheduled and the statistical arrival failure time of a distribution power equipment, the NSGA-II heuristic model is used to obtain a Pareto front, and help to make the best maintenance decision. Two objective functions are considered, minimize maintenance cost while maximize the reliability of a equipment.

Optimal, Reliability, Minimize, Maximize, Statistical

Resumen

El objetivo del mantenimiento en los equipos eléctricos, es que estos se desempeñen adecuadamente y así, garantizar de manera confiable el suministro de la energía eléctrica. Muchas compañías eléctricas tienen mantenimientos programados para sus equipos, sin tomar en cuenta su historial de fallas. Éste artículo, presenta una propuesta para ayudar en la toma de decisiones sobre el mantenimiento que se le tiene que dar a un equipo eléctrico de distribución para su correcto funcionamiento, y garantizar así su confiabilidad. Basado en un mantenimiento programado y el historial de fallas de un equipo eléctrico de distribución, se utiliza el modelo heurístico NSGA-II, para la obtención de un frente de Pareto, y ayudar así a tomar la mejor decisión sobre el mantenimiento. Se toman en consideración dos funciones objetivos, minimizar los costos del mantenimiento mientras que se maximiza la confiabilidad del equipo.

Óptimo, Confiabilidad, Minimizar, Maximizar, Estadística

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Introduction

The purpose of maintenance is to extend the lifetime of any equipment, or at least to extend the average time to the next failure. In addition, it is hoped that maintenance can reduce the frequency of power service interruptions. However, equipment maintenance is a function of the budget allocated by utilities. In this sense, utilities seek to optimise maintenance for their equipment, i.e. maximise the availability and serviceability of their existing equipment at the lowest cost used for maintenance. Reliability and cost are two important aspects considered by the power system operator in many deregulated power systems (J.E., 2016). Maintenance in electricity systems is divided according to the three entities that comprise it: Generation companies (GENCOs); Transmission companies (TRANSCOs) and Distribution companies (DISCOs) [1]. Force (2011) presents the results obtained from the strategies used for maintenance in the electric power industry. Reliability Centred Maintenance (RCM) is increasingly used; Maintenance based on probabilistic models; Mathematical models; Markov Chains; Statistical distribution; Stochastic processes; etc.

In Yssaad B. (2014) they use the RCM and the program called: failure types and criticality of their effects (FMECA). The two tools (RCM and FMECA) are used to plan future maintenance based on the available failure information from an Algerian power company. The data used by the FMECA are from the equipment of: 1) Power line, 2) Circuit breaker, 3) Bus bar, 4) Power transformer and, 5) Sectionaliser. The reliability, availability and maintenance distribution are based on the estimated failure rate reported by the equipment. The two-parameter Weibull distribution is the distribution used to represent the equipment failures. The costs used for optimal maintenance effectiveness are: material, device location, parts in stock, unavailability, personnel, technical data and outage time. The two-parameter Weibull function is again used in A. (2018) to represent the failure rate, and obtain the optimal maintenance of a piece of equipment. To determine the maintenance, a minimisation of the expected total maintenance cost function is performed.

The cost function used takes into account the costs of: Replacement, Minimum imperfect maintenance, Minimum repair, Operational cost and Cost per failure. Because electrical equipment is subject to different deterioration factors (covariates), maintenance optimisation for GENCOs and TRANSCOs with covariates is presented in Wang Y. (2016). Two covariates are used for generators and transmission lines. To simulate the random failures in the power system, the Monte Carlo technique applied to power systems is used. To describe the degradation process in the equipment, the two-parameter Weibull distribution is used and the Exponential function is used to quantify the effects of the covariates.

The mathematical model used for maintenance optimisation is based on four main causes: 1) minimisation of maintenance costs of generators, transmission lines and their operating costs; 2) time constraints on maintenance in generation units; 3) time constraints on maintenance in transmission lines; 4) security constraints, which include: limits on generation capacity, cost of starting and stopping a generation unit, limit on/off time of generation units, balance in the power system, limit on transmission power flows. These main causes are optimised by a Lagrangian relaxation. In Shayesteh E. (2018) the use of RCM in the generators and transmission lines of the IEEE 14-bus test power system is presented. In this article, electric power generation using renewable sources is included. For the application of RCM, the Severity Risk Index (SRI) proposed by the North American Electric Reliability Corporation (NERC) is used to select the most critical components within an electrical system. Three percentages are proposed as maintenance strategies (according to the desired level): 100%, 50%, 50% and 0% for fully maintained, half-maintained and maintenance-free equipment, respectively. Seven different costs are taken into consideration for each maintenance strategy. Within these costs, there is the environmental cost for the different types of generators, which evaluates their power output, heat generated, amount of CO_2 emission and social cost of CO_2. Optimal power flows are used to determine the impact of maintenance strategies through the expected energy not supplied (EENS) of the system.

In Carnero M.C. (2017), a maintenance selection strategy for electrical distribution devices in hospital facilities is proposed. This strategy is mainly based on the incorporation of a model that takes into account the maintenance of facilities; maintenance of medical equipment; health and safety; environment; admission programme and medical areas. Maintenance is based on the methodology of Markov chains and on a programme called: Measuring Attractiveness through Category Based Evaluation (MACBETH). A group of specialists is included for each department incorporated into the model, to analyse the different devices of the hospital under study, through MACBETH. In L., L., & Z. (2018) a deterministic piecewise Markov process is presented, an interval methodology is used to model maintenance based on the condition of the equipment. This methodology is used to model the different parameters faced by the equipment such as: temperature, pressure, wear and tear, etc. A multi-objective algorithm called differential evolution of non-dominated classification is used for the optimisation of maintenance costs. The proposed methodology is applied to a centrifugal pump and a pneumatic valve in series of a nuclear power plant. For the determination of the failure rate of the elements, the technique of failure types and effects analysis (FMEA) is used.

Zhang S. (2019) presents the optimisation of maintenance in a nuclear power plant. Three objectives are presented to be considered which are: 1) a reactor is considered as a multi-component system, i.e. between multiple reactors there are structural dependencies, dependencies between internal and external units; 2) Optimisation from multi-component to multi-system; 3) Fuel minimisation. Minimisation is done to a valve system supplying water to two different reactors. The failure rate used in this paper is the exponential distribution, and the non-dominated sorting multi-objective genetic algorithm (NSGA-II) is used for the minimisation of the three objectives. NSGA-II is again used in Ayoobian N. (2016), three objectives are used to minimise: 1) Unavailability; 2) Costs and 3) Exposure time. The third objective is very important due to the existence of radioactive material in nuclear plants. Optimal maintenance is done to a high pressure water injection system. To take the best solution on the Pareto front, the help of an index of sensitivities is taken. The use of RCM and NSGA-II for maintenance scheduling in an electrical distribution system is presented in Piasson D. (2016). The objectives are twofold: to minimise preventive maintenance costs while maximising the reliability of the whole system. The equipment considered are: distribution transformers; voltage regulators; circuit breakers; capacitor banks; switchgear, protection and primary cables. Eleven years of historical fault data were used to model the reliability indices of the equipment. Su C. (2019) presents the use of NSGA-II for the optimisation of the maintenance of an electromechanical part of a wind turbine: the gearbox. The objectives to be optimised are availability and a cost function. The cost function includes the costs of: repair, inspection, failure and replacement. The failure rate used for the gearbox was made using historical data and the two-parameter Weibull distribution function is used, in addition, two adjustment factors are used for the distribution function: age reduction factor and failure rate increase factor.

The present research work has its fundamental basis in César L. Melchor-Hernández (2015), where historical failure data of an electrical equipment is used to determine the optimal maintenance that should be given to this equipment. Through the two-parameter Weibull distribution function, and the assumption of scheduled maintenance by the electric company (TBASE), the minimisation is made to a cost function to determine the optimal maintenance. However, in (César L. Melchor-Hernández, 2015) only one objective (minimisation of the cost function) is taken into account to determine the time (T) and the number of times (N) that the equipment should be maintained. In this research work it is proposed to use a multi-objective genetic algorithm to add another function, the reliability of the equipment.

By minimising the cost function and maximising the reliability of the equipment, a Pareto front is obtained, the objective of which is to help in maintenance decision making, to ensure that the resources allocated are used in the best way possible, without affecting the reliability of the electrical equipment under study.

Model

The distribution function (equation 1) is used to represent the behaviour of the equipment, according to its statistical failures [13].

$$\lambda(t,T) = \left(\frac{T}{T_{BASE}} \right)^{\beta} \frac{\beta}{\alpha} \left(\frac{t}{\alpha} \right)^{\beta-1} \tag{1}$$

Where:

t = statistical time of failure.

T = Optimal maintenance.

TBASE = Company scheduled maintenance.

β = Shape parameter.

α = Scale parameter.

The model used is based on a policy of imperfect maintenance with minimum repairs at each statistical failure. The total expected cost, includes the costs of: minimum repair; scheduled maintenance and; equipment replacement cost (equation 2), where the replacement cost will always be greater than or equal to scheduled maintenance (César L. Melchor-Hernández., 2015), (Nakagawa., 2005):

$$C(N,T) = \frac{1}{NT} \left[C_1 \sum_{j=0}^{N-1} \int_0^{NT} \lambda(t,T)dt + (N-1)C_2 + C_3 \right] \tag{2}$$

Where:

C1 = Cost of minimum repair.

C2 = Cost of scheduled maintenance.

C3 = Cost of equipment replacement.

N = Number of optimal maintenance.

T = Optimal maintenance period.

Doing:

$$\frac{\partial C(N,T)}{\partial N} = 0$$
$$\frac{\partial C(N,T)}{\partial T} = 0 \tag{3}$$

Is obtained [13]:

$$C(N_k,T_k)_k = \left(\frac{C_2(N_k - 1) + C_3}{(2\beta - 1)C_1} \right)^{1-\frac{1}{2\beta}} \frac{2\beta C_1}{\sqrt{N_k \alpha T_{BASE}}} \tag{4}$$

However, this model only minimises the cost function, without taking into account the reliability of the electrical equipment. The maintenance of electrical equipment must consider two fundamental aspects: minimising maintenance costs while maximising reliability. When you want to maximise and minimise the objectives, you cannot demerit any of them, i.e., there cannot be a solution that optimises all the objectives. For this reason, multi-objective evolutionary algorithms are used, as they have the ability to find multiple solutions in a single iteration, the results of which are known as the Pareto front. The multiple solutions are of great help in decision making for maintenance budgeting and reliability of electrical equipment.

The use of the NSGA-II model in the electrical industry has been considered on many occasions. The model presented in this paper aims to use the basic data of any electrical distribution company and the use of the NSGA-II heuristic model to maximise equipment reliability while minimising maintenance costs. Equipment reliability is the probability that a piece of equipment will perform its function properly over a period of time under normal operating conditions.

For this work, equipment reliability will be based on equipment failures, depending on the maintenance costs used. Therefore, equipment failures will be determined by:

$$\int \lambda(t,T)dt \tag{5}$$

However, to ensure the optimisation of the maintenance, the following restrictions will be taken into account:

The number of failures obtained by NSGA-II will be:

$$\sum_{j=0}^{N-1} \int_{0}^{NT} \lambda(t,T)dt \geq 0 \tag{6}$$

To ensure that N and T are within the range of statistical failures (t), the average life of the equipment is taken as the maximum allowable:

$$0 < NT < \alpha\Gamma\left(1+\frac{1}{\beta}\right) \tag{7}$$

Case studies

In Stillman (2003) the failure history of a 33kV insulator, which is part of an urban feeder, is presented. The statistical failure times of the electrical distribution equipment under study are as follows:

No.	Failure (Month)	No.	Failure (Month)	No.	Failure (Month)
1	90	11	145	21	191
2	100	12	160	22	193
3	104	13	165	23	193
4	109	14	170	24	195
5	111	15	175	25	195
6	113	16	178	26	198
7	124	17	180	27	199
8	130	18	181	28	200
9	133	19	186	-	-
10	138	20	190	-	-

Table 1 Failure times of the electrical equipment

To carry out the sensitivity analysis of the model, we will use the data of: C1 = 1000; C2/ C1 = 3; C3/ C1 = 3, 10, 20, 50, 100 and a TBASE = 12 months; from (César L. Melchor-Hernández., 2015). We will start with case 1. Figure 1 shows the reliability of the equipment with the proposed failure rate (1); the failure rate of the two-parameter Weibull distribution and the statistical failures of the equipment. If the costs for case 1 and its current 12-month maintenance are analysed, it can be verified that the equipment replacement cost is equal to the cost of the scheduled maintenance. Therefore, in Figure 1, the proposed reliability function -red colour- is shown. The function indicates that this equipment has no improvement with annual maintenance, and should not be maintained at all. The best option is to replace it, when it fails, as its costs (maintenance and replacement) are equal.

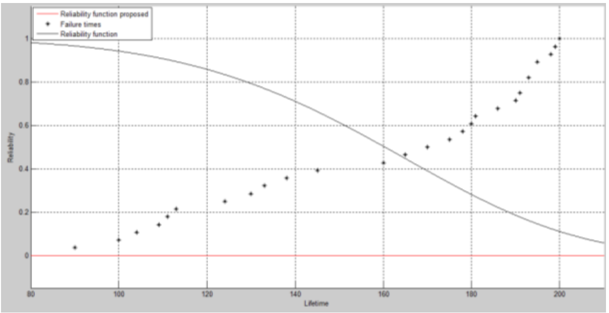

Figure 1 Reliability of the equipment with case 1 parameters

Table 2 shows the results obtained by NSGA-II. 150 generations are used, with a mutation and outcrossing rate of 0.8. For practicality, we put the most outstanding results, of which we can describe the following. If we have semi-annual maintenance, the costs are between 468.75 and 434.78; however, the number of failures is less than zero, constraint (6) is not satisfied, therefore, it is not plotted on the Pareto front. If we have annual maintenance, the costs will be 245.90, again constraint (6) is not met. After the annual maintenance, we have maintenance that indicates that maintenance can be given at 2 and 3 years, without affecting the number of failures of the equipment. This is because instead of maintenance, it is better to replace the equipment with a new one when it fails (due to the costs involved).

N	T (months)	Cost	Number of failures
1	6.4	468.75	1.25E-09
1	6.6	454.545455	1.73E-09
1	6.9	434.782609	2.75E-09
1	12.2	245.901727	1.07E-06
1	24	125.052587	0.001262076
1	35	87.5796397	0.065287388
1	37.2	83.9654946	0.1235164
1	40.1	81.5668227	0.270829589

Table 2 Results obtained with NSGA-II, for case 1

Figure 2 shows the Pareto front for this case. NSGA-II cannot find a balance between the costs and the expected number of failures, the main reason being the costs used, as the replacement cost of the equipment is equal to the cost of the scheduled maintenance. Therefore, the proposed reliability function shows that this equipment should not be maintained at all and wait for the failure of the equipment to be replaced by a new one.

The Pareto front shows costs between 81.5 and 83.96 for the optimisation of the two objective functions under study, complying with constraint (6).

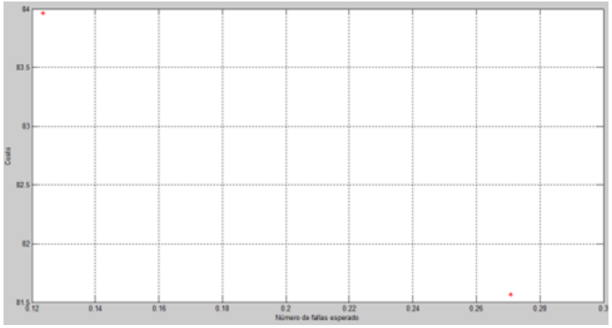

Figure 2 Pareto front with NSGA-II, for case 1

For case 2, the costs used show that the cost of replacement is approximately three times higher than the cost of scheduled maintenance, therefore, NSGA-II starts to find a balance between reliability and maintenance costs.

César L. Melchor-Hernández (2015) shows that the minimum cost for case 2 is a value of 213.79. In Figure 3 it can be seen that a value lower than 215 results in more than one equipment failure. In this case, the reliability of the equipment can be improved by assigning a budget greater than 215, which ensures less than one failure in the average life of the equipment (7).

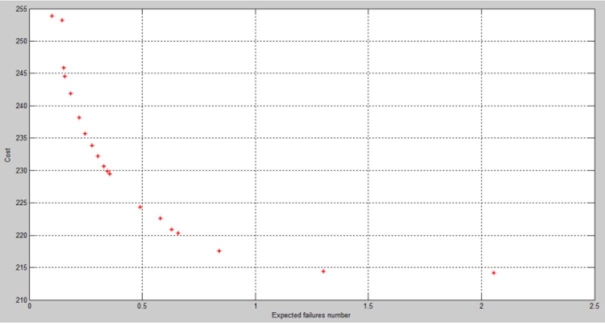

Figure 3 Pareto front with NSGA-II, for case 2

When the cost of replacing a piece of equipment is six times more than the cost of scheduled maintenance, case 3, NSGA-II starts to find more balancing options between the two objective functions, as shown in Figure 4. Figure 4 shows that, if we address a budget between 320 and 400, we could obtain less than one equipment failure, i.e., maintain the equipment every 15 or 20 months, and 6 or 5 times, respectively; however, the cost increases with an approximate value of eighty-three more, compared to the minimum (306.5982).

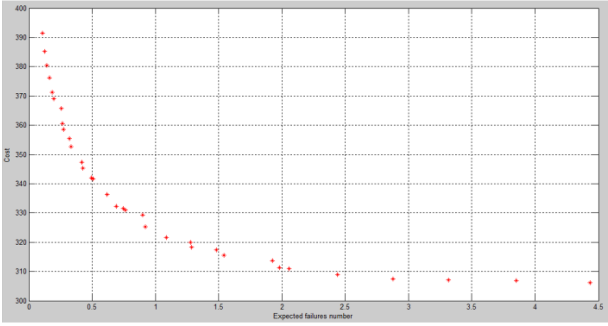

Figure 4 Pareto front with NSGA-II, for case 3.

Table 3 shows the most important results for case 3. The minimisation of this case, coincides with César L. Melchor-Hernández (2015), in which we have an N of 7 and a T of 19, however, with these values we have almost five failures in the equipment. With a higher budget, for example 328,4749, the equipment can be serviced 5 times every 20 months and less than one failure would be obtained in the average life of the equipment.

N	T (months)	Cost	Number of failures
6	15	390.0946	0.1085
7	14	388.96	0.1180
4	19	383.6092	0.1543
6	18	330.8382	0.7305
5	20	328.4749	0.8474
7	18	314.5697	1.6357
6	21	306.8480	3.6628
7	19	306.5982	4.9237

Table 3 Results obtained with NSGA-II, for case 3

For case 4, the cost of replacing the equipment is approximately 16 times more than the cost of scheduled maintenance. Table 4 shows that with a budget of 526.52, there would be only one failure during the average life, restriction (7), of the equipment, so reliability would be guaranteed for this equipment. With a lower budget, 461.70, and with a maintenance period of 13.1 months, there will be approximately 11 failures in the equipment. By means of a risk matrix of the configuration of the system under study, it can be determined which is the best budget that would be assigned to this equipment.

N	T (months)	Cost	Number of failures
1	1	50000	4.63E-18
7	7.7	1261.59	2.27E-04
8	12.2	728.03	0.05
16	11.4	526.52	1.03
20	10.9	500.40	2.08
17	12.4	481.19	3.43
19	12.2	471.03	5.18
19	13.1	461.70	10.91

Table 4 Results obtained with the NSGA-II, for case 4

Figure 5 shows the Pareto front for case 4. The dispersion of NSGA-II works well, due to the costs used for this case. A balance between the two objective functions is observed, which allows us to have a wide number of solutions, for the best management of the allocation of financial resources to the maintenance to be given to the equipment under study.

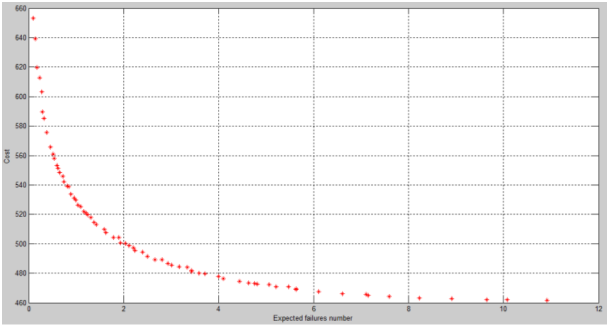

Figure 5 Pareto front with the NSGA-II, for the case 4

For case 5, we have that the cost of replacement is approximately 33 times more than the cost of scheduled maintenance; therefore, maintenance should have a short periodicity, in order to prolong the life of the equipment. Table 5 shows an optimal period of 9.6; however, the number of failures would be approximately 23. By allocating six-monthly maintenance, the reliability of the equipment can be guaranteed, without failures, during the average life of the equipment, however, the budget would increase by more than two hundred and forty, compared to 9.6 months.

N	T (months)	Cost	Number of failures
1	1	100000	4.63E-18
32	2.7	2233.79	1.12E-05
43	6.1	862.61	0.26
32	9.4	658.85	5.18
36	9.4	634.14	9.59
41	9.1	625.81	13.49
33	10.3	623.23	15.83
41	9.6	618.91	23.60

Table 5 Results obtained with NSGA-II, for case 5

Figure 6 shows the reliability function of the equipment, with the different maintenance periods of Table 5. If the equipment is located in a risky place, e.g., hospitals, laboratories, banks, etc., a budget of 862.61 can be allocated to ensure reliability in this area of the electrical network.

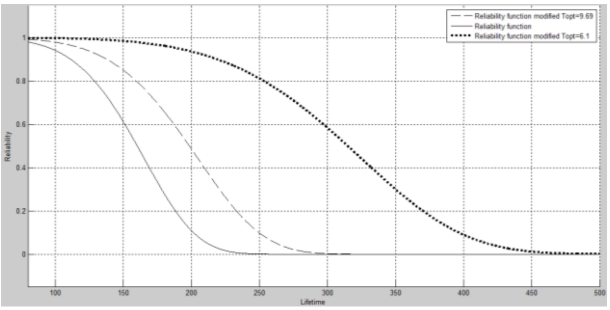

Figure 6 Reliability function of the equipment with the parameters of case 5 and Table 5

Figure 7 shows the Pareto front for case 5. It can be seen that there are several budget options, depending on the required reliability of the equipment.

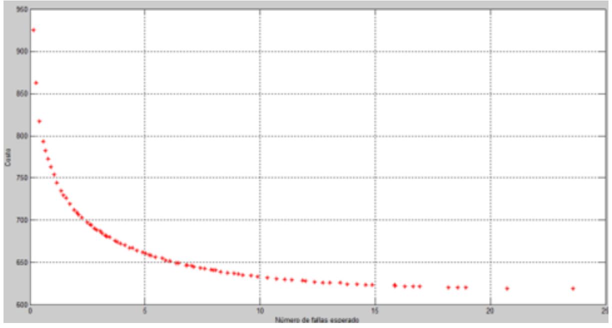

Figure 7 Pareto front with the parameters of case 5 and Table 5

Table 6 shows the end-of-life failure times for a group of generators. Out of 36 generators, the end-of-life failures of 16 pieces of equipment are used, let us assume that the generators are under the same operating conditions and maintenance policies. For this study, only the failure data of the 16 sets will be taken (L Seung-Hyuk, 2009).

Failure number	Time of failure (year)	Failure number	Time of failure (year)
1	6	9	18
2	7	10	18
3	12	11	20
4	12	12	20
5	13	13	25
6	16	14	25
7	16	15	27
8	18	16	31

Table 6 Failure time of a group of generators

Table 7 shows the parameters obtained in L Seung-Hyuk (2009) and the results obtained with the model proposed in César L. Melchor-Hernández (2015).

	Hybrid method	Maximum likelihood estimation method	Analytical method	Proposed method
Beta	2.593	2.897	2.680	2.897
Alpha	19.541	19.931	20.070	20.005
Half-life	17.341	17.757	17.875	17.856
Standard deviation	7.206	7.195	7.193	6.544

Table 7 Parameters: beta, alpha, half-life and standard deviation

The cost data used for this new case are: C1 = 1000; C2/ C1 = 3; C3/ C1 = 100 and an annual maintenance policy. Table 8 shows the most important results obtained with NSGA-II. For the first result, the logical result can be observed with NSGA-II, since, if annual maintenance is given, the equipment will not have any failure; however, the costs are equal to the cost of equipment replacement. So, in order to have no failures, the model suggests replacing the equipment every year. Since the number of failures is less than one, constraint (6) is not met. If one wants to opt for the lowest cost used in the maintenance of the equipment, it is suggested to have maintenance every seven years, with the consequence of expecting a large number of failures, forty. On the contrary, if we have biannual or minor maintenance, the failures can be reduced between sixteen and one, with a cost of 1609.20 and 2248.99, respectively.

N	T (years)	Cost	Number of failures
1	1	100000	8.43e-8
12	5	2248.99	1.93
16	5	1869.50	4.56
14	6	1762.65	9.06
17	6	1609.20	16.13
16	7	1595.48	33.69
17	7	1582.73	40.34

Table 8 Results obtained with NSGA-II, for the failure data of the group of generators

Figure 8 shows the Pareto front of Table 8. It can be seen that the options have a good spread of results. Because sixteen equipment failure data are used, the maintenance options are few.

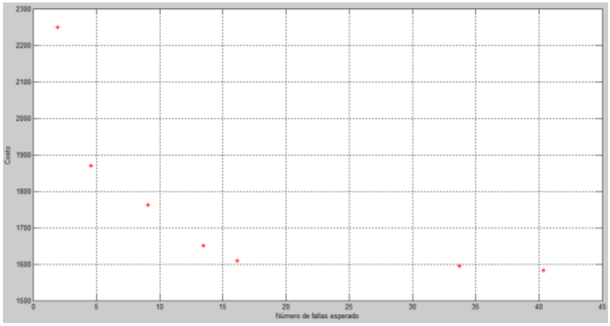

Figure 8 Options for determining maintenance on transformers

Conclusions

The main objective of this research work is to use the NSGA-II with the work developed in (César L. Melchor-Hernández., 2015). In (César L. Melchor-Hernández., 2015) only the optimal maintenance of the equipment was determined; however, with the help of the NSGA-II, the failures that the equipment will have with the maintenance obtained can be determined. In addition, with the Pareto front, different maintenance periods and the failures that the equipment under study will have are obtained. With these options, the decision making for the maintenance of the equipment will be based on: total costs, maintenance periods and expected failures. With this information, the department in charge of maintenance can make the corresponding decisions based on the reliability needed for the equipment under study. For the case of the 33kV insulator, twenty-eight equipment failure data and annual base maintenance are used. In case 1, no maintenance is required, as the cost of replacement is equal to the cost of scheduled maintenance, therefore, the Pareto front is null, as the best option is to replace the equipment when it fails. However, when equipment replacement costs tend to be higher (cases 2, 3, 4 and 5), the Pareto front works very well in giving different options of periods and, the failures that will occur in the equipment with different maintenance periods. Table 7 shows the comparison of the different statistical parameters, in a group of generators. In which we can observe that the proposed model has a lower standard deviation. The Pareto front in Figure 8 shows 7 maintenance options, this is due to the few failures used for this case, sixteen; however, the model fits well with the results obtained in previous research.

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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

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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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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.

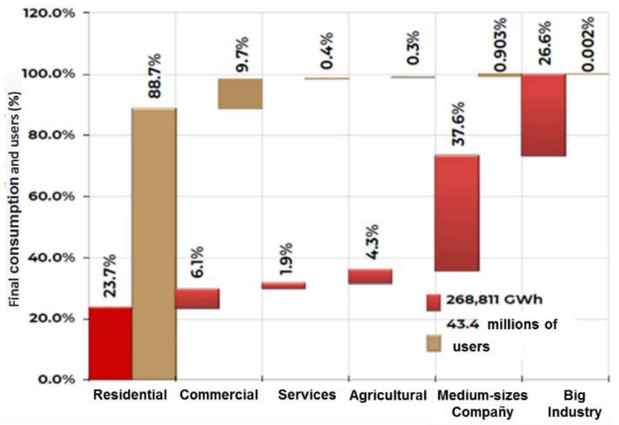
Problem statement

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).

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 120° 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:

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

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

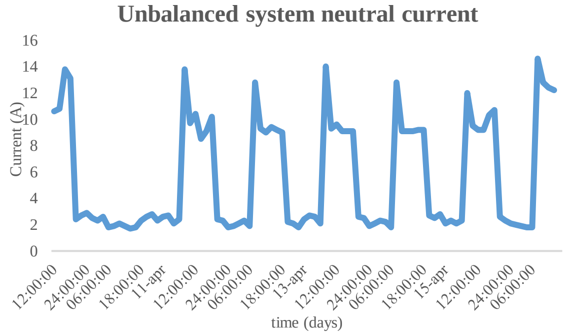
Load	kW phase A	kW phase B	kW phase C	kW total
TAB 1, MARCH SQUARE D, MOD. JG250M81B, 460/318.94 V				
Squirrel-cage induction motor, three-phase, 460 V., 60 Hz, 100 HP (breaker)	24.866	24.866	24.866	74.6
Squirrel cage induction motor, three-phase, 460 V., 60 Hz, 20 HP (conveyor belt)	4.97	4.97	4.97	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

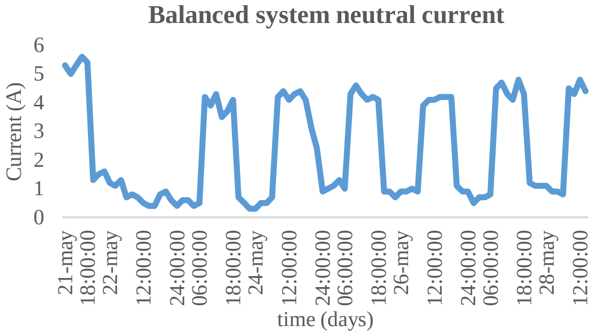
After the survey and measurements made with the network analyser during one week in April 2022, it is observed that the electrical installation 3F-4H is unbalanced. Graph 2 describes the major problem of having high current values in the neutral. At the beginning of each working day, all the motors are 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%.



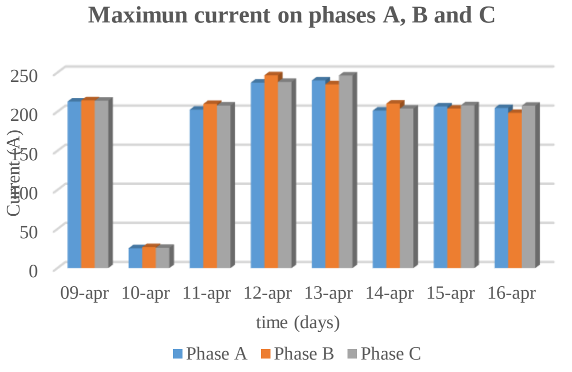
Graphic 3 Values of current in the electrical system when it is balanced in the Breaker Plant
Source: Own elaboration

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.

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

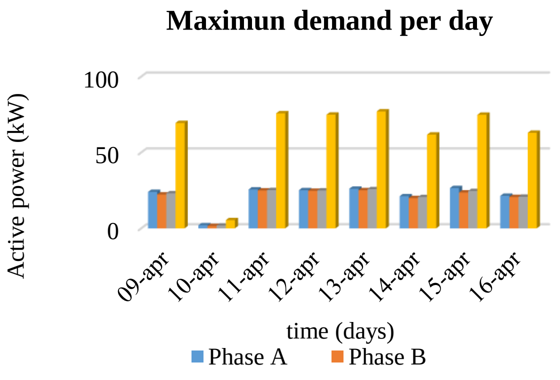
$$I_{protección} = 1.25\ (124\ A) + 56.6A + 65.3A = 276.9\ A$$

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

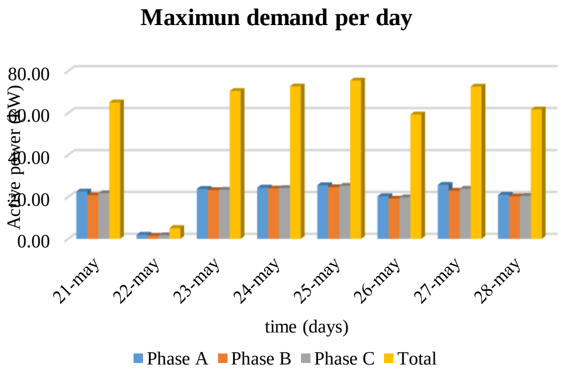
In relation to table 3, the box marked with orange indicates that it was detected with the hook ammeter, that the 10 HP motor, which has more than 20 years of service, without maintenance and obsolete, consumes 22 amperes; this is a current greater than its current at full load with a value of 14 amperes, 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.



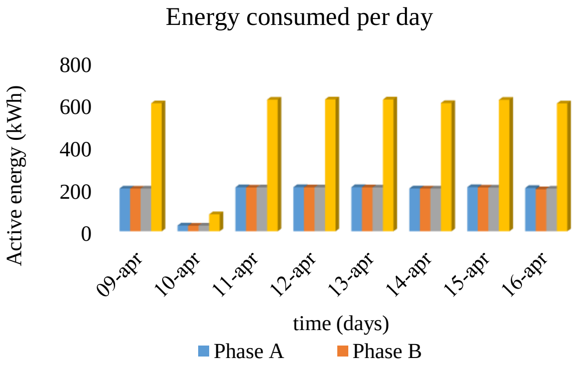
Graphic 5 Demand by phase and total demand of the Quebradora Plant during the measurement before load balancing
Source: Own elaboration

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.



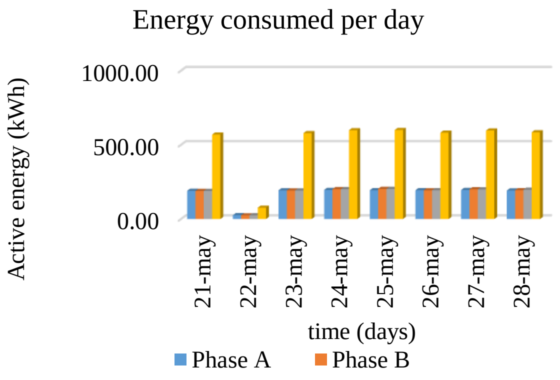
Graphic 6 Demand by phase and total demand of the Cracker Plant during the measurement after the modifications and load balancing
Source: Own elaboration

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.

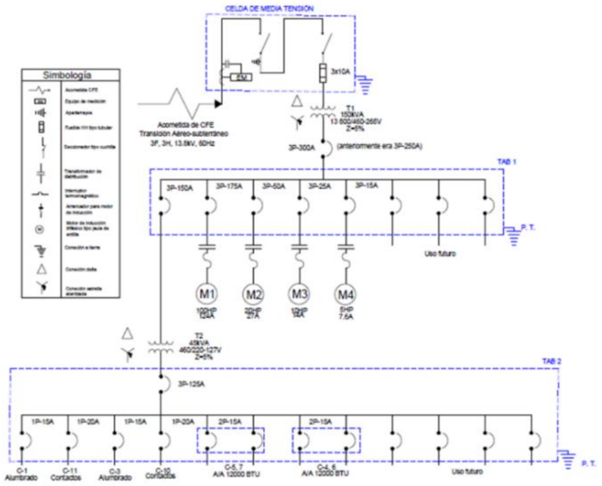


Figure 1 Updated single-line diagram
Source: Own elaboration

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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Evaluation of a refrigerated container using photovoltaic solar energy for its implementation in the Mayan train

Evaluación de un contenedor refrigerado mediante energía solar fotovoltaica para su implementación en el tren Maya

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Abstract

In this work, the energy evaluation of a refrigerated container is carried out for the transport of perishable products produced in the Southeast of Mexico, through the Mayan Train, for this design meat, products were considered. The design of the container is carried out through the selection of materials for its construction, the calculation of thermal loads, which are obtained from the climatic conditions of the place, and the properties of the meat that will be transported. Therefore, the refrigeration system used for this design is a simple vapor compression system, using R152a as refrigerant. For the sizing of the autonomous photovoltaic system, the amount of energy supplied is determined from the area available in the container, and the analysis of irradiation, over the last 10 years, in the states proposed by the Mayan Train route; Quintana Roo, Yucatan, Campeche, Chiapas and Tabasco. As a result, the power of the compressor, the COP coefficient of performance was obtained and a comparison is made with the energy required by the refrigeration cycle, along the proposed route.

Meat, Solar energy, Photovoltaic system, Refrigerated container, Mayan Train, Energy performance

Resumen

En este trabajo se realiza la evaluación energética de un contenedor frigorífico para el transporte de productos perecederos producidos en el Sureste de México, por medio del Tren Maya, para este diseño se consideraron cárnicos. El diseño del contenedor se realiza mediante la selección de materiales para su construcción, el cálculo de cargas térmicas, que se obtienen a partir de las condiciones climáticas del lugar, y las propiedades de los cárnicos que se transportaran. Por lo tanto, el sistema de refrigeración ocupado para este diseño es un sistema de compresión a vapor simple, que utiliza R152a como refrigerante. Para el dimensionamiento del sistema fotovoltaico autónomo se determina la cantidad de energía suministrada a partir del área disponible en el contenedor, y el análisis de la irradiación, a lo largo de los últimos 10 años, en los estados propuestos por la ruta del Tren Maya; Quintana Roo, Yucatán, Campeche, Chiapas y Tabasco. Como resultado se obtiene la potencia del compresor, el coeficiente de desempeño COP y se realiza una comparación con la energía requerida por el ciclo de refrigeración, a lo largo de la ruta propuesta.

Cárnicos, Energía solar, Sistema fotovoltaico, Contenedor refrigerado, Tren Maya, Eficiencia energética

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Introduction

The Mayan Train is a project that aims to boost the growth of the economy in the southeast of Mexico, as it will allow the transport of a greater quantity of products from the region, but it is important that this transport is profitable over the years.

The proposed route to be covered by the train includes the states of Tabasco, Chiapas, Quintana Roo, Campeche and Yucatan, 70% of the transport will be cargo. Part of this cargo will be perishable foodstuffs.

Perishable foods are those that deteriorate due to the presence of factors such as pressure, temperature and humidity. Therefore, it is important to transport them in refrigerated containers, where the main objective is to ensure the quality and safety of the product.

Although vapour compression refrigeration systems have good efficiencies, they require a large amount of energy for their operation, when the thermal load of refrigeration is high, which generates a high cost. An alternative to reduce these costs could be the use of solar energy, by means of photovoltaic systems, which could partially or totally satisfy the electrical energy required by the compressor in the refrigeration system.

The aim of this work is to estimate the amount of energy that could be generated by a photovoltaic system installed on a refrigerated container to supply the power required by the compressor, and to analyse whether it is possible to satisfy the demand for electrical energy required by the refrigeration system along the route of the Tren Maya.

The energy evaluation of the system is based on sizing the container and selecting the construction materials, calculating the thermal loads and obtaining the power required by the compressor, as well as the performance coefficient of the refrigeration system. Similarly, the sizing of the photovoltaic system is obtained, based on the available space on the roof of the railway container, obtaining the electrical energy generated along the route.

Finally, the electrical energy generated is compared with the electrical energy required, determining what fraction of the energy required by the system is satisfied.

Methodology

To establish the design of the refrigerated container, factors such as the product to be transported, four types of meat, the ambient temperature of the five states, as well as the speed at which the Mayan train travels were considered.

The design of the refrigerated container takes into account the temperature and humidity of the four products to be transported, in separate containers, using a compression refrigeration system. The sizing of the container was based on the quantity of product to be stored and in accordance with Mexican and international standards for rail transport of perishable foodstuffs.

To calculate the heat extracted from the refrigeration system in the container, the different thermal loads were calculated; by product, by solar radiation, by lighting and by infiltration, proposing efficient insulation for the system.

From the thermal loads, the work of the compressor is obtained, considering its electrical efficiency, and this will be the energy that the photovoltaic system needs to supply.

In the sizing of the photovoltaic system, parameters such as: type of panel, panel efficiency, power and the solar resource of the route proposed by the Mayan train were considered.

Finally, the compressor power is obtained and the amount of energy that can be supplied to the refrigeration cycle is determined, as well as the energy required by the compressor. This is done for each of the containers that will transport the meat products. The calculations of the thermal loads, the required electrical energy of the refrigeration system and the energy supplied by the photovoltaic panels were obtained in Microsoft Excel spreadsheets.

Description of the methodology

Thermodynamic properties of the products to be preserved

In the Southeast of Mexico, different types of perishable products are produced, mainly meat products (Ministry of Agriculture and Rural Development), which require refrigeration to conserve their organoleptic characteristics during transport, which is why it is necessary to design a refrigerated train container. The design of this container must consider the thermodynamic properties of the products to be transported. Table 1 describes the thermodynamic properties of the four types of meat that will be transported separately in the different containers (Codex Alimentarius 2005).

Meat	Temperature (°C)	Relative humidity (%)	C.P (KJ/KgK)
Poultry	0	85	3.01
Pork	-1.1	85	2.72
Beef	-0.5	95	3.01
Fish	-0.50	80	3.42

Table 1 Thermodynamic properties of the different types of meat
Source: (Cold engineering theory and practice 2005).

Selection of container structure

Based on the standard for rail containers (ISO 668, 2013) the container dimensions shown in table 2 were selected.

	Door (m)	Size (m)
Length	2.28	13.71
Width	------	2.556
High	2.195	2.896

Table 2 Container dimensions
Source: (ISO 668)

Choice of materials used

In accordance with the heavy use of rail transport, suitable materials were selected to withstand both the speed at which the train travels (160 km/h) and the quantity of product to be stored.

Table 3 shows the properties of the materials proposed for the construction of the container.

Material	Thickness (m)	Conductivity [W/mK]
Aluminium.	0.003	152
Polyurethane foam.	0.0762	0.28
Wood.	0.0508	0.12

Table 3 Properties of the construction materials
Source: Own elaboration

Calculation of thermal loads

The thermal load is the amount of heat that must be extracted from the refrigerated container to cool and maintain an optimum temperature that guarantees the quality of the product (Sánchez, 2009).

The thermal loads taken into account for the design are as follows:

- Thermal load through the walls.

The thermal load through the walls is the heat transfer that occurs through the different walls, due to the difference in temperature between the inside and outside of the chamber. The temperature inside the container was considered to be -5 °C, and the outside temperature equal to the average ambient temperature along the route. Equation (1) gives the thermal load through the walls, and equation (2) the overall heat transfer coefficient.

$$Q_{a.m} = U * A * \Delta T \tag{1}$$

$$U = \frac{1}{\frac{1}{h_1}+\frac{e}{k}\dots\dots\dots+\frac{1}{h_2}} \tag{2}$$

Where:

$Q_{a.m.}$: Thermal load through the walls.

U: Overall heat transfer coefficient.

A: Area of the enclosure.

ΔT: Difference between the outside and inside air temperatures of the container.

h_1: Convective coefficient inside the chamber.

h_2: Convective coefficient of the outside of the chamber.

e: Thickness of the materials

k: Thermal conductivity of the materials

Thermal load due to lighting

The thermal load produced by the lighting inside the container, considering 23W lamps, is calculated using the following equation:

$$Q_{lamp} = \#_{lamparas} * P \quad (3)$$

Where:

Ql_{amp}: Thermal load per lighting

$\#_{lamps}$: Number of lamps

P: Power of each lamp

Heat load per infiltration

The thermal load due to infiltration is generated by the technical air renovations Q_1, and the equivalent air renovations Q_2, this is calculated by the following equation:

$$Q_{inf} = Q_1 + Q_2 \quad (4)$$

The following mathematical expression is used to calculate Q_1:

$$Q_1 = m * \Delta h \quad (5)$$

$$m = V * \rho * n \quad (6)$$

Where:

m: Mass of air

Δh: Enthalpy difference of the air, inside and outside the chamber

V: Volume of infiltrated air

ρ: air density

n: number of technical air changes

The infiltrated heat Q_2 due to the equivalent air renewals is calculated from the air mass and its enthalpy difference, inside and outside, as shown in the following equation:

$$Q_2 = \ m * \Delta h \quad (7)$$

The enthalpies of indoor and outdoor air are obtained by means of the psychrometric chart, and for the calculation of the air mass the door opening time is considered (θ).

$$m = V * \rho * \theta \quad (8)$$

The volume of infiltrated air is calculated by the following mathematical expression:

$$V = \frac{a*H}{4}\sqrt{0.072} * H * \Delta T \quad (9)$$

Where:

m: Mass of air
Δh: Enthalpy difference of the air, inside and outside the chamber
V: Volume of air
ρ: Mean air density
θ: Door opening time
a: Door width
H: Door height
ΔT: Outside air temperature difference

Heat load generated by the product

This is the heat given up by the product, at a temperature higher than the refrigeration temperature, until it reaches its storage temperature.

To guarantee the safety of the meat products, they must be transported in different containers, so the thermal loads are calculated separately for each product, considering the temperature at which the meat enters the container (pre-cooling temperature), the temperature inside the container and the time it will take for the meat products to reach their optimum storage temperature, which is calculated using the following mathematical expression:

$$Q_{sencible} = \frac{m*Cp*\Delta\mathrm{T}}{t} \quad (10)$$

Where:

m: Mass quantity of the product

Cp: Specific heat of the product

ΔT: Temperature difference, initial and final of the product.

Total thermal load

Since no more than one type of meat can be transported in the same container, the total thermal load is obtained for each of the four cases presented:

Case 1 pork.

Case 2 beef.

Case 3 poultry meat.

Case 4 fish meat.

For each of the cases, the sum of all the thermal loads mentioned above is added up, giving the total thermal load as a result.

Obtaining the power required for the refrigeration cycle

The refrigeration cycle selected for this design is the simple compression cycle (Cengel and & Boles, M, 2001), the proposed refrigerant is R-152a, the thermodynamic properties of each state of the cycle were obtained from the National Institute of Standards and Technology (NST, 2022).

Table 4 shows the thermodynamic states of the refrigeration cycle.

State	T(°C)	P(kPa)	h(KJ/Kg)	S (KJ/Kg K)	Phase
1	-8	196.14	501.56	0.5107	Saturated steam
2	49	909.26	543.54	0.5107	Superheated vapour
3	40	909.26	271.35		Saturated liquid
4	-8	196.14	271.35		Mixture

Table 4 Thermodynamic states of the refrigeration cycle
Source: own elaboration

The mass flow is calculated by the following equation:

$$\dot{m} = \frac{Q_L}{(h_1 - h_4)} \tag{11}$$

Where:

m: Mass flow rate

Q_L: Total heat load

$(h_1\text{-}h_4)$: Enthalpy difference

The compressor power is calculated as:

$$W_{comp} = \dot{m}(h_2 - h_1) \tag{12}$$

Where:

W_{comp}: Compressor work

m: Mass flow rate

$(h_2\text{-}h_1)$: Enthalpy difference

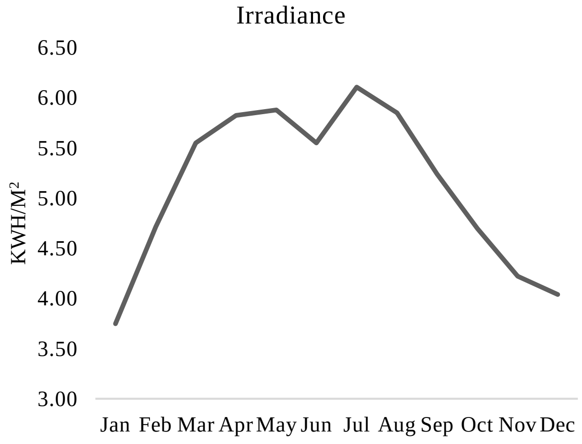
$$COP = \frac{Q_{total}}{W_{compresor}} \tag{13}$$

Analysis of the solar irradiation of the different places along the route of the Mayan Train

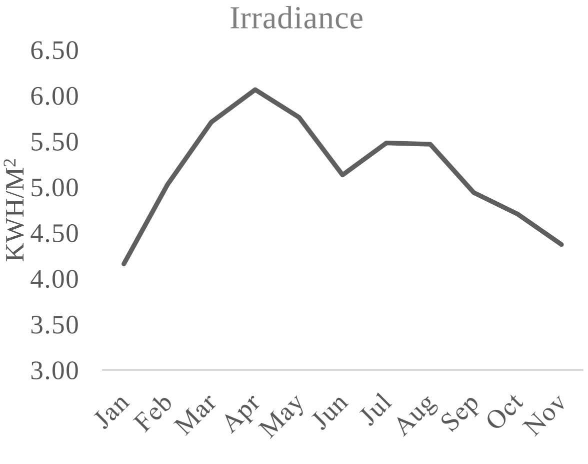
An analysis is made of the irradiation during 10 years (2010-2020) of the states through which the Mayan Train will pass, this data is obtained from the Power | Data Access Viewer page (NASA, 2022).

The graphs below show the average irradiation for the states of Tabasco, Chiapas, Yucatán, Campeche and Quintana Roo in KWh/m^2.

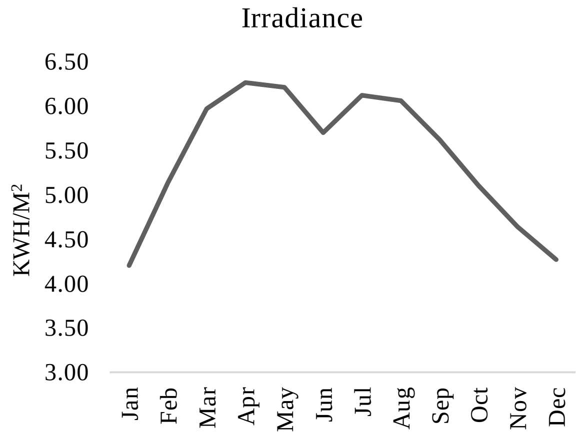
The calculation of the COP performance coefficient is equal to the heat extracted from the system, total heat loads, divided by the compressor power.



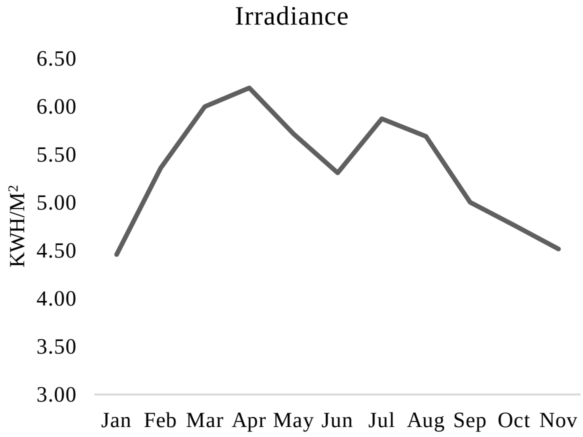
Graphic 1 Irradiance data for Tabasco
Source: NASA



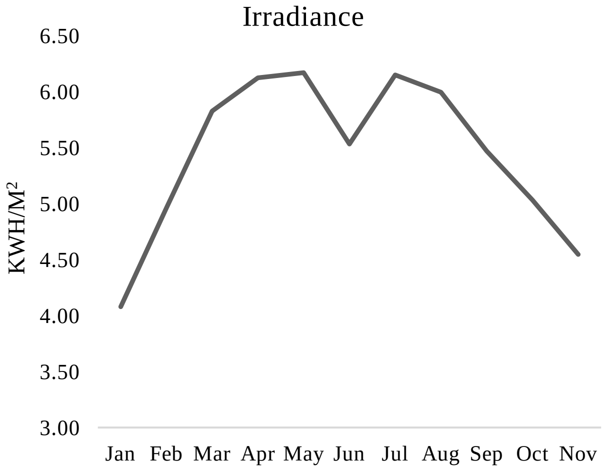
Graphic 2 Irradiance data for Quintana Roo
Source: NASA



Graphic 3 Irradiance data Campeche
Source: NASA



Graphic 4 Irradiance data Chiapas
Source: NASA



Graphic 5 Irradiance data for Yucatan
Source: NASA

Dimensioning of the Photovoltaic System

Figure 1 shows a diagram of the components of the photovoltaic system used for this design, which will be installed on the roof of the container.

Figure 1 Solar photovoltaic system
Source: Own elaboration

Energy supplied by the panels

The daily energy supplied by each photovoltaic panel depends on the electrical power of the panel, and the average solar resource on the train route.

Energy supplied by the panels

The daily energy supplied by each photovoltaic panel depends on the electrical power of the panel, and the average solar resource on the train route.

$$E_s = P * R.S \tag{14}$$

Where:

E_s: Energy supplied.

P: Panel power.

R.S: Solar resource.

To obtain the solar resource it is necessary to know the average solar irradiation of the states that comprise the route, data obtained from the NASA website "The Power Project".

$$R.S = \frac{Irradiation\ Wh/m^2}{1000\ W/m^2} \tag{15}$$

Selection of the proposed solar panel for the design

The length and width of the container was considered in order to propose the solar panel to be used in the system, with the aim of covering most of the roof of the container.

The characteristics of the solar photovoltaic panel selected are detailed in table 5.

Features	
Maximum power	540 W
Module efficiency	20.90%
Dimensions	2279 x 1134 x35
Weight	28.6 kg
Maximum system voltage	1250 V

Table 5 Solar panel characteristics

Electrical energy required

For the electrical consumption, the efficiency of the compressor is considered, which is between 80 and 90%; for this design, an efficiency of 80% was considered.

Considering that the compressor works between 60% and 70% of the operating time of the chamber, 66% of the working time is proposed for this design, which is equivalent to 6 hours and 30 minutes of a route of 9 hours and 52 minutes. Therefore, the electrical energy required by the compressor is obtained from the following equation:

$$Electricity = \frac{P_C * H_T}{\eta_{Electricity}} \qquad (16)$$

Where:

$\eta_{electric}$: Compressor efficiency.

P_c: Compressor power.

H_T: Compressor working hours.

Results

Total thermal loads

The total thermal loads for each product are shown in table 6. It can be seen that the highest thermal load is in the month of May, as this month has the most extreme climatic conditions.

Total thermal loads [Watts]				
Months	Case 1	Case 2	Case 3	Case 4
Jan	31377.50	45336.67	32533.087	40993.74
Feb	31661.29	45620.47	32816.88	41277.53
Mar	32552.88	46512.06	33708.47	42169.13
Apr	31321.08	45280.26	32476.67	40937.32
May	32353.40	46312.57	33508.99	41969.64
Jun	31610.63	45569.81	32766.23	41226.88
Jul	32132.46	46091.64	33288.05	41748.70
Aug	30406.24	44365.43	31561.84	40022.49
Sept	31548.33	45507.50	32703.92	41164.57
Oct	30176.98	44136.16	31332.57	39793.22
Nov	30962.35	44921.53	32117.94	40578.60
Dec	32014.07	45973.25	33169.66	41630.32

Table 6 Total thermal loads per month and per product
Source: Own elaboration

Analysis of compressor power requirements

The power required by the compressor, the coefficient of performance (COP) and the maximum thermal load of each of the containers are shown in table 8. It can be seen that the greatest compressor power is for the beef container, as it is the container with the greatest weight.

Parameters	Poultry	Pig	Bovine	Fish
Mass flow (Kg/s)	0.15	0.14	0.20	0.18
Compressor power [KW]	6.11	5.90	8.45	7.65
QH [KW]	39.62	38.25	54.76	49.62
QL [KW]	33.51	32.35	46.31	41.97
COP	5.48	5.48	5.48	5.49

Table 7 Compressor power
Source: Own elaboration

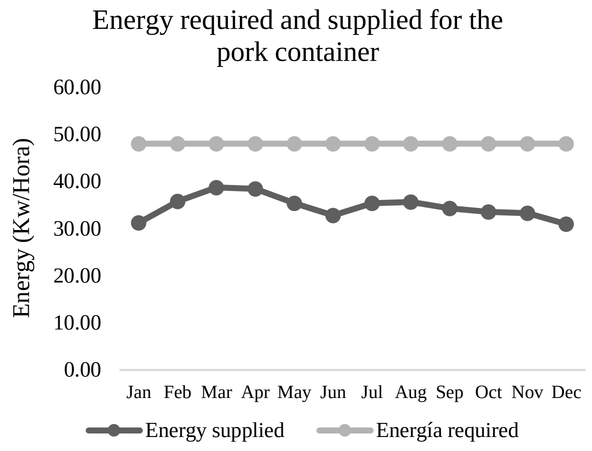
Analysis of the photovoltaic system

Table 8 shows the electrical energy required by the refrigeration chamber, the energy supplied by the photovoltaic system and the hours of solar energy supply. Twelve photovoltaic panels were considered, with the characteristics described above, and an average solar resource of 4.76 hours.

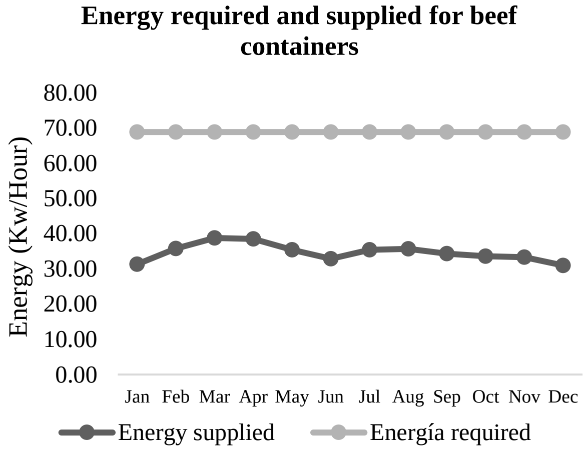
Product in container	Electrical energy required (KWh)	Electrical energy supplied (KWh)	Hours of supply
Pork Meat	48.04	30.56	5.2
Bovine Meat	68.81	30.56	3.6
Poultry Meat	49.75	30.65	5.0
Fish Meat	62.29	30.56	4.0

Table 8 Electrical energy required and supplied
Source: Own elaboration

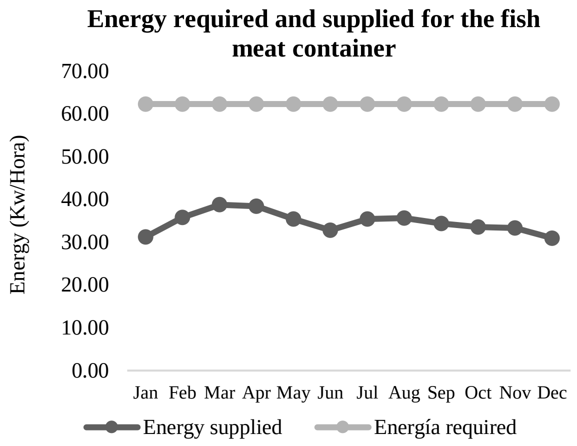
The following graphs show the amount of energy supplied by the twelve panels during the year, for each of the containers, making a comparison with the energy required by the system.



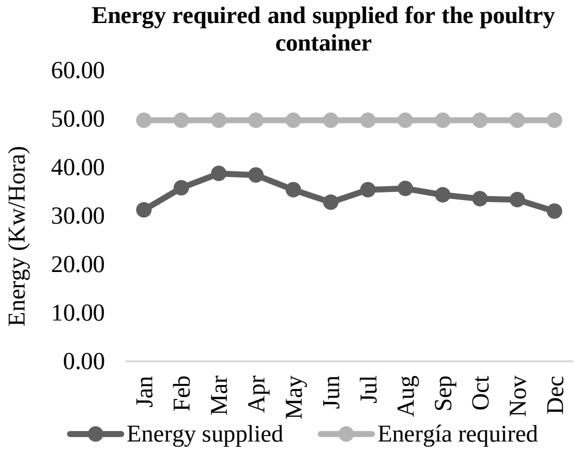
Graphic 6 Energy required and supplied for the pork container
Source: Own elaboration



Graphic 7 Energy required and supplied for beef containers
Source: Own elaboration



Graphic 8 Energy required and supplied for the fish meat container
Source: Own elaboration



Graphic 9 Energy required and supplied for the poultry container
Source: Own elaboration

Conclusions

This work shows a proposal for the design of a refrigerated container for the train Maya, which allows four types of meat to be transported, for which the average climatic conditions of the train route were considered. The results show that the refrigerated container that requires a larger compressor is the 10.92 KW beef container, due to its greater weight; the COP for all cases is the same, as the refrigeration system is equivalent in all cases.

Similarly, it can be seen that the energy supplied by the photovoltaic system to the different containers in none of the cases satisfies the energy demand 100%, however, approximately 50% of the train route can be satisfied. The container that is supplied most of the route is the pork container, as it is the compressor that requires the least power, 5.90 KW, as it is the one with the smallest weight to be refrigerated.

In general, the use of a photovoltaic system as a source of electrical energy for the railway container refrigeration process is feasible and viable, considering both the economic savings in fuel and the reduction of greenhouse gases in the environment.

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Text in Times New Roman No.12, single space.

General explanation of the subject and explain why it is important.

What is your added value with respect to other techniques?

Clearly focus each of its features

Clearly explain the problem to be solved and the central hypothesis.

Explanation of sections Article.

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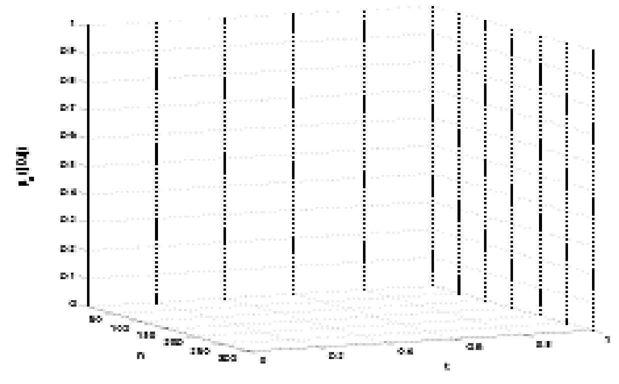

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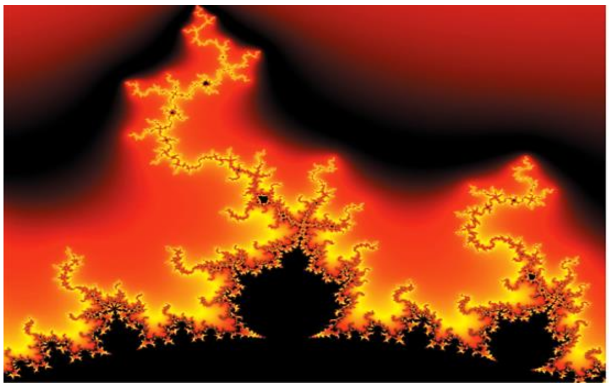

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$$Y_{ij} = \alpha + \sum_{h=1}^{r} \beta_h X_{hij} + u_j + e_{ij} \qquad (1)$$

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Develop give the meaning of the variables in linear writing and important is the comparison of the used criteria.

Results

The results shall be by section of the article.

Annexes

Tables and adequate sources

Thanks

Indicate if they were financed by any institution, University or company.

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Explain clearly the results and possibilities of improvement.

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