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Journal Electrical Engineering

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Knowledge Area

The works must be unpublished and refer to topics of Electromagnetism, electrical distribution sources, electrical engineering innovation, signal amplification, electric motor design, material science in power plants, management and distribution of electrical energies and other topics related to Engineering and Technology.

Presentation of the content

As the first article we present, *Simultaneous electricity and biogas generation of vinasses and cattle manure* by López-Velarde, S., Mónica, Rodríguez-Morales, José Alberto, Mendoza-Burguete, Yesenia and Hensel, Oliver with adscription in the Universidad Autónoma de Querétaro and University of Kassel, as the next article we present *Analysis of thermal loads using BIM methodology to reduce the energy consumption of buildings in Morelos, Mexico* by Vázquez-Fuentes, Erick E., Montiel-González, Moisés, Alvarado-Juárez, Roberto and Morales-Gómez, Laura, with adscription in the Universidad Autónoma del Estado de Morelos and Instituto Tecnológico Superior de Perote. as the next article we present *Electricity consumption measurement device for the design of an energy management system* by Sifuentes-Godoy, David, Mar-Luna, Felix, Irigoyen-Campuzano, Rafael and López-Zumaran, Ivan, with adscription in the Universidad Tecnológica de Durango and Centro de Investigación en Materiales Avanzados, as the next article we present *Electric parameters analysis for the detection of possible failures in the insulation of electric motor windings* by Terrazas-Flores, Luis Emilio, Melchor-Hernández, Cesar Leonardo, Sánchez -Medel, Luis Humberto and González-Sobal, Martín, with adscription in the Instituto Tecnológico Superior de Huatusco, as the last article we present *Study of transformer network to comply with standards, electrical safety, and avoid failures due to Inrush current* by Pérez-Lozano, Luis Alberto, Juan-Jiménez, Diana Alejandra, Herrera-Galicia, Rubén and Sánchez-Alegría, Avisai, with adscription in the Tecnológico Nacional de México IT de Tuxtla Gutiérrez.

Content

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Article

Simultaneous electricity and biogas generation of vinasses and cattle manure

Producción simultanea de electricidad y biogás a partir de vinazas y estiercol de vaca

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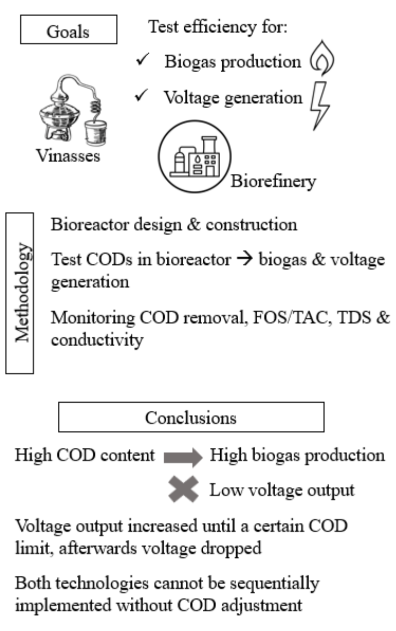
Abstract

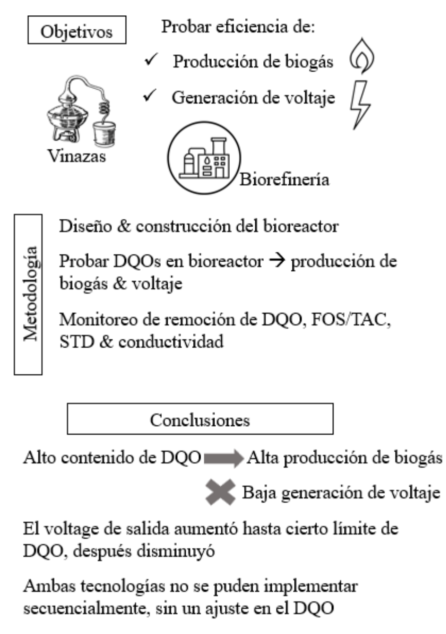
A new design for the simultaneous generation of electricity and biogas was constructed. The voltage production in a microbial fuel cell and the biogas generation through anaerobic digestion were tested at different concentrations of mezcal vinasses and cattle manure. When comparting the control test with the concentrations using vinasses, these resulted in inhibition of voltage output. On the contrary, if no vinasses were used, no biogas production took place, revealing that the inoculum did not have activity itself. The concentration with the lowest organic matter content showed the poorest AD efficiency and lowest voltage output. By increasing the organic matter, power density increased until a certain limit. Contrary to the effect of organic matter content on the voltage production, biogas yield and methane content increased with increased organic matter. These results show that the combination of these technologies is not suitable for the simultaneous voltage production and biogas generation.



Bioenergy, Efficiency, Microbial

Resumen

Se probó simultáneamente la producción de voltaje en una celda de combustible microbiana y la generación de biogás mediante digestión anaerobia en diferentes concentraciones de vinazas de mezcal y estiércol de vaca. Al comparar la prueba de control con las concentraciones usando vinazas, estas resultaron en inhibición de la producción de voltaje. Cuando no se utilizaron vinazas no se produjo biogás. La concentración con el menor contenido de materia orgánica mostró la peor eficiencia de digestión anaerobia y la menor salida de voltaje. Al aumentar la materia orgánica, la densidad de potencia aumentó hasta cierto límite. Contrariamente al efecto del contenido de materia orgánica sobre la producción de voltaje, el rendimiento de biogás y el contenido de metano aumentaron con el aumento de materia orgánica. Estos resultados muestran que la combinación de estas tecnologías no es adecuada para la producción de voltaje y generación de biogás simultáneamente.



Bioenergía, Eficiencia, Microbiana

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Introduction

There are a broad variety of technologies either on use or on development, for the utilization of organic wastes to generate bioenergy. The concept of a biorefinery comprehends an integrative overall concept, where the biomass will be sustainable converted into biofuels, bioplastics or chemical intermediates (FNR 2012, Garcia and Ensinas 2024).

Conversion routes for bioenergy production are mostly thermal and biochemical technologies. Anaerobic digesters and microbial fuel cells (MFC) are both suited technologies for biomass treatment and energy production. Anaerobic digestion (AD) is one of the most common technologies of bioenergy production at industrial scales, while MFCs have not yet found significant practical applications.

Through MFC technology electrogenic bacteria is used to oxidize a great amount of substrates such as glucose, acetate, organic acids or also inorganic substances like sulfates. MFCs transform chemical energy contained in the substrate into electricity by means of REDOX reactions. Therefore, through bacterial respiration, the reduction and oxidation of organic molecules take place (Higgins et al. 2013). Through AD almost all organic wastes can be anaerobically degraded for biogas and methane production. The nutrient-rich digestate remaining after AD is normally used as fertilizer. Nevertheless, it has been demonstrated, that an important amount of gases, such as methane NH_3 and N_20 remaining in the digestate, are released to the environment when using as a fertilizer. This is still an important and challenging topic since the use of biomass should be climate neutral (Lukehurst et al. 2010, Menardo et al. 2011, Rico et al. 2011 and Rosillo-Calle 2016). If the digestate is used before its release in the environment, gas emissions could be diminished.

Not only the efficient bioenergy generation but also the removal of organic matter is pursued in laboratory and industrial scales. A plenty amount of substrates, such as vinasses, consist of a high concentration of mineral salts and high recalcitrant organic matter in terms of chemical and biological oxygen demand (COD and BOD).

Besides bioenergy generation, the target is to reduce the degradable organic matter, convert major toxic organic substances to compounds that can be easily biodegraded and reach the permissible levels of contaminants in waste discharges.

Until now, the power generated by MFCs is low for large-scale wastewater treatment. According to Vilas Boas et al. (2022) power outputs of 4 W/m^2 could be achieved. A MFC design used on large scale produces electricity by embedding an anode in sediment and connecting it to the cathode, which is placed in the overlying aerobic seawater, through an electrical circuit (Pant et al. 2010).

The development of this technology is challenging, especially because of the cost of membrane and electrodes, potential of substrate-biofouling and high internal resistance that limits the power generation (Slate et al. 2019).

Some improvement on MFC design point out that the use of open air bio-cathodes and replacement of platinized with non-platinized cathodes, as well as the use of stainless steel and nickel or manganese dioxide cathodes are alternatives to be used (Pant et al. 2010). The research in regards to new alternative substrates for the efficient use of MFCs at large scale is necessary, especially regarding substrates with high organic loads which are produced in high amounts.

A variety of vinasses conversion technologies has been developed and implemented for biomass combustion and gasification, anaerobic digestion to biogas, fermentation to bioethanol, and direct electricity production using microbial fuel cells (Gbadeyan 2024).

Coupling AD and MFC could be one step of a biorefinery concept, where the effluent of AD is used in MFCs. Few research regarding coupling AD and MFC technologies has been carried out. Typically, AD has been used for COD reduction, especially when processing high strength wastewaters. MFC was proposed for AD effluents treatment and for enhancement of organic matter removal.

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In the practice, total ammonia nitrogen hinders COD removal during AD, if AD effluent could be used in a MFC, ammonia nitrogen could be removed (Higgins et al. 2013, Kim et al. 2015). Also the diminution of toxic gases released to the environment could be goaled, when using digestate in MFC. No studies have described the approach of AD and MFC technologies operated with vinasses, for the simultaneous biogas and electricity production. This substrate is, due to the low pH-value and high organic content, very promising not only to produce electricity, but also to treat the vinasses before they are being discharged onto soils and water. On this account, aim of this work is to test a new design developed as a small biorefinery, where the digestate of vinasses AD could be used as input material for the MFC operation. The configurations of open air cathode and membrane-less MFCs will be studied to make this technology a low-cost alternative for green energy production at large scale.

This paper intends to present the research of a biorefinery concept, in which the AD digestate could be used as input material on a MFC.

Based on that, section 2 describes the methodology proposed and used to perform this research, including the bioreactor design and operation, characterization of substrate and inoculum, as well as a description of the measurement methods. Section 3 describes the results and discussions regarding voltage output, biomethane and biogas production, as well as COD removal, FOS/TAC, TDS and conductivity. Section 4 summarizes the conclusions obtained through this work.

Methodology

Reactor design

The reactor consisted of three chambers placed side by side. The first chamber (under anaerobic conditions) was a bioreactor, in which 400 cm^3 vinasses and cattle manure were digested. The second chamber, anodic chamber, was designed also to guarantee anaerobic conditions and had a fluid volumetric capacity of 400 cm^3. The last chamber, cathodic chamber, was designed so that one side of the cathode had direct air contact, to guarantee aerobic conditions. Thus, the open air cathode would make the costs of MFC construction and operation much cheaper.

The volumetric capacity of the cathodic chamber was 700 cm^3. The total fluid volume contained in the reactor was 1500 cm^3. Anode and cathode were connected through an external resistance of 1000 Ω and a stainless steel wire of 0.7 mm diameter. The distance between anode and cathode was approximately 7 cm. Anode and cathode were made of activated carbon felt, with volumes of 115 cm^3 and 255 cm^3, correspondingly. Anode and cathode were inoculated with cattle manure, one month before experiments startup. The reactor was kept under mesophilic temperatures around 32 – 33 °C, with a ceramic hotplate SP88857100 from Thermo Scientific. A 250 ml Erlenmayer flask was connected to the first chamber, in order to collect the daily biogas produced. An external feeding tank with the mixture mezcal vinasses and cattle manure was placed next to the reactor and was connected to it by a peristaltic pump TS7892K07 from Thomas Scientific. The effluent from the reactor was recirculated to the feeding tank. The reactor was designed with the solid modeling computer-aided design (CAD) Solidsworks 23 and the simulation of the substrate flow was done with the computational fluid dynamics (CFD) software ANSYS Fluent 14.5. The CFD simulation was done in order to analyze the dynamics and fluid displacement in the reactor, according to the fluid density, anode-cathode porous mediums related to a loss of pressure and the minimal inlet velocity reached with the available peristaltic pump. With the CFD simulation, the correct dimension regarding the inlet diameter, could be found. Figure 1 shows the designed bioreactor and figure 2 shows the CFD analysis performed in ANSYS.

Box 1

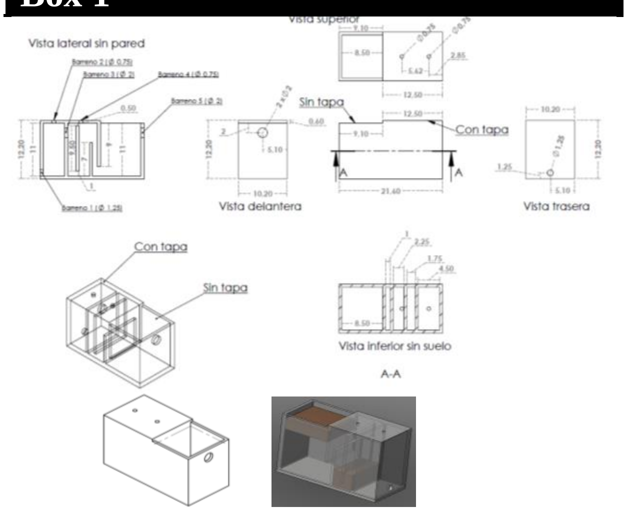

Figure 1
Scheme of the designed bioreactor
Source: Own elaboration

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The streamlines show the path that a mass particle (substrate) would take through the current flow. The lowest speed achieved with the peristaltic pump was 0.347 cm^3/min. According to [1] for flow rate estimation, the calculated flow speed, with the optimal inlet diameter of 0.0125 m, was 4.172 x 10-5 m/s, which corresponds to the velocity streamline in the green area of figure 2. With the parameters of inflow velocity and inlet diameter, no accumulation of sediments could be seen through the CFD simulation. After simulation, reactor was manufactured from an external supplier, according to figure 1.

$$V = \frac{V\,\pi\phi^2}{4} \qquad [1]$$

Box 2

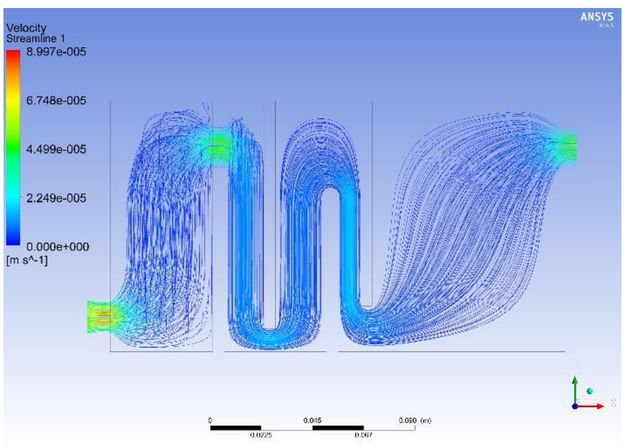

Figure 2
Streamlines velocity analysis in reactor in m/s
Source: Own elaboration

Reactor operation

Experiments were carried out for 92 days. Four different concentrations of mezcal vinasses digested with cattle manure, diluted with deionized water, were tested. Concentration were tested one after the other. Each concentration test was interrupted, when whether voltage nor biogas were produced. CA was tested for nine days, CB for 24, CC for 26 and CD for 23. A control test, with only cattle manure was performed for 12 days at the beginning of the assays. Table 1 shows the tested concentrations CA, CB, CC and CD, chemical oxygen demand (COD) in mg/L related to each concentration, as well as substrate to inoculum ratio (SI-ratio).

Box 3

Table 1
Tested concentrations CA, CB, CC and CD, chemical oxygen demand COD (mg/L) and substrate to inoculum ratio (SI-ratio)

	Control	CA	CB	CC	CD
Mezcal vinasses (L)	0	0.4	0.6	0.8	1
Cattle manure (L)	3.5	1	1	1	1
Deionized water (L)	3.5	4	4	4	4
COD (g/L)	12.20	8.95	11.90	14.85	17.80
SI-ratio	N/A	0.26	0.40	0.53	0.66

Source: Own elaboration

Inoculum and substrate

Vinasses generated from the mezcal production from Agave Salmiana were collected from the mezcal factory Laguna Seca in San Luis Potosí, Mexico and were stored in the refrigerator at 4 °C prior to use. Cattle manure was collected from a local pasture-raised dairy and was left at room temperature, in order to eliminate the microbial activity of the inoculum itself (VDI 2016). Table 2 shows the characteristics measured in both, mezcal vinasses and cattle manure, before the experiment started.

Box 4

Table 2
Characteristics of cattle manure and mezcal vinasses

	Cattle manure	Mezcal vinasses
pH @ 27 °C	7.95	4.41
Chemical oxygen demand COD (g/L)	12.20	63.73
Total solids TS (% FM)	3.70	5.26
Volatile solids VS (% FM)	1.80	2.88
Total dissolved solids TDS (g/L)	8.11	5.87
Conductivity (µS/cm)	12.24	11.75
REDOX (mV)	-211.00	-142.00
Volatile organic acids (gHAc/L)	1585.00	N/A
Total inorganic carbonate (gCaCO3/L)	9525.00	N/A
FOS/TAC (volatile organic acids/total inorganic carbonate)	0.17	N/A

Source: Own elaboration

Measurements

The amount of biogas was determined according to the water displacement principle. The water displaced from the Erlenmeyer flask connected to the first chamber, was weighed with a digital scale from Media Data PS-5 and converted to volume biogas, according to the biogas density 1.2 kg/m^3 (Uni Bremen 2009). The biogas quality, regarding CH_4, CO_2, O_2, H_2S and CO contents, were measured with a biogas analyzer Multitec 540 from Sewerin GmbH.

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The voltage produced between the anode and cathode was daily recorded with a Fluke 115/EFSP Digital Multimeter. Power density P was estimated according to [2] and current I according to [3], where R means resistance, V means voltage and V anode means the volume of the anodic chamber. Polarization curves were calculated with Excel 2013 and plotted with the software Minitab 17.

$$P = \frac{V\ x\ I}{V\ anode} \qquad [2]$$

$$I = \frac{V}{R} \qquad [3]$$

Each concentration was characterized at the beginning and end of every test, regarding pH, REDOX, FOS/TAC, TDS (ppm) and conductivity (μS/cm) with a waterproof tester from HANNA Instruments HI-98311 and a pH-meter VWR-110. FOS/TAC, the ratio of volatile organic acids and total inorganic carbonate, was measured throughout the titration of sulfuric acid 0.05 M (H_2SO_4) to pH 5 and 4.4 (Lossie and Pütz 2008). FOS indicates the amount of volatile organic acids, mostly acetic acid (mgHAc/L) and TAC indicates the total inorganic carbonate or buffer capacity (mg$CaCO_3$/L) (Mézes et al. 2011, Moerschner 2015). COD, total solids (TS) and volatile solids (VS) were measured according to the norms DIN 38414-9:1986-09 (DIN 1986) and VDI 4630 (VDI 2016).

Results and discussion

Voltage output

The results of the voltage produced are shown in figure 3. It can be said, that vinasses content in substrate inhibit the voltage production. Control test was tested for 12 days and achieved the highest voltage of 0.436 V already the third day. CA, with the lowest COD and vinasses content, showed the worst results, producing only 0.032 V the second day of tests and was carried out only nine days. CB produced 0.202 V by day 14 and was carried out for 22 days, while CC generated the highest voltage output 0.317 V by day 15 and was carried out for 26 days. CD was carried out for 23 days and achieved 0.25 V by day 19.

Few values for Agave vinasses were found for comparison. López-Velarde S. et al. (2017) used vinasses diluted with deionized water for the electricity production in aerated-cathode with proton exchange membrane (PEM) at batch conditions. For short term operation (10 days), using a COD of 4060 mg/L, the highest voltage output of 0.12 V was achieved. The highest vinasses content with a COD of 17143 mg/L produced the lowest voltage output of 0.04 V. Results of the presents study showed a higher voltage and power output, using an open air cathode with no PEM at continuous operation. When comparing the results of the present work with the results of the long term operation (70 days) reported by López-Velarde S. et al. (2017), results in this assay show lower values.

Box 5

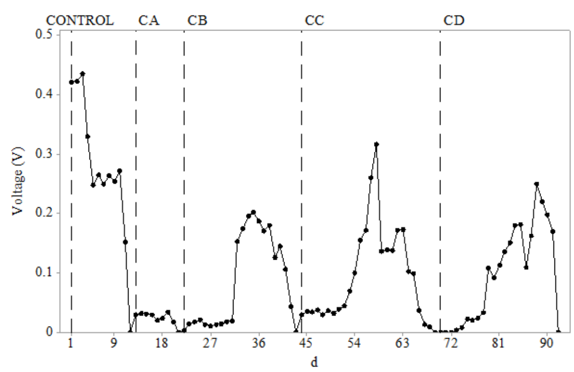

Figure 3
Voltage produced by control test, CA concentration, CB concentration, CC concentration and CD concentration
Source: Own elaboration

Another finding in this study was that the highest the vinasses content, the longest the time to achieve the highest voltage output. This suggests that the microorganisms in the anode took more time to oxidize substrate with high organic matter content. This fact can be confirmed by Vogl et al. (2016), who reported that easily degradable substrates produce higher power densities. In this study the voltage output and power density increased with increased vinasses content (CODs of 8950, 11900 and 14850 mg/L), until a certain point (COD of 17800 mg/L). Afterwards a voltage drop took place, when the saturated state of the electrolyte inhibit the oxidation mechanisms. Figure 4 shows the polarization curves of the concentrations tested.

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When considering only the assays with vinasses, the highest power and current densities were generated with CC, 251 mW/m^3 and 792 mA/m^3, correspondingly. The worst results were obtained with CA, which contained also the lowest vinasses content and COD.

Results of this assays are comparable to Belafi-Bako et al. (2014). AD effluent, from a sugar factor wastewater plant was used in a MFC for electricity production. With a COD of 7150 mg/L, the highest power density of 8652 mW/m^2 was achieved. The lowest power density was generated with the highest COD of 19800 mg/L. Nam et al. (2010) found similar results. The highest power density of almost 3 W/m^2 was obtained with an organic loading rate (OLR) of 3840 mg/L*d, whilst an increase of OLR to 4800 m/L*d resulted in a decrease of the power density. The reduction and oxidation reactions of the microorganisms adhered in the anode determines the power output of a MFC. If the electrolyte solution has a high organic matter content, a difficult electron and proton transfer takes place (Nam et al. 2010). Schievano et al. (2016) reported that MFC performance decreased at higher COD concentrations, which were tested to avoid high dilutions of the AD effluent.

Box 6

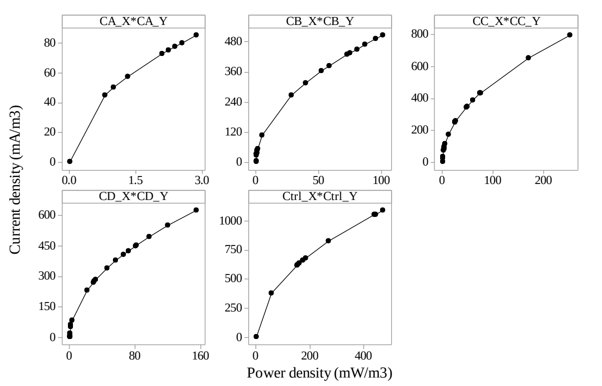

Figure 4
Polarization curves of control test, CA concentration, CB concentration, CC concentration and CD concentration
Source: Own elaboration

Biogas and methane production

The bar charts regarding the cumulative biogas and methane production generated by CA, CB, CC and CD are shown in figure 5.

CA produced 63 L_{biogas}/$kgVS_{vinasses}$ with a highest methane content of 45 %. CB produced 257 L_{biogas}/$kgVS_{vinasses}$ with a highest methane content of 57 %. CC generated 127 L_{biogas}/$kgVS_{vinasses}$ and achieved a methane production of 35 %, and CD produced 347 L_{biogas}/$kgVS_{vinasses}$ with the highest methane content of the concentrations tested (59 %). The highest biogas production was generated by CD. Similar results were reported by Alkhrissat (2023), who achieved the highest cumulative methane production, with the highest substrate concentration tested, whilst the minimum concentration tested resulted in a methane production reduction. CB showed the highest methane production of 117 L_{CH4}CH4/$kgVS_{vinasses}$, one of the highest methane content of 57 % and showed also the highest COD removal of 93 %, suggesting a successfully conversion of organic matter into methane. CC, which produced the highest voltage output, as well as power and current densities, did not show significant biogas and methane yields, and showed the lowest methane content of 35 %. CA showed the worst results regarding not only electricity production, but also AD efficiency. This indicates that the lack of organic matter available was insufficient for both electricity and biogas production.

An important finding was that CC produced less biogas and methane in comparison to CB and CA, but generated the highest power density and voltage output recorded. The conversion of organic acids into biogas was not successfully, but the microorganisms in anode could oxidize the organic acids to generate more voltage. Zhao et al. (2012) carried out experiments using the anode chamber as anaerobic digester. The results suggested that fermentation, more precisely the methanogenesis, compete with the electricity generation, what resulted on a power output and biogas yield. The coulombic efficiency was 2.79 % and the biogas yield persisted only 8 days with a maximum production of 0.285 L/d on a 15 L biodigester. Contrasting results were found by Li et al. (2015), who reported a decrement of methane production at higher organic loading rates, attributed to the high amount of Total Ammonia Nitrogen (TAN) levels in bioreactor when increasing substrate concentration, causing AD inhibition.

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An adequate organic loading rate an thus TAN content should be done in order to ensure the process stability, so that operational failures, as well as TAN and FOS decrease could be avoided (Alkhrissat 2023).

Box 7

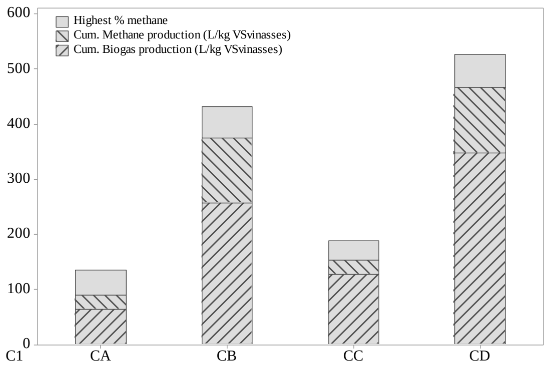

Figure 5
Cumulative biogas and methane production, as well as methane content generated by CA, CB, CC and CD

Source: Own elaboration

COD removal, FOS/TAC, TDS and conductivity

Table 3 shows the results regarding COD removal in CA, CB, CC and CD. CC showed the best removal of 93 % and CD the lowest. Results are comparable to López-Velarde S. et al. (2017), who obtained the worst COD removal with the highest COD tested. The high amount of organic matter results in a saturated state of the electrolyte inhibiting the oxidation mechanisms for COD removal.

Box 8

Table 3
Characteristics of cattle manure and mezcal vinasses

	CA	CB	CC	CD
Initial COD (mg/L)	8950	11900	14850	17800
Final COD (mg/L)	1343	833	2079	9434
COD removal (%)	85	93	86	47

Source: Own elaboration

The amount of TDS and conductivity were higher with a higher vinasses content and COD. Table 4 indicates the amount of volatile organic acids (FOS) and total inorganic carbonate (TAC), as well as the quotient FOS/TAC. With the increase of vinasses content, the volatile organic acids as well as the FOS/TAC increased.

The buffer capacity of the system decreased with a high COD. When comparing the beginning and end of each concentration test, the amount of volatile organic acids decreased dramatically, what indicates that they were quickly adhered to the anode. When comparing beginning and end of every concentration tested, the buffer capacity of the system achieved always higher values than at the beginning. A lowest REDOX was shown, when the vinasses content, COD and SI-ratio diminished. Although FOS/TAC values where optimal for CA and CB according to values proposed by Lossie and Pütz (2008) of 0.3-0.4, the separated FOS and TAC values where much lower than recommended. FOS values should be higher than 10000 mg/L and TAC values should lie between 8500 and 13000 mg/L (Mézes et al. 2011, Moerschner 2015). This was the reason of the low AD efficiency of the system. For concentration CC, the FOS/TAC value of 1.26 was higher than recommended by Moerschner (2015) and Lossie and Putz (2008). This resulted in a drop of the biogas and methane yields.

According to Kretzschmar et al. (2016), volatile fatty acids are correlated to the currrent production. Inhibitions in MFC were found out when the amount of organic acids increased above 4000 mg/L. In the present study, the best voltage output was obtained when the amount of FOS were 2166 mg/L, which showed also the highest amount of organic acid concentration.

Box 9

Table 4
FOS/TAC values measured at the beginning and end of each assay

	FOS mgHAc/L	TAC mgCaCO3/L	FOS/TAC
CA_I	713.5	1750	0.41
CA_F	174	2400	0.07
CB_I	838	1950	0.43
CB_F	49.5	2312.5	0.02
CC_I	2166	1725	1.26
CC_F	49.5	2625	0.02
CD_I	1253	1425	0.88
CD_F	215.5	2687.5	0.08

Source: Own elaboration

Conclusions

The combination of bioenergy technologies offers a wide range of both sustainable energy generation and byproducts further utilization.

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Substrates consisting of high amounts of organic and inorganic matter should stay in focus for treatment before discharge in soil and water. Through this study, the consecutive implementation of AD and MFC technologies was tested with mezcal vinasses and cattle manure as inoculum source for AD. It was found out that the use of vinasses in MFC inhibits the process of voltage generation. Besides, MFCs do not tolerate substrates with high amounts of COD. In the present study, voltage output increased with increasing vinasses content, until a certain limit of 14850 mg/L.

The highest COD tested was 17800 mg/L, at which the voltage dropped. In regards to biogas, the higher the COD content, the higher the biogas yield and methane content. It can be concluded that both technologies cannot be sequentially implemented without COD adjustment. This study presents an alternative for the further and deeper investigation of the use of both technologies consecutively, so that the organic acid content in substrate could result in a successfully MFC operation. Computational modeling could be used to simulate and study the hole biorefinery system using mathematics, physics and computer science. Through this tool the combination of alternatives could be analyzed regarding not only to the technological processes involved, but also economic feasibility

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

López-Velarde S., Mónica: Contributed to the project idea, methodology and development.

Rodríguez-Morales, José Alberto: Contributed to the development and revision.

Mendoza Burguete, Yesenia: Contributed to the project idea and revision.

Hensel, Oliver: Contributed to the project idea and revision.

Availability of data and materials

Data related to this research is available at the Kassel University Library in Campus Witzenhausen.

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Abbreviations

AD	Anaerobic digestion
BOD	Biological oxygen demand
$CaCO_3$	Total inorganic carbonate
CAD	Computer aided design
CFD	Computational fluid dynamics
CH_4	Methane content
CO	Carbon monoxide
CO_2	Carbon dioxide
COD	Chemical oxygen demand
FOS/TAC	Flüchtige organische Säuren / Total anorganic carbonate
H_2S	Hydrogen sulfide
H_2SO_4	Sulfuric acid
HAc	Acetic acid
MFC	Microbial fuel cell
N_2O	Nitrous oxide
NH_3	Ammonia
O_2	Oxygen
PEM	Proton exchange membrane
REDOX	Reduction-oxidation reaction
SI-ratio	Substrate to inoculum ratio
TAN	Total Ammonia Nitrogen
TDS	Total dissolved solids
TS	Total solids
VS	Volatile solids

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Article

Analysis of thermal loads using BIM methodology to reduce the energy consumption of buildings in Morelos, Mexico

Análisis de cargas térmicas mediante la metodología BIM para disminuir el consumo energético de edificaciones de Morelos, México

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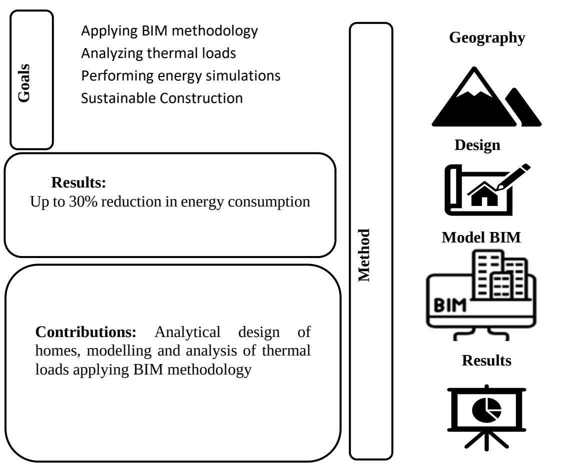
Abstract

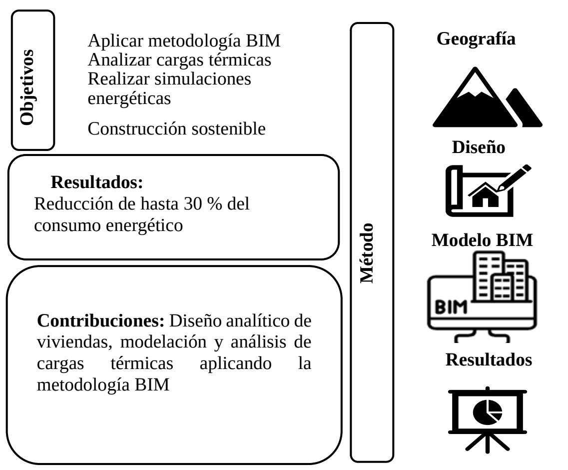
A Net Zero Energy Building (NZEB) is a building with a highly reduced operational energy consumption where energy efficiency measures have been implemented that allow the energy demand to be supplied by renewable sources. To this end, this paper describes the adaptation and implementation of a methodology to transform an existing residential building into a net zero energy building and thus achieve a self-sustainable building, considering as a case study a warm sub-humid climate in the state of Morelos, since this climate predominates in 85% of the total area of the state. The types of feasible and affordable eco-technologies to be implemented in Morelos are analysed and discussed. The energy efficiency of the building is analysed considering the combination of construction techniques, suitable materials for the envelope, thermal loads, and electrical energy consumption, with the aim of reducing the high dependence on fossil fuels in the construction sector.



Net zero energy, BIM methodology, Ecotechnologies, Thermal loads, Thermal comfort

Resumen

Un edificio de energía neta cero (NZEB, por sus siglas en inglés), es un edificio con un consumo energético operacional altamente reducido donde se han implementado medidas de eficiencia energética que permiten que la demanda de energía pueda suplirse mediante fuentes renovables. Para esto, en el presente trabajo se describe la adaptación e implementación de una metodología para transformar una edificación residencial existente en una edificación con energía neta cero y así lograr una edificación autosustentable, considerando como caso de estudio un clima cálido subhúmedo del estado de Morelos, ya que este clima predomina en el 85% de la superficie total de la entidad. Se analizan y discuten los tipos de ecotecnologías factibles y asequibles para implementarse en Morelos. Se analiza la eficiencia energética del edificio considerando la combinación de técnicas de construcción, materiales adecuados para la envolvente, las cargas térmicas y el consumo de energía eléctrica, con la finalidad de reducir la alta dependencia de los combustibles fósiles en el sector de la construcción.



Energía neta cero, Metodología BIM, Ecotecnologías, Cargas térmicas, Confort térmico

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Introduction

Due to population growth, there is an increase in the extraction of natural resources, leading various sectors worldwide to seek to eliminate or significantly reduce human-induced greenhouse gas emissions. It is argued that the consequences of inaction in this area would be uncorrectable if no action is taken. The so-called decarbonisation of the economy involves adopting changes in technologies in the sectors with the greatest impact on polluting emissions. Among these is the construction sector and the short and medium term objective is that, from design, during construction and during the useful life of a building, the energy balance should be minimal or zero. In this sense, a Net Zero Energy Building (NZEB) is a building with a highly reduced operational energy consumption where energy efficiency measures have been implemented that allow the consumption to be supplied through the use of renewable sources (Agudelo, 2022). Although interest in this concept is growing, its implementation in LATAM is incipient for various reasons such as: insufficient information or lack of knowledge about sustainable construction, lack of public policies to promote NZEB projects, as well as uncertainty about investment costs, among others.

On the other hand, it is important to mention that in the framework of the Ordinary Session of the National Council of the 2030 Agenda for Sustainable Development, held in virtual mode on 11 November 2020, the roadmap, plans and programmes promoted by the Government of Mexico in favour of the 17 Sustainable Development Goals (SDGs) were presented. The roadmap seeks to reduce existing social gaps and move towards a development model focused on well-being, promoting an inclusive economy and care for the environment.

This paper describes the application of the Building Information Modelling (BIM) methodology for the analysis of thermal loads of 4 existing residential buildings in the state of Morelos, Mexico, considering the 4 predominant microclimates in the state, with the aim of proposing ecotechnologies to reduce the energy consumption of housing and thus contribute to the energy efficiency of buildings.

In addition, it is also intended to contribute indirectly to the following SDG:

- Affordable and clean energy.
- Industry, innovation and infrastructure.
- Sustainable cities and communities.

Impacts of the construction sector

According to the International Energy Agency (IEA), the construction sector (residential and non-residential buildings) is responsible for the largest share of the energy consumption in the world:

- 36% of global final energy consumption.
- 54% of global electricity consumption.
- 45% of waste generation.
- 3% annual increase in buildings.

In addition, heating and cooling of buildings in cities generates more than 40 % of energy-related carbon dioxide emissions (IRENA, 2020):

- 28% comes from operation and activities such as maintaining a building with air conditioning, heating and electrical power.
- The remaining 12% relates to the actual construction of the building and the waste it generates: from rubbish to demolition waste.

Sustainability of a building

To understand the sustainability of a building, it is recommended to consider the potential of renewable sources available in each region. Figure 1 shows some eco-technologies that can be implemented in a building to achieve net zero energy. Only such a model can reflect the complex future reality of an energy sustainable society. The roadmap approved by the National Council of the 2030 Agenda envisages: Increasing investment for sustainable growth that contributes significantly, not only to Gross Domestic Product (GDP), but also to the Human Development Index (HDI), Designing and implementing sectoral programmes with a sustainability focus, accompanying legislatures for the development of laws with a sustainable vision (López, 2019).

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Box 1

1. Panel solar.	5. Smart thermostats.
2. Solar inverter.	6. Floor radiation heating.
3. Battery storage.	7. Certified mestic electrode of energy efficiency.
4. Geothermal pumps.	8. Doors and frames insulating from the outside.

Figure 1
Representation of a building with net zero energy

Source: Own elaboration

In the Netherlands, the energy sprong team has developed a methodology to transform existing houses into net zero energy buildings, i.e. the house generates as much energy as it needs for heating, hot water, light and appliances resulting in a warm and comfortable home environment. This is possible through the use of new technologies such as prefabricated, new and smart facades, heating and cooling installations and insulated roofs equipped with solar energy and solar panels. People do not even have to leave their homes because the transformation is completed within a week. After the house is net zero energy, the house looks bright and modern from the outside and is no longer damp or draughty inside. This makeover comes with a 30-year guarantee on both indoor energy and climate performance (CAF, 2019).

So how did the Dutch do it? In order to implement this change, an initial group of social housing associations joined forces to secure a first market for these performance-based makeovers, in addition to making adjustments to government regulations that were implemented.

This allowed social housing associations to charge tenants rent and energy service fees in exchange for providing them with a net zero energy home. At the same time, assessments of the new reforms were carried out by banks in order to provide affordable finance to social housing associations.

The independent market development team at energy sprong coordinated all these activities to ensure that each of the market conditions are met at the same time. This creates a level playing field for innovative companies willing to invest in and develop these net zero energy retrofits. All retrofits are based on prefabrication and industrialisation allowing for increased performance and cost reduction.

Methodology

Study area

The analysis of thermal loads will be applied in four dwellings located in different microclimates in the state of Morelos, of which four predominate: warm zones (from 22°C to more) occupy 68.17% of the state territory, followed by semi-warm zones (between 18 and 22°C) which occupy 18.85%, then temperate zones (between 12 and 18°C) which occupy 9.7% and finally semi-cold zones (between 5 and 12°C) which occupy the remaining 3.28%. Figure 2.

Box 2

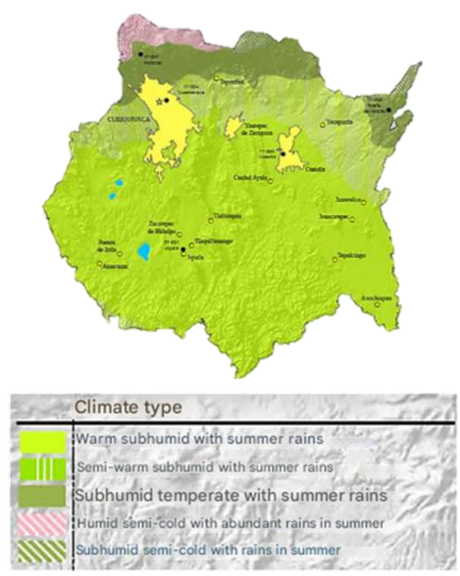

Figure 2
Predominant microclimates of the state of Morelos
Source: Own elaboration

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The first case study is located in the municipality of Atlacomulco Jiutepec, Morelos, the building is a 2-storey house and is oriented towards the geographical North as shown in Figure 3.

Box 3

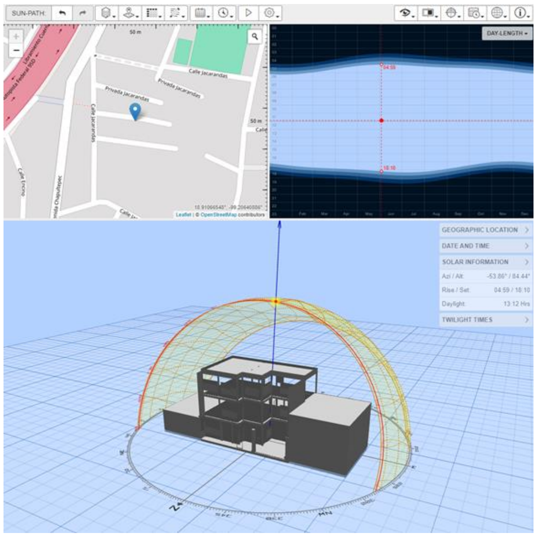

Figure 3
Orientation of housing in Jiutepec
Source: Own elaboration

With the 2D plans Figure 4, the design was transferred to the IFC Builder, by which the structure is placed again as shown in Figure 5 for analysis in the different BIMserver programs, highlighting the orientation, the types of walls and the type of space (habitable or non-habitable).

Box 4

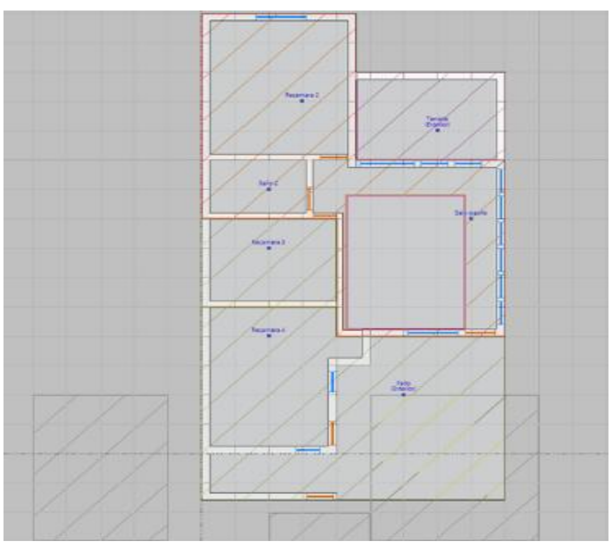

Figure 4
2D plan of the building in IFC Builder
Source: Own elaboration

Box 5

Figure 5
House in Jiutepec designed in CYPE Architecture
Source: Own elaboration

Taking into consideration nearby buildings that will be shaded with an orange volume (Figure 6), to be considered in the following programmes for analysis.

Box 6

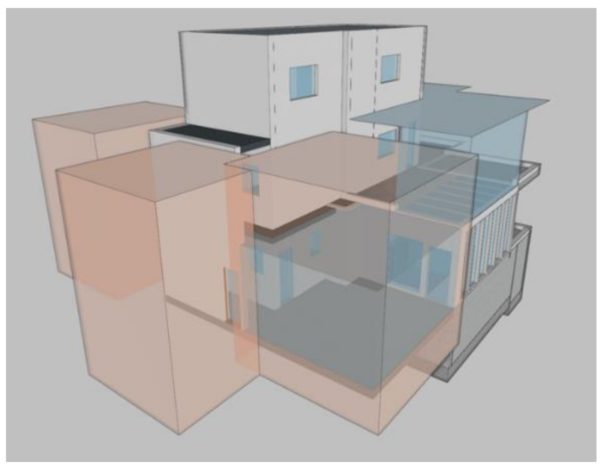

Figure 6
3D house view with IFC Builder

Source: Own elaboration

For the analysis of thermal loads, the properties of building materials as well as the material of doors, windows and other enclosures are defined and introduced. The outdoor design conditions for the load calculation are provided by default by location-specific climate data as shown in Figure 7, which are taken from the Instituto Nacional de Estadística, Geografía e Informática (INEGI), but are also compared with data from NASA, weatherspark and ASHRAE.

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Box 7

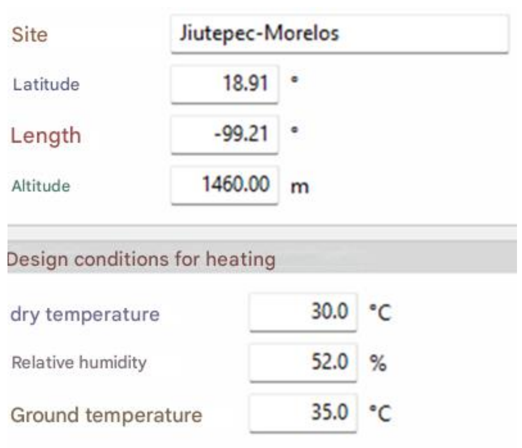

Figure 7
Location data locality

Source: Own elaboration

After entering the external data, the properties and characteristics of the building materials are entered in order to determine the thermal transmittance and thermal capacity coefficients of the walls, as shown in Figure 8.

Box 8

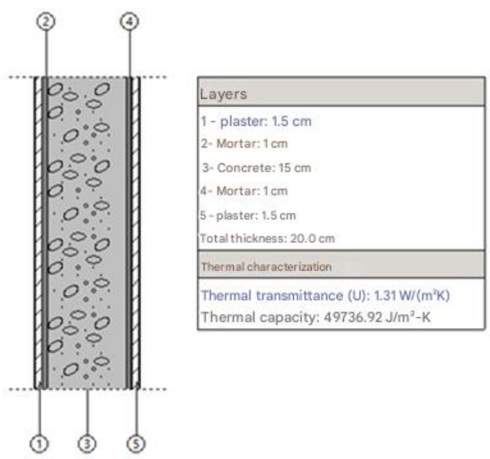

Figure 8
Characteristics of the wall in the building

Source: Own elaboration

Results

After entering the parameters required by the CYPETHERM LOADS software, the calculation and analysis of thermal loads for each building is carried out using the Radiant Time Series Method (RTSM).

The data obtained includes the magnitude of power required for both cooling and heating of the building and thus achieve thermal comfort according to the annual, monthly and daily behaviour of the climate, considering the thermal loads of the hottest months in the total and daily results.

Thermal loads in the case studies

Case study 1.- Housing in Jiutepec

Preliminary results obtained with the CYPETHERM LOADS software reveal that the Jiutepec Morelos dwelling lacks heating requirements, resulting in negative values for the thermal loads associated with heating. On the other hand, it is identified that the space located on the ground floor - referred to as the living room - presents the highest cooling demand, establishing an estimated cooling thermal load of 7372 W (Figure 9).

Box 9

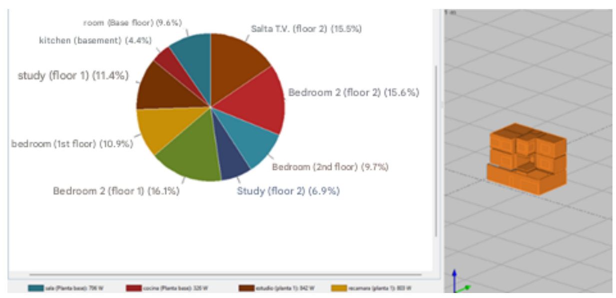

Figure 9
Maximum simultaneous cooling load in the Jiutepec household

Source: Own elaboration

The time of peak cooling demand, related to location and orientation, occurs on 21 July at 16:00 hours. This result provides important information for the planning and design of air conditioning systems.

Case study 2.- Housing in Temixco

According to the results obtained with CYPETHERM LOADS in the house located in Temixco, the maximum cooling load required is 5784 W (Figure 10) and heating load 12855 W (Figure 11), where the highest percentages of heating and cooling are in bedrooms 1 and 2, respectively.

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Box 10

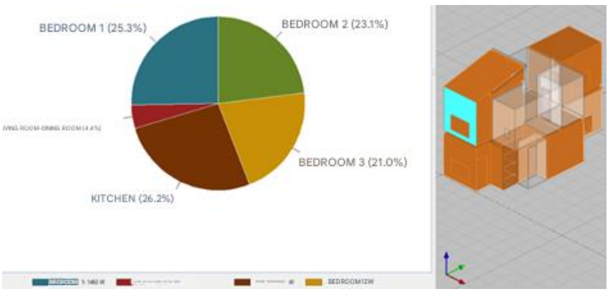

Figure 10
Maximum simultaneous cooling load in housing in Temixco

Source: Own elaboration

Box 11

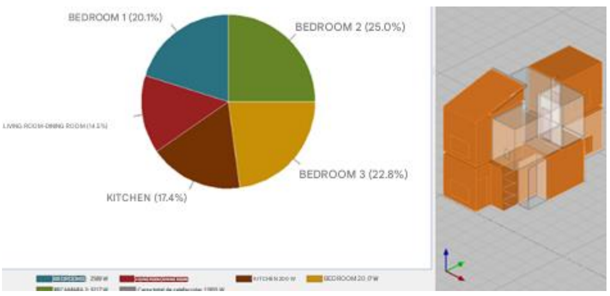

Figure 11
Maximum simultaneous heating load in a Temixco home

Source: Own elaboration

Case study 3.- Housing in Cuernavaca

For the case study in Lomas de Ahuatlán Cuernavaca, the maximum cooling load required is 11024 W Figure 12 and the cooling load is 139 W in the whole building, so it is considered a very low value to be taken into account for the load analysis.

Box 12

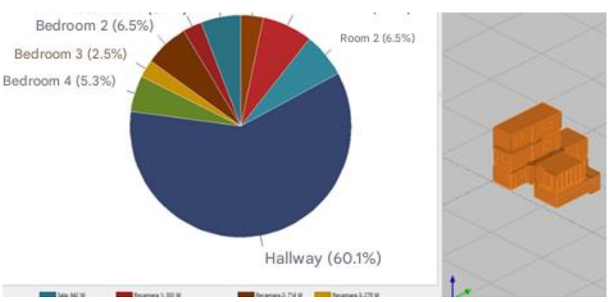

Figure 12
Maximum siultaneous cooling load in housing in Cuernavaca

Source: Own elaboration.

Case study 4.- Housing in Huitzilac

According to the results obtained in the Huitzilac house, the maximum cooling load required is 2035 W (Figure 13) and the heating load 6942 W (Figure 14), where the highest percentages of heating and cooling are in the living room and master bedroom, respectively.

Box 13

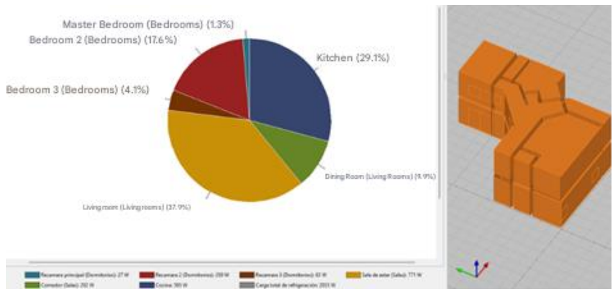

Figure 13
Maximum simultaneous cooling load in the Huitzilac household

Source: Own elaboration

Box 14

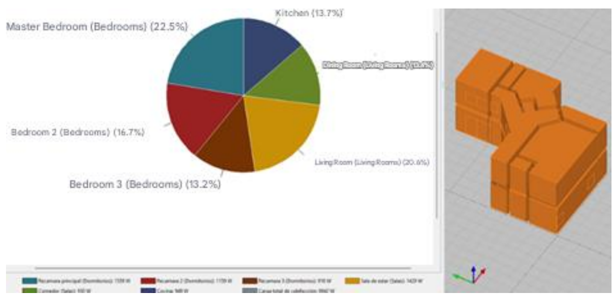

Figure 14
Maximum simultaneous heating load in housing in Huitzilac

Source: Own elaboration.

Implementation of efficient eco-technologies

The ecotechnologies considered in the implementation were selected because of their practical implementation and ease of purchase in different markets. Energy saving light bulbs, thermal coatings and photovoltaic panels are taken into consideration for their calculations.

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Energy-saving light bulbs

One of the applications of eco-technologies was the implementation of 15 LED saving light bulbs in some of the houses, which as shown in Table 8, in an interval of 15 years (duration of LED bulbs) is a better investment than conventional CFL and common saving bulbs, since the latter are not functional and the final investment would be much higher than LEDs and over time, the price of LED bulbs decrease, while their performance and durability increase.

Box 15

Table 1

Comparison of light bulb types for primary residences

focus	Price per unit (MXN)	Duration (years)	W consumption	Brightness	Total price(MXN) per unit in 15 years	Number of lamps	Total (MXN)
CFL	75	5	30	2000	225	45	3375
LED	125	15	30	3000	125	15	1875
Commn	30	1	30	450	450	225	6750

Source: Own elaboration.

Implementation of cladding

The CYPETHERM LOADS application helps us to implement cladding on the inside or outside of the building to check whether it is feasible to insulate it. The technical data of the material can be entered in the same programme to subsequently implement it in the structure. For the analysis, the thermal insulators mentioned in Table 2, Table 3 and Table 4 were taken into account, as well as the implementation of protective films to reduce heat transfer in the glazing, obtaining the following results:

Box 16

Table 2

Comparison of light bulb types for primary residences.

	Thermal loads (Watts)						
Building	Uncoated	Denim waste	Polyurethane	ibreglass	lineral wool	sphalt nembrane	Bituminous asphalt
Jiutepec	7372	6199	6215	6140	6144	5952	5955
Temixco	5784	6501	6448	6236	6256	5716	5716
Ahuatlán	11024	7700	7746	7810	7802	7893	7894
Huitzilac	2035	1900	1855	1731	1744	1437	1435
Jojutla	43086	41258	41328	41416	41404	41552	41556

The table shows the energy consumption in Watts (W) of different types of building envelopes in five municipalities in Morelos: Jiutepec, Temixco, Ahuatlán, Huitzilac and Jojutla. The type of cladding with the lowest energy consumption is bituminous asphalt, followed by asphalt membrane, mineral wool, glass fibre, polyurethane, denim waste and finally no cladding. With the help of Figure 15, the comparison of the individual coatings can be seen.

Box 17

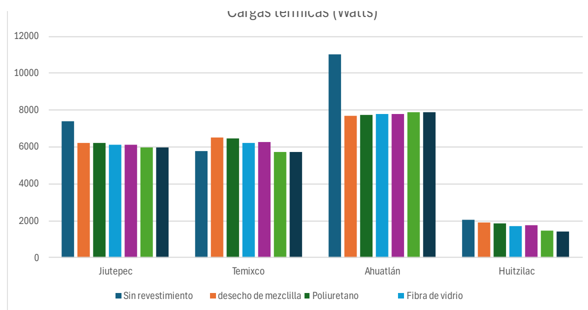

Figure 15

Comparative graph of the different coatings in each municipality

Source: Own elaboration

Conclusions

The implementation of eco-technologies in the short and medium term in buildings in Morelos can contribute to energy efficiency and moving towards net zero energy has the potential to revolutionise the construction industry in terms of sustainability. While there are notable financial, technical and regulatory challenges, the benefits in terms of energy efficiency, emissions reduction and economic development are promising. Addressing these challenges will require close collaboration between government, the building sector and academia to create an enabling environment for the adoption and advancement of these cutting-edge technologies.

Based on the results it can be concluded:

- The coating type with the lowest energy consumption is bituminous asphalt in all municipalities, followed by asphalt membrane, mineral wool, glass fibre, polyurethane, denim waste and finally uncoated.

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- The difference in energy consumption between bituminous asphalt and uncoated asphalt varies between 1.2% and 30% in the different municipalities.

- The choice of the best type of cladding for a specific municipality will depend on several factors, such as climate, building size and shape, building materials, and heating and cooling systems.

Regarding the thermal load analysis of the case study in Temixco, the implementation of ground-air heat exchangers is recommended, as well as reflective coatings on glazed doors and windows to reduce the cooling thermal load.

The use of sustainable building materials and efficient heating and cooling systems should be considered to further reduce the energy consumption of buildings. In addition, a more detailed analysis of the specific needs of each municipality and building should be carried out to determine the most appropriate type of cladding.

For the case of the house that had CFL energy saving bulbs, the use of LED bulbs will have a better performance, the waste from changing bulbs will be reduced by a third and the final expenditure over a period of 15 years will be less than CFL bulbs without taking into account that the price of LED bulbs continue to reduce, making it easier to purchase them.

On the other hand, the implementation of grid-interconnected photovoltaic (PV-IR) systems can also be considered, however, the feasibility of implementing solar panels depends on specific factors such as location, energy consumption, initial investment costs and payback rate. In general, there are several studies that demonstrate the viability of PV-IR as a sustainable energy option for buildings and businesses, as it can save money on electricity bills in the short term, reduce the carbon footprint of buildings and increase the value of buildings.

Authors' contribution

The contribution of each researcher in each of the points developed in this research was as follows:

Vázquez-Fuentes, *Erick E:* Carried out the design and modelling of the case studies, simulation and analysis of thermal loads. He also contributed to the analysis of climatological data and the systematisation of results.

Montiel-González, Moisés: Generated the idea, approach and structure of the article, application of the BIM methodology, as well as the analysis and systematisation of the results.

Alvarado-Juárez, Roberto: Contributed to the design and structure of the article, application of the BIM methodology, as well as the analysis and presentation of results.

Morales-Gómez, Laura: Systematised the literature review, analysed the results and drew conclusions.

Availability of data and materials

Climate data for each location were obtained from NASA Power. The designs were obtained from residences located in Morelos and were made using IFC Builder software and simulated in CYPETHERM LOADS, which are free programs located on the BimServer server.

Conflict of interest

The authors declare that they have no conflict of interest.

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Abbreviations

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc
BIM	Building Information Modeling
CFL	Compact Fluorescent Lamp
IDH	Índice de Desarrollo Humano
LATAM	Latinoamérica
LED	Light Emitting Diode
NASA	National Aeronautics and Space Administration
NZEB	Net Zero Energy Building
ODS	Objetivos de Desarrollo Sostenible
PIB	Producto Interno Bruto
RTSM	Método de las Series Temporales Radiantes

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Article

Electricity consumption measurement device for the design of an energy management system

Dispositivo de medición de consumo eléctrico para el diseño de un sistema de gestión de la energía

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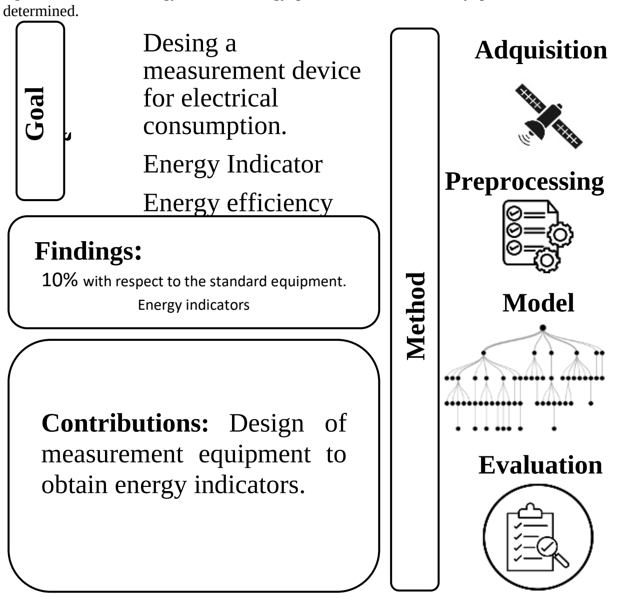
Abstract

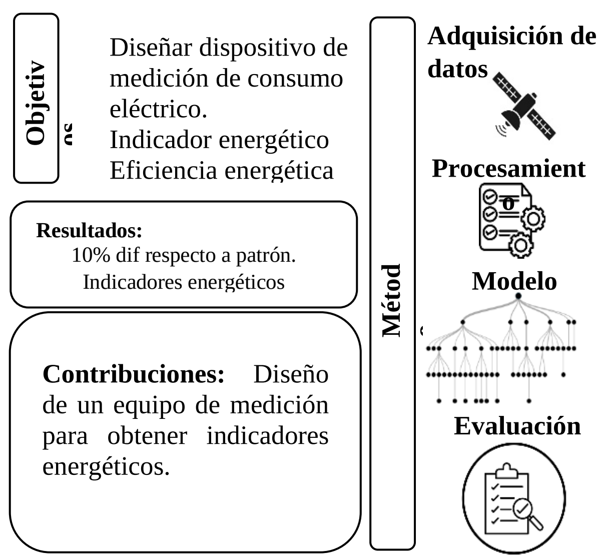
As the industry prioritizes energy efficiency, the implementation of Energy Management Systems has become a strategic necessity. One of the basic aspects for this type of system is the evaluation of energy performance that requires the collection of energy data as an essential input, so this project has as objective design a measurement device focused on the acquisition of voltage, current, power, power factor and electrical consumption through an iterative and progressive approach with elements adapted from a cascade model for determining the significant uses of energy and energy indicators of the production area of a bottling plant. The results of the measuring equipment has a difference of 10% with respect to the standard equipment so the significant uses of energy and the energy performance indicators by production line were determined.



Energy, Efficiency, SGEN

Resumen

A medida que la industria prioriza la eficiencia energética, la implementación de Sistemas de Gestión de la Energía se ha convertido en una necesidad estratégica. Los aspectos base para este tipo de sistemas es la evaluación del desempeño energético que necesita como insumo esencial la recopilación de datos energéticos por lo que este proyecto tiene como objetivo diseñar un dispositivo de medición enfocado a la adquisición de voltaje, corriente, potencia, factor de potencia y consumo eléctrico mediante un enfoque iterativo y progresivo con elementos adaptados de un modelo en cascada para la determinación de los usos significativos de la energía y los indicadores energéticos del área de producción de una planta embotelladora. Los resultados que el equipo de medición tiene un 10% de diferencia respecto al equipo patrón así mismo se determinaron de los usos significativos de la energía y los indicadores de desempeño energético por cada línea de producción.



Energía, Eficiencia, SGEN

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Article

Introduction

It is a reality that most production processes aim to carry out the same work with a smaller amount of resources. One of the resources that is most used in any production process is energy and its maximum use is a central issue for the production sector. One of the tools for controlling, planning and organising energy consumption are energy management systems.

This project is developed within a production process focused on the production, distribution and sale of mostly carbonated beverages and aims to contribute to the implementation of an energy management system (EMS).

The bottling plant uses three energy sources for the development of all its activities, however, electricity has a greater presence in the plant because it is used within the production lines for the production of beverages and therefore is the one that has the greatest potential for savings and to improve its performance and efficiency through the implementation of an SGEN. Within the production area of the bottling plant there are four production lines in operation, three of which are for soft drinks in different presentations and one for jug water.

B0x 1

Table 1
Product type per line

Line	Presentation
Líne 1	Non-returnable-PET
Líne 1	Glass
Líne 2	PET Bottles
Líne 3	Returnable-PET
Líne 3	Non-returnable-PET
Líne 4	Non-returnable-PET

The context of development of this project is within these four production lines and has as its general scope the design and implementation of an SGEN to achieve a sustained and continuous improvement of energy performance in the bottling plant.

The SGEN can be defined as a methodology to achieve sustained and continuous improvement of energy performance in organisations in a cost-effective way (Flores, 2016).

The methodology is based on a PDCA (plan-do-check-act) continuous improvement model and has eight stages (E0 to E7) and 29 steps for its design (Figure 1).

Each of these stages presents a series of steps (Figure 2), which must be elaborated in a systematic way. One of the stages considered fundamental for the design of the SGEN is stage 2, corresponding to the evaluation of energy performance, as it allows identifying the current situation of the system, as well as monitoring the evolution of the various indicators.

Box 2

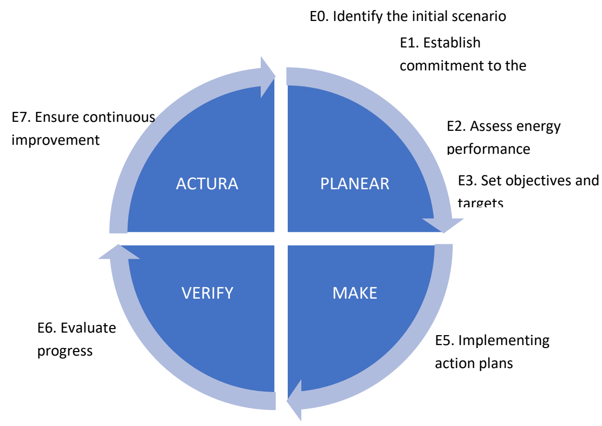

Figure 1
Stages of the SGEN

Source: (Flores, 2016)

This stage determines the uses to which energy is put (USEN), how energy is consumed, the energy required to produce a unit of output (energy indicator) and the measures available to promote energy efficiency and savings (ISO, 2011).

Box 3

PLANEAR	E0. IDENTIFY THE INITIAL SCENARIO	STEP 0.1 DETERMINE THE CONTEXT OF THE ORGANISATION
		STEP 0.2 DEFINE SENIOR MANAGEMENT RESPONSIBILITIES
	E1. ESTABLISHING THE COMMITMENT TO THE SGEN	STEP 1.1 DEFINE SCOPE AND BOUNDARIES OF THE SGEN
		STEP 1.2 APPOINT A MANAGEMENT REPRESENTATIVE
		STEP 1.3 ESTABLISH AN ENERGY MANAGEMENT TEAM
		STEP 1.4 DEFINE AN ENERGY POLICY
	E2. ASSESSING ENERGY PERFORMANCE	STEP 2.1 IDENTIFY AND ASSESS LEGAL AND OTHER REQUIREMENTS
		STEP 2.2 COLLECT ENERGY DATA

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		STEP 2.3 ESTABLISH SIGNIFICANT ENERGY USES
		STEP 2.4 DEFINE ENERGY BASELINE AND ENERGY INDICATORS
		STEP 2.5 RECORD OPPORTUNITIES FOR IMPROVEMENT
		STEP 2.6 DEVELOP A MONITORING SYSTEM
	E3. SETTING OBJECTIVES AND TARGETS	STEP 3.1 DETERMINE THE FRAMEWORK
		STEP 3.2 ESTIMATE THE POTENTIAL FOR IMPROVEMENT
		STEP 3.3 DEFINE OBJECTIVES AND TARGETS
	E4. CREATE ACTION PLANS	STEP 4.1 DEFINING STEPS AND GOALS
		STEP 4.2 ASSIGN ROLES AND ALLOCATE RESOURCES
MAKE	E5. IMPLEMENTIN G ACTION PLANS	STEP 5.1 STRENGTHEN COMPETENCIES
		STEP 5.2 DEVELOP A COMMUNICATION AND AWARENESS PLAN
		STEP 5.3 ESTABLISH DOCUMENTATION OF THE SGEN
		STEP 5.4 GENERATE OPERATIONAL CONTROLS
		STEP 5.5 INCORPORATE ENERGY PERFORMANCE INTO THE DESIGN PROCESS
		STEP 5.6 ESTABLISH PROCUREMENT CRITERIA
VERIFY	E6. ASSESSING PROGRESS	STEP 6.1 MONITOR AND CONTROL
		STEP 6.2 MEASURING RESULTS
		STEP 6.3 REVIEW THE ACTION PLANS AND THE SGEN
EVALUA R	E7. RECOGNISING ACHIEVEMENT S	STEP 7.1 CONDUCT MANAGEMENT REVIEWS
		STEP 7.2 MAKE DECISIONS TO IMPROVE THE SGEN
		STEP 7.3 ASSESS CONFORMITY

Figure 2
Steps of the SGEN
Source: (Nadege, 2017)

As shown in Figure 2, after identifying and assessing the legal requirements, it is necessary to collect data on past and present uses and consumptions of energy used by the organisation, including energy sources (step 2.2), and it is in this step where the development of the project is focused. The level of depth with which energy data collection can be carried out is directly related to the technological capacity to measure or estimate energy consumption (Vazquez, 2020). If direct measurement of the energy consumption of equipment or facilities is not available, it is possible to estimate it based on design and operational information.

The data must be appropriate, as it will be used to set energy objectives and targets. Within the bottling plant, there are only records of total electricity consumption measurements (billing receipt) but there are no measurements of electricity consumption per production line, which means that it is not possible to determine the USENs and energy indicators (EI) per production line. However, being a high production bottling plant, it is clear that it has specialised measurement equipment such as a power quality analyser, this equipment is of great help for energy diagnostics and specialised measurements, among the measurements that this equipment can perform is that of power and energy (electricity consumption, power factor, etc.), it would be logical to use this equipment to measure the energy consumption of the bottling plant. It would be logical to use this equipment to determine the electrical consumption of each line, but it is impractical because on the one hand it is necessary to take measurements for long periods of time and on the other hand, as it is specialised equipment, it is expensive and normally there is only one piece of equipment per plant, which would be an inefficient use of the bottling plant's resources.

It is for this reason that this project aims to design a measurement device focused on the acquisition of voltage, current, power, power factor and electricity consumption through an iterative and progressive approach with elements adapted from a cascade model to determine the significant uses of energy and energy indicators in the production area of the bottling plant.

In this way, it is intended to establish the basis for determining objectives and targets, as well as relevant action plans for energy efficiency and the establishment of a culture of continuous and sustained improvement.

Methodology

The prototype was implemented on a Raspberry Pi 2 (RPi), which is a single board computer with a quad-core ARM Cortex-A7 processor and 1GB RAM, the operating system used was Raspbian GNU/LINUX Version 11 (Bullseye) and the software was developed in Python 3.9.2.

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The system took as a design consideration the needs of measurement and monitoring of current and electrical power data in real time, as well as the generation of reports with the intervals defined in the IEC 61000-4-30 Standard for Class A devices (CCA, 2019).

The designed data acquisition system (DAQ) considered the selection of components according to their performance, communication protocols and their respective configuration, so that their integration resulted in a cohesive solution. After the operational tests to verify the correct functioning of the prototype in real time, the generation of reports at specific intervals of 200 ms, 3 s, 10 min. and 2 h was supervised, the result of which required the calculation of data averages (Equation 1) for subsequent storage in a simple text file in CSV format.

$$U_{RMS_{200ms}} = \sqrt{\frac{1}{200ms}} \quad (\tau)d\tau \qquad [1]$$

The system acquires the electrical signals by means of a current sensor SCT-013 with a current measurement range of 100 A, placing a module for each power supply line of the three-phase or single-phase line of the production area as required to then perform the conditioning of the signals by means of a 16-bit ADS1115 analogue digital converter (ADC) ADS1115. Figure 3 shows the basic connection of the sensor with the ADC to the Rpi 2 b+ and Figure 4 describes the operation of the algorithm for the acquisition and capture of the generated data.

Box 4

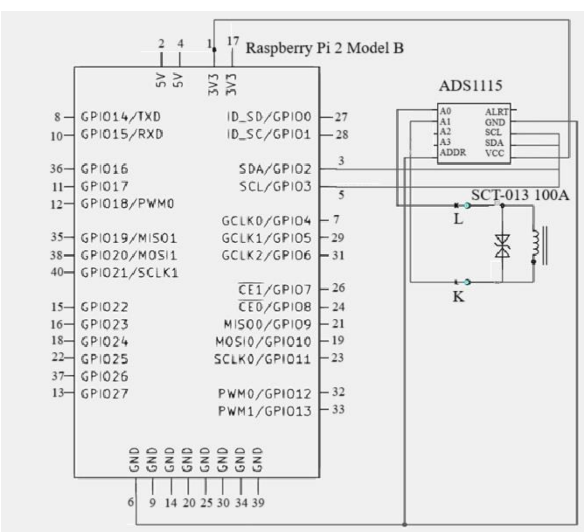

Figure 3
Basic connection diagram of the ADC ADS1115 and the SCT-013 100A sensor to the Rpi 2 B+.

Data records are captured every 200ms, 3s, 10min and 2 hours according to the current Standard and in their respective individual files to facilitate their analysis and processing.

Box 5

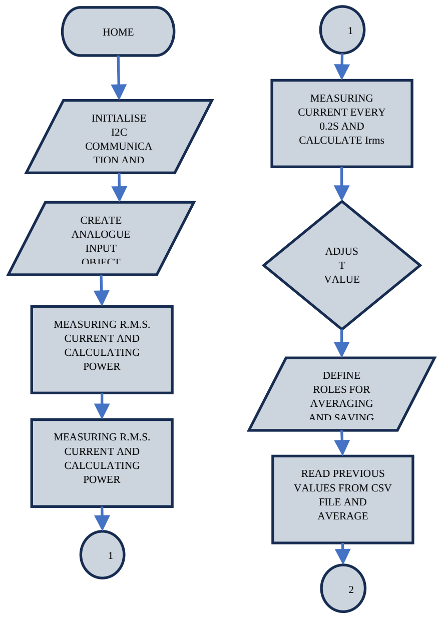

Figure 4
Algorithm of operation of the electricity consumption metering device

Results

The designed measuring equipment performs very closely to the measurements of the standard equipment. Figure 5 shows that the designed equipment shows a 10% difference with respect to the measurements of the standard equipment.

Box 6

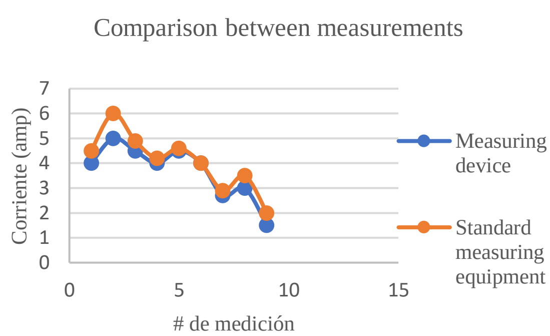

Figure 5
Performance of the measuring equipment against the standard equipment

Table 2 shows the installed load per production line:

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Box 7

Table 2
Load per line

Line	KW
Line 1 NR-PET	256.91
Line 1 VIDRIO	473.13
Line 2	152.26
Line 3 RT-PET	143.72
Line 3 NR-PET	299.42
Line 4	161.11

It can be seen that 45% of the installed power is on line 1, followed by 28% on line 3 and with a lower percentage on line 4 with 14% and line 2 with 13% of the installed power. With regard to the USENs, the following behaviour is shown in figure 6.

Box 8

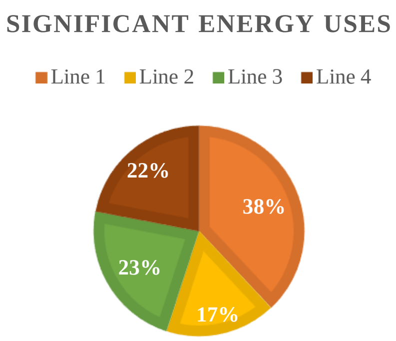

Figure 6
USEN bottling plant

Figure 6 shows that the highest electricity consumption is on line 1 followed by line 3, which is consistent with the lines with the highest installed load.

Energy indicator

For the determination of the energy indicators it is necessary to measure the production of beverage during the period of measurement of electricity consumption, figure 7 shows the percentage of production per production line.

Box 9

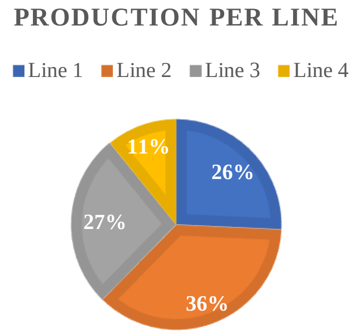

Figure 7
Percentage of production per production line

Figure 7 shows that the highest production is on line 2, followed by line 3 and 1, which is far from the behaviour of energy consumption per line.

Finally, now that the electricity consumption and production per line are available, it is possible to determine the energy indicator.

Box 10

Table 3
Energy indicator by line

Line	IE (kWh/m^3)
Line 1 NR-PET	0.743
Line 1 VIDRIO	0.916
Line 2	0.262
Line 3 RT-PET	0.366
Line 3 NR-PET	0.561
Line 4	1.139

Table 3 shows that the highest energy indicator is presented in line 4, followed by line 1 in its glass presentation, which indicates that line 4 consumes the highest amount of energy per cubic metre of beverage produced.

According to the results obtained, it can be seen that although line 1 has the highest installed load and the highest percentage of significant energy use, its energy indicator is below that of line 4, which has the lowest installed power and significant energy use. This indicates that line 4 is consuming energy not associated with the major product, either for equipment not directly related to beverage production (lighting, office equipment, etc.) or as wasted energy.

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Conclusions

The implementation of Energy Management Systems (EMS) in industry aims to promote energy efficiency and sustainable energy use.

The designed measuring device has an accuracy of +/- 10% with respect to the standard device and has been used to determine the significant energy uses and energy indicators of the production area of a bottling plant. This measuring device is an important tool for monitoring energy consumption in production and for identifying opportunities to improve energy efficiency.

In conclusion, the design and construction of a low-cost, high-precision device such as the one presented in the paper is of great importance in the implementation of an SGEN in the production sector. The results obtained demonstrate that the implementation of energy efficiency and electricity consumption reduction measures are viable and feasible in the production of carbonated beverages, and that there is a great potential for improvement in the reduction of energy costs allowing the industry to improve its competitiveness through the optimisation of energy use.

Statements

Conflict of interest

We declare that there is no conflict of interest. There are no known competing financial interests or personal relationships that could have influenced the article reported in this paper.

Contribution by author

Authors *David Sifuentes* and *Rafael Irigoyen* contributed to the design and implementation of the Energy Management System.

Authors *Felix Mar* and *Ivan Lopez* contributed to the design and construction of the electronic device.

Availability of data and materials

The availability of the data obtained depends on the availability of the company.

Funding

There is no funding for this project.

Abbreviations

SGEN: Energy Management System

USEN: Significant Energy Uses.

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Article

Electric parameters analysis for the detection of possible failures in the insulation of electric motor windings

Análisis de parámetros eléctricos para la detección de posibles fallas en el aislamiento de los devanados de motores eléctricos

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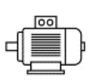
Abstract

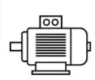
Knowledge of electric motors is of utmost importance in the industry. Knowing the anticipated data on the good or bad functioning of the equipment we work with allows us to make better decisions for their optimal development. This article presents a proposal for analyzing electrical data in induction motors, allowing a study of their behavior to be carried out to detect a possible failure in the windings due to a short circuit, defect or degradation of the insulation. With the help of a simulator, it is easier to develop this analysis. The Simulink software provided by the Matlab software shows us graphic results that we can view to predict and take preventive measures for the equipment.

Objetives	Methodology	Contribution
Detection of possible faults in the electric motor windings. 	• Engine data analysis • Develop simulation model • Result comparison	The development of a simulation model predicts the detection of a short circuit in the winding of an electric motor.

Induction, Circuit, Windings

Resumen

El conocimiento en los motores eléctricos, es de suma importancia en el área de la industria, conocer los datos anticipados del buen o mal funcionamiento de los equipos con los que se trabaja nos permite tener mejores tomas de decisiones para el óptimo desarrollo de los mismos. Este artículo presenta una propuesta de análisis de datos eléctricos en los motores de inducción permitiendo que se realice un estudio de su comportamiento para detectar una posible falla en los devanados a causa de un corto circuito, por defecto o degradación del aislamiento. Con ayuda de un simulador se facilita desarrollar dicho análisis. El software simulink que nos brinda el software de Matlab nos muestra resultados gráficos que podemos visualizar para predecir y tomar medidas de prevención del equipo.

Objetivos	Metodología	Contribución
Detección de posibles fallas en los devanados de los motores eléctricos. 	• Análisis de datos del motor • Desarrollo del modelo de simulación • Comparación de resultado	El desarrollo de un modelo de simulación predice la detección de un corto circuito en el devanado de un motor eléctrico.

Inducción, Circuito, Devanados

Citation: Terrazas-Flores, Luis Emilio, Melchor-Hernández, Cesar Leonardo, Sánchez -Medel, Luis-Humberto and González-Sobal, Martín. [2024]. Electric parameters analysis for the detection of possible failures in the insulation of electric motor windings. Journal Electrical Engineering. 8[20]-1-6: e40820106.

Journal Electrical Engineering 8[20]1-10: e40820106
Article

Introduction

Most processes in industry use induction motors. Due to the various activities, they carry out, as well as the electrical and mechanical stresses to which they are subjected, they cause failures in the motors.

It is necessary to know the status of the induction motors on a daily basis, in order to detect any faults that may occur, even when they are in a stationary state. There are numerous circumstances due to which failures occur in electric motors, for example short circuits between turns, insulation losses and insulation degradation (Marot, 2022).

Failures in induction motors are caused by breakdowns that occur in their components, one of these components is the highly relevant winding turns located in the stator of induction motors. This breakdown is caused by progressive wear or degradation of the insulation between the winding conductors (Yuchechen Guillermo.D., 2020).

With a model, the behavior of the electrical parameters will be analyzed and possible failures in the windings of the electric motors detected.

The contribution of this work is to simulate a short circuit in the motor winding and analyze the value of the electrical parameters.

Equations will be used to find the values of the electrical parameters and be able to substitute them in a simulator and be able to observe graphical results of the behavior of the electric motor.

Model

An equivalent electrical circuit will be used for the analysis of the motor parameters, which has 2 circuits: one for the stator and another for the rotor.

Figure 1 shows the circuit for the analysis of the electric motor, with this circuit an analysis can be carried out to find the values of the parameters of the electric motor (Pozueta, 2018).

Box 1

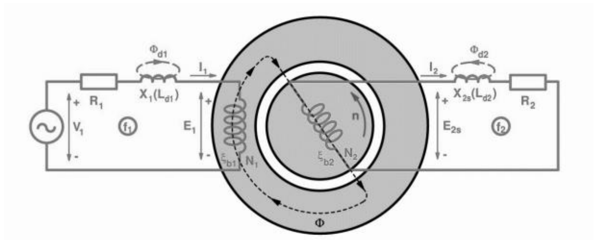


Figure 1
Equivalent circuit of an induction motor

Source: *Rodríguez Pozueta Miguel Ángel*

Figure 2 shows the equivalent circuit with the variables that will be used for the study of the electric motor. The analysis of the electrical parameters is based on this equivalent circuit.

Box 2

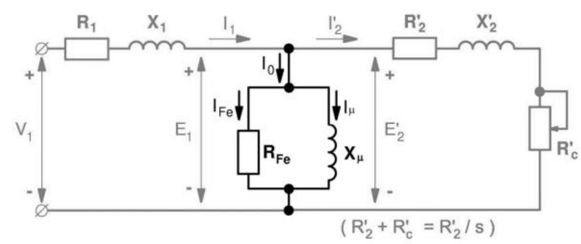


Figure 2
Equivalent diagram of an induction motor

Source: *Rodríguez Pozueta Miguel Ángel*

To find the value of these parameters it is necessary to perform the following tests on the induction motor:

- Vacuum test.
- C.D. test.
- Locked rotor test.

Vacuum test

The vacuum test consists of energizing the motor without any load, the factors that act on the motor would be friction losses and air friction losses. In these tests, the magnetization reactance XM and the losses in the core Rc are determined. This test also provides the magnetization current. To this test, the wattmeters, voltmeters and three ammeters are connected to the motor.

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In this case, as the motor rotates without any load, other than friction and air friction, the speed of the rotor is similar to the speed of the field, the slip of the motor is very small. Therefore, the losses in the stator copper are:

$$P_{PCE} = 3I_1^2 R_1 \quad [1]$$

Therefore, the input power will be:

$$P_{entr} = P_{PCE} + P_{nucl} + P_{FyR} + P_{misc} \quad [2]$$

Rotor losses are defined as:

$$P_{rot} = P_{nucl} + P_{FyR} + P_{misc} \quad [3]$$

Substituting equations 2 and 3 we are left with:

$$P_{entr} = 3I_1^2 + P_{rot} \quad [4]$$

So, by having the input power and obtaining the rotational losses. According to the equivalent circuit, the magnetization reactance X_M is in parallel with RC and R2 (1-s) /s, the approximate equivalent input impedance is obtained (Chapman, 2012):

$$|Z_{eq}| = \frac{V_\varphi}{I_{1,sc}} \approx X_1 + X_M \quad [5]$$

C. D. Test

The DC test consists of applying direct current voltage to the stator windings of an induction motor. Since it is direct current, there is no induced voltage to the rotor circuit, this means that there is no resulting current in the rotor. Therefore, the reactance of the rotor is zero, this provides that the only measure of current flow existing in the motor is that of the resistance of the stator windings, with this test we determine the resistance of the stator. Since the current passes through the two windings, the total resistance is 2R1, so we have:

$$2R_1 = \frac{V_{CD}}{I_{CD}} \quad [6]$$

Solving R1 we obtain:

$$R_1 = \frac{V_{CD}}{2I_{CD}} \quad [7]$$

But if the motor is connected in delta, then the equation is:

$$R_1 = \frac{3V_{CD}}{2I_{CD}} \quad [8]$$

Locked rotor test

In this test the rotor is locked, an A.C. voltage is applied. to the stator, but it is taken into account that it should not exceed the full load current, when setting the voltage and frequency the amperage is adjusted so that it is close to the nominal, and the power, amperage and voltage are measured quickly, trying not to overheat the engine. Then the magnitude of the total impedance of the circuit is (Chapman, 2012).

$$|Z_{RB}| = \frac{V_\emptyset}{I_1} = \frac{V_T}{\sqrt{3}I_L} \quad [9]$$

An example taken from Chapman's book is presented to calculate parameters that will be used in the equivalent circuit where they will be substituted in the simulation in Matlab-Simulink, and will give us values that will be graphed which we can interpret and thus identify if there is a possible failure in the induction motor.

Methodology

An exercise will be used to calculate the electrical parameters that are taken from the tests carried out on the electric motor, to obtain the values that will be used in the equivalent circuit of Figure 3, obtaining these parameters they will be substituted in the simulator, from the which we will obtain graphic results, to analyze the behavior of said equipment (Chapman, 2012).

Figure 3 shows the equivalent circuit used for the calculations and the values to be used.

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Box 3

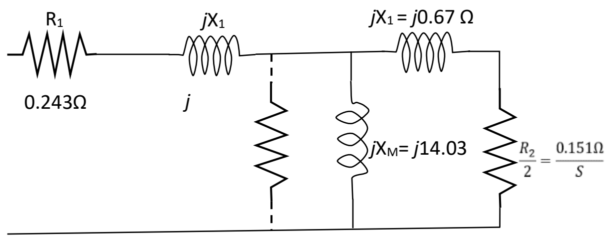

Figure 3

Equivalent circuit with parameters obtained from the calculations made to the induction motor

Source: Máquinas eléctricas Stephen J. Chapman

According to the formula for calculating the approximate full load current of a three-phase induction motor (Wildi, 2007), the following formula is used:

$$I = \frac{600\ P_h}{E} \quad [10]$$

For the no-load current it is:

$$I_o = 0.3\ I \quad [11]$$

And for the starting current it is:

$$I_{LR} = 6\ I \quad [12]$$

Figure 4 shows graphically the result obtained from the simulator, with the data that was calculated in the exercise in Figure 3, when the motor is working in a normal state, the current values that the motor takes at the same time are observed. start-up, as well as the response time it takes to stabilize without current variations or alterations.

Box 4

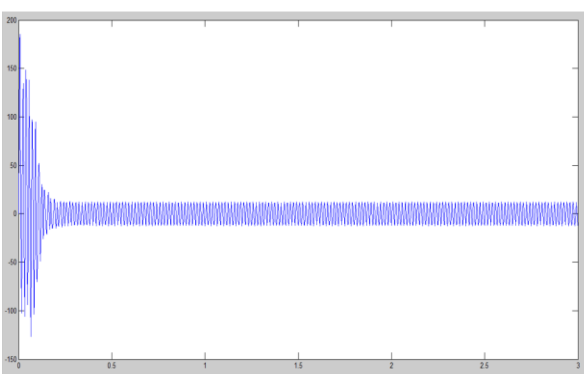

Figure 4

Amperage graph obtained in the simulator, where the motor starting amperage is observed with respect to time, and the stabilized amperage, in normal state.

Source: Own elaboration

Figure 5 shows the enlarged graph and the value of the current can be better observed when it stabilizes, as well as the time it takes to do so, with the motor in good condition.

Box 5

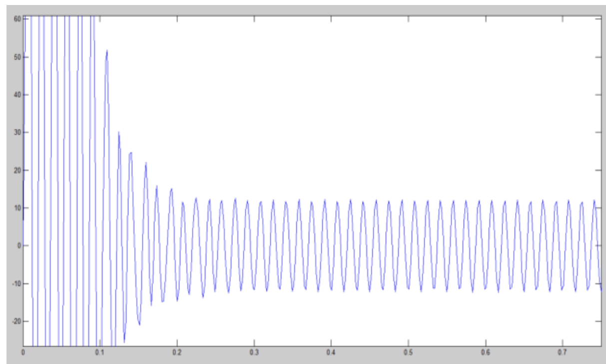

Figure 5

Graph of the simulator amperage with zoom, to be able to observe the current consumed by the motor.

Source: Own elaboration

Figure 6 shows the engine speed, and the variations it has with respect to time, up to the maximum revolution point.

Box 6

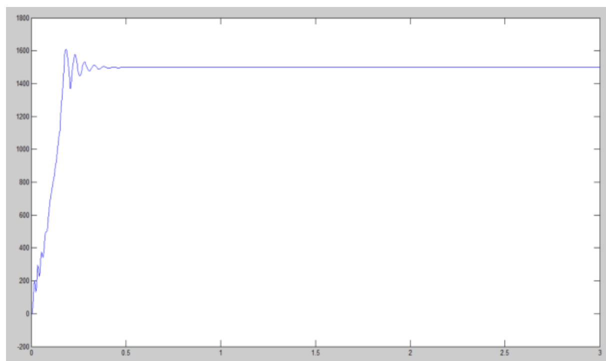

Figure 6

Graph of engine speed in RPM shown by the simulator, with the engine in good condition.

Source: Own elaboration

Figure 7 shows the maximum torque at which the motor breaks, starting in a state of rest until the motor reaches its state of stability, with the motor being in good condition.

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Box 7

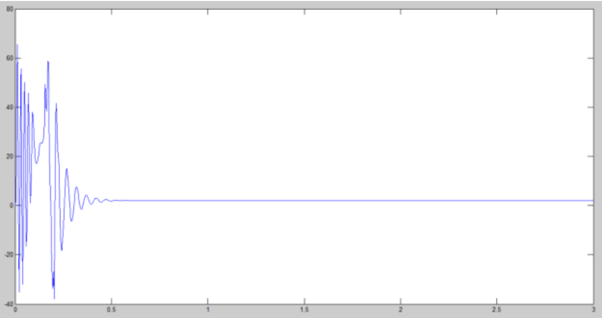

Figure 7
Mechanical torque graph showing engine simulator in good condition
Source: Own elaboration

Results

With the data obtained we can observe the behavior obtained from the motor, we observe the starting amperage which we can compare with the result we calculated, and we observe how the amperage stabilizes. Figure 6 and 7 show the speed and maximum torque of the motor which we can analyze and comparing with the data obtained, the result of the graph coincides with the calculated data.

Figure 8 shows the result of the motor, displaying the value of the current that the motor takes when reducing the resistance by 50%. The increase in current is observed, although it stabilizes but the current it consumes is more.

Box 8

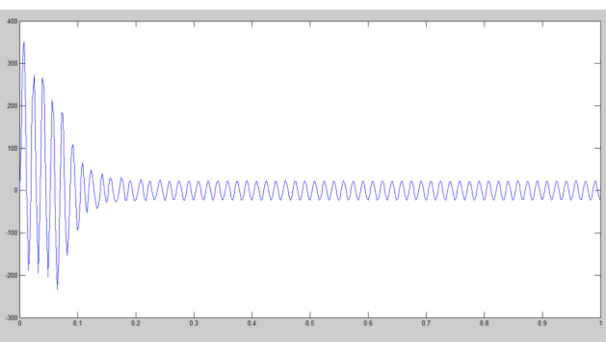

Figure 8
Motor result with 50% less resistance.
Source: Own elaboration

In Figure 9 you can better see the values obtained in the simulator, better visualizing the current value that the motor takes.

Box 9

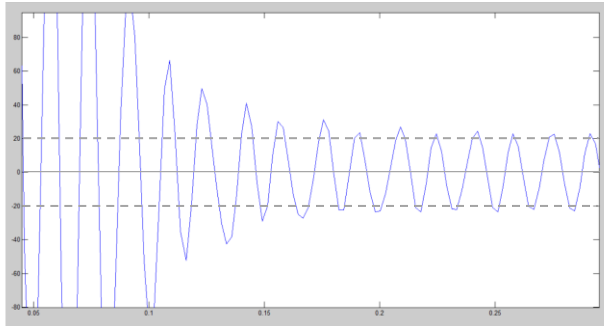

Figure 9
Amplified graph showing the amperage at 50% less resistance
Source: Own elaboration

Table 1 shows the values in the normal state of the motor and at 50% less, simulating a short circuit by reducing the parameters of the induction motor to 50%.

Box 10

Table 1
Engine values in normal state and values reduced to 50%.

	Engine values in normal state	Values reduced to 50%
R_1	0.243	0.1215
R_2	0.151	0.075
X_1	0.67	0.335
X_2	0.67	0.335
X_M	14.03	7.015

Source: Own elaboration

Conclusions

Having a tool that allows us to model failures in an electrical machine without affecting the equipment helps us to have good control of its operation. Simulation is that tool in which it is possible to carry out analysis with real parameters without that the engines are affected. In this research work, a methodology was presented to detect a short circuit in the windings of an induction motor through tests that are carried out on the motor to perform calculations of electrical parameters, and use them in an equivalent circuit in this way they will be analyzed and with the help of a simulator, interpret them graphically, observing how the engine behaves.

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According to the data obtained, we can make decisions to determine when it is necessary to apply preventive action to avoid generating a short circuit in the winding. Some of these failures in the windings are when the insulation stops doing its job and a short circuit occurs, then the current no longer circulates throughout the winding, generating a decrease in resistance, but at the same time an increase in current, which sometimes A certain time causes the engine to burn out or stop working and the process or activity it is carrying out stops.

Conflict of interest

The authors of this article declare that they have no conflict of interest. They have no known competing financial interests or personal relationships that could have influenced the work reported in this article.

Author contribution

The contribution to this work that each researcher made in developing this research was defined:

Terrazas-Flores, Luis Emilio: Contributed with the idea of the project, method and research technique. Support in writing the article and data analysis.

Melchor-Hernández, César Leonardo: Created the structure of the article, revised the writing, and analyzed the data.

Sánchez-Medel, Luis Humberto: Contributed to the study of documented research for publication, as well as data analysis.

González-Sobal, Martín: Carried out the research design, the type of research, and the writing of the article.

Availability of data and materials

The MATLAB-Simulink software was used, which is an element analysis tool that helps us understand the behavior of the electric motor through the analysis of parameters which can be graphed to better visualize its behavior.

Financing

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Article

Study of transformer network to comply with standards, electrical safety, and avoid failures due to Inrush current

Estudio de red de transformadores para cumplir normas, seguridad eléctrica, y evitar fallas por la corriente Inrush

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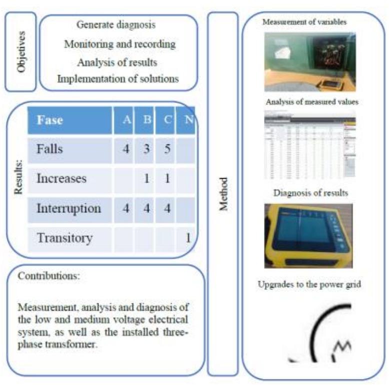
Abstract

The challenges of energizing a transformer, in an electrical power system, are critical aspects, due to the magnitudes of the currents and the importance of the transformers. These currents cause system instability; current peaks, and transient voltages. The instabilities affect the transformer and the connected equipment. It is crucial to manage power timing to avoid load imbalances and interruptions. Energization planning and execution are essential to ensure transformer integrity and system stability. The objective is to study the process of energizing the network of six transformers, responsible for the energy supply of the National Technological Institute of Mexico IT of Tuxtla Gutierrez, to identify opportunities that guarantee electrical safety, comply with applicable regulations and minimize the adverse effects of inrush currents. A load survey was carried out on the distribution transformers. A one-line diagram was constructed. The behavior of the Electrical Power System was studied. Transient monitoring was carried out in the secondary circuits of the transformers. With these actions, opportunities were identified to mitigate failures, which translate into safety and energy savings.



Inrush current, distribution transformer, SEP protections

Resumen

Los desafíos de energizar un transformador, en un sistema de energía eléctrica, son aspectos críticos, debido a las magnitudes de las corrientes y a la importancia de los transformadores. Estas corrientes causan inestabilidad en el sistema; picos de corriente y tensiones transitorias. Las inestabilidades afectan al transformador y a los equipos conectados. Es crucial gestionar la sincronización de la energía para evitar desequilibrios de carga e interrupciones. La planificación y ejecución de la energización son esenciales para garantizar la integridad del transformador y la estabilidad del sistema. El objetivo es estudiar el proceso de energización de la red de seis transformadores, responsables del suministro de energía del Instituto Tecnológico Nacional de México IT de Tuxtla Gutiérrez, para identificar oportunidades que garanticen la seguridad eléctrica, cumplan con la normatividad aplicable y minimicen los efectos adversos de las corrientes de entrada. Se realizó un estudio de cargas en los transformadores de distribución. Se construyó un diagrama unifilar. Se estudió el comportamiento del sistema eléctrico de potencia. Se realizó una monitorización de transitorios en los circuitos secundarios de los transformadores. Con estas acciones, se identificaron oportunidades para mitigar fallas, que se traducen en seguridad y ahorro de energía.

Corriente de irrupción, transformador de distribución, protecciones SEP

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Introduction

This study deals with the study of an electrical power system of an underground distribution network in a ring configuration consisting of six pad-mounted transformers, responsible for the supply of electrical energy to the Tecnológico Nacional de México IT in Tuxtla Gutiérrez. The objective is to guarantee electrical safety, minimising potential risks for users and goods in the medium and low voltage installations, and to comply with the applicable regulations.

The main result is expected to establish the basis for designing a system with protections for energising the circuit of six transformers in no-load conditions, avoiding faults caused by transient inrush current.

At the Tecnológico Nacional de México IT in Tuxtla Gutiérrez, the MV supply network consists of six transformers in ring configuration, with different power; two 500 , two 300 , one 225 , and one 150 . Voltage ratios; (13.8 - 220 /127. Total system power; 1975.)

When a transformer is energised, a transient current, magnetising current during start-up, flows several cycles, until normal flux conditions are established. In a number of cases, this current transient is of little importance, provided that in the ferro-magnetic core of the transformer, the magnitude of the remaining flux is small, which is related to the phase angle of the voltage during transformer disconnection.

However, when in the ferro-magnetic core of the transformer, the remanent flux is high, it causes this start-up to momentarily affect the proper operation of the system, causing a current similar to the short-circuit current, circulating through the transformer primary.

In [Beder, 2021] they mitigate the inrush current of the system, due to the magnetisation of the core and the voltage that when energised is out of synchrony. The inrush current is up to 30 times the rated current of the transformer, and its magnitude is affected by factors such as residual flux, saturation flux and the angle of the energising voltage. Inrush currents have the potential to activate trip signals in protective relays, such as differential and overcurrent (O/C) relays, resulting in malfunctions.

In [Yang, 2020] they define that at the moment of switching on the supply voltage, an inrush current (inrush current) equivalent to a value between 5 and 10 times the rated current is generated inside the transformer. This inrush current represents a danger to the safe and stable operation of the electrical network. Such an inrush current of this magnitude causes malfunctioning of the protections and prevents the transformer from connecting to the mains. Harmonic signals, in inrush current, cause damage and malfunctioning of power electronic equipment.

In [Moradi, 2017] they state that the switching on of a power transformer creates an energising inrush current (EIC), which leads to a sympathetic inrush current (SIC) in adjacent in-service transformers (IT). The sympathetic inrush current changes the waveform and prolongs the duration of its EIC origin. The EIC voltage causes conditions similar to an internal short circuit when energising the transformer. Identifying the short-circuit fault current during EIC is a challenge for transformer differential protection. The SIC current induces an error in the earth fault protection of the adjacent transformer in service.

In [Moradi, 2017] they propose an equivalent circuit based on the DC component of the inrush current, which is efficient for identifying concurrent EIC and SIC. They derive predictive formulas for EIC and SIC based on this equivalent circuit. They identify the internal transformer fault during the inrush current, based on the comparison between the predicted and measured waveforms, which prevents the differential protection from failing and tripping.

They compare the SIC waveform with the measured waveform to prevent the ground fault protection of the CT transformer from tripping during the SIC inrush current. They verify, the proposed equivalent circuit and formulas using the results of the ETAP-EMTP simulation of a network, under different system conditions.

The inrush current increases the reactive power loss of the transformer, and causes the transformer in the adjacent zone to respond to the induced current in the secondary of the first transformer, causing malfunction in the overcurrent protection (50/51 or 67) and extending the scope of the power outage.

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Consequently, the problem of the deterioration of the safety and stability of the electrical power system, due to the influence of the inrush current in the transformer, and the tripping of the differential protection, is the subject of worldwide research.

In [Lu, 2024] they explain that; differential protection is used as the main protection of transformers, because of its fast action and high sensitivity; the inrush current is identified by the differential protection as fault current and causes malfunction. They comment that in an increasingly complex electrical system, existing methods have shortcomings and the discrimination rate is low, in the case of current transformer (CT) saturation and remanent magnetisation.

They obtain the waveform characteristics using the mathematical morphology gradient (MMG) operator. They then use the morphological pattern spectrum (MPS) to extract the differences between the inrush current and the fault current. Finally, they use the normalised spectrum value and the gradient criterion as input to the least squares support vector machine (LSSVM) to identify the inrush current and differentiate it from the fault current.

Development of headings and subheadings of the article with subsequent numbers

1. Introduction.

2. Methods.
2.1. Measurements and analysis.
2.2. Applicable Standards.
2.3. Underground systems.
2.4. Underground and Overhead Power Cables.
2.5. Differential protection.

3. Results.
3.1. Underground network.
3.2. Earthing systems.
3.3. Transformer protection.
3.4. Power analyser.
3.5. Power quality faults.

4. Discussion.
4.1. Coordination of protections.
4.2. Protection 87T.
4.3. Economic and social cost.
4.4. Cost of negligence.
4.5. Second harmonic.
4.6. Star-Star connection.
5. Conclusions.
5.1. Summary.
5.2. Recommendations.

6. References.
7. Abbreviations.

2. Methods

2.1 Measurements and Analysis

The electrical parameters are measured and analysed for a safety diagnosis, compliance with the applicable regulations, and to establish strategies to identify and mitigate inrush currents, with the aim of safeguarding users and assets. A study of the physical survey of the electrical power system was carried out to determine the characteristics of the installations, the types of existing protections and their functionality, the transformers and the loads fed by them. The electrical variables were measured The electrical variables were measured with an energy analyser; Fluke brand, model 1775, class A.

2.2 Applicable Regulations

The [NOM-001-SEDE-2012] helps electrical installations to be efficient and durable, reducing the likelihood of electrical failures and potential risks.

2.3 Underground Systems

The [CFE DCCSSUBT] specifies the types of systems applicable in underground installations, provides the regulations applicable to Medium Voltage installations.

2.4 Power Cables

The [NRF-024-CFE] specifies the types of conductors used in medium voltage installations, provides information for verification and diagnosis (single pole, 5kV to 35kV).

2.5 Differential Protection

The 87T detects faults within the transformer, including short circuits between turns, earth faults or faults between phases. The operation is based on the calculation of the difference between the input current and the output current of the transformer.

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In the relays the currents are adapted in magnitude and phase angle and the difference (differential current) is determined. If the differential current exceeds a predetermined limit value, the differential protection of the relay operates. The differential protection acts to disconnect the affected transformer from the rest of the system, minimising damage and preventing the fault from propagating.

3. Results

The main connection circuit of the supply network. It has a connection point with a concrete pole, a medium voltage main protection system of; 3 fuse cutouts, 3 current transformers and a lightning arrester system.

An overhead-underground transition. Provides the possibility of continuing the medium voltage circuit supply underground, with 1/0 gauge XLP power cable, with an interconnected earthing system and RMTA4 register.

3.1 Underground network

It leads to the first transformer (T1), 500 pedestal type, with a protection system, with lightning arrester 15, 200. The transformer is connected internally, in the wall, see figure 1, to a MV shunt in order to continue with the power supply to the next transformer (T2).

At the rear of the wall (M1), power is supplied to the three-phase transformer (T2) of 225, with a lightning arrester protection system in each of the phases. The output of the transformer primary (T2) is transmitted and connected to the MV branch circuit busbar (M2), see figure 2, which provides the possibility to feed the nearby transformers (T3) of 150 and (T4) of 300.

3.2 Earthing System

Accidents caused to people in industrial activities, or in the electrical field, have been caused by discharges through contact with metal parts. These accidents have been caused by the lack of an adequate earthing system. Therefore, there remains the risk of electric shock by contact and deficient protection of equipment against short circuits or earth faults.

It is planned to measure each of the systems of each transformer to verify the efficiency of the grounding system, and to propose a more efficient one if necessary.

Box 1

Figure 1
Wall M1 three-phase MV shunt to (T2)

3.3 Transformer Protection

The importance of having protections in transformers lies in the need to prevent damage from short circuits, overloads or ground faults, which compromise the integrity of the operation and assets. Optimal protection. For the protection system, it is proposed to use overcurrent relays (50/51), medium voltage cubicles and fuses for each transformer and for each feeder wall. 50/51 overcurrent relay. It is equipped with algorithms to reduce inrush current tripping by means of adjustable timing and harmonic blocking. Relay 50/51 is suitable for detecting overloads and short-circuits in transformers.

Relay 50 operates on instantaneous overcurrents, while relay 51 has an inverse time curve, set to protect against prolonged overloads. Both are essential to prevent transformer damage by quickly disconnecting the equipment in the event of an overload or short-circuit. The implementation of this solution aims to increase the reliability of the network and reduce outage time in case of faults.

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Box 2

Figure 2
225 three-phase transformer (T2) (kVA)

The implementation of a protection system requires careful planning. The steps for installation are; A) Coordination of Protections. A coordination study is necessary to determine the appropriate setting values for 50/51 relays and fuses. This allows the protections to operate selectively, avoiding unnecessary interruptions and limiting the affected area in case of failure. B) Configuration and testing.

The overcurrent relays (50/51) must be configured and tested according to the specific characteristics of each transformer. Initial testing includes checking the response to overload and short-circuit simulations to ensure that the system performs within the expected times and values.

3.4 Energy Analyser

Measurements were made with a Fluke power analyser, model 1527. The measurements were made for 7 days, starting on 24 October and ending on 31 October 2024. The variables that are within the limits of the applicable standards are: frequency, total harmonic voltage content, flicker, and unbalance.

Box 3

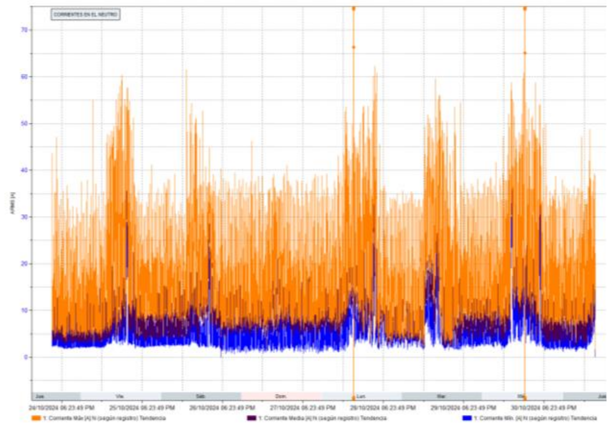

Figure 3
Maximum, average and minimum neutral current.

3.5 Power Quality Failures

There were 5 voltage drops, three of which were below 6 (V), with a duration of more than 5 (s). There was one overvoltage greater than 144 (V). There were four interruptions, with a duration of less than 180 (s). There were 141 power quality failure events, see table 1. Of the graphs provided by the energy analyser, the average current in phases is interesting, where a considerable current through the neutral is observed, see figure 3.

Box 4

Table 1
Summary of registered events

Event	Duration of voltage drop			
	Phase	Phase B	Phase C	Neutro
Fall	4	3	5	
Increase	0	1	1	
Interruption	4	4	4	
Shape deviation	27	26	18	
Changes	7	8	9	
Transient		0	0	1

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Box 5

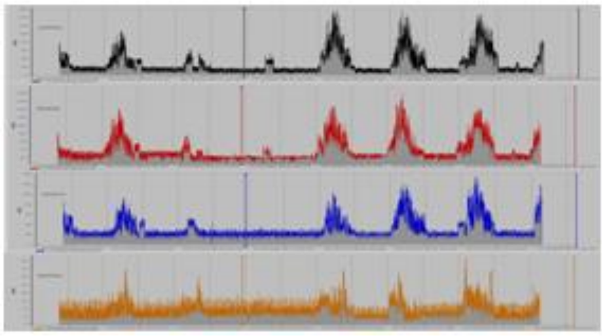

Figure 4
Average phase and neutral current

4. Discussion

4.1 Coordination of Protections

One of the aspects derived from the analysis of the physical infrastructure of the electrical installations (MV and LV) of the IT of Tuxtla Gutiérrez, is that it lacks a coordination of protections, which provides protection for the people who work there and the goods, in the face of the different possible faults.

4.2 Protection (87T)

There is no differential protection in the transformers. This protection detects and mitigates internal transformer faults due to short circuits between transformer phases, and acts immediately by disconnecting the affected equipment from the rest of the system. The disconnection minimises damage to other transformers and to the entire underground LV and MV electrical network that is connected.

4.3 Economic and Social Cost

If the system lacks the necessary protections and a medium voltage (MV) fault occurs, it causes interruptions to the electrical service within the institute's facilities (LV). If a transformer is damaged, it causes a power outage in a specific area, but it also causes an outage in some other area, due to the internal connection of the transformers in a ring, as they share the same power supply. A fault is a potential risk that damages people and equipment.

The proper use of transformer protection prevents electrical hazards and ensures a safe power supply. This impacts on the safety and well-being of the community and those who handle the power grid by avoiding risks associated with transformer failures.

4.4 Cost of Negligence

Damaged equipment results in power outages and economic repair costs (corrective maintenance).

4.5 Second Harmonic

For certain types of transformers the inrush current is made up of harmonics, the second harmonic being the one with the highest energy content, which is used to set the blocking of the differential protection at the moment of transformer energisation to avoid unwanted tripping.

4.6 Star-Star connection

In distribution systems star-star connection is used on the primary side of the transformer to minimise single-phase faults. In this connection the inrush current flows into the power system and causes significant voltage distortion in the secondary winding of the supply transformer.

5. Conclusions

5.1 Summary

A) A first analysis of the installations was made. It was checked that they have the characteristics and equipment indicated in the applicable regulations, for the correct operation of the electrical network. B) It was observed that there is a lack of a restorer (according to the installed load) to protect the overhead electrical system. C) A protection coordination system is being developed, through simulations, to mitigate the effects of the inrush current, without unduly activating the protections.

5.2 Recommendations

Following the analysis of the processes that take place in the equipment of the electrical installations of the Tuxtla IT, and the installed load of the different interconnected transformers, it is recommended to

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1) To have the necessary protections to mitigate faults, including inrush current, which is capable of triggering different protections. 2). It is recommended that through the differential protection, a block be programmed and at the moment of energising the transformers, the inrush current is identified and the protection is prevented from being activated. It is also recommended to design and implement a scheme for the coordination of protections. 3) Optimisation of efficiency and power quality is recommended.

Author contribution

Pérez-Lozano, Luis Alberto: Contribution in the idea of the project, as well as in the physical survey of the existing MV network, connection and disconnection of the metering equipment. Analysis of results.

Juan-Jímenez, Diana Alejandra: Analysis of equipment measurement results, knowledge of underground MV networks.

Herrera-Galicia, Rubén: Contribution to the project idea, as well as knowledge and mathematical analysis of the behaviour of the inrush current.

Sánchez-Alegría, Avisaí: His contribution is the simulation and analysis of the coordination of protections and the behaviour of medium voltage faults.

Availability of data and materials

The physical survey of the MV transformer installations and connections resulted in a single-line diagram that gives us a clear distribution of the equipment, which will also allow us to carry out the corresponding simulations to plan a protection system to protect the equipment, as well as to obtain a mathematical model to determine the scope of the transients in the system. The measurements obtained from the transformers have been very important due to the visualisation of possible faults, prevention of damage to the equipment and to propose improvements to the installations and operation of the equipment.

Funding

The project does not have any funding that would allow further scope and development.

Abbreviations

A	Amperaje.
BT	Low voltage
CT	Current Transformer.
CFE DCCSSUBT	Construction of Underground Systems
CFE	Federal Electricity Commission.
EIC	Energising Inrush Current
IT	Institute of Technology.
k VA	Kilo Volts Ampere.
kV	Kilo Volts.
M1	Wall one.
MMG	Mathematical Morphological Gradient.
MPS	Morphological pattern spectrum
MT	Medium Voltage.
NRF-024-CFE	Reference Standard 024
RMTA4	Medium Voltage Register in Arrollo type 4
S	Seconds.
SEP	1. Electrical Power Systems.
SIC	Sympathetic Inrush Current.
T1	Transformer one.
V	Volts.
XLP	Cross-linked Polyethylene Insulation.
87T	Protection System.

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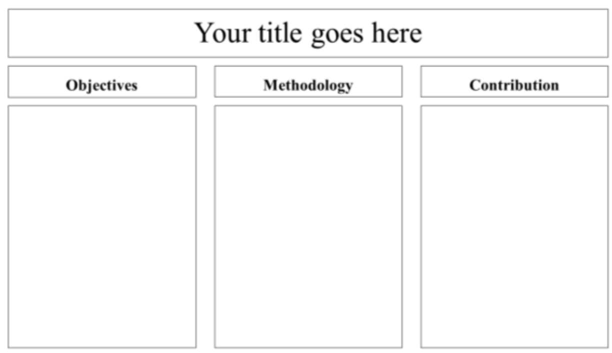

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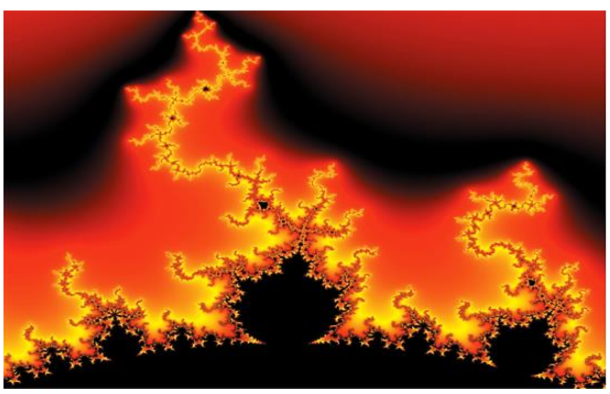

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Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

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Author contribution

Specify the contribution of each researcher in each of the points developed in this research.

Prot-
Benoit-Pauleter, Gerard: Contributed to the project idea, research method and technique.

Availability of data and materials

Indicate the availability of the data obtained in this research.

Funding

Indicate if the research received some financing.

Acknowledgements

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

Abbreviations

List abbreviations in alphabetical order.

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ANN	Artificial Neural Network

References

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