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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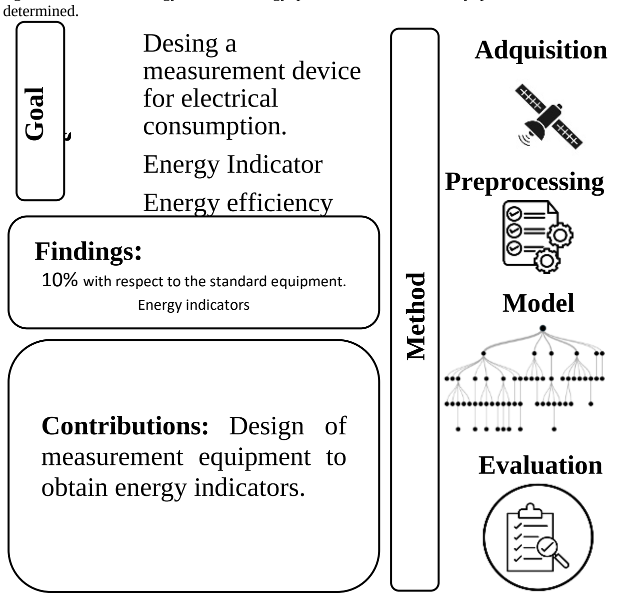
Abstract

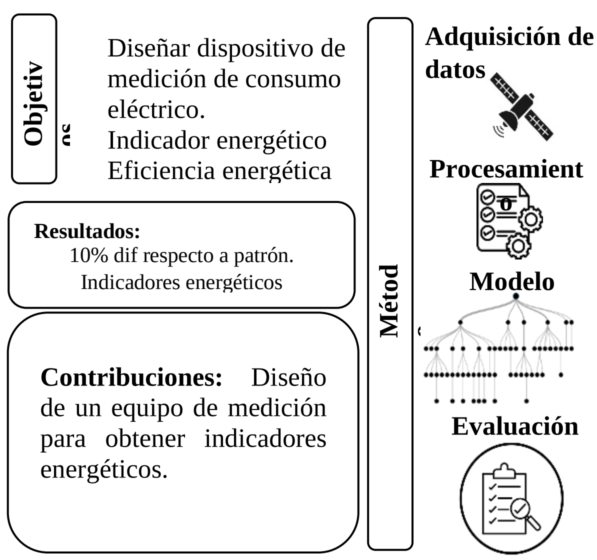
As the industry prioritizes energy efficiency, the implementation of Energy Management Systems has become a strategic necessity. One of the basic aspects for this type of system is the evaluation of energy performance that requires the collection of energy data as an essential input, so this project 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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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

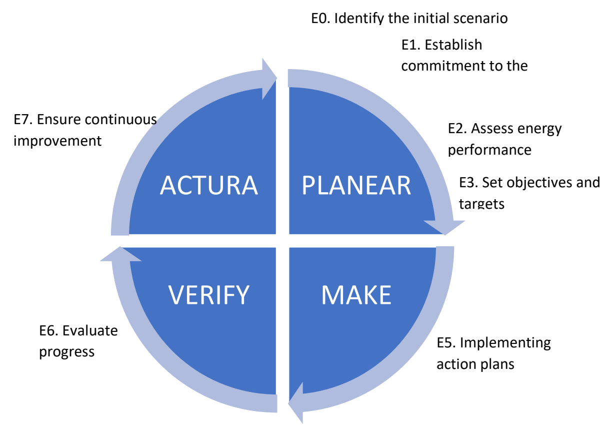

Figure 1
Stages of the SGEN

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

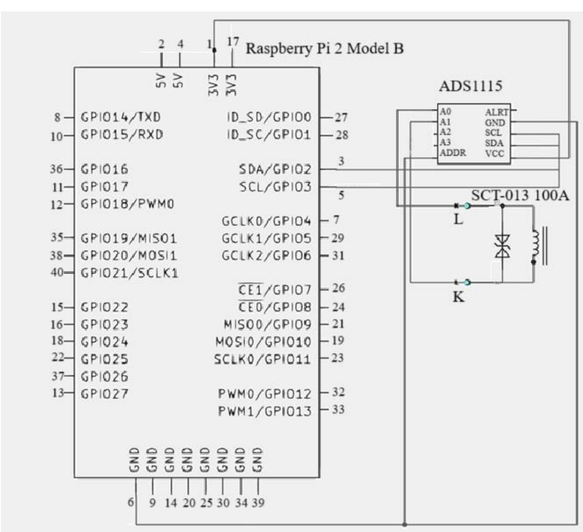

Figure 3
Basic connection diagram of the ADC ADS1115 and the SCT-013 100A sensor to the Rpi 2 B+.

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

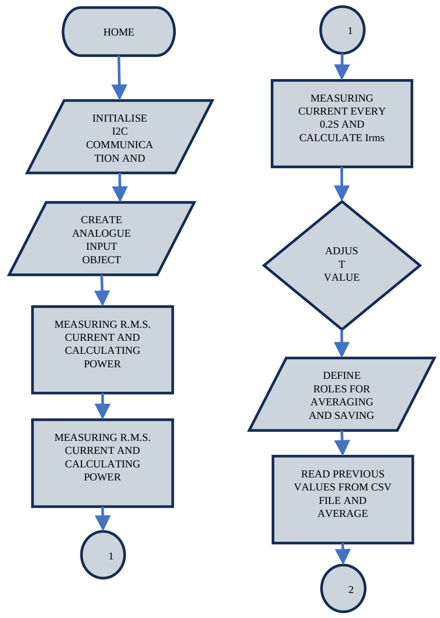

Figure 4
Algorithm of operation of the electricity consumption metering device

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

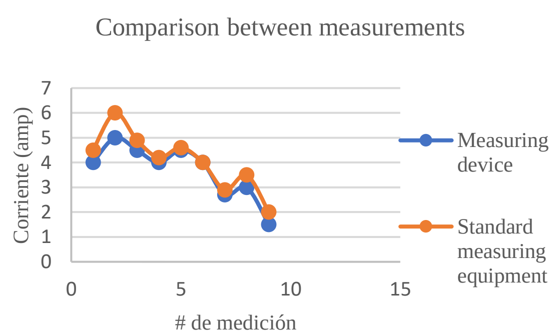

Figure 5
Performance of the measuring equipment against the standard equipment

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

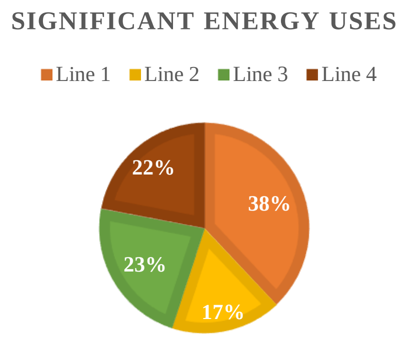

Figure 6
USEN bottling plant

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

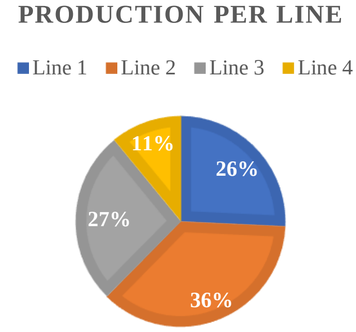

Figure 7
Percentage of production per production line

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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Background

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