Load study at ESUNI Transport Workshop Enterprise Unit in Moa municipality

Estudio de carga en la Unidad Empresarial de Transporte Taller ESUNI de Moa

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Abstract: This research presents a diagnosis conducted at ESUNI Transport Workshop Enterprise Unit in Moa municipality, with the purpose of characterizing the installed loads and analyzing the low power factor in its 440 V substation. Through electrical measurements and billing analysis, it was determined that the average power factor is 0.3, significantly below the minimum required value of 0.9. This deficiency generates penalties that account for approximately 57 % of the total electricity bill. The main cause lies in operating the asynchronous motors at low load, which are inherently inductive. The results reveal that the technically viable solution identified is the installation of an automatic capacitor bank to compensate for reactive energy, improving the power factor above 0.92, and eliminating penalties. Additionally, technical-organizational measures are recommended, such as updating the single-line diagram and improving infrastructure, to optimize the energy efficiency of the facility.

Keywords: electrical load networks, electrical properties, transformers

Resumen: Se presenta un diagnóstico energético de la Unidad Empresarial de Transporte Taller ESUNI de Moa, con el objetivo de caracterizar las cargas instaladas y analizar el bajo factor de potencia en su subestación de 440 V. Mediante mediciones eléctricas y el análisis de la facturación, se identificó que el factor de potencia promedio es de 0.3, por debajo del mínimo requerido de 0.9, lo que genera penalizaciones que representan en promedio el 57 % del importe total de la factura eléctrica. La causa principal radica en la operación a baja carga de motores asíncronos, inherentemente inductivos. Se concluye que la solución técnicamente viable es la instalación de un banco de capacitores automáticos para compensar la energía reactiva, mejorar el factor de potencia por encima de 0.92 y eliminar las penalizaciones. Adicionalmente, se recomiendan medidas técnico-organizativas como la actualización del diagrama unifilar y mejoras en la infraestructura para optimizar la eficiencia energética de la instalación.

Palabras clave: carga de redes eléctricas, propiedades eléctricas, transformadores

Introduction

A large number of problems related to the inefficient use of energy in industry and services are not caused by the existing productive or service technology capacity or updating, but by the inadequate management when handling these resources. Nowadays, to achieve sustainable energy systems, it is necessary to achieve efficiency (Fernández Gómez, 2021; Giler-Sarmiento & Sandoya-Sánchez, 2022).

Electric power is a relevant element at the organizational level, representing one of the main components for production, and therefore must be managed responsibly (Villamarín-Tapia *et al.,* 2023; Maldonado *et al*., 2025). According to Fazendeiro & Simões (2021), energy efficiency indicators have the capacity to guide organizations towards the adoption of more efficient technologies, contributing to the achievement of sustainable development goals within the society as socially responsible organizations.

There is a low-investment path that manages to reduce and control current energy costs in industry and services, mainly through technical-organizational measures. The most important factor to achieve energy efficiency in a company is not only having an energy saving plan, but also counting on an energy management system that guarantees constant improvement (García & Hernández, 2021; Ladeuth, López & Socarrás, 2021).

Masapanta, Pazuña & Corrales (2025) warn that institutional buildings demand a high amount of electric power due to their functions. As reducing energy consumption is a priority goal for any economy (Martínez, 2025; Alvarez & Concha, 2025), all work aimed at allocated energy rational use is important for the management and optimization of energy and energy resources (López, 2017). Therefore, it is important that business organizations have an energy management system because energy expenses represent a significant part of the operating costs; their reduction favors performance and competitiveness (Piñeres, Cabello & Hinojosa, 2022; Prado-Díaz *et al*., 2023).

The energy consumption diagnosis facilitates the understanding on how energy is used in a specific system and the establishment of institutions' consumption. Energy diagnosis, as an initial tool, allows for the development of energy efficiency plan proposals in public buildings while helping to generate awareness about electric power efficient consumption (Bermejo, Cabello & Correa, 2022; Calla & Maldonado, 2023).

ESUNI Workshop Transport Unit's building belongs to *Cubaniquel* business group. Its main purpose is providing transportation services to all entities of the nickel business group—by covering its different work shifts—, as well as to other dependencies of the Basic Industry Ministry. It has two substations, one for three-phase 440 V and another for three-phase 220 V and single-phase services; from which three types of loads are derived (three-phase 440 V, three-phase 220 V, and single-phase 220 V). These electrical voltages' diversity, along with the existence of two substations, difficult the analysis of load influence and energy effectiveness.

These substations are similar regarding the type of connection —incomplete three-phase with two distribution transformers—; which is appropriate for low-power three-phase loads where three-phase transformer is not justified due to economic reasons. Problems with the electrical system original configuration persist in the facility, which can generate difficulties for normal operation such as the lack of a plan identifying the loads.

In this paper, a diagnostic characterization of the installed loads is carried out, the power factor is analyzed, and technical-organizational measures are proposed aiming at eliminating problems associated with energy consumption and penalties due to low power factor in the 440 V substation of Moa's ESUNI Workshop Transport Business Unit.

Materials and Methods

To develop the research, the Measurement Method was used to verify different magnitudes, in numerical, quantitative, and graphical forms, from the distribution system's equipment such as engines and loads in general.

The energy diagnosis was developed using a preliminary energy audit methodology, based on the ISO 50001 standard, which combined on-site inspection, electrical measurements, and billing data analysis. The research was executed through the following stages:

1. Inspection and field survey: All electrical loads connected to the 440 V substation were identified and characterized. The nameplate information from the main equipment (lathes, drills, hacksaw, welding machine) was collected to record their rated powers and operating conditions. The power supply system configuration was verified, identifying the existence of two substations (440 V and 220 V) and the absence of an updated single-line diagram.

2. Electrical measurements, by assessing the following elements:

-Instrumentation: A portable Class A power grid analyzer (according to IEEE Std 1159-2019) was used, it can record voltage, current, active power (P), reactive power (Q), apparent power (S), and power factor (PF) averaged values.

-Procedure: Measurements were taken at the 440 V substation during an uninterrupted 2-hour period, capturing data at 1-minute intervals. This period was selected as being representative of the regular workshop operation, including the active lathe running and other loads sporadic connection.

-Measured parameters: The minimum, maximum, and average values of phase-phase voltages (Vab, Vbc, Vca), line currents (Ia, Ib, Ic), powers (P, Q, S), and power factor were recorded.

3. Billing Data Analysis: Electricity bills for one year were analyzed to determine the historical behavior of active (kWh) and reactive(kVArh) energy consumption, maximum demand, and the monthly power factor calculated by the electric company. The monthly penalty percentage on the total bill amount was also calculated using the formula established by national regulations.

4. Reactive Energy Compensation Calculation: Starting from the measured average active power (P) and the average power factor obtained from billing, the necessary reactive power (Qc) to raise the power factor to 0.92 and 0.96 was calculated by using the standard methodology.

The power factor calculation method (cos φ): results from applying the cosine φ to the arctangent of the division between the reactive energy (kVArh) and the active energy (kWh), measured over a period longer than 24 hours, up to the billing period. The Power Factor calculation uses the following equation:

$$Power\ Factor = \cos\left(arctan\left(\frac{kVArh}{kWh}\right)\right)$$

Reactive energy can be produced where it is consumed through capacitor banks, hence, it can be penalized or incentivized.

Power factor incentives: Customers who register a power factor greater than 0.92 are eligible for incentives. Normal billing excludes penalties and the power factor considered is the actual value for the period up to a maximum of 0.96 (González, 2018).

$$Incentives\ = Normal\ Billing\ \left[\frac{0{,}92 - Actual\ PF}{Actual\ PF}\right]$$

Penalties for power factor: If the power factor is below 0.90, the customer is penalized. The penalty is the amount resulting from the equation where normal billing excludes other penalties and the power factor considered is the actual value for the billing period.

$$Penality\ = Normal\ Billing\ \left[\frac{0{,}90 - Actual\ PF}{Actual\ PF}\right]$$

-With a power factor less than 0.90, a penalty is applied.
-Between 0.90 and 0.92, there will be no penalty or incentive.
-A power factor ranging from 0.92 up to 0.96 is incentivized.

When the power factor is greater than 0.96, the incentive is calculated using the power factor value up to 0.96.

440 V Load Survey

Loads are characterized by a discontinuous and non-coincident operating regime, except on occasions when equipment simultaneously operating from 440 V occur (Table 1).

Table 1. List of 440 V Equipment and Powers

No.	Description	Power
1	Lathe 1 (in maintenance)	3,6 kW
2	Lathe 2 (asset)	3,6 kW
3	Drill 1	3,5 kW
4	Drill 2	3,2 kW
5	Mechanical hacksaw	3,7 kW
6	Welding machine	10 kWZ

Each equipment's power is defined by electric engines and/or converters comprising it. The power factor is associated with each equipment; the less active power the work demands, the lower its value. Thus, an active lathe will have a lower value when only the lubrication pump is running and will be higher for drilling.

General Behavior of Active (P), Reactive (Q), and Apparent Power (S) for the 440 V Substation

In the 440 V substation, the presence of connections to provide three-phase service was verified. It was confirmed that measurements of the installed energy and demand recorder are correct and consistent with what happens in the internal circuit (the load) (IEEE Std 1159-2019).

Figure 1 shows the general behavior of the active power, reactive power, apparent power, and power factor measurements recorded over a two-hour period. During this time, the power factor did not exceed 0.70. The measurements were taken while the facility operated under normal load and under typical service conditions. During the measurement period, the lathe and other sporadic loads were in operation.

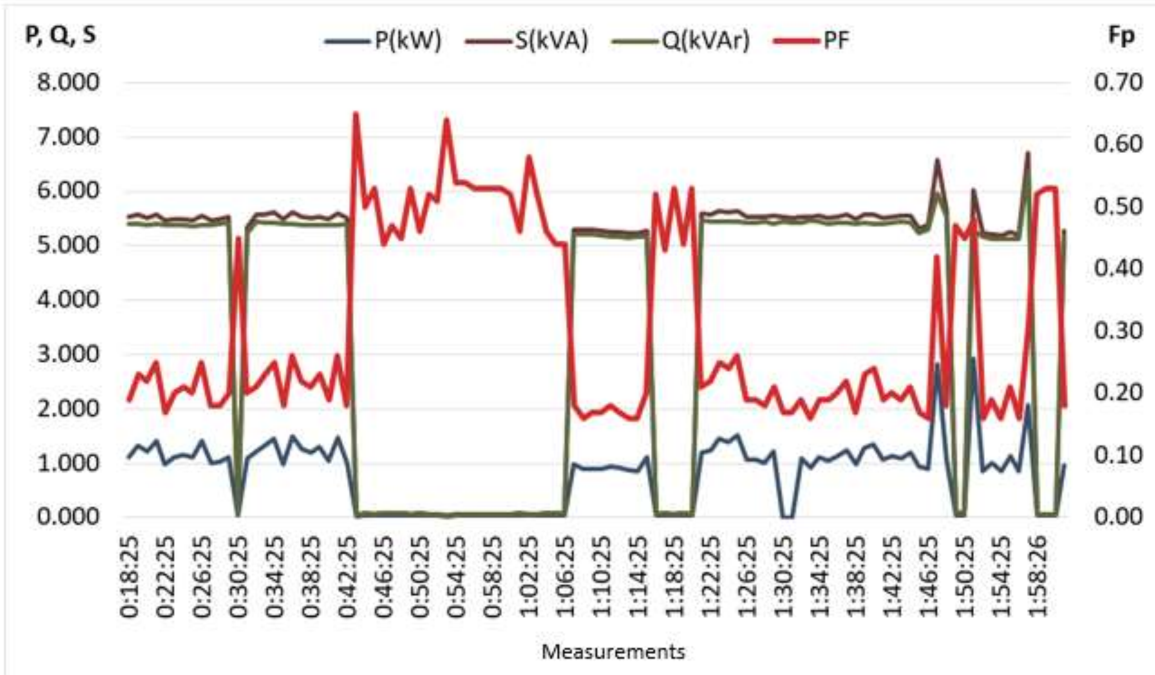

Figure 1. 440 V Substation Behavior.

440 V load discontinuous operation derives from the measurements and behavior described in Figure 1. Voltages are within established values and currents depend on the power demanded by each equipment, hence they sometimes display a zero value, as detailed in Table 2.

Table 2. General Measurement Statistics

	Vab (V)	Vbc	Vca	Ia (A)	Ib (A)	Ic (A)	P(kW)	S(kVA)	Q(kVAr)	PF
Minimum	460,7	450,8	457,5	0,0	0,1	0,0	0,0	0,0	0,0	0,2
Average	464,5	455,2	461,4	4,9	4,2	4,7	0,8	3,7	3,6	0,3
Maximum	468,5	459,5	463,8	10,3	8,5	8,0	2,9	6,7	6,4	0,7

The maximum active power recorded was 2.9 kW. However, the reactive power was 6.4 kVAr, which conditions the low power factor, being higher than the active power and almost equal to the apparent or total power (S).

Voltage unbalance (VU): relationship between the maximum voltage deviation and the average value, expressed as a percentage. Standards establish that, for three-phase asynchronous electric motors, this value must not exceed 5 % (González, 2018).

$$VU\% = \frac{max[abs(Vab - Vavg); abs(Vbc - Vavg); abs(Uca - Uavg)\ ]}{Vavg} 100\%$$

$$VU\% = \frac{max[abs(464{,}5 - 460{,}4); abs(455{,}2 - 460{,}4); abs(461{,}4 - 460{,}4)\ ]}{460{,}4} 100\% = 1{,}12\%$$

The voltage unbalance value of 1.12% complies with what is established in the standards (up to 5%).

Figure 2 shows the powers behavior. Absence of loads or zero values is observed; however, during "standard" work, the active power is always less than the reactive power because the motors driving the lathe (at the time of measurement) have a power lower than their design rating. Asynchronous motors have a low power factor by default, therefore, operating at low load exacerbates this aspect.

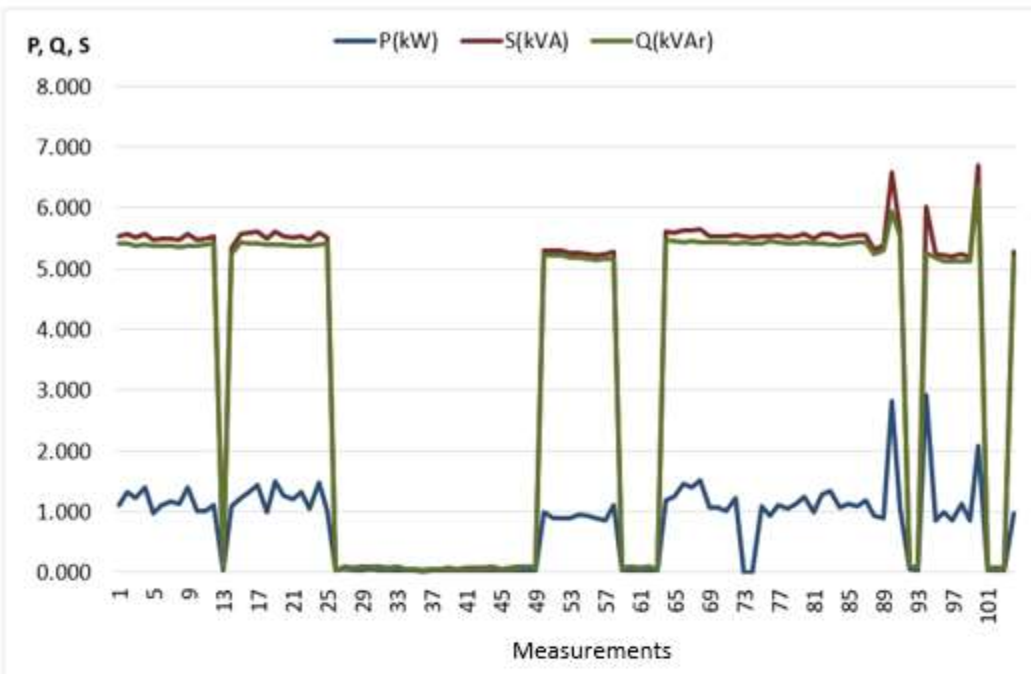

Figure 2. Active, Reactive, and Apparent Power for 440 V.

The power factor has a variation that characterizes the load. According to the electricity billing, it will be penalized for its low values. According to the measurements taken, the average power demanded by the system is 1 kW with a power factor of 0.3. From this, it can be presumed that the power factor varies with the transformers' load state and the way it occurs, which can yield high values at certain moments and low values at others. However, due to the calculation expression used by the National Electrical Union, its value can result below 0.9 for the billed month, thus the enterprise unit can be penalized (Figure 3).

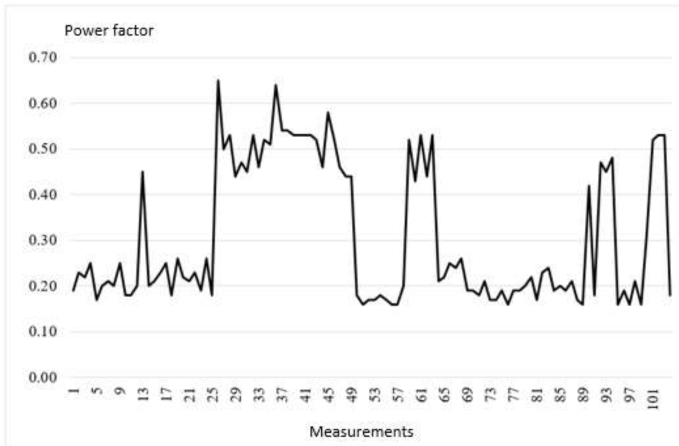

Figure 3. 440 V Substation Power Factor.

Analysis of the Electricity Bill

The electricity bills reveal irregular energy consumption patterns throughout the year, with monthly values ranging arbitrarily from 442 kWh up to 658 kWh, including transformer losses (208 ÷ 424 kWh excluding transformer losses). Actual demand consistently remains below the contracted level. As shown in Table 3, the low power factor and the average penalty ratio of 57 % relative to the total amount billed are particularly noteworthy.

Table 3. Billing Summary

	kWh	Amount	kVAh	Fp	Penalization	Total Amt.	Pen/Total Amt.	Actual kWh
Minimum	442,00	3475,40	527,00	0,30	3089,51	7723,77	0,40	208,00
Average	532,86	3830,44	779,29	0,39	5177,43	9007,88	0,57	298,86
Maximum	658,00	4634,26	1057,00	0,54	7206,90	10810,35	0,67	424,00

The power factor is determined from the actual kWh, excluding transformer losses, which explains its lower value (Figure 4).

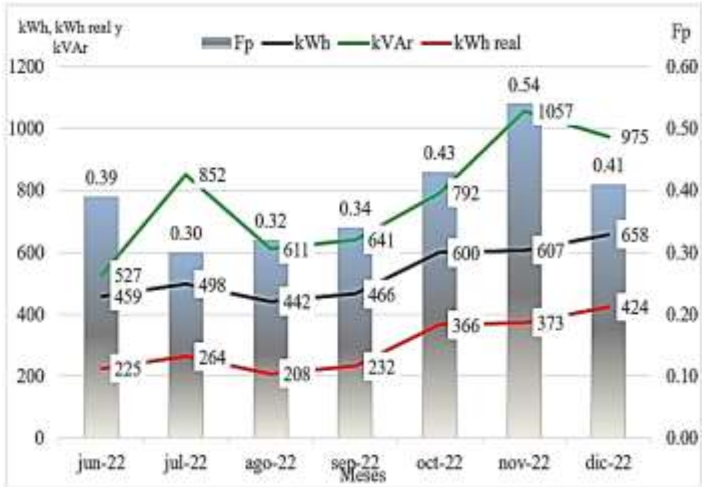

Figure 4. Electricity Bill Compilation (2022). Consumption and Power Factor.

Figure 5 illustrates the breakdown of the total amount paid per bill, including the penalty component. The low power factor stems from the installed power capacity.

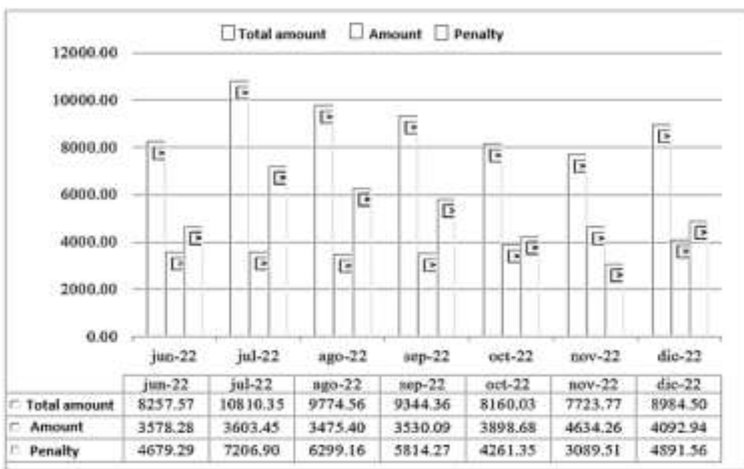

Figure 5. Electricity Bill Compilation (2022). Amount.

Table 4 reflects the analysis of power factor compensation with a capacitor bank.

Table 4. Calculation of the capacity to be Installed

	Value	Ang. Degree	Tangent	Q = P(tg1-tg2) kVArC
Power factor per bill	0,30	72,542	3,179	
Desired power factor	0,92	23,074	0,426	2,754 kVArC
Desired power factor	0,96	16,260	0,292	2,888 kVArC

Power of the capacitor bank to be installed by calculation for a power factor of 0.92

$$\varrho cap_{0,92} = Preal\,(tan\varphi_{actual} - \tan\varphi_{desired}) = 1(tan72{,}542 - tan23{,}074) = 2{,}754kVArc$$

Power of capacitor bank to be installed by calculation for a power factor of 0.96

$$\varrho cap_{0,96} = Preal\,(tan\varphi_{actual} - \tan\varphi_{desired}) = 1(tan72{,}542 - tan16{,}26) = 2{,}888kVArc$$

Technical-Organizational Measures to Improve Energy Efficiency

To achieve energy efficiency at Moa's ESUNI Workshop Transport Business Unit, it is proposed to enhance roof waterproofing in order to prevent accidents and preserve the company's electrical equipment.

Similarly, it is necessary to update the single-line diagram, specifying the loads connected to 440 V and 220 V, thereby facilitating the analysis of energy use within the area and enabling the accurate identification of the causes underlying anomalies in energy variable patterns, such as power factor and each equipment degree of loading.

Conclusions

The power factor of the electrical system is determined by the main equipment operation, which exhibits a low value; therefore, the possibility of penalties will always exist.

The transformers' installed capacity far exceeds the three-phase load.

The presence of two three-phase services (440 V and 220 V) and single-phase services (220 V and 110 V) complicates the internal power usage distribution system.

Consideration should be given to supplying these services through an alternative system or substation such as 440 V directly, and 440 V to 220 V three-phase dry-type transformers, thereby eliminating the need for two supply lines.

Compensation with automatic banks can be implemented at the main panel, with values ranging between 2.75 and 2.88 kVArC.

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