ENERGY QUALITY MANAGEMENT SYSTEMS: FRAMEWORK OF TECHNICAL REQUIREMENTS FOR MATURITY ANALYSIS

ABSTRACT

Sustainability is nowadays a watchword in large companies and is always part of their strategies. Understanding how electrical energy is used is increasingly necessary to seek ways to improve its applications in industrial operations and guarantee sustainability. To this end, energy quality information is an indispensable asset. Energy Quality Management Systems (EQMS) are essential tools in this strategy. Therefore, it is necessary to have a minimum set of requirements that meet the needs. Many EQMS providers are on the market, but their solutions are at different maturity levels. This study proposes a framework of technical criteria that can be used to analyze these tools. This framework was evaluated on the leading commercially available EQMS to assess its efficacy. The results showed that the current EQMS solutions still need more maturity to meet these requirements fully.

Keywords: Sustainability, Energy, Quality, Maturity, Requirements

Introduction

The operation of energy systems is currently considered a key factor for the planet's sustainability and for the survival of companies, which motivates maintenance and operation managers to pursue risk reduction, continuous improvement, and cost reduction methods [1]. Energy is a critical resource, and its integrated management can provide substantial economic and environmental benefits [2].

Integrated energy management can be done through Energy Management Systems (EMS) that, in addition to providing control of assets, provide important information that can help in planning and making daily decisions [1]. Energy Quality Management Systems (EQMS) are an essential component of EMS, focusing on power quality parameters.

EQMS is a collection of applications and software programs that provide energy quality information used by utility operations staff to solve supply and energy management issues associated with achieving their objectives [1].

As EQMS is an essential tool, it is necessary to establish criteria to determine its maturity and facilitate the choice of the tool that best meets the requirements so that the information flows according to expectations. This work aims to establish these criteria through a framework of requirements and, from it, to analyze the main EQMS tools on the market to analyze the current level of maturity.

Theoretical framework

In the context of EMS, there are important international standards. ISO 50001:2018 and ISO 50004:2020 are guidelines that empower organizations to follow requirements that enable continual improvement of energy performance and EMS. The first one brings general requirements related to EMS applicable to any organization in the context of activities that affect energy performance [4]. To complement ISO 50001, ISO 50004 brings the practical point of view with examples for establishing, implementing, maintaining, and improving an EMS [5].

Still, in the context of energy management systems, it is essential to consider the parameters defined for the electrical system of the location where the analysis will be carried out. In the location where the analysis of the EQMS was developed, there is a national regulatory agency for electrical systems, called the National Electric Energy Agency (ANEEL), and the technical agency responsible for the control and supervision of the national electrical system, called the National System Operator (ONS). Considering that there is no predictability of isolating the organization from the national interconnected system, it is necessary to consider the standards and requirements mapped by the regulatory and controlling entities of the National Interconnected System (SIN).

The ANEEL and ONS agencies clarify requirements of Electric Power Quality that set out the appropriate settings for energy systems and installation to be high-performance and maintain power

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quality. In the context of EQMS, that standard considers what should be measured and data to be collected and analyzed [6]. In the same way, there are also minimum requirements of the measurement systems used in the energy distribution. It interferes with the volume of data to be processed and, consequently, with the requirements proposed for the EQMS [7].

To reduce costs, which is one of the reasons for managing the energy in the organization, requirements related to energy billing were also considered in this work. ANEEL and ONS defined, under the functional aspect, the factors that must be measured in terms of energy quality to evaluate adequate billing indicators [8].

National and international standards are important for requirements elaboration, and they became the basis for quality parameters definition for the systems. However, another important aspect was analyzed in the industrial context: the knowledge of technical specialists dedicated to the Energy subject and the knowledge of specialists in operational technology, information technology, information security, and technology in general. The following chapter presents the methodology for building a requirements list and analysis.

Methodology

The methodology was structured in a series of sequential and rigorous steps. Initially, an in-depth analysis of the fundamental concepts and definitions of the Power Quality Management domain was carried out. This survey phase allowed a comprehensive and solid understanding of the terms and central elements involved in the context. Next, an extensive search of relevant national and international standards and regulations was conducted, which ensured that the study aligned with established standards, providing validity and compliance for subsequent analyses. The requirements for the technologies underlying the Power Quality Management domain were explored.

A crucial step consisted of forming a multidisciplinary group of more than 30 specialists in energy, operational technology, reliability, maintenance, operational technology architecture, application support, and inspection. This group actively collaborated in generating requirements, ensuring a broad approach. Sixty-one requirements were selected, carefully categorized into two main classes - functional and non-functional requirements - and subdivided into 13 subcategories. Additionally, the requirements were qualified by the group of specialists as mandatory and desirable according to their importance for the business. The categorization and qualification allowed for a clear and systematic organization of the identified needs. There is the Requirements Framework presented in Figure 1. It is essential to emphasize that functional interoperability is related to data ingestion and import data processes that depend on user action. Non-functional interoperability is for interoperability with other systems. Functional configuration and operation deal with the meter's programming by the user; non-functional configuration, operation, and support are if the software has automatic actions.

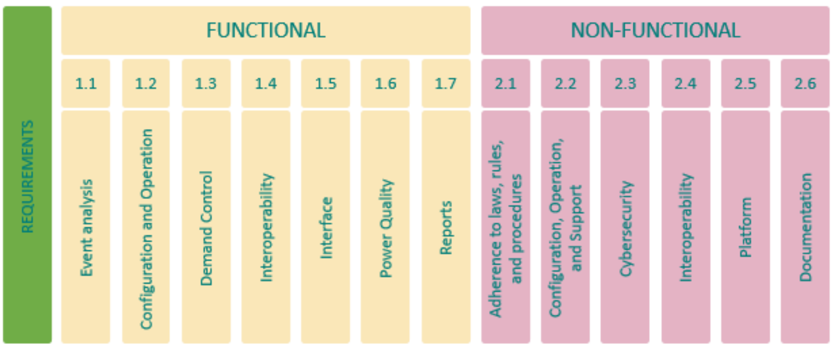

Figure 1 – Requirements Framework

Supplier responses to the RFI were meticulously evaluated. Each requirement was analyzed for compliance. For each requirement that the supplier indicated as fully satisfied, they received 5 points. The resulting score from these analyses was then consolidated to build a final ranking of suppliers. This ranking, based on a comprehensive and objective assessment, reflects the ability of the solutions to meet the requirements identified for EQMS. The score result is applied in a correspondence analysis, or perceptual mapping, to transform numerical information into a graphical display. The relationships among multiple variables are represented in two-dimensional space. The proximity between solutions and requirements can be compared to gain insight into how solutions are positioned against one another in the minds of the target requirements, how each requirement compares to other requirements, and where the solutions sit in perceptual space [3]. The methodology adopted in this study offers a systematic approach to defining and evaluating EQMS requirements.

Results and Discussions

The names of the solution providers, as well as the names of the compared systems, have been omitted and represented by the letters A through E. According to the framework, the results, as shown in Table 1, were divided into functional and non-functional.

A. Non-functional Requirements

Suppliers C and D stood out in the non-functional requirements, having the fulfillment of interoperability requirements as a significant differential. The explanation is that these vendors offer their solutions through software architectures as a service. Cloud computing-based architectures are built to be interoperable with various forms of integration.

Table 1 – Non-Functional Requirements

Requirements	**A**	**B**	**C**	**D**	**E**	**Maturity**
2.1 Adherence to laws, rules, and procedures	15	13	15	13	11	89.3%
2.2 Configuration, Operation, and Support	40	40	40	40	37	98.5%
2.3 Cybersecurity	30	26	30	30	24	93.3%
2.4 Interoperability	67	61	70	70	64	94.9%
2.5 Platform	36	40	40	40	36	96.0%
2.6 Documentation	25	25	25	25	25	100%
Total	213	205	220	218	197	95.7%

The maturity column shows the degree of compliance with the requirements when all market solutions are considered. Compliance with laws and regulations was the requirement in which the market showed low maturity, and the documentation requirement was the best met. It is noticed that there are still gaps in issues related to cybersecurity, platform, interoperability and configuration, operation, and support. Overall, 95.7% of the non-functional requirements were met. It can be considered a good number, which shows that the market solutions partially adhere to the requirements.

Figure 2 shows the perceptual map of non-functional requirements. The map shows that solutions A, C, and D are the most promising in meeting the requirements, leaving solutions B and E far behind.

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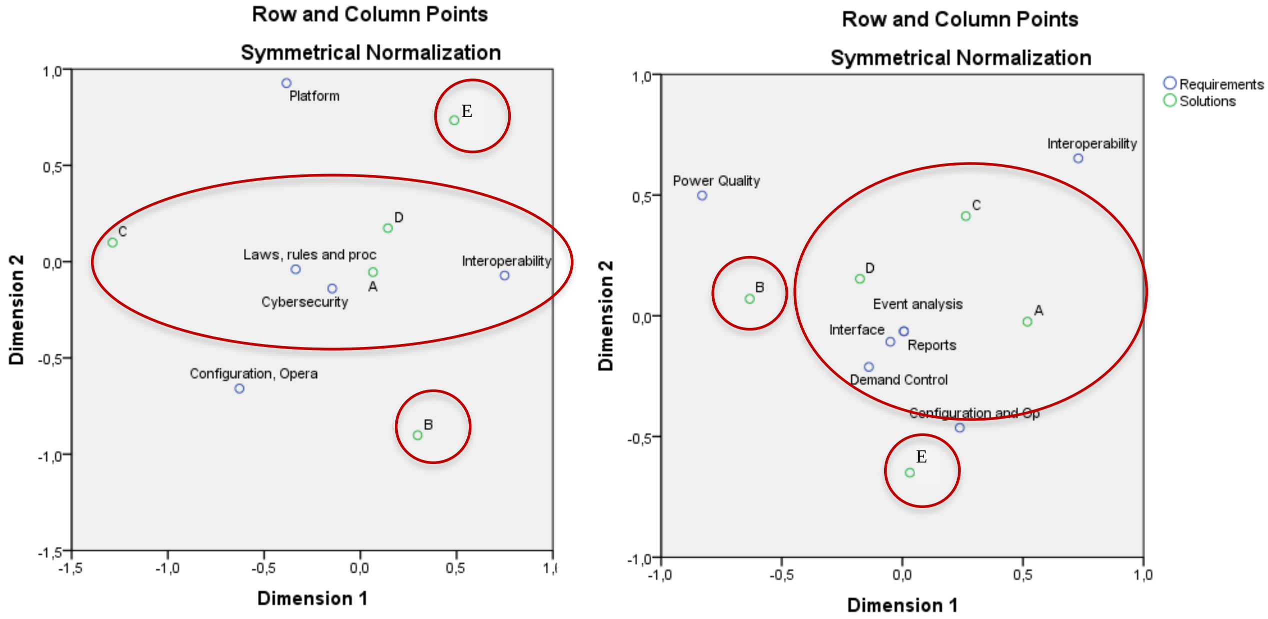

Figure 2 – Perceptual Map

B. *Functional Requirements*

Table 2 presents the results of the functional requirements. Functional requirements are linked to user-visible access features or functions that developers must implement to enable users to accomplish their tasks. Solution D stood out to the others but did not reach 100% of the requirements. Three solutions do not have power quality features, which is the least met requirement. Interoperability, power quality, and configuration and operation requirements have low maturity that still need to be developed by suppliers. In general, functional requirements were less adherent than non-functional requirements.

Table 2 – Functional Requirements

Requirements	**A**	**B**	**C**	**D**	**E**	**Maturity**
1.1 Event analysis	5	5	5	5	5	100%
1.2 Configuration and Operation	5	3	3	5	5	84%
1.3 Demand Control	9	10	8	10	10	94%
1.4 Interoperability	10	4	10	8	4	72%
1.5 Interface	32	34	33	35	35	96,7%
1.6 Power Quality	2	5	3	5	2	68%
1.7 Reports	15	15	15	15	15	100%
Total	78	76	77	83	76	91.8%

Figure 2 also shows the perceptual map of functional requirements. The map shows that solutions A, C, and D are the most promising in meeting the requirements, leaving solutions B and E far behind.

An important point raised while collecting information from suppliers is that those who provide the solution as SaaS can make data collection difficult when energy sensors are arranged in automation networks. As they are in the cloud, it is necessary to include specialized gateways for the data ingestion to be carried out, which can substantially increase the cost of the solution.

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On a consolidated basis, the result drew attention to three improvement points, in non-functional terms concerning cybersecurity and compliance with laws and regulations, and from a functional point of view in interoperability. These results can serve as insights for suppliers to evolve their products. All suppliers participating in this study committed to adding unmet requirements to their roadmaps to evolve EQMS solutions.

Conclusion

This study achieved its objective by proposing a requirements framework to analyze EQMS tools. In addition, a comparison was made with the current market-leading tools to analyze the framework's effectiveness and evaluate the maturity level of the currently available solutions. The results showed the effectiveness of the analysis and that, although we have good tools available on the market, it is still necessary to evolve so that they reach a high level of maturity.

This study fostered a movement towards evolving commercial solutions to meet the desirable requirements of an EQMS solution, contributing to advancing efficiency and reliability in the energy sector.

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