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RESEARCH ARTICLE

Industrial Energy Management System: Design of a Conceptual Framework Using IoT and Big Data

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ABSTRACT Industrial activities consume a large portion of the total energy demand worldwide and thus significantly contribute to greenhouse gas emissions. One of the most effective ways to reduce energy consumption in the industrial sector is to implement an energy management system. Current research into Industrial Energy Management System (IEnMS) remains insufficient, and to the best of our knowledge, a holistic framework for an IEnMS using the Internet of Things (IoT) and big data does not exist. This paper provides a comprehensive systematic literature review of the existing academic publications on IEnMS from where the main requirements and components of an IEnMS are identified. We further verify this study by conducting a detailed survey with specialized employees of ten (10) large companies to acquire expert opinion about using the modern technologies like IoT, big data, and data analytics in IEnMS. We have then proposed a theoretical framework for the IEnMS using IoT, big data and data analytics to construct an effective cyber-physical system architecture including steps from data acquisition to the end-user decision-making process. These findings demonstrate how the suggested framework provides an objective methodology for selecting the most appropriate IEnMS for various businesses based on their specific needs.

INDEX TERMS Energy management systems, big data, IoT.

I. INTRODUCTION

Climate change is a major global issue that poses a threat to humanity's health and safety. The energy sector needs a significant shift from a fossil-fuel-dominated system towards one dominated by more environment-friendly sources. Hence, it is critical to not only incorporate renewable energy sources but also the latest technologies to boost energy efficiency and contribute positively to combat this urgent issue, and thereby, help to protect current and future generations [1].

One approach is to modify use patterns and increase energy efficiencies in electrified sectors such as residential, commercial, and industrial sectors [2]. Industries consume a tremendous amount of energy, estimated as 42.3% of all the energy produced globally [3]. It then becomes critical to develop and implement energy efficiency and management policies tailored to the industrial sector's specific issues.

In practical terms, industries should be encouraged to prioritize the management and operation of their own energy systems to ensure their long-term sustainability. One approach is to explicitly deploy energy management and control policies as a viable strategy for reducing energy consumption, associated energy expenditures, and carbon emissions in the workplace. Because energy prices have not traditionally acted as a strong constraint to the production size in large-scale corporations, and decrease in greenhouse gas emissions was not an aim in the 20th century, industries have usually grown without any specific focus on energy-related aspects, including energy efficiency in general and environmental

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sustainability related to energy sources in particular. However in the 21st century, the situation has changed: energy prices show a strong tendency to increase together with unstable geopolitical situations in different energy producing countries. Further, nuclear sources have regulatory issues. There is also a strong push towards decreasing emissions from fossil fuel energy carriers, that lead to high carbon and environmental footprints. As a result, the industrial sector has begun to place greater emphasis on energy management by targeting the deployment of energy efficient solutions by decreasing consumption or by using intelligent production schedule. Energy efficient solutions may also result from the deployment of more efficient equipment, or from improvements in the process design. These aspects are also combined with the use of new distributed energy sources such as solar and wind, which can be combined with new industrial processes related to power-to-X and long-term storage units. In the context of economical and political uncertainties, many corporation are today developing long-term energy strategies to meet the specified energy usage targets and values.

With the fast-paced development of dedicated Information and Communication Technologies (ICTs), the widespread deployment of Internet of Things (IoT) is potentially beneficial in this domain because of the possibility to logically interconnect production elements through advanced sensors, mainly after the push towards digitalization that took place during the pandemics. IoT can play a major role in energy efficient utilization of physical production systems by serving as the key enabler for an Industrial Energy Management System (IEnMS) that includes improved situational awareness in monitoring, increased intelligence and automation in operation and control, and increased efficiency in energy dispatch and management to enable cheaper and cleaner energy usage.

In particular, the IEnMS can provide via specific sensors and/or actuators different ways of changing the energy demand of industries. For example, a given industrial process can be automatically scheduled to operate during the time when energy from solar PVs are available. The IEnMS can also monitor the power demanded by different industrial tools, and thus, it is capable of indentifying those that demand more energy; this might guide the responsible personnel to replace such tools with the most energy-efficient ones. A last example is related to the flexibility of industrial loads, which might be used by controllers and actuators, that may follow operational signals to turn on or turn off (or decrease or increase the power demanded if this is a feature of the device/process). It is also important to highlight that although home energy management systems (HEMS) may share some of the basic aspects of the IEnMS, they have a much more simplified network architecture based on already existing local area networks, or already deployed cloud solutions that also have less strict constraints if compared to industrial processes. Moreover, electricity markets are structured such that they usually leads to a differentiation of industrial and residential consumers with different impacts on the functioning of IEnMS and HEMS.

The complete process of regulating energy consumption, reducing greenhouse gas emissions, decreasing energy usage, and achieving considerable cost savings is implemented using an IEnMS. In this scenario, IEnMS can—and should—be implemented considering larger time horizons and different factors, which often contradicts the typical operational approaches that aim at short-term minimization of costs or maximization of profits, only.

This contribution proposes a high-level architecture for IEnMS that incorporates IoT, big data processing, and data analytics. Although this topic has been extensively studied [4], [5], [6] as the basis of HEMS, the focus on IEnMS implementations is still lacking. HEMS and IEnMS, in particular, have roughly similar goals, but they face quite different challenges because of their different concrete aims with clear diverse operational scales and needs. Our goal is to give a basic framework that different industrial players can use to choose the best appropriate IEnMS for their specific needs. To put it in another way, this article expects to assist industries in doing a complete analysis of their own energy requirements and comprehending the major components of their energy management schemes in order to identify the greatest fit for their IEnMS.

In this context, the aim of this paper is to establish an energy-centric approach to organize industrial environments employing the state-of-the-art in ICTs. As argued above, the existing literature gives far too much attention to HEMS, while neglecting IEnMS. Here, our aim is to fill part of this research gap by identifying general guidelines to construct and operate information systems for different industries with energy as the main focus. Specifically, this paper focuses on finding the answers to the following four questions:

1) What are the current energy management methods in the industrial sector?
2) What are the main requirements and components of Industrial Energy Management Systems?
3) What are the views of the energy employees in industries about the role of latest technologies such as IoT and big data in Industrial Energy Management Systems?
4) How can a high-level architecture, that incorporates latest advanced technologies such as IoT and big data, be designed for an Industrial Energy Management System?

To answer these questions, a detailed literature review is provided to identify the best practices in energy management in the industrial sector. We present the results of a survey with experts who gave their opinions on the importance of the most advanced ICTs to support the energy management activities of their corporations; these results reveal the willingness to use IEnMS as a tool to support decision-making in different aspects that concern energy consumption and efficiency, as well as environmental sustainability. Finally, from the literature review and the survey results, we have proposed a general framework to build an IEnMS considering

IoT connectivity and big data analysis. Note, however, that our paper focuses on a high-level design, and thus, the specific details of which type of IoT devices and their respective communication protocols and data frames are out of scope. We acknowledge that these aspects are essential in the deployment of any particular IEnMS, but our aim here is to provide general designing principles that should be in place so that the IEnMS would function properly.

The rest of the paper is organized as follows. Section II describes the background of the paper, related literature, and the identified research gap. Section III explains the Industrial Energy Management and how energy can be managed in industries. Section IV elucidates a more systematic approach toward industrial energy management: here, we define and explain an Industrial Energy Management System and explain in detail why a systematic approach is both necessary and beneficial for industrial energy management. Section V explains the working of IoT and big data and contains the benefits of the combination of IoT and big data. Section VI presents the survey questions, results, and discussion. In Section VII, we present our proposed theoretical framework for the Industrial Energy Management System using IoT and big data. Finally, in Section VIII, we discuss and conclude the paper.

II. BACKGROUND

Numerous researches on industrial decision-making processes on energy-related concerns exist, with universal agreement on answers and techniques but considerable disagreements on the long-term repercussions of extreme change. Some companies believe that investing in Energy Management (EnM) programs will have a significant financial benefit, and that the financial impact will be the key factor motivating EnM program implementation [7], [8]. Other authors [9], [10] consider that energy policy, pricing, expertise, and mindset are all energy-related choice factors that influence EnM programs. More recently, some authors [1], [11], [12], [13] have shown that energy-related decisions are based on the strategic links between the organization's main business and goal with respect to their investments. In today's industrial sector, the importance and necessity of implementing EnM for optimal energy use is a well-established reality, and most organizations acknowledge the need for a correctly employed energy management system [14]. As a result, many companies are enacting or have enacted some form of EnM policy. Nonetheless, there is still a misconception about the relationship between EnM and Energy Management System (EnMS), necessitating a thorough research program to further clarify the differences [15].

According to [16], the procedures and processes by which the organization strategically handles energy challenges and management are referred to as EnM. EnMS is the instrument that is utilized to put those practices and processes into action. Thus, for example, EnMS must be applied in order to successfully build and apply EnM methods and processes aimed at reducing energy consumption, cost, and greenhouse gas emissions. Another study found that participation of top management as well as almost all the employees of a company in all energy-related activities is essential not just for successful EnMS deployment, but also to ensure that the best EnM practices are implemented company-wide [17].

In the literature, EnM has a systematic approach that comprises of practices and activities that are considered supporting functions for an industrial EnM. Despite the fact that EnM is a critical goal at the moment, it has yet to be fully implemented in the industrial sector. This is due to the interdisciplinary character of EnM in industries, which includes numerous aspects other than economics and technology, such as social acceptance, political viewpoints, and managerial established procedures. To ensure the effective implementation of EnM, a type of EnMS applied to industries—Industrial EnMS (IEnMS)—is desirable, so that an objective means to monitor, plan, and regulate energy consumption and efficiency can be built, and the intended energy positive goals may be met. This is the phase that is frequently misunderstood, and as a result, the majority of the industrial sector fails to perform it effectively and correctly. Furthermore, while IoT and big data are essential enabling technologies that can be utilized to support complicated energy management processes, their precise roles in the literature have yet to be determined. These are the research gaps that have been identified in this study, and they are the focus of this paper. In the following sections, we'll first go through EnM in the context of industry, i.e., Industrial Energy Management (IEnM), and then show how an IEnMS can be utilized to accomplish efficient IEnM.

III. INDUSTRIAL ENERGY MANAGEMENT

Growth in the industrial sector, as well as its consequent increase in energy consumption, is one measure of economic progress [18]. It is then critical to establish IEnM approaches that support the efficient use of energy while reducing carbon emissions to counteract the negative effects of such expansion [3]. In order to enhance their operational efficiency in this domain and thereby reduce their respective consumption with their related carbon emissions, many companies have turned their attention to energy-related issues in recent years. Our studies have revealed that there are few identifiable key components that IEnM should have-planning/strategy, operation/implementation, controlling, organization, and culture, as depicted in Fig. 1 [18], [19], [20], [21], [22]. The details of each of these components are presented next.

A. PLANNING/STRATEGY

The Planning/Strategy component is the initial phase of IEnM, and it is divided into three sections: (1) Formulation of a company's long-term energy policy that is conducive to a successful IEnM [23]. (2) Energy planning and goal-setting, in which a company establishes plans and sets goals for future energy usage [24], [25]. (3) Strategic energy risk management, in which firms assess any sort of energy-related

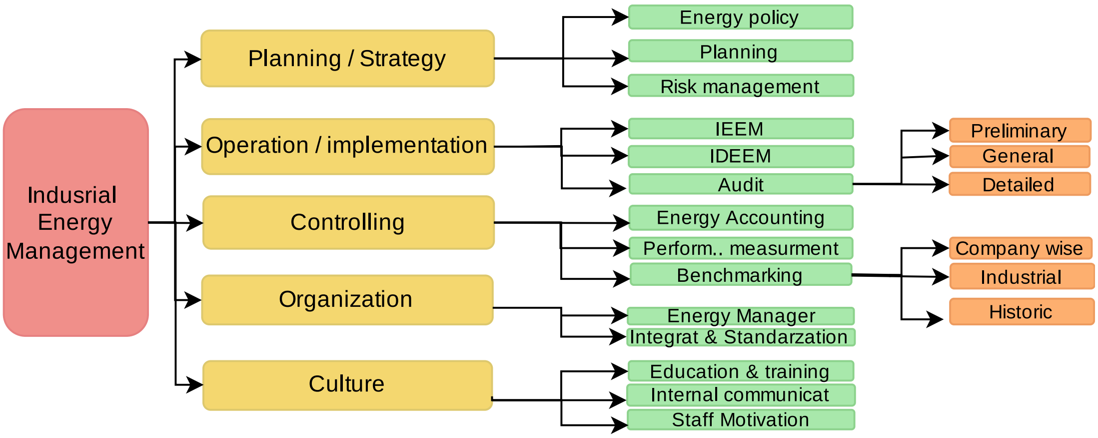

FIGURE 1. Components of industrial energy management.

risks and provide risk management strategies depending on the company's financial goals and risk tolerance [26].

B. OPERATION/IMPLEMENTATION

IEnM's second component is made up of three parts: (1) Energy efficiency measures are implemented, in which businesses implement specialized energy projects and energy efficiency technologies in order to reduce electricity consumption [27]. (2) Investment decisions based on energy efficiency, in which corporations perform systematic economic calculations to determine the return on investment [28]. (3) Energy audit, in which organizations involved in energy management activities assess the status quo on a regular basis and identify energy-saving opportunities.There are three types of audits—preliminary audits, general audits, and detailed audits [27].

C. CONTROLLING

The third component of IEnM, controlling, is divided into three parts: energy accounting, performance assessment, and benchmarking. Energy accounting is the practice of continuously analyzing and reporting energy consumption as well as monitoring energy efficiency [29]. IEnM includes performance measurements that define the key performance indicators (KPIs) for energy efficiency, which characterize the relationship between an activity and the amount of energy consumed [20]. Energy benchmarking is a performance-oriented activity that can be defined as the process for comparing energy efficiency between or within entities. Benchmarking is a useful tool for lowering energy consumption, prices, and emissions. There are three forms of benchmarking: company-level benchmarking, industrial benchmarking, and historical benchmarking [30].

D. ORGANIZATION

There are two parts to the organization: (1) Appointment of an experienced energy manager to keep top management informed about the energy management's actions and progress; the energy manager and top management should have a good working relationship [31], [32]. (2) Integration and standardization, in which industrial organizations' energy management should be connected with their production management processes through the use of Information and Communication Technology (ICT) tools and standardization [29].

E. CULTURE

Culture is the fifth and final component of IEnM, and it is divided into two parts: (1) Training and education: personnel with adequate basic education to meet the energy-usage standards are required by the energy manager, or training may be required [33]. (2) Employee motivation: Businesses must encourage employees to take an active role in improving energy efficiency, and they should frequently award technical and operational personnel [29], [34].

To achieve effective and efficient IEnM that incorporates the abovementioned components, industries have to implement a comprehensive, company-wide, energy management system. We argue here that this can be successfully performed by an Industrial Energy Management System (IEnMS). The key features that the IEnMS should have is presented in the next section below.

IV. INDUSTRIAL ENERGY MANAGEMENT SYSTEM

An ICT solution developed to facilitate the deployment of an effective IEnM is known as an Industrial Energy Management System (IEnMS). An IEnMS monitors, analyzes, and manages the energy demand (and potentially its generation and storage) in a manufacturing plant following the schematic presented in Fig. 2. It is also utilized to diagnose issues like overuse and leaks throughout the entire facility. IEnMS helps to dynamically modulate the (supply-demand) energy profiles based on the current state of the energy system and to improve the efficiency of the energy consumption as a whole by indicating potential sources of faults and unexpected performance in terms of energy.

An IEnMS is designed for large-scale industrial energy consumers to manage their energy usage considering that their specific type of loads are different than residential ones;

in industrial environments, the load flexibility and consumption levels are quite specific, considering that some industrial processes cannot be turned on and off like a household heating system. To develop an efficient IEnMS based on their own special needs, industries must follow a set of basic processes, which can be divided in the following phases: (i) defining an energy policy and assigning duties, (ii) emphasizing major energy consumers, (iii) setting measurable goals and targets, (iv) putting in place actions to accomplish the goals, (v) determining whether the actions are successful, and (vi) conducting continuous system evaluations.

The IEnMS operation can be conceptualized as a cyber-physical system that requires four basic steps, from data collection to semantic interpretation. In the following discussion, these steps are systematically presented.

A. BUILD DATA COLLECTION STRATEGY

Real-time, precise, and granular data, as well as information on where and when the energy was utilized, and by which device, is collected (machine). Sensors/smart meters, sub-meters, and major energy consumer devices such as HVAC (heating, ventilation, and air conditioning) equipment, production lines, boilers, and other large energy consumer devices are used to collect data. The goal of this section is to keep track of the real-time data collection and determine where the majority of the energy is being consumed.

B. TRANSFORM RAW ENERGY DATA INTO USEFUL INFORMATION

The collected data is processed, evaluated, and turned into meaningful information during this step. Big data software is used to easily extract raw data from IoT devices and convert it into usable information in the form of user-friendly graphics. The raw data obtained might be linked to production levels, weather data, and other variables that influence the amount of energy consumed to generate the company's KPIs.

C. ASSIGN RESPONSIBILITY, ANALYZE DATA

The information provided must be transformed into useful and meaningful reports during this phase; this can only be done by adding the information to the knowledge of facility, which can be done by an energy manager. The energy manager's job is to understand the information provided by the Energy Management System, combine it with the company's processes, and create appropriate targets.

D. INTERPRET THE RESULTS, AND AGREE TO AN ACTION PLAN

The energy manager gets access to the energy usage reports throughout this phase. The energy manager and staff begin to speak with the departments in order to establish an energy strategy and a plan of action.

From the points just mentioned, the IEnMS may enable different benefits to industries; the main ones are listed next.

- **Reducing cost and saving energy:** IEnMS enables a continuous process that can lead to increased energy efficiency and productivity to lower energy expenses over time.
- **Planning future targets:** IEnMS supports the visualization of trends of energy demand, and guide the definition of new strategic and operational goals.
- **Reducing greenhouse emissions:** IEnMS can be used to monitor greenhouse emissions from the plant operation (considering also the energy sources and emissions produced as byproduct of the industrial process itself). This is necessary for defining concrete targets related to emissions.
- **Increasing machine lifespan:** Data collected from IEnMS can also be used for predictive maintenance, which can result in a longer life cycle for the monitored machines, also saving natural resources and decreasing investment costs.
- **Mitigation of risks related to fossil fuel:** IEnMS may help to integrate local energy sources by having local generation from solar and power-to-X solutions developed for long-term storage like power-to-gas (PtG).
- **Improvements in company projects:** Data from IEnMS can also be used to improve post-investment project performance, also indicating how energy use and carbon emissions can to be minimized in a systematic way.

V. WORKING OF IoT AND BIG DATA

IoT and big data refer to two different ICTs that have emerged in recent years; they have been developed in relative autonomy, but they are clearly interconnected [35]. IoT is playing a promising role in connecting the devices/machine together using data communication network so that they can share information with each other. These IoT-enabled devices have generated huge volume of data [36]. The handling of massive amounts of structured, unstructured, and semi-structured data results requires special processing for such big data [37]. The current intensive data processing needs from IoT devices indicate a promising path of combining big data technologies specially aiming at IoT applications [38]. The massive amount of data needs high storage and high computing power and strong data analytics, as the traditional database systems are not able to store, process, and analyze such a huge amount of data [39]. The data generated from these devices are analyzed and used for the current and future decision-making processes.

The three primary determinants of big data, known as the "3Vs of big data," are volume, velocity, and variety. The term "volume" refers to the massive amount of data collected, which causes datasets to be too vast for traditional database technologies to handle. Larger data units, such as terabytes, petabytes, and exabytes, are used to describe this type of data. Velocity is the speed with which the data is generated, processed, and moved around in real time. The nature of data, whether it is structured or unstructured, is a source of variety. Big data analytics can handle massive amounts of structured,

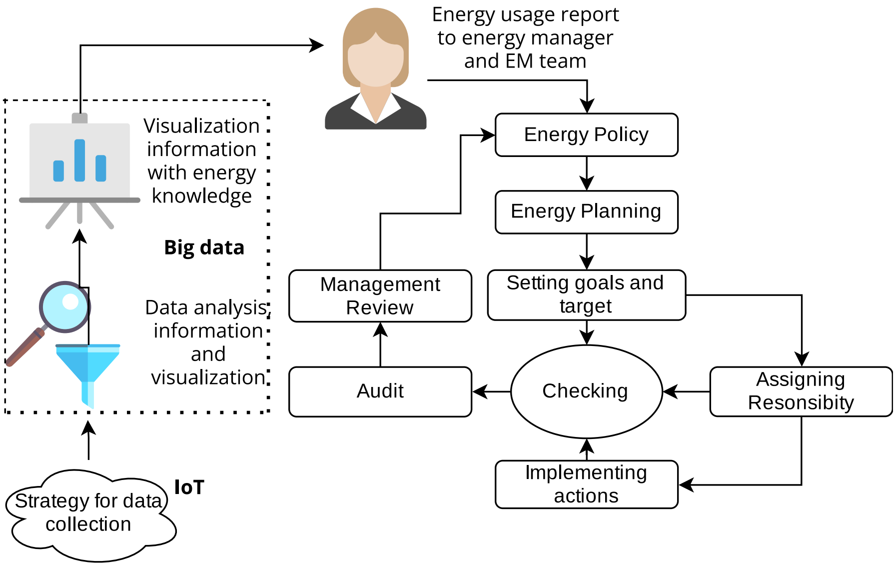

FIGURE 2. Parts of an industrial energy management system.

unstructured, and semi-structured data created by IoT devices in industrial equipment etc. Big data analytics can help companies produce and store and generate information from the data.

There are a few requirements that the data network related to the IoT needs to fulfill in order to support big data analytics. In the following, we present such necessary features.

Connectivity: Machine-to-machine (M2M) communication protocols that manage a large number of streams are the most common foundation for IoT services, and they benefit directly from cloud distributed storage and computation infrastructure [40]. Secure connectivity for enormous data and analytics is the first and most basic requirement of the Internet of Things (IoT). Because of reliable connectivity, big data and analytics will be able to efficiently aggregate and integrate massive amounts of machine-generated sensor data [41].

Storage: In IoT, big data storage must be able to manage large amounts of unstructured data while also providing low latency for analytics. One problem is that there are numerous sources of IoT data, such as sensor data and social media, and they are all modeled differently utilizing different communication protocols and interfaces. Big data technology can help with data storage for IoT devices, but better solutions are needed.

Quality of services: Quality of service (QoS) refers to the capacity to ensure a specified level of performance for a data flow. The IoT network is responsible for providing the assurance of an effective transmission of data from the sources that generate large data. The quality of service (QoS) in an IoT network is critical for big data analytics [42].

Real time analytics: Information regarding IoT-connected objects is exchanged in real time, and it must be processed in real time. For most streaming data from web-enabled devices, big data analytics uses real-time queries to extract information fast, make choices, and interact with devices and people in real time [43].

Benchmark: Many corporations have begun to migrate their operations online utilizing IoT as a result of the rapid digitization of operations. Benchmarking is critical in this situation because it allows businesses to compare the quality of big data and analytics solutions [44].

BENEFITS OF USING IoT AND BIG-DATA IN INDUSTRIES

For the industrial sector, there are numerous benefits of IoT and big data analytics. They provide information in a better way for the current and future decisions of the companies, using which the companies can build future business strategies and plans. Some of the benefits are listed below.

Improve energy efficiency: Energy is one of the biggest expenses in the industries, and industries are trying to reduce and save energy consumption. IoT with the help of big data is providing help to the industries in achieving that goal by providing the energy data at the devices level in real time. This can identify the under-performing devices in the network, and the energy management team can take the necessary actions to improve the energy wastage.

Improved forecasting and predictive maintenance: Using IoT and big data, automated alerts from the device provide useful information of the machine's maintenance, instead of waiting for the historic data. The staff concerned can know the machine's health in real time and plan the repair and replacement more efficiently, saving a lot of time.

Improved product quality: Product quality is the most important part of the industry. High-quality products improve customer satisfaction, sales, profit, and ultimately reduce waste. Using IoT, sensors can detect slight changes in the configuration, and big data analytics can make quick calculations and send alerts to the concerned staff. Thus, any defects can be fixed easily, thereby improving the product quality.

TABLE 1. Survey questions and the opinions percentages.

S.No	Topic	Total Disagree	Disagree	Neutral	Agree	Totally Agree	Mean	Median
Q1	An Industrial Energy Management System is good for energy saving energy saving	0%	0%	0%	30%	70%	4.7	5
Q2	An Industrial Energy Management System can reduce greenhouse gas emissions reduce greenhouse gas emissions	0%	0%	0%	50%	50%	4.5	4.5
Q3	There is lack of management awareness in industries for energy management for energy management	0%	20%	30%	30%	20%	3.5	3.5
Q4	An Energy Management System will provide energy saving opportunities saving opportunities	0%	0%	%	50%	50%	4.5	4.5
Q5	The company's energy policy plays an important role in designing energy management system in designing energy management system	0%	10%	10%	20%	60%	4.3	5
Q6	Long term energy planning is important for industries	0%	0%	0%	30%	70%	4.7	5
Q7	An energy manager should create an energy management team management team	0%	0%	30%	40%	30%	4	4
Q8	It is important for the energy manager to be environment friendly environment friendly	11%	0%	11%	11%	67%	4.2	5
Q9	It is important that companies should display department-wise energy usage status using screens to motivate staff members wiseenergy usage status using screens to motivate staff members to save energy	0%	0%	20%	40%	40%	4.2	4
Q10	It is important for companies to give incentives and rewards to staff to encourage them to achieve energy targets tostaff to encourage them to achieve energy targets	0%	10%	20%	20%	50%	4.1	4.5
Q11	Companies need some renovation in the existing infrastructure to improve energy management infrastructure to improve energy management	0%	0%	22%	22%	56%	4.3	5
Q12	It is important for companies to add green energy like solar and wind energy to their existing energy usage solar and wind energy to their existing energy usage	0%	0%	10%	20%	70%	4.6	5
Q13	Companies should have a strong policy to reduce greenhouse gas emissions greenhouse gas emissions	0%	0%	10%	0%	90%	4.8	5
Q14	Installing sensors on machines, so that these machines can use IoT-based techniques to share real data with each other, will lead to improved energy efficiency and performance	0%	0%	0%	50%	50%	4.5	4.5
Q15	Using IoT and Big data in Industrial Energy Management Systems will facilitate timely identification and prevention of faults	0%	0%	0%	50%	50%	4.5	4.5
Q16	Companies should invest more in Industrial Energy Management Systems (IEnMS)	0%	0%	10%	60%	30%	4.2	4
Q17	IoT is helping to improve HVAC (heating, ventilation, and air conditioning) systems in manufacturing plants.	0%	0%	20%	50%	30%	4.1	4
Q18	IoT devices are capable of collecting a huge amount of real time data about different machines. Therefore, collecting and using Big Data is a good option for companies to perform real time data about different machines.	0%	0%	11%	33%	56%	4.4	5
Q19	IoT and Big Data will make data analysis and processing easier and will give energy information very quickly and this can be useful for business decisions in the future.	0%	0%	11%	22%	67%	4.6	5
Q20	Industries should use the latest IoT-enabled technologies in their Energy Management System to improve energy activities in their Energy Management System to improve energy activities like efficiency, performance, usage, cost etc.	0%	0%	10%	20%	70%	4.6	5

Decrease downtime: Using IoT, the performance of industrial machines is improved; this not only enhances the quality of the products but also improves the speed and performance of production, thus helping to complete the production on time without any issues.

Quick accurate decisions: The decision process in industries has improved using IoT. Using a machine's performance data, which, after collection by the sensor, is calculated by the big data, the managers take necessary steps to improve the organizational processes and overall productivity.

Customer satisfaction: The success of a company depends on the customer's satisfaction. If a company provides good products of high standards, the customers will recommend the same products to others as well, and the company business will be high. IoT and big data analytics together thus facilitate the company to develop high-quality products.

VI. SURVEY RESULTS AND DISCUSSION

The survey conducted in this study contains reply from ten (10) big companies. The survey questionnaire contains twenty (20) questions. Table 1 and Figure 3 show the survey questions and answers. The percentage of respondents with responses of ''totally disagree'' and ''disagree'' is almost negligible. A few of the company's experts were neutral to some of the questions, such as those on the lack of management awareness towards IEnMS and the creation of an energy

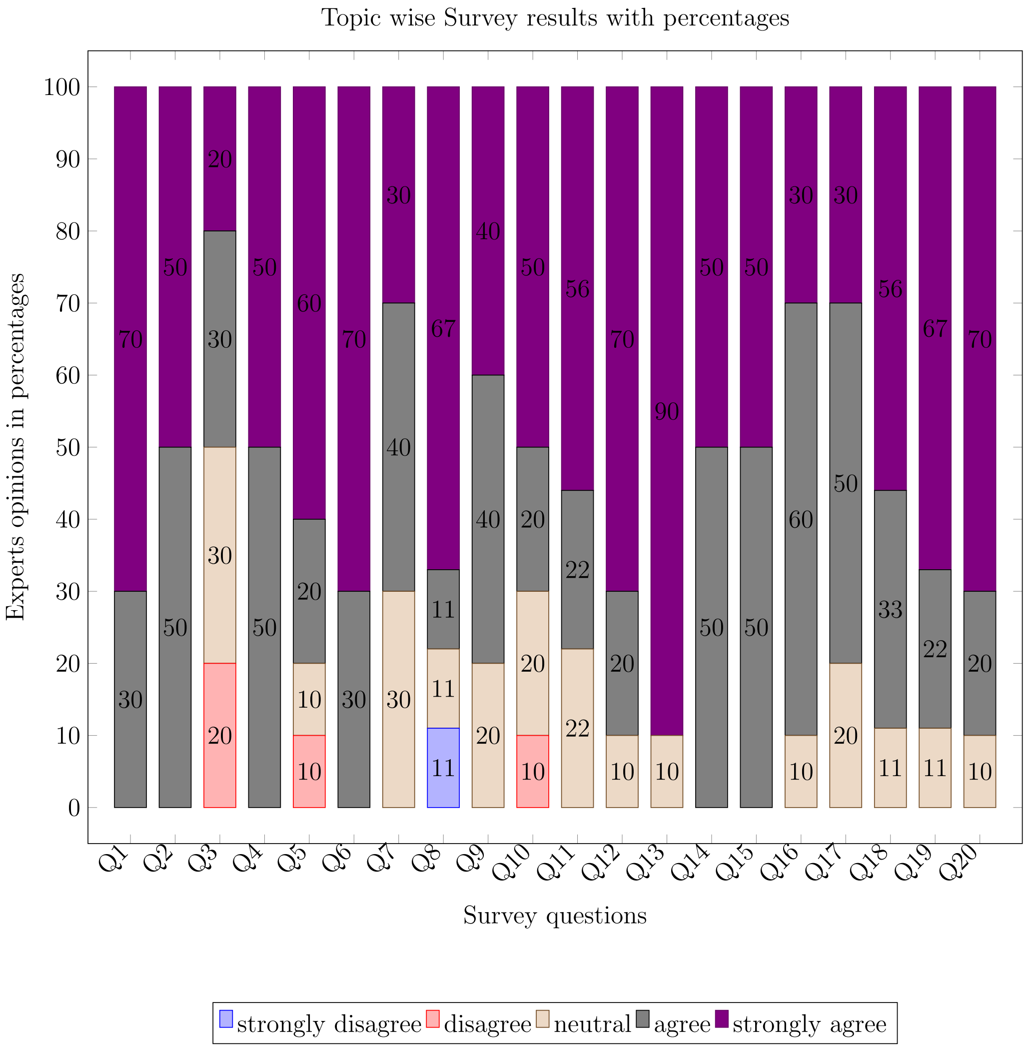

FIGURE 3. Topic wise survey results with percentages.

management team by the energy manager. In general, most of the companies expressed the opinion of either ‘‘totally agreed’’ or ‘‘agreed’’ to most of the points, for example, the questions about whether the industries should use IEnMS using the latest technologies like IoT, big data and data analytics and whether this will facilitate the industries in terms of less energy consumption, efficient utilization of energy, reduced energy bills and costs and reductions in greenhouse gas emissions.

Figure 3 gives a pictorial representation of the company results of the survey questions.. Here, purple color shows ‘‘totally agree’’; light gray shows ‘‘agree’’; light orange shows ‘‘neutral’’; red line shows ‘‘disagree’’; and blue shows ‘‘totally disagree’’ opinions of the industrial experts. In general, all the companies were more than 80% in agreement with the twenty questions that we have asked. The companies agreed about the importance of IEnMS in terms of energy efficiency, energy consumption, reduction in energy costs, and reductions in greenhouse emissions by utilizing renewable energy.

VII. PROPOSED HIGH LEVEL ARCHITECTURE FOR IEnMS

The huge amount of data generated by the IoT services creates opportunities to improve industrial services and customer values. For example, the data generated from IoT sensors can be analyzed in real time using big data and analytics to help present the information from the data in a better manner, help make better future decisions, and will result in continuous improvements within operations.

The proposed architecture is explained in Fig. 4. The process is divided into different phases, which are presented next.

A. INITIAL PHASE

Data is collected from a variety of sources in the early phase, including machines, HVAC, data creation from renewable sources (solar, wind), lighting, CCTV, and a variety of other energy-consuming devices, using sensors and actuators. The vast amount of data generated by these devices is stored in the cloud at a minimum cost.

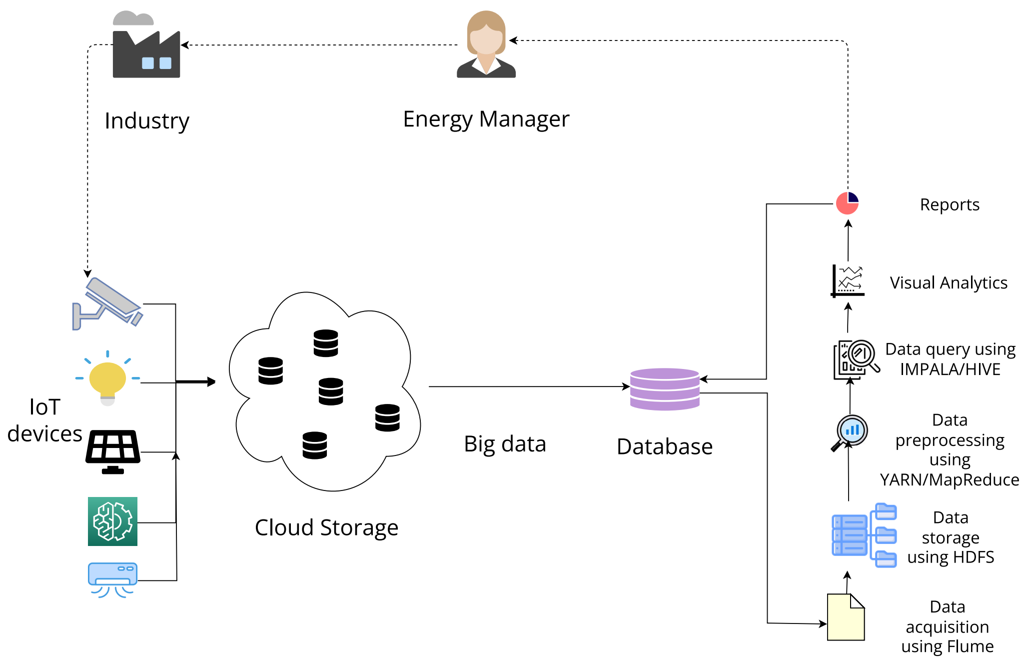

FIGURE 4. Data generation using IoT and processing with big data. The solid arrows mean data flow from one element to another; dashed line means possible information about the industrial operations based on the data reports from the IEnMS.

B. SECOND PHASE

The second phase is data acquisition, in which the generated big data is stored in a shared distributed fault tolerant database depending on volume, velocity, and variety. The acquired data is then sent to the Hadoop cluster's master node(s). Because the data is acquired from a variety of heterogeneous devices, it may contain a variety of data formats and information, necessitating data preparation. Accurate and incomplete data are handled in data preparation, and incomplete data is either repaired or removed. The data collecting method is carried out using Flume. Flume's main job is to gather, combine, and send enormous amounts of data to the Hadoop master node. Flume stores the data it receives in a single or several channels.

C. THIRD PHASE

The data is subsequently transmitted to an external Hadoop Distributed File System (HDFS) repository, where it is serialized and written in the desired format. Note that HDFS works by dividing large files into multiple blocks and stores these individual blocks on multiple data-nodes that are linked to the master node. HDFS is generic enough that allows basically all types of data (structured, unstructured or semi-structured data) to be stored. The serializers rearrange and alter the Flume data to fit the intended format. The data is pre-processed, resulting in a unified picture of the data. For processing, the data is stored in several HDFS clusters. DataNodes make up the HDFS clusters. In the DataNodes, the actual data and file system meta data are kept. YARN analyzes data stored in HDFS; the two run on the same set of nodes, allowing jobs to be handled on nodes where EnM data is present.

D. FOURTH PHASE

This stage involves running SQL queries. Hive and Impala are two tools that may be used to run SQL queries on HDFS data. HIVE is used for data querying, to select, analyse, and to make calculations on the data of interest.

E. LAST PHASE

Data analytics is the final phase, in which the calculated data is shared with energy management, particularly the energy manager, to allow for better planning and decision-making in order to achieve efficient energy utilisation, reduced greenhouse gas emissions, increased machine efficiency, energy policy design, and improved energy planning, among other things. The tool used in Hadoop for data analytics is Scalable Advanced Massive Online Analysis (SAMOA), a distributed streaming machine learning framework that comprises programming abstraction for distributed streaming algorithms for data mining and machine learning applications. Tableau is used for data visualisation (graphs, reports, and so on). Tableau is a popular tool for interactive data visualisation.

All in all, the expected outcome of the IEnMS process can be systematized into two different approaches, namely operational and strategic. At the operational level, the IEnMS serves as either an autonomous agent that is capable of intervening in the energy consumed throughout the targeted industrial process by, for example, an energy-centric schedule policy of operation or it can be used to monitor the energy demanded by different industrial tools in order to detect anomalies in their operation in terms of energy consumption. At strategic levels, the IEnMS may serve to support administrative policies targeting sustainability and energy efficiency by creating detailed data-driven reports that locate the most energy hungry or energy inefficient devices/processes that might be the target of future changes. It is nevertheless important to reinforce that our guidelines are general ones, which would be valid across different industries and cases; therefore, we avoid using particular cases and specific standards that would decrease the scope of our findings.

VIII. CONCLUSION

This research highlights the importance of IEnMS and outlines its components in detail. The IEnMS describes the practices and processes of industrial energy management, which are typically thought of as supporting functions, as well as how they are carried out. We've addressed why IEnMS should use cutting-edge technologies like IoT, big data, and data analytics, as well as the benefits they provide to the industrial sector. To obtain the opinions of industrial experts about the importance of using the modern technologies in IEnMS, we conducted a detailed survey of large companies. The results show that most of the industrial experts are in favor of utilizing modern technologies in IEnMS. Based on the industrial experts' opinions, we have designed a theoretical framework for obtaining energy information using IEnMS and modern technologies. In this framework, the data from machines are collected using IoT devices and then transferred to a database from where the big data process and data analytics begin. The information generated from the data is finally send to the energy management expert (energy manager). Through this approach, industries are expected to improve their energy efficiency while reducing their energy consumption, costs, and greenhouse gas emissions. Moreover, the information retrieved from the data can be used for the current and future business decisions and for the maintenance of industrial machines. In particular, a survey carried out with energy experts from different companies indicate that gains in energy efficiency are expected to be achieve using IEnMS as a centralized entity that will support the company to take better strategic and operational decisions based on data, while enabling an energy-centric operation through specialized IoT devices, sensors and actuators. In future, the same study can be extended to include Power-to-Gas (PtG) technology that mainly convert the electric energy (in this case from renewable) into H_2 using electrolysis process and later synthetic methane using the chemical reaction called methanation. These two (H_2 and methane) can be store for longer period which can solve the long storage problem of renewable energy.

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