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Implementation and Evaluation of an Industry 4.0-Based Energy Monitoring System: A Case Study of PT Communication Cable Systems Indonesia Tbk

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Abstract

The industrial shift to the 4.0 age necessitates the adoption of an energy monitoring system capable of giving real-time, precise data that is integrated into the manufacturing process. This research looks at the design and implementation of an Internet of Things (IoT)-based Energy Monitoring System (EMS) for PT Communication Cable Systems Indonesia Tbk (CCSI), a fiber optic cable manufacturing firm with a relatively high operating energy consumption. The system was created through the following stages: issue identification, architectural design, prototyping, field implementation, technical validation, and financial analysis. A total of 88 monitoring points were mapped using a mix of digital kWh meters, NodeMCU 8266, RS485-TTL, and Hi-Link power supply modules that were linked via Wi-Fi to a central server for real-time dashboard viewing. The installation results showed enhanced energy data visibility, accuracy of electrical parameter readings, less mistakes due to manual recording, and the ability to spot consumption anomalies using heatmap visualization and performance indicators. Return on Investment (ROI) research revealed net profits beginning in the 21st month with an initial ROI of 2% and increasing to a cumulative ROI of 73% by the 36th month. This study demonstrates that IoT-based EMS may improve energy efficiency, lower operating costs, and enhance digital transformation capabilities in the industrial industry.

Keywords: Energy, Monitoring, Industry, Transformasi, IoT

Introduction

The industry 4.0 paradigm's digital revolution has brought about substantial changes in the industrial industry, notably with the integration of the Internet of Things (IoT), big data analytics, and intelligent automation in numerous production processes. These advancements not only improve device connection, but also foster the development of a more flexible, responsive, and data driven industrial environment. In this setting, with rising energy consumption and worldwide demand to improve operational efficiency, energy management has emerged as an increasingly essential strategic emphasis for manufacturers. Energy is no longer considered as a supporting resource. Rather, it has become a significant variable in determining competitiveness, manufacturing costs, and company sustainability (Deng, et al., 2024). However, the implementation of effective energy management is frequently hampered by the limitations of traditional energy monitoring systems, which typically don't provide real-time data, don't integrate well with other devices or platforms, and don't support data analysis as a basis for strategic decision making.

These constraints lead to imprecise detection of consumption anomalies, a limited predictive capacity to anticipate load surges, and a lack of visibility into energy usage trends throughout the production process (Sankhyan, Chand, Kumar, Uday, & Dutt, 2025). As a result, there is an increasing need to create an Industry 4.0-based energy monitoring system that can provide high accuracy, real-time data access, and connection with production management systems and advanced analytics platforms. This invention is projected to give a more holistic solution, supporting not just energy savings but also process optimization techniques, industrial sustainability, and the attainment of overall digital transformation objectives.

The manufacturing industry is one of the greatest contributors to global energy consumption, hence energy efficiency is critical to ensuring industrial sustainability and competitiveness (Boricic, Blagojevic, Stankovic, Despotovic, & Petrevska, 2025). However, energy optimization efforts in this sector continue to face several fundamental challenges, including energy waste caused by inefficient processes, limited data visibility, which prevents a comprehensive understanding of consumption patterns, and a lack of monitoring systems that adapt to the dynamics of modern factory operations. Many industrial plants' existing monitoring systems are fragmented and unsuitable for providing the real-time insights required to detect irregularities and exploit opportunities. As demand to reduce operating costs and fulfill sustainability standards grows, the sector requires energy monitoring systems that produce detailed, timely, and accurate data, allowing for informed, evidence-based decision making (Ncube & Ngulube, 2024). Dynamically evaluate energy metrics, detect inefficiencies, and deliver immediately actionable advice, a method that focuses both data collecting and powerful analytical skills is required. As a result, the development of modern energy monitoring systems that use digital technology, automation, and data analytics is a strategic requirement for increasing energy efficiency, improving production process reliability, and supporting the industry's transition to a smarter, more sustainable future.

The integration of the Internet of Things (IoT) into energy management has provided business with new potential for real-time data capture, remote monitoring, and more extensive and accurate data-driven analysis. With high connection capabilities, IoT devices allow for continuous monitoring of every energy consumption point on a manufacturing line, offering full visibility into operational conditions that were previously difficult to attain using traditional approaches. The use of an IoT-based Energy Management System (EMS) has also been shown to improve energy efficiency, increase equipment dependability, and improve early detection capabilities for possible system breakdowns and consumption abnormalities. This method not only aids in the diagnosis of wasteful energy consumption patterns, but it also enables data-driven predictive maintenance and process improvement techniques. However, a review of previous research indicates that the use of IoT technology in energy consumption tracking is mostly implemented on a small scale, such as energy monitoring of single equipment, buildings, or laboratories, and rarely covers large-scale manufacturing environments with higher operational complexity. Furthermore, most studies do not provide the long-term financial evaluations necessary to understand the economic impact of IoT-based EMS implementation on energy costs, downtime reduction, and return on investment (ROI). These limitations indicate the need for more comprehensive research, encompassing IoT integration on a broader industrial scale, end-to-end system performance analysis, and long-term financial benefit evaluation that can inform managerial decision-making.

Reseach by (Mirani, Awasthi, O'Mahony, & Walsh, 2024) have been detailed about design and implement an IioT edge computing-based energy monitoring system for the factory floor with energy meters (wired & wireless), an edge gateway, a local database, plus analytic and reporting functions. Provide a concrete technical architecture and performance test results. Discussion regarding investment and profitability is not explained. Research by (Suwarjono & Afriza, 2025) also analyzes the impact of IoT on manufacturing operational efficiency, covering aspects such as downtime reduction and energy efficiency. While not always focused on monetary ROI. Research by (Budi, Setya, & Muhammad, 2024) has been detailed about the Internet of Things (IoT) has emerged as a significant technology for revolutionizing a variety of industries, including manufacturing. The purpose of this study is to examine the influence of IoT adoption on operational efficiency in the industrial sector using secondary data analysis and a literature review. IoT provides automation and real-time data integration, which may boost productivity, lower costs, and enhance manufacturing processes. According to this report, using IoT in the manufacturing business gives a variety of benefits, including greater production control, decreased downtime, and increased energy efficiency. However, significant barriers to IoT adoption include high initial investment costs and limited infrastructure.

PT Communication Cable Systems Indonesia Tbk (CCSI) is a fiber optic cable manufacturing company in Indonesia. CCSI is known as a premium-quality fiber optic cable producer. The company has a production capacity of 1,600,000 km of fiber optic cable per year (CCSI, 2025). The continuity of the production process at CCSI relies heavily on various supporting factors, one of which is the availability of adequate electrical power, which plays a determining role in the development and expansion of infrastructure. This study intends to create and implement an Energy Management System (EMS) based on the industry 4.0 paradigm in a real-world industrial setting, with Internet of Things (IoT) devices serving as the backbone for data collecting and transmission. The development process comprises designing the system architecture, selecting and calibrating sensors, integrating communication protocols, and implementing monitoring and control interfaces. Furthermore, the research will conduct a thorough technical performance evaluation, including data acquisition accuracy and consistency under various operating conditions, system stability during continuous operation, communication channel capacity and reliability, and end-to-end integration with existing production systems and analytics platforms, to ensure that the proposed solution meets the plant's operational requirements. From an economic standpoint, this study investigates the financial feasibility of EMS implementation by calculating Return on Investment (ROI) over a relevant time period, cost components (hardware, installation, maintenance, and network infrastructure), and measurable benefits (energy savings, reduced downtime, and improved operational efficiency). Finally, the study assesses the system's scalability and adoption potential in other manufacturing sectors with similar process characteristics, as well as the factors inhibiting and enabling adoption, and makes recommendations for best practices and business models that can be replicated across multiple industry scenarios. The implementation of an IoT-based EMS is crucial for CCSI as it replaces slow, error-prone manual monitoring with a modern, integrated system capable of tracking energy usage in real time, enabling faster corrective actions, strengthening data-driven decision-making, and supporting continuous operational improvements that collectively enhance energy efficiency, reduce operational costs, increase productivity, and accelerate the company's digital transformation through the development and implementation of an IoT-based EMS at PT Communication Cable Systems Indonesia Tbk's production facilities.

Method

This study combines a case study research technique with an engineering design process. The case study technique is used to analyze the real-world implementation of the Energy Monitoring System (EMS) at PT Communication Cable Systems Indonesia Tbk (CCSI), whilst the engineering design method guides the creation, integration, and optimization of the IoT-based system. The research framework includes issue identification, system design, prototyping, system validation, technical assessment, and financial analysis. This dual method assures that the investigation yields both scientific and practical engineering results. Figure 1 below shows the flow of the research method.

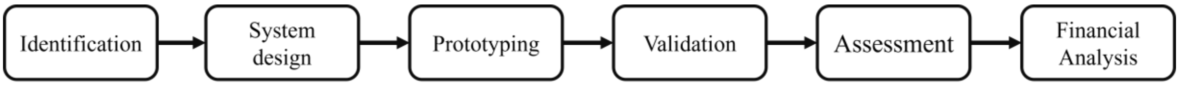

Figure 1 Research Flow Method.

The problem identification stage serves as the foundation for the whole research and development process of an IoT-based EMS system. At this step, information is gathered on the operational and technological issues that the sector faces in terms of energy management. Problem identification begins with an examination of energy consumption trends in manufacturing facilities, such as electrical load characteristics, production schedules, fluctuations in operation intensity, and environmental factors that may impact equipment performance. A detailed mapping of hurdles is carried out through observation and interviews with engineers, operators, and management, including restricted energy data visibility, monitoring systems that are not real-time, not integrated, and unable to enable data-driven decision-making. Other challenges include difficulty in early detection of consumption anomalies, inefficiencies in the manufacturing process owing to a lack of detailed information, and limits in estimating future energy loss. This stage also assesses the current state of the information technology infrastructure, including network readiness, device compatibility, and the possibility for future system integration. Problem identification is subsequently translated into a set of system requirements, including real-time data collecting capabilities, communication dependability, operational stability, and cost effectiveness. The findings from this stage serve as the foundation for creating more focused and relevant technical standards and research objectives.

The system design phase is intended to create an IoT-based EMS architecture that satisfies the previously mentioned needs and challenges. The design process begins with defining the system structure, which includes device-level sensors, communication networks, edge computing, and integration with monitoring and analytics tools. In this phase, sensors with high precision and compatibility with production settings are chosen, such as current, voltage, and energy sensors that use industrial protocols such as Modbus RTU/TCP. Communication architecture is critical, with both wired and wireless networks addressed to provide reliable data transfer while taking into account the possibility of electromagnetic interference in the facility. Next, a data processing mechanism is implemented on edge devices to ensure that data can be handled even if the network is disrupted. A relational or time-series database, whether on a local server or in the cloud, is built to handle frequent data collecting from dozens to hundreds of monitoring points.

The interface system is also intended to provide real-time data visualization, anomaly warnings, and analytical reports to aid decision making. Scalability, modularity, and interoperability are among the design elements used to ensure that the system may be expanded or connected with other production systems such as ERP or SCADA. The design outputs serve as a foundation for further development and execution. This study consists of three main stages in building the Energy Monitoring System (EMS), namely: planning, implementation, testing, and evaluation. The block diagram of the planning stage is shown in Figure 2.

Figure 2 Block Diagram of the Planning Stage.

The diagram illustrates the network architecture that represents the EMS, consisting of a total of 88 nodes connected to a central server at PT CCSI. Each node contains devices including an existing kWh meter, RS 8495 to TTL, and NodeMCU 8266, as shown in Figure 3.

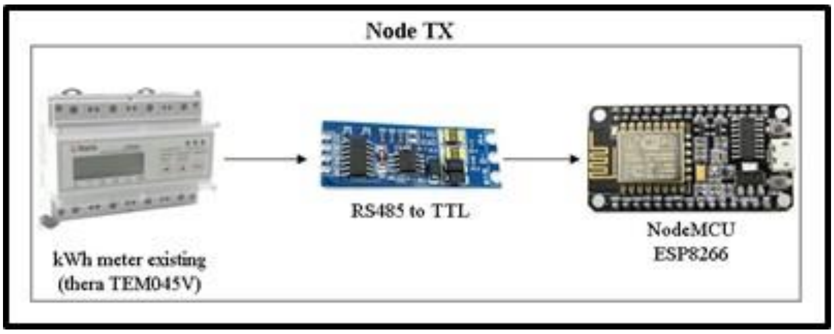

Figure 3 Node Device Included.

Each node collects real-time energy usage data from machines or devices located in the factory area. The data collected from the 88 nodes is then transmitted to the central server at PT CCSI. This server is responsible for storing the received data in a database and also serves as the analytics center for processing the incoming information. Subsequently, the server sends the processed data to a system or web-based dashboard visualization platform.

The prototype phase entails developing an early version of an Industry 4.0-based EMS system that incorporates IoT devices, connectivity modules, and a monitoring platform. The prototype is developed to ensure that the design idea is technically possible and can work in accordance with industry standards. During this stage, hardware including energy sensors, microcontrollers, IoT gateways, and data storage systems are installed and configured. Then, firmware or software is created to handle data collecting, device control, and node communication. The prototype also comprises the development of a dashboard or basic web application that shows real-time energy statistics in the form of graphs, load indications, and alerts. Initial testing is performed to confirm that the device can read data reliably and consistently throughout a specific time period. Prototyping also helps to uncover possible problems including network outages, data inconsistencies, excessive latency, and electromagnetic interference from industrial machines. Prototyping device showed at Figure 4.

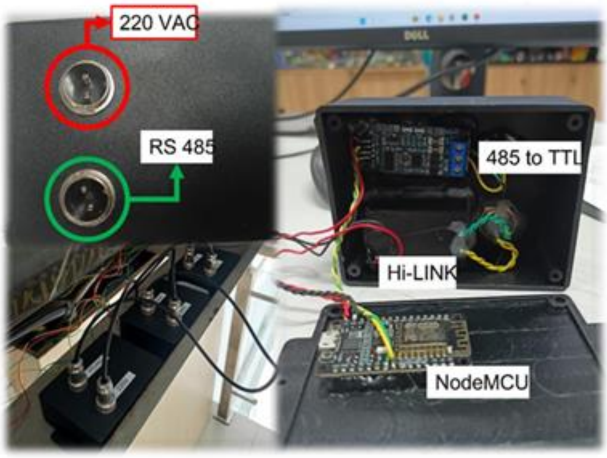

Figure 4 Prototyping Device.

Furthermore, coding optimization, power consumption monitoring of IoT devices, and sampling rate modifications are carried out to collect enough granular data without overloading the network. Before moving on with full-scale implementation, incremental changes are made based on the outcomes of prototype testing. This stage assures that the designed technology is both technically practical and adaptable to real-world situations in the field.

System validation is performed to guarantee that the built IoT-based EMS performs properly and can fulfill industrial operating requirements. At this time, the system is being tested live in a production setting with a greater number of monitoring points and operational circumstances. Validation entails determining the long-term stability of data acquisition, verifying the accuracy of sensor readings through comparison with standard measuring instruments, and assessing network reliability in the presence of electromagnetic interference, load fluctuations, or extreme environments. Figure 5 showing the flowchat system.

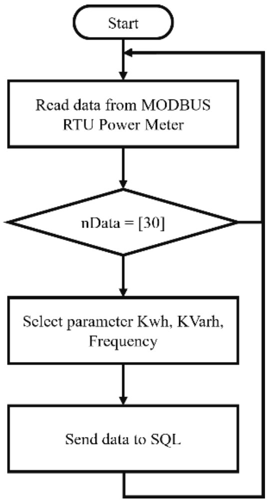

Figure 5 Flowchart System.

Furthermore, the system's capacity to manage enormous data volumes from tens to hundreds of nodes at once is evaluated. Testing involves analyzing performance characteristics such as data loss rate, communication latency, time synchronization consistency, and device dependability when functioning without operator intervention. System validation also includes evaluating dashboard functionality, the system's capacity to provide anomaly warnings, and the accuracy of daily, weekly, and monthly energy usage estimations. Industrial users, such as engineers and operators, are asked to offer input on usability and information relevance. Based on the validation results, a gap analysis is performed to discover system flaws and improvements before the system is pronounced ready for full implementation. Successful validation assures that the EMS will function consistently and effectively in real-world industrial settings.

A technical evaluation evaluates system performance using quantitative and qualitative metrics. Sensor accuracy, operational stability, communication reliability, and overall system performance are among the key factors examined. Sensor accuracy is determined by comparing measurements to approved reference devices. System stability is assessed by examining the device's capacity to log data consistently for a certain length of time, such as 30-60 days, without severe faults or outages. Communication dependability is measured using factors such as packet loss, time delay, network speed, and recovery capabilities during temporary disturbances.

The technical examination also evaluates the edge device's ability to process data and deliver it to the server without bottlenecks. On the software side, load testing is done on the database and the dashboard's capacity to handle thousands of data points per hour without performance deterioration. In addition to technical criteria, system security measures such as data encryption, access control, and resistance to external interference are examined. This assessment gives a thorough analysis of the EMS's technical performance and analyzes if the system fulfills industry requirements for IoT-based energy monitoring. The technical evaluation results are used to fine-tune and improve the system prior to the financial assessment.

The financial study is to determine the cost viability of adopting an IoT-based EMS in an industrial setting. This stage entails determining all cost components, including hardware expenses (sensors, gateways, and servers), installation and integration costs, maintenance costs, and long-term operating costs such as IoT device energy consumption and network needs. The economic advantages are then assessed, including energy savings, decreased machine downtime, better operational efficiency, and lower predictive maintenance costs. Calculations employed include Return on Investment (ROI), Net Present Value (NPV), and Payback Period. A 36-month ROI is frequently used as a broad metric to determine if a project is economically viable in the medium term. Sensitivity analysis may also be used to determine how changes in variables like power pricing, the number of sensors, and the size of implementation influence financial outcomes. Furthermore, this approach considers indirect effects such as higher operator productivity as a result of a more automated system and less human error. The financial analysis findings serve as a foundation for management to make strategic decisions about the EMS implementation's viability, growth, or replication. This stage ensures that the system is not only technically superior but also provides significant economic value to the industry.

Before installing the Energy Monitoring System (EMS) on the machines, data collection was carried out related to the machine's power meter, such as Wi-Fi signal strength, CT ratio, and device codes. Next, the second phase of procurement was conducted, specifically for the installation needs on the machines, which was carried out after the completion of the previous phase. After that, dashboard development was carried out to display energy data visualization, covering both the frontend (user interface) and backend (data processing). The testing phase began from the initial planning through to execution and testing, both in terms of dashboard appearance and the accuracy of the displayed data. This phase included the installation of transmitters, dashboard development, and database integration. Each phase was accompanied by an evaluation process to ensure that the system functioned as planned and was capable of delivering the expected results in energy management.

Result

This chapter summarizes the study findings from a series of tests, measurements, and analyses carried out in line with the methods described in the preceding chapter. The data reported in this part is the confirmed result of an experimental approach designed to achieve the study objectives. The findings are given methodically, beginning with the display of raw data, followed by data processing and an initial interpretation of pertinent findings.

Problem Identification

The key issue found is the disparity between power use and the amount of goods produced. Ideally, increasing power consumption should be proportionate to the length of the product generated, whereas decreasing electricity consumption would normally result in shorter items. However, this trend does not appear in the real data. This irregularity suggests an oddity that warrants additional investigation. Figure 6 illustrates the variation in pattern.

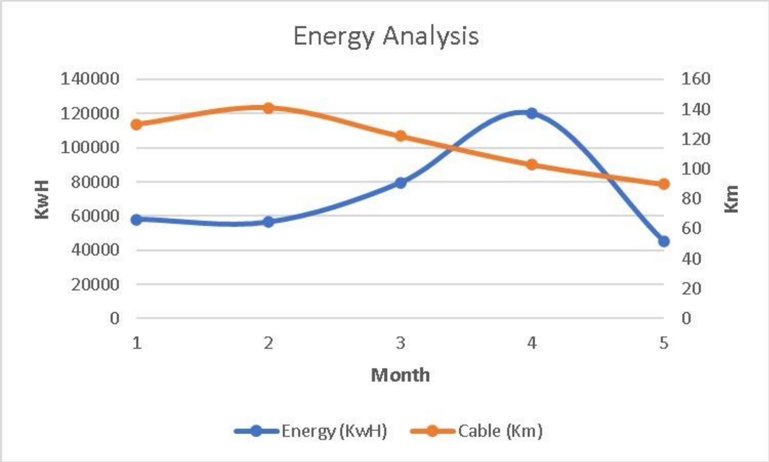

Figure 6 Energy Analysis

The Energy Analysis graph compares energy use (kWh) and cable length (km) over five months. In general, both variables show distinct patterns of change throughout time. In terms of energy, the kWh value stayed at 58,000 in the first month, dropped slightly in the second month, and then surged dramatically beginning in the third month. Energy consumption peaked in the fourth month, reaching approximately 120,000 kWh, before rapidly falling in the fifth month. Meanwhile, the trend in cable length followed a roughly opposite pattern. During the first two months, the cable length rose from roughly 115 km to approximately 123 km. Following that, the figure rapidly declined between the third and fifth months, from around 105 km to approximately 80 km. In addition to the discrepancy between yield and energy consumption, it appears that in-depth analysis has not been conducted. This is because the data has only been recorded manually, making it impossible to access it in real time. The recording process is carried out every morning for almost three hours, as shown in Figure 7 below.

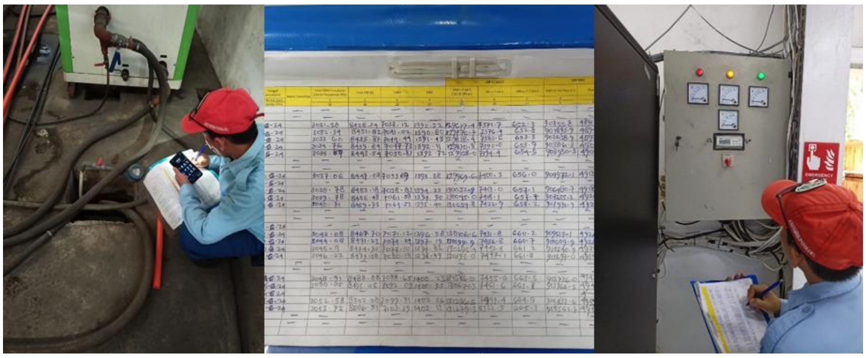

Figure 7 Manual Reporting.

Hardware Implementation

The device installation was successfully completed at 88 places around the plant. Each location was chosen based on the production process monitoring requirements and the coverage region judged most suitable for collecting complete operational data. Figure 8 depicts the distribution of devices across the plant, from the primary manufacturing line to additional supporting sections. This equal distribution guarantees that the collected data offers a complete view of the factory's state.

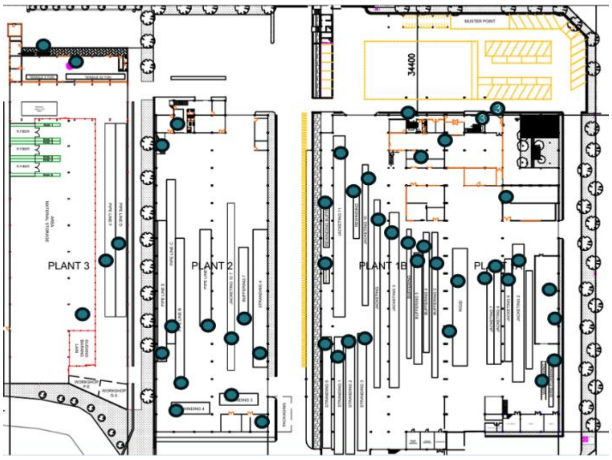

Figure 8 Energy Monitoring System Plan

Figure 9 Hardware Implementation

Based on the planning, Figure 9 depicts the outcomes of component assembly and device installation on the power meter. The front view displays two connections for power supply and data transmission lines. The components are then linked within the box to ensure they are safe, sound, and dependable for use as data transmitters. All components were installed in accordance with the proposed block diagram and tested for functionality, security, and dependability.

This device is intended to connect to energy meters using the RS485 communication protocol, which is often used in energy monitoring systems. RS485 allows for consistent and dependable communication in industrial settings, where energy consumption data is transmitted from the energy meter to this unit. The device is powered by a 220V AC connection, which the Hi-Link module converts to DC voltage and used to power the NodeMCU and a 485-to-TTL converter. The NodeMCU analyzes the data before sending it to a central management system, presumably over Wi-Fi, allowing for interaction with a server or dashboard for real-time energy monitoring.

Website Display

Figure 10 depicts the site's user-friendly interface. It is intended as a monitoring and analysis tool that displays both real-time and historical energy use data. This interface enables users to do in-depth analyses of energy usage trends, identify possible inefficiencies, and help decision-making to increase industrial energy efficiency.

Figure 10 Website View for Monitoring

Energy consumption monitoring results are displayed through the CCSI 4.0 Energy Management System, which provides comprehensive visualization of power usage behavior across multiple production units. The main dashboard displays active energy consumption (kWh and MWh), reactive power (kVAr), and supporting data such as current and voltage at each phase. Measured energy consumption varies between units, with some points reaching usage of up to 1.10 MWh, while others range in the hundreds of kWh range. Furthermore, reactive power in some areas was recorded as quite high, reaching 367 kVAr, indicating the need for an evaluation of the system's power factor. The gauge meter visualization on the dashboard provides a quick assessment of each unit's energy performance, with a performance index ranging from 107 to 253. This index serves as a preliminary indicator for assessing the relative efficiency levels between units. The system also features an energy consumption heatmap that illustrates load variation patterns over time; areas with higher color intensity indicate periods of significantly increased power consumption.

The summary tabular section displays detailed numerical data for each machine, including daily energy consumption (kWh Today), the previous day's consumption (kWh Last), cumulative energy total (kWh Total), and current values for each phase. The table also includes color-coded indicators to facilitate identification of abnormal conditions: red indicates high energy consumption or load anomalies, while green indicates stable and efficient operating conditions. Overall, these results indicate that energy consumption patterns vary significantly between units, both in terms of active energy and reactive power. The digital dashboard provides a real-time overview of electrical conditions, supporting faster, data-driven decision-making to improve energy efficiency in production areas.

Wifi Signal Measurement

Wi-Fi signal measurements are made by measuring the signal strength in the region where the power monitoring device is situated. This is done to determine and confirm that data submitted to the server is received accurately. Furthermore, these data are utilized to identify any interference from materials or the manufacturing process.

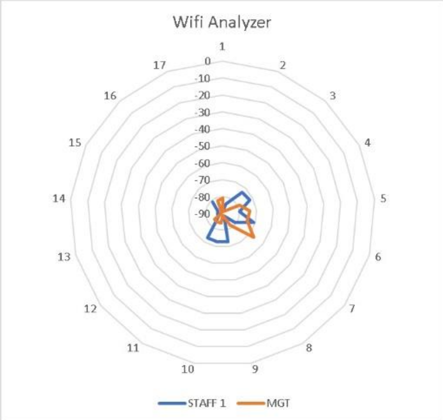

Figure 11 Wifi Signal Analyzer

Figure 11 depicts a radar chart-based representation of WiFi signal strength data. Signal reception quality was measured at two user sites, STAFF 1 and MGT, to compare it across different regions. Signal strength is measured in decibels (dBm), with higher numbers indicating greater quality and lower ones indicating weaker transmissions. The measurement findings demonstrate that both sites exhibit varying signal dispersion patterns in many directions. However, STAFF 1 has a more steady signal range, with most readings lying between -70 and -85 dBm. Meanwhile, the MGT point displays broader signal variance and tends to be weaker in certain spots, with values around -90 dBm. This discrepancy represents differences in network coverage quality in the region, which may be impacted by distance to the access point, physical barriers (such as walls or equipment), or interference from other devices. Overall, this radar graph demonstrates that, despite the fact that both measurement stations connect to the same WiFi network, the received signal quality varies. This study shows that access point placement, network distribution tactics, and potential WiFi configuration improvements should all be evaluated further in order to improve service quality throughout the workplace.

Data report error system

When the system fails to react effectively to the information requested by the user, the relevant department generates a system error report. This reporting mechanism is a key measure of the system's overall dependability and usefulness. Each incoming report is used as an evaluation tool to discover the root cause, repair inefficient functionality, and verify that the system continues to work reliably and meets user operating requirements.

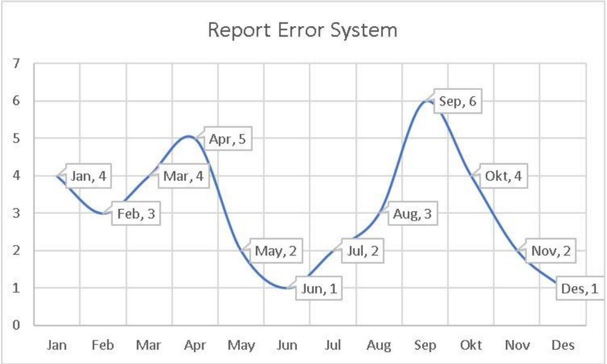

Figure 12 Graph for Report Error System

Figure 12 shows that the number of system error reports varies throughout the course of the year. September saw the most reports, at six. This chart shows a considerable rise in interruptions compared to previous months. In contrast, June had the fewest reports, with only one, indicating that the system was reasonably stable at the time. Furthermore, successive months revealed a comparable amount of reports. January, March, and October each had four reports, showing a trend of repeating interruptions. February and August showed a somewhat lower number of complaints, with three. Meanwhile, May, July, and November each recorded two reports.

Further study of each error report indicated that the majority of interruptions were caused by external factors impacting system performance rather than device breakdown. Power outages and poor WiFi signals were found as the two most common reasons at many device installation locations. Power failures prohibited devices from working and transferring data, but a loss of WiFi signal prevented data from reaching the server even when the devices were turned on. These findings highlight the significance of upgrading supporting infrastructure, notably a reliable power supply and a consistent Wi-Fi network across the facility. By increasing these two critical characteristics, the number of error reports is predicted to decrease dramatically, allowing the system to run more reliably. Furthermore, these findings can help to improve monitoring techniques and future system development.

Return of Investment

Based on the results of the research conducted, it can be concluded that the implementation of the Industry 4.0-based Energy Monitoring System (EMS) at PT Communication Cable Systems Indonesia Tbk (CCSI) involved a comprehensive and structured development process across 88 monitoring points distributed throughout the production facility. This system was built using a combination of hardware components such as digital kWh meters for electrical parameter measurement, NodeMCU 8266 microcontrollers for wireless data transmission, RS485 to TTL converters for communication signal adaptation, and Hi-Link power supply modules to ensure stable and safe system operation. All components were integrated through a Wi-Fi communication network that transmitted real-time data to the central server and dashboard for further processing and visualization. By the evaluation stage, 17% of all monitoring points equivalent to 15 nodes had been successfully installed, configured, and tested, providing initial validation of system performance and confirming that the EMS infrastructure functioned reliably under actual production conditions.

	Months	Investment	Income	Profit	ROI
	6	IDR 31.709.931	IDR 9.375.000	-IDR 22.334.931	-70%
	18	IDR 32.025.792	IDR 28.125.000	-IDR 3.900.792	-12%
Payback Period	21	IDR 32.104.757	IDR 32.812.500	IDR 707.743	2%
	30	IDR 32.341.653	IDR 46.875.000	IDR 14.533.347	45%
	36	IDR 32.499.583	IDR 56.250.000	IDR 23.750.417	73%

Figure 13 ROI Calculations

Based on the figure 13 the EMS implementation was also assessed from an economic perspective through a detailed Return on Investment (ROI) analysis, which examined the balance between initial installation costs, operational savings, and potential long-term benefits. The financial evaluation showed that the system began generating net profit in the 21st month after installation, achieving an early positive ROI of 2%, which demonstrated that the payback period aligned with the projected economic model. Over time, as more monitoring points were integrated and energy efficiency improvements became more consistent, the ROI continued to increase significantly. By the 36th month, the system recorded a cumulative ROI of 73%, indicating strong financial sustainability and confirming that the EMS provides measurable long-term profitability.

Conclusion

Based on the research results and implementation of an IoT-based EMS at PT CCSI, several key conclusions can be formulated as follows:

1. Conventional energy monitoring systems have proven incapable of providing fast, accurate, and real-time data, thus hampering the analysis of energy consumption anomalies and data-driven decision-making. The implementation of an IoT-based EMS successfully overcomes these limitations by providing automatic, continuous, and centralized data.
2. A total of 88 monitoring points were successfully planned and implemented, with 15 nodes (17%) initially functioning stably. The system uses a combination of NodeMCU 8266 devices, digital kWh meters, RS485–TTL, and a Wi-Fi network integrated with a central server. All devices are capable of operating in industrial environments with a high level of stability.
3. The EMS dashboard provides comprehensive visualization of energy parameters, including kWh, MWh, current, voltage, and reactive power. Features such as heatmaps, anomaly alarms, and production unit performance indices enhance the company's ability to identify energy inefficiencies early.
4. System disruptions were generally caused by external factors, particularly power outages and weak Wi-Fi signals in some production areas. This indicated the need to improve supporting infrastructure to ensure maximum reliability.
5. Financial analysis showed that the EMS implementation was economically feasible. The system began generating net profits in the 21st month with a 2% ROI, and increased significantly to reach a 73% ROI in the 36th month. These results confirmed that the EMS not only improved operational efficiency but also provided long-term financial value for the company.

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