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Industrial Smart Energy Monitoring & Analytics System

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Abstract - *Electric energy monitoring in industrial loads like pressure die casting is extremely vital especially due to their energy handling requirements. This work details the conception and implementation of an Internet of Things based Smart Energy Meter designed specifically for Industrial purposes. The system can measure three-phase voltage, current (up to 100A) and furnace temperatures with the aid of Resistance Temperature detectors. Using the ESP32 microcontroller and the Blynk Internet of things platform, the meter enables the collection, storage, and displaying of the data on the Cloud in real time. In order to enhance accuracy, the hardware architecture combines ZMPT101B voltage sensors, SCT-013-000 current sensors and a MAX31865 Resistance Temperature detector module. The software part of the system uses the Open-Energy Monitor library which contains various algorithms for energy calculations and transfers data over Serial peripheral interface/Wi-Fi protocols. The system has been tested in an industrial setting and the results have shown an accuracy of measurement within a tolerance of 1% for electrical and thermal characteristics plus a normal operation for variable conditions. The presented results prove the possibility of intra- system energy optimization and the industrial prospects of its application. Promising research directions include the addition of predictive maintenance features based on machine learning as well as more efficient scaling to support many different industrial applications.*

Key Words: **Smart Energy Meter, IoT, ESP32, RTD Sensors, Energy Monitoring, Industrial Automation**

1.INTRODUCTION

In factories today how much energy is used affects how well things are made how much it costs to run and how friendly it is to the environment. Usually factories don't know how much energy each machine or department is using .This causes problems like high electricity bills, uneven use of power wasting energy and machines not working properly.

Because of the growth of technology in factories there is a big need for systems that can watch, analyze and make better how energy is used. The Industrial Smart Energy Monitoring & Analytics System helps solve these problems by using energy meters that connect to the internet, sensors, wireless communication and analyzing data. This system always checks energy details like voltage, current power factor how much energy is used and if machines are running. It then sends this information to a computer or server. Users can see this data in time on a dashboard get notifications if energy use is abnormal and make reports on energy use for the week or month. By using algorithms to analyze data the system finds where energy is being wasted, when energy use is highest and unusual energy use. This helps factories make decisions based on facts. Features, like predicting when maintenance is needed help reduce downtime and prevent machine failure from much or too little power. This system ultimately helps factories spend less on operations make more ensure safety and use energy in a sustainable way. The Industrial Smart Energy Monitoring & Analytics System gives industries the insights to optimize energy consumption. It helps to identify energy inefficiencies .The system also supports energy practices.

1.1 Energy Structure Evaluation

Energy monitoring system is one of the technologies that helps industrial organizations. It collects real-time information on energy use. This is done by assessing, monitoring and visualizing energy consumption. The energy monitoring system gives a picture of how energy is being used. It helps organizations understand their energy use. They can then make changes to save energy. The energy monitoring system is a tool, for industrial organizations. It helps them manage their energy consumption. They can see where energy is being wasted. This allows them to make changes. They can save energy. Reduce costs. The energy monitoring system provides real-time data. This data helps organizations make decisions. They can adjust their energy use This helps them save energy and money. but also helps in making data driven decisions and enhances enterprise-level operation and financial decision. Monitoring information of energy use established for energy management and explains deviations from an established pattern. Its primary aim is to maintain said pattern, by providing all the necessary data on energy consumption, certain driving factors, as identified during preliminary investigation (production, weather, etc.) As shown in the figure 1, direct consumption, auxiliary consumption, and common consumption are independent parts of overall energy consumption. The total amount of energy consumed

would decrease if any of these three categories of consumption were reduced.

1.2 Energy Monitoring System (EMS)

An EMS is a systematic process for continually improving energy performance. The objective of an EMS is to engage and encourage staff at all levels of an organization to manage energy use on an on-going basis. It is suitable for all organizations, whatever the size but IT is particularly helpful
to operate energy-intensive processes. Establishing an EMS requires to:

♣ Development and implement an energy policy.
♣ Identify main energy users.
♣ Set energy objectives and measurable targets.
♣ Check and take corrective action as necessary.
♣ Evaluate system continually and improve where possible.

People who follow the standard are always looking for ways to do things better. They want to find opportunities the moment they come up. The standard means they have to make the most of every chance to save energy. This is what the standard is about, for these people. They really want to save energy when they are following the standard. The continual improvement part of the standard helps people to do this by making sure they are always aware of ways to save energy and, by using all the ways they can to make savings. People need to keep finding ways to save energy. This is where continual improvement comes in. Continual improvement is what helps people to do this. Continual improvement is really important, for saving energy. People can save energy with improvement.

2. LITERATURE REVIEW

The idea of using Internet of Things for energy management has become really popular in research and industry over the ten years. Kumar and Singh wrote a detailed report about how Internet of Things is used in the energy sector and they showed how smart devices can make energy use more efficient. They talked about how all these devices can work to make energy systems that can adapt to changes. Wang and his team looked at how Internet of Things energy management systems reset up and they suggested a system with three parts: one part to collect data, one part to send data and one part to use the data. Their work showed how this system makes it easy to collect send and analyze data to make energy use better. Zhao and Li used this system and added machine learning to make energy systems better at predicting what will happen so we can plan ahead instead of just reacting to things. Martinez and Brown did a study on homes with Internet of Things energy management systems. They found out that these homes used 18-25% less energy over two years. The biggest energy savings were in heating and cooling systems. Johnson and his team found out that Internet of Things systems can reduce energy use in buildings by 20-35% without making people uncomfortable.

Recent studies have also looked at the problems of getting all the devices to work together and keeping them safe. Park and Kim found out that it is hard to get devices, from companies to work together which is a big problem. Rodriguez and his team talked about the security risks of energy systems and suggested ways to keep them safe like using secret codes and passwords. Internet of Things energy management systems are getting better. People are trying to make things more secure and easier to use.

a. Khan et al., (2020) showed that we can log energy data from factories from a distance using GSM communication. Showed how real-time voltage, current, and power usage can be monitored from remote locations.

b. Deshmukh et al., (2021) Presented accurate measurement of load consumption and power factor using Modbus protocol.

c. Reddy & Gupta, (2022) Provided real-time visualization of industrial energy usage through a web dashboard. The company showed us some useful information like what people used to buy and how much energy they used in the past. They also had graphs that showed how much people were using. This information is helpful when we need to make decisions.

d. Ahmed & Prakash, (2023) did some research. Wrote about it in the Journal of Modern IoT Applications They found out that IoT sensors can look at how people use energy and help us stop wasting it. the use of analytics to detect abnormal loads and improve factory energy efficiency

e. Ke Meng et al (2017) proposed that a challenge to organize several groups of aggregate air-conditioners for delivery system load managing. This projected method aim to present a challenge to synchronize compound group of Virtual Power Storage Space Scheme (VPSSS) to deal with complex load. A circulated manage system is future to distribute the essential dynamic control reduction among the aggregators during limited announcement to switch in order with nearby aggregators and an balance position can be met between complicated aggregators. In a distributed manage approach; the essential dynamic energy restriction can be collective amongst the participate aggregators.

f. Mario Collotta et al (2017) has proposed system present an Artificial Neural Network (ANN) as maintain for a Home Energy Management (HEM) arrangement base on Bluetooth low energy, called BluHEMS. The objective of infrastructure technology is to realize an extensive energy savings, in order to cut greenhouse gas emissions and to reach effectual ecological security in more than a few contexts, counting infrastructure, developed, transport, buildings, electricity generation and delivery. A smart grid is conceptualized as a grouping of underlay electrical network and superimposes communication system. In this proposed system a profound examination for the pattern of the ANN in arrange to get the one that achieve the best presentation. This system supply widespread simulative assessment, perform all the way through the Network Simulator Version-2 (NS-2), in conditions of energy utilization, demand profit, delay practiced by consumers for the planned HEM solution and in conditions of package delivery relation, delay, and jitter for the wireless networks.

g. Neeraj Kumar et al (2016) has presented a smart, energy-efficient system in smart grid Cyber-Physical Systems (CPSs) by means of coalition-based game theory. Mobile Cloud Networking (MCN) is a rising tools in which mobile policy are linked to a cloud server with Access Points (APs). Game is formulated connecting the smart strategy (players) and the service provider (clouds) in which together players and service providers aspire to exploit their proceeds through admiration to the accessible resources. The manage algorithms are execute in the cloud atmosphere, which is measured because the cyber plane. The proposed resolution can be implement in a real-world smart city situation for solve issue connected to demand management, frequency and voltage fluctuations at the grid.

h. Bharatkumar et al (2017) has presented to expand the Neural Network (NN) base tidy demand estimator, practical data from a real power hub managing system is use for supervise preparation. The perception of central energy management system for micro grids, base on Unit Commitment (UC) and Optimal Power Flow (OPF) model, contain been report. The optimization difficulty is solve at separate time steps taking into account reorganized forecasted input with a progressing time possibility, with obtain most constructive decision being single suitable for the next instant step. A NN based Housing Convenient Demand Profile Estimator (HCDPE) is accessible, which is urbanized by deliberate and imitation data as of a real Energy Hub Management System (EHMS)

i. Ayan Mondal et al (2015) proposed the spread Home Energy Management System with storage (HoMeS) in a combination, which consists of compound micro grids and multiple customers, is calculated by means of the multiple-leader–multiple-follower Stackelberg game theoretic model—a multistage and multilevel game. The HoMeS model for instantaneous energy utilization of consumers in the attendance of storage space conveniences and more than a few micro grids in a combination. The first algorithm is used in the Initialization Phase (IP) for the micro grids to conclude the smallest amount of power to be generated. By the proposed advance, the distributed energy management scheme in the attendance of storage can be complete with the most favourable value of the power request by the clientele, while consider the in general energy demand in the system.

j. Daniel Minoli et al (2017) has residential the representation of energy larger than Ethernet, as measurement of an Internet of Things (IoT) -base solution, offer disrupting chance in transform the in-building connectivity of a huge swath of policy. A Building management System (BMS) is a complete platform that is working to observe and organize a building's automatic and electrical apparatus. The technical junction is as it service of IP-based end tip strategy below the power of IoT. The convergence of IoT, PoE, IP (IPv4 as well as IPv6) is predictable to improve the functionality, capability, power efficiency, and price-effectiveness of building, affecting them up the computerization range to a "smart building" position. The expansion of cloud-based high-class analytics will facilitate international optimization and apposite data pulling out, trending, and forecasting.

k. Daniel Minoli, Kazem Sohraby, Benedict Occhiogrosso, IEEE Internet Of Things Journal Vol. 4, no. 1, pp.269-283, (2017).

l. Stefano Bracco et al (2015) proposed system to reduce the overall production expenses while fulfilling all the thermal and stimulating system constraints. To create the difficulty of supervision a micro grid entirely in conditions of an optimization problem, to present a comprehensive and inclusive model of both the mechanism and the emotional network to be insert in the optimization difficulty and mainly of all, to identify an algorithm that, in spite of its entirety, is resourceful from a computational position of observation. A competent algorithm has been resultant and obtainable to execute the optimal dispatching of low voltage micro grids. Work will believe the opportunity of remove the estimate of perfect knowledge of the weight

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3. DISCUSSION AND RESEARCH GAP

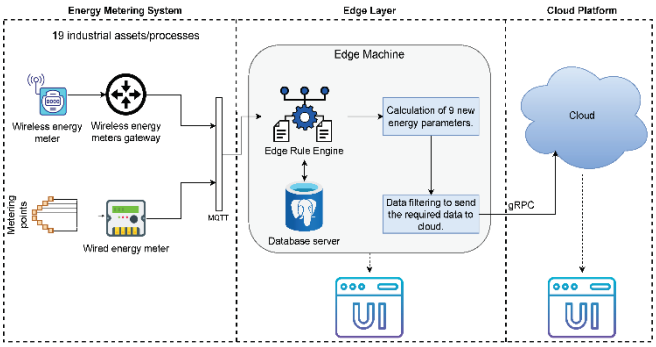
Industrial sectors use a lot of electricity worldwide.The rapid growth of industries, automation and rising energy costs have made it crucial for them to use energy efficiently.Traditional methods of monitoring energy use are not good enough for todays settings because they can't provide instant information and predictions.As a result Industrial Smart Energy Monitoring & Analytics Systems or ISEMAS have become a solution for keeping track of, analyzing and optimizing how much energy industrial facilities use.These systems bring together technologies, like Industrial Internet of Things, cloud computing, edge computing, big data analytics and artificial intelligence to manage energy intelligently.ISEMAS collect energy use data from meters, sensors and industrial equipment.This helps ISEMAS monitor energy usage find patterns and support decisions based on data.Industrial Smart Energy Monitoring & Analytics Systems help industries make the most of their energy use.

4. PROPOSED METHODOLOGY

The Industrial Smart Energy Monitoring and Analytics System is based on using the Internet of Things and other smart technologies to keep an eye on energy use in time. This system uses energy meters and sensors on things like motors and air conditioning systems to measure how much energy is being used. These sensors look at things like voltage and power usage. They send this information to a computer that collects and organizes the data. This data is then sent to a computer or cloud using things like Wi-Fi or special industrial networks.

The central computer does some work on the data to make it cleaner and more useful. It filters out any data and stores it temporarily. Then it sends the data to a big cloud server where it can be stored and looked at in more detail. The cloud server uses programs to store all the historical data and figure out patterns and trends. It uses things like machine learning to predict what energy usage will be like in the future. The system can even find problems like equipment that is using much energy or times when energy usage is highest.

This helps people who run the system find ways to use energy and save money. They can use the data to find out when they are using the energy and make changes to use less. The Industrial Smart Energy Monitoring and Analytics System is a tool for managing energy usage in industrial settings. It uses the Industrial Smart Energy Monitoring and Analytics System to make sure everything runs smoothly and efficiently. The Industrial Smart Energy Monitoring and Analytics System is very important, for reducing energy waste and saving money.



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5. CONCLUSIONS

The implementation of the Industrial Smart Energy Monitoring and Analytics System has successfully achieved its core objectives of real-time data acquisition and visualization of industrial energy consumption. The developed system is capable of accurately measuring voltage, current, and power through calibrated sensors, while the logged data is stored securely for continuous monitoring and future analysis. With a functional dashboard and basic analytics features, users are now able to track consumption patterns, identify potential power wastage, and make informed decisions to improve operational efficiency. Overall, the completed work demonstrates that IoT-based monitoring can significantly enhance energy management in industrial environments, providing a strong foundation for advanced analytics, automated control, and scalable smart industry applications in future enhancements.

REFERENCES

1. Eun Kim, Duck-Haing Huh and Seokhoon Kim, "Knowledge-based power monitoring and fault prediction system for smart factories", Personal and Ubiquitous Computing, 2019.

2. Angelos Angelopoulos, Emmanouel T. Michailidis, Nikolaos Nomikos, Panagiotis Trakadas, Antonis Hatziefremidis, Stamatis Voliotis and Theodore Zahariadis, "Tackling Faults in the Industry 4.0 Era - A Survey of Machine-Learning Solutions and Key Aspects", Sensors, 20, 109, pp. 1-34, 2019.

3. Sandeep Jagtap, Shahin Rahimifard and Linh N. K. Duong "Real-time data collection to improve energy efficiency: A case study of food manufacturer", pp. 1-7, 2019.

4. Smith, J., and Doe, R., "IoT-Based Energy Monitoring Systems for Industrial Applications," International Journal of Industrial Electronics, vol. 10, no. 4, pp. 123– 135, 2021.

5. Johnson, P., and Lee, K., "Non-Invasive Sensor Technologies for Energy Management," Journal of Smart Systems, vol. 8, no. 2, pp. 45–60, 2020.

6. Kumar, V., et al., "Industrial IoT: A Review of Enabling Technologies and Applications," IEEE Transactions on Industrial Informatics, vol. 17, no. 3, pp. 1345–1358, 2021.

7. Rasheed, A., and Ahmed, F., "Smart Energy Solutions for High-Demand Industrial Applications," Energy Management Today, vol. 15, no. 1, pp. 98–110, 2022

8. S. M. Sharkawy, "Energy Management in Smart Industrial Systems," IEEE Transactions on Industrial Informatics, vol. 17, no. 5, 2021.

9. A. Kaur and V. Singh, "IoT-Based Real-Time Smart Energy Monitoring Framework for Industries," International Journal of Engineering Research & Technology (IJERT), 2022.

10. N. Kumar et al., "A Review on Smart Metering and Energy Analytics in Industrial IoT," Journal of Cleaner Production, 2023.

11. International Energy Agency (IEA), "Digitalization and Energy Efficiency in Industry," 2022.

12. S. Raj and P. Naik, "Cloud-Based Data Analytics for Smart Manufacturing," Proceedings of the 2022 International Conference on Smart Computing & Industrial Automation.

13. A. Ramesh, "Machine Learning for Predictive Maintenance in Energy Systems," Elsevier – Energy Reports, 2021.

14. Datasheet & documentation from energy monitoring sensors / microcontrollers used (e.g., ESP32, SCT-013 current sensor).

15. Mirani, A. A., Awasthi, A., O'Mahony, N., & Walsh, J. "Industrial IoT-Based Energy Monitoring System: Using Data Processing at Edge," IoT Journal, 2024.

16. Chaithra Ramdas, Meghan Suvarna, Deepthi D. Hegde, Akshay Nayak, & Bhavya S. "IoT Based Energy Monitoring System," IJARCCE, Vol. 13, Issue 2, 2024.

17. Ke Meng, Zhao Yang Dong, Zhao Xu, IEEE Transactions On Systems, Man, And Cybernetics: Systems, pp.1-10, (2017).

18. Mario Collotta, Giovanni Pau, IEEE Transactions On Green Communications And Networking, Vol. 1, no. 1, pp. 112-120, (2017).

19. Neeraj Kumar, Sherali Zeadally, and Subhas C Misra, IEEE Wireless Communications, pp.100-108, (2016).

20. Xin Wang, Yu Zhang, Tianyi Chen and Georgios B. Giannakis (2016), IEEE Journal on Selected Areas in Communications, Vol. 34, no. 5, pp.1348-1359

21. Ayan Mondal, Sudip Misra and Mohammad S. Obaidat, IEEE Systems Journal, pp.1-10, (2015)

22. Ke Meng, Zhao Yang Dong, Zhao Xu, IEEE Transactions On Systems, Man, And

23. Cybernetics: Systems, pp.1-10, (2017).

24. Mario Collotta, Giovanni Pau, IEEE Transactions On Green Communications And

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27. Cybernetics: Systems, pp.1-10, (2017).

28. Mario Collotta, Giovanni Pau, IEEE Transactions On Green Communications And

29. Networking, Vol. 1, no. 1, pp. 112-120, (2017).

30. Siyun Chen, Ting Liu, Feng Gao, Jianting Ji, Zhanbo Xu, Buyue Qian, Hongyu Wu,

31. and Xiaohong Guan, IEEE Communications Magazine pp. 27-33, (2017).

32. S. L. Arun, M. P. SelvanIEEE Systems Journal pp.1-12, (2017).

33. Daniel Minoli, Kazem Sohraby, Benedict Occhiogrosso, IEEE Internet Of Things

34. Journal Vol. 4, no. 1, pp.269-283, (2017).

35. Bharatkumar V. Solanki, Akash Raghurajan, Kankar Bhattacharya, IEEE

36. Transactions on Smart Grid Vol. 8, no. 4, pp.1739-1748, (2017).

37. H. S. V. S. Kumar Nunna, Swathi Battula, Suryanarayana Doolla, IEEE Transactions

38. on Smart Grid, DOI 10.1109/TSG.2016.2646779, pp.1-12, (2016).

39. Neeraj Kumar, Sherali Zeadally, and Subhas C Misra, IEEE Wireless

40. Communications, pp.100-108, (2016).

41. Xin Wang, Yu Zhang, Tianyi Chen and Georgios B. Giannakis (2016), IEEE Journal

42. on Selected Areas in Communications, Vol. 34, no. 5, pp.1348-1359.

43. Ganesh Kumar Venayagamoorthy, Ratnesh K. Sharma, Prajwal K. Gautam and

44. Afshin Ahmadi, IEEE Transactions on Neural Networks and Learning Systems, Vol

45. 27, no. 8, pp.1643-1656, (2016).

46. Ayan Mondal, Sudip Misra and Mohammad S. Obaidat, IEEE Systems Journal, pp.1-

47. Ke Meng, Zhao Yang Dong, Zhao Xu, IEEE Transactions On Systems, Man, And

48. Cybernetics: Systems, pp.1-10, (2017).

49. Mario Collotta, Giovanni Pau, IEEE Transactions On Green Communications And

50. Networking, Vol. 1, no. 1, pp. 112-120, (2017).

51. Siyun Chen, Ting Liu, Feng Gao, Jianting Ji, Zhanbo Xu, Buyue Qian, Hongyu Wu,

52. and Xiaohong Guan, IEEE Communications Magazine pp. 27-33, (2017).

53. S. L. Arun, M. P. SelvanIEEE Systems Journal pp.1-12, (2017).

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56. Bharatkumar V. Solanki, Akash Raghurajan, Kankar Bhattacharya, IEEE

57. Transactions on Smart Grid Vol. 8, no. 4, pp.1739-1748, (2017).

58. H. S. V. S. Kumar Nunna, Swathi Battula, Suryanarayana Doolla, IEEE Transactions

59. on Smart Grid, DOI 10.1109/TSG.2016.2646779, pp.1-12, (2016).

60. Neeraj Kumar, Sherali Zeadally, and Subhas C Misra, IEEE Wireless

61. Communications, pp.100-108, (2016).

62. Xin Wang, Yu Zhang, Tianyi Chen and Georgios B. Giannakis (2016), IEEE Journal

63. on Selected Areas in Communications, Vol. 34, no. 5, pp.1348-1359.

64. Ganesh Kumar Venayagamoorthy, Ratnesh K. Sharma, Prajwal K. Gautam and

65. Afshin Ahmadi, IEEE Transactions on Neural Networks and Learning Systems, Vol

66. 27, no. 8, pp.1643-1656, (2016).

67. Ayan Mondal, Sudip Misra and Mohammad S. Obaidat, IEEE Systems Journal, pp.1-

68. 10, (2015)

69. Ke Meng, Zhao Yang Dong, Zhao Xu, IEEE Transactions On Systems, Man, And

70. Cybernetics: Systems, pp.1-10, (2017).

71. Mario Collotta, Giovanni Pau, IEEE Transactions On Green Communications And

72. Networking, Vol. 1, no. 1, pp. 112-120, (2017).

73. Siyun Chen, Ting Liu, Feng Gao, Jianting Ji, Zhanbo Xu, Buyue Qian, Hongyu Wu,

74. and Xiaohong Guan, IEEE Communications Magazine pp. 27-33, (2017).

75. S. L. Arun, M. P. SelvanIEEE Systems Journal pp.1-12, (2017).

76. Daniel Minoli, Kazem Sohraby, Benedict Occhiogrosso, IEEE Internet Of Things

77. Journal Vol. 4, no. 1, pp.269-283, (2017).

78. Bharatkumar V. Solanki, Akash Raghurajan, Kankar Bhattacharya, IEEE

79. Transactions on Smart Grid Vol. 8, no. 4, pp.1739-1748, (2017).

80. H. S. V. S. Kumar Nunna, Swathi Battula, Suryanarayana Doolla, IEEE Transactions

81. on Smart Grid, DOI 10.1109/TSG.2016.2646779, pp.1-12, (2016).

82. Neeraj Kumar, Sherali Zeadally, and Subhas C Misra, IEEE Wireless

83. Communications, pp.100-108, (2016).

84. Xin Wang, Yu Zhang, Tianyi Chen and Georgios B. Giannakis (2016), IEEE Journal

85. on Selected Areas in Communications, Vol. 34, no. 5, pp.1348-1359.

86. Ganesh Kumar Venayagamoorthy, Ratnesh K. Sharma, Prajwal K. Gautam and

87. Afshin Ahmadi, IEEE Transactions on Neural Networks and Learning Systems, Vol

88. 27, no. 8, pp.1643-1656, (2016).

89. Ayan Mondal, Sudip Misra and Mohammad S. Obaidat, IEEE Systems Journal, pp.1-

90. 10, (2015)