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Making the Case for Industrial Internet of Things Based Energy Monitoring System for Manufacturing Facilities

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Abstract

With rising tariffs energy is fast becoming a significant contributor to manufacturing costs. Thus it becomes essential for businesses to reduce energy utilization without affecting the production. This can be achieved by monitoring energy consumption. This paper proposes a solution to identify energy saving opportunities by monitoring Energy Performance Indicators in manufacturing environments. The solution is developed as a result of interactions with industry people at every level to understand their expectations. Use of modern technology like Industrial Internet of Things and commercial products like ARC1000R and PowerGist are considered while developing the proposed solution.

Keywords: *Energy Monitoring System, Energy Performance Indicators, Industrial Internet of Things (IIoT), Manufacturing Industry.*

1. Introduction

Internet of Things (IoT) was introduced in 1999 and since then it has gained traction in domestic and commercial applications. It can be understood as *Things* or objects like sensors, devices, etc. connected to each other and cloud computer and communicating over the internet [1], [2]. Industrial IoT (IIoT) is IoT applied to industrial environments. In other words, IIoT is connecting industrial sensors working on industrial protocols communicating on industrial Machine-to-Machine (M2M) routers to generate humongous amount of industrial data that is captured, processed, stored and analysed by a software program on cloud computers. It provides advantages like data availability in real time, seamless integration of new and retro fit equipment, easy and faster implementation and many more [3], [4].

Energy consumption by humans across the globe is estimated to be 198,654 ZW in 2030 as compared to 116,614 ZW in 2000. Industrial use of energy has the biggest share in this as it consumes about 37% of total energy produced globally [5]. The manufacturing sector is slowly gearing up to environmental challenges and understanding the importance of reducing demand by improving efficiency. Its positive effects like lower energy costs, lower carbon footprint and enhanced socio-economic growth have already started showing [6]. To increase energy efficiency, there is a need for innovative methods to manage energy consumption in a structured manner [7], [8]. Management guru Peter Drucker's quote *"You cannot manage what you do not measure"* holds true for energy management. Guidelines from agencies like International Organization for Standardization (ISO), United Nations Industrial Development Organization (UNIDO) and The American Council for Energy Efficient Economy (ACEEE) recommend installing monitoring software for measurement and analysis of energy data for success of energy management programs [9]–[11].

To address the huge global demand for improving energy efficiency, this paper presents IIoT based Energy Monitoring System (EMS) for industrial use. IIoT based EMS has generated a huge interest in

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industry as well as academia. Extensive literature on the topic is available in the form of research papers, project reports, program documents, etc. This paper is a result of study of this literature and experience gained from the industry. During the study it was found that a lot of research has gone into topics like need of energy management, developing multi-level metering approach for effective monitoring, IIoT architecture for EMS, real time monitoring and defining Energy Performance Indicators (EnPI). This paper is a step towards building an industry ready EMS solution by combining theories from the available research material.

The paper is structured as different sections. Section 2 is Literature Review, Section 3 is IIoT based EMS – it presents technical overview of the proposed solution, Section 4 is Energy Performance Indicators – it explains various aspects related to EnPIs included in the solution and Section 5 is the Conclusion.

2. Literature Review

Studied literature is presented in the sequence of implementation of the proposed IIoT based EMS. First step of any project is to get management approvals, both strategic & financial. But factors like non availability of data, very less understanding of energy parameters, limited budget and unclear visibility of savings & efficiency are few of the biggest roadblocks in decision making process of implementing energy management programs [12], [13]. Implementing IoT in industrial environments is on the rise. Business and technical aspects of adopting IIoT to solve pressing problems of the manufacturing sector are explained in [4], [14]–[16]. An EMS project starts with energy meters to measure important electrical parameters. Traditional energy analysis was done from the monthly utility bills. But this approach missed many energy saving opportunities as individual machines were left out of the analysis. Thus it is important to place appropriate sub-meters for monitoring energy consumptions at different levels in industrial environments as explained in [17], [18]. As meters read various energy related parameters, this data needs to be taken to the server for further processing. A fast, low latency and higher throughput communication between energy meters and server without human intervention is required. From [19], it can be seen that IIoT devices like M2M gateways are capable of establishing 2 way communications between factory and servers. Out of various industrial protocols, utility of Modbus & Message Queuing Telemetry Transport (MQTT) is studied from [20]–[22]. The data thus reaching server is still in raw form, it needs processing so that it can be converted into information that can be consumed by humans. Here, EMS application serves the purpose. Features of EMS are i) to sanitize the incoming data, ii) store the sanitized data, iii) process the data with various algorithms, iv) provide real time monitoring and v) generate various reports & dashboards. Various aspects of centralized EMS are discussed in [6], [23]–[25]. Implementing EMS alone does not provide energy saving opportunities. To identify such opportunities certain energy related Key Performance Indicators (KPI) or EnPI should be developed and monitored continuously. Authors of [26]–[28] have discussed various EnPIs and their significance in finding inefficient energy usage.

Overall it is observed that research on IIoT and its usage for EMS is going in right direction. This paper takes the on-going research a step further. The solution proposed in the paper is capable of overcoming the barriers in decision making by harvesting the latest IIoT technology and creating opportunities for energy saving. The solution when implemented will help industries reduce energy consumption, GHG emission, losses and utility bills. It will also help in increasing productivity and profitability of a manufacturing plant.

3. IIoT based EMS

To explain IIoT based EMS, a hypothetical manufacturing unit with electricity as the sole source of energy is considered. Schneider $EM6400_{NG}$ energy meters are used to measure various electrical parameters. ARC1000R is used as M2M communications device. ARC1000R is a Wi-Fi enabled M2M device that communicates on Modbus & MQTT at the same time. PowerGist EMS is installed on the server. Reports and dashboards to monitor various EnPIs are built in PowerGist.

Architecture of the project consists of 4 layers; viz. Data Acquisition, Data Transmission, Data Processing and Data Consumption [7]. Schematic diagram of the actual project is seen in Fig 1. Each layer is explained as follows.

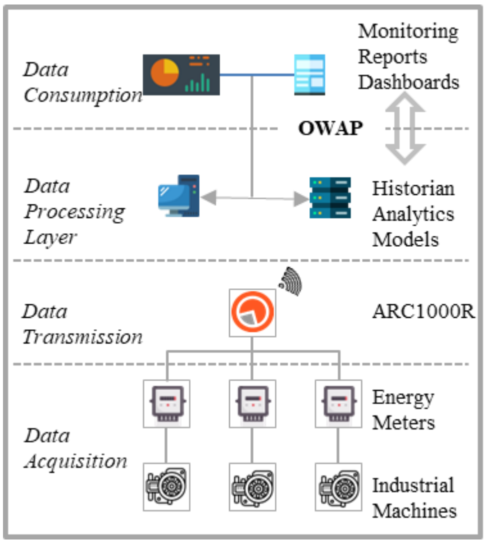

Fig 1: Schematic Diagram of 4 Layered Architecture for IIoT based EMS

3.1 Data Acquisition Layer

As the energy tariffs are rising, so are the energy bills. That is the reason why industry needs to think beyond data provided by distribution companies. There has to be a transparent way to analyse energy consumption across the network inside the plant. To achieve this, a sub-metering approach is taken. The entire network is divided in 3 levels as given in Fig 2 [17], [18]. Each level and its importance are explained below.

1. First level is marked as '*Incomer'* for monitoring main supply coming from utility company. It is important to monitor energy at Incomer Level as it directly reflects into monthly electricity bills.
2. Second level is marked as *'PCC/MCC'* for supply to different groups of machinery working in the same line of production. As shown in *Fig 2*, all machines on Assembly Line 1 are clubbed under one energy meter to measure the energy parameters of the entire Assembly Line. Similarly entire factory is divided into such groups and energy meter is installed for each group. Benefit of installing meters in this layer is that these groups can be compared on energy data. Another advantage is to calculate copper losses in the downstream circuit.
3. Third level is marked as *'Load Centres'*, it includes individual loads under each PCC/MCC. Energy meter is installed on each load centre as energy performance of each machine is identified here.

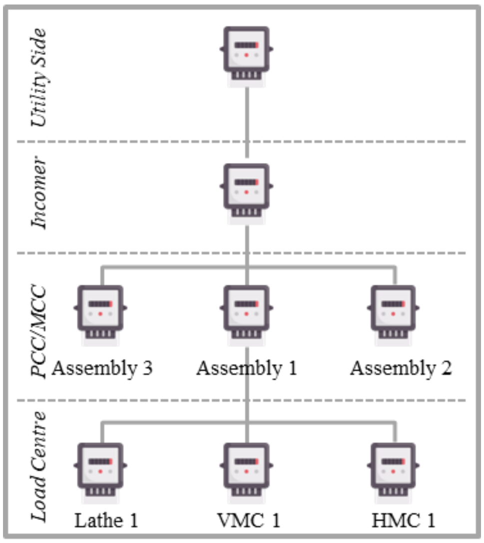

Fig 2: Multiple Layers of Sub-Metering Approach for Energy Monitoring

In this way a factory is strategically divided in 3 levels of energy consumption and meters are installed. Energy monitoring starts from Data Acquisition Layer as actual energy related data is generated by the meters installed.

3.2 Data Transmission Layer

This layer has 2 important functions namely, fetching data from energy meters using Modbus requests and transmitting this data to cloud server using MQTT communication. Usually 1 device is installed to perform each function; like PLC is used to read data from energy meters and M2M router is used to take this data to server. Since ARC1000R is available and it is capable of communicating on Modbus & MQTT at the same time, a single device suffices instead of 2. This reduces the setup cost of the project as requirement for communication hardware is reduced to half.

3.3 Data Processing Layer

In this layer the data reaches EMS. PowerGist sanitizes the data by filtering out the incomplete payloads received on MQTT topic. MongoDB is used as database where data from each energy meter is stored in separate collection. Next task in this layer is to prepare EnPI data. Python scripts, with algorithms that sift through entire collections and develop datasets required for further analysis, are installed.

3.4 Data Consumption Layer

This is the most important layer in EMS as the decisions are made here. This is also called as application layer as humans get an interface to access energy data. Users can utilize data in PowerGist in 4 ways; viz. a) Real Time Monitoring, b) Tabular & Graphical Reports, c) Dashboards & d) Alerts. An auto emailing feature in PowerGist, where reports are generated and emailed automatically at scheduled time, can also be utilized.

4. Energy Performance Indicators (EnPI)

Previously energy was considered as necessary overhead cost towards value creation in manufacturing industry. But with rising energy costs and competition, industries are forced to reduce expenditure on energy to stay relevant in the market. Energy Costs can be reduced by either reducing energy consumption or by reducing time for which energy is consumed or by increasing production by consuming same energy [28]. All this can be achieved only if corrective measures are taken at regular time intervals based on insights gained from analysis of EnPIs.

EnPI	Formula	EMS Function	Benefits	Metering Level	Assigned To	Frequency
Specific Energy Consumption	Energy Consumed / Products	Report - Auto Email	Reduce Unproductive Energy/Time	Level 1-2-3	Management / Department Head	per Shift / Day / Week / Month
Cost	Energy Consumed * Rate / Products	Report - Auto Email	Cost Reduction / Time Reduction	Level 1-2-3	Management / Department Head	per Shift / Day / Week / Month
Product Time	Energy Utilization Time / Products	Report - Auto Email	Higher Productivity	Level 1-2-3	Management / Department Head / Technicians	per Shift / Day / Week / Month
CO_2 Emission [29]	$8.2 * 10^{-4}$ * Energy Consumed	Report - Auto Email	Sustainable Development	Level 1-2-3	Management / Department Head	per Shift / Day / Week / Month
Active Energy	From Energy Meter	Report - Auto Email / Dashboard	Reduce Consumption	Level 1-2-3	Department Head / Technicians	per Shift / Day / Week / Month
Apparent Energy (KVAH)	From Energy Meter	Report - Auto Email / Dashboard	Reduced Electricity Bills (If KVAH Billing)	Level 1-2-3	Department Head / Technicians	per Shift / Day / Week / Month
Reactive Power (KVAR)	From Energy Meter	Report - Auto Email / Dashboard	Reduced Losses / Improved System Health	Level 1-2-3	Department Head / Technicians	per Shift / Day / Week / Month
Voltage Unbalance	From Energy Meter	Dashboard	Improved Health	Level 1-2-3	Department Head / Technicians	Instantaneous
Maximum Demand (MD)	From Energy Meter	Report - Auto Email / Dashboard / SMS	Avoid Penalties	Level 1	Management / Department Head	per Month
Power Factor (PF)	From Energy Meter	Report - Auto Email / Dashboard / SMS	Penalties Avoided / Rebates Earned	Level 1	Management / Department Head	per Month

Table 1: Energy Performance Indicators (EnPI) by PowerGist

Energy performance in a manufacturing plant depends upon factors like efficiency of machinery, its state of maintenance, production process and human resources working on the machine. Thus, indicators should consider these factors and reflect energy performance. Significance of energy consumption varies at different metering levels. EnPIs at Incomer level provide general idea of

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consumption and expenses of a factory, whereas those at PCC/MCC level provide benchmarking for similar processes in the factory while Load Center Level deals with actual machines and provide information about its efficiency and cost per part produced. Moreover EMS would not serve the purpose if responsibility of taking actions is not assigned to a person or a department [26]. These factors are considered while PowerGist EnPIs for manufacturing industry were developed. Table 1 provides detailed information about each EnPI. By monitoring these EnPIs, it becomes easier for responsible persons to take informed decisions. The decisions can be

a. Replacing old with new high efficiency equipment to reduce energy consumption, cost & time.
b. Installing Automatic Power Factor Correctors to maintain PF at unity and reduce Reactive Power.
c. Reallocating single phase loads equally on 3 phase supply to reduce Voltage Unbalance.
d. Time required to manufacture 1 part can be reduced either by improving process and training human resources.
e. Implementing any of the above results in reducing GHG emission.
f. Operation scheduling to avoid rise in Maximum Demand.

In the table it can be seen that production data is used in many EnPIs. A form was developed in PowerGist where user can feed production details of each machine. In this way production data required for EnPI is maintained in the same application as that of energy data. This avoids the use of excel or other tools for monitoring important indicators.

5. Conclusion

The IIoT based EMS is an essential component of energy management programs. The proposed solution can be an attractive proposition for factories that have limited budgets. A multi-level sub-metering approach provides flexibility for companies to start small and scale up when needed. ARC1000R eliminates the need of 2 devices by replacing them, bringing the cost down. Cloud hosted EMS further reduces the initial cost as companies do not need to invest in hardware and software licences.

The EnPIs listed in Table 1, provide in-depth analysis of the energy consumed and costs associated, all to the last machine. This works as Decision Support System (DSS) and helps authorities initiate energy saving actions. Reports, dashboards & Alerts encourage personnel on floor to change their behaviour and improve the way the energy is consumed on their stations. This results in efficient operations, reducing energy consumption.

With PowerGist EMS opportunities for reducing energy consumption can be identified and companies can set energy saving targets. Pre-developed EnPI help track targets and additional EnPIs can be customized as per the requirement.

In conclusion, the proposed IIoT based EMS is an industry ready solution and can be implemented in any manufacturing plant.

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