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Energy Management System for Smart Factories

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Abstract – *An efficient energy management system was developed to reduce the energy consumption by identifying the wastage of power and abnormalities in the consumption pattern. The product, termed as Energeiá was developed and this can be deployed in smart factories. Energeiá is a real time monitoring system that eases the work of the facility managers at a smart factory by relieving them from the burden of doing regular manual energy audits, which are both time-consuming as well as inaccurate. The system can provide insights about machines and appliances by recognizing their unique signatures and it also generates power usage graphs to predict faults and prevent failures. This system helps the smart factories in taking necessary actions, which leads to 20% savings in their electricity bills.*

Key Words: Factory energy management, signature analysis, time series analysis, power utilization, energy audits.

1. INTRODUCTION

Energy is one of the key factors which is required for the socio-economic growth of a country. As a rapidly developing nation, India is highly vulnerable to the energy crisis. Energy utilization of Indian manufacturing industries is among the highest in the world. Wastage of energy in Indian manufacturing industries is also very high due to various factors.

The industrial sector accounted for nearly 44% (532 billion kWh) of total electricity consumed (1,208 billion kWh) in India for the year 2015. Even considering 30% of this energy input is wasted by industries, the wastage amounts to 160 billion kWh annually, equivalent to 20,000 MW of coal-based power generation capacity. By implementing efficient energy management systems around 15-35% of energy wastage can be reduced. Indian industry's energy consumption costs amount to nearly 30% of total production costs and this comes next only to the material procurement costs.

The existing energy monitoring systems only provide data about the power usage patterns and they lack an analytical tool, which makes the interpretation of data difficult. The energy management systems currently deployed in large-scale manufacturing industries use energy monitors and power meters and these have been installed in most of the machines. To analyse the data acquired from these power meters, tedious manual audits are necessary. An external energy auditor spends nearly one-month time in these manufacturing industries, studying every equipment. This study is performed to obtain insight reports, which is tedious as well as time-consuming task. The small and medium scale manufacturing industries do not have access to affordable energy management solutions to control and mitigate their energy losses. In the current scenario, there is a huge demand for efficient energy management systems for smart factories. Beneficiaries of energy management system for smart factories would be Facility managers, Energy auditors and Chief Operating Officers.

The facility managers and energy auditors of smart factories face huge challenges in monitoring the energy consumption pattern of various equipment and devices and implementing effective solutions for reducing the wastage of power. The current solutions or alternatives available are manual audits, usage of energy meters and implementation of basic energy management systems. The prevailing solutions involve tedious manual audits at regular intervals. However, the expenses incurred for manual audits are very high and they are also prone to errors and tend to be less accurate. The effectiveness in reduction of energy consumption is low by implementation of such energy management systems. The energy meters just provide basic power consumption data and they lack an integrated analytical tool. No insights or suggestions could be obtained from this system. The lack of an analytical tool is a problem for facility managers as they should assume some data and perform manual calculations to get the necessary insights.

2. LITERATURE REVIEW

Due to the advent of 4th industrial revolution, many existing factories are being converted into smart factories. Researchers have successfully designed and implemented an IoT based electrical power monitoring and data collection system. This system is capable of monitoring the energy consumption and sensing the abnormal power consumption in a smart factory. This will lead to improvements in not only cost-efficiency but also product quality (Eun Kim *et al.*, 2019).

In the recent times, smart factory technology is rapidly evolving where the smart machines collaborate with each other and with the customers. The prerequisites for installing a smart factory are zero waiting-time, inventory, defects and down-time (Suk Keun Cha *et al.*, 2015).

A survey was conducted on the important processes like fault detection, prediction and prevention in Industry 4.0 by the researchers and recent developments in machine learning-based solutions were presented by them (Angelos

Angelopoulos *et al.*, 2019). The various cloud, fog and edge architectures were studied in detail, highlighting their importance in acquiring manufacturing data to train the machine learning algorithms. Researchers also provided details regarding the machine learning based human–machine interaction techniques.

Researchers have demonstrated an energy management system for smart factories based on context-awareness. IoT sensors are utilized in such smart factories to collect the personnel, equipment and environmental data (Hyunjeong Lee *et al.*, 2016). The smart factory is composed of the three layers. The data collection and control system are the first layer, which collects and sends environmental and control data to the second layer. The second layer is the energy management system based on context-awareness layer. This layer analyses the data and infers the context from them. Finally, the energy service layer provides energy management services to users through monitoring and controlling the status of energy consumption.

Researchers have presented a case study of a beverage factory where an IoT based sensing technology was installed. This system was based on the embodied product energy model and it helped to achieve significant savings in power consumption. (Sandeep Jagtap *et al.*, 2019). The system proposed by the investigators enabled collection of real-time energy data to support energy efficient operational decisions. This led to optimized power consumption and significant savings of nearly 163,000 kWh in the year 2017.

The Facility Manager in a manufacturing industry monitors the individual energy consumption of various equipment and devices and thereby he identifies the wastage of power. After this, the Facility Manager initiates steps to reduce the wastage of power effectively. Despite these measures, they achieve only minimal savings in cost which does not help their cause. Based on the literature review it was determined that at least 20% of the energy loss can be minimized significantly if better 'Energy Management' strategies are implemented. To surmount these difficulties, a product named as Energeiá was developed and this can be deployed in smart factories. Energeiá is a real time monitoring system that eases the work of the facility managers at smart factories.

3. ENERGY MANAGEMENT SYSTEM FOR SMART FACTORIES

The smart factory energy management system termed as Energeiá, can be effectively utilized by facility managers and energy auditors in manufacturing industries for minimizing wastage of energy. Energeiá provides precise and accurate real-time insights, unlike manual auditing methods which are tedious and time-consuming and energy monitors that must be attached to each device. Implementation of Energeiá can prevent energy wastage by 20%.

This product consists of a modular current sensing device that is non-invasive and which can be clamped onto the MCBs. All the MCBs are connected to a current sensor that transmits real-time data through a nRF (near Radio Frequency) node. All the nRF nodes send data to the nRF gateway which is connected to a microprocessor that performs the device split up by using machine learning algorithms. The machine learning algorithm identifies the unique signatures of the devices and finds the split-up of the main signal acquired from the MCB and identifies the individual devices connected in the line by using the signature signal analysis. The various components of Energeiá like the micro-controller module, non-invasive current sensor and nRF24L01 Transceiver are displayed in Figure 1.

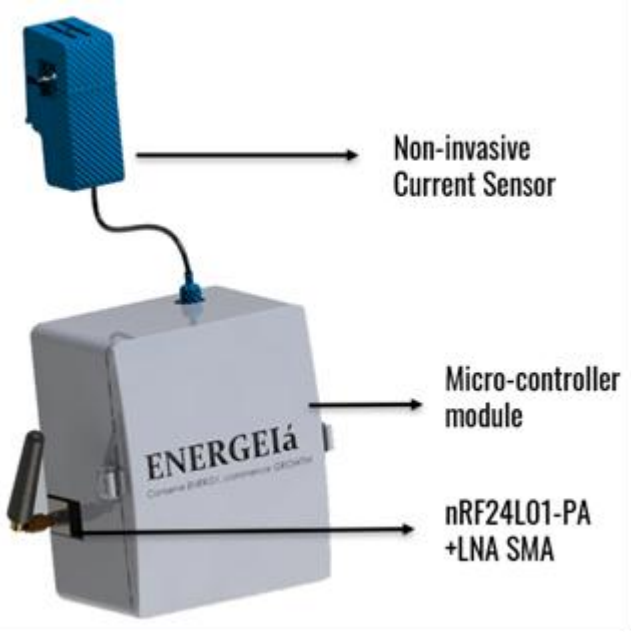

Fig -1: Energeiá – Energy Management System

The product can perform time series analysis and signature analysis. Time series analysis is the process of prediction and signature analysis is a process of splitting the combined MCB signal and finding the individual equipment. The signature patterns of various connected devices are measured. Once the devices' signature is recorded, it is possible to track the power consumption and the duration of time for which the device is switched on. The power usage pattern of individual devices can be monitored. Over time, the system gains awareness of all devices connected to the MCBs and gives us detailed, analytical, accurate, real-time and understandable insights about power usage patterns. Energeiá records the signature patterns of the various devices and uniquely distinguishes each device using machine learning algorithms which helps to find faulty machines and identify devices that use the most energy and provide a clear history of various equipment usage.

All the insights will be displayed to the user through the web application. The cases were designed in such a way that their sizes are compact and thus they are portable. In future,

it is planned to build a factory automation system combined with a decision-making system and predictive analysis for each device. The block diagram of Energeiá is shown in Figure-2.

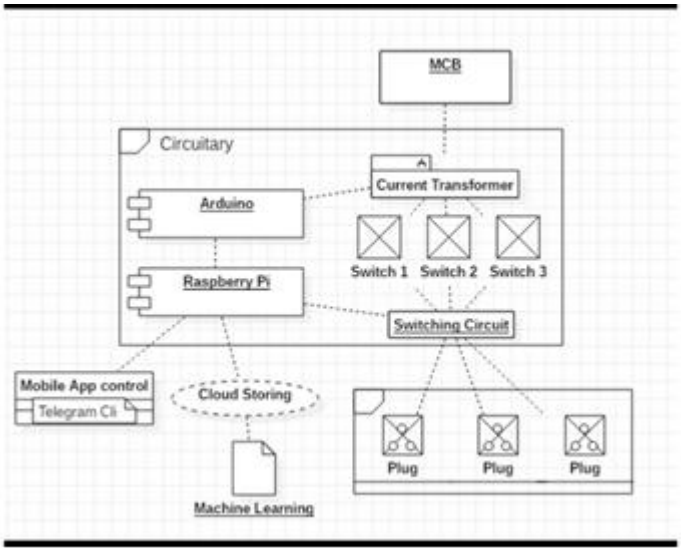

Fig -2: Block Diagram of Energeiá

3.1 Features and Functionalities of Energy Management System

The features and functionalities of Energeiá energy management system for smart factories are:

- ✓ Records power usage of devices/equipment and provides detailed, analytical, accurate, real-time and understandable insights.
- ✓ 24/7 monitoring and data acquisition.
- ✓ Identifies power consumption anomalies of machines/equipment.
- ✓ Effectively reduces the time for energy audits.
- ✓ Helps reduce energy usage and thereby conserving and reducing the cost of electricity bill.
- ✓ An alert system is available, which gives quick notifications to the facility manager, in case of any unwanted usage of power by any device or when the equipment is being overclocked beyond a certain time.
- ✓ Faulty machines can be identified by detecting any anomaly in the functioning of the devices.
- ✓ A web application which will display the detailed reports.
- ✓ Minimal product training is required, since the number of variables presented to end-user for modification is low.
- ✓ The intuitive dashboard could be used with a minimal learning curve. Minimal customization required before switching to operational mode.
- ✓ The product can be easily integrated to the existing production line and works through the 'plug and play' mechanism.
- ✓ Saves 20% of electricity losses occurring in the smart factories leading to lowered production costs for components and thereby providing higher revenue generation.
- ✓ It can be used in hospitals, homes, commercial complexes and multiplexes for energy management.

4. COMPONENTS OF ENERGEIá

The important components of Energeiá energy management system are current sensor, micro-controller, processor and nRF nodes.

4.1 Current sensor

The system was initially built with the deployment of an invasive current sensor (ASC758). The deployment of this sensor was not feasible as the wires of smart factories are needed to be tampered and severed to attach this type of sensor. Therefore, a non-invasive CT sensor (SCT013) was deployed instead of the previously mentioned sensor as they are portable and also easy to deploy.

4.2 Micro-controller

Arduino Nano micro-controller is used to interface with the current sensor because of its compact size and less power consumption. The PCB fabricated for the module requires very less number of pins and this is best suited for the required operation.

4.3 Processor

Raspberry Pi 4 processor was used to implement the machine learning algorithms and for transferring the data from the gateway to cloud for visualization using web applications. This processor can perform machine learning processes with minimal usage of power. A processor is used to record data for the plug and play training kit and for signature acquisition. The acquired signal is then fed to the gateway, where the machine learning is implemented.

4.4 nRF node

The communication method which was first tried was Wi-Fi and it was found out that the industries have many areas that are not covered with Wi-Fi signals. Because of this reason, the communication method was switched to nRF, which has a base range of 100m. This base range could be scaled up to 1000m with another model that comes with a SMA (Sub-Miniature Version A) antenna. LoRaWAN which is

a Low Power, Wide Area (LPWA) networking protocol could also be utilized in the future to boost the range.

4.5 Technical Specifications for Components

Controller: Raspberry PI 4

Connectivity: nRF24L01 Transceiver

Battery: 9V Battery

Cloud platform: Firebase

HMI: Web Application

Sensors: Current Transformer SCT-013-030

5. CONCLUSIONS

An efficient energy management system was developed to reduce the energy consumption by identifying the wastage of power and abnormalities in the consumption pattern. Energeiá is a real time monitoring system that eases the work of the facility managers at a smart factory by relieving them from the burden of doing regular manual energy audits, which are both time-consuming as well as inaccurate. The system can provide insights about machines and appliances by recognizing their unique signatures and it also generates power usage graphs to predict faults and prevent failures. This system saves 20% of electricity losses in the factories leading to lowered production costs and thereby providing higher revenue generation.

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