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Smart Energy Monitoring Node

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ABSTRACT

The current phase in the industrial revolution, "Industry 4.0" has transformed the concept of automation and robotic precision. With increased automation follows complex sets of machines. And complex set of machines bring in complex energy usage patterns. The current systems measure the power consumed in a unit time but, does not comment on the input obtained at the machine end. The proposed solution gives an idea about measuring the AC input power fed to the machine and progressively calculate the amount of power consumed and the power lost during the machine execution cycle. The numerical data does not always give the user can opt understanding about the parameters thus, real-time adjustable charts are used to justify the insights. Dynamic data processing is implemented to reduce the latency.

The Embedded System consists of an 8-bit MCU attached with AC Voltage and AC Current Sensors, Wi-Fi transceiver, OLED display and has a backend supported with Python, MySQL, PHP and HTML-CSS.

***Keywords*—** Embedded Systems, Energy Monitoring, Flask, RMS AC Power Measurement

I. INTRODUCTION

Energy can be defined as the ability to do work. In Electrical and Electronic systems, work can be defined as the potential or the force required to move a charged particle from point A to point B in a particular medium/field. Mathematically it can be expressed as:

$$W = q * V * d$$

where W – Work done by the charged particle
q – Charge of the particle
d – uplift distance (dist. between 2 points in space) from the reference plane

The recent advancements in the manufacturing and production sector need energy efficient and energy conserving machines. In order to work on energy utilization and conservation, we must understand the possible sources of energy generation. The untreated natural resources being the renewable sources of energy like the Solar, Hydro, Water etc which are non-exhaustible. Whereas, the naturally available products and derivatives of fossil fuels are known to be non-renewable sources of energy which, upon excessive usage get exhausted. We thus, need to divert the current load of energy utilization on some of the renewable sources of energy. To achieve this goal, first we need to understand the prime sites of energy consumption in the residential, industrial and commercial areas. We then need to measure the energy utilization through the [1]I-to-O method. This method helps us to understand the input power characteristics for a machine.

Literature Survey

The Energy supplied to the consumers includes 4 major steps namely: a) Step-up the generated voltage b) Transfer the energy from the generators to the distribution sites c) Step-down the received energy and d) Distribute the stepped down energy. The studies conducted at [1] give us an idea about the amount of energy and linked energy getting lost during the 4 phases of energy supply. As per the study, the average power/energy loss taking place between the energy generation and distribution, is found out to be 8-15%. The stage specific energy losses are:

1. 1-2% during the Initial Step-up phase
2. 2-4% during the transmission phase
3. 1-2% during the Secondary Step-Down phase
4. 4-6% during the actual energy distribution to the consumers

To understand the importance of the subject, consider a machine with a functional, optimum input power of say 200W. To work efficiently, the machine must be provided the rated power for it but, practically it faces losses due to the steps aforementioned. As an example, let's consider a loss of 10%, being observed at the input end, then the net input power fed to the machine turns out to be 180 W with a loss of 20W. With time and age of the machine, this loss tends to increase.

Important research carried out at [2] tells us about the energy losses taking place inside some common AC coupled DC devices like mobile chargers or power banks. As per the study, 1-3W of power gets wasted in the form of heat with an input of 5W. The loss of power taking place at the site comes out to be 50-60%. The research and study indicate that, the power wastage is majorly caused due to the step-down transformer used in the chargers. With every charging cycle, the transformer

[1] I-to-O method: This method of energy measurement includes Input Power measurement directed towards the machine and then the Output Power utilized by the machine.

steps-down the input voltage to the rated output of the charger w.r.t the necessary application. Every stage in the power delivery penalises the charger with an average loss of 1-2%. With each cycle and the age of the charger, the load connected and other functional parameters, these losses increase and hence contribute in wasting energy on a consistent basis.

As per few studies carried by [3], Oil and Gas extraction industry is listed as the highest energy wasting industries. The extraction of oil, gas and petroleum products require a high amount of raw power and crude sources of energy which are either powered through fossil fuels like coal, petrol or petroleum products or by electrical generators where the energy requirements are comparatively less. Power generation industry lists at 4th rank on the list of highest energy wasting industries at 33% energy wastage that of generated. This proves to be the very first reason why measurement of energy loss is necessary.

The reference book Industrial Power Systems, [4] and the book on Electric Distribution Network and Planning, [5] describes the need of energy for today's complex electrical power systems and the use of small-scale, locally operated renewable energy sources. It discusses about the requirement of additional tools and operative methods that be included in the current grid for residential and industrial users. It examines the integration of the new sources of energy with the legacy systems of centralized energy converters, as well as how the new technologies can operate effectively in isolated systems. Industrial power distribution, lighting, motor control and protection are discussed in detail. It also helps us identify the areas where we need to replace the pre-existing systems with the new ones.

The work done in Smart Energy Monitor [6], [7] discusses about the ability of the embedded systems to convert the traditional energy meters into smart meters by integrating Wi-Fi, relay modules and other necessary hardware circuitry. For integrating the IoT applications with the embedded systems we need a compatible interface with the embedded system. The microcontroller board acts as the MPU of the system and Wi-Fi Technology being the connecting tissue between the hardware and the software. This provides a platform for the user to monitor and control the appliances.

Some research work done in the Smart Grid Technology like [8] and [9] gives us a clear idea about the vast application of the designed solution in the industrial, residential and commercial sector for Green Energy, Energy Conservation and in turn reducing the capital expenditure. The designed node can be easily integrated with the Smart Grid Technology and the preinstalled nodes. It can assist the Smart Grid nodes by sending the necessary energy consumption information by the appliances connected to the node or a system of machines connected to the node.

II. METHODOLOGY

The current phase of the modern industries, the 'Industry 4.0' aims to develop advanced and sophisticated machines which are not only more efficient but also energy conserving and environment friendly. The current method which is employed for calculating the energy consumption of a machine or a system of machines is calculated is by the traditional means of the ESP (Electricity Service Provider) meters which act as surrogate markers and are not the true indicators of the energy consumption. The reason being the fact that, they work on an Output-to-Output[2] method of measurement.

For e.g. – Let's consider a machine which requires say 600W of power to work optimally. Now, this required power can be fed to the machine with variety of combinations, say 100V*6A, 50V*12A or 200V*3A and so on. The ESP meters only give us the energy consumption of the machine taking place in a fixed amount of time which is expressed in 'Units'. The aforementioned power combinations experienced by the machine are not recorded in the traditional meters, thus not allowing the user to understand the usage patterns of the machine. The change in voltage and current consumption might signal towards potential loss of power or could also indicate at a particular problem. An increased current consumption from the source to keep the load power constant, could lead to loading effect issues in the distribution sections which could lead to potential failure of the machine or the entire transmission system.

This problem can be mathematically expressed with energy equations for theoretical cases as:

$$\text{Energy Consumed} = \text{Input Energy} \tag{2}$$

But the practical application, the machine does loose some of the input power supplied to it in the form of heat. Thus, the efficiency of the machine and consequently its power factor is hampered. The power loss taking place can be due to multiple reasons. Internal losses, external losses, material losses can be a few of them. The external losses include the transmission losses, connector losses etc. whereas the internal losses include internal resistive losses, inductive losses, current coupling losses etc. The practical energy consumption of the machine can thus be mathematically expressed as:

$$\text{Energy Consumed} = \text{Actual Energy Consumption} + \text{Losses} \tag{3}$$

[2] Output-to-Output – This is the traditional method of calculating the energy consumption of a machine or a group of machines. It simply calculates between the energy output of the electricity sub-station and the energy output of the machine. It does not take into consideration the input that is actually taken in by the machine during its entire cycle of operation. Thus, they act as the surrogate markers of the energy consumed by the machines.

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III. CURRENT SYSTEMS

The current systems deployed for energy measurement include the Energy meters provided by the ESPs. They work on the principle of counting the number of units-energy consumed by the device connected to it where 1 Unit = 1kWh of energy. The meters do not consider, the amount of energy that is actually received by the machine or how much does it actually need to work optimally.

As an option to the manual measuring and noting the energy consumption, some research experiments like the ones done in employ embedded systems designed specifically to automate the process of monitoring and

noting the unit consumption. IoT applications working over dedicated platforms help the embedded system to work and the communication protocols employed helps it to communicate with the system over wireless medium. Few other research projects have employed different algorithms which are responsible to predict the energy utilization, inspired from the historical data available of the machine or system of machines. But the energy measurement technique still remains the same.

Figure 1: Current Systems with automatic ESP meters

IV. PROPOSED SYSTEM

The proposed system includes 2 major blocks:

1. Hardware system – It consists of hardware PCB based circuitry for Power and Energy Measurement along-with the IoT and communication modules.
2. Software system – It consists of RDB management with database connectivity, data analysis and chart plotting algorithms for the sensed energy data.

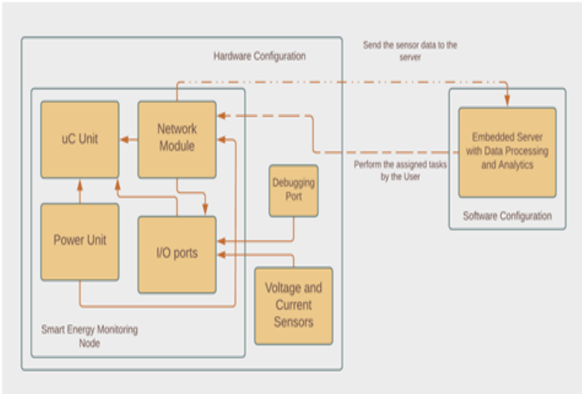

Figure 2: Block Diagram of the Smart Energy Monitoring Node

The proposed system inculcates the input power measurement provided to the machine. This allows us to understand the actual power fed into the system. This is the methodical difference between the present systems and the proposed solution. The proposed system calculates the input energy that is supplied into the system and then simultaneously calculates the energy consumed by the machine.

The hardware section consists of the Voltage and Current sensors which are employed for sensing the power. It also consists the required amplifiers, supporting IC's and allied circuitry for signal processing. The MPU is based on an 8-bit microcontroller which functions as the main processing node for the entire system. The data generated from the sensors is sampled using the Analog to Digital Converters of the microcontroller which is then mapped as per the input power. The sampled and mapped data is then sent over to the database using the Wi-Fi enabled board.

The software section consists of a RDB management system with a local server hosted on a local network where the real-time energy values get stored and are routed to the client-side UI. The UI consists of a dashboard which displays the real-time sensor values of the voltage, current, power and energy which helps the user to identify the high-power devices with the time period in which those machines worked. Visual data always helps us understand the data more efficiently and allows us to give a better idea of the data flow or its characteristic pattern.

To achieve this, JavaScript, PHP, HTML-CSS and Python are used to analyze the data and plot the charts as per appropriate scales.

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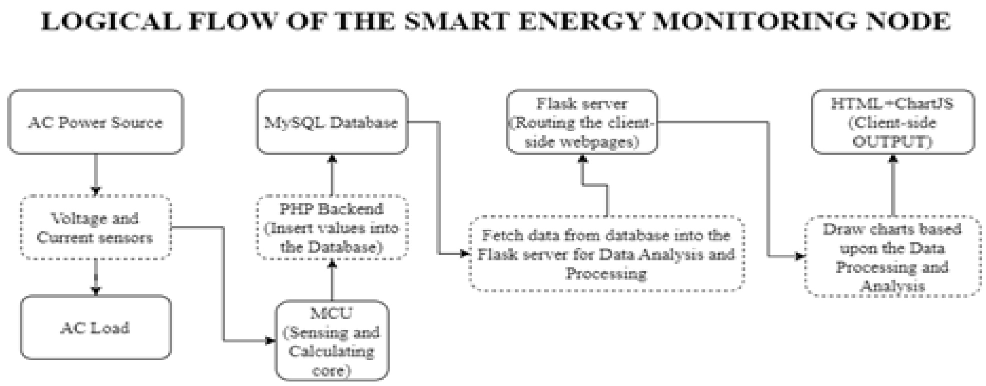

Figure 3: Logical flow diagram of the proposed solution

The logical flow of the proposed solution is as shown above and has sequential and parallel processing methods of obtaining the best results. The most important and key feature of the entire project is that, the AC power measurement is carried out through non-invasive methods of power measurement thus, the connected load utilizes its optimum power for its execution cycle. It thus does not interfere or drop any power during the load's execution cycle. The firmware section of the hardware blocks is designed using Embedded C and the necessary software back-end is programmed using Python, HTML-CSS, JavaScript and PHP. Python is used for updating real-time data generated from the embedded system, Embedded C acts as the basic firmware for the microcontroller and Wi-Fi board for sensing, measuring and transmitting the data respectively from the hardware section to the designed database. The Client-side UI or the front-end is designed using HTML-CSS and JavaScript which has the role of fetching the data values from the database, processing the data and then displaying it in the form of graphs and charts on the webpage for better understanding of the generated data, visualizing the visible data patterns in it and an overall good user experience.

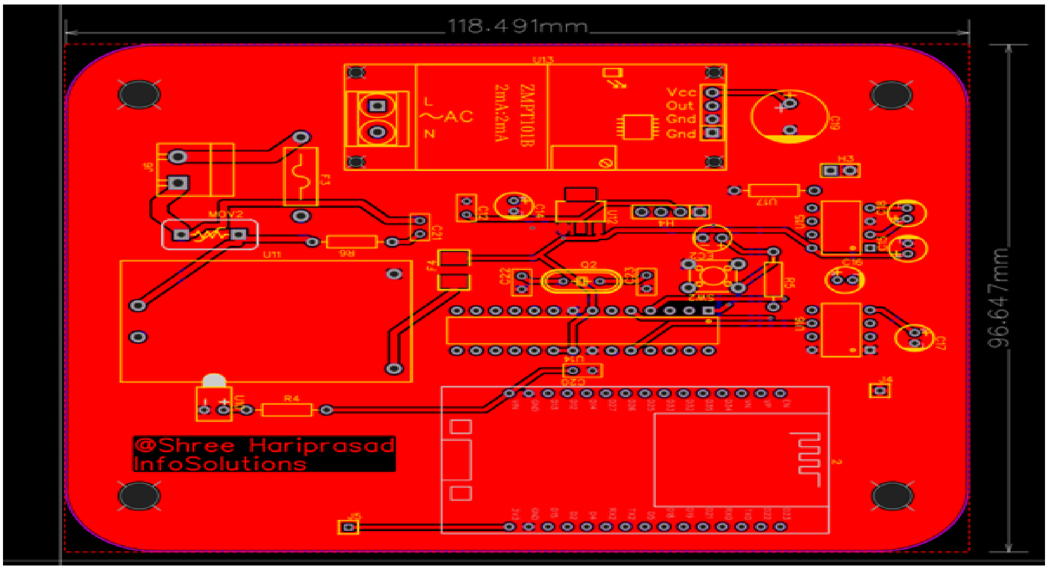

Figure 4: PCB Prototype of the project

V. RESULTS AND DISCUSSION

The proposed solution was tested upon 3 types of loads including purely resistive, inductive and low power switching loads. The data obtained from the experimentation is as follows:

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Table 1: Experimental Result analysis of the Proposed System

Sr No.	Test Load	Actual AC Voltage		Actual AC Current		Sensor measured AC Voltage		Sensor measured AC Current	
		ON	OFF	ON	OFF	ON	OFF	ON	OFF
1.	Heating Iron (1600W)	220-224V	235-240V	5.9-6.02A	0.00A	221-225V	236-241V	6.0-6.08A	0.00A
2.	200W Bulb Level 1	233-237V	234-238V	0.14-0.16A	0.00A	234-236V	234-237V	0.13-0.15A	0.00A
3.	200W Bulb Level 3	230-235V	233-238V	0.31-0.33A	0.00A	229-234V	233-237V	0.32-0.34A	0.00A
4.	200W Bulb Level 5	229-234V	234-239V	0.7-0.8A	0.00A	229-234V	233-237V	0.69-0.81A	0.001A
5.	Drilling Machine	225-232V	235-239V	1.2-1.5A	0.0005 A	224-233V	236-238V	1.1-1.6A	0.000A
6.	700W Food Processor	220-225V	237-240V	2.8-3.1A	0.00A	222-226V	236-241V	1.7-2.1A	0.00A

The project experimentation was carried out 4 different types of loads namely: 1) Low power resistive load with variable power 2) High power resistive load 3) Low power inductive load 4) High power adjustable load The resistive load being an ideal load for power measurement, gives us an idea about the solution's working territory in the best possible case. On the other hand, the inductive loads are known to be one of the worst types of loads due to their current lagging phenomenon and helps us understand the operation of the solution in the worst cases. In order to successfully represent the power and energy measurements, the design is made in such a way that, the proposed solution would work excellently during worst possible cases.

The adjustable power for an appliance can be achieved using 2 main methods, either by varying the voltage or by varying the current. In this particular situation, varying current proved to be a more feasible approach than an adjustable voltage method. This power variable parameter helps us to know about the accuracy and efficiency of the project at greater depths.

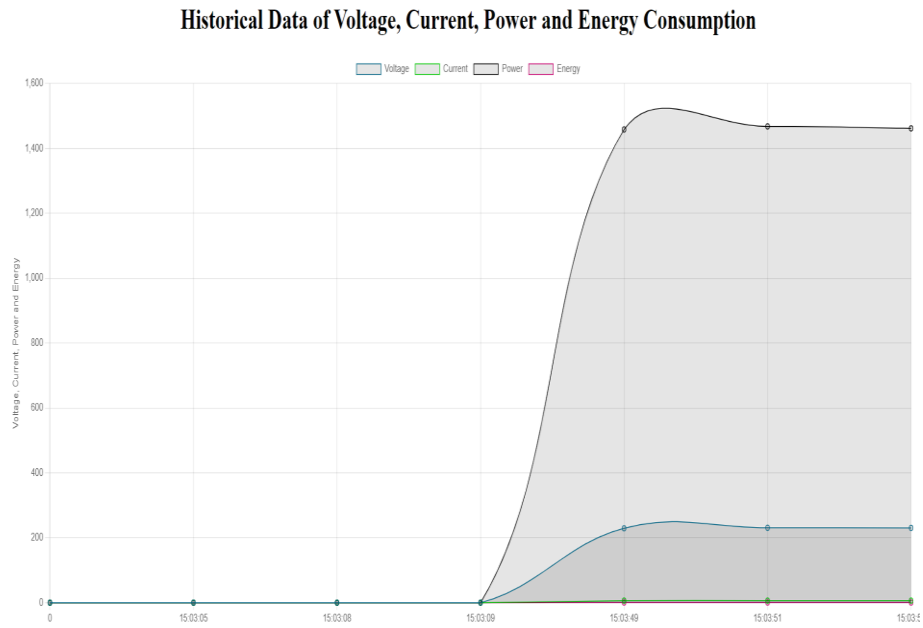

Figure 5: Historical Data for Voltage, Current and Power displayed on the Client-side

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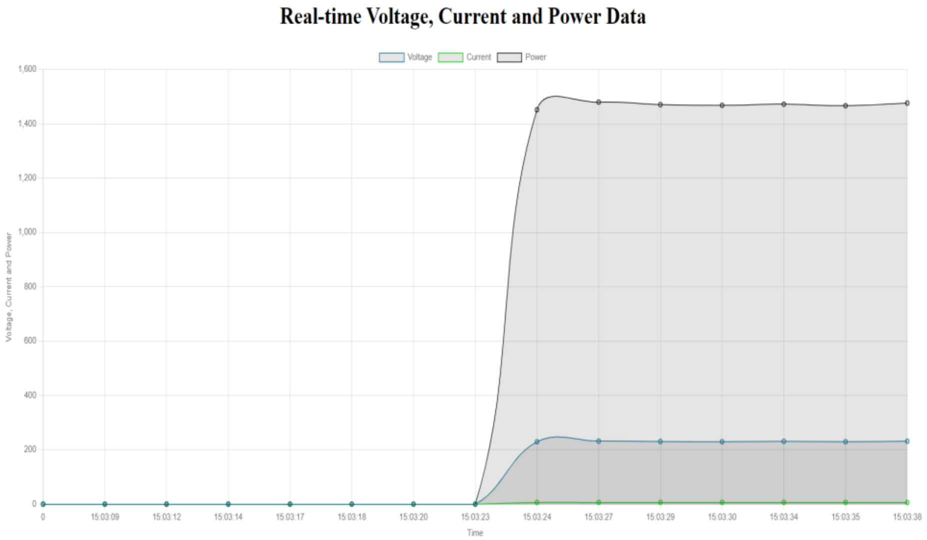

Figure 6: Real-time Voltage, Current and Power Data

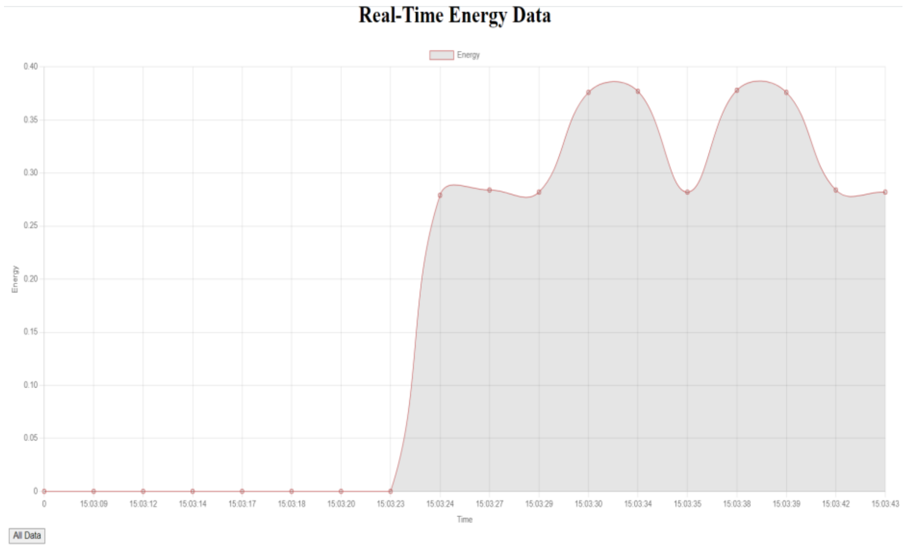

Figure 7: Real-time Energy Data

The embedded system that is designed to monitor, regulate and control the energy measurement of the load devices, works efficiently with an input DC power of <5W, powered by an 8-bit microcontroller consisting of ADC, I2C, SPI and UART features for connecting the device with the wireless communication module.

This is an innovative attempt to bridge the gap between the actual and perceived power consumption of appliances.

The PCB prototype, has a comparatively small footprint w.r.t the other resources so found. It also has screw terminals to which we can easily plug in the power measurement extensions. The system proves to be portable due to its small form factor and good galvanic isolation (due to the presence of isolated Voltage and Current measurement techniques).

VI. CONCLUSION

The research-work clearly states that, the proposed solution can be implemented as an individual node of energy consumption sensing, measurement, calculation and can be employed for separate appliances installed at various sites based on the requirement and application. The experimentation results give us an idea about the fact that, this solution is scalable and can be integrated with other IoT services and is backward compatible with present day systems. The small size of the solution helps the consumer to carry it along-with them and install it in the required location.

VII. ACKNOWLEDGEMENT

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