Design and Implementation of Raspberry Pi Based Real time Industrial Energy Analyzer

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***Abstract*— Electrical Energy demand and generations are growing rapidly. Utilization of generated energy, effective usage, and saving energy is a recent challenge to meet the fastest growing energy demand. Statistical and a clear picture of total energy consumptions is the foremost criteria to research and to design optimum energy usage practice. Monitoring individual loads in the industrial plant rather monitoring the whole plant solely is results impactful to get precise energy statistics and utilized usage. Even in the recent past, individual consumer level, energy usage information, bill predictions, economic bill planning, real-time and historical power consumptions data is found demanded economic power usage planning. Therefore, real-time electrical power consumptions, environment monitoring is essential for both industries and general consumers to maintain their expected energy demand level. This paper discusses micro-controller and Raspberry Pi based smart monitoring, measurements, data logging, online monitoring, remote access, and statistical analysis system. The pilot Implementations in a data center monitoring (150 KVA) system found more productive in determining different factors like peak hour or energy efficient operations.**

Index Terms*— Energy Analyzer, Smart Power Monitor, Data Logger, E-lyzer, Micro-controller, Raspberry Pi, Real-Time and Statistical Analysis, Electrical Parameter monitoring, Online Monitoring, Arduino, High Power Application

I. Introduction

Finding sustainable and efficient energy management system is the trending research topic recently. To meet the continuous demand for electrical energy, to reduce energy waste, to design sustainable energy policy precise measurement is essential components. Precise data of electrical load, load curve, statistical analysis is necessary. Electrical and environmental data of plant or load center is a parameter to consider wisely. For precise power measurement, a lot of work has done [1]. These are techniques introduced to develop and measure the energy of power plant or other loads [2]–[5]. But for precision in the overall measurement system, measuring individual load real-time rather than measurement of the whole plant or loads power consumption data is more insightful. In fact, getting instantaneous data of power consumption will alert the consumer about their expected threshold level and other fault warnings if occurs. In this paper, real-time industrial or in general consumer power, environmental data measurement technique will be discussed. Some already proposed paper shows the smart microcontroller based measurement techniques dominant other power meter based conventional metering techniques [1]–[5]. The proposed microcontroller and Raspberry Pi based smart monitoring system will introduce another way of more user-friendly data analysis, online monitoring, data logging, remote web-based graphical user interface, and consolidated with more other features, which will be discussed in this paper.

Electrical and environmental variable measurement is essential for any electrical system because reducing waste or optimizing energy consumption is the key to any sustainable development. To take any decision about the system, the pattern and data from the load duration curve are important. Load duration curve helps to analyze the system about how power is consumed, peak demand at a certain period of time, efficiency. Continuous data logging and statistical analysis can be used to predict future energy consumption. It helps the user to plan their system operation and procedure according to their requirement. Real-time data monitoring also helps the authority to monitor the health condition of the system. If any fault occurs, the analyzer determines it and necessary steps can be taken immediately to tackle the fault. In many systems, this variable measurement is carried out by the analogous method. After a certain period of time, the human operator measures system data like voltage, current etc. and stores in a log book. And in some case costly, complex and multifunctional distributed control system (DCS) like PLC based SCADA, Plant-scape are used [6], [7].

The proposed microcontroller and Raspberry Pi based energy monitoring system device *E-Lyzer* which will ease human efforts [8]. The proposed system is integrated with features like data logging, monitoring and statistical data prediction, real-time online monitoring and in server data storing. Data logging system facilitates system administration to access stored and real-time data from any period of time. It is very important to analyze the system when any fault occurs. Post-fault troubleshooting and cause of the fault detection requires electrical and environmental data from the pre-fault condition. Our proposed microcontroller based *E-Lyzer* will be much advantageous in these conditions.

The microcontroller is a single integrated circuit that contains the necessary elements of the complete computing system like CPU, memory, a clock oscillator, input, and output. In embedded system designing it has been using widely. Arduino is an integrated development board contains AVR family micro-controller embedded in it [9]. Raspberry Pi is a single boarded micro-computer consolidated with many integrated features like built-in Wi-Fi, video outputs,

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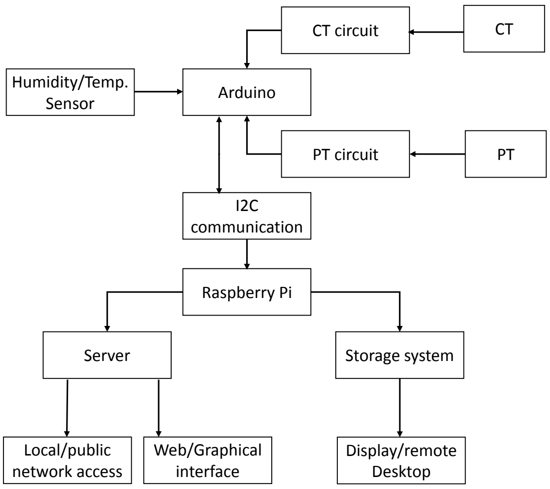

Fig. 1. Block diagram of the proposed system

USB ports etc.

The proposed system consumes very little power as it requires only 5V DC to operate with less than 2A current. It is also a distributed monitoring system which will allow multiple data of different node to be monitored from a single platform. The user can monitor different variable data from one platform.

The *E-Lyzer* can measure and plot real-time system data. It measures electrical and environmental parameters such as real-time voltage, current, power, real power, apparent power, power factor, humidity, and temperature. The proposed system includes data logging and graphical display features. Graphical and statistical data analysis will give a clear discernment of load curve which will help industries to create energy efficiency and conservation Plans to increase productivity and thus profit. The online monitoring system can be integrated into local and/or public network as per user requirement.

Data logging system has been designed using python programming language to receive data from Arduino and store in a Raspberry Pi's SD card. Details discussed in the methodology section. The stored file format is a ***comma separated file (CSV)*** which is easy to analyze using common software like Microsoft Excel which is being used in industries.

As a test implementation, the proposed Arduino and Raspberry Pi based real-time data monitoring system to monitor a 24/7 operating data center having 150 KVA power system. The real-time electrical and environmental data gathered from the data center and thus the performance of the proposed *E-Lyzer* will be discussed in the result section. The *E-Lyzer* stored and measured the electro-environmental variables in SD card and displayed the real-time data graphically in a web interface.

A. *Measurement Principle*

Electrical Power can be measured from an instantaneous value of voltage and current data [1]. The simplified form of three-phase power measurements is described as

$$P_{3\phi} = 3|v_p||I_p|cos\theta \tag{1}$$

here, $\cos\theta$ represents the power factor of the system, to implement in the system RMS power is required, the RMS value of the instantaneous value of voltage and current can be found from

$$p = \sqrt{\frac{1}{1+N}\sum_{n}^{N}(V_n i_n)^2 n = 0,1,2,...N} \tag{2}$$

however, to get the data of the power factor, the apparent power (S) needs to be calculated. Power factor p.f refers to

$$p.f = cos\theta = \frac{P_{rms}}{S_{rms}} \tag{3}$$

the apparent power for any phase can be denoted as

$$S_{1\phi} = V_a i_a \tag{4}$$

therefore, to calculate the RMS value of apparent power

$$S_{1\phi} = \sqrt{\frac{1}{1+N}\sum_{n}^{N}(V_{an})^2} * \sqrt{\frac{1}{1+N}\sum_{n}^{N}(i_{an})^2} \tag{5}$$

from above data of apparent power and p.f, the data of real power and reactive power can be determined as Reactive power,

$$Q = |V_n||I_n|sin\theta \tag{6}$$

and real power,

$$P = |V_n||I_n|cos\theta \tag{7}$$

from aforementioned equations, electrical data can be calculated and environmental value like humidity and temperature can be measured by sensors.

II. Design Method

E-Lyzer device design is divided into five section - measurement, communication protocol, data storing, server creating and web interfacing.

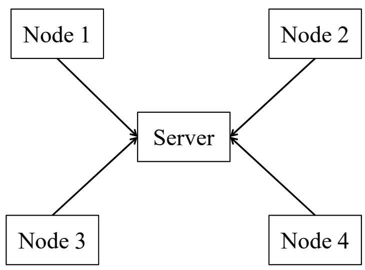

Fig. 2. Visual Concept of Connection with Multinode-Server

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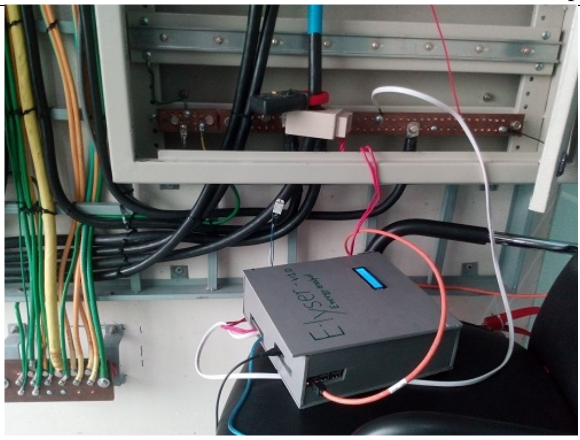

Fig. 3. Typical *E-Lyzer* Installation image in Electrical panel

- ***Measurement***
  To calculate the mentioned seven electro-environmental variables, it requires measuring current, voltage, temperature and humidity data. All the electrical parameters can be calculated from real-time voltage and current data. To read voltage and current data, Arduino analogue pin and two analogue circuits have been used to convert high voltage (Fig. 4) and current (Fig. 5) data into Arduino capable low voltage signal with DC offset. One Circuit uses Potential Transformer (PT) and other one uses the current transformer (CT) to measure and convert the voltage and current data into Arduino readable signal voltage. As microcontroller cannot directly detect the negative value of voltage and current data from ADC (Analogue to Digital converter) pin, a DC offset voltage is supplied to increase the reference voltage shown in circuit diagram in Fig. 4 and Fig. 5. This offset supply is powered by the microcontroller board to consider if any voltage fluctuation occurs in DC offset value and to count this effect in the measurement of a DC value. This continuous measurement of DC offset and the subtraction of DC offset value increases measurement accuracy.
- ***Communication***
  Communication between Arduino and Raspberry Pi is established by using I2C protocol [10]. I2C protocol is used for inter-board communication among different multi-slave ,multi-master serial computer bus. To execute I2C system Arduino ***Wire.h*** library is used. Arduino send sensor variables and other measured data to Raspberry Pi via I2C communication protocol system.
- ***Data Storing***
  To call data from Arduino and to receive data in Raspberry Pi, an environment and python based algorithm has been created. Several python library ***smbus, csv, datetime, os.path, url encode, request, urlopen*** has been used for data manipulation and to store in data in SD card. An HTML, JS, PHP, MySql based web database is used to provide real-time data plots.
- ***Server Creating***
  Real-time electro-environmental data is shared with users by means of local network via the web interface using the raspberry pi. A local server and a database are created to store data for the web interface. PHP, MySQL, HTML, and CSS used for web and database to show in the local network. Fig. 2 shows the block diagram of data from the node transferring to the server for storage and monitoring purposes. The server communicates to visualize information using a web interface.
- ***Web Interfacing***
  The task of the web interface is to plot and visualize information in a graphical user interface and to communicate with the database interlinked with Raspberry Pi. Web interface shows the data graphically in real time.

III. Device Parameter

A. *Circuit diagram*

The circuit diagram designed for measuring electrical parameter is shown in the Fig. 3, Fig. 4, and Fig. 5. These figures show the physical connection of Arduino with the DTH sensor and Raspberry Pi.

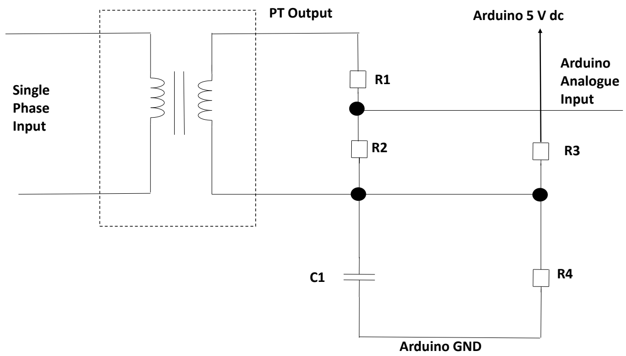

Fig. 4. System voltage to Arduino Signal Converting Analogue (PT) Circuit

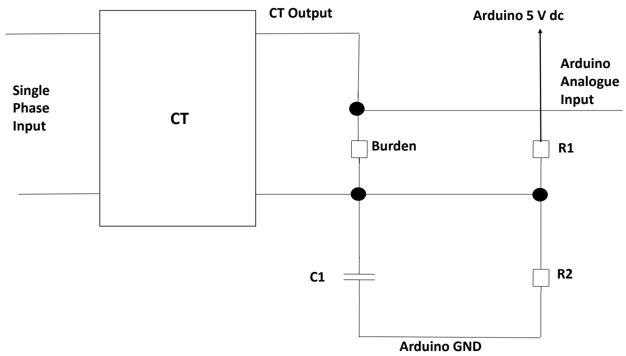

Fig. 5. System Current Data to Arduino Signal Converting Analogue (CT) Circuit

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B. Device Hardware component

Ratings and specification of hardware components used in *(E-Lyzer)* are shown in Table I. All the Arduino and Python libraries used in the proposed device is shown in Table II.

- Current Transformer
- Potential Transformer
- Arduino
- Raspberry Pi
- CT and PT to Arduino signal converter circuit
- DTH Sensor [11]
- LCD Display

TABLE I
DEVICE PARAMETERS

CT Rating	200/5 A
PT Rating	220/9 V
Arduino Input	5 V (DC)
Arduino Signal	1 V (AC)
DC Offset	2.5 V(DC)
CT Burden	0.35 Ω
Raspberry Pi Input	5 V (DC)

TABLE II
LIBRARIES

Arduino	Wire.h, Serial.h, EmonLib.h, EEPROM.h, LiquidCrystal.h, DTH.h
Python/Raspberry Pi	Smbus, csv, date time, os.path , request, urlopen , urlencode

IV. RESULTS AND DISCUSSIONS

TABLE III
MEASURED DATA

Time	V_{rms} (V)	I_{rms} (A)	Humidity (%)	Temp. (Celsius)	P_{real} (KW)
12 am	235	87	34	25	20.58
4 am	238	92	34	25	21.87
8 am	241	85	34	25	20.66
12 pm	235	79	34	25	18.75
4 pm	239	102	34	25	24.40
8 pm	236	96	34	25	22.70

After designing and wrapping the device in a prototype box, the device was successfully implemented in a data center having 150 KVA system to monitor and store required data. Fig. 7 and Fig. 8 are respectively showing the **E-Lyzer** real-time voltage and current curve, real-time temperature, and humidity and finally, real-time power curve showed in Fig:6. Measured and calculated data is also stored in CSV file format in the SD card of Raspberry Pi. From these real-time data plots, One can monitor the actual status of the system. If any abnormalities occur, it can be detected from the curve/device display and alert will help to take the necessary steps for neutralizing the abnormalities. An alarm system also included showing a loud warning if any abnormalities occur. All these values were measured, calculated and plotted in real time (4 sec intervals). Data plots in the web interface can be structured and viewed as

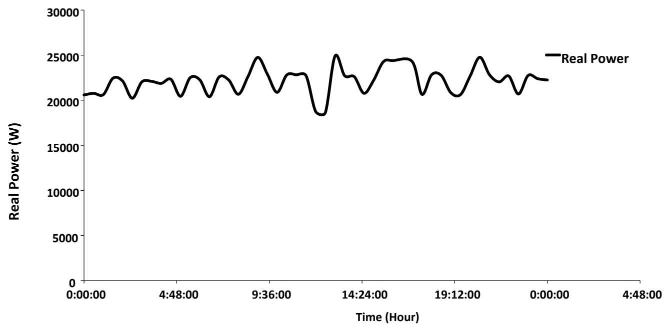

Fig. 6. Typical data collected from E-lyzer for Real Time Power

per requirement of the system administrator. As an example, for better understanding Fig. 7, Fig. 8 and Fig. 6 shows real-time data plot of a whole day extending time intervals.

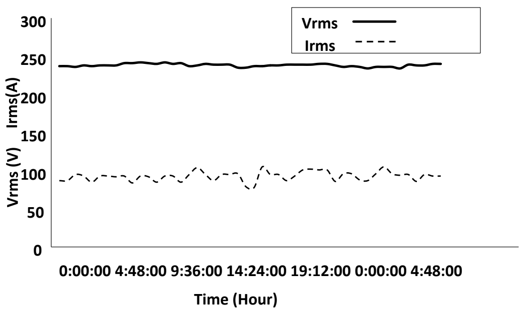

Fig. 7. Typical data collected form E-lyzer showing Real Time Voltage and Current log

V. CONCLUSIONS

In this paper, The presented microcontroller and Raspberry Pi based industrial/home real-time data monitoring and measurements system device ***E-lyzer*** enables data logging, real-time data monitoring and precise measurements of electrical and environmental variables. As measurements of individual loads rather than the whole plant of the industry provide more accurate picture, the proposed method of Raspberry Pi and microcontroller based model enables a smart and user-friendly way for monitoring loads. With smart features like statistical analysis, online, remote monitoring which can be used for both industry and home appliance. The ***E-Lyzer*** performed effectively and monitored precise real-time data when it was implemented in a high power (150 KVA) system shown in Fig. 3. From the aforementioned description, it

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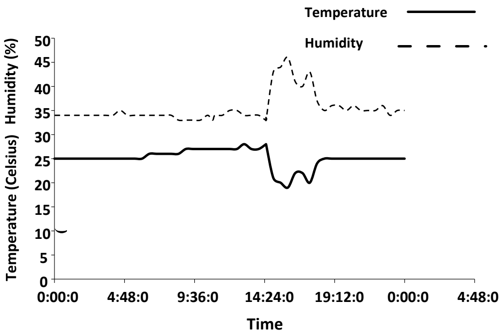

Fig. 8. Typical Temperature and Humidity data collected from E-lyzer realtime data log

is pictured that raspberry pi based power measurements is another approach to dominant conventional power meter reading in terms of described smart features.

FUTURE WORK

Implementing and designing the device for three-phase system with synchronizing operation. Also, multi-node implementation of ***E-Lyzer*** has a lot of promise for it to become a bigger scale distributed monitoring system.

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