A Low-Cost Non-Intrusive Load Monitoring System for Rural Applications

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***Abstract*— This paper explains the implementation of a low cost, non-intrusive load monitoring system. The proposed design implementation uses hardware of open source nature – Arduino and readily available sensors which lends itself to low cost and easy maintenance. This system is intended to service rural and low income consumers unable to afford existing expensive home automation systems. A device identification module (DIM) that identifies various devices is implemented. The energy usage is continuously monitored and the user is notified of his consumption over a twenty-four-hour period through a LCD Display. This data is logged onto a SD-Card and may be used by service provider for future system planning, optimization and demand side management.**

***Keywords*— consumer behaviour ; current measurement ; energy consumption ; load management ; monitoring**

I. INTRODUCTION

Enhancement of energy generation and its access has been of foremost importance for the modern civilization to fulfill its demands for progress and development. But as of 2013, more than 350 million citizens in a developing nation-n such as India continue to be deprived of electrical–grid infrastructure and hence access to energy [1]. The percentage of rural households that remain unelectrified in India lies at 56.5% as per the study conducted by the Ministry of Power, Government of India [2]. In recent times, however, the access to electricity has begun penetrating low-income groups and rural areas in the country, owing to the rise of microgrid utilities and also the steady increase in the installation of renewable-energy based power systems by State Governments, especially solar power [3] [4] [5]. In tandem with this increased power production comes the factor of efficient consumption. As stipulated by the National Action Plan on Climate Change by the Government of India, energy efficiency in household and industrial sectors play a major role in bringing about energy sustainability [6]. Energy conserved is energy generated. In the urban Indian scenario, a typical urban household consumes up to 900 KW/Year in comparison to the consumption of 96 KW/Year by a rural household considering the default presence of commonly required devices/appliances in both cases [7]. Presently, there are several technologies that have surfaced to allow home energy consumption monitoring [8]. The costs of urban home automation units are relatively high considering the economic conditions of such areas. These technologies wouldn't be applicable for sub-urban (low income) areas and rural households when considering complex functionalities. Hence, the need to develop low-cost home automation devices that can monitor and control a pre-defined number of power ports or devices in these residential units would lead to energy and financial savings for the utility and consumer respectively. In this paper, we propose a low-cost system that exploits the functionality and robustness of open-source, off-the-shelf components. Inexpensive associated sensors and ICs are used to measure the power consumption at the device level by measuring their current patterns. Device usage information is then generated based on the predefined current pattern comparison algorithm in the ATmega328 microcontroller. This information is then communicated to the user via a display on the energy monitoring unit. This aims to achieve a change in user consumption and behavior which in turn leads to better energy management at the household level. Collectively, this would lead to lowered energy costs for the users who are typically low-income consumers.

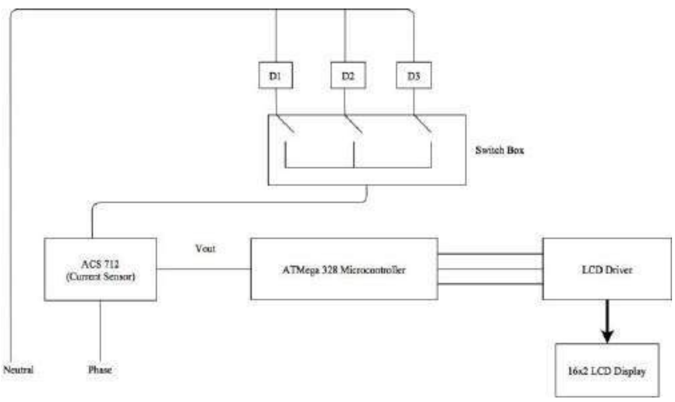

Figure 1 System Schematic

Figure 2 hardware setup of system

II. RELATED WORK

Tutun Juhana [9] et al described a home energy monitoring system using Bluetooth Low Energy (BLE) and non-invasive sensors. Monitoring process of electrical parameter such as voltage RMS, current RMS, real power, apparent power and power factor is realized. However, system is not low cost and complex as it involves server based architecture. The system implemented and presented in this paper measures provides a non-intrusive method for identifying individual devices based on their current consumption patterns for all possible device combinations. Suresh Sankaranarayanan and Au Thein Wan describe a home energy monitoring system that measures the various energy consumption parameters at individual rooms using wireless sensor networks. The user is alerted via an Android application on their smart phones [10]. In a similar manner, in the system described by Ansis Avontins et al, current patterns are measured at individual socket outlets and are transmitted over WEB for further analysis [11]. Our system involves device identification through parameter sensing at the utility service entrance. The user is alerted by displaying an appropriate message on a Liquid Crystal Display (LCD).

III. PROBLEM STATEMENT

Energy access in rural and in developing countries like India is limited. Owing to the issue of irregular energy accessibility, monitoring systems are of paramount importance. Existing sophisticated, high-end, and in turn, expensive home energy monitoring systems are suited to urban residential units. The intrusive functionality of the systems further adds to their cost.

This makes these systems unsuitable for rural homes where residents are typically low-income consumers. Given the limited access to energy and economic Constraints, low-cost systems are required that are built using low cost and open-source hardware. Furthermore, a system that is non-intrusive too would allow easy installation and maintenance. This paper deals with the design and implementation of a system that would be more appropriate for this category of consumers.

IV. METHODOLOGY

A. Residential Energy Monitoring

A residential energy monitoring system tracks the energy consumed by individual devices in a home. This helps the user take cognizance of the energy consumed and help him optimize his energy usage. This is achieved using various device identification algorithms which involve measuring parameters like voltage, current, real power and reactive power etc. Such device identification systems fall under two major categories, intrusive systems and non-intrusive systems. Non-intrusive systems require little or no rewiring during their installation. Such a non-intrusive system has been implemented in this paper. The block diagram of the system is given in figure 1. The current consumed by various loads are measured using the ACS712 current sensor. The currents are measured at the utility service entrance to ensure non-intrusiveness of the system. The sensed current values are fed to the analog pin of the Arduino ATMega328 microcontroller where all the computations regarding the power consumption take place. The user is notified of his consumption on a 16x2 LCD display through a 7459-shift register. All the consumption data are also logged into an SD card.

B. Phase One - Installation and Training

During the system installation, the Device Identification Module (DIM) undergoes a training process to obtain the

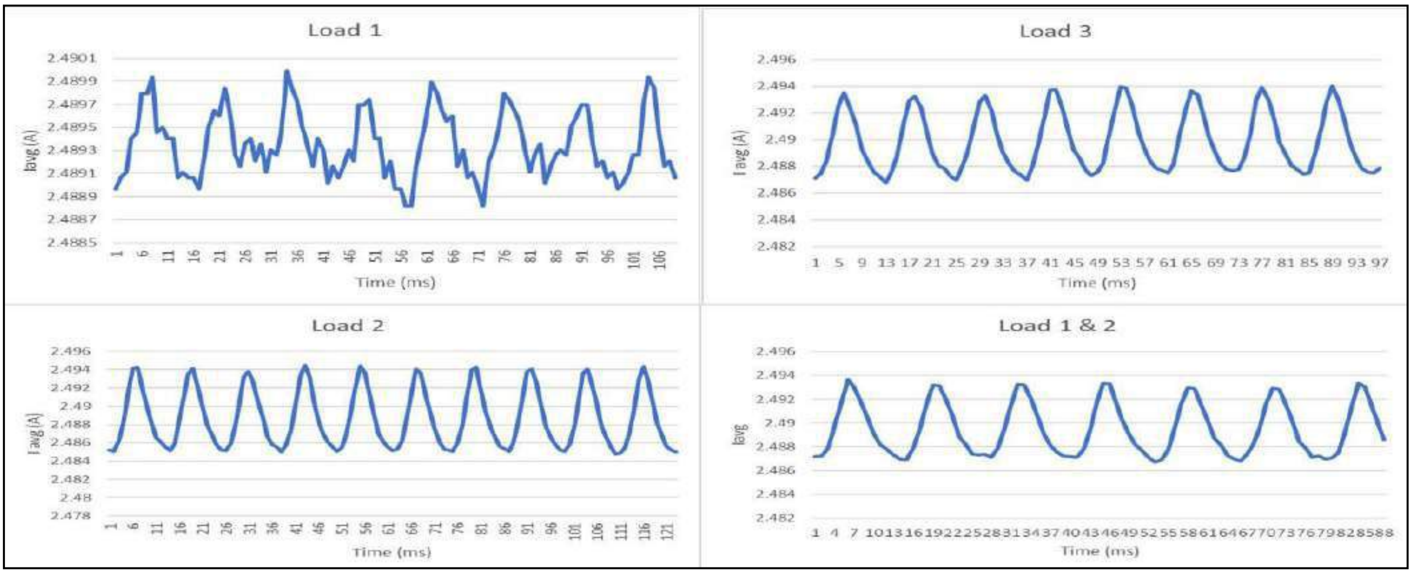

Figure 3 waveforms of a) Device 1 b) Device 2 c) Device 3 d) Device 1&2

load parameters. The current patterns for various combinations of loads are obtained and stored in a look up table. A device's current pattern is a plot of its current consumption over a period of time. The values obtained during training serve as the reference for device identification during run time.

1) Current Sensing:

The current drawn by various devices when measured at the utility service entry ranges between 0-15 A. This is sensed using a current sensor (ACS712) which works on the Hall Effect principle. The current rating of the sensor ranges between 0-30A with an output sensitivity of 185mV/A. Sample current patterns for individual devices and combinations (devices 1 & 2) are shown in figure 3. The output of the current sensor ranges between 0-5 V (I_{inst}) which in turn is fed to the analog input pin of the Arduino. The corresponding current value stored in Arduino (I_i) is given by the formula

$$I_i = (k * (I_{inst}) - V_m)/S_A \quad (1)$$

S_A is the sensitivity of Arduino and equals 66 mV/A. V_m= 2.5V is the middle sensing voltage. K = 0.0049 is the stepwise increment for values mapped between 0 to 1023 bits. Thousand such samples are obtained and the average value is found through the iterative process defined by

$$I_{eq} = I_{eq} + I_i \quad (2)$$

$$I_{avg} = I_{eqt} \quad (3)$$

I_{eq} is the sum of thousand samples. t is the number of samples, which in this case is 1000.

2) Device Identification and Mapping

For the purpose of the experiment, three loads were considered. The ratings of the selected loads are given in table I.

TABLE I. DEVICE RATINGS

DEVICE	TYPE OF LOAD	POWER RATING	VOLTAGE RATING	CURRENT RATING
DEVICE 1	Resistive	80 watts	220 V	0.36 A
DEVICE 2	Resistive	1000 watts	220 V	4.54 A
DEVICE 3	Inductive	55 watts	220 V	0.25 A

During the training period, a single device is operated. I_{inst} is sampled at the utility service entrance and the I_{avg} value is computed for one thousand iterations by the formula given in equation (3). The pseudocode for the training phase is given in table II.

Training:
1: Call *learn ()*
2: Initialize n to zero
3: call *getvalue()*
4: store device[n] value in lookup table in EEPROM of the Arduino.
  if another device is available, increment n=n+1 and go to step 3.
  Else break
5: get combination of n devices and call *getvalue*() for each combination
6: Obtain the reset time for a 24-hour period from the user; default value - 0600.
Getvalue()
1: Initialize i to zero
2: For i=1 to 1000 iterations
  2.1: read the sensor value from A0 pin.
  2.2: calculate $I_{eq}(i+1) = I_{eq}(i) + (0.0742 * \text{analogRead}(i) - 37.87)$
End for
3: Calculate $I_{avg} = I_{eq} / 1000$
4: return the I_{avg} value

Table II Pseudocode of training phase

A look u table is formed which consists of the device combinations and their corresponding I_{avg} values. This process is repeated for each individual load by using the buttons 1 & 2. The I_{avg} values for various device Combinations are calculated and stored in the look up table. Once the table is completed the user must set the Real-Time Clock (RTC) in the 24-hour format. The look up table formed during experimentation is given in table III.

LOOK UP TABLE	
NAME OF THE DEVICE	I_{avg}
Device 1	2.88
Device 2	2.94
Device 3	2.92
Device 1 and 2	2.95
Device 1and 3	2.945
Device 2 and 3	2.96
Device 1 and 2 and 3	3.14

TABLE III LOOK UP TABLE

C. Phase Two - During Runtime

1) Current Sensing:

The current at the utility service entry is monitored continuously. If there is a change in current of 0.054mV or more in the current sensor output, then device mapping is performed as 0.054mV/A is the sensitivity slope.

2) Device Mapping

The current is sensed at the utility service entry by means of the current sensor and I_{avg} value is calculated. The sensed I_{avg} is compared with the I_{avg} values in the look up table and the device is identified using bubble sort algorithm. I_{avg} values of each pair of adjacent devices in the look up table are compared to obtain the closest match to the sensed I_{avg} value. Whenever the measured I_{avg} value does not concur with the existing values ± 0.054 mV (sensitivity slope of current sensor) in the look up table, it is identified as a new device and the training process is repeated. The pseudocode corresponding to this process is given in table IV.

1: Read current sensor voltage through pin A0
2: Call getvalue()
3: Compare I_{avg} with look up table values using best match algorithm.
4: Sort out best suited device using the bubble sort algorithm.
5: Check ON time from log data.
6: Append ON time value of device for present day.
7: Display the identified device with its ON time
8: Log device's I_{rms} value and present timestamp to SD card.

Table IV Pseudocode of device mapping

The flowchart describing phase two is given in figure IV.

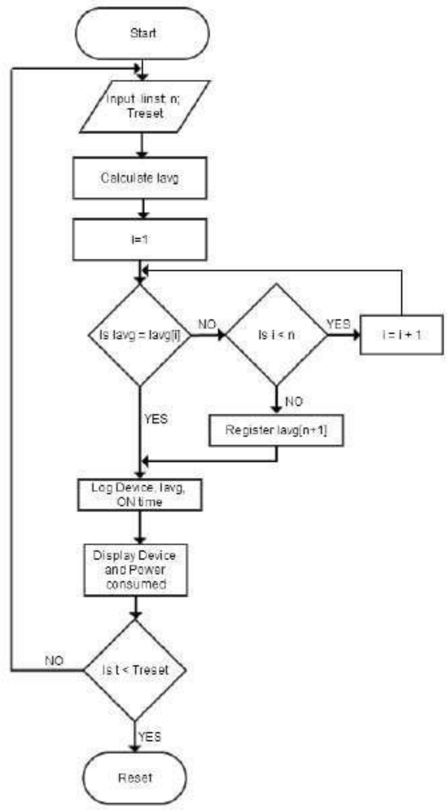

Figure 4 Flow chart of phase 2

V. CONCLUSION

Thus, the system on low cost, non-intrusive load monitoring System is implemented and carried out using a single current sensor, ACS712 and an Arduino Micro-controller employing a current comparison algorithm. This can track load usage and subsequently lead to energy and financial savings.

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