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Design and Performance Analysis of a Home Energy Monitoring System

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Abstract

Due to the rising cost of energy, many researches have been done on energy saving technique to aid in cost reduction for electricity consumers. In this work a home energy monitoring system has been presented as a decision support system for saving energy cost. The system measures current using ACS712 hall effect sensor, voltage through a voltage divider interface and calculates power and energy using sensed voltage and current parameters. In order to ensure the reliability of the data presented by the energy monitoring system, a statistical test was conducted to compare the mean difference between the voltage measured by the energy monitoring system and a standard multimeter. The result of the statistical test showed that there was no significant statistical difference when the system was tested at an alpha level of 5%..

Keywords: *ACS712, Arduino Uno, Energy Monitoring, Consumption Profile, Energy Saving, data logger.*

1. Introduction

Electricity distributors in Nigeria use either the post-paid meters [fig. 1a] or prepaid meters [fig.1b] for electricity data and consumption revenue collection[1]. Each consumer's bill is determined by several factors which include tariff code, consumption, fixed charges, etc [1].

a. *b.*

Fig.1 a. Post Paid meter. b. Prepaid Meters

Consumed energy is a major determinant of the electricity cost accrued to the consumer. C3onsumers in most cases are unaware of the core component loads that constitute to the energy cost on real-time. Hence, they tend to accept the electricity bills without proper intelligence that could lead to cost savings and consumption optimization. Smart energy monitoring system provide intelligence on the consumption rate, pricing policies and effect of energy choices of the user on real-time[2]. This method of metering offers decision flexibility to the consumer when saving energy cost is a factor.

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In this work, an energy monitoring system has been presented. The design displays on real-time the nominal voltage supplied to the loads, current consumed by the loads, the total power delivered to the system and finally the cumulative energy consumed with respect to time.

The main idea of this work is to present an in-house display system and data logging system which displays and logs electrical information to support energy saving decision of the consumer.

In order to trust the data presented by the system, a comparative statistical analysis was conducted to ascertain the reliability level of the system data with respect to standard measuring system.

The paper is structured in sections. Section II is a brief overview of related literatures. Section III describes the developed system. Section IV presents experimental results and test analysis of the system. The paper is concluded in section V.

2. REVIEW OF RELATED WORKS

A. Smart Energy Meters

Smart meters are modification of traditional moving coil meters. These devices record energy with respect to time and communicate meter data regularly to the utility managers for monitoring and billing purposes [3]. This type of meters offers many advantage such as theft detection, consumer profiling, consumption optimization[4, 5] and challenges like information management, security, etc [6].

Many researchers have proposed a smart meter model for some specific objectives. An energy saving and management system with data recognition pattern using support vector machines was presented in [7]. In [8] a three-phase electric quantity measurement system was designed using raspberry pi to measure voltage current and energy consumed. Similarly, a load control management system was designed with a remote communication interface based on Zigbee module [9].

In these researches [7-9], Current, Voltage and Power are the primary measured quantities with AC712 hall effect sensor used as the primary current sensor while voltage divider format was used for sensing voltage in [8]. The measuring techniques used in these literatures [7-9] informed the choice of using ACS712 hall effect sensor and voltage divider circuit for current and voltage measurement presented in this work. However, while the data presented by these researches appear closely related to standard values, a comparative test was not conducted to ascertain the actual level difference between their design and standard values.

B. Energy Measurement

The relationship between the core measured quantities is expressed as follows

$$P=VI\cos\theta \qquad (1)$$

Where P is the Power expressed in KW, V is the voltage in Volts, I is the current in Ampere and cos θ is the power factor [10]. While Energy consumed is expressed as

$$E=P\times t \qquad (2)$$

Where E is the consumed energy in KWh, P is the power expressed in KW and t is time in seconds[10]. While voltage and current parameters are obtained directly from sensors, Power and Energy are calculated by the control system using equation (1) and (2).

C. Statistical Analysis

Since the data are acquired from a sensor IS in a raw form, there is need to validate the data before use in order to assure the reliability of results from the data [11]. Reliable data play a key role in the analysis, as bad quality data may result in an erroneous decision. In order to ascertain the level of acceptance of the data acquired from the energy monitoring system, an independent-samples t-test as illustrated in [12] using equation (3) was conducted to check if there is a significant difference between the two measurements with a hypothesis that there is no difference between the mean expressed as.

$$t = \frac{(\overline{x_1} - \overline{x_2}) - (\mu_1 - \mu_2)}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \qquad (3)$$

H0:µ1=µ2 and significance level (α=0.05) placed at 5%.

3. SYSTEM ARCHITECTURE

A. Hardware Setup

The system has six major units: The current sensing unit, Voltage sensing unit, the control unit, display, clocking and memory unit, and power supply unit as shown in fig. 2.

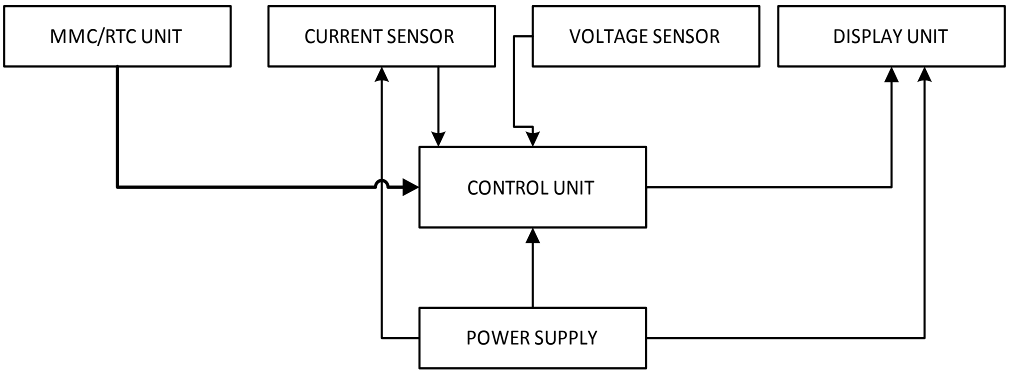

Fig 2. System Block diagram

The ACS712 hall effect sensor is the main component used for current sensing. A 30A rating version of this sensor was connected in series with the load. The voltage sensor uses the voltage divider principle to draw a percentage of the peak voltage without damaging the microcontroller. However to ensure protection of the microcontroller unit, a Zener diode was added to ensure that the percentage of the peak voltage does not exceed 5V.

The principle of voltage division ratio was applied to ensure that at peak voltage of 240Vac, the measurable DC equivalent at the microcontroller is set to 4.9Vdc. This enables a potentiometric calibration of the voltage levels. A 16x2 LCD was used as the main display unit. It showed the current, voltage, power and energy consumed in real-time. A data logger was incorporated to log the electrical data to a multimedia card (MMC) at an interval of 15 minutes clocked from a Real Time Clock (RTC). The circuit diagram used for the system design is shown in fig 3.

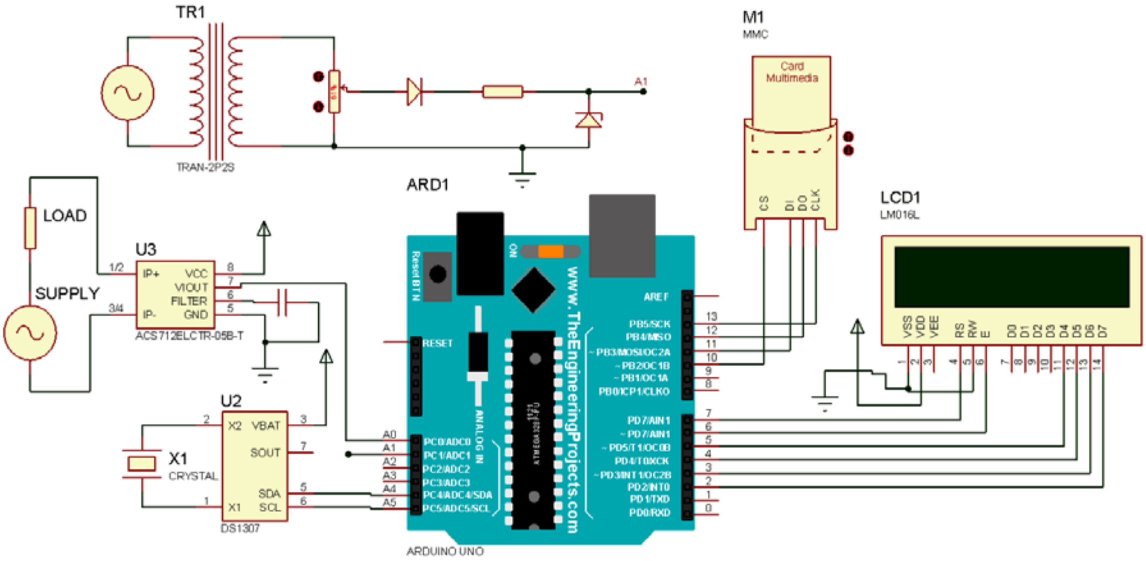

Fig. 3. Circuit diagram

A pictorial view of the experimental setup showing the loads and the display unit is shown in fig 4.

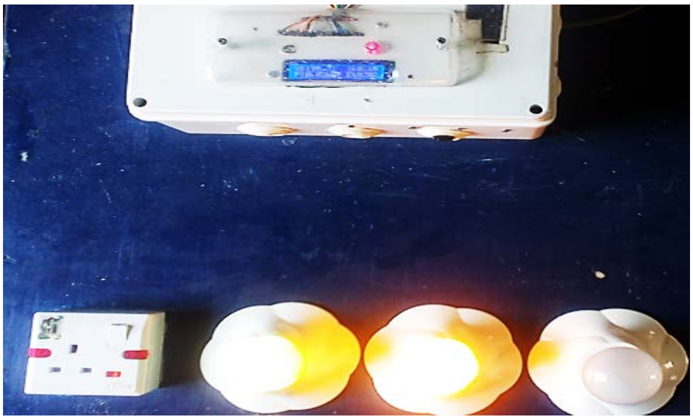

Fig 4. Experimental Setup

B. Software Architecture

The control system coordinates the activity of other hardware peripheral using the flowchart shown in fig. 5 A mean value of twenty current and voltage samples were collected in order to reduce non-coherency in data collection as a result of the ADC sample rate. The result of the sensors and calculation are displayed on real time and a copy sent to the MMC unit at every fifteen (15) minute interval.

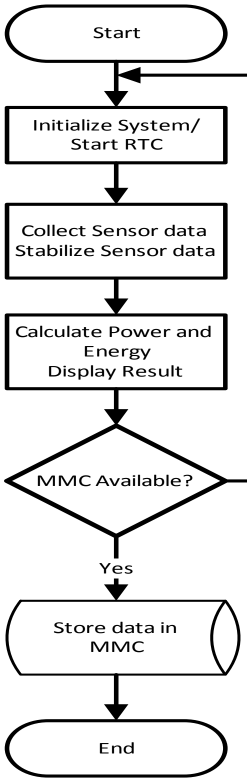

Fig 5. Flowchart of the Control Unit

The data logging interface was designed to be accessible by an external system. Hence the sensor data was converted to strings and comma delimiters used for easy grouping of the data by an external processing software. A snippet of the source code used for the data formatting is shown in fig 6.

```
    SD_Data += String(tm.Day);
SD_Data += "/";
SD_Data += String(tm.Month);
SD_Data += "/";
SD_Data += String(tmYearToCalendar(tm.Year));
SD_Data += ",  ";
SD_Data += String(tm.Hour);
SD_Data += ":";
SD_Data += String(tm.Minute);
SD_Data += ":";
SD_Data += String(tm.Second);
SD_Data += ",";
SD_Data += String (voltage);
SD_Data += ",";
SD_Data += String (current);
SD_Data += ",";
SD_Data += String (power);
SD_Data += ",";
SD_Data += String (Energy);
Serial.println(SD_Data);
sMeter= SD.open("sMeter.txt",FILE_WRITE);
if(sMeter){
sMeter.println(SD_Data);
sMeter.close();
```

Fig 6. Data Formatting

4. RESULT AND DISCUSSION

A. Experimental Measurements

The system was tested under different load condition as specified in Table 1.

Table 1. Test Conditions

Load ID	Type of Load	Manufacturer's Rating (Watt)
L1	13A Socket	300
L2	Light Bulb	12
L3	Light Bulb	100
L4	Light Bulb	26

Twelve samples were collected and the system performance for different load conditions were also analyzed with respect to specified manufacturer's ratings. The result of the measurement is shown in table 2

Table 2. Experimental Measurements

S/N	Multimeter Voltage (V)	System Voltage (V)	Current (A) $x10^{-3}$	Ammeter (A) $x10^{-3}$	Load	Power (KW)
1	220	219	1.73465	1.35	L1	0.30391
2	218	220	0.06568	0.04	L2	0.01156
3	219	221	0.57222	0.55	L3	0.10117
4	220	216	0.1471	0.21	L4	0.02542
5	220	219	1.79755	1.68	L1,L2	0.31493
6	217	220	2.31455	2.22	L1,L3	0.40736
7	215	211	2.45705	2.71	L1,L2,L3	0.41475
8	221	218	2.4769	2.68	L1,L2,L3,L4	0.43197
9	216	217	0.69631	0.72	L4,L3	0.12088
10	219	215	0.66994	0.62	L2,L3	0.11523
11	219	220	1.76006	1.79	L1,L2	0.30977
12	218	191	2.12107	2.25	L4,L1	0.3241

B. Performance Analysis

The voltage measured by the designed system was compared with the voltage measured from the supply source using a standard MASTECH MY64 multimeter. Fig. 7 is plot of the two voltage measurements.

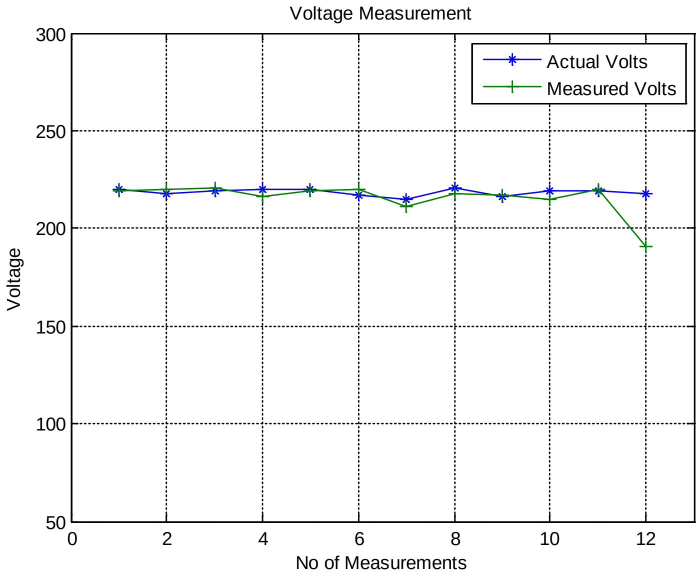

Fig. 7. Voltage Measurement

C. Energy Consumption Profile

While evaluating the performance of the system, a historical chart of the energy consumption for a period of one (1) hour clock at two (2) minute interval is shown in fig 8.

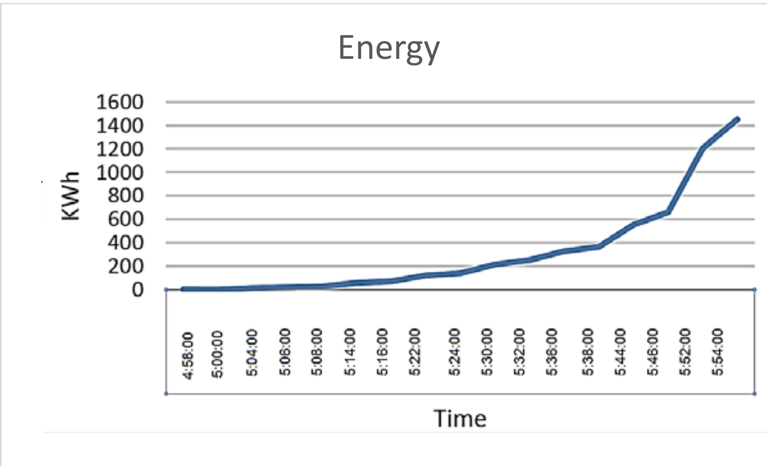

Fig. 8 Energy Consumption

D. Statistical Analysis

An independent t test analysis was conducted on the two samples to compare if there is a significant difference on the averages of the voltage and current samples

Table 3. Voltage t-Test: Assuming Unequal Variances

	Multimeter (V)	System (V)
Mean	218.5	215.5833
Variance	3.181818182	67.7197
Observations	12	12
Hypothesized Mean Difference	0	
Df	12	
t Stat	1.199912737	
t Critical two-tail	2.17881283	

Table 4. Current t-Test: Assuming Unequal Variances

	Ammeter (A)	System (A)
Mean	1.401666667	1.40109
Variance	0.912851515	0.826967
Observations	12	12
Hypothesized Mean Difference	0	
df	22	
t Stat	0.00151448	
t Critical two-tail	2.073873068	

The result of the t-test for the voltage and current samples is shown in Table 3 and 4 respectively. The voltage measured using the System (Mean=215.58, n=12) was hypothesized to be equal to the voltage measured with a standard multimeter (Mean=218.5, n=12). The difference was not significant, since the t statistics value of 1.199 is less than the t critical value of 2.1788 at a significance level (α) of

CONCLUSION

A home energy monitoring system was presented in this work. The system has the ability to record and display on real-time voltage level from supply, current consumed by loads, the power and total energy used for a period of time. The aim of the design is to use the energy monitoring system as a decision support system that will help users save energy cost. In order to ensure the reliability of the data presented by the energy monitoring system, a statistical test was conducted to compare the mean difference between the voltage and current measured by the energy monitoring system and a standard multimeter. The result of the statistical test showed that there was no significant statistical difference when the system was tested at an alpha level of 5%.< 0.05. Hence, the null hypothesis was accepted since there is no statistical difference between the mean of the Multimeter group and the system group.

Also, considering the outcome of the current t-test, the System (Mean =1.40109, n=12) was hypothesized to be equal to the current measured with a standard ammeter (Mean=1.4010667, n=12). The difference was not significant, since t statistics = 0.00151 is less than t critical = 2.1788. Hence, the null hypothesis was accepted since there is no significant difference between the mean of the ammeter group and the system group.

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