Abstract

The design and development of a Smart Power monitoring device has reported in this paper. System has been designed that can be used to monitor electrical parameters such as voltage, current and power of household appliances. The system consists of a smart sensing unit that detects and controls the home electrical appliances used for daily activities by following different tariff rates. It can reduce costs for the consumers and thereby improve grid stability. A developed prototype has been extensively tested and experimental results have compared with conventional measuring devices.

Keywords: Wireless Sensor Networks, Power, Voltage, Current, ZigBee.

I. INTRODUCTION

A smart grid is an electrical grid that uses computer and other information technologies to gather and act in an automated fashion to improve system’s reliability and efficiency [1]. Smart grid term was coined in year 2005[1]. The smart grid enables information technology as a root to penetrate into existing today’s electrical distribution system through information technology by using wireless sensor network.

Smart Grid utility system encapsulates the net metering system for facilitating consumers to optimally utilize the power consumption. The gaining importance and urgency of an integrated smart grid monitoring system use wireless sensors network for advancements in metering of the electrical meters to provide more efficiency, reliability and options to consumer. Smart meters’ Advanced Metering Infrastructure (AMI) provide interface between the utility and its customers providing bi-direction control mechanism, advanced functionalities, real-time electricity pricing, accurate load characterization and outage detection or restoration [2].

II. CURRENT RESEARCH WORKS

Projects like Smart grids utilising wireless sensor network technologies are being promoted by US government as a way of addressing energy independence, global warming and emergency resilience issues. A report on revenue for Smart Grid from sales of smart grid sensing, monitoring, control systems and related software sold to the worldwide smart grid sector are $6.3 billion by 2014 and double to $13 billion by 2018. Software for home area network applications will bring revenue five times greater than $1.1 billion by 2014. While home energy monitoring has been popular in the past, subsidized smart meter deployments will make it cost effective [3].

Wired sensor networks have already been reached and deployed in many applications over a decade; because of the wireless extension, smart grids have witnessed a tremendous upsurge in interest and activities in recent years. New technologies include cutting-edge advancements in information technology, sensors, metering, transmission, distribution, and electricity storage technology, as well as providing new information and flexibility to both consumers and providers of electricity. The ZigBee Alliance, the wireless communication platform is presently examining Japan’s new smart home wireless system implication by having a new initiative with Japan’s Government that will evaluate use of the forthcoming ZigBee Internet Protocol (IP) specification and the IEEE 802.15.4g standard to help Japan create smart homes that improve energy management and efficiency [4].

It is expected that 65 million households will equip with smart meters by 2015 and it is a realistic estimate of the size of the home energy management market [5]. Smart Grid and wireless sensor networks provides an intelligent functions that advance interactions of agents such as telecommunication, control and optimization to achieve adaptability, self-healing, efficiency, cyber security and reliability of power systems while reducing the cost and providing efficient resource management and utilization.

A wide range of smart meter research is being carried during the last decade. Various architectural design and development methods of smart grid utility system for effectively managing and controlling the household appliances for optimal energy harvesting have been presented [6-7].

In order to connect various domestic appliances and have wireless networks to monitor and control based on the effective power tariffs have been proposed [7-8], but the prototypes are verified using test bed scenarios. Also, smart meter systems like [9], have been designed to specific usages particularly related to geographical usages and are limited to specific places.

Different Information and Communication technologies integrating with smart meter devices have been proposed and tested at different flats in a residential area for optimal power utilization [10-11], but individual controlling of the devices are limited to specific houses.

Considering performance and cost factors related to design and development of smart meters and also predicting the usage of the power consumption have been demonstrated [12-14]. However, low-cost, flexible and robust system to continuously monitor and control based on consumer requirements are at early stages of development.
In this paper, a low-cost, flexible and real-time smart power management system which can easily integrate with the home monitoring systems like [15] is presented.

III. SYSTEM OVERVIEW

The system has been designed for measuring voltage and current readings of electrical household appliances. Fundamental to the system is the ease of modelling, setup and use. From the consumer point of view; electrical current and voltage consumed are the key elements to measure power consumption of various appliances in a house. Fig.1 shows the functional description of the developed system to monitor electrical parameters and control appliances based on the consumer requirements.

![Figure 1. Functional block diagram of the system](image)

The input signal from the sensors are integrated and connected to XBee module (end device). The measurands are wirelessly transmitted to XBee Module (coordinator) which is connected through USB cable of the host computer, which stores the data into an Access Database of computer system.

By analysing the power from the system, energy consumption can be controlled. A tariff plan can be installed to run various appliances at peak and off peak tariff rates. It can be controlled either manually or automatically.

The smart power metering circuit is connected to mains 240V/50Hz supply. Fig. 2 shows the circuit diagram of smart voltage and current sensing circuitry.

![Figure 2: Designed smart voltage and current sensing circuitry](image)

A. Voltage measurement

The voltage transformer used in our work is the 44127 voltage step down transformer manufactured by MYRRA [16]. The striking features include two bobbins compartments including self-extinguishing plastics and very light weight (100gms). Fig. 3 shows the circuit design layout for voltage measurement.

The step down voltage transformer is used to convert input supply of 230-240V to 10 V<sub>RMS</sub> AC signal which is rectified and passed through the filter capacitor to get a DC Voltage. This output signal is then fed to analog input channel of ZigBee end device. The acquired voltage signal is directly proportional to the input supply voltage. A voltage regulator is connected to the rectified output of voltage transformer to give the precise voltage output for the operation of ZigBee and operational amplifier. The scaling of the signal is obtained from the input versus output voltage graph.

![Figure 3: Circuit schematic for voltage measurement](image)

B. Current Measurement

For sensing current, we used ASM010 current transformer manufactured by Talema [17]. The main features of this sensor include fully encapsulated for PCB mounting and compact size. The primary current ratings range from 1 to 100 Amps and operating temperature range from -40° C to +120° C. The circuit design layout for current measurement is shown in Fig. 4. In this current sensor, the voltage is measured across the burden resistor of 50 ohms.

The line wire is connected to the load, which is passing through the current transformer. When the mains are turned on, the current sensor will produce isolations in the current transformer. The amplified signal is then fed to analog input channel of ZigBee module. The desired voltage setting is achieved by using burden resistor on secondary side. The output sensed signal is directly proportional to the input current. Scaling is required to get correct input current of the appliance. The resolution of measured signal can be improved by increasing the number of primary turns.
C. Power Measurement

In order to calculate power of a single phase ac circuit, the product of volts and amperes must be multiplied by the Power Factor. Power Factor is the cosine of the phase angle of voltage and current waveforms as shown in the Fig. 5.

Power factor is one, if the voltage and current are in-phase. The output signal of the current transformer completely depends on the nature of the connected appliance whether the connected load is purely resistive, capacitive or is inductive. In most of the cases, the output waveforms are not proper sinusoidal as shown in the following graphs Fig.6 (a,b,c,d). From the graphs, it is inferred that zero-crossing determination is difficult to measure for some of the appliances and elimination of noise is not trivial.

Hence, in our work, instead of measuring power factor, we have introduced correction factor to normalize the received power with respect to the actual power based on the scaling factors of the voltage and current measured.
Power is calculated in the computer system after receiving voltage outputs from corresponding current and voltage sensors by following eq. (1)

$$P = (m_1 \cdot m_2 \cdot v_1 \cdot v_2) \cdot C_f$$

(1)

Where

- $P$ = Calculated Power
- $m_1$ = Scaling of the signal from voltage transformer to get the input Voltage
- $m_2$ = Scaling of the signal from Current Transformer to get the input Current
- $v_1$ = output voltage from the voltage circuit
- $v_2$ = output voltage from the current circuit
- $C_f$ = Correction factor

Scaling factors ($m_1$ and $m_2$) from both outputs are multiplied with the corresponding output signals to calculate the power. The term correction factor is introduced to calculate power accurately by the system. The correction factor is the ratio of reference power to the measured Power.

The power is calculated using CSharp programming after receiving voltage outputs from corresponding current and voltage sensors. Scaling factors from both outputs are multiplied with the corresponding output signals to calculate the power. Fig. 7 shows the schematic of the prototype and Fig. 8 depicts the fabricated system with the integrated sensing circuit and ZigBee module. Developed system includes two current transformers; one used for the measurements of loads up to 100W and the other current transformer is used for the measurements of loads from 100W to 2000W. The number of turns is increased up to five turns to improve the resolution of the low current signal. Both outputs from the current transformers are fed to the analog input channels of ZigBee.

IV. EXPERIMENTAL RESULTS

By monitoring consumption of power of the appliances, data is collected by a smart coordinator, which saves all data in the system for processing as well as future use in software. The parameters which will be entered in the data coordinator in software from appliances include voltage, current and power. These parameters will be stored in a database and analyzed. These parameters data will be displayed on graphic user interfaced (GUI) window so that appropriate action can be taken from the GUI.
The processed voltage, current and power values are displayed in the GUI running on a computer. The processing of the voltage readings are processed using C sharp programming.

Correction factor is required for the power measurement for some loads. This correction factor can be obtained by plotting graph for calculated power against the reference power. The prototype has been tested and results achieved for certain home electrical appliances. Table I below show the percentage error for all measured parameters with the corresponding references.

From the very low percentage error of power, it can be decided that power can be calculated without considering power factor.

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**Figure 9.** Prototype of the smart power monitoring system and Graphical User Interface

**Figure 10(a, b)** shows the scaling factor for voltage and current signals.

(a): Scaling factor (m1) of voltage signal

(b): Scaling factor (m2) of current signal
V. CONCLUSIONS AND FUTURE WORK

We aim to determine the areas of daily peak hours of electricity usage levels and come with a solution by which we can lower the consumption and enhance better utilisation of already limited resources during peak hours. The sensor networks will be programmed with various user interfaces suitable for users of varying ability and for expert users such that the system can be maintained easily and interacted with very simply. This study also aims to assess consumer’s response towards perceptions of smart grid technologies, their advantages and disadvantages, possible concerns and overall perceived utility.

At present, system is independently tested with different loads of domestic appliances. In the later stage, system will be integrated with co-systems like smart home behaviour recognitions systems to determine the wellness of the inhabitant in terms of energy consumption.

REFERENCES: