J. Bangladesh Electron. 11 (1-2); 73-79, 2011

Design and Implementation of a Smart Energy Meter with Data Sending Ability

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Abstract

In this paper the authors proposed and implemented a smart energy meter with data sending ability. At first a brief review about the definitions and procedure to measure the energy consumed from a single phase line. Whole model is developed starting from the proper measurement of current and voltage and their fluctuating behavior is taken into account. . Then a design of experiment that allows testing the energy meter. The design ensures exact calibration and display of the measured values with a software implemented by a microcontroller. A cell-phone using cellular network sends data of energy consumption. Finally, the complete hardware and software system that allows sending the data is presented in this document.

Keywords: Energy Meter, Microcontroller, Current Sensor, Voltage transformer

1. INTRODUCTION

Economical development of a nation depends vastly on Energy consumption. Our quality of lifestyle, industrial and agriculture development is verily associated with energy. In addition, our socio-economic condition is indicated by electricity consumption. Bangladesh as a developing country has lower consumption compared to other countries of the world. Still it is very crucial how efficiently we are using our energy with making profit nationally. The power sector of Bangladesh is currently facing some serious problems like financial damage due to transmission and distribution losses. Each honest consumers of electricity would like everyone else that uses electricity also to pay for their fair share of electricity so that quality of distribution can improve. However, unexpected commercial losses include losses other than technical factors such as theft of power, poor collection efficiency, revenue non-billing, billing error etc. This is high time our utility companies should think of combat against this kind major problems faced by the energy suppliers. So, Smart Energy Meter can be the best possible solution at present situation. In most of the houses, electricity is distributed on two wire line or single phase line. This Energy Meter is technically capable of measuring energy consumption of this single-phase connections. So every house can attach this meter with no technical difficulties or change in infrastructure. For monitoring communication channel is required collect consumption information from all energy meters. The existing cellular networks like GSM, CDMA can be used to do the part of communication. So, no need to establish any extra communication infrastructure. On the consumer's end, meters are driven by cost microcontroller, which is programmed and dedicated to sense energy consumption, display it on a LCD screen also stores in memory. Another low cost microcontroller is programmed and dedicated to response whenever this meter is requested to send meter reading. This request is made, by a sms and the microcontroller is programmed to receive request and send data, with minimum error.

2. THEORETICAL BACKGROUND

Smart energy meter is designed to measure energy or power consumed over time from a single-phase line. As, electrical power is the product of voltage and current. We are intended to repeatedly measure of both instantaneous voltage and current, or V_i and I_i, A running total of their products over time is kept upto 100 samples gives the instantaneous power in watts as shown in Equ.1. By dividing the total accumulated energy over 100, we have the average power or real power in watts as shown in Equ.2[1]. Multiplying the average power by time gives the total energy consumed. Square root of average values of running total instantaneous current and voltage values up to 100 samples gives the RMS voltage and current shown in Equ.3~4[1]. When RMS voltage and RMS current is multiplied apparent power is found according to Equ.5[2]. Power factor is measured by dividing the real power by apparent power, shown in Equ.6[2]. When time is multiplied with real power , we can get energy consumption as in Equ.7[2,3]. Is is also required to measure power at any kind of harmonic distortion in the distribution system[4].

$$\textbf{Instantaneous power(watts)} = \sum_{m=1}^{N} V_{im} * I_{im} \cdots \dots (1)$$

$$\textbf{Real power(Watts)} = \frac{\sum_{m=1}^{N} V_{im} * I_{im}}{N} \dots \dots \dots \dots (2)$$

$$\textbf{RMS current(amp)} = \sqrt{\frac{\sum_{m=1}^{N} I_{im}}{N}} \dots \dots \dots \dots \dots (3)$$

$$\textbf{RMS voltage(volt)} = \sqrt{\frac{\sum_{m=1}^{N} V_{im}}{N}} \dots \dots \dots \dots \dots \dots (4)$$

$$\textbf{Apparent power} = \textbf{RMS voltage} * \textbf{RMS current} \dots (5)$$

$$\textbf{Power factor} = \frac{\textbf{Real Power}}{\textbf{Apparent Power}} \dots \dots \dots \dots \dots (6)$$

$$\textbf{Energy(Watt-hour)} = \left(\frac{\sum_{m=1}^{N} V_{im} * I_{im}}{N}\right) * t \dots (7)$$

In Equ.1-7 the following meaning of the symbols used:

V_{im}= instantaneous voltage of single phase line

I_{im}= instantaneous current flowing from single phase line

t= time passed

N= number of samples taken

3. PRINCIPLE OF SMART ENERGY METER

For accurate measurement of power consumption for an single phase AC system, it is important to continuously measure values of current and voltage.

A microcontroller PIC16F877A is programmed to measure current and voltage. But it is not possible for a microcontroller to make direct measurements when the supply voltage is coming straight off the single phase mains, which is 220V at up to 50A.This makes it necessary to indirectly measure line voltage and current at a level consistent with a microcontroller, then rescale these measurements to arrive at the original value. The best

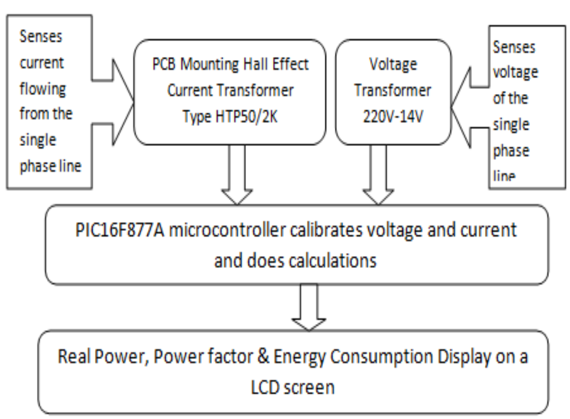

Fig. 1 Block diagram of Smart energy meter

way to do this is to reduce the voltage to a level and dynamic range that is compatible with digital circuitry. This case voltage is reduced to 0-5 volt. 5 volt is the maximum operating voltage of the microcontroller [5]-[6]. Again, measuring current here is essentially the same as measuring voltage, in that we will use a current sensor that generates a voltage proportional to the load current. The actual voltage and current readings can then be derived by proper calibration inside microcontroller. In Fig. 1, the block diagram of how smart energy meter will give reading is shown.

4. PRINCIPLE OF DATA SENDING DEVICE

Smart energy meter is interfaced with a data sending device. A very easily available and cheap cell phone NOKIA1100 is used to send meter reading. This cell phone sends data when requested . request is done by either if any SMS received by the cell phone or ringing is detected. Any SIM of any mobile operator can be used for communication network. This cell phone is driven by a cell- phone interfacing circuit. In this circuit a microcontroller PIC16F877A is programmed to detect any request to send meter reading. Whenever a request is detected, this microcontroller detects meter reading of that instant. Then via the isolation circuit microcontroller starts typing the meter reading in the messaging option. And finally it sends the reading by a SMS. The block diagram of data sending device is shown in Fig. 2.

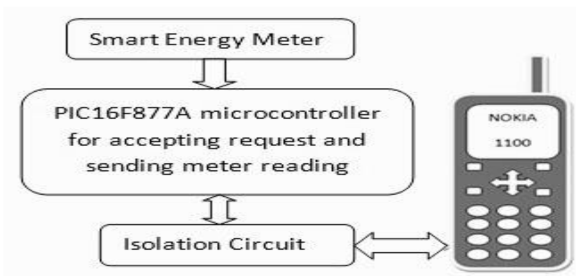

Fig. 2 Block diagram of Data Sending Device

5. ENERGY METER TEST SYSTEM

5.1 Architecture of The Hardware

In Fig. 3 the architecture of smart energy meter is shown. The single phase line is serving a load of a consumer. A transformer of 200V~14V ac rating is used to sense the voltage of the mains. So, basically the primary end of the transformer is parallel connected with the mains. The secondary end of the transformer which is giving 14V ac for 220 V ac. This 14V ac is served to the microcontroller via a voltage divider circuit. The voltage divider circuit is calibrated in such a way that the microcontroller get 5 V for 220V ac of the mains. For sensing current flowing to the load from the main a PCB mounting hall effect current transformer is used. When the main line is passed through the current transformer output voltage is generated. It is calibrated such a way that for maximum 50 amp current to the load output of the current transformer is 5 volt[6]. So, both voltage and current is sensed and fed to the microcontroller to calculate power, energy consumption.

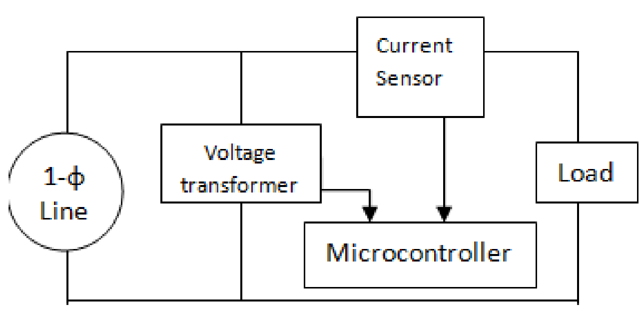

Fig. 3 Architecture of Energy Meter

5.2 Software Implementation By PIC Microcontroller

PIC16F877A microcontroller is programmed to take ADC of line voltage and current. A flow diagram of operation of the microcontroller is shown in Fig.4. After initializing the ADC module ADC of instantaneous current and voltage is taken. As the microcontroller get ADC value between 0-5 volt range. It has to do necessary calibration to take the voltage back to original voltage or current value. After calibration the original value of voltage and current is used to calculate real power, apparent power and power factor. There is a TIMER module inside the microcontroller to keep track of time passing. Using this module time is calculated. After each ADC taking and calculation microcontroller checks whether the data sending device is asking for meter reading or not. If not the microcontroller, simply displays the values on a two-line text LCD display. Microcontroller continuously does the ADC operation and calculates all the values.

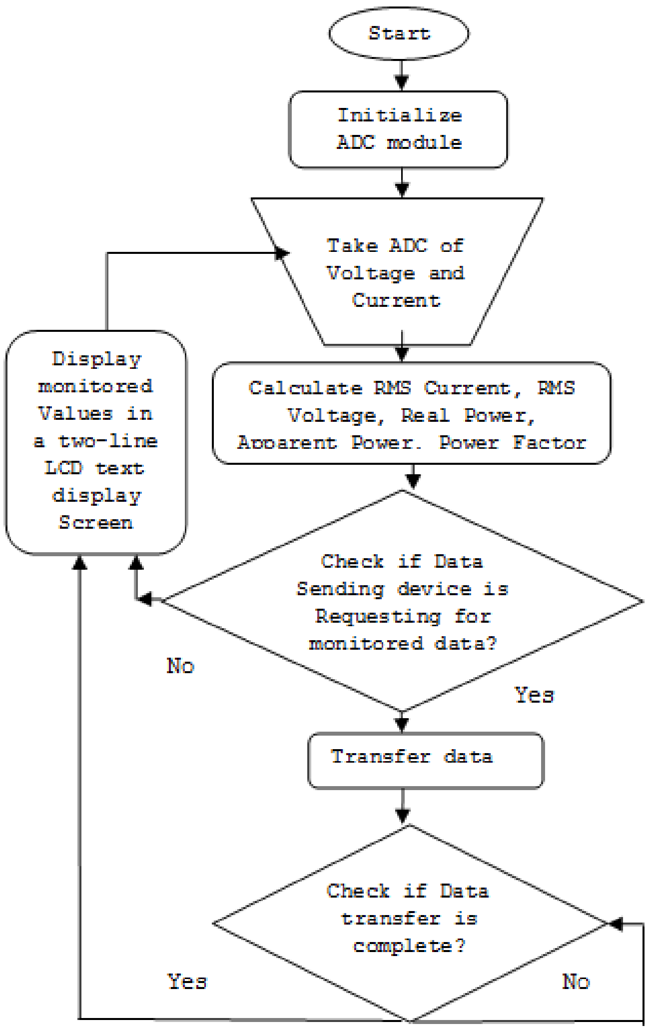

Fig.4 Flow Diagram of Microcontroller operation of Energy Meter

6. DATA SENDING DEVICE TEST SYSTEM

6.1 Cell-Phone Interfacing Circuit

Considering the basic idea of sending the meter reading automatically whenever requested by a SMS or ringing. There must e circuit which may drive this cell-phone. So, a microcontroller is interfaced with both the cell-phone and the energy meter. Microcontroller is attached with a cell-phone by optpcoupler isolated circuit. Cell phone is driven by nine PINs of the microcontroller. Any key of the cell phone can be pressed by making two of the nine pins high for 80ms. This is how each button of the cell-phone can be operated. Microcontroller of the data sending device is connected with the microcontroller of the energy meter by nine PINs. Among the nine PINs eight are used to transfer reading of the energy meter to the data sending device. And the ninth PIN is used to acknowledge request among them. Another PIN of the microcontroller is connected with a ringing or sms detecting circuit to recognize requests.

6.2 Software Implementation By PIC Microcontroller

Microcontroller (PIC16F877A) of data sending device first initializes microcontroller PINs for collecting data from energy meter. Then it checks microcontroller PIN coming from the cell phone detecting circuit. If a SMS or ringing is made. Microcontroller sends a signal to the energy meter to transfer meter reading. Energy meter acknowledges reading request and starts transferring data to data sending device. Just after receiving data microcontroller start SMSing by the optocoupler isolated circuit. Is can make SMS to multiple receivers or a single. The number of the recipient has to be saved in the cell phone before putting into operation. Once the SMSing is completed. The microcontroller waits for the next request.

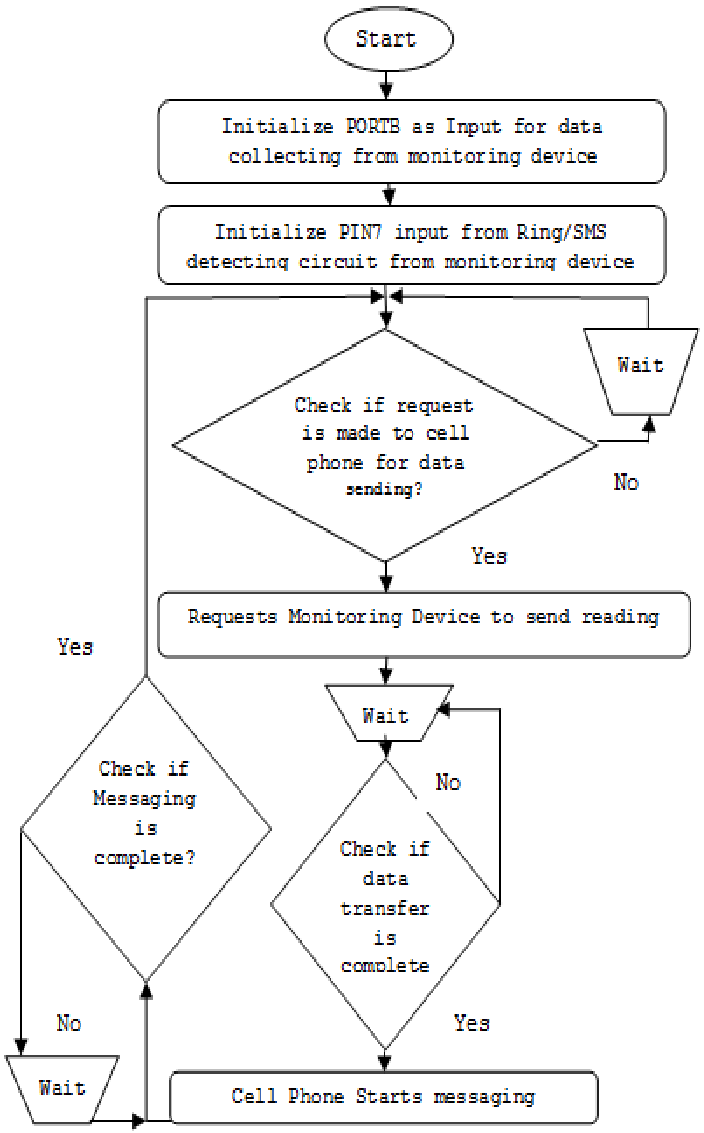

Fig.4 Flow Diagram of Microcontroller operation of Data Sending Device

7. EXPERIMENTAL SETUP & RESULTS

All the circuitry is build in the laboratory as shown in Fig. 5. Cell-phone interfacing circuit interfaced between the energy meter and the cell phone.

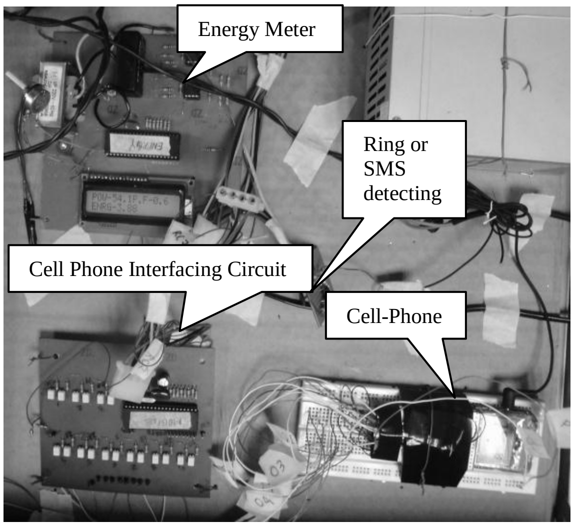

Fig.5 Combining Energy Meter with Data Sending Device

This energy meter is tested using a single-phase load. With the single-phase load 3 bulbs of 60 watts, each had been powered. In addition, the loads were resistive. So expected power factor should be close to 1.0. And energy consumption must be increasing with time.

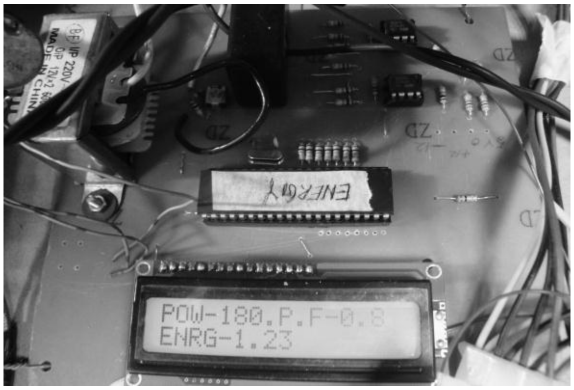

Fig.6 Displaying meter reading with a LCD display

As, in Fig.6 we can see real power is 180 watts. Power factor is 0.8 which indicates resistive load. Energy is shown in watt-hour was increasing rapidly. Also the data sending device response to sms and ringing.

CONCLUSION

This meter is capable of measuring energy consumption with minimum error. Also meter reading was successfully delivered. This meter highly compatible in our existing distribution system. It will not require any kind of maintenance. This meter will not require any extra communication network or any wired infrastructure to send data. As mobile phones have became a part of our life and it's network is available all over the country, so the idea of using mobile phone network instead of others is most reliable and cost efficient. Any kind of mobile operator can do the part of communication with a little change in the software. This Smart Energy Meter can provide these following facilities:

1. Ability to monitor each and every energy meter of the country from a remote place.
2. Loss of revenue due to corruption, misuse and theft will reduce significantly.
3. Frequent reading can produce a usage pattern of every consumer
4. Manual meter reading can be eliminated.

FUTURE WORK

In future, the GPRS modem can be used instead of cell phone. Energy Meter presented in this paper receives request send data via cell-phone. But use of USB GPRS modems can make this meter more feasible and robust. In addition, this will make the meter to receive commands from remote end. Another fact is the behavior of these meters, widely based on digital signal processing (DSP) techniques, is not independent on the input waveforms and their measurement uncertainty has to be evaluated [8].

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