

Microcontroller Based Single Phase Digital Prepaid Energy Meter for Improved Metering and Billing System

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Abstract

This paper presents a single phase digital prepaid energy meter based on two microcontrollers and a single phase energy meter IC. This digital prepaid energy meter does not have any rotating parts. The energy consumption is calculated using the output pulses of the energy meter chip and the internal counter of microcontroller (ATmega32). A microcontroller (ATtiny13) is used as a smart card and the numbers of units recharged by the consumers are written in it. A relay system has been used which either isolates or establishes the connection between the electrical load and energy meter through the supply mains depending upon the units present in the smart card. Energy consumption (kWh), maximum demand (kW), total unit recharged (kWh) and rest of the units (kWh) are stored in the ATmega32 to ensure the accurate measurement even in the event of an electrical power outage that can be easily read from a 20x4 LCD. As soon as the supply is restored, energy meter restarts with the stored values. A single phase prepaid energy meter prototype has been implemented to provide measurement up to 40A load current and 230V line to neutral voltage. Necessary program for microcontrollers are written in c-language and compiled by Win-AVR libc compiler.

Keywords: Energy meter IC, Microcontroller, LCD, Relay control unit, Smart card.

1. Introduction

The present system of energy metering as well as billing in Bangladesh which uses electromechanical and somewhere digital energy meter is error prone and it consumes more time and labor. The conventional electromechanical meters are being replaced by new electronic meters to improve accuracy in meter reading. Still, the Indian power sector faces a serious problem of revenue collection for the actual electric energy supplied owing to energy thefts and network losses. One of the prime reasons is the traditional billing system which is inaccurate many times, slow, costly, and lack in flexibility as well as reliability [1].

Meters, in the past and today in a few countries, were electromechanical devices with poor accuracy and lack of configurability. Theft detection was also a challenge. Recent developments in this direction seem to provide opportunities in implementing energy efficient metering technologies that are more precise, accurate, error free, etc. [2].

A Prepaid Energy Meter enables power utilities to collect electricity bills from the consumers prior to its consumption. The prepaid meter is not only limited to Automated Meter Reading but is also attributed with prepaid recharging ability and information exchange with the utilities pertaining to customer's consumption details. The use of electronic token prepayment metering has been widely used in UK for customers with poor record of payment [3]. A paper suggests a design of a system which can be used for data transmission between the personal computer and smart card [4]. Another paper suggests making use of state of art technologies like WiMAX in Prepaid Energy Meter owing to the idea of centralized accounting, monitoring and charging [5]. Polyphase prepaid energy metering systems have also been proposed and developed based on local prepayment and a card reader [6]. Wireless prepaid energy metering system has been proposed which incorporate RF based system [7]. Digital energy metering system as an alternative for the electromechanical system has been proposed and developed with the Peripheral Interface Controller (PIC) and necessary software [8]. Due to the low cost of microcontrollers, Prepaid Energy Meter has been developed using a microcontroller from the Microchip Technology Inc. PIC family [9].

In this paper, we have proposed a microcontroller based single phase digital Prepaid Energy Meter using two microcontrollers from the Atmel AVR family because of its performance, power efficiency and design flexibility and an Energy Meter IC. In this paper a credit card is used which is capable of communicating with both the distributor unit from where the credit card have to be recharged and the energy meter to which the number of recharged units to be loaded. An electronic circuit called USB burner circuit is used to load the recharged units both in energy meter and smart card. Softwares have been developed in c- language and compiled by Win-AVR libc compiler. The proposed energy meter has been implemented in the laboratory and finally results obtained have been presented and compared with electromechanical energy meter.

2. Development of The System Architecture:

The system architecture of microcontroller based single phase digital prepaid energy meter for improved metering system is shown in figure 1.

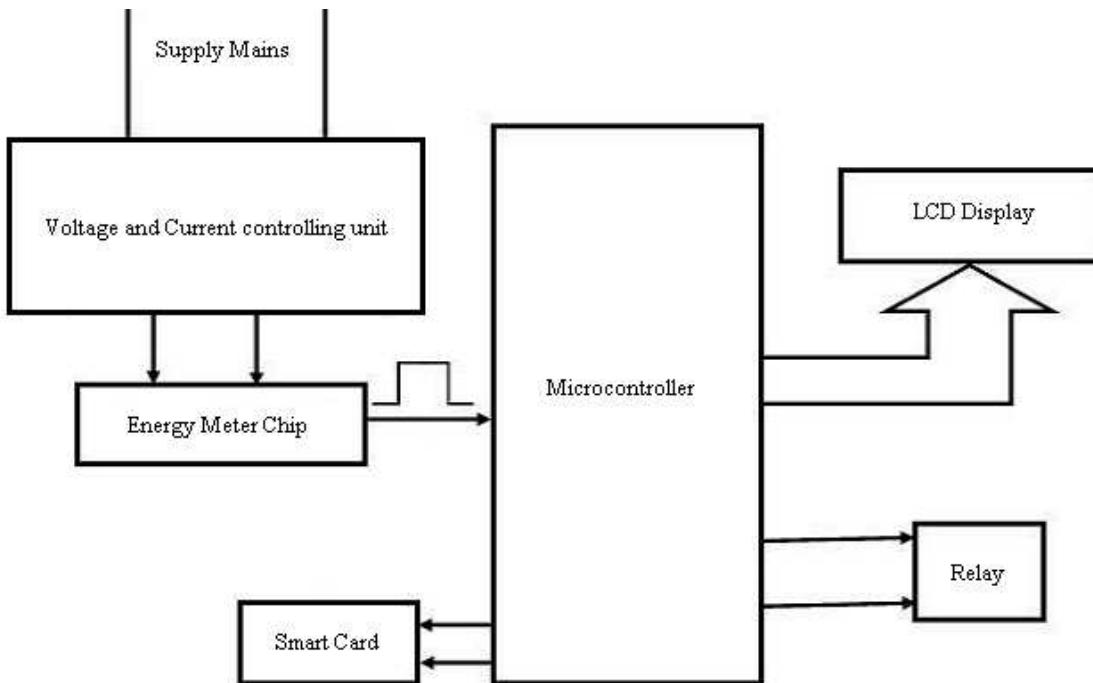


Fig. 1 Prepaid energy metering system

The energy metering system consists of Energy Meter chip, Microcontroller, Voltage and Current controlling unit, Smart cart, Relay and Liquid Crystal Display (LCD).

- Energy Meter IC generally produces electrical pulses proportional to the power consumed by the consumer and the power supply of microcontroller.
- Microcontroller calculates the energy consumed by the consumer utilizing the output of Energy Meter Chip and programs loaded on the microcontroller.
- Voltage and Current controlling unit feeds the actual current and voltage of load connected to consumer side to the energy meter chip.
- Smart Card interfaces with the microcontroller unit in which the number of units recharged by the consumer are written.
- Relay mainly performs the opening and closing of a connection between energy meter and load through supply mains depending upon the number of units present in the smart card at a moment.
- Liquid Crystal Display shows the energy consumption, number of unit recharged by the consumer, rest of the unit and maximum demand.

The energy billing system is shown in figure 2. The energy billing system mainly consists of a user operated PC, USB Burner circuit and Smart card.

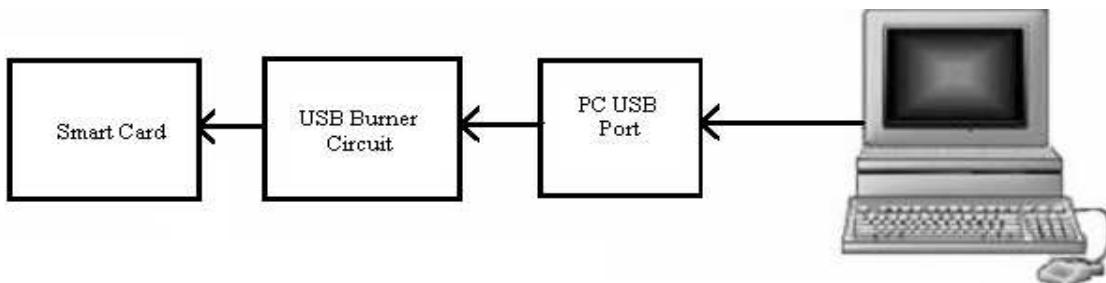


Fig. 2 Prepaid energy billing system

The server unit sets number of units in the smart card according to the consumer's demand. The tariff rates are already programmed in the PC of energy billing system and the system will only load the number of units into the smart card.

3. Hardware Development of Prepaid Energy Meter

The hardware architecture of Microcontroller based digital prepaid energy meter is shown in the Fig. 3. The energy consumption is being calculated using the energy meter IC and Microcontroller (ATmega32). In order to prevent unauthorized connection, a tampering detection unit is present in the Energy Meter IC.

The Microcontroller based digital prepaid energy meter system can be divided into eight parts as Voltage sensor, Current sensor, Energy Meter IC, Microcontroller, Smart Card and its Communication with Server Terminal, Relay Control Unit, Display Unit and Power Supply Unit. In the following circuit diagram, V_{cc} represents the positive supply and G_{nd} represents ground. The hardware description of eight parts is separately introduced as follows

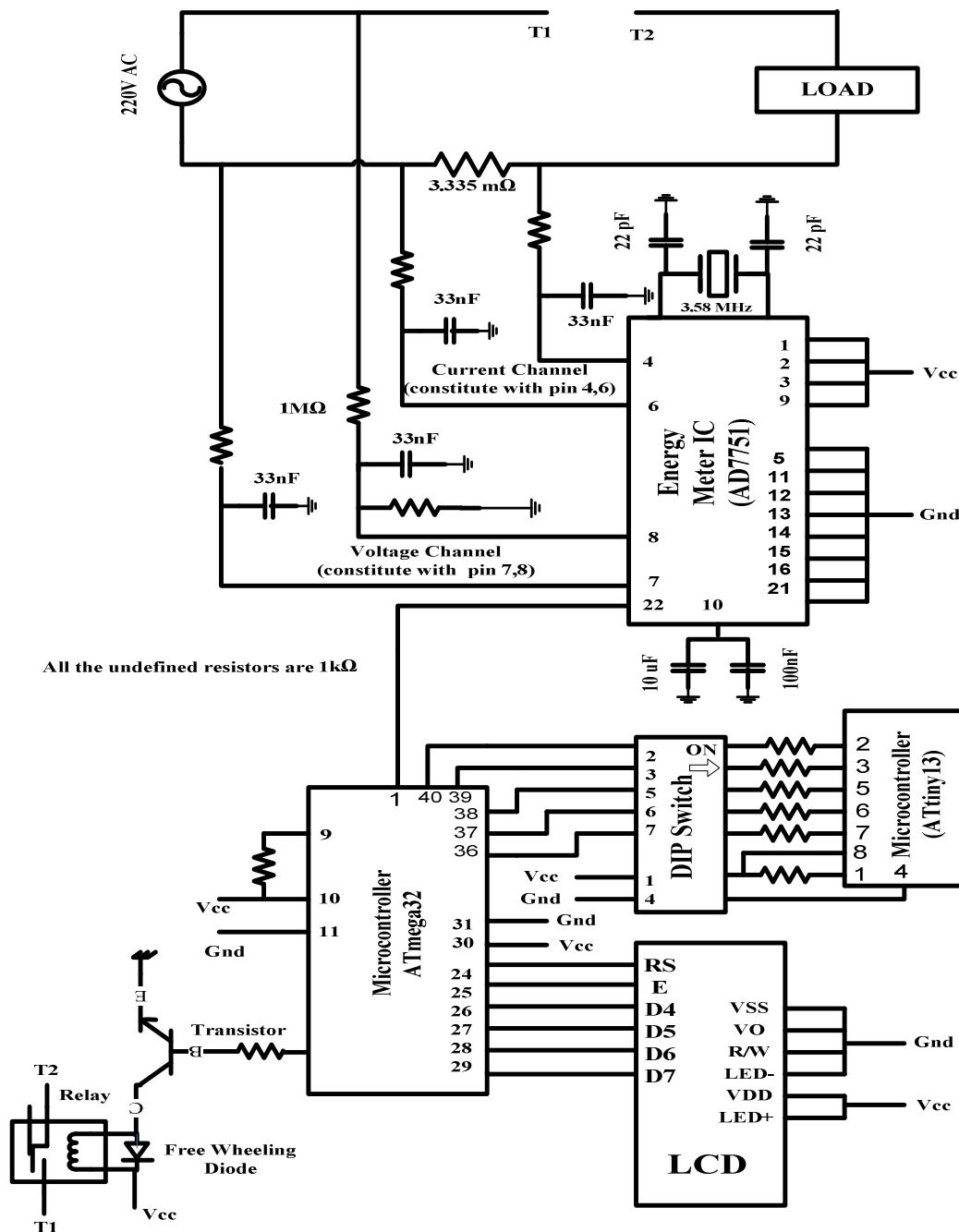


Fig. 3 Hardware of digital prepaid energy meter

a. Voltage Sensor

In this scheme, energy meter IC (AD7751) is biased around the neutral wire and a resistor divider is used to provide a voltage signal that is proportional to the line voltage. A voltage divider is made in combination of $1\text{ M}\Omega$ resistor and $1\text{ k}\Omega$ resistor. The output voltage across the $1\text{ k}\Omega$ resistor is applied to the voltage channel of the energy meter IC.

b. Current Sensor

The voltage outputs from a calibrated resistor of $3.335\text{ m}\Omega$ connected with the neutral wire is applied to the current channel of the energy meter IC. Current channel has a programmable gain amplifier with gains of 1, 2, 8, or 16. The maximum peak differential voltage is $\pm 660\text{ mV}$ divided by the gain selection.

c. Energy Meter IC

Energy meter IC has two ADCs that digitizes the voltage and current signals from the supply main. These ADCs are 16-bit second order sigma-delta converters with an over sampling rate of 900 kHz. A high-pass filter in the current channel removes any dc component from the current signal. This eliminates any inaccuracies in the real-power calculation due to offsets in the voltage or current signals. The real-power calculation is derived from the instantaneous power signal. The instantaneous power signal is generated by a direct multiplication of the current and voltage signals. In order to extract the real-power component, the instantaneous power signal is low-pass filtered. The low frequency output of the energy meter IC is generated by accumulating this real-power information. The output frequency is therefore proportional to the average real-power. This average real-power information can in turn be accumulated by a counter to generate real-energy information.

d. Microcontroller

Microcontroller is a programmable device which contains a microprocessor, memory, input-output ports etc which can be compared with the microcomputer. Microcontroller is a single chip computer. As microcontroller is a low cost programmable device. It is used in the automatic control application. Now the pulses produced at the pin CF is directly applied to the counter pin of the microcontroller. The microcontroller counts the pulses that appear at pin 1 of Microcontroller (ATmega32) within every 20 seconds. The number of pulses per second appeared at pin 22 of Energy Meter IC is directly proportional to the instantaneous real power information for a particular load. Information such as power, energy, and maximum demand are stored at the EEPROM of the Microcontroller (ATmega32).

e. Smart Card and its Communication with Server Terminal and Energy Metering System

A microcontroller (ATTiny13) is used as a smart card in which the numbers of units to be recharged are loaded by interfacing with the USB port and the user operated PC of server terminal. The ATTiny13 will send the information contained on it to the microcontroller (ATmega32), when the DIP switch connected with the two microcontrollers is switched on. Then the information of microcontroller (ATTiny13) will be transferred to the microcontroller (ATmega32) and stored in the EEPROM of the microcontroller (ATmega32) while erasing the content of the ATTiny13. The number of recharged units are contained in the EEPROM of the microcontroller (ATmega32) and will be gradually decreased with the increment of the energy consumption by the load. The updated value after the execution of the every step will be stored in the EEPROM of the microcontroller (ATmega32). Now the consumers have to recharge the smart card from server terminal for further use of energy after finishing the previously recharged units.

f. Relay Control Unit

Five relays each of rating 10A are used. One relay is only used to provide the coil current. When this relay will conduct then it energizes the rest of the relays and consequently the load current will flow through the four relays only which acts as one relay of rating 40A. When the number of units stored in the EEPROM reaches zero, the microcontroller (ATmegs32) initiates a pulse to the base of the transistor. Then the transistor will be switched on which initiates the operation of the relay and consequently the relay will be off. When the credit card is again recharged, the ATmega32 will send a pulse for which the relay establishes a connection between the load and the supply mains.

g. Display Unit

The liquid crystal display controller displays alphanumeric characters and symbols. It can be configured to drive a dot-matrix liquid crystal display under the control of microcontroller. In this paper, LCD is mainly used to display energy consumption of the load, the number of units recharged by the consumer, rest units, maximum demand of consumer.

h. Power Supply Unit

Every electronic circuit needs appropriate power supply for its operation. Basically Microcontrollers, Energy Meter ICs, Liquid crystal display and relays operate on ± 5 volts supply. For this reason, we have used a ± 5

volt power supply. We have taken into consideration the small energy consumed by the power supply itself that will be paid by the consumers.

4. Basic Data Acquisition and Energy Calculation

a. Data Acquisition for Calculating Power

The Energy Meter IC AD7751 produces an output frequency that is proportional to the time average value of the product of two voltage signals. The input voltage signals are applied across pin 4, 6 and pin 8, 7 of Energy Meter IC. The Energy Meter IC also provides an output frequency at pin 22 of Energy Eeter IC equal to the output power that can be calculated using an equation as

$$F = \frac{5.74 \times V_1 \times V_2 \times \text{Gain} \times F_{l-4}}{V_{\text{REF}}^2} \quad (1)$$

where, V_{REF} = Nominal reference voltage for Energy Meter IC =2.5 volts

$$F_{l-4}=1.7$$

$$\text{Gain}=1$$

$$V_1= \text{Voltage applied across pin 4 and 6 which is proportional to load current}$$

$$V_2= \text{Voltage applied across pin 8 and 7 which is proportional to line to neutral voltage}$$

This output frequency is proportional to the real power information. During calibration we have got the frequency $F=0.5$ Hz against 1.5 kW load. When $F= 0.5$ Hz, then power=1500 Watt. So for any value of the frequency at F (say $F= X$ Hz), Power, P will be

$$P = \frac{1500 \times X}{0.5} \quad (2)$$

$$P = 3000 \times X \quad (3)$$

b. Energy Calculation

The complete equation for determining the energy or units consumed from Power, P is obtained as follows

$$\begin{aligned} 1 \text{ WattSec} &= \frac{1 \text{ kWSec}}{1000} \\ 1 \text{ WattSec} &= \frac{1 \text{ kWh}}{1000 \times 3600} \\ \text{Energy} &= \frac{P \times \text{Sec}}{1000 \times 3600} \text{ Units} \end{aligned} \quad (4)$$

$$\text{Energy} = \frac{3000 \times X \times \text{Sec}}{3600000} \text{ Units} \quad (5)$$

5. Software Development for Prepaid Energy Meter

The system software is implemented by C language and the developed code is edited, compiled and debugging by Win-AVR software.

a. Algorithm for Energy Metering system at consumer's end

- 1 Start
- 2 Initialize the display.
- 3 Decide whether the number of units in Microcontroller is sufficient or not. If the balance is insufficient then disconnect the load from supply otherwise connect to the load to supply.
- 4 Count the number of pulses initiated from Energy Meter IC AD7751 with the help of counter0 when the load consumes power.
- 5 Measure time with the help of timer1.
- 6 Calculate power, $P = 3000 \times X$ using this equation, where X denotes the frequency of pulses that is produced by the Energy Meter IC.
- 7 Calculate energy using the following equation, $\text{Energy} = \frac{3000 \times X \times \text{Sec}}{3600000} \text{ Units}$

- 8 Store energy and power reading into the EEPROM of ATmega32 Microcontroller for future use.
- 9 Check whether the button for number of units recharge is pressed or not. If the button is pressed check whether a valid smart card is inserted or not. If the inserted card is valid then read, store and update the recharge information and display the update status on the LCD
- 10 If the valid smart card is not inserted then repeat the step 3

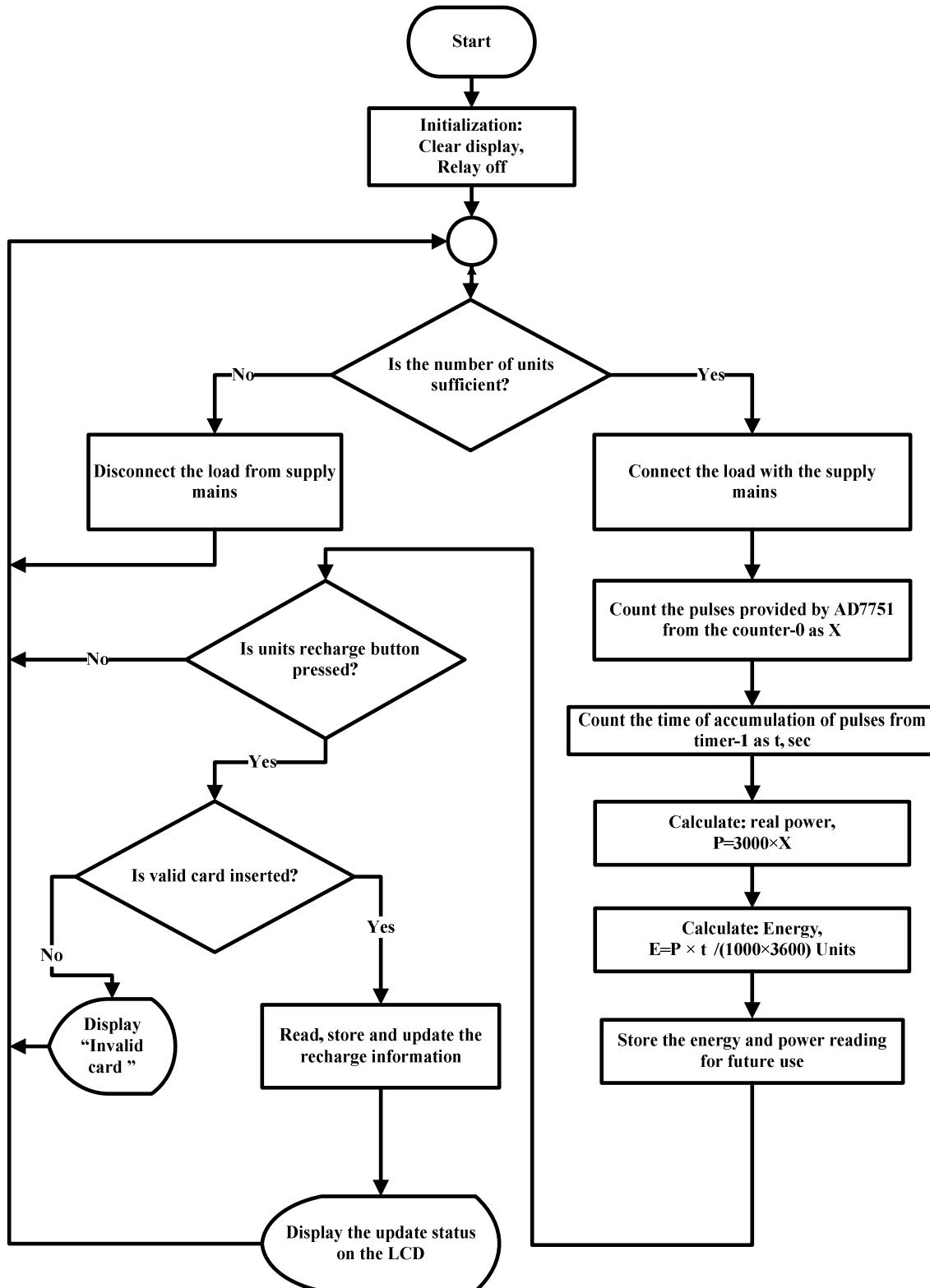


Fig. 4 Flow chart for energy metering system at consumer's end

b. Algorithm for Energy Billing System at Server End

1. Start
2. Initialize the signal
3. If the push button is pressed, start data transfer to the ATmega32 from ATTiny13 microcontroller otherwise go to step 2.
4. If the confirmation message is found from ATmega32, then erases the content of the smart card (ATTiny13) and finish otherwise go to step 2.

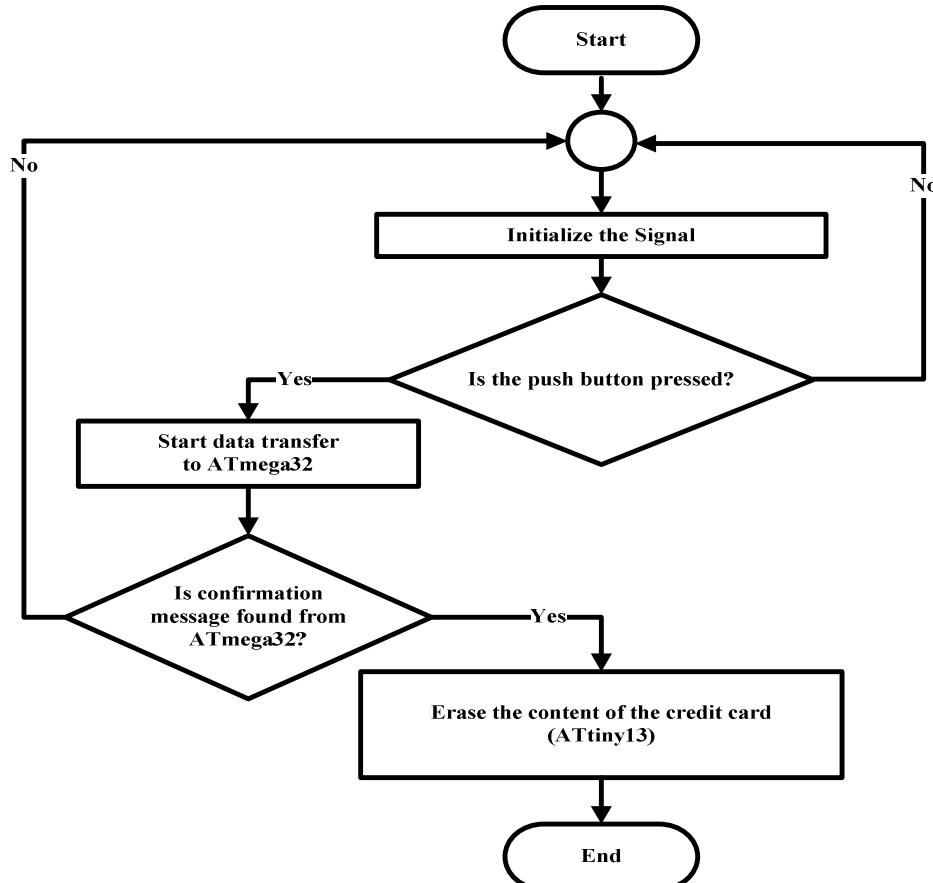


Fig. 5 Flow chart for energy billing system at server terminal

Table 1. Test Result of Energy Measurement by the Proposed Prepaid Energy Meter

Time (sec)	Expected Energy output (kW-sec)	Energy Output from Measurement (kW-sec)	Percentage of error
0	0	0	Not Applicable
20	24	23	4.17
40	48	47	2.08
60	72	70.6	1.94
80	96	97.5	-1.56
100	120	122	-1.67
120	144	145	-0.69
140	168	168.5	-0.30
160	192	192.3	-0.16
180	216	215.7	0.14
200	240	240.3	-0.13
220	264	264.1	-0.04
240	288	288.05	-0.02

6. Results and Analysis

The Energy Meter was tested in the Measurement Laboratories of Rajshahi University of Engineering & Technology, Bangladesh. An Electric Heater of 1.2 kW rating was used as a load that draw currents of up to 5.5 A. The supply voltage was between 210 V and 230 V. Energy measurement process is described step by step. At first, A



wattmeter was used to measure the power consumed by the load. Then energy consumption was measured after every 20 seconds using the obtained power information from the load. The computed energy consumption is read from the Liquid Crystal Display. The experimental result for the testing of prepaid energy meter is summarized in Table 1.

The results shown in Table 1 are the expected energy output in kW-sec obtained from the load power, 1.2 kW and time and energy output from measurement that is displayed by LCD after every 20 sec. A certain amount of power is supplied to the load, this power is maintained over a certain period of time and the energy consumption is calculated and finally displayed. The tests were done over a 3 minute period, measurements were taken every 20 sec and a very high accuracy level is observed particularly after longer periods of time.

7. Conclusion

This paper has demonstrated for measuring the electrical energy consumption of an electrical load for two wire distribution systems with the proposed energy meter as an alternative to the conventional electromechanical meters. This microcontroller based energy meter prototype has been implemented to provide measurement up to 40 A load current from a 230 V line to neutral voltage. The proposed energy meter is capable of measuring energy consumption for all loads conditions i.e. power factor and non-sinusoidal voltage and current waveforms. It does not possess any rotating parts that help in the prevention of meter tempering, which is an attractive feature for the utilities. The proposed energy meter includes a “no load threshold” feature that will eliminate any creeping effects in the meter. In addition, the process of reading the energy consumption is facilitated by the LCD display that is simpler than that for the analog meters which reduces human errors while noting down the meter reading. This energy meter has the potential to change the future of the energy billing system in Bangladesh. The energy billing system may help the energy distribution companies to reduce costs and increase profits, to improve metering and billing accuracy and efficiency, and to contribute the energy in a sustainable way. To recharge the microcontroller chip, it must be taken to the server terminal or unit. The energy billing system provides employment for nearly 2-3 people in every server terminal for jobs like recharging smart card and processing the distribution of power in a convenient way. In future, mode of recharging the smart card can be improved by wireless communication between the server terminal and energy meter unit..

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