# Electronic Energy Meter with Remote Monitoring and Billing System

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*Abstract*—**Electronic energy meter is capable of taking readings and can store it into its memory. Taking energy meter reading is time consuming and an expensive task. The meter reader travels for a long distance and take the reading manually to prepare the bill. Consumers have to go to the billing office, stand in a long line and submit the bill. This is a boring job and time consuming also. It can be avoided by remote monitoring of electronic energy meter and prepaid billing system by the use of cash card. In this paper measurement of energy, remote monitoring, preparing of bill and billing system is presented. Low cost ATMEGA8L microcontroller is used here to control the whole system. Sampling of voltage and current is done by it. Then it processes data to achieve power in that instant. Then it stores the value of total energy consumed by the consumer and can calculate energy charge according to the tariff. LCD display is attached with this system to show total energy consumed, power factor and amount of charge etc. Communication between central energy distribution office and energy meter is done through power line. Complex tariff rate set up and cash card based billing is possible in this system. Electronic meter gives high accuracy for nonlinear loads than conventional rotating disc type electro-mechanical meter. Greater accuracy and stability can be maintained in this system.**

***Index Terms***—**Remote monitoring, cash card payment, communication via power line, complex tariff setup**

## I. Introduction

Electric energy can be measured by conventional electro-mechanical energy meter. It suffers from some disadvantages. These meters have low accuracy. Its performance can be changed by temperature and electromagnetic interference. It consumes more power to measure electric energy. Moreover the rotation of disc is interrupted by vibration and even rotates on no load condition. Electronic energy meter takes place of these meters because of low power consumption, higher accuracy, temperature independency, storage facility, remote communication and security. An electronic energy meter is presented in this paper which is capable to communicate with central distribution office to provide great facility. Current transformer (CT) is attached with line to measure current flowing through the load and potential transformer (PT) is connected to the line to measure terminal voltage of load. 8 bit microcontroller ATMEGA8L is connected with the secondary of CT and PT. It has built in 6 channel analog to digital converter (ADC). Microcontroller takes samples of the current and voltage from its ADC. Then it multiplies them to get power in that instant. Then it processes these values of power to calculate the total power consumed by load.

Power distribution office can communicate with energy meter to set up complex tariff rate and can take bill from it by means of cash card. Electricity stealing defence is possible in this system [1]. The time of stealing and quantity of it can be determined. The location of stealing can be determined also.

Three phase energy measurement is possible by a single microcontroller because it has multi channel ADC. A 0.02 SB1300 standard electrical energy meter can be designed based on the approved products of wide-range and multi-purpose standard electrical energy meter [2].

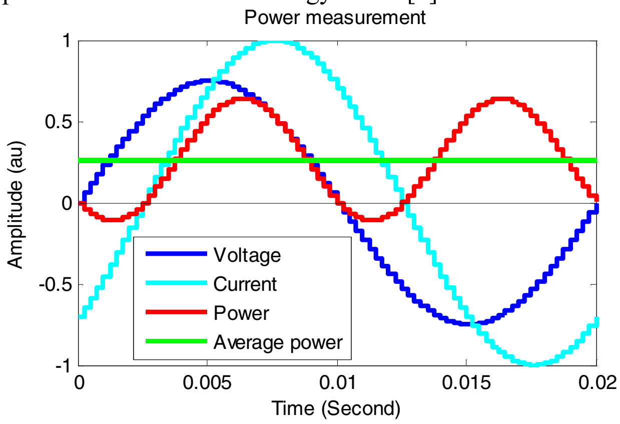


Fig. 1 Graphical representation of power measurement by digital technique.

Recently electronic energy meters are continuously replacing electro-mechanical meters. For wireless meter reading Bluetooth technology can be chosen [3]. But its range is very short.

Network communication system for energy meter reading is done using integrated communication technology and software system. A wireless or wired communication system may be integrated with electronic energy meter to have remote access over the usage of electricity. The communication channel may be identified by the consumer's number and secured by any cryptographic standards [4]. Automated billing of energy meter may be possible by connecting a GSM modem to the energy meter. One can know due bill instantly and can even pay for it [5]. Cash card system may be implemented to pay bill easily.

After exceeding the maximum demand, the meter and hence the connection can be disconnected by an embedded system automatically. Electric supply authority can detect a power hacker also [6]. A complex tariff rate (different rate for different time in a day) can be settled in this system. Energy consumption is stored in the microcontroller's EPROM memory. This action is necessary to ensure a correct

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measurement even in the event of an electrical outage or brown out. Accuracy was better than 97% in the work of authors mentioned in [7]. To attain reduced manufacturing cost, improved measurement accuracy, increased timely information and miniature size digital wireless communication technique in energy meter is adopted. Authors in [8] developed wireless ZigBee network that practically involving no manpower.

Electronic meter provides high accuracy for nonlinear loads. It is more robust and accurate. Authors in [9] have designed energy meter based on Motorola 56800 DSP family. The on-chip ADC is capable of simultaneous dual sampling of current and voltage in each phase. Energy computations consist mainly of multiplication and addition operations, easily be handled by this DSP. The high ADC sampling rate (up to two samples at 830 KHz) gives high accuracy. ARM-7 microcontroller and GPRS network can be implemented for energy measurement and management. The intelligent terminal is used to acquire information from kWh meter, control the energy-consuming device and communicate with management centre via GPRS network [10].

The performance and accuracy of this system is better compared to the conventional rotating disc electro-mechanical energy meter. This system shows high accuracy even for nonlinear loads.

This paper is organized as follows: Section II describes the energy measurement methodology. Section III explains the complete design of the system. Results and calculation are shown in section IV. Finally, section V concludes the entire paper.

## II. METHODOLOGY

Power absorbed by a load at any instant can be expressed as (1).

$$p = vi \tag{1}$$

Where, $p$ is instantaneous power, $v$ is instantaneous voltage at the terminal of load and $i$ is instantaneous current flow through the load as shown in Fig. 1. Energy consumed by a load for a time interval T is as given in (2).

$$E = \int_0^T pdt = \int_0^T vidt \tag{2}$$

For unity power factor load voltage, current and power wave shape is shown in Fig. 2.

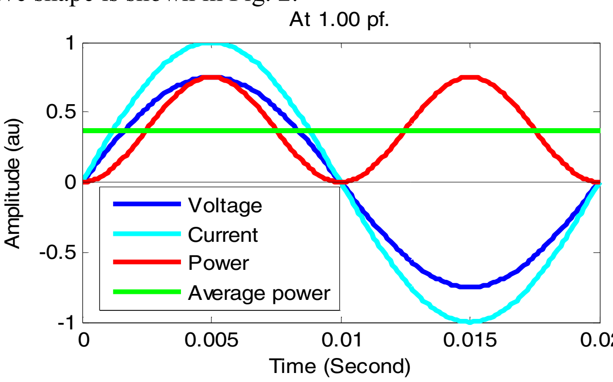


Fig. 2 Power measurement at 1.00 power factor.

The average power, $P_{avg}$ can be expressed as given in (3).

$$P_{avg} = \frac{E}{T} \tag{3}$$

Where, $T$ is the total time period and $E$ is the energy consumed by $T$ time.

At different power factor the wave shape of voltage, current and power is shown in Fig. 3.

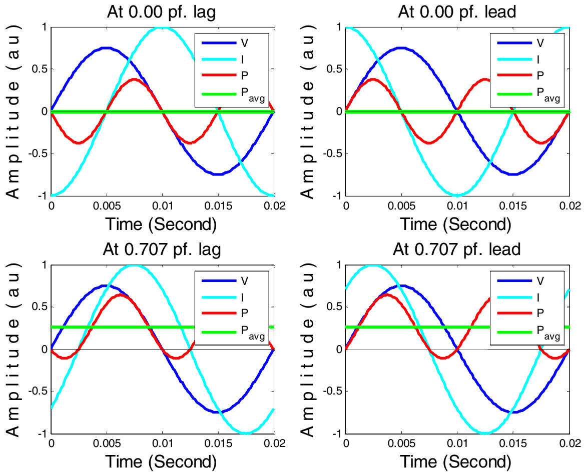


Fig. 3 Power measurement at different power factor.

$P_{avg}$ can be expressed as (4) also.

$$P_{avg} = \frac{V_m I_m}{2} \cos\theta \tag{4}$$

Where, $V_m$ is the peek voltage or maximum voltage, $I_m$ is the peek current or maximum current and $\theta$ is the phase difference between voltage and current. Power factor is the value of $\cos\theta$. Calculation of average power, $P_{avg}$ from this system can be explained from Fig. 4.

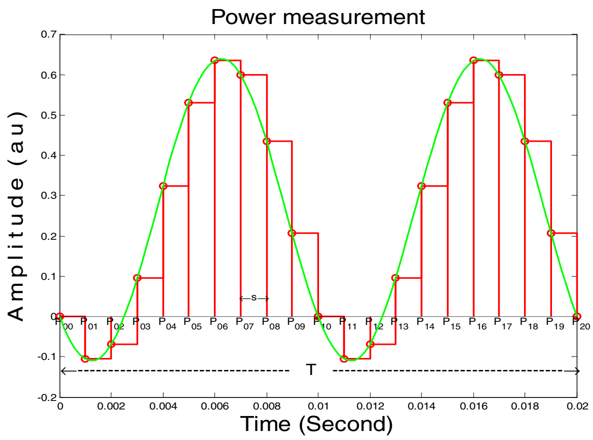


Fig. 4 Energy measurement from rectangular slot.

Let, total energy consumed by the load be $E$, number of sample in a period be n and slot width be s. Then,

$$\begin{aligned} E &= sP_0 + sP_1 + sP_2 + sP_3 + \dots\dots\dots\dots + sP_n \\ &= s(P_0 + P_1 + P_2 + P_3 + \dots\dots\dots\dots + P_n) \end{aligned} \tag{5}$$

Let, T be the total time period. Then $P_{avg}$ can be calculated from (5). It is expressed in (6).

$$\begin{aligned} P_{avg} &= \frac{E}{T} = \frac{1}{T}\left[s(P_0 + P_1 + P_2 + P_3 + \dots\dots\dots\dots + P_n)\right] \\ &= \frac{s}{T}\sum_{i=0}^{n} P_i = \frac{1}{n}\sum_{i=0}^{n} P_i \left[\because n = \frac{s}{T}\right] \end{aligned} \tag{6}$$

Actually average power is the real power. Instead of rectangular slot if trapezoidal slot is considered then accuracy will increase. It can be shown from Fig. 5.

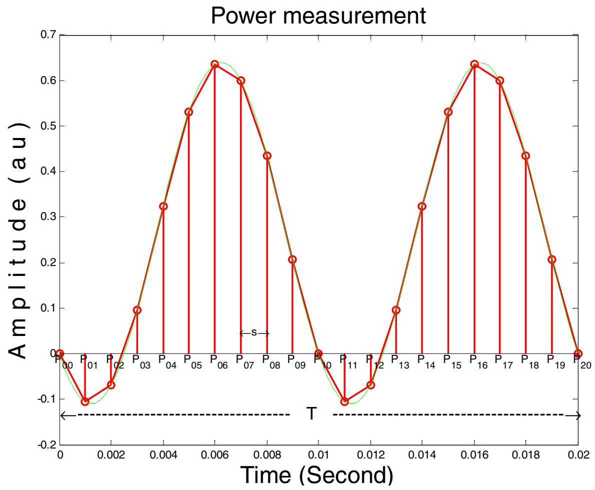


Fig. 5 Energy measurement from trapezoidal slot.

Then, total energy consumed by the load is expressed as given in (7)

$$\begin{aligned} E' &= \tfrac{s}{2}(P_0 + P_1) + \tfrac{s}{2}(P_1 + P_2) + \tfrac{s}{2}(P_2 + P_3) + \ldots \\ &\ldots\ldots + \tfrac{s}{2}(P_{n-2} + P_{n-1}) + \tfrac{s}{2}(P_{n-1} + P_n) \\ &= s\begin{bmatrix} \tfrac{1}{2}P_0 + P_1 + P_2 + P_3 + \ldots\ldots \\ \ldots\ldots + P_{n-2} + P_{n-1} + \tfrac{1}{2}P_n \end{bmatrix} \\ &= s\left[\sum_{i=0}^{n} P_i - \tfrac{1}{2}(P_0 + P_n)\right] \end{aligned} \tag{7}$$

Therefore, average power can be calculated from (7). It is expressed in (8).

$$\begin{aligned} \therefore P_{avg}{}' &= \tfrac{E}{T} = \tfrac{1}{T}s\left[\sum_{i=0}^{n} P_i - \tfrac{1}{2}(P_0 + P_n)\right] \\ &= \tfrac{s}{T}\sum_{i=0}^{n} P_i - \tfrac{s}{2T}(P_0 + P_n) \\ &= \tfrac{1}{n}\sum_{i=0}^{n} P_i - \tfrac{1}{2n}(P_0 + P_n)[\because n = \tfrac{T}{s}] \\ &\approx \tfrac{1}{n}\sum_{i=0}^{n} P_i \approx P_{avg}\ [\because 2n >> 1] \end{aligned} \tag{8}$$

If, $P_0$=0 and $P_n$=0 then, $P_{avg}{}'$ is reduced to $P_{avg}$. It is shown in Fig. 5. Therefore, in this paper average power is calculated by considering rectangular slot from (6). Value of T is 0.02 second for 50 Hz power source as shown in Fig. 4 and Fig. 5. Value of n is 20 here. But, value of n is greater than 3000 that is used practically for greater accuracy.

When sampling number in a time period increases then accuracy increases. But, sampling number can't be increased so large due to limitation of ADC. Quantization error is also added with result. ATMEGA8L microcontroller has 6 channel 10 bit built in ADC. So its range varies from 0 to 1023. Output of ADC can be expressed in (9).

$$x(t) = 511\sin(2\pi ft) + 511 \tag{9}$$

Value of $x(t)$ is integer and varies from 0 to 1022. Derivative of $x(t)$ is given in (10).

$$\begin{aligned} \frac{dx(t)}{dt} &= 511 \times 2\pi f\cos(2\pi ft) \\ &= 160535.76\cos(2\pi ft)[\because f = 50] \\ \therefore dt &= \frac{dx(t)}{160535.76\cos(2\pi ft)} \end{aligned} \tag{10}$$

Maximum effective slot width $dt$ can be expressed in (11).

$$dt = \tfrac{1}{160535.76\times 1} = 6.23\mu\sec \tag{11}$$

Minimum effective number of sample in a time period is given by (12).

$$n = \tfrac{0.02}{6.23\times 10^{-6}} = 3210.27 \approx 3210 \tag{12}$$

Therefore, minimum effective sampling frequency can be expressed by (13).

$$f_s = 3210 \times 50 = 160500Hz = 160.5KHz \tag{12}$$

## III. DESIGN OF THE SYSTEM

Complete system can be easily presented by block diagram as shown in Fig. 6. From distribution office electric power is supplied to the consumer (load). PT is connected to the line to step down the voltage level (5 volt peek to peek). CT is connected in series to step down the current level. Here current to voltage converter (CVC) is used to get corresponding voltage (5 volt peek to peek) of line current. Two analog to digital converter (ADC) is used to get value of voltage and current at any instant. Then from (6) and (5) it can calculate power and energy respectively. ADC is consists of sample & hold circuit and quantization circuit.

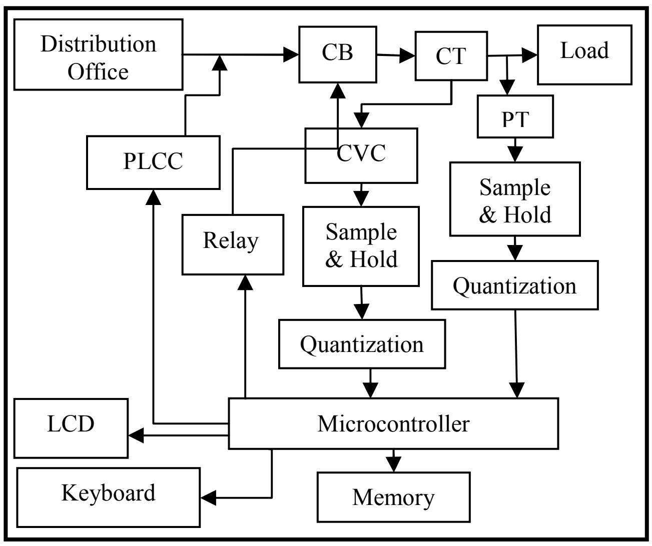


Fig. 6 Complete block diagram of energy measurement system.

In this work, ATMEGA8L microcontroller is used because it has built in 6 channels 10 bit ADC. Therefore no external ADC is needed. Microcontroller stores value of instantaneous energy, tariff and other information in Memory to calculate total energy used by consumer, bill, maximum demand etc. Load duration curve can be formed. So load forecasting becomes easy and accurate. Complex tariff (different rates for different hours, maximum demand and power factor etc.) rate can be settled. This system has a LCD to display energy information (total energy consumed, maximum demand, bill, pf. etc.). One keyboard is attached with the system for the purpose of cash card payment of bill. Communication between distribution office and microcontroller is done by power line communication circuit (PLCC). In PLCC, digital is modulated by modulator to high frequency and transmitted to power line through transformer. In receiving section a band pass filter (BPF) is used to get modulated signal. Then it is demodulated and original signal is achieved. PLCC is attached with both energy meter and distribution office. The complete block diagram of PLCC is shown in Fig. 7. First distribution office sends ID number of required energy meter only. Then microcontroller of that energy meter sends all information to it. Here power line is used for communication channel. Therefore no external communication line (optical fibber etc.) is needed. Also no GPRS Modem or Bluetooth is needed. Overall cost is reduced and system security is enriched.

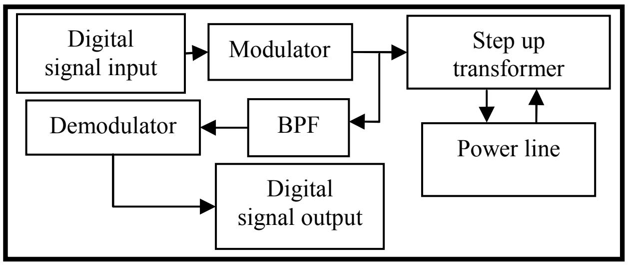


Fig. 7 Block diagram of PLCC.

## IV. Results

Difference between calculated power and actual power delivered by the distribution centre is the error of power. Error of power decreases exponentially with increase of sample number in a time period. It is calculated and shown in Fig. 8.

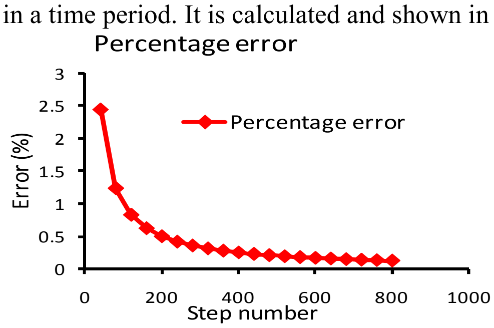


Fig. 8 Relation between percentage error with number of sample.

The error of power has a relation with power factor of the system. Maximum system has nonlinear relationship with power factor. However it can be shown that for this system error of power does not change with power factor. It is represented in Fig. 9.

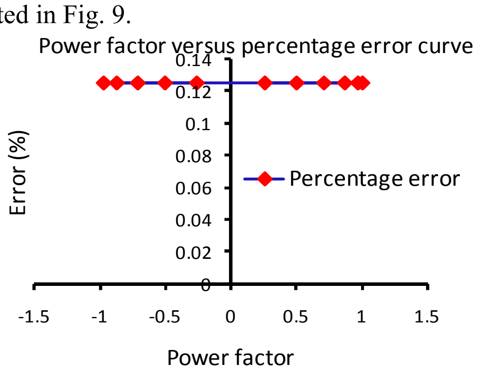


Fig. 9 Relation between percentage error with power factor.

Connection diagram of microcontroller with mini LCD is shown in Fig. 10. It displays terminal voltage, line current, power, power factor, total energy and total charge.

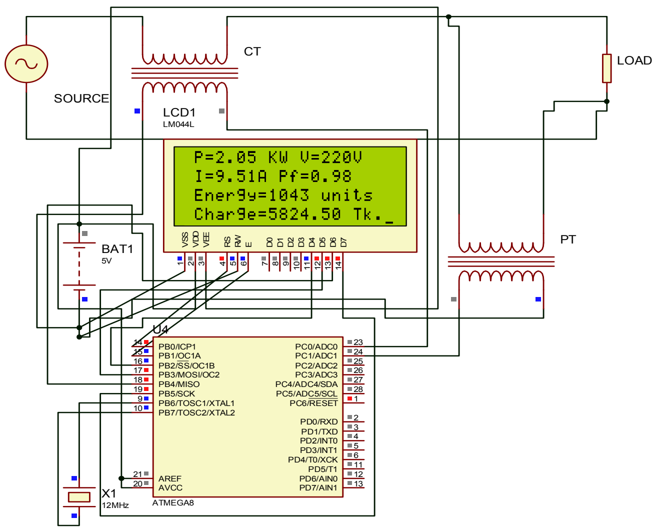


Fig. 10 Simulated results of energy measurement system.

## V. Conclusions

Digital energy measurement becomes popular now a day. Still now remote monitoring of power and cash card payment is not implemented worldwide. Complex tariff rate cannot be settled due to analog type of meter. Also it has no storage device. Therefore it can't play any vital role in load forecasting. However accuracy of maximum system varies with power factor and rating of load. Mainly for nonlinear load it shows very poor result. In this work accuracy is approximately 100 percent. It can play a vital role in load forecasting, complex tariff rate set up, cash card bill payment, system protection and power stealing defence. This system is more reliable, accurate, and cost effective.

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