Design and Implementation of Enhanced Smart Energy Metering System

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ABSTRACT

In this work, the design and implementation of a smart energy metering system has been developed. This system consists of two parts: billing center and a set of distributed smart energy meters. The function of smart energy meter is measuring and calculating the cost of consumed energy according to a multi-tariff scheme. This can be effectively solving the problem of stressing the electrical grid and rising consumer awareness. Moreover, smart energy meter decreases technical losses by improving power factor. The function of the billing center is to issue a consumer bill and contributes in locating the irregularities on the electrical grid (non-technical losses). Moreover, it sends the switch off command in case of the consumer bill is not paid. For implementation of smart energy meter, the microcontroller (PIC 18F45K22) is used. For communication between billing center and smart energy meters, ZigBee technology is adopted. The necessary program for smart energy meter is written in MicroC PRO, while the program for billing center is written in visual C#.

Key words: smart energy meter, billing center, ZigBee, power factor correction

تصميم وتنفيذ منظومة مقاييس طاقة ذكية مطورة

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الخلاصة

في هذا العمل تم تصميم وتنفيذ منظومة مقياس طاقة ذكية تتكون من مركز جباية و مجموعة من المقاييس الذكية للطاقة الموزعة. وظيفة مقياس الطاقة الذكي هي قياس وحساب كمية الطاقة المستهلكة و تكلفتها وفق نظام التعرفة المتعددة. وهذا يساهم بشكل فعال في تقليل الاجهاد على الشبكة الكهربائية وزيادة وعي المستهلك. اضافة الى ذلك يساهم مقياس الطاقة الذكي في تقليل الخسائر التقنية من خلال تحسين عامل القدرة. وظيفة مركز الجباية هي اصدار فاتورة المستهلك والمساهمة في الكشف وتحديد مكان وجود المخالفات على الشبكة الكهربائية (الخسائر غير التقنية). كما يقوم ايضا على ارسال الايعازات الخاصة بقطع او توصيل القدرة الى المستهلك وذلك اعتمادا على دفع الفاتورة. استخدم المسيطر الدقيق (PIC18F45K22) في تنفيذ مقياس الطاقة الذكي. كما واعتمدت تقنية ال ZigBee كوسيلة اتصال بين مركز الجباية ومقاييس الطاقة الذكية. تمت كتابة البرنامج للمسيطر الدقيق داخل المقياس الذكي بواسطة لغة (MikroC Pro) بينما البرنامج الخاصة بمركز الجباية فتمت كتابتها بواسطة لغة (Visual C#).

1. INTRODUCTION

Smart grid combines renewable energy with information technology to provide a quality power for consumers. The existence of two-way flow energy and information between consumer and provider enables a variety of advanced utility applications; such as energy management services, advanced metering and reporting, power quality management, and many other functions, **RAHMAN, and MTO, 2011**. Smart grid helps in decreasing the transmission and distribution losses and improves power quality by managing the power consumption of the consumer. Smart energy meter is considered essential component to smart grid that reduces technical and Nontechnical losses, **Pedro, 2009**. It performs real time calculations of consumed energy and its price according to a multi-tariff scheme to mitigate the problem of peak demand.

The problem of peak demand can be mitigated by increasing the number of power plants but the disadvantage of this approach is not only the high cost but also increasing CO_2 emission. Onother approach to mitigate peak demand problem is applying a multi tariff in smart energy meter for calculating the consumed energy, imposition punitive tariff at peak demand time pushes the consumer for switching off unnecessary appliance at peak demand time, **Depuru, et al, 2011**. There are two main methods for achieving multi tariff scheme, the first method is done by receiving notification signal from billing center each time zone as in **Anjana, and Prasanna, 2014**, but this way is inefficient when the number of consumers' nodes is increased to a more realistic number. In this case, the network will suffer from high collisions and may break down. Onother approach for achieving multi tariff scheme is done by smart energy meter using real time clock (RTC) module, RTC module is used to keep track of time, support multi-tariff scheme and it can be used to provide historical peak demand, in addition a RTC module is used to determine the day of sending data to the billing center, a table of tariffs are stored in the smart energy meter that can be updated by billing center via ZigBee. This method is more expensive compared with the first method but it is efficient.

On other side, the network load is inductive, i.e., load contains inductive component such as air conditioner, refrigerator, induction motor and etc. which causes poor power factor where up to 0.7 in summer in Iraq. Smart energy meter improves power quality by achieving residential power factor correction (PFC). Residential PFC is becoming more popular in some regions of the world. In 2001, a distributer of electrical energy in Peru performed a project to improve power factor for a limited region including 26,000 households. It was found that improving power factor from 0.84 to 0.93 led to saving of around 19, 300 MWh per year that means a cost saving of close to 900,000$. The advantages of residential PFC go far beyond the energy savings; because PFC reduces the current of loading that leads to reduce losses in transmission line (I^2R) and increases the grid capacity, **Alexandre, 2007**. The proposed smart energy meter achieved power factor correction based on developed algorithm and capacitors bank in order to compensate reactive power, thus bringing power factor near to 0.95.

2. RELATED WORKS

With the development of electronic chips and programming languages, smart energy meters evolved gradually with more hardware and software capabilities. So many researches have been conducted to develop a general purpose of smart energy meter in both hardware and software.

Smart energy meter was designed and develop to measure energy consumption by consumer and send it to the service provider. Both ZigBee and GSM technologies are used to perform Bi-directional communication between service provider and consumer. ZigBee technology is used to transmit information from meter to the base station where the bill is calculated. GSM network is installed at base station for messaging all consumers and service provider employees, **Vivek, and Ranthkenthiwar, 2014**. Advanced metering infrastructure based on power line carrier (PLC) is proposed to automatically collect information from different kinds of meters. Energy consumption, water and gas can be measured by the meters and then data is sent to the gateway through PLC. A gateway reads different data and communicates with data acquisition center (DAC) through GSM. The gateway consists of two parts Neuron Core and Transceiver. Transceiver is used to transfer data on the PLC while Neuron Core represents the processing unit, **Popa, 2011**. Smart energy meter is designed and implemented to vehicle-to-grid. This energy meter is interface between electric vehicles and smart grid. It is able to measure bi-directional consumed energy, voltage and current. This energy meter also achieves bi-direction measurement when the difference in phase angle between voltage and current determines the direction of energy consumption, **Libiao, et al, 2011**. A remote meter-reading system is designed to get data from the sensors and meters and control on the appliance in residence area. The structure of this system consists of sensors, measure meters, intelligent terminal, management center and wireless communication network. Bluetooth technology is used to send and receive data and control signal between intelligent terminal and meters, while GSM network is used to communicate between intelligent terminal and management center, **Liting, et al, 2006.**
Automatic meter reading system based on GSM technology is implemented enables the consumer to check the status of electricity from anywhere. It also enables utility to cut off and reconnect the meter connection by SMS, **Zahid Iqbal, 2014**. Wireless sensor and actuator network are implemented for monitoring the energy consumption of appliances in the home. The structure of the network consists of energy measurement nodes and central server, the central server displays the reading from measurement nodes via user interface in real time and enables user to remotely power on or power off individual device. This system presents a practical way to control the energy consumption in home, **Edwin, et al, 2013**. The prepaid electricity meter is designed to be able to conduct money transactions remotely in order to enable the consumer to recharge his account from home, besides; the proposed meter helps utility companies to eliminate electricity theft, **Sai, et al, 2014**. A power factor corrector is designed and implemented using PIC microcontroller, it can improve power quality by compensating excessive reactive components. The system includes sensing and measuring power factor value of the load. A proper algorithm is used to determine and trigger sufficient capacitors to improve power factor, **Nader, 2007**.

In this paper, the proposed system provide a low cost smart energy meter, monitoring and improving power quality by developing a proper algorithm, achieving multi tariff with proper solution by using a dedicated IC (DS1307), bi-directional communication is achieved to ensure sending and receiving data and commands between smart energy meter and billing center by using ZigBee technology.

3. PROPOSED SMART METERING SYSTEM

The proposed system consists of two parts, smart energy meter for the consumer and the billing center for the service provider.

3.1. Smart Energy Meter

Smart energy meter provides the real time measurement and calculation of amount and cost of consumed energy and displays related information for consumer. When the inductive load undermines power quality as result of poor power factor, the smart energy meter can improve power quality by switching on the capacitors bank for continuously keeping the power factor of the load near unity. Moreover, the smart energy meter can be used to detect the irregularities on the electrical grid. Smart energy meter is composed of the analog unit, controller unit (PIC microcontroller), real time clock and calendar (RTCC), liquid crystal display, wireless communication module and capacitors bank. The hardware architecture of the proposed smart energy meter is shown in the **Fig.1**.

3.1.1 Analog unit

Smart energy meter interfaces to the relatively high voltage while the acceptable input voltage of PIC microcontroller is 5V, so the analog unit scales and converts the voltage and current to voltages which are sufficiently small and cannot cause damage to delicate electronics. The voltage of power line is usually 220 Vrms (-312 to 312 Vp-p), therefore it is scaled by the voltage divider to a level and dynamic range is compatible with the analog to digital (ADC) of PIC microcontroller, a low power consumption resistors are used to divide measured voltage. The values of current are sensed by using current sensor IC (ACS712). ACS712 current sensor is a precise, low offset, linear hall sensor circuit. Current sensor IC converts applying AC current flowing through two of its pins into proportional voltage using integrated Hall IC.

3.1.2 Controller unit

The values sensed by the voltage and current sensors are provided to the analog channel of the PIC microcontroller. The processing unit calculations of PIC microcontroller rescales all the measurements by sensors to get the original value and performs all the power parameters calculations. All the calculated values are displayed on display unit as shown in **Fig.2**. The controller unit selected for smart energy meter design is the PIC18F45K22 microcontroller from Microchip, due to it's multiple on-chip resources, low cost and suitable processing accuracy that can reduce and simplify the design appropriately. PIC18F45K22 microcontroller has 10 bit ADC with a multiple of channels. The multiplexer provides the capability of connecting multi-analog signals to a single ADC. It has a multiple of timers that are used to provide interrupt to notify the CPU every time interval. Regular interrupt is important to execute a certain instructions at a certain time. This technique enables to create multitasking easily which executes multiple application programs. The built-in serial port of the microcontroller represents smart energy meter communication port. This is used with aid of ZigBee module to send and receive data.

3.1.3 Real time clock and calendar (RTCC)

The proposed smart energy meter contains a tiny real time clock and calendar module (RTCC) to keep track of time, support multi-tariff scheme and it can be used to provide historical Peak demand, in addition a tiny RTCC module is used to determine the day of sending data to the billing center. A tiny RTCC module is based on the chip DS1307 which supports the I2C protocol. This tiny RTCC module provides seconds, minutes, hours, day, month, and year information. The end of the month date is automatically adjusted for months with fewer than 31 days, including corrections for leap year. The clock operates in either the 24-hour or 12-hour format with AM/PM indicator. A Tiny RTCC module contains Lithium cell battery (CR1225) to save time and 56-Byte Nonvolatile (NV) RAM for data storage. A tiny RTCC module uses the I2C bus to communicate with PIC microcontroller.

3.1.4 Power quality and size of capacitors bank.

Usually the network load is inductive, i.e., load contains inductive component. PFC removes inductive component by adding (equal in magnitude) capacitive component through connecting a capacitor. Due to the load of the home is varied, fixed capacitors is inappropriate to improve the power factor and may led to overcompensation, so automatic switching of capacitors is a good method of obtaining the full electrical benefits from a capacitor installation. In order to calculate the amount of required capacitor compensation for improving power factor, an effective algorithm for switching sufficient capacitors bank has been developed (in PIC microcontroller).

In this work, PFC is performed in smart energy meter by using capacitors bank. The capacitor banks consist of eight capacitors of different values, the values of these capacitors are chosen in such away like the weight of binary digits representing a decimal number. These values are 128, 64, 32, 16, 8, 4, 2 and 1 μFas shown in **Fig.3**. The value of chosen capacitors provide a high value of micro farad reach to 255 μF, so the number of capacitors can be reduced according to the expected loads in each and individual home.

4. BILLING CENTER

The main function of the billing center as the name implies is to bill consumers according to the amount of consumed energy. It receives a consumption data from the smart energy meter which represent the amount and the cost of the consumed energy to issue a consumer bill and the other measurements to give a good estimate of the grid status. Moreover, the billing center can send the commands of switching on or off the electrical power. It sends the switch off command when the bills are not paid, and it sends the switch on command when the bills are paid.

Detection and localization of a faulty meter, irregularities on the electrical grid, and leakages can be determined at billing center by using a master meter with each group of home meters. A difference between the power reading of the master meter of the group and the summation power of individual home meters within the same group means either one or more meters are faulty, or there is an irregularity, or a leakage in the electrical grids.

The billing center is implemented by using personal computer (PC), communication transceiver (ZigBee module) and the interfacing circuit which is used to establish the proper connection between the communication transceiver and the personal computer as shown in **Fig.4**. The transceiver used in the billing center is the same as in the smart energy meter. The difference in the two ZigBee modules is in the addresses in the network and some of setting which makes the billing center represents a coordinate, while smart energy meter represent node. The data from the meters is received through ZigBee module then sends it to PC.

5. SOFTWARE DESIGN OF THE PROPOSED SYSTEM

The software used in the proposed metering system consists of two parts; first part is executed in smart energy meter whereas the second part is executed in the billing center.

5.1 Software of the Smart Energy Meter

The software of smart energy meter is responsible for initializing and managing the operation and interaction among hardware modules of the smart energy meter. The software operations of the smart energy meter are illustrated in the flowchart of the main program shown in **Fig.5** and the flowchart of interrupt service routine shown in **Fig.6**. Interrupt service routine (ISR) occur once every 2 msec in order to sample voltage and current at regular time. ISR ensures that the sampling rate (Fs) to be 500 Hz which provides 10 samples per cycle. ISR is also responsible for the flags condition. Flags conditions are required for executing the operations in the main program as shown in **Fig.6**. First, for sampling rate (Fs) and N samples of the power line source, the RMS voltage can be calculated by using Eq. (1).

$$V_{rms} = \sqrt{\frac{\sum_{i=0}^{N-1} v_i^2}{N}} \qquad (1)$$

Where N is the number of samples, v_i is the sampled voltage.

As mentioned early the voltage of power line is scaled to level that is compatible with delicate electronics, so the measured value must be rescaled to the engineering value (actual voltage) in the processing unit calculations. To do so, the sampled voltage in Eq. (1) multiplies by voltage proportionality constant for the circuit design (K) as shown in Eq. (2).

$$V_{rms} = \sqrt{\frac{\sum_{i=0}^{N-1} (K\, v_i)^2}{N}} \qquad (2)$$

The time taken to calculate the RMS voltage can be reduced by modifying Eq. (2) to Eq. (3):

$$V_{rms} = T * \sqrt{\sum_{i=0}^{N-1} v_i^2} \quad (3)$$

Where $T = \frac{k}{\sqrt{N}}$

The divisions and multiplications are reduced to one operation in Eq. (3) for each RMS voltage calculation. In this Eq. (3), T can be calculated offline.

The same above procedure is used for RMS current and energy calculations using Eq. (4) and Eq. (5), respectively.

$$I_{rms} = \sqrt{\frac{\sum_{i=0}^{N-1} i_i^2}{N}} \quad (4)$$

$$E = \frac{1}{fs} \sum_{i=0}^{N-1} v_i * i_i \ , \quad (5)$$

where fs is sampling frequency and i_i is ith sampled of the current.

The second part of the program represents subroutine for displaying where the parameters on the screen are updated every 1 sec.

The third part of program is responsible for measuring and correcting power factor of the load where the smart energy meter enters this subroutine every 3 seconds. The flowchart shown in **Fig.7** illustrates the operations of power factor correction.

The power factor (PF) of the load can be calculated by dividing the active power (P) by apparent power (S), when the PF of the load is equal to 0.9 or more, no need to add capacitors to the load, if the PF of the load is less than 0.9, the processing unit of PIC microcontroller calculates the desired capacitances to improve the power factor of the load.

The reactive power utilized in the load ($varL$) is calculated as:

$$var_L = \sqrt[2]{S^2 - P^2} \quad (6)$$

In order to improve PF to 0.95, new reactive power is calculated as:

$$var_a = P * \tan \hat{\theta} \quad (7)$$

$\hat{\theta}$: The phase angle between voltage and current that is chosen 18° for obtaining PF=0.95.

Now, the reactive power is required to compensate(var_c):

$$var_c = var_L - var_a \quad (8)$$

The required capacitors to improve power factor to be 0.95 is

$$C = \frac{var_c}{2\,\pi * f * (V_{rms})^2} \quad (9)$$

After calculating the required capacitances, the control unit sends control signal to the relay unit to connect the required capacitors.

The last part of the program is responsible for sending data to the billing center which is executed every month. The accumulated amount of consumed energy and the cost are delivered to the billing center.

During its operation, the smart energy meter checks whether there is a command message from the billing center that requests switching on or off the building as shown in flow chart of interrupt service routine in **Fig.6**.

In order to perform the functions of the smart energy meter, the control unit is programmed with MikroC PRO programming language.

5.2 Software of the Billing Center

The flowchart in **Fig.8** shows the methodology of performing billing center functions.

1. First the billing center enters the initialization routine, in which:
   - The transceiver communication module parameters are initialized.
   - Communication network is established.
   - Smart energy meters are joined to the network.
2. Second, after receiving the data, the billing center creates a table that stores the data and indicates the current status of the each consumer.
3. Third, the billing center sends command signal to the smart energy meter to reset energy counter.

4. Forth, the billing center checks the budget and the bill of the consumer, where it has ability to send a command to the smart energy meter for switching the power on or off at any time.

Any failure in communication between the billing center and the smart energy meter is unacknowledged and retransmitted. The programming language Visual C# is used to create a GUI for the billing center to facilitate the operation of the billing and controlling the status of the consumer, **Fig.9** shows the GUI for billing center. The table in the bottom left of the figure is related to the multi-tariff and the time zones, where the rectangles labeled "Currently" indicate the current time zone and tariff. The text boxes "Time zone" indicate the duration of the time zone, where all the four time zones, in this work, has the same period (6 hours). The text boxes "Price" indicate the price of consumed energy in the corresponding time zone. It must be mention that the price must be proportional to the energy demand.

6. MEASUREMENT ERRORS

Reducing the error to the minimum possible level in any measurement system is extremely important. Instrumental error is a common source of the measurement errors that are inherent in manufacture of an instrument. It arises due to the operation principle of instrument such that arises in the analog to digital convertor (ADC), **Morris, 2001**. The accuracy of ADC has an effect on overall measurement system performance and efficiency. Systematic errors arise in ADC due to the sampling operation, **STMicroelectronics, 2003**, the effect of sampling error (e_s) in power measurement is inversely proportional to the sampling frequency, sampling errors can be calculated as shown in the equation below, **Gerard, 1984**:

$$e_s = \frac{V_p\, I_p}{2N} \cdot \frac{sin\, N\gamma}{sin\, \gamma} cos(N-1)\ \gamma \tag{10}$$

Where $\gamma = \frac{2\pi f}{f_s}$,f_s: sampling frequency, f: power line frequency, γ:samples interval in radian, N : number of samples.

Quantization errors affect measurement accuracy in sampled-data-acquisition systems. Mean square value of error quantization is

$$e_{eq} == \frac{\Delta^2}{12} \tag{11}$$

Where $\Delta = \frac{2V_p}{2^n}$, V_p is amplitude value of signal, n is number of bit, It is also known as successive approximation register.

And

$$e_{eq} = \frac{V_p^2}{3 * 2^{2n}} \tag{12}$$

It is clear from the Eq. (12) that the error caused by quantization is reduced when the resolution of ADC (n) increases, **Istevan, 1985**. In this research the proposed smart energy meter: *fs* =500 Hz, N= 25, n = 10 bit. The accuracy is proportional to the number of taken energy samples per period, where a number of eight samples per period (*fs* =400) of the power line give a percentage of error of less than 1%. The total errors due to the sampling process and quantization can be calculated by adding the two errors together.

Limiting error is considered another type of measurement error that arises in electrical circuit due to the tolerance in the circuit components such as resistors, capacitors, etc. This error can be reduced by choosing components with low tolerance. For precise measurement systems, the error in passive components is compensated using calibration. Calibration here means applying a signal with a known value then adjusts the meter (resistors or parameters) until getting compatibility between the signal value and the meter's reading. This calibration may implemented by the hardware or software, **Microchip, 2005**.

The temperature coefficient of circuit components must be taken into account in the design and implementation of the smart energy meter, especially in the case of device works in extremely hot conditions, as in Iraq.

7. IMPLEMENTATION AND TESTING

Fig.10 shows the Proteus simulation of smart energy meter. Voltage and current sensor of smart energy meter are connected to the resistor and inductor load which are connected in series to measure all power parameters, and then trying to correct power factor by using capacitors bank.

The smart energy meter is tested in real scenarios by using real loads as shown in **Fig.11**, where the smart energy meter is connected to some of household appliance to test different cases of the loads, the accuracy of the smart energy meter readings were compared with the professional power clamp meter as shown in **Table 1**. The measurement values by analog unit are given to the PIC microcontroller, and then displaying on LCD screen. The readings that are displayed on LCD are compared with that are received in billing center. The connecting and disconnecting of smart energy meter to the wireless network is also checked.

8. CONCLUSIONS

The characteristics of the metering system are investigated and there are several facts that had become clear when testing overall implemented system. These facts are: firstly, implementation of smart metering system can be constructed in Iraq by using available local market components. Secondly, smart metering system can play an important role in increasing the consumers' awareness through displaying instantaneous power consumption and its cost. Moreover, the system can effectively improve power factor of electrical grid. Increasing consumers' awareness and improving power factor can effectively reduce wasted energy and consequently ensure reliable power supply. Thirdly, ability of real time calculating of the consumed energy and its cost enables implementing a multi tariff scheme. This scheme cannot be achieved in a traditional meter. Finally, the smart metering system can be effectively detect and locate irregularities on the electrical grid and a malfunction smart energy meter(s).

9. REFERENCES

- Anjana Shree M, Prasanna Vadana D, *2014, Smart Meter for Power Factor Enhancement in Real Time*. International Conference on Embedded Systems, IEEE, Vol.3, No.14.
- Alexandre José, 2007,*Homecap: Residential Power Factor Correction*, TDK EPCOS Worldwide Company, Peru, Application Note.
- Cao Liting, Tian Jingwen, And Zhang Dahang, 2006. *Networked Remote Meter-Reading System Based On Wireless Communication Technology*, International Conference on Information Acquisition, Shandong, China, IEEE, No. 6, pp. 172-176, August .
- Edwin Chobot, Daniel Newby, Renee Chandler, 2013. *Design And Implementation Of A Wireless Sensor And Actuator Network For Energy Measurement And Control At Home*.International Journal of Embedded Systems and Applications, Vol. 3, No. 1, pp. 1-15, March .
- Gerard N. Stenbakken, 1984. *Wideband Sampling Wattmeter*, IEEE, Vol. 103, No. 10, pp. 2919-2926, October .
- H. M. Zahid Iqbal, M. Waseem, 2014. *Automatic Energy Meter Reading using Smart Energy*, Conference paper, IEEE, Vol. 1, No. 11.
- Istevan Kollar, 1985.*Programming Error introduced by digital power/energy measurement*. International Journal of Technical University of Budapest, pp. 1-7.
- Libiao Qiao, Xiaojun Liu, 2011. *Design and Implementation of the Smart Meter in Vehicle-to-Grid*, ,International Conference on electric utility and power technology, IEEE, Vol. 2, No. 11, pp. 618-621, August .
- MD M RAHMAN, and AMANULLAH MTO, 2011. *Technologies Required for Efficient Operation of a Smart Meter Network*, Conference on industrial electronics and application, IEEE Vol.3, No.8, PP.125-130.
- Microcontroller Division Applications, 2003. U*NDERSTANDING AND MINIMISING ADC CONVERSION ERRORS*, STMicroelectronics Technology Inc., U.S.A., Application Note.
- Pedro Antmann, 2009. R*educing Technical And Non-Technical Losses In The Power Sector*, The Energy Unit Of The World Bank, Background Paper.
- Popa Mircea, 2011.*Smart Meters Reading Through Power Line Communications*, Journal Of Next Generation Information Technology, Vol. 2, No. 3, pp. 92-100, August.
- Reddy, Sreenadh,Soma Shekara Depuru, Lingfeng Wang, And Nikhil Gudi, 2011.*Smart Meters For Power Grid – Challenges,Issues, Advantages And Status*, ELSEVIER, No. 11, pp. 1-7.

- R. Barsoum Nader, 2007.*Programming of PIC Micro-Controller for Power Factor Correction,* In International Conference on Modeling & Simulation, Malaysia.
- Sai Kiran Ellenki 1 , Srikanth Reddy G 2014 . *An Advanced Smart Energy Metering System for Developing countries , International Journal Of Scientific Research And Education*, Vol. 2, No. 1, pp. 242-258.
- S., Morris Alan, 2001. *Measurement and Instrumentation Principles*, Third Edition Ed.: ELSEVIER.
- Sandip chattopadhyay, 2005. *Designing Energy Meters with the PIC16F873A*, Microchip Technology Inc., U.S.A., Application Note.
- Vivek A. Dongre And Prof. A P. Rathkanthiwar., 2014. *Zigbee And Gsm Based Wireless Meter With Tamper Detection And Control System*, International Journal of engineering research and application, International Conference on Industrial Automation and Computing (ICIAC-12-13th) pp. 37-48, April.

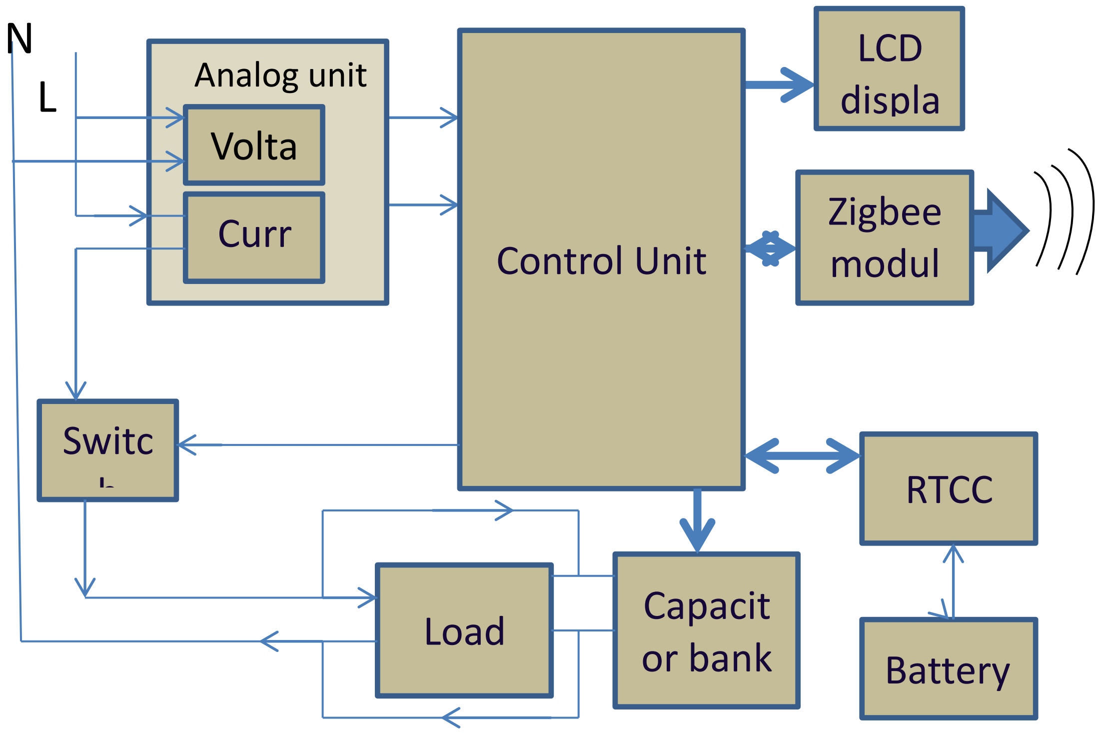

Figure 1. Block diagram of smart energy meter.

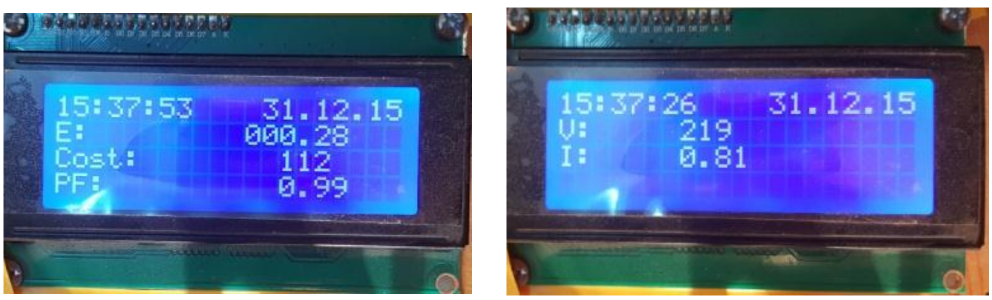

Figure 2. Two page of smart energy meter's LCD screen.

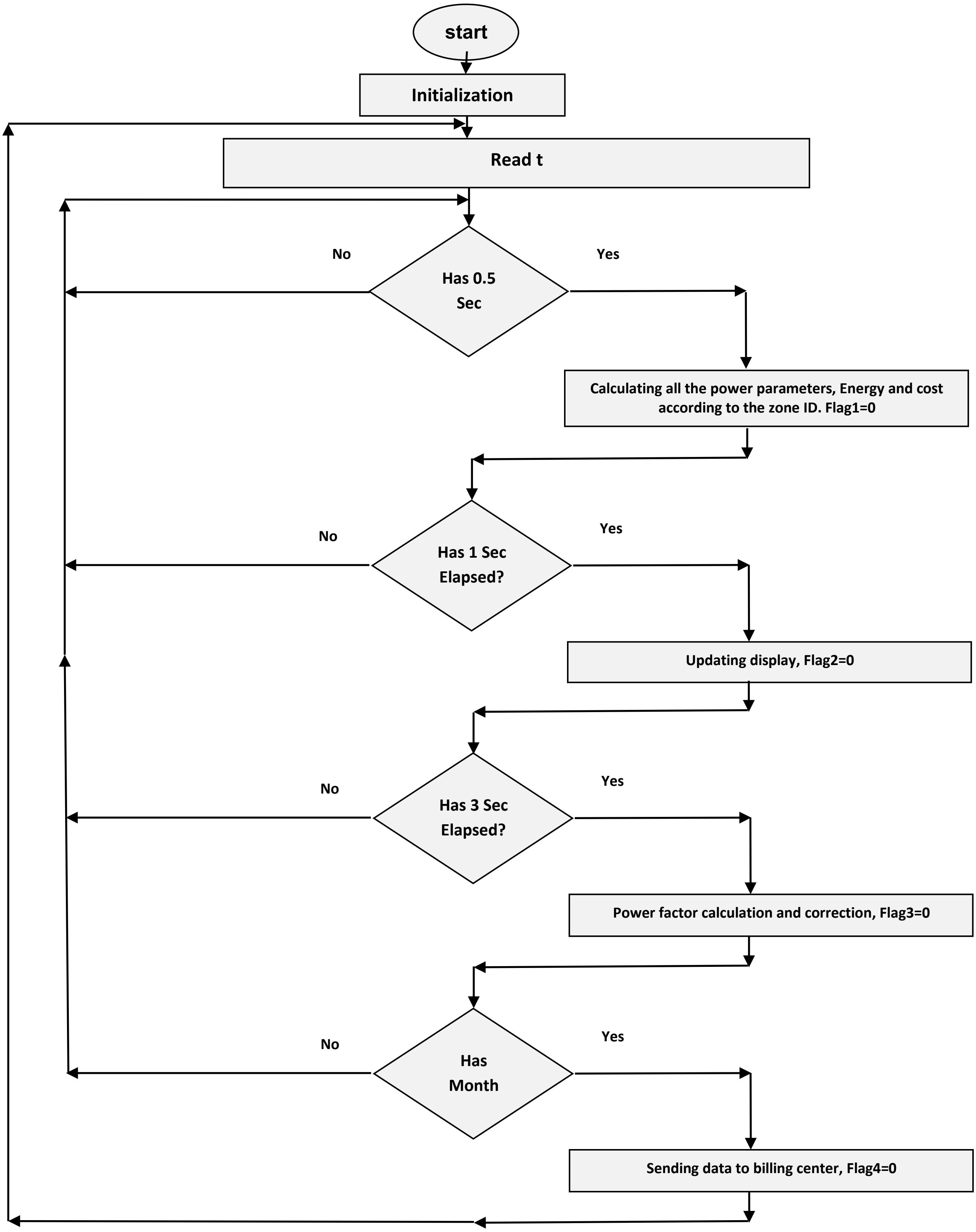

Figure 3. Flowchart of main program of smart energy meter.

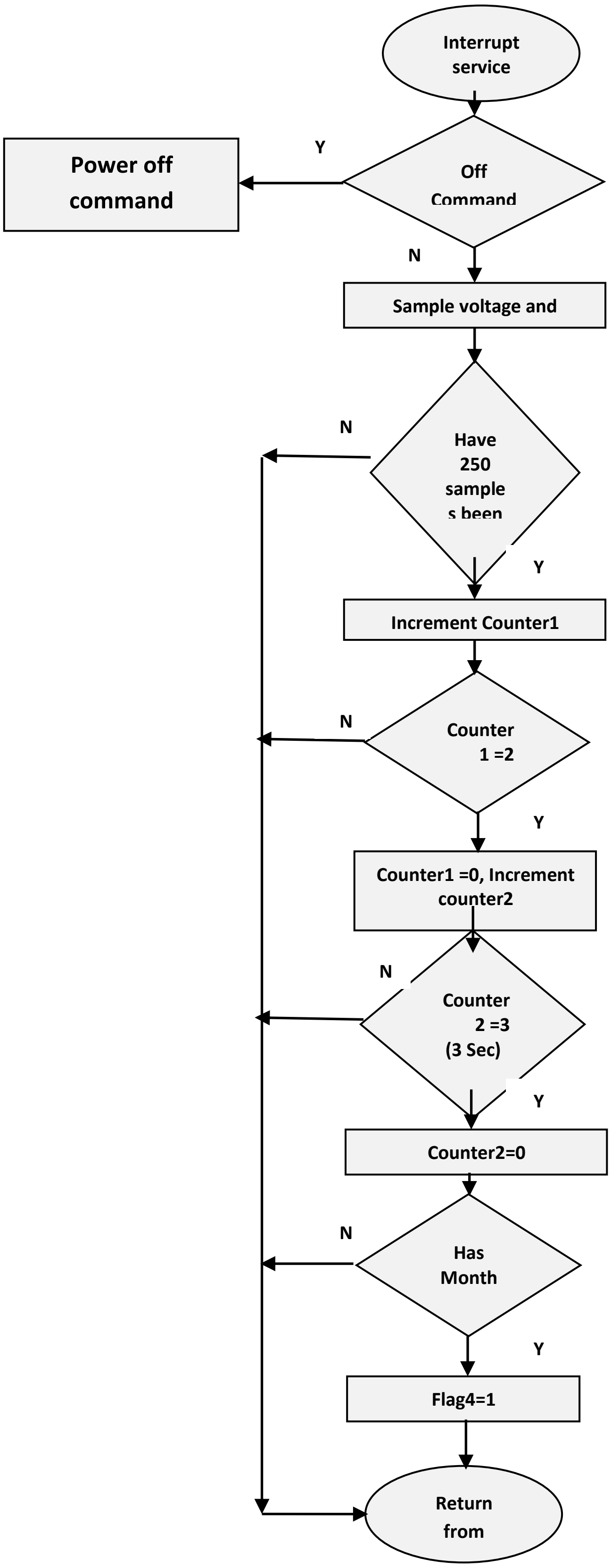

Figure 4. Flowchart of interrupt service routine.

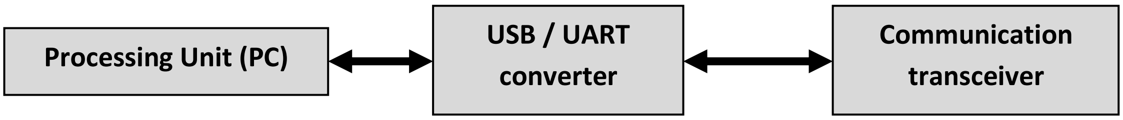

Figure 5. Block diagram of the billing center.

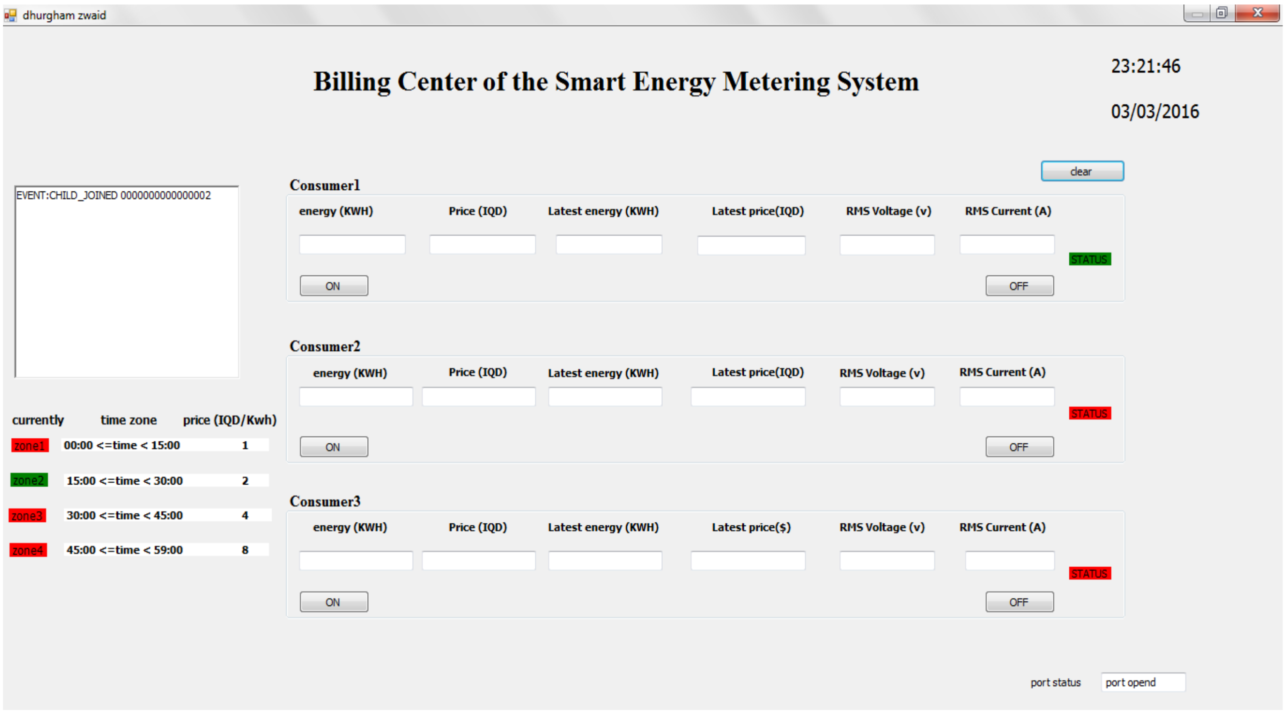

Figure 6. The GUI of the billing center.

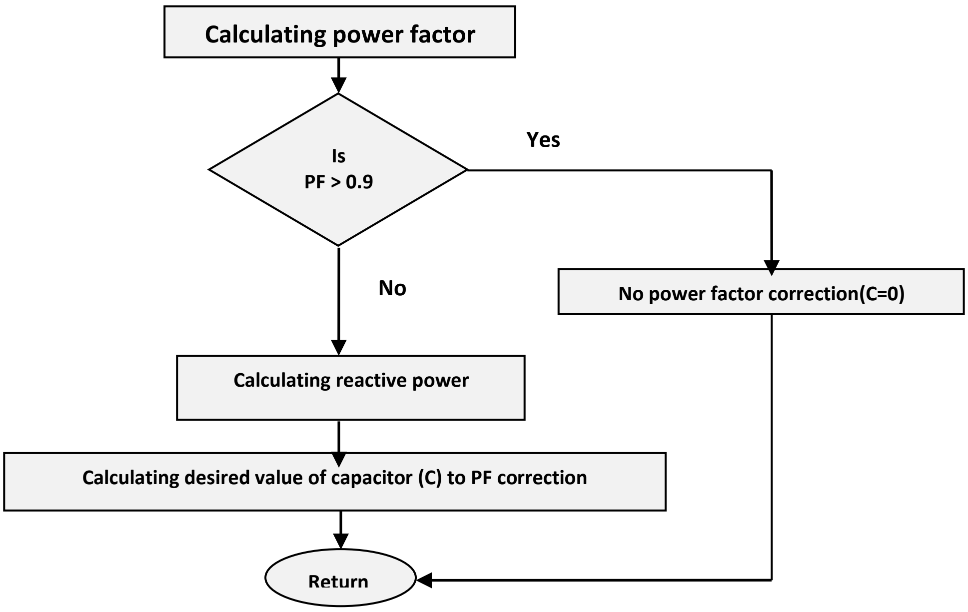

Figure 7. Flowchart of power factor correction.

Table 1. Smart energy meter readings comparing with professional power meter.

Type of load	Current (A)			active power (W)			Apparent power (VA)			Power Factor		
	Smart Meter reading	Professional Power meter	error (%)	Smart Meter reading	Professional Power meter	error (%)	Smart Meter reading	Professional Power meter	error (%)	Smart Meter reading	Professional Power meter	error (%)
Refrigerator	0.65	0.63	3	127	125	1.6	149	146	2	0.85	0.84	1.1
Water dispenser	0.87	0.9	3.3	116	113	2.6	199	200	0.5	0.59	0.56	5.3
One lamp 195 W	0.83	0.85	2	197	195	1	200	195	2.5	0.98	0.99	1
Two identical lamps 390 W	1.63	1.66	1.8	391	389	0.5	392	389	0.7	0.97	0.99	2

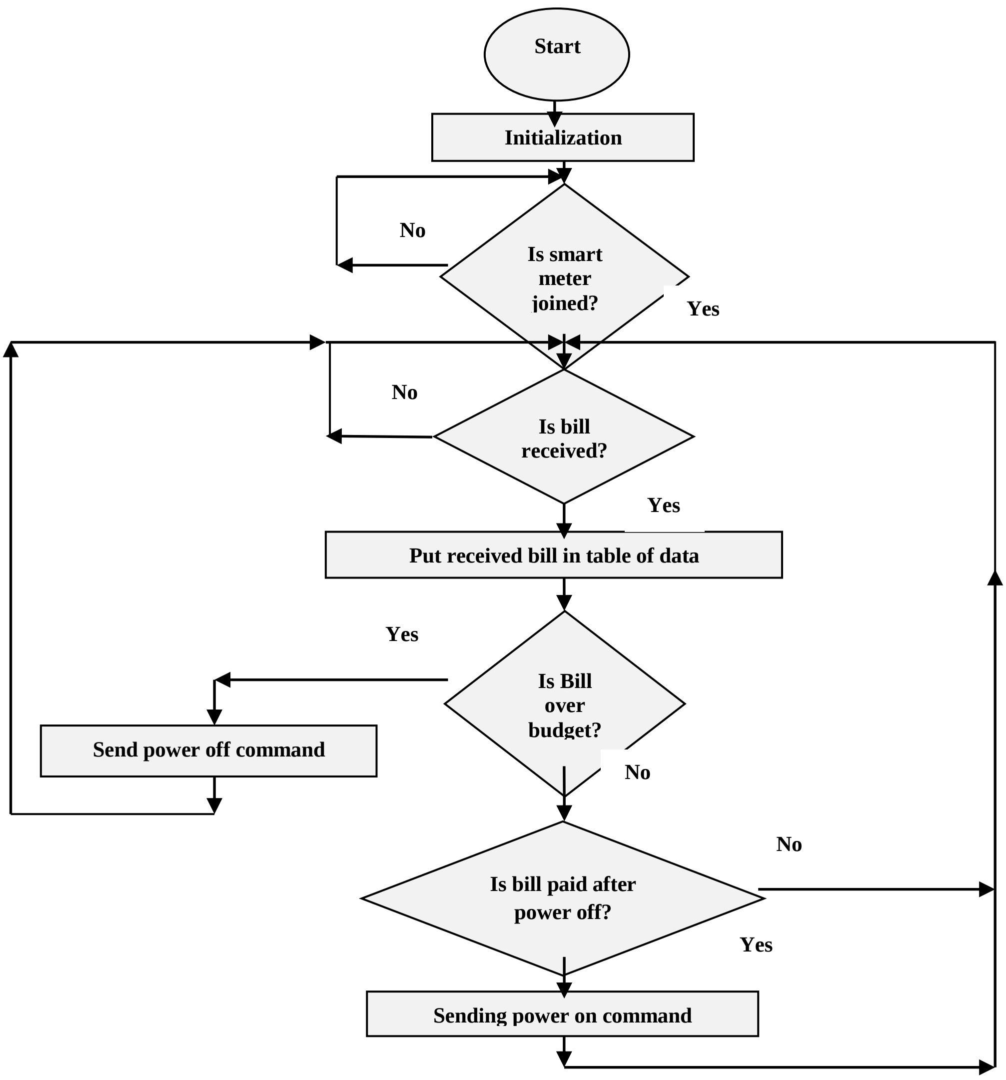

Figure 8. Flowchart of the billing center.

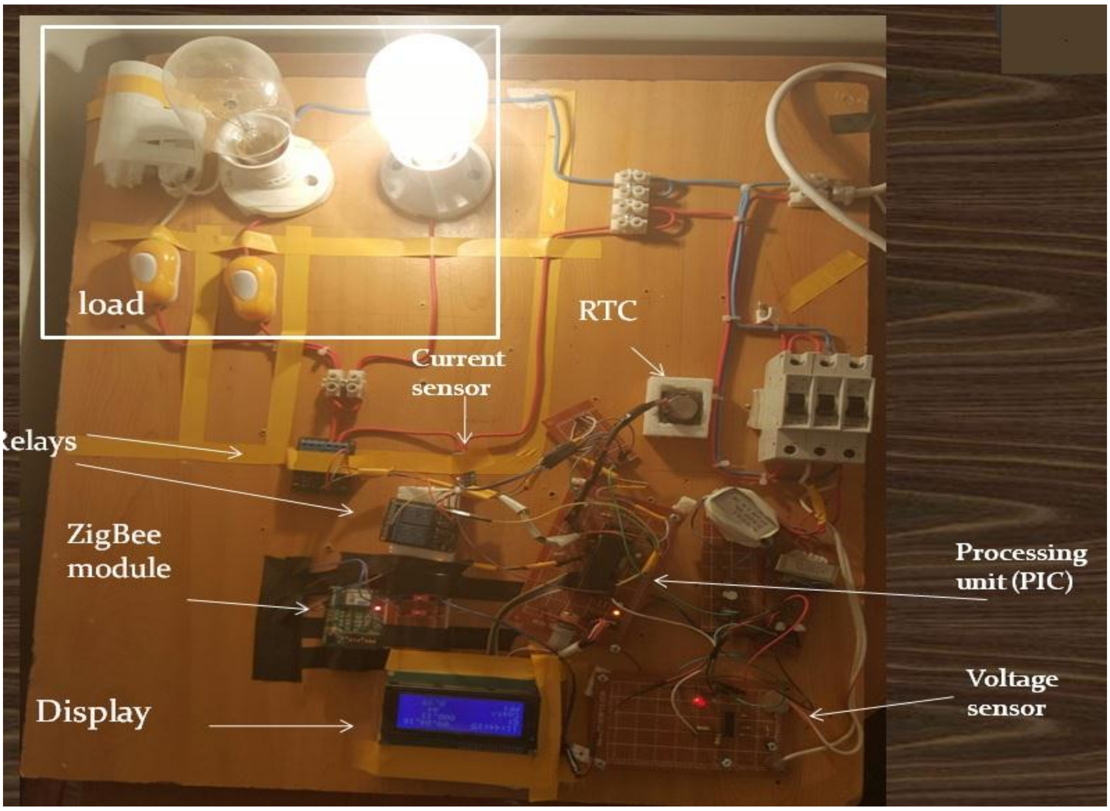

Figure 9. Implemented smart energy meter.

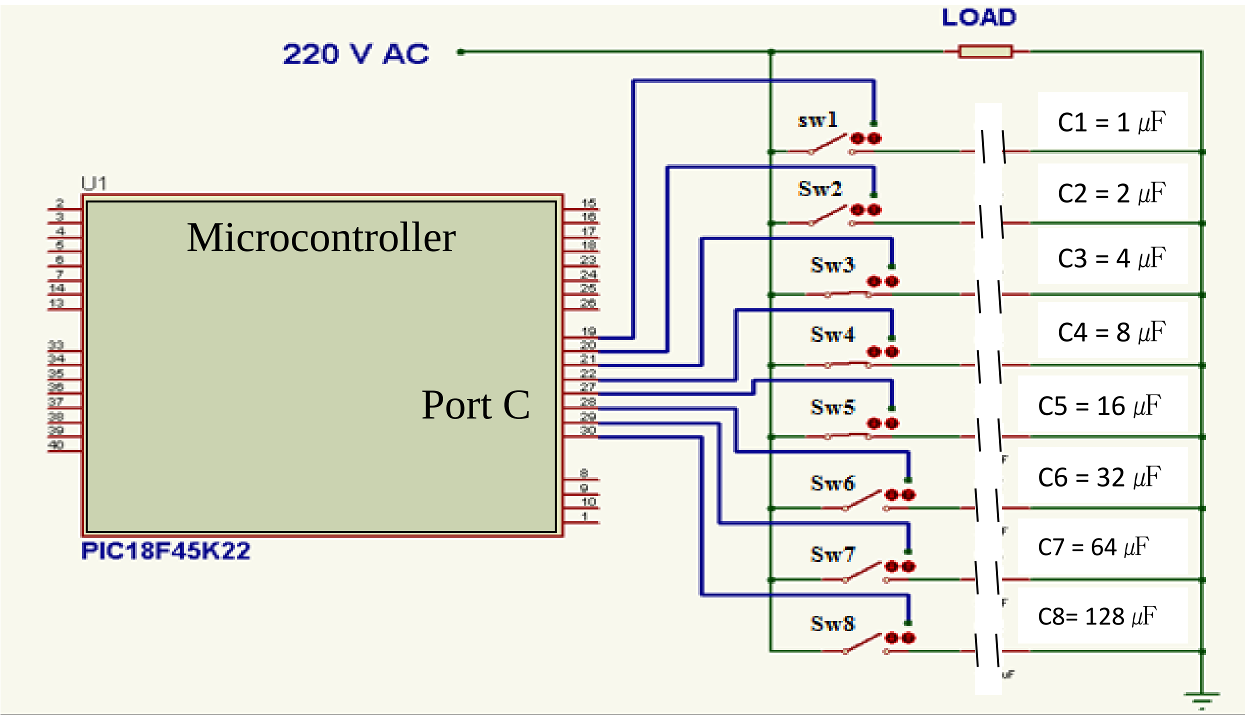

Figure 10. Connection capacitors bank to the controller unit.

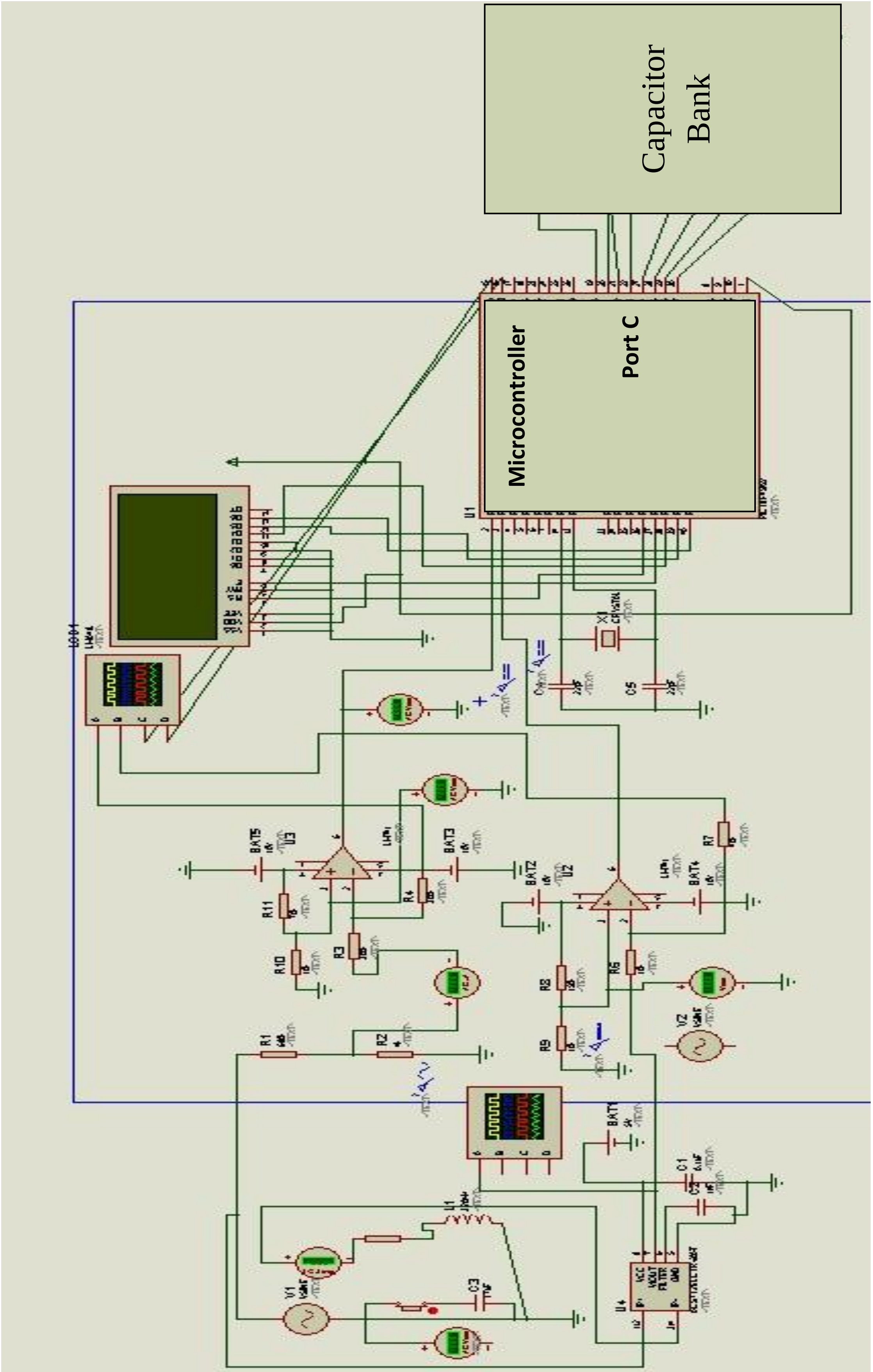

Figure 11. Proteus simulation of smart energy meter.