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Electrical Energy Billing System Based On Smart Meter And GSM

Mahmoud Shaker Nasr and Ahmed Mohammed Merza

Department of Electrical Engineering-University of Babylon-Hilla-Iraq
ahmedmerza2661991@yahoo. com mahmoud111957@yahoo. com

Abstract
There are many problems in metering and billing processes like the going of meter reader to each customer meter to manually take the meter reading, the probability of the non-existence of the customers at their houses during that time, the lack of integrity and credibility of some of the meter readers, the safety (especially in Iraq) and the outback areas represent a huge drawback cannot be neglected. In other hand, the in service classical energy meter type (generally induction type) suffers from well-known measuring errors. The above problems result in a two significant points, waste of much money due to the large number of employees (meter readers) and the weakness in electricity management which results in lack in electric power. The presented paper provides an excellent solution (Automatic electrical energy billing) to the problems mentioned above where the system has been designed based on the use of energy smart meter to read electrical energy consumed to get an accurate reading. Then the energy meter reading is sent to the control center in the electricity department based on GSM/SMS technology. The system in the electricity department receives readings and makes processing operations on them and extracts the bill that must be paid by the customer. The system also sends a message to the own customer mobile phone which contains the current bill, due bill, and total bill every two months (according to Iraqi regulations) have to be paid. In addition the system has the ability to print out a hard copy of the customer bill. Finally the proposed system has the ability of automatic power outage if the customer refrains or delays for certain time in paying the bills by means of an SMS massage. The designed system is implemented practically and applied to three customers in coordination and cooperation with the engineers in the General Directorate of Electricity Distribution for Middle Euphrates and it has been proven by the results obtained and presented in this paper, the system has high accuracy and reliability. Also the engineers in Babylon province electricity department praised the results obtained and the feasibility and economic interest of the presented system.

Keywords— Automatic electrical energy billing, energy smart metering, GSM based system, automatic power outage.

Introduction

There are many problems in distribution, metering and billing processes face the power distribution utilities and the metering and billing processes are considered complex problems. The existent classical method to retrieve the energy meter data and billing is become not suitable and time exhaustion where the meter reader human must goes to each meter and manually take the reading of that meter then return to the electricity distribution office to issue the bill for each customer. In addition, these collected data from meters would be entered manually to the software billing system for issuing bills and payment the rents. These operations of retrieving meters data and issuing bills in the classical method are suffering many problems. The main problems are the non-existence of the customers sometimes at their houses which leading the meter reader to retry the process of meter reading and sometimes because of the lack of integrity and credibility of some of the meter readers, they didn't retry meter reading where they estimate the meter reading. Also we must not forget the problem of the safety especially in Iraq. The outback areas also form a problem against the meter reader which should be taken into consideration. The existing electromechanical energy meters used suffer well known measuring errors and these meters affected by the circumstances surrounding the meters like temperature, vibration due to their design in nature in where meters contains mechanical parts.

Related Work

As depicted previously electrical energy billing process represents a complex problem confronts the electrical power distribution utilities. This problem causes a waste of large amount of money and large labor every billing operation. There are many proposed solutions to this problem in the world vary from one to other.

Paper [1] suggests a traditional analog meter, IR transmitter sensor, photo diode and GSM unit to measure the energy consumption and send it to the provider. The IR sensor is placed in the meter rotating part. The photo diode receiver part placed in a particular place used to calculate the number of rotations received from IR sensor part then gives these data to the microcontroller which processes these values then sends them to provider via GSM module.

Paper [2] deals the design and implementation of wireless energy meter based on the integration of a single phase class1, IEC61063 standard digital kWh meter and GSM module. The GPM uses the GSM network to send the billing to the power provider upon request from the power provider.

Automatically energy meter readings and detection of energy theft introduced in [3]. Current transformer was used for measuring whole consuming of the power. The recorded reading sent to electricity office each sixteen days using GSM technology, precisely, using Short Messaging System 'SMS'. For avoiding steal, infrared sensor (IR) must be kept in the bolt part of meter specified portion of seal. If this bolt is taken away from the meter, an alarm dispatch is transmitted to the electric office.

Design and application of automatic energy meter depending on ZigBee and GSM/GPRS is presented in paper [4]. In this project the readings of all the meters are transmitted by ZigBee transceiver to a ZigBee/GPRS transceiver gateway to send these data to the power provider side via GSM/GPRS technology. The drawback of this system is that it can't inform the customer wirelessly about the billing.

Design and building of a cheap smart meter [5] shows design of an inexpensive intelligent energy meter based on internet. The system based on ARDUINO ADK R3 board as a meter of energy and Ethernet board for communication between the customer and the power office. The data transmitted from the customer side to the power office side via Ethernet technology. The bill is issued at the power office side and transmitted to the customer side via the same technology. From our study to this paper, it is only theoretical study and did not implemented practically.

In our paper, The OLIMEX ARDUINO ENERGY SHIELD (MCI-TDD-00797) is used which contain all the necessary components with high reliability and flexibility required to calculate all the needed quantities in one integrated board. The mentioned shield composed from ADE7753 energy metering IC, real time clock IC and all the necessary pins (input &output) required to calculate the energy integrated in one chip. Also it has the capability to calibrate any quantity that is in doubt.

The units consumed will be sent to the PDUC by GSM/SMS technology which has high reliability. Also the PDUC inform the customer about their bill via SMS on their mobile phone where there are a data base in the PDUC contain all the data of all the customers.

Proposed System

All the mentioned problems would be reduced if the metering and billing operations are proceeding by an automatic manner. So the solution is to design a wireless digital energy metering and billing system. This system is introduced in the presented paper as shown in figure (1). The presented system consists from two parts. The first part is a GSM smart energy meter containing from microcontroller Arduino UNO type, Arduino energy shield, Arduino GSM Shield, current transformer (C. T) to measure load current, voltage transformer (V. T), relay and LCD. The GSM smart meter calculate the watt hour consumed units digitally with high accuracy, storing these units in Arduino EEPROM, displaying on LCD and send them to the power distribution utility center (PDUC) via SMS. These operations were programmed in C++ language of Arduino IDE.

PDUC is the second part of the system where it receives the meters data, storing them in data base, issuing the bill for each customer and sends him SMS telling him about his bill details. The PDUC has the ability to cut the power automatically about anyone who refrains from pay his bill and automatically returns the power to the customer after paying his debts. The operations of PDUC and GUI of base station were programmed in Visual Basic 2012 software program.

Energy measurements and data transmission

Measurement of energy quantities and data transmission, and all the necessary operational considerations will be presented.

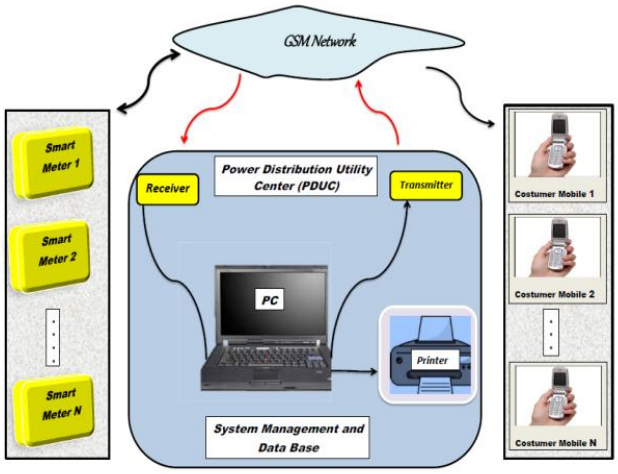

Fig. 1. Proposed System

A. Energy Measurements

Energy can be defined as the ability to do work and it is measured in joules. It is symbolized by '*W*'. The amount of electrical energy supplied or absorbed via a particular component from time (t_0-t) can be calculated by equation (1).

$$W = \int_{t0}^{t} P.dt \qquad (1)$$

This means that electrical energy is the real power over a specified period of time.

$$W = P.t \qquad (2)$$

$$P = V.ICos(\theta) \qquad (3)$$

Where:

W: electrical energy; P: real power; t: time period; V: supply voltage; I: load current; COS (θ): power factor.

There are two methods for measuring electrical energy, analog method and digital method. Since the paper studies the smart meter, then the digital method only will be introduced.

- Digital energy measurements

The block diagram of measuring electrical energy digitally is shown in figure (2).

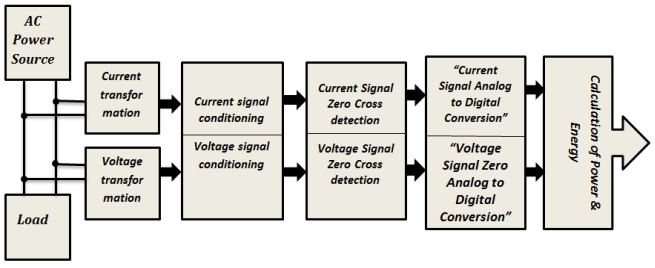

Fig. 2. Digital Energy Measurement.

The process of power or energy measuring in digital aspect requires many steps. The steps of digitally measuring electrical energy are:

1. Analog signal conditioning for voltage and current signals and filtering the resulted signals to remove the unwanted components.
2. Detection the zero cross points for current and voltage signals to calculate the power factor.
3. Converting the stepped down signals from analog form to digital form.
4. Multiplication the digital quantities (voltage and current) to get apparent power.
5. Summing the specified samples of active power to compute energy.

B. Data Transmission

After gathering voltage and current signals by the specified detectors and calculating the required energy quantities, now the units consumed must be transmitted to the PDUC in order to generate the bills. In this paper an efficient and reliable method is proposed to transmit the data from the customer to the power provider. This method of transmission is a (GSM/SMS) technology.

i. Global System Mobile (GSM)

GSM is an acronym of Global System for Mobile Communications and it was discovered at 1981. Nowadays, GSM is the generality public mobile radio standardization in the world. A growth is ongoing, so that many GSM users find their life without their mobiles in practice unbelievable [6].

GSM technology is characterized by the followings: [7] [8]

1. Frequency Band: The frequency of GSM ranges from 1850MHz to 1990MHz. This is from mobile station until base station.
2. Downlink/Uplink Frequencies:

- GSM900:
  - Uplink frequency: (890MHz-915MHz) (mobile until base station).
  - Downlink frequency: (935 MHz-960 MHz) (base station till mobile station).
- GSM1800:
  - Uplink frequency: ranges from 1710MHz into1785MHz.
  - Downlink frequency: ranges from 1805MHz to 1880MHz.
- GSM1900 (PCS-1900):
  - Uplink frequency: from 1850MHz until 1910MHz.
  - Downlink frequency: from 1930MHz to 1990MHz.

3. Channel Separation: there is 200KHz separation frequency among adjacent carrier frequencies.
4. Modulation: it is the process whereby some features of carrier waveform is changed in corresponding with the message signal. The type of modulation used in GSM system is Gaussian Minimum Shift Keying (GMSK).
5. Access Method: the TDMA, which is an acronym of Time Division Multiple Access is the access method used by GSM. TDMA is a technique whereby many users share the same channel at the same frequency but at different times. Each radio channel is divided into many time slots using TDMA.

ii. Short Messaging Service (SMS)

Short messaging service defined as a technique by which short messages delivered to a particular destination via a mobile network. SMS acts a store and front way for sending short message to mobiles and from theme. A message transmitted from the sender mobile will be storing in a central utility named (SMC) which is an acronym of short message center then forwards SMS to a destination required mobile. In this case if a recipient is not accessible, this message stored and then would be sent automatically later. Short message may be 160 characters long and less. The characters may be text form or binary form message. An important characteristic of SMS is a return receipts.

System Architecture

According to the mentioned problems and requirements, the author presents a system whose architecture is shown in figure (1). Each part of the block diagram will be discussed in the following.

i. Smart Meter

Smart meter is the device which calculates the energy consumed units, save these units, and sends them to the PDUC. Smart meter is constructed from the following parts:

a. Voltage and Current Sensors

a. 1 Voltage Sensor

EI – 41X20, 220/12V is the voltage transformer which has been used in the smart meter to sense the voltage and its view is shown in figure (3).

Fig. 3 Voltage Transformer.

a. 2 Current Sensor

SCT013, 30A is the used clamp on current sensor shown in figure (4) which used to sense the load current. This is a split core current transformer depends on the principles of operation of the current transformer.

Fig. 4 SCT013 Current Sensor.

b. Energy Metering IC

Consumed energy units are measured by Arduino Energy Shield (MCI-TDD-00797) [9] whose view is shown in figure (5) which integrates ADE7753 IC that considered the CPU of the meter. This shield is capable of computing apparent power, active power, reactive power, power factor, R. M. S voltage and current and energy of any load. This shield also contains embedded RTC which is a Real Time Clock IC that can set the date and time.

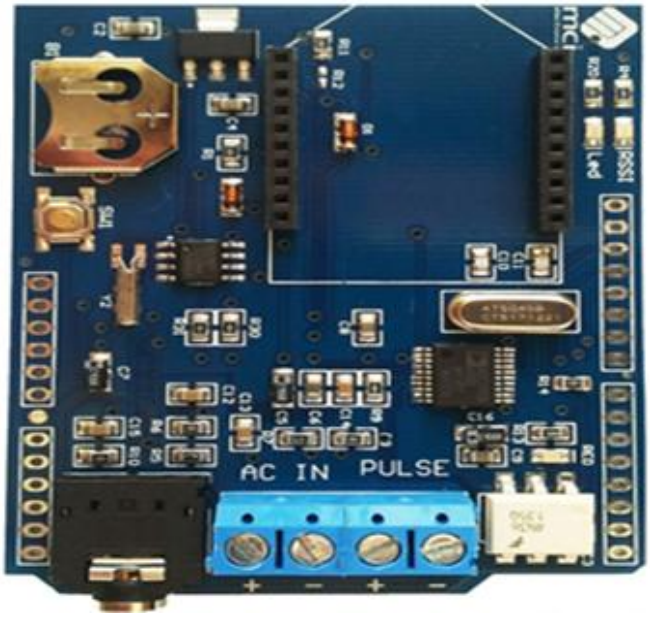

Fig. 5 Arduino Energy Shield.

c. Microcontroller (ARDUINO UNO)

The microcontroller is considered the control unit of the smart meter where it runs the ARDUINO Energy Shield and gives it all the commands and instructions required to perform its operations. Also microcontroller controls the GSM subsystem to send and receive specified commands. Arduino Energy Shield connected by Arduino UNO which used in this paper by SPI (Digital pin13, Digital pin12, Digital pin11, and Digital pin10). These pins connected to the same pins numbers of the Arduino Energy Shield. [10].

d. Arduino GSM Shield

At this stage all the related aspects of power and energy calculation are finished, then the watt-hour units consumed for each customer should be transmitted to the power distribution utility to issue the bills for each one. In this paper, the suggested way for transmitting the meter readings to the distribution center is done wirelessly and without any human intervention using GSM/SMS technique. The selection of this method for dispatching the consumed units is for many reasons like low cost of SMS and its reliability. ARDUINO GSM Shield CE 0700 [11] shown in figure (6) is the device used to send the units consumed from each meter to the distribution utility. This device exists in each meter and it is energized from the ARDUINO board.

Fig. 6 Arduino GSM Shield CE 0700.

This shield has high reliability and flexibility in operation and it is energized from the Arduino board itself. This shield requires a SIM card to connect with the GSM network and it is compatible to work with any SIM card from any operator.

e. LCD display.

Liquid Crystal Display LCD (16*2) based on Hitachi HD44780 driver [12] is used to display the watt-hour consumption. The advantages of this type are low cost, small size, and appropriate to mount with the meter simply. LCD (16*2) used in this thesis is shown in figure (7).

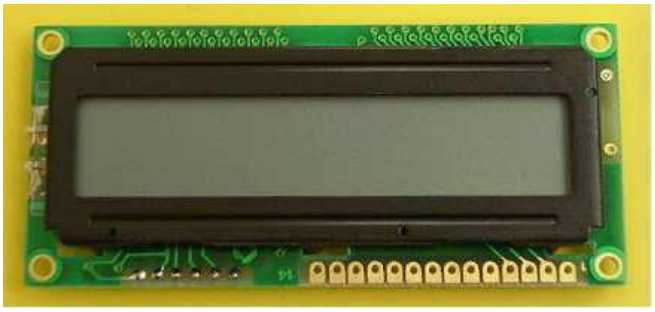

Fig. 7 HD44780 LCD.

The LCD uses several digital pins for driving its operation which made it wastes the microcontroller pins that can be used for other aspects. Therefore I2C PCF 8540 [13] driver connected to LCD and both connected Arduino shown in figure (8) is used with the LCD to reduce the number of pin used. Analog pin4 and Analog pin5 as SDA and SCL respectively of ARDUINO UNO is used with I2C.

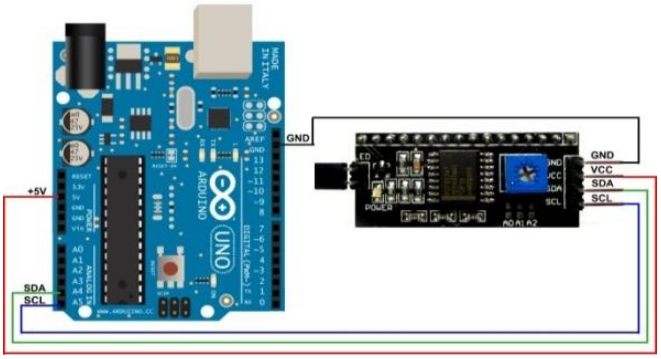

Fig. 8 LCD connected to ARDUINO via I2C.

f. Relay

Relay is an electrically switch used for turning on and off the electrical networks by low voltage signal from microcontroller (5V) for passing or disconnecting the electrical power to or from the load. Relay is the final part of the smart meter using for disconnecting the electrical power from the customer house if that customer refrains from payment his bill. The process of disconnecting the meter is done wirelessly via SMS signal transmitted from the base station automatically after the amount of money of his bills exceeds a specified value. If the customer pays his debts, automatically a SMS signal transmitted from base station to the meter and returns it on. The relay used in the system is a two channel 5V, 10A relay module which is shown in figure (9). [14]

Fig. 9 Two Relay Module.

g. Meter storage Unit

The selected storage unit is the EEPROM of the ARDUINO UNO itself which is estimated at 1024 Bytes. For more reliability and accuracy each 30 seconds the meter reading is written to the EEPROM and each reading uses one byte. As known each byte of EEPROM can be written up to 100000 cycles in standard. Really the number of writing times to the EEPROM is much more than 100000 and whenever the writing process done as fast as possible the EEPROM life time would be longer. If each 30 seconds there is 1 writing cycle then, the life of the EEPROM is 97. 412 years as minimum. The flowchart of smart meter is shown in figure (10).

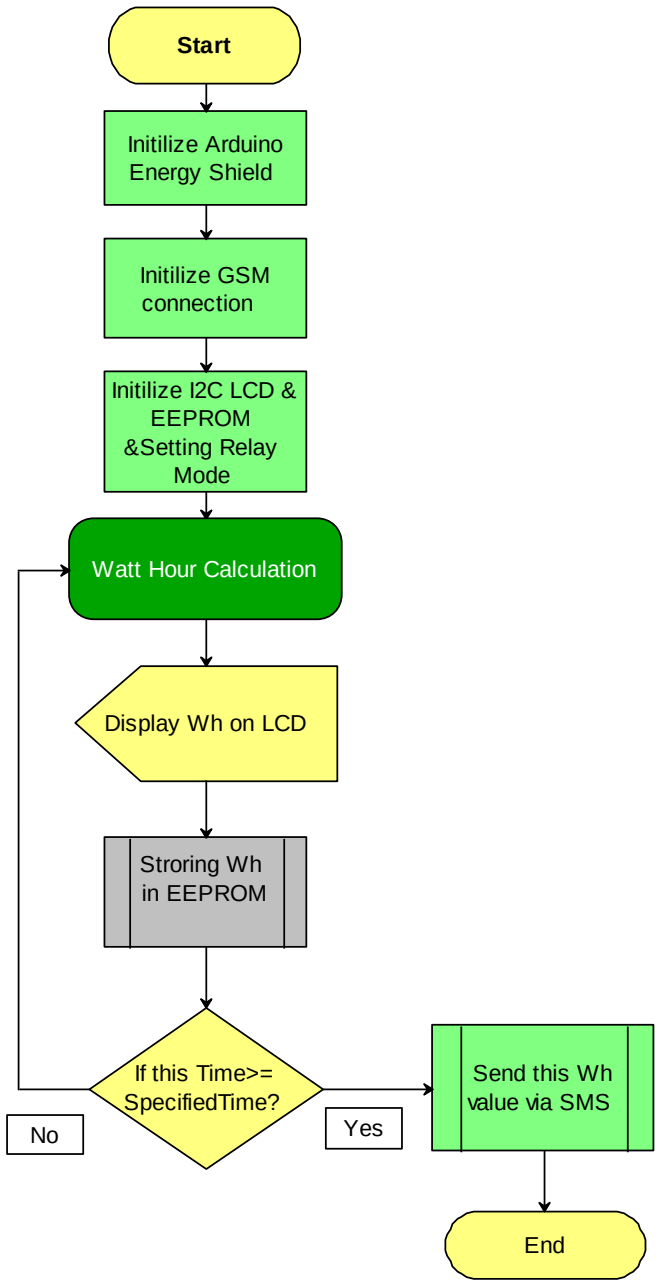

Fig. 10 Smart meter flowchart.

All the mentioned parts that need software programs to operate take its commands and instructions from Arduino which is programmed in C/C++ programming language which is compatible with Arduino IDE software program.

ii. Power Distribution Utility Center (PDUC)

Power Distribution Utility Center (PDUC) is the directorate of electricity distribution which is constructed from the following parts:

- Transmitter and Receiver.
- Base Station.
- Printer.

The PDUC receives data from all meters, stores these data in the system data base, issues bills for each customer and sends back SMS to each customer telling him about his bill. Also the PDUC has the ability to disconnect the power from any customer who refrains from paying his bill.

a. Transmitter, Receiver and Printer.

Each node (transmitter or receiver) is composed from microcontroller (Arduino UNO) which is discussed in previous paragraph and Arduino GSM shield which is also discussed. As mentioned before, these nodes are programmed in Arduino C++ software. To avoid the interference, two nodes one for receiving and the other for transmission are selected instead of one node. Printer is used for printing the reports of electricity bill for the customer.

b. Base station

Base station is considered the heart of the PDUC where all the necessary software programs required for receiving the Wh units, sending the bills by SMS to the customers, shut down the power on the abusers, and the information of all customers were found in it. This part contains many features and branches will be presented. All the operations and processes done in base station were writing in Visual Studio-Visual Basic 2012 software program.

b. 1 Login to base station

Figure (11) is the first window that appears at the beginning of the program starting. The employer person who works on base station should have a username and password enable him to enter to the system.

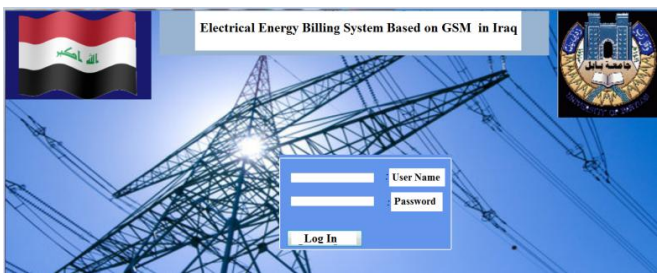

Fig. 11 Login to Base Station.

The employer has three attempts to login to the base station to prevent the illegal entrance, if any one tries to enter to the system and begin entering experimental username and password, the program will warn him and if he exceeds the specified number of attempts alarm sound will turn on and exit from the program.

b. 2 Main Lists

After the employer person enter the correct username and password, the next window shown in figure (12) will be appeared.

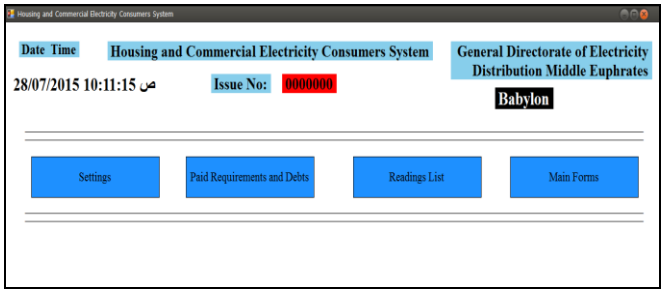

Fig. 12 Main lists

b. 3 Add New Customer

By clicking on the "Main Forms" icon shown in figure 12, the following list will appeared shown in figure 13.

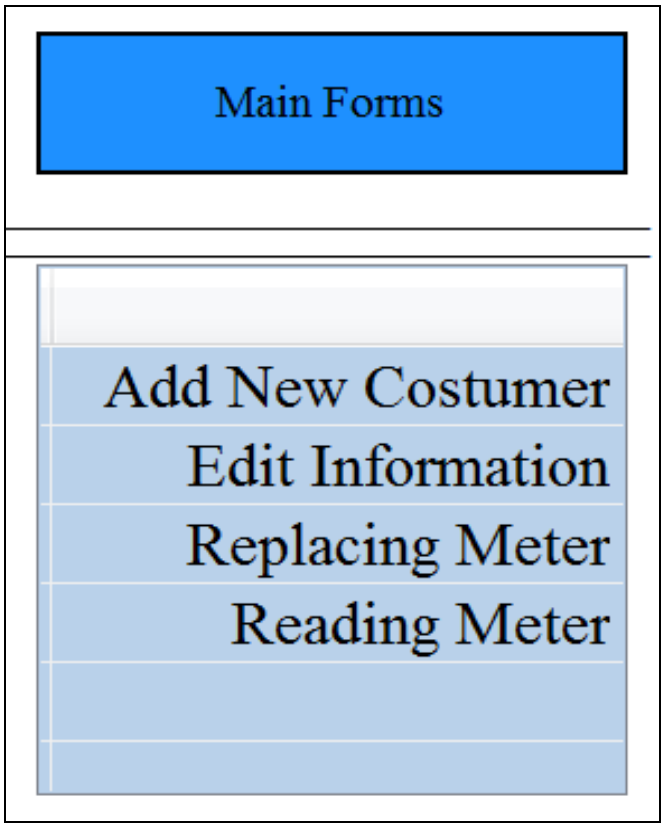

Fig. 13 Add New Customer

When clicking on “Add New Costumer” icon, the list of entering customer information shown in figure (14) will appear.

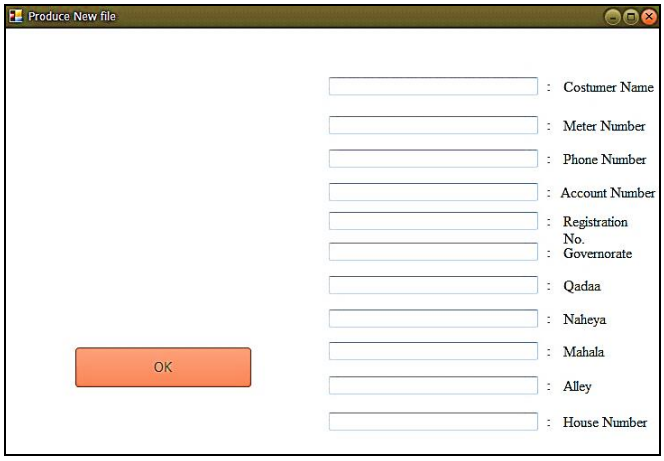

Fig. 14 Generation of a new file.

Now the employer must enter the customer information shown in figure (14) and click on "OK", then new customer would be added.

If there is an error in the customer information or any one of these information is changed, then the employer can change them by click on "Edit Information" option shown in figure (13), then the list shown in fig. (15) will appear. Here the employer needs the meter number of a customer to bring his information to change the required one to change. Also when changing the information and clicking on "OK" the customer information will be changed.

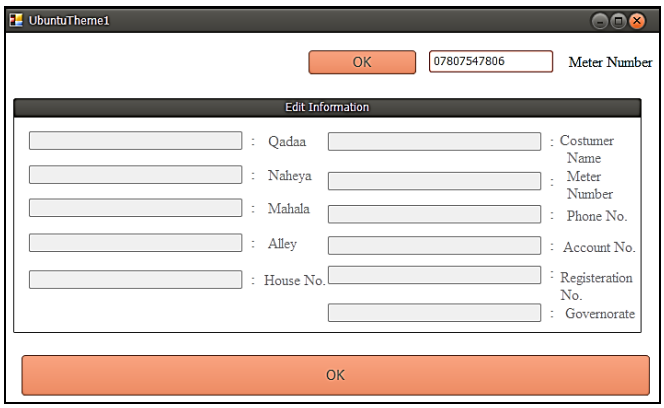

Fig. 15 Edit Information.

b. 3 Reading List

When the employer wants to check the list of readings of all customers for the last month, he must click on the "Reading List" the second option in the "Main List" shown in figure (12) and as shown in figure (16).

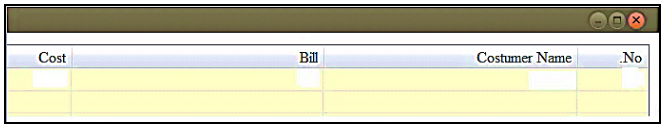

Fig. 16 Reading List.

b. 4 Payment of Requirements and Debts

After the meters readings transmitted to the PDUC and PDUC send reports to the customers, now the customers must pay the requirements imposed on them. When the employer click on the "Pay Requirements and Debts" option as cleared in figure (12), the list shown in figure (17) will be appeared.

When the customer wants to pay his bill, the employer will ask him about his meter number and enter it in the "Meter No. " as shown in fig. (17), then click "Display" and the list of cost, date and bill will appeared. The data pointed in red color refers to the unpaid money and the data pointed in green color refers to the paid money.

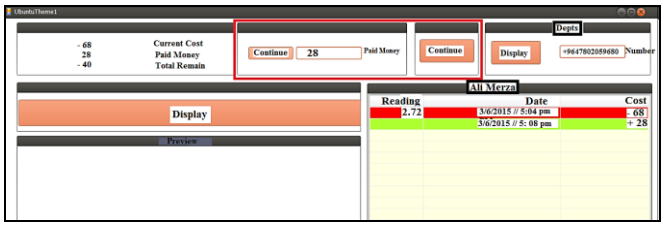

Fig. 17 Pay requirements and Debts.

System Operation

The system operation can be summarized as follows:

The smart meter calculates the amount of electricity consumption and transmits this amount at a specified time to the base station located on PDUC via SMS. The base station will receive the units consumed for each customer, save these units in data base, computes the bill amount and sends SMS to each customer to tell him about his bill.

The customer will go to the PDUC to pay the rents imposed on him and he can get a hard copy bill if he wanted in addition to the soft copy on his mobile phone. If the customer pays his bill, automatically SMS sent to his personal mobile phone to tell him about the paid money he had paid.

If any customer refrains from paying his requirement and the accumulated bills exceeds a specified value, a signal transmitted automatically to that meter to cut the power from that customer.

Results

i. Smart Meter Results

In this section the measurements of the designed smart meter will compared with measurements of standard calibrated meter. The loads used in this test shown in figure (18).

Fig. 18 Loads used with Smart Meter.

a. Current Measurements

Table (1) shows the measured current of the designed smart meter and the measured current of standard calibrated meter which is the (DW6060).

Table (1) DW6060 and Smart meter measured current

Current measured by DW 6060 RMS (A)	Current measured by Smart meter in RMS (A)	Percentage Error %
0. 21	0. 22	-0. 0476
1. 47	1. 47	0
2. 76	2. 73	0. 0108
4. 24	4. 23	0. 00235
4. 69	4. 7	-0. 00213

b. Voltage Measurements

As standard case the voltage might be assumed constant with varied loads, but really it is not. Table (2) shows the voltage of standard meter and smart meter, also the percentage error.

Table (2) DW6060 and smart meter measured voltage.

DW 6060 Voltage measured in RMS (volt)	Smart Meter Measured Voltage in RMS (volt)	Percentage Error %
221	221	0
219	219. 1	-0. 00045
217. 2	217. 05	0. 00069
214	213. 88	0. 00056
214	213. 82	0. 00084

c. Consumed Power Measurements

The watt-hour units that the power provider takes in accordance are the accumulation of active energy consumed along with time. So the active power calculated of smart meter must be calibrated to achieve better readings. Table (3) shows the measured consumed power of both designed smart meter and standard meter.

Table (3) DW6060 and Smart meter power measurements.

DW6060 Measured power (watt)	Smart Meter Measured power (Watt)	Percentage Error %
21	21. 2	-0. 00952
261	260. 19	0. 00310
471	472. 6	-0. 00339
695	693	0. 0028
819	820. 4	-0. 00170

iii. ***Watt hour readings at smart meter and at base station***

Table (4) lists the watt hour consumed measured by the smart meter and the values received by the base station.

Table (4) Watt hour measured units at smart meter and base station.

Watt Hour Measured at Smart Meter (Wh)	Watt Hour sent at Base Station (Wh)	Percentage Error
2. 72	2. 72	0
3	3	0
3. 2	3. 2	0

From table (4) it is cleared that the percentage error is zero in the operation of transmission the watt hour units from meters to base station via SMS which indicates that this method of transmission is accurate and very reliable.

iv. **Customer Informing about his bill**

When the reading of meter reaches to the PDUC, immediately PDUC sent SMS to the customer on his mobile informing him about his bill as shown in figure (19).

Now if the customer pays amount of money of his bill, also automatically SMS sent from PDUC to tell that customer about paid money and the remaining unpaid money as shown in figure (20).

Finally, figure (21) shows a practical view of the proposed designed smart meter.

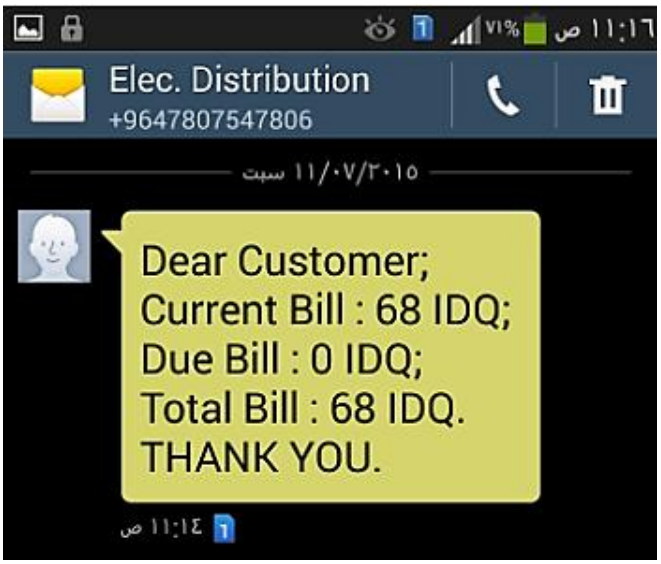

Fig. 19 SMS on customer mobile telling him about bill.

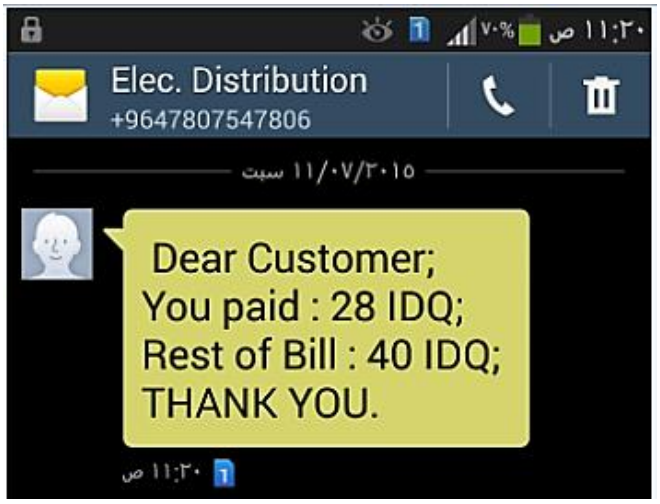

Fig. 20 SMS on customer mobile informing him about paid money.

Fig. 21 Practical view of the Smart Meter based on GSM.

Conclusion

- The problem of metering and billing is one of the important issues that the ministry of electricity suffers for long time ago and causes lack of much money.
- The presented system is portable and flexible for practical usage because it is designed according to the requirements of the beneficiary from the project which is the General Directorate of Electricity Distribution of Middle Euphrates.
- The designed smart meter is accurate and suitable for practical usages and not only as a laboratory device where it experimented with various types of loads and it proved its worth and reliability. The practical results obtained demonstrate the accuracy, the flexibility, and the usefulness of the presented system.
- The transmission of data via GSM/SMS being reliable and secure where it prevents hacking and theft the information.
- The system has the capability of developing with the necessities according to specialists requirements.
- The urgent need to this system where the General Directorate of Electricity Distribution of Middle Euphrates sees that it is the best solution to the found problems.
- It should be noted that there is another version of the system in Arabic.

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Dr. Mahmoud Shaker Nasr obtained his Ph. D. degree in electrical Engineering in 1988 and assistant professor degree in 1995. He is with the department of electrical engineering, university of Babylon, Hilla, Iraq. His interest in power electronics systems, digital control, E-health and I-health applications of WSN, sensors and transducers, GSM and Internet based systems, and SCADA systems.

Eng. Ahmed Mohammed Merza obtained his B. Sc. degree in electrical Engineering in 2013. He is currently a postgraduate student in the department of electrical engineering, university of Babylon, Hilla, Iraq. His interest in power electronics systems, sensors and transducers, GSM and Internet based systems.