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Remotely Controlled Single-Phase Electric Meter Supporting Different Tariffs

Ali O. Gliwan[1], Mohamed E. Aifa[2], and Mohamed B. Abobaker[3]
Electrical Department, Misurata University, Libya

[1] Ali.Gliwan@eng.misuratau.edu.ly, Ph.D., Libya
[2] Mohammed.Aifa.91@gmail.com, B.Sc., Libya
[3] Mohammed.Belaed@gmail.com, B.Sc., Libya

Abstract- The purpose of this project is to follow up on earlier research aimed at enhancing Libya's electric service as well as offering a working prototype of the entire system. In continuation of the previous study, we have improved the design of the single-phase electric meter. The new and improved meter can accommodate a range of tariff options such as Day and Night, Domestic, or Commercial, and two payment methods - Postpaid or Prepaid. We ensured that the meter display was user-friendly while utilizing an existing mobile network. To streamline electric meter readings and minimize the need for human intervention, the national mobile network is leveraged to communicate with all meters within its range. This approach significantly reduces the likelihood of errors caused by human involvement, while also driving down the cost of the entire reading process. To enable two-way communication with the Remote Central Server (RCS) via Short Message Service (SMS), a communication protocol has been developed. This allows for real-time monitoring and analysis of customers' electric meters, facilitating tasks such as generating invoices, adjusting tariffs, selecting payment options, and activating or suspending electric service. Additionally, a user-friendly payment system has been implemented to facilitate payments via SMS using a top-up voucher.

***Keywords*:** lectric meter, Arduino, IoT, SMS, Prepaid

I. INTRODUCTION

A recent trend in electric meter design is the incorporation of wireless communication for remote access, monitoring, and control. Previous work [1] has shown that using Radio Frequency (RF) waves for communication between the mobile reader and electric meters is a better option compared to the traditional manual reading method. This method provides a fast, accurate, and error-free way for electricity companies to access meter data. However, there are still some drawbacks such as reaching limitations caused by obstacles or maximum distance between the reader and meters. This may require the mobile reader to resend reading requests or move closer to the meters to collect data.

Rather than relying on RF waves, General Electricity Companies worldwide are now communicating with electric meters via the country-wide mobile network. The system, illustrated in Figure 1, involves Remote-Controlled Single-Phase Electric Meters (RCSPEMs) installed in customers' buildings. These RCSPEMs communicate with a Remote Central Server (RCS) located in the Electricity Company's control room via SMS. Additionally, customers can use SMS to communicate with the Electrical Company's Billing Server, which offers a variety of top-up services and supports different tariff categories.

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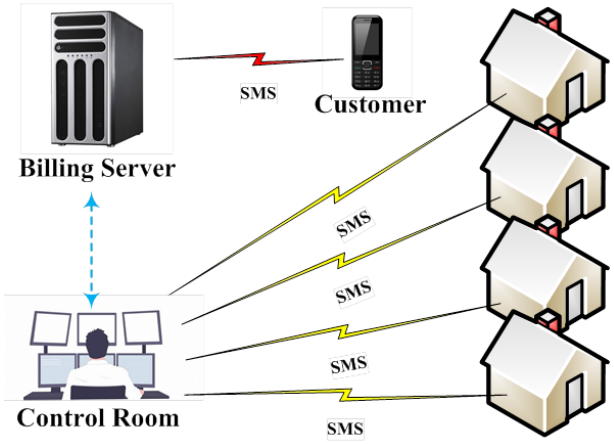

Figure 1: Remote-Controlled Single-Phase Electric Meter System

I. Related Work

The Arduino board has become an increasingly popular choice for implementing prototype circuits due to its ease of use and programming capabilities. It has been successfully utilized to create various types of electrical meters, as referenced in [1-8]. With regards to connectivity between the meter and the electric company, wireless RF connectivity has been used in [1, 9-13], while Zigbee has been utilized in [14-18]. All works rely on mobile networks using a SIM card in the electrical meter for communication, with some also utilizing SMS messaging [6]. Furthermore, [10, 18-26] have provided electrical meters with various tariffs, making it a versatile and comprehensive solution.

II. System Description

A. Remote-Controlled Single-Phase Electric Meter

The meter discussed in [1] has RF communication and only supports postpaid tariffs. However, the meter in this study has two additional hardware features. Firstly, the RF connectivity is replaced with the Arduino GSM shield SIM 900. This enables the use of a wireless mobile network for SMS services. Secondly, a relay module is added to the meter to allow for the electricity service to be switched Off/On.

The meter's firmware code enables all primary functions of the meter in [1] additionally the SMS communication (sending/receiving) with a remote control room, tariff category and service type adjustments, and service information display on the meter's screen. Figure 2 displays a prototype of the meter for reference.

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Figure 2: Remote-Controlled Single-Phase Electric Meter

B. Remote Central Server Interface

Figure 3 shows that to establish wireless duplex communication between the meter and the remote-control system, a hardware interface is utilized. This interface involves using an Arduino Uno V3 along with the Arduino GSM shield module SIM 900 to send and receive SMS messages to and from the remote meters through the control system software.

Figure 3: Remote Central Server Interface (RCSI)

C. Billing Server Interface

To create a comprehensive system proposal, the billing server software-hardware interface includes the use of an Arduino Mega and the Arduino GSM shield SIM 900 module. This setup enables the sending and receiving of SMS messages, allowing the meter owner to top-up their account with the electric company through the use of top-up vouchers. Figure 4 provides a visual representation of this process.

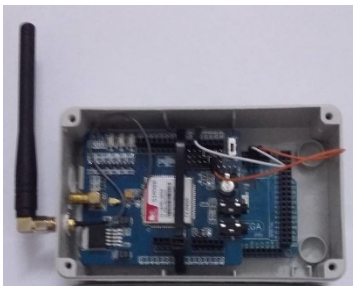

Figure 4: Billing Server Interface (BSI)

D. Prepayment feature in electric meter

The electrical meter system has been designed to allow for a switch from invoice-based billing to prepaid-based billing. This is achieved through a hybrid firmware code that supports both types of billing in the same meter. However, this has resulted in a larger code size, which is why the Arduino Mega is now used instead of the Uno. This provides more code storage space for the meter.

In terms of the display screen, previous work has explained the invoice-based service. When the electricity company instructs the meter to switch to a prepayment-based service, the data displayed on the screen changes accordingly. There is also a transitional period between the two services which clears any outstanding accounts between the meter-owner and the electricity company. Figure 5 shows the display screen for the prepaid-based service.

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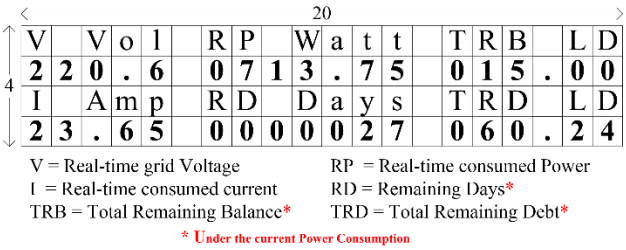

Figure 5: Display screen in prepaid service

The figure above displays the remaining days, current balance, and depreciation value. The current bill is replaced by the balance value, and the previous invoice field shows the debts resulting from the use of the early version meter in [1].

To offer top-up services, a balance server is created. The top-up cards consist of 10, 50, and 100 dinars, which are only used to prove the system's concepts.

The operation works as follows: when the meter owner wants to add credit to their account, they will send an SMS message containing the security recharge number and the meter ID to the billing Server mobile number. The billing server will process the SMS and add the top-up card value to the meter account, provided that the card is valid compared to the database cards. After adding the credit, the billing server will notify the meter owner by SMS if the operation was successful or not (in case of invalid card information). Additionally, the billing server will send the downstream frame to the meter to update the newly added credit. Once the meter receives the updated balance information, it will display the new balance, which includes the existing balance and the newly added credit. The display information is based on the current electricity usage.

E. Communication Protocol

To ensure secure communication between electric meters and the remote-control room, both the meter and RCSI use Attention (AT) commands to enable machine-to-machine communication through the GSM modem. This allows for control of the Arduino GSM Shield module. As is customary in communication protocols, data sent in one direction is referred to as upstream, while data sent in the opposite direction is referred to as downstream. In this particular case, data sent from the RCSI to the electric meter is considered downstream, while data sent from the electric meter to the RCSI is considered upstream. The downstream frame is depicted in Figure 6, while Figure 7 displays the upstream frame.

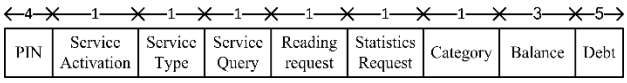

Figure 6: Downstream Data Frame

Downstream Frame Description:

PIN: It consists of 4 digits, and is used to secure the reading process.

Service Activation (*SA*): used to activate/Suspend the service. It consists of one digit and it is either "0", "1" or "2"

- *SA*= 1, the meter resumes the service
- *SA*= 2, the meter suspends the service.

Service Type (*ST*): This is used to change the service. It consists of one digit and is either "0", "1" or "2",

- *ST= 1, changes the service to an invoice-based system.*
- *ST= 2, it changes the service to a prepaid-based system.*

Service Query (*SQ*): It consists of one digit and is either "0" or "1".

- *SQ =1, executes the query command.*

Reading request (*Rreq*): It consists of one digit and is either "0" or "1".

- *Rreq= 1, the meter will send the reading to the control room.*

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Statistics Request (*Sreq*): It consists of one digit and is either "0" or "1".

- *Sreq=1, the meter will send statistics to the control room.*

Category (*Cat*): It represents the kilowatt pricing categories defined by the electrical company, and it consists of one digit and takes the numbers from "0" to "9".

- *Cat= any number from 1 to 9, represents a specific category, i.e., a certain kilowatt price.*

Balance: It consists of three digits and contains the value of the balance when the service is prepaid.

Debt: It consists of five digits and is used in the protocol of changing from prepayment to invoice-based service or vice versa, this value will be decreased with an agreed amount for every top-up.

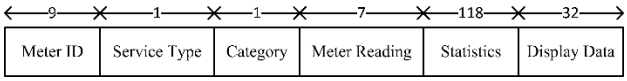

Figure 7 : Upstream Data Frame

Upstream Frame Description:

The Meter ID is composed of nine digits and represents the unique meter number that is assigned by the electrical company.

Service Type (*ST*): it is used to tell the remote room the service type of this meter. It consists of one digit and is either "0", "1" or "2",

- *ST= 1, the service is an invoice-based system.*
- *ST= 2, the service is a prepaid-based system.*

Category (*Cat*): It represents the kilowatt pricing categories defined by the electrical company, and it consists of one digit and takes the numbers from "0" to "9".

- *Cat= any number from 1 to 9, represents a specific category, i.e., a certain kilowatt price.*

Meter Reading: It consists of 7 digits, and represents the power consumed in kilowatts per hour, which is the meter reading.

Statistics: It consists of 117 digits and contains all the meter statistics.

Display Data: It consists of 32 digits and contains all the meter's display values at the time of the transmission.

F. Electric meters Control Software:

A simple Microsoft Visual Basic system has been developed to enable seamless USB port communication with RCSI. With this system, it can easily connect to all meters in the network coverage through SMS service. Our user-friendly interface features a main window that leads to a group of windows, each with specific functions that are identified, making it easy for you to navigate and use.

In Figure 8, the main window of the control system contains five buttons, each leading to a different window: Request reading, Request service information, Request statistics, Service Disconnect/activation, Tariff change, and Type of service change. In addition, two buttons are used: General reading request, and Balance system.

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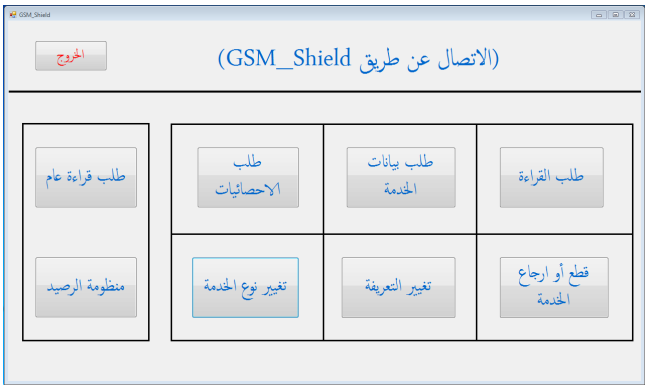

Figure 8: Main window in the control system

In Figure 9, you can find the reading request window. This window allows you to send a reading request meter by meter by entering the meter number and pressing the send request button. Once the request is sent, the window displays the received data and a table including the subscriber's name, meter ID number, and reading. It also shows the remaining time in seconds to determine the validity of the message so that it does not remain pending.

Figure 9: Reading request window

In Figure 10, the service information request window can be seen. This window is used to request service data for a specific meter. To do so, simply enter the meter number and the window will display the received data alongside the meter's display data. This includes a table containing the type of service, tariff type, and whether the service is suspended or resumed.

Figure 10: Service information Request Window

Figure 11 shows the statistics request window, which is particularly useful for the electric company. It allows the control room to gather network information from the user level, helping the company monitor any service degradation and load issues, and use this data for any future network expansions.

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Figure 11: Statistics Request Window

This window can be used to request statistics about a specific meter or multiple ones. In this case, the received information includes data on maximum and minimum voltage, current, power factor, frequency, and the date and time of occurrence for each statistic.

The images above depict two separate windows for managing meter electricity service. The first window in Figure 12, labeled "Disconnect/Return Service," allows users to suspend or resume service for a specific meter by entering its number and selecting the desired action. If resuming service, users can also choose between two tariff types. Once the request is sent, the window displays the transmitted data for verification purposes.

Figure 12: Disconnect or Return Service window

The second window in Figure 13, labeled "Tariff Change" is used to send the tariff value based on the company's service price per Kilo Watt/h per customer type (Home, Small Business, or Factory). Users can enter the meter ID and determine the tariff value, with two examples provided as references. As with the first window, the user can verify that the SMS message was sent off by checking the transmitted data displayed in the window.

Figure 13: Tariff Change Window

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In Figure 14, there is a window that allows for the changing of service type. This window is used to switch the service type from billing to prepayment and vice versa. To make the change, the user enters the meter ID that needs to be updated and selects the desired type of service before sending the request.

For a convenient way to obtain all meter readings upon request, Figure 15 displays the window for sending a general reading request. This request is sent to all registered meters, and as each meter responds by sending its reading back via the upstream frame, the received data is displayed in the window. The window also includes a table that shows the subscriber's name, reading, and meter ID. It can be noted that this service was only tested on a small scale due to resource limitations, with only two meters being implemented for this project.

Figure 14: Service Type Change Window

Figure 15: General Reading Request Window

Top-up Server:

As previously stated, to create a comprehensive system, we implemented a billing system (consisting of software and an interface) to demonstrate the proposed concept. Figure 16 displays the window for sending the balance.

Figure 16: Balance Server System Window

This interface facilitates communication between the control system and the balance system. It allows the control system to turn the balance system on and off, and send debt values and discount rates to the balance system when the subscriber switches from invoice-based to prepayment service (if there are outstanding debts). Additionally, this interface stores information on the charged balance, deducted balance, and remaining debts for each customer.

III. RESULTS

This research builds on previous work to enhance electric meters in Libya. The objective is to create a single-phase electrical meter that is easy to use for both the electricity provider and the consumer. The new meter reduces reading time and costs while

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improving accuracy for the electricity company by enabling remote communication through the national mobile network. This feature allows the electricity company to easily access all meters within the mobile network's scope from a single control or sub-control room.

The new meter provides consumers with detailed information such as consumed capacity, actual voltage in the house, current drawn, real capacity, current balance, and debts. It also allows for remote disconnection and restoration of electrical service, making it easier for electricity companies to be fair in load-shedding processes. Additionally, the meter regularly saves data to prevent loss of readings and records energy consumption statistics, including the highest and lowest voltage and current drawn, to help identify peak times and areas of consumption growth.

The introduction of the new meter provides a prepaid service, which helps the electricity company overcome the issue of payment evasion. Moreover, it comes with a customer notification system that sends a text message to the customer, informing them about their invoice while reading it. This feature enables customers to connect their payments directly to their bank account and avoid estimated bills.

The new meter also provides the facility to change service types remotely, eliminating the need for personnel to visit the meter. It also enables the customers to modify the meter tariff price per kilowatt hour or make it work at multiple tariffs.

IV. CONCLUSION

The demand for a faster and more cost-effective way of collecting readings in the country is increasing, and the use of wireless connections in meters has proven to be an effective solution. With this technology, the meter and system offer additional features such as the ability to change service type and tariff, and remotely disconnect or reconnect the service. This has greatly improved the experience for consumers and technicians when it comes to electricity usage. Additionally, the prepayment service has proven to be a cost-effective solution for the state as more citizens pay their dues on time.

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