# Design and Implementation of a Smart Meter

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**Abstract.** This paper presents the design and the implementation of a smart meter for prepaid electricity using an Arduino microcontroller, a global system for mobile communication (GSM) module, and a liquid crystal display (LCD). The smart meter allows users to remotely recharge their meter after purchasing prepaid electricity using a mobile phone. It also allows the meter owner to receive notifications about the level of prepaid credit available in the meter, the meter status, and a threshold for recharge notifications. This paper also discusses the advantages of the proposed system to customers, and the utility company, as well as some of the challenges encountered, and provides recommendations to various stakeholders.

**Keywords:** Smart meter · GSM module · Arduino microcontroller

## 1 Introduction

Smart electric meters are more capable, more reliable, and more accurate than traditional electric meters, driving the replacement of traditional meters with smart meters. Smart electricity meters track energy consumption, automatically recharge prepaid electrical credit, and provide feedback to users about the energy consumption of household appliances or business equipment. Smart electricity meters fall under the domain of Internet of Things (IoT) devices because they can communicate with other existing systems without human interaction [1].

Many projects have been carried out to enhance the capabilities of smart electricity meters [2]. These projects include providing feedback to users and semi-automatically recharging the meter credit using either wired or wireless communications. These systems typically recharge the meter using messages sent by mobile phone to interact with the utility company. However, this approach is not entirely automated because the user must load a code or token into the meter manually. The system explained in this paper completely automates the process. Tokens from the utility company are sent directly to a wireless GSM communication module that communicates with a microcontroller, and the microcontroller is used to recharge the meter credit automatically.

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### 1.1 Problem Statement

Prepaid electric meters are in everyday use in many parts of the world, and the majority of electricity meters are conventional in type, with metal discs and electric motors that rotate at a speed that is proportional to the amount of power supplied during electricity consumption. These meters are inexpensive and are less vulnerable to lightning strikes than electronic meters. In a traditional prepaid electricity system, a meter is recharged using a token provided to the users when they have purchased electricity. The token number obtained from the vendor is then manually typed in the meter to update the new electricity balance. This process is time-consuming and is vulnerable to human error. When the meter cuts power to the user due to expired credit, there is no warning, and the process of recharging the meter credit is inconvenient and may involve lengthy delays during reconnection. For instance, it may be necessary to travel to a vendor authorized to sell electricity tokens, purchase the desired amount of credit, and travel back to recharge the meter. These factors, combined with the lack of communication between the users and the utility company, resulting in inconveniences to the user. To solve this, we designed and implemented a smart electricity meter that is user-friendly and reduces most of the errors and inconveniences faced when using conventional meters. This smart electricity meter is automated and requires few user interventions. It can remotely load power tokens, alert the user when electricity reaches a minimum threshold, and send a notification when the meter credit is recharged. Moreover, our proposed metering system is programmed to keep track of power usage and communicates directly with the utility company through the GSM infrastructure of a telecommunication company. This data facilitates further analysis by the power company.

### 1.2 Objectives

- Automatic recharge of smart electricity meters using wireless communications.
- Provide real-time updates to the user and the utility company.
- Allow domestic power consumption management.

## 2 Related Work and Background

The prepaid metering system eliminates disadvantages of postpaid billing system, such as the need for meter reading, bill calculations and bill delivery. The prepaid system can be implemented in any country and is beneficial to both consumers and power distribution companies [1].

Smart meter systems can collect power consumption data in real time, and can display price information, enabling variable market pricing based on supply and demand, and demand-side management of connected loads. Wired and wireless communications facilitate this exchange of data between the user and the utility company [2]. A survey on the use of smart electricity meters provided economic, social, and environmental benefits for multiple stakeholders. One of the critical factors that will determine the success of smart meters is smart meter data analytics, covering data acquisition, transmission, processing, and interpretation [3].

A smart electricity meter is a type of IoT device that can be programmed to control the electricity consumption of home appliances and uses two-way communication to give and transmit real-time electricity prices [4]. Weiss et al. developed an application that can send information about the power consumption of each device connected to the circuit and relay it to the consumer. This application aims to address the complexity of other methods of monitoring individual loads and to address a lack of feedback on the power consumption of individual devices in existing systems [4]. It stores this information in a microcontroller, making utility and price information accessible in real time, and summarizes user's consumption data [2].

The smart meter system consists of metering equipment connected to the electrical circuit that measures total electric consumption. It has a software-based application that manages collected data and serves as a lightweight communications gateway. The gateway has a mobile user interface to provide real-time data from a database [5]. Several communications technologies typically exist in each meter and can be selected based on data rates, distance, type of data, and protocols. Communications and data exchange help to quantify demand habits so that utilities and consumers can better predict their base and peak load, enable demand-side management, and provide rapid automatic outage detection and restoration. The life expectancy of smart meters is about 20 years [6].

### 2.1 Conventional Electricity Meter Design

Conventional meters have a minimal user interface. Their design does not allow the integration of other platform modules like protocols and functions. The portability of one coding language to another is platform-dependent. Currently, 8-bit microcontrollers are used and have limited memory and performance capabilities. The software architecture of a conventional electricity meter is shown in Fig. 1. It consists of six components: an energy measurement and calculation unit, a processing module, a load survey tamper detection and processing module, a power management and real-time clock (RTC) module, a display and key module, and a universal asynchronous receiver-transmitter (UART) interface and communication Modbus.

### 2.2 Smart Electricity Meter Design

A smart electricity meter is integrated into a 32-bit microprocessor implemented on a shared peripheral and memory interface bus, which makes the system flexible and scalable [6]. Smart meters are optimized for resource-handling reliability and scheduling management. This design helps in scheduling policies, inter-process communication, and resource sharing. The meter architecture provides interrupt handlers, task priority assignments, synchronizes concurrent processes and threads, and manages measurements and billings as shown in Fig. 2 [6].

A smart electricity meter has two main components: communications and processing. The communications component manages the internal communications and information-sharing between the meter and the user. The processing component uses an analog-to-digital converter to convert the voltage and current of a load into digital a form representation, and stores data in an internal memory. These data are used to

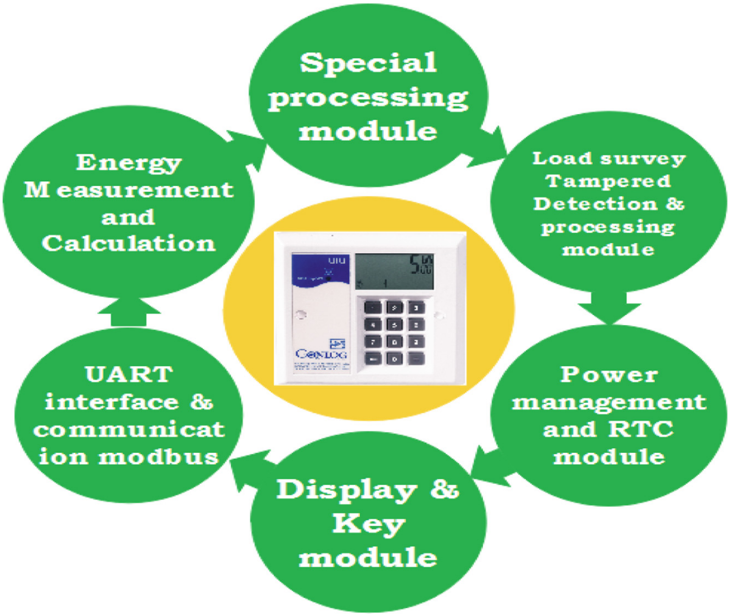



**Fig. 1.** Software architecture of a conventional electricity meter, showing communications with other meter components [4].

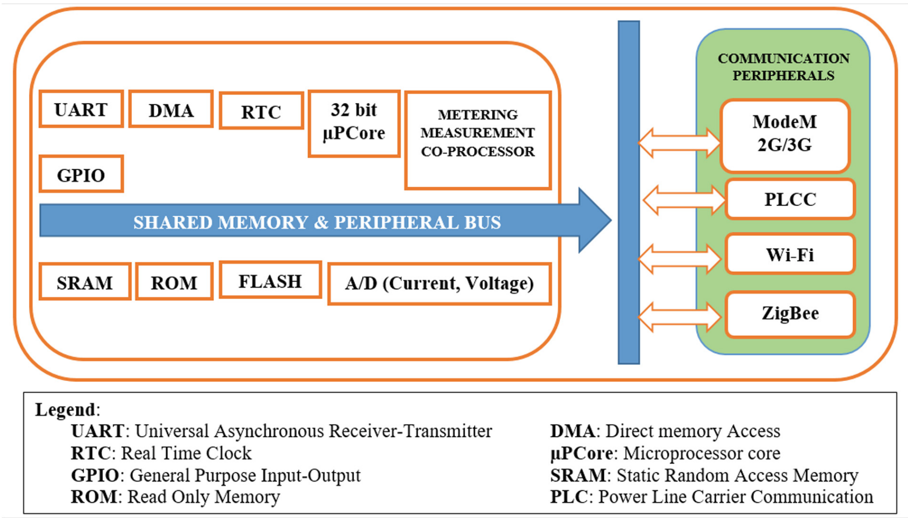



**Fig. 2.** Smart meter architecture adapted from [5].

calculate power consumption and record outage events. The most common topologies used in smart electricity meter communications are star, tree, and mesh [7]. Figure 2 shows the hardware architecture of a silicon-and-chip-based smart electricity meter. Its main components are a shared memory and peripheral bus, a metering measurement co-processor, an analog-to-digital converter, and common peripherals.

### 2.3 Requirements and Challenges in the Design and Implementation of Smart Meters

There are a number of requirements and challenges in the design and implementation of smart electricity meters. These include:

- Communication security: Secure communications may require regular security upgrades.
- Interoperability: Communications and command sets should be interoperable with existing advanced metering infrastructure.
- Communication ports: Port specifications should be based on a common standard to enable longevity, upgradeability, and interoperability.
- Input/output capability: A sufficient number of interfaces should be available for current and future connections [6].
- Limitations on network coverage, data capacity, and propagation can be problematic for the utility company.
- Network maintenance is difficult in large, widely-distributed systems, particularly if physical access is required [5].

## 3 Design of the Proposed System

The main objective of this project work is to design and implement a smart meter system that interacts with the utility companies and meter users. We focus on prepaid electricity where a meter is charged/recharged after the owner has purchased electricity. Traditionally, this is done manually where a token number obtained from the vendor is manually typed in the meter to update the new electricity balance. We replace this manual transaction by a transaction where the token is sent directly to update meter by the utility company or the user using their phones. We also aim to programming the meter to keep track of the remaining power and communicates directly with the utility company through the GSM infrastructure of a telecommunication company.

The system requires human intervention in the recharging process only. It facilitates power management by prioritizing the use of home appliances and providing the data necessary for upcoming plans.

The proposed system is designed by putting together electronic devices composed of a microcontroller, GSM module, push button circuit and a physically-connected LCD. These components communicate using an electric current. The control and communication mechanisms are aided by a software component that was developed by programming the microcontroller. The communication processes of this smart electricity meter are based on flowchart and block diagram in Fig. 3 that explain the working principles of the system and shows the physical interconnection of the different parts.

Our smart meter has four main systems: the control and management system, the display system, the communication and database system.

## 3.1 Control and Management System

This is comprised of the microcontroller and push button. The microcontroller is designed to perform management and control while the push button is used to emulate the load. These are explained below:

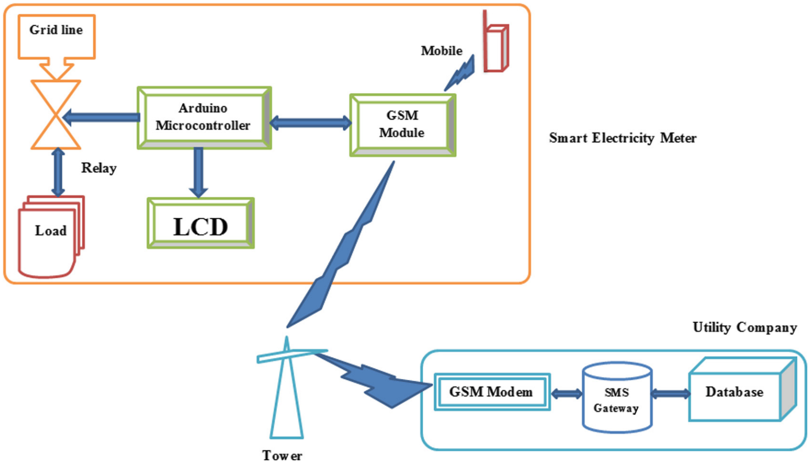



**Fig. 3.** System block diagram of a smart electricity meter showing all the parts of the metering system.

As shown in Fig. 3, the circuit design has a programmed microcontroller which controls the overall system operations. It reads the input signal in the form of a current and uses the installed software to provide the necessary output. The output action connects or disconnects the loads to/from the grid and, switches on or off certain appliances. It also instructs the GSM module to send the message to the user when the power is low, when any amount of electricity has been recharged or when a system error has occurred. This microcontroller is able to communicate with the GSM module and LCD.

## 3.2 Display System

Our metering system uses a 16 × 2 LCD which serves as an output device for displaying the electrical energy balance. This system can receive and display the remaining power balance from the microcontroller. It can also respond to all microcontroller signals and perform the display actions as requested.

### 3.3 Communication System

The communication system consists of wired and wireless systems. Apart from the internal communication of devices inside the meter, the external communication is based on the interface between the SIM900A GSM module and the Arduino microcontroller. The GSM module acts as a link between the user and the smart meter circuit. It receives the powering message from the utility company and sends it to the microcontroller. It also receives the signals from the microcontroller and communicates them to the user via a wireless channel. The owner of the meter, herein termed "the user", receives the information from the meter as an SMS with the help of this GSM module. On the server side, a token generated by the utility database will be sent to the GMS module on the client side via a MODEM and telephone line.

### 3.4 Database System

The database system will be owned by the utility company. It will hold a status of valid tokens so that those which have been used cannot be reused. It will also generate random token numbers whenever a user buys electricity, and send them to Ozeki SMS gateway to the GSM module at the client's home. It will be designed and implemented through the Xamp open platform and MYSQL database. The Ozeki SMS Gateway will be used to send electricity token number from the utility company to home GSM module in the form of an SMS. The communication between all of the above systems is illustrated on the flowchart in Fig. 4 below:

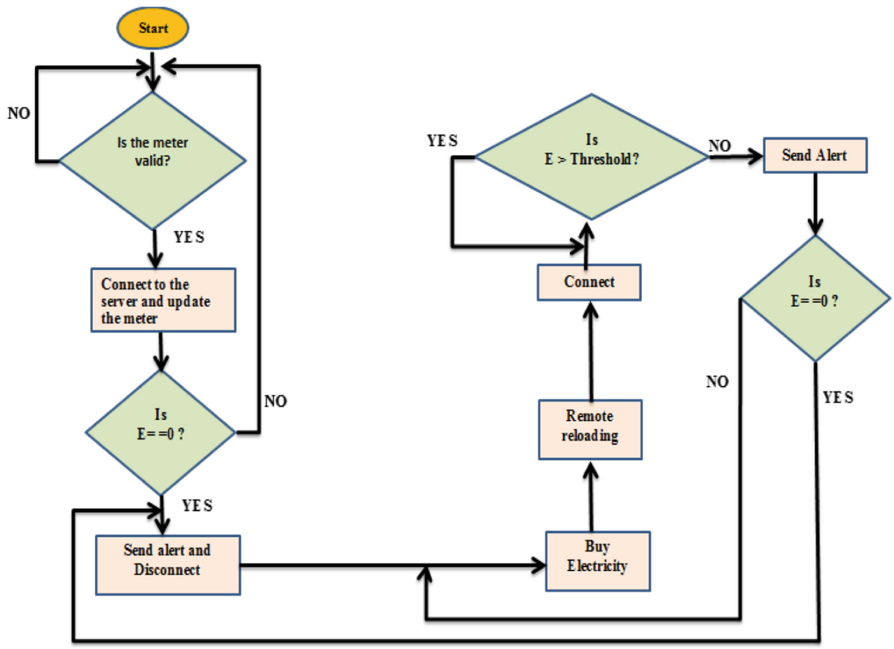



**Fig. 4.** System flowchart showing the information flow during communication from the different parts of the meter.

As shown on the flowchart in Fig. 4, whenever the meter is connected for the first time, the system will check whether the meter is valid and allow it to be used for further operations. Whenever the meter is connected, the system continuously checks the electricity level to determine whether it is equal to zero or not, and sends an alert message to the user or home owner's phone when the balance reaches the threshold. When the electricity balance reaches zero, the system sends an alert message and disconnects the meter. By the time a user buys electricity, the meter is reconnected and goes in a state of electricity level tracking so as to alert the user whenever it reaches the threshold value or zero.

## 4 Implementation and Demonstration

The implementation is structured in three steps: circuit design and implementation, software implementation, and database design and implementation. The system testing is structured in such a way that each part is first tested individually and then again after interconnecting it with other parts. However, the database has not been implemented. The implementation of the system uses open source hardware like Arduino boards and software.

### 4.1 Circuit Design and Implementation

The design of the smart electricity circuit was based on the block diagram of the smart electricity meter. The circuit design and simulation were conducted using Fritzing software. The circuit design details the physical connection of the meter components and is shown in Fig. 5 below:

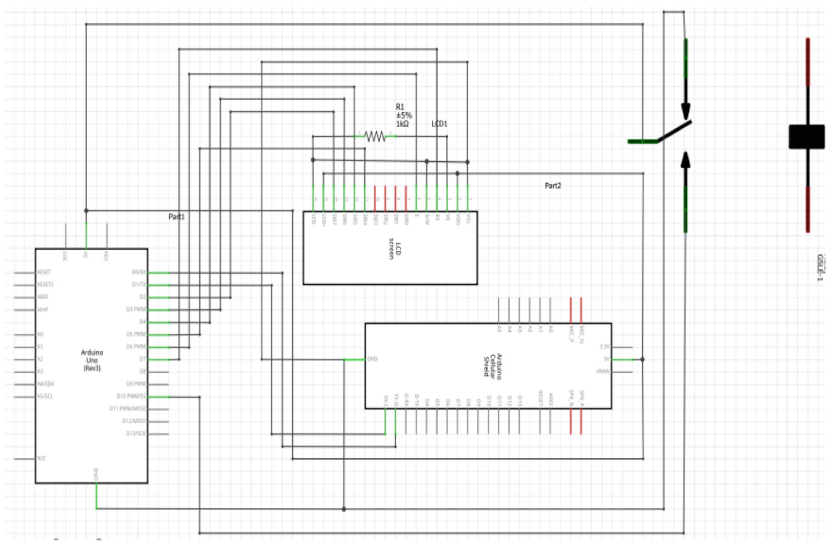



**Fig. 5.** Circuit design of a smart electricity meter showing all internal connections of components of the meter.

### 4.2 Circuit Software Implementation

We have implemented a software which allows the user visualize the amount of electricity remaining in the meter using an Arduino integrated development environment (IDE) platform. This is made by activating an LCD display which displays the amount of initial or pre-configured of electricity units on the meter. The current system accepts the message from the utility company for loading the meter (Fig. 6).

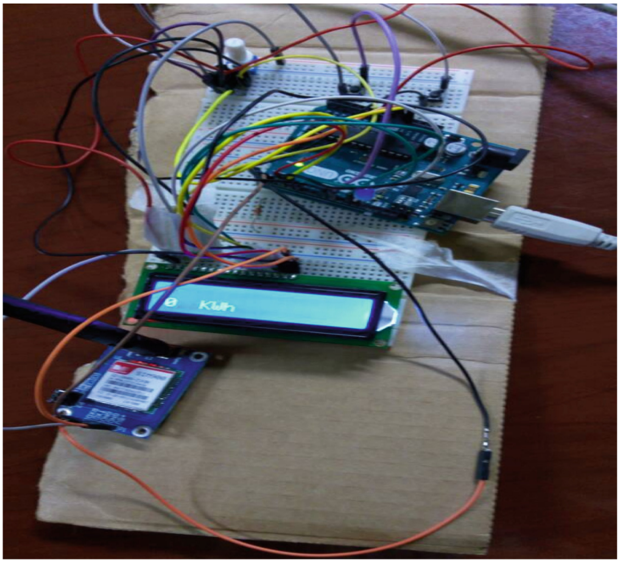


**Fig. 6.** Display on the screen of a smart electricity meter is shown as the number of units.

The GSM module can communicate to the external mobile device with the help of an embedded SIM card. Since this SIM card belongs to the telecommunication company, there should be the agreement between the telecom and the utility company so that it can freely send SMS to the user and remain in service without requiring airtime.

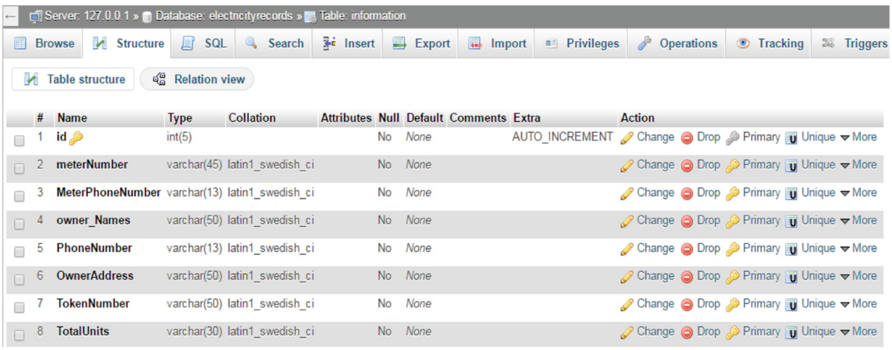
The message on the Fig. 7 should begin with # and end with * for the software to decode it and save it as units. The units loaded in the meter decrease as the load is connected and increase whenever the user recharges it with new credits. In case the load is not connected, the amount of electricity in the meter stays constant.

### 4.3 Database Implementation

The database component of the meter has not been implemented in this paper. The format of the required database tables is shown on table in Figs. 8 and 9. Nonetheless, the working mechanism of the smart electricity meter will involve the use of the database that will store the information about the meter and its working history. This meter will be based, owned and monitored by the utility company. It will contain two tables: one for the meter information and the other for the used and unused token


**Fig. 7.** Message as sent by the mobile phone to the meter.

numbers. The information in the table below will be responsible for keeping the ID of the meter, the meter number, the name of its user, the phone number of the meter embedded SIM card, the user's phone number, the address, the used the token number and the number of units. The meter number, its phone number, and the name and contact addresses of the user will be installed at the time the user collects the meter from the utility company. However, the token number and the units will be automatically loaded as the user recharges meter. The token table will contain the token number and its status (i.e. used or unused).

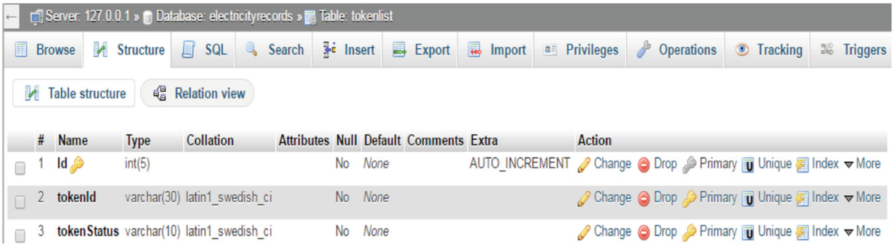



| # | Name | Type | Collation | Attributes | Null | Default | Comments | Extra | Action |
|---|---|---|---|---|---|---|---|---|---|
| 1 | id | int(5) | | | No | None | | AUTO_INCREMENT | Change Drop Primary Unique More |
| 2 | meterNumber | varchar(45) | latin1_swedish_ci | | No | None | | | Change Drop Primary Unique More |
| 3 | MeterPhoneNumber | varchar(13) | latin1_swedish_ci | | No | None | | | Change Drop Primary Unique More |
| 4 | owner_Names | varchar(50) | latin1_swedish_ci | | No | None | | | Change Drop Primary Unique More |
| 5 | PhoneNumber | varchar(13) | latin1_swedish_ci | | No | None | | | Change Drop Primary Unique More |
| 6 | OwnerAddress | varchar(50) | latin1_swedish_ci | | No | None | | | Change Drop Primary Unique More |
| 7 | TokenNumber | varchar(50) | latin1_swedish_ci | | No | None | | | Change Drop Primary Unique More |
| 8 | TotalUnits | varchar(30) | latin1_swedish_ci | | No | None | | | Change Drop Primary Unique More |

**Fig. 8.** Information table database of a smart electricity meter detailing all the necessary information of the meter and the owner.

## 4.4 Case Study

The meter prototype was tested by loading electricity using a cell phone. The meter was recharged by dialing # Electricity units* on a cell phone and automatically loads itself. The load that was supposed to consume electricity was emulated using a push button.




| # | Name | Type | Collation | Attributes | Null | Default | Comments | Extra | Action |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Id | int(5) | | | No | None | | AUTO_INCREMENT | Change Drop Primary Unique Index More |
| 2 | tokenId | varchar(30) | latin1_swedish_ci | | No | None | | | Change Drop Primary Unique Index More |
| 3 | tokenStatus | varchar(10) | latin1_swedish_ci | | No | None | | | Change Drop Primary Unique Index More |

**Fig. 9.** Token table database of a smart electricity meter containing tokens and their status.

Whenever the push button was pressed, the electricity level in the meter was reducing. By recharging new electricity units, the meter calculates the current balance by adding it to the initial balance. The meter sends notifications to the user when electricity has been consumed up to a certain threshold so that he can recharge.

## 5 Discussion

In the design of this smart electricity meter, we used a push button to replace the load which can consume the full units of electricity as you press it. This meter is designed in such a way that it can receive and decode the message sent to it and display the units. However, not all messages can be decoded into units; only those with some specifications can be decoded.

Furthermore, users may face various challenges with the adoption and use of this electricity meter. Most of these are cost and policy-related. Smart electricity meters are more expensive than conventional meters. Another challenge is that this meter is using GSM technology; it may require a final agreement between telecommunications operators and utility companies. However, the most important challenge that has to be addressed with the advent of smart meters is cyber security. Since smart meters are becoming digitized and automatic, they face security attacks like data hacking and the introduction of malware.

In designing this meter, we planned the functionality of sending a message alert to the user when the units balance reaches a certain threshold. However, due to time limitations, this feature is not yet implemented. We aim to implement it in our future work.

For the use and adoption of smart electricity meters, we offer the following recommendations to; governments and other stakeholders: governments should give some incentives and grants to utilities so that customers can afford the smart electricity meters; utilities should cooperate with telecommunications operators for the use of the communication and billing systems; utilities are also recommended to invest in security to ensure the security and privacy of users and their devices.

## 6 Conclusion

This paper proposes a smart electricity meter that allows users to load prepaid electricity remotely using their phones and to receive notifications about the status of their electricity consumption. The proposed meter provides updated information to the users about their use of energy and its management. Utility companies can also use real-time data about electricity consumption to set tariffs according to the load status.

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