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Design and Construction of a Multi-User Prepaid Meter

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ABSTRACT

The Nigerian government has used prepaid metering for nearly two decades to eliminate post-paid and estimated billing system. There is no doubt that this billing system has benefited house owners who do not have renters as well as a few persons who have the advantage of knowing the exact number of prepaid meters for their apartments. Those living in rental apartments, on the other hand, experience the identical problem with postpaid when a single prepaid meter is divided among inhabitants. Sharing a single prepayment frequently violates the aim of prepaid metering because individual use cannot be reliably tracked. To address the issue of sharing, a unique type of prepaid meter that can handle multiple users on a single prepaid is required. As a result, this study proposes a multi-user prepaid meter that completely prevent conflicts that arise from the sharing of prepaid meters. A prototype for four users was planned and built around Radio-Frequency Identification (RFID) technology for individual user identification; a quasi-current sensor to measure energy usage and an Arduino Uno microcontroller ATmega 328p to manage the activities of the system. From the process of recharging to the display unit and other aspects that permit remote transaction of the device, the designed multi-user prepaid energy monitoring system functions well. To address the demand for unmetered houses across the country, the prepaid meter could be mass produced. Considering the different obstacles people have as a result of the low distribution of prepaid meters, this multi-user prepaid meter will undoubtedly be a promising technology to suit Nigerians' demands while also eliminating potential problems with prepaid meter sharing.

Keywords:
ATmega 328p Microcontroller,
Multi-user,
Prepaid,
RFID,
Smart meter.

INTRODUCTION

In recent years, Nigeria has seen numerous court cases; conflicts within homes and communities due to insufficient distribution of prepaid meters. As many residents continue to use post-paid meters, which result in assaults on electric distribution company staff while attempting to disconnect power in such area. This is the situation for people who desire a prepaid meter in order to avoid the negative effects of postpaid metering. Prepaid electricity meters offer a technological solution to the non-payment problem (Kambule, 2018), combating theft and electricity usage optimization.

In some developing countries like Nigeria, accurate energy metering and billing is a challenge. This is due to inadequate power generation, transmission and distribution infrastructures, combined with inefficient energy metering. Thus, energy consumers being billed unfairly by Electricity Distribution Companies (DISCOs) for unused energy, a practice known as "crazy bill."

Neighbours are also at odds when trying to reconcile the quantity of electricity utilized and the amount to be paid when a prepaid meter is shared.

As many residents have yet to get prepaid meters, some buildings share a single prepaid meter among flats occupants. The common issue with the sharing of prepaid meters is the splitting of bills among users, irrespective of who consumes more. The power supply drains faster when shared with a neighbour who does not know how to save energy. Also, an occupant that is hardly around may end up paying for energy that he does not consume.

Many landlords think, once one or two prepaid meters are acquired; they have automatically escaped estimated billing, forgetting that one or two prepaid meters among six occupants is never an ideal solution. They later realize that solution profess, gives rise to another bigger

problem until all occupants are attached to separate meters. There are still significant metering gaps in prepaid meter distribution to consumers, resulting in the distorted or limited implementation of both estimated billing prepaid and systems at the same time. As a result, non-cost-reflective tariffs are imposed on electricity consumers (Hariharan, Agarwal, Kandamuru, & Abdul-Gaffar, 2021).

The report, which covers electricity consumption statistics from 2015 - 2020, focuses on estimated billing customers, customer numbers, metered customers and electricity supply, as well as revenue collected; found that 30.08 million Nigerians were affected by estimated electricity billing during the review period (Olaoluwa, 2022). The Nigerian Electricity Regulatory Commission (NERC) recommended installing prepaid meters for all customers to accomplish this but there is no full compliance with this regulation. Adekitan, Adetokun, Aligbe, Shomefun, & Orimogunje (2018) conducted an investigation on energy metering in Ota community, Nigeria; on 214 residents, it observed that 47.7% of the residents are on prepaid metering systems (Figure 1), 31.3% are on shared metering systems (Figure 2) and 38.7% are on estimated bills (Figure 3).

According to NERC, the number of registered electricity consumers was 8,292,840 at the end of August, 2020 (Usman et al., 2022). Out of this figure, only 3,592,168 consumers were metered while 4,700,672 were still hoping. That is about 43 %, gap needed to be closed. Some electricity consumers argued that the failure of DISCOs to provide meters, especially pre-paid ones, was deliberate. They are using estimated and arbitrary billing as a way of recouping their investments in the privatization of the power sector (Ajibade, 2019).

Hariharan et al. (2021) proposed a system for monitoring home appliance energy consumption. The device could calculate household energy consumption and keep the user informed about electricity consumption via an Android application system. Although the scope of this work directly addresses individual energy consumption measurements, it does not address people who share prepaid energy meters. Soh et al. (2019) used an Internet of Things (IoT) framework to monitor energy consumption data at home. The system makes use of a sensor module that is linked to an Intel Edison microcontroller. The power consumption data is collected and saved on Ubidots IoT Cloud Services. Consumers could monitor their energy consumption at home on a daily basis and thus control the amount of energy they use. Yun et al. (2012) created wireless smart power sockets that can be used to measure electrical device power consumption. They send the collected data set to an access point that is linked to a host server. Controlling the energy consumption of devices and electronics is possible by switching on and off relays embedded in smart sockets. It also has the capability of displaying real-time energy consumption graphs on smartphones. These literature reviews on energy consumption meter and their shortcomings are summarized in Table 1.

Table 1: Summary of Related Works on Energy Consumption Meter

Author	Research work	Function	Shortcomings
Hariharan *et al*. (2021)	System for monitoring home appliance energy consumption	Their study focused on a device that can be used to calculate household energy consumption and keep the user informed via an android application system.	Although their research could allow users control the amount of electricity they consume, it couldn't solve the problem of prepaid meter sharing
Soh *et al.* (2019)	Monitoring energy consumption at home using Internet of things (IoT)	They proposed a system by which consumers can monitor their energy consumption at home on a daily basis and control the amount of energy they use.	It could only allow consumers to measure the amount of energy neglecting the other problems associated with prepaid metering.
Yun *et al*. (2012)	Wireless smart power sockets to measure electrical device power consumption.	They designed a system for controlling the energy consumption of devices and electronics. It can also display real-time energy consumption graphs.	Their work could not resolve the unavailability of prepaid meters alongside sharing among commercial residents.

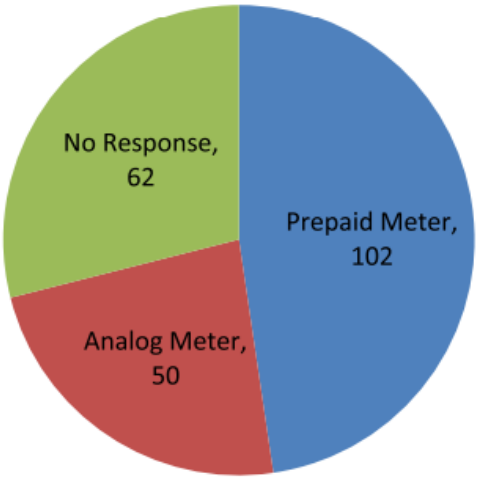

Figure 1: The type of energy meter installed (Adekitan et al., 2018)

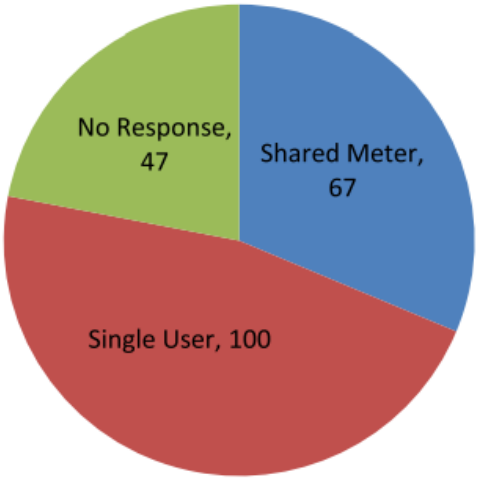

Figure 2: Sharing of one energy meter (Adekitan et al., 2018)

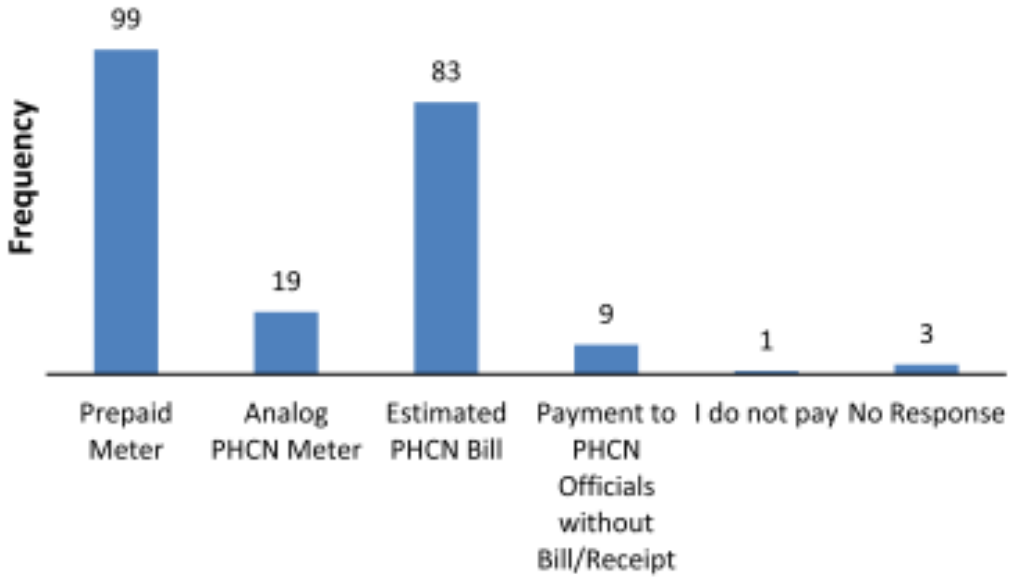

Figure 3: Mode of Energy Billing and Payment (Adekitan et al., 2018)

Makanjuola, Shoewu, Akinyemi & Ajose (2015) investigated the problems of prepaid metering systems in Nigeria using questionnaires within Eko Electricity Distribution Company (EKEDC) jurisdiction. A few of the solution they proffer include the use of high-quality meters, the availability of energy at all times and the computerization of the prepaid metering system. Mohammad (2013) proposed a prepaid metering system to control electricity theft, they suggested a prepaid energy metering system in order to prevent electricity theft. They installed a Global System for Mobile communication (GSM) module with a server in the prepaid meter, enabling two-way communication between both using the GSM network that already exists. By Short Message Service (SMS) sending a Personal Identification Number (PIN) disguised in a scratch card to the server, consumers may effortlessly replenish their energy meters. Dike et al. (2015) studied how numerous families engage in various types of electricity theft and unauthorized tampering with electric metering equipment. They suggested meter should be programmed to save a distinctive Identification (ID) number, such as the customer's phone number. As the GSM module sends a communication to the distribution provider, electricity theft is discovered.

Al-Naima & Jalil (2012) proposed a prototype prepaid electricity metering system based on RFID. An RFID reader, a microcontroller, a digital meter and a wireless gateway make up the planned prepaid meter. Clients provide a server in the neighborhood substation with their card IDs and the server checks and/or updates the

database before sending the card ID information back to the client. Batiller *et al*. (2016) studied prepaid metering system for isolated micro grids: two prepaid metering solutions for remote micro grids were described. The initial implementation communication channel is GSM; in which smart meters with GSM capabilities and a utility server manages all accounting and reloading procedures of the system. In the second implementation, a Zigbee module took the place of the GSM module to enable communication in locations without cellular service. Omijeh and Ighalo (2013) discussed the modelling of a GSM-based energy recharge scheme for prepaid meters. Their paper modelled a GSM-based energy recharge interface which contains a prepaid card equivalent to a mobile SIM card. The GSM communication network is used by the prepaid card to communicate with the power utility. When the prepaid card is out of balance, the latching relay disconnects the consumer load from the utility supply. Based on customer requests, the power utility could remotely recharge the prepaid card via GSM/SMS mode. These literature reviews on various prepaid meter function and their shortcomings are summarized in Table 2.

Table 2: Summary of Related Works on Prepaid Project

Author	Research work	Function	Shortcomings
Makanjuola *et al.* (2015)	Investigating the problems of prepaid metering systems in Nigeria.	Their work proposed solutions to the problems of prepaid metering system like lack of vending, delays in installation etc.	Their research was limited to one geographic location and could not resolve other problems of sharing prepaid meters.
Mohammad *et al*. (2013)	Prepaid metering system to control electricity theft.	Focused on designing a prepaid meter that prevents electricity theft and its control.	Their study could not solve existing problem on billings, distribution and sharing of prepaid meters.
Dike *et al.* (2015)	Minimizing Household Electricity Theft in Nigeria Using GSM Based Prepaid Meter	Their study was on the illegal tampering of meters and the design of a GSM based meter that detects electricity theft.	Their study could not solve existing problem on billings, distribution and sharing of prepaid meters.
Al-Naima & Jalil (2012).	Building a prototype prepaid electricity metering system based on RFID.	Their design provided a working prototype of a management system for prepaid meters which uses RFID and card IDs	Their design could not resolve the problem of sharing and distribution of prepaid meters to citizens.
Batiller et al. (2016)	Prepaid metering system for isolated microgrids	Prepaid metering solutions for remote microgrids were discussed while GSM and Zigbee module were used to enable communications.	Their research could not resolve the problem of sharing prepaid meters among commercial residents with the distribution of prepaid meters to citizens.
Omijeh and Ighalo (2013)	Modelling of a GSM-based energy recharge scheme for prepaid meters.	Their work focused on the use of GSM-based recharge interface.	The problem of sharing prepaid meters among commercial residents could not be resolved.

There is no doubt that prepaid metering systems are very relevant innovations to escape the adverse effect of epileptic power supply which is accompanied by estimated bills. However, sharing can lead to worse experiences. In this paper, a multi-user smart meter that enables each resident occupant to operate on a single meter as though they were using a separate meter is discussed as a way out of the menace that is associated with the sharing of prepaid meters.

MATERIALS AND METHODS

A Multi-User Prepaid Meter Design and Cost

Figure 4 depicts the overall design of the proposed multi-user prepaid meter, materials and its operation; while Table 3 shows the list of materials used, quantities and cost. This consists of the RFID technology, Bluetooth module, microcontroller and android application message. There are four users therefore we have four RFIDs for users' identification. When a user

is identified a message can then be composed and sent for the user unit value to the prepaid meter, to update and add the recharged value to the users' account. The controller used in this work is ATmega 328p microcontroller, same found in Arduino Uno, this is the heart of the system. Here, all logic and arithmetic calculation takes place.

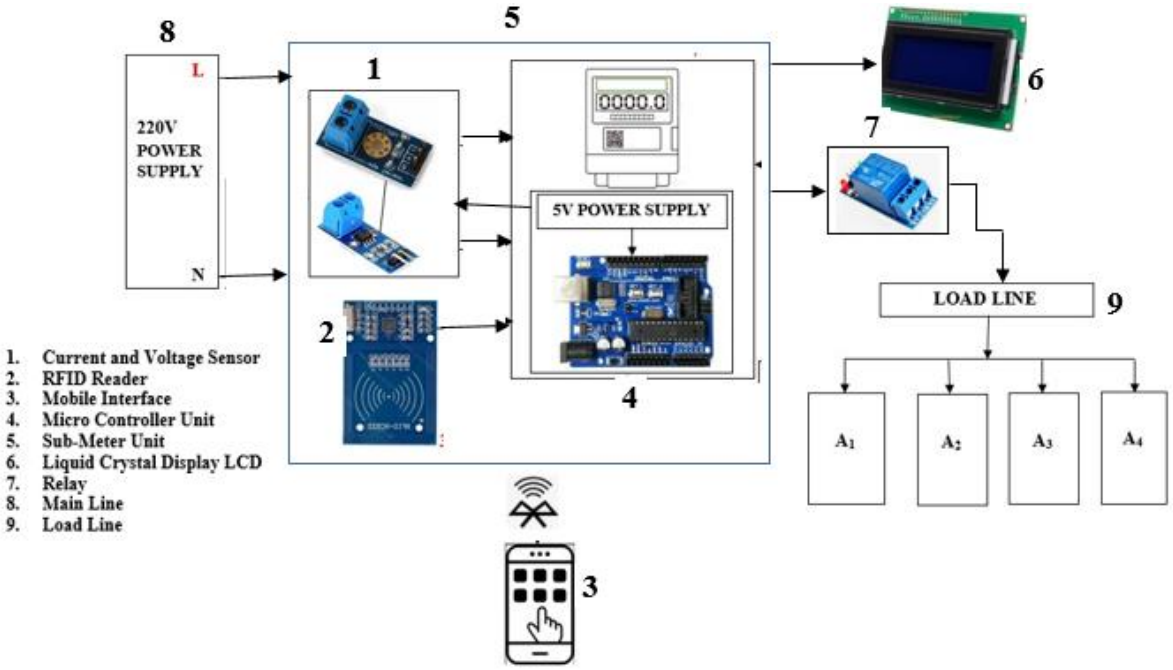

Figure 4: The Design of Multi-user Prepaid Meter

The display comprises of a four line by sixteen characters liquid crystal display interface to the controller for visual display of all data. Four users load go to four receptacles for individual load connection. Only users with unit balances get power supply to their load receptacle. The power supply is made of a switch mode alternating current, AC to direct current, DC power supply at 12V for relays, the same was regulated to 5V for the controller board. AC power at 220V goes to the receptacle for alternating power board.

Table 3: List of Materials, Quantities and Cost

S/N	Component	Value	Quantity	Unit Price (₦)
1	Microcontroller	ATmega 328p	1	7,000
2	Current Sensor	AC712	1	2,000
3	Liquid Crystal Display	20x4Module	1	5,500
	RFID Module	RC522	1	3,500
4	Transistor	2N2222	4	50
5	Resistors	1K, 10K, 220R	4, 4, 4	20
6	Variable Resistor	1K	5	100
7	Capacitor	10uf	4	30
8	Diode	1N4007, 1N4733A	4,4	40
9	Relay	SRD-09VDC	4	600
10	Electric Sockets	13A/250V, 1 Gang Switched Socket	4	1,250
11	Printed Circuit Board (PCB)/Processing	Copper Clad	1	2,000
12	Connectors	Cables and Connecting wires		1,200
13	Casing	-		6,500
14	Transportation/Logistics			3,500
			TOTAL	**39,980**

The Circuit Diagram of the System

The complete system circuit diagram is presented in Figure 5. We used variable resistors to represent current sensors in order to detect each user's power consumption; which generate a signal corresponding to the power consumption. The heart of the system is the ATmega328p microcontroller. It manages and coordinates the activities of all the components that interact with it. It reads the input from the sensors, which are connected to the Arduino board's analog inputs A0-A3, and converts it into an output that is displayed on the liquid crystal display (LCD).

The LCD is responsible for displaying the users' power unit status. The 16x4 LCD module used in this project can display twenty characters across four rows. This means that eighty characters can be displayed on a single screen. At least six pins are usually required to display characters programmed into an LCD module. The number of pins is reduced by connecting it via an expander PC8574 module, which allows it to use two Arduino board pins instead of six.

The relay circuitry connected to Arduino board pins 4–7 is used to represent an action based on an individual user's consumption. It also aids in indicating the presence or absence of power based on unit balance. The virtual terminal connected to the Arduino's Transmitter (Tx) and Receiver (Rx) pins represents the software for charging and displaying a condition for sending SMS to users with less data.

The circuit diagram also shows an RFID reader connected to pins 9–13 of the Arduino pins. It serves as a means of identification and authentication for individual users.

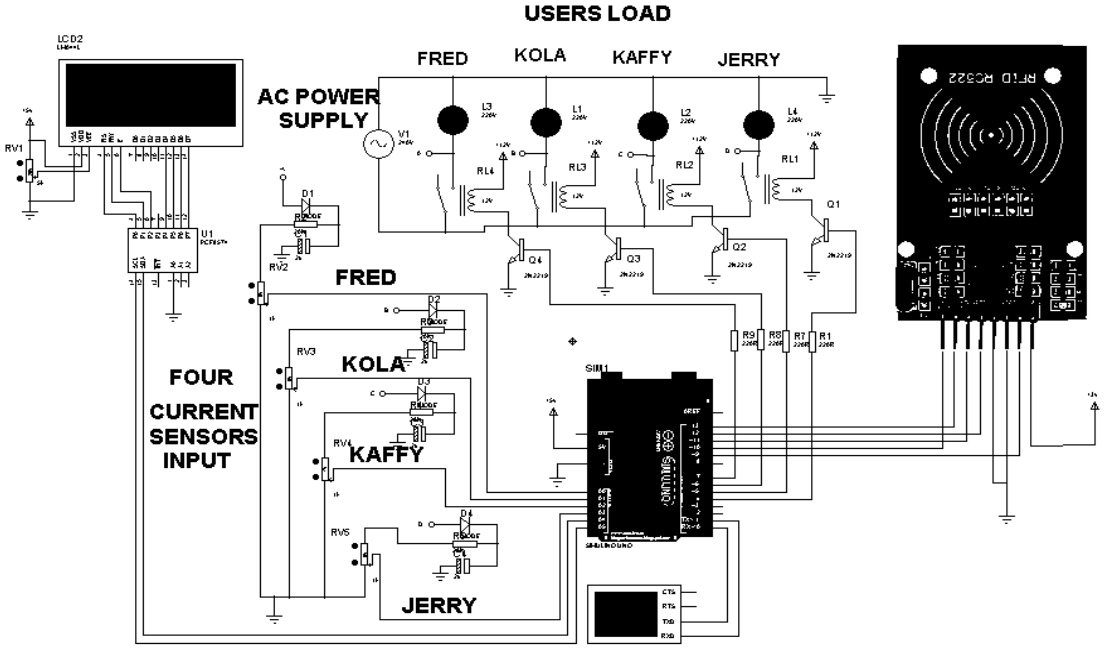

Figure 5: The Circuit Diagram of the System

RESULTS AND DISCUSSION

Software Development

Figure 6 shows the fraction of coding for the system. According to the program, the system checks if any of the user's power units is greater than one. A YES gives a line activation for that individual, and a NO deactivates it. The unit remains static until a load is connected to it. A load that has run for a thousand watts will get a decrement of one unit.

The Arduino Uno board microcontroller ATmega 328p is first programmed before it can be used in the hardware structure of the system. The program is written in C++, a human-readable language. This is converted to machine code with the help of a compiler in the Integrated Development Environment (IDE) of Arduino software. The code effectiveness was tested on the Proteus 7.10 version. The hex file generated is stored in the memory of the microcontroller.

```
if(interval > 0){
   digitalWrite(LOAD_FRED, HIGH);
 }
 else{
 digitalWrite(LOAD_FRED, LOW);

if (energy > 1000.00){
 if (interval > 0){
  interval = interval - 1;
  EEPROM.update(INTERVAL_ADDR1,interval);
    energy = 0;
 }
 else if(interval < 1){
  interval = 0;
 energy = 0;
 digitalWrite(LOAD_FRED, LOW);
 }
```

Figure 6: Code Fraction of Multi-user' Prepaid Meter

Comparison of the Prototype Multi-User Prepaid Meter with NERC Supplies

The developed multi-user prepaid meter system was successfully constructed and tested (Figure 7 - 9) at a cost of about ₦40,000 per unit as enumerated in Table 5 compared to the NERC single-phase prepaid meter cost of ₦81,975.16; this approved NERC meter price exclude 7.5% Value Added Tax (Uko, 2023, para. 2). The NERC value for the single-phase prepaid meter is completely at variance with the street price which is in excess of ₦100,000.

The cheaper cost of production of the experimental prototype of this multi-user prepaid meter has eliminated the issues associated with prepaid meter sharing, such as: it works as if users were on separate meters, so it is not concerned with other neighbors' loads; users are free from estimated bills; it encourages begetting and management of energy at users' convenience; it resolves conflicts that may arise among commercial resident occupants; it is portable and cost-effective; it eliminates the problem of one user consuming the other's power units and reduces the risk of non-payment.

Figure 7: Controller Unit on PCB

Figure 8: Multi-users credit unit

Figure 9: The Multi-user Prepaid Meter Complete Project with Casing

CONCLUSION

The advantage of prepaid metering over postpaid metering has paved the way for consumer convenience, as the major issue associated with postpaid metering and billings has been resolved. However, traditional prepaid meters have not proven to be the ultimate solution to the problems that consumers frequently face. Given the number of studies and research on prepaid metering to mitigate its drawbacks, a major flaw in the studies has been identified. This study suggests a solution to the disadvantages of a shared prepaid metering system. It emphasizes the need for a special multi-user prepaid meter that allows commercial residents to use the prepaid meter independently without the resentful feelings that often occur when the conventional prepaid meter is shared. Its testing and viability demonstrate that there is no limit. A prototype of the proposed multi-user prepaid meter has been constructed and ascertained to be feasible. It could be developed and mass produced for the real-life situation.

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