Jurnal ELTIKOM :
Jurnal Teknik Elektro, Teknologi Informasi dan Komputer

Vol. 4, No. 2, Desember 2020, hal. 105-120
ISSN 2598-3245 (Print), ISSN 2598-3288 (Online)
DOI: http://doi.org/10.31961/eltikom.v4i2.205
Available online at http://eltikom.poliban.ac.id

PREPAID RFID-BASED ELECTRICITY PAYMENT SYSTEM FOR ROOMING HOUSES

Erwin Sitompul, Khoerrudin Syirli
Study Program of Electrical Engineering, Faculty of Engineering, President University, Bekasi, Indonesia
e-mail: sitompul@president.ac.id, khoerrudinsty@gmail.com

Received: May 25, 2020 – Revised: July 14, 2020 – Accepted: July 14, 2020

ABSTRACT

A prepaid RFID-based electricity payment system is proposed in this paper. The system is intended for rooming houses where residents' electricity overconsumption and outstanding payment are to be avoided by the house owner. An RFID-card is used as the payment instrument. The system features accuracy of electricity usage measurement and simple top-up mechanism, while giving options regarding the top-up amount and allocation of power limit to each room. The system consists of two units, the card balance top-up unit (CTU) and the energy credit top-up unit (ETU). The balance of the RFID-card is topped up by using the CTU. With the balance stored in it, the RFID-card is to be used to top-up the energy credit at the ETU. Each of the CTU and the ETU is equipped with a microcontroller, an RFID reader/writer and a user interface in the form of keypad and liquid crystal display (LCD). Furthermore, the ETU utilizes a relay to control the flow of electricity. If the energy credit of a room is exhausted, then the supply of electricity to the room is cut off by the relay. The electricity consumption is calculated based on the number of pulses of the calibration LED of a standardized electronic energy meter. The pulse is transmitted to the microcontroller by using an optocoupler. The RFID-card records the current card balance, the card's top-up history, and the card's usage history. The energy credit is stored in the EEPROM of the ETU's microcontroller. The energy meter is tested to measure the energy consumption of two loads based on the pulses of its calibration LED. The power consumption of the two loads are 87.25 % and 94.23 % of the corresponding power rating. The card balance top-up process at the CTU and the energy credit top-up process at the ETU are successfully checked. After every balance top-up and credit top-up, the current card balance is calculated and stored correctly. During the electricity usage, the LCD of the ETU shows the remaining energy credit in IDR and kWh. These are accumulatively reduced every time the pulse count reaches a certain reset number, which corresponds to the electrical energy's unit price applied. The proposed electricity payment system can be a solution for owners of rooming houses to secure electricity payments from the residents. The installation cost of the system is low and without the need to change the existing electricity purchase method of the house. The house owner also can individually adjust the maximum power limit for each room.

Keywords*: EEPROM, prepaid electricity, RFID, rooming house*.

ABSTRAK

Suatu sistem pembayaran listrik prabayar berbasis RFID diajukan dalam tulisan ini. Sistem ini ditujukan untuk rumah-rumah kos, dimana pemilik rumah berkepentingan agar penyewa kamar tidak menggunakan listrik secara berlebihan atau menunggak pembayaran tagihan listrik. Kartu RFID dipergunakan sebagai instrumen pembayaran. Sistem ini menawarkan akurasi tinggi dalam pengukuran penggunaan listrik dan mekanisme isi ulang yang sederhana, selain juga memberikan pilihan dalam jumlah saldo isi ulang dan dalam alokasi batas daya pada tiap kamar. Sistem ini terdiri dari dua unit, yaitu unit isi ulang saldo kartu (UIK) dan unit isi ulang kredit energi (UIE). Saldo kartu RFID diisi dengan menggunakan UIK. Dengan saldo tersebut, kartu RFID dipergunakan untuk mengisi ulang kredit energi di UIE. Masing-masing UIK dan UIE dilengkapi dengan mikrokontroler, pembaca/penulis RFID, dan antarmuka pengguna dalam bentuk papan tombol dan layar LCD (liquid crystal display). Selanjutnya, UIE menggunakan relay untuk mengontrol aliran listrik. Jika kredit energi suatu kamar habis, maka relay akan memutuskan pasokan listrik ke kamar tersebut. Konsumsi listrik dihitung berdasarkan jumlah impuls LED kalibrasi dari suatu meteran listrik elektronik terstandar. Impuls ini ditransmisikan ke mikrokontroler dengan menggunakan optocoupler. Kartu RFID memuat catatan saldo terkini, riwayat pengisian, dan riwayat penggunaan. Kredit energi disimpan pada EEPROM mikrokontroler UIE. Meteran listrik diuji coba untuk mengukur konsumsi energi dari dua beban berdasarkan impuls LED kalibrasi. Persentase konsumsi daya dari kedua beban tersebut adalah 87,25% dan 94,23% dari daya tertulis. Proses isi ulang saldo *kartu di UIK dan proses isi ulang kredit energi di UIE berhasil diujicoba dengan sukses. Setiap proses penambahan saldo atau penambahan kredit diikuti dengan penghitugan saldo kartu terkini dan penyimpanan secara benar. Selama listrik digunakan, layar LCD dari UIE menunjukkan sisa kredit energi dalam IDR (Rupiah) dan kWh. Nilai-nilai ini berkurang secara akumulatif setiap kali jumlah implus yang dideteksi mencapai suatu angka reset, yang berkaitan dengan satuan harga energi listrik yang diberlakukan. Sistem pembayaran listrik ini dapat menjadi solusi bagi pemilik rumah kos untuk memastikan perolehan pembayaran listrik dari penyewa kamar. Biaya pemasangan sistem terhitung rendah dan tidak perlu mengubah moda pembelian listrik yang telah ada di rumah tersebut. Pemilik rumah juga dapat secara khusus mengatur batas daya maksimum untuk tiap-tiap kamar.*

Kata Kunci*: EEPROM, listrik prabayar, RFID, rumah kos.*

I. INTRODUCTION

ELECTRICITY customers in Indonesia are given possibility to conveniently choose whether to pay their electricity expense prepaid or postpaid. Each of the payment methods has its own advantages and disadvantages. By having prepaid electricity, a customer pays the electricity before it is consumed. The customer is always in check regarding his electricity expense. There is no payment deadline to follow, and thus no risk to pay late fine or to get the electricity line shut off. Nevertheless, the burden is for the customer to maintain the electricity credit. There may come a situation when the credit is exhausted at an improper time, where the possibility to immediately replenish the credit does not exist. In this case, the customer must pass some time in his premise without any supply of electricity. On the other hand, postpaid electricity allows a customer to get an uninterrupted electricity, but with the risk of having an unpredicted increase of electricity expense. Furthermore, the burden is for the customer to set the bills on schedule.

Indonesia's state-owned electricity company, Perusahaan Listrik Negara (PLN) launched the prepaid electricity in 2008 [1]. According to PLN's Annual Report 2015, the share of costumers using prepaid electricity in that particular year was 36.3 % of the total 61.2 million customers [2]. From 2019, with the costumers increasing to 75.7 million, until now, this share increases continuously, as the prepaid electricity also becomes an effective instrument for the government to give subsidy to households entitled to it [3][4].

The cost per unit energy between the postpaid and the prepaid electricity is indeed not exactly the same, but the difference is negligible to become the motive to migrate from one payment method to the other. The main reason for a customer to prefer a method is how he gives weight to the advantages and the disadvantages related to the method. For a rooming house, where one or more rooms in a house are available to rent, the prepaid electricity is more suitable. The prepaid method will avoid outstanding payments of the residents' electricity bills, since the residents are required to buy electricity before they use it.

At the meantime, the use of RFID in automatic identification procedure comes to prominence in recent years. RFID finds increasing applications in areas such as service, purchasing, distribution, and manufacturing. In [5], RFID-card is used to record the usage time of manufacturing machines, for accurate production cost calculation and better machine maintenance scheduling The automatic identification provides information about people, animal, goods, product, and even money in transit [6]. RFID systems are now beginning to conquer the market, in Indonesia with the example of contactless smart cards for cashless payment in public transportation and toll roads.

In this paper, a prepaid electricity payment system for rooming houses by using RFID-cards as payment instrument is proposed by the author. The measurement of energy usage is expected to be accurate and the system should eliminate the problem of outstanding electricity bill payments. Previous related work can be found in [7], where a credit monitoring and tamper warning system for energy meter is proposed. The emphasis is on the user's early notification via text messages. [8] proposed an RFID-based prepaid power meter, but the power is measured by using a microcontroller instead of a standardized energy meter. Besides, the balance of the RFID-cards is fixed and must be used completely at once. A similar approach by using a smart card is presented in [9], with also using a provisional energy meter made from a microcontroller. No clear implementation can be found regarding how to add and

Figure 1. Arduino Uno board

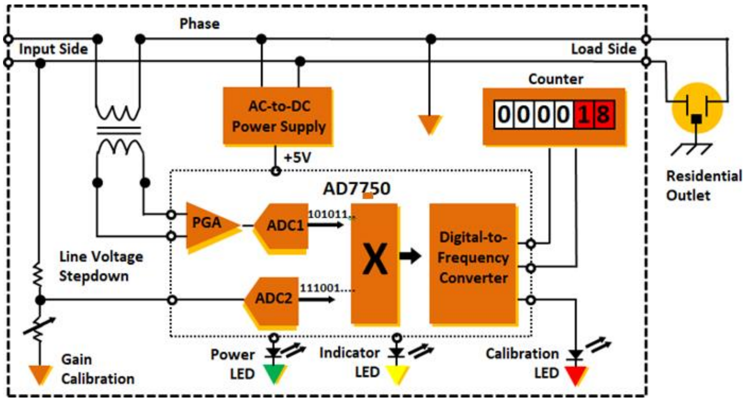


Figure 2. Functional block diagram of a single-phase power meter using AD7750 [15].

(a) (b)
Figure 3. Electronic energy meter produced by PT. Smart Meter Indonesia [17];
(a) SMI 200S; (b) SMI 800

deduct the smart card's balance.

In the proposed system presented in this paper, several issues will be addressed and solved, thus differentiating the proposed system from the existing works. The accuracy of electricity usage measurement will be guaranteed by the use of a standardized energy meter and error-free data transmission. The mechanism of how the card balance is added or deducted will be addressed thoroughly. Furthermore, a number of options regarding the top-up amount will be provided. Additionally, it will be possible to assign a certain maximum power to every room in the house. The house owner becomes the sole customer to an electricity company, to whom he pays his electricity bill directly. The residents buy the electricity from the house owner. The house owner uses a card balance top-up unit (CTU) to store the resident's payment in an RFID-card. Later, the resident uses this card to top-up the energy credit at a standardized electronic energy credit top-up unit (ETU), located in the resident's room. Thus, RFID reader/writer is required at both CTU and ETU. The energy credit will be deducted in proportion to the use of electrical energy, which can be known from the number of pulses that occur to a calibration LED of the energy meter. If the credit at a certain room is exhausted, the electricity to the room will be shut off. Even though the proposed system requires a standardized energy meter in each room, the installation cost is low. The maximum power for each room can be determined and adjusted by the house owner, since the whole electricity circuit inside the house is under his authority.

II. Research Method

A. Arduino Uno Microcontroller

Arduino Uno, as shown in Figure 1, is a microcontroller board based on the ATmega328 chip [10]. Arduino Uno has EEPROM (Electrically Erasable Programmable Read-Only Memory) with the size of 1 kB (kilobyte). This memory can be used to store data, which will be securely kept although the microcontroller is reset or turned off. The EEPROM of the Arduino is divided into 16 sectors, and one sector is again divided into 4 blocks. Each block can contain 16 bytes of information. One byte is a group of 8 bits, equivalent to 2 digits of hexadecimal number. Password can be assigned to each block in order to prevent any unauthorized data reading.

With its 14 digital-input/output pins and its wide-ranged compatibility, the Arduino Uno microcontroller fulfills the requirement to regulate all the processes at the CTU and the ETU.

B. Energy Meter

Energy meter is a device used to measure the amount of electric power consumed by domestic or industrial electric loads. The basic unit of electric power is watts (W), which is voltage (V) multiplied by current (I). The energy consumption equals power multiplied by time. The common unit used to calculate energy consumption is kilowatt hour (kWh). Based on the measured instantaneous voltage and current, an energy meter calculates the product of both. This yields instantaneous power. The energy utilized over a period is the integration result of this instantaneous power.

Based on the technology used, the energy meter is classified into *electromechanical induction* and *static electronic* [11]. The electromechanical induction energy meter, the one belongs to the old generation, consists of a rotating disc, mounted on a spindle between two electro magnets. The disc rotates with the speed proportional to the consumed power. The number of rotations is summed up by a set of counter mechanism and gear trains. Finally, the result is shown on a mechanical counter. The static electronic energy meter, the one belongs to the newer generation, uses analog-to-digital converters (ADC) to convert the analog value of voltage and current into digital form. The accuracy of this conversion has been improved in the course of time, with feature increase in effective noise-free bits and sign al bandwidth [12][13]. Then, the product of the two quantities is calculated and incremented over a time by an integrated circuit (IC). Eventually, the result is fed into a frequency converter that delivers pulses with a frequency proportional to the consumed power. The pulses drive a counter mechanism which can be analog or digital. In analog form, the result is displayed on a mechanical counter, while in digital form, the result is displayed on a liquid-crystal display (LCD).

Figure 2 shows an exemplary block diagram of a static electronic energy meter. The energy meter uses the IC AD7750, a member of AD77XX family, in a typical application to measure a single-phase real power [14]. In this case, a programmable gain amplifier (PGA) is used to support the ADC for current's stepped-down measurement. Three indicator LEDs are installed in the circuit. The green LED indicates power availability. The yellow LED indicates tampering, *i.e.* any action that causes damage or unauthorized alteration of the energy calculation. The red LED indicates the power consumption as it pulses for a certain amount of times for every 1 kWh. The red LED becomes instrumental in the proposed system, since it can be used as a calibrated measure of energy consumption. From this point onward, the red LED of the power meter will be referred to as the calibration LED.

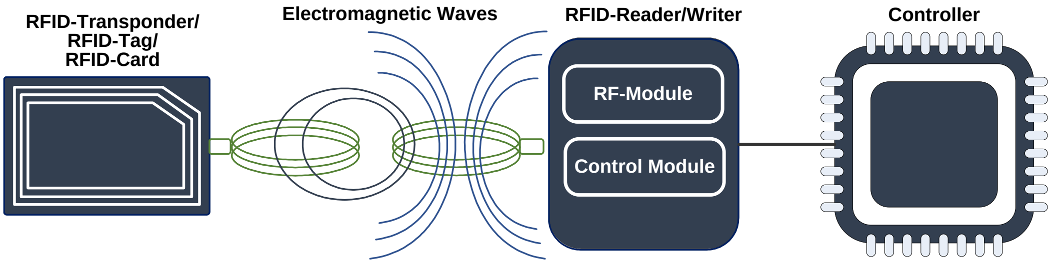
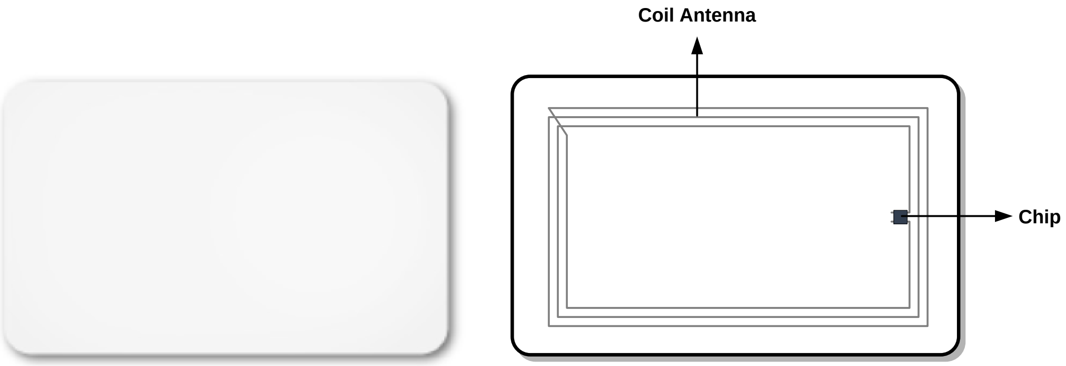


Figure 4. Basic components of an RFID system



(a) (b)

Figure 5. The RFID-card;
(a) The blank card; (b) The transponder inlays within the card

Figure 6. RFID MFRC522

PT. Smart Meter Indonesia (SMI), as the first domestic manufacturer of electronic energy meters, is becoming one trustworthy partner of PLN. Currently, the company offers a line of products, two of which are shown in Figure 3. Both the SMI 200S and the SMI 800 are actually electronic energy meters. The SMI 200S uses an analog display in the form of a mechanical register, while the SMI 800 a digital display in the form of an LCD. Each type of energy meter has 3 LED indicators, with the functions as explained before. The SMI 200S is acknowledged by PLN to follow the PLN Standard for single-phase active static energy meter [16]. This research utilizes the SMI 200S in integration with the ETU, which is installed in a resident's room. The calibration LED of the SMI 200S pulses for 3,200 times/kWh. This information will be transmitted by an optocoupler to the microcontroller of the ETU.

C. RFID Reader/Writer MFRC522

RFID system is an identification system using wireless communication. The communication is established via radio electromagnetic wave between a data-carrying device (transponder) and a reader/writer. The input received by the reader/writer from the transponder is processed by a controller. If the process requires, the controller can also store new data into the memory of the transponder. [18]. Figure 4 shows the basic components of an RFID system.

An RFID-reader/writer consists of a radio frequency module, a control unit, and a coil antenna that generates radio electromagnetic wave. The controller can be a host computer, realized with a microprocessor or a microcontroller. The last component, the RFID-transponder, is made of two elements, an integrated circuit (chip) and a coil antenna. The transponder inlay, in the form of thin etched filament, can easily be inserted to other objects. Therefrom, the terms such as RFID-tag or RFID-card are derived.

Figure 5(a) shows a blank RFID-card. Inside the card, the transponder inlay can be found, consisting of the coil antenna and the chip. Based on the application, the chip can have memory up to 128 kilobytes [18].

In a reading process, the RFID-reader/writer emits the wave to activate the RFID-tag. This responds by sending back the data stored in the chip memory to the RFID reader/writer [6].

The MFRC522, as depicted in Figure 6, is an RFID-reader/writer that performs contactless RFID communication at 13.56 MHz [19]. It is capable to push the antenna designed to communicate with a standard RFID-transponder within a 50-mm range without additional active circuitry. This RFID-reader/writer is to be used with the compatible MF1ICS50 RFID-card [20]. The MF1ICS50 has 1 kB memory, organized in 16 sectors with 4 blocks of 16 bytes each. The same as the EEPROM of Arduino Uno, it is possible to set a user-defined access conditions for each memory block of the RFID-card.

Before any operation to the RFID-card's memory can be carried out, the card has to be authenticated. The authentication consists of several measures such as mutual challenge, response authentication, data ciphering, and message authentication. An access to a memory block requires one correct key, chosen from two available keys specified for the particular block. The unique identifier (UID) of the card's chip is used as the base of the security measure, which can limit only selected cards to access a certain system [20].

D. 4N35 Optocoupler

The pulse of the power meter's calibration LED is to be transmitted to the microcontroller, since it represents the power consumption. One way to do it is by using a light dependent resistor (LDR), put close to the LED. Every blink of the LED will be detected by the LDR circuit. Then, the signal is passed through to the microcontroller. Instead in the proposed system, in order to avoid disturbance from ambient light while avoiding additional load to the energy meter, an optocoupler is used. By using an optocoupler, the energy meter circuit, in this case the calibration LED, and the microcontroller circuit are electrically separated [21]. They are interconnected only by means of light sensitive optical interface.

4N35 Optocoupler, as shown in Figure 7, is utilized to transmit the pulse information from the energy meter to the microcontroller. The input of the calibration LED is connected to the input of the optocoupler (pins 1 and 2), which is an infrared LED. On the other side, the output of the optocoupler (pins 4 and 5), which is a phototransistor, is connected to the microcontroller.

Current flows to the infrared LED every time the pulse of the calibration LED comes. The infrared beam switches on the phototransistor. Then, current will flow through the phototransistor, to reach the microcontroller. The microcontroller detects this digital signal and count it. In addition, the sensitivity of the optocoupler is stabilized by using an external resistor, so that the information transmission can be resistant to any electrical noise or spikes.

E. Block Diagrams

As already mentioned earlier, the prepaid electricity payment system consists of two parts, the CTU and the ETU. The block diagram of the CTU can be seen in Figure 8, while that of the ETU is shown in Figure 9. The blue line shows the flow of information or data, while the red line indicates the flow of power only.

Each unit has one Arduino Uno board. The microcontroller is connected to RFID-reader/writer, LCD, keypad, and LED indicators. The colors of the LED indicators are red and green. They are used to show the states of the process running at the CTU and the ETU. The CTU is DC-powered and is operated by a house owner. The ETU is AC-powered and is placed at a resident's room. Furthermore, the ETU is also equipped with an optocoupler and a relay. The optocoupler transmits the pulses of the power meter's calibration LED to the microcontroller. The relay closes or open the connection between the power line

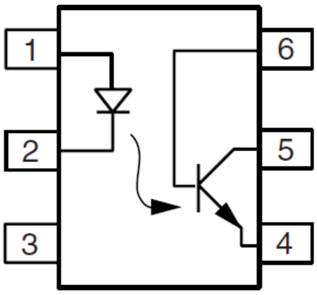


Figure 7. 4N35 Optocoupler and its pinout [22]

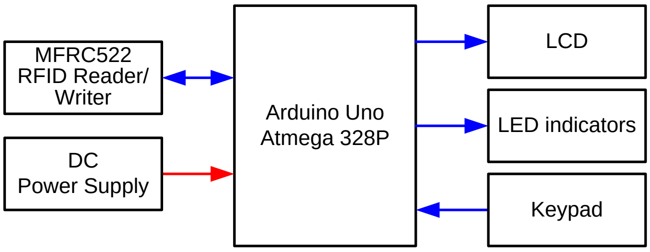


Figure 8. Block diagram of the CTU

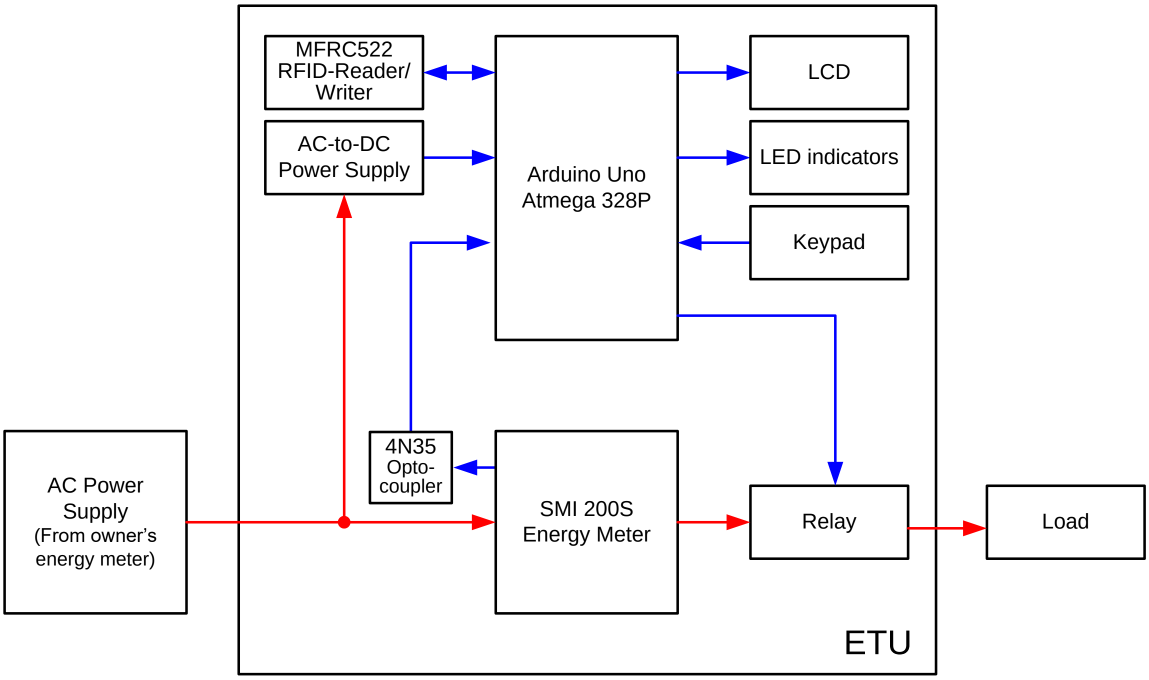


Figure 9. Block diagram of the ETU

and the load, based on the energy credit of the resident. The resident must always keep the energy credit positive. If the credit is exhausted or reaching a minimum value, the electricity is directly shut off.

One possible scheme for the real implementation of the proposed system at a rooming house is shown in Figure 10. The ETUs use standardized energy meters exclusively. The house owner subscribes the electricity from an electricity company, while the room residents buy the electricity from the house owner in prepayment. The purchasing price is set in mutual agreement between the house owner and the room residents. In case of doubt, a comparison of the consumption record between the one displayed at the energy meter's counter and the one stored in the microcontroller's memory can always be done.

While one ETU is to be installed in each room, the scheme does not require the house owner to change his energy meter. He can keep his preferred payment method, either prepaid or postpaid. Besides, the

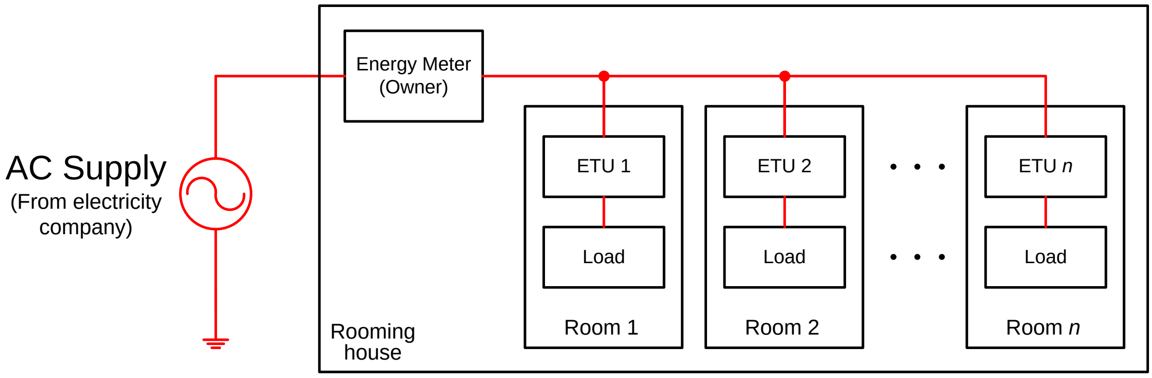


Figure 10. Implementation scheme of the proposed system

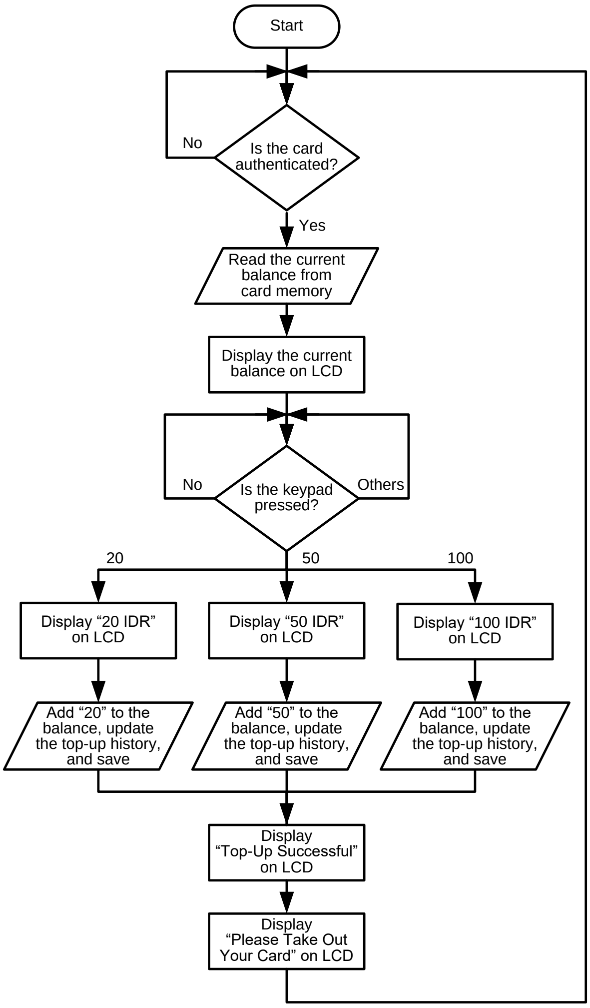


Figure 11. Flowchart of the CTU

house owner can allocate a different maximum electricity power limit for each room, as long as the subscribed total electricity power allows.

F. Software Implementation

The implementation of the software is conducted by using Arduino Integrated Development Environment (IDE), which is compatible with Arduino Uno 328 P. The Arduino IDE is a cross-platform application that is written in functions from C and C++. Two algorithms are devised, each for the CTU and the ETU, based on the flowcharts that will be discussed in the followings.

TABLE 1
MEMORY MANAGEMENT OF THE RFID-CARD

Sector	Block	Notation	Allocation
8	34	A	Current balance
8	33	B	Last top-up amount
8	32	C	Previous last top-up amount, shifted from B
7	30	D	Last usage for energy credit top-up
7	29	E	Previous last usage, shifted from D
7	28	F	Before -previous last usage, shifted from E

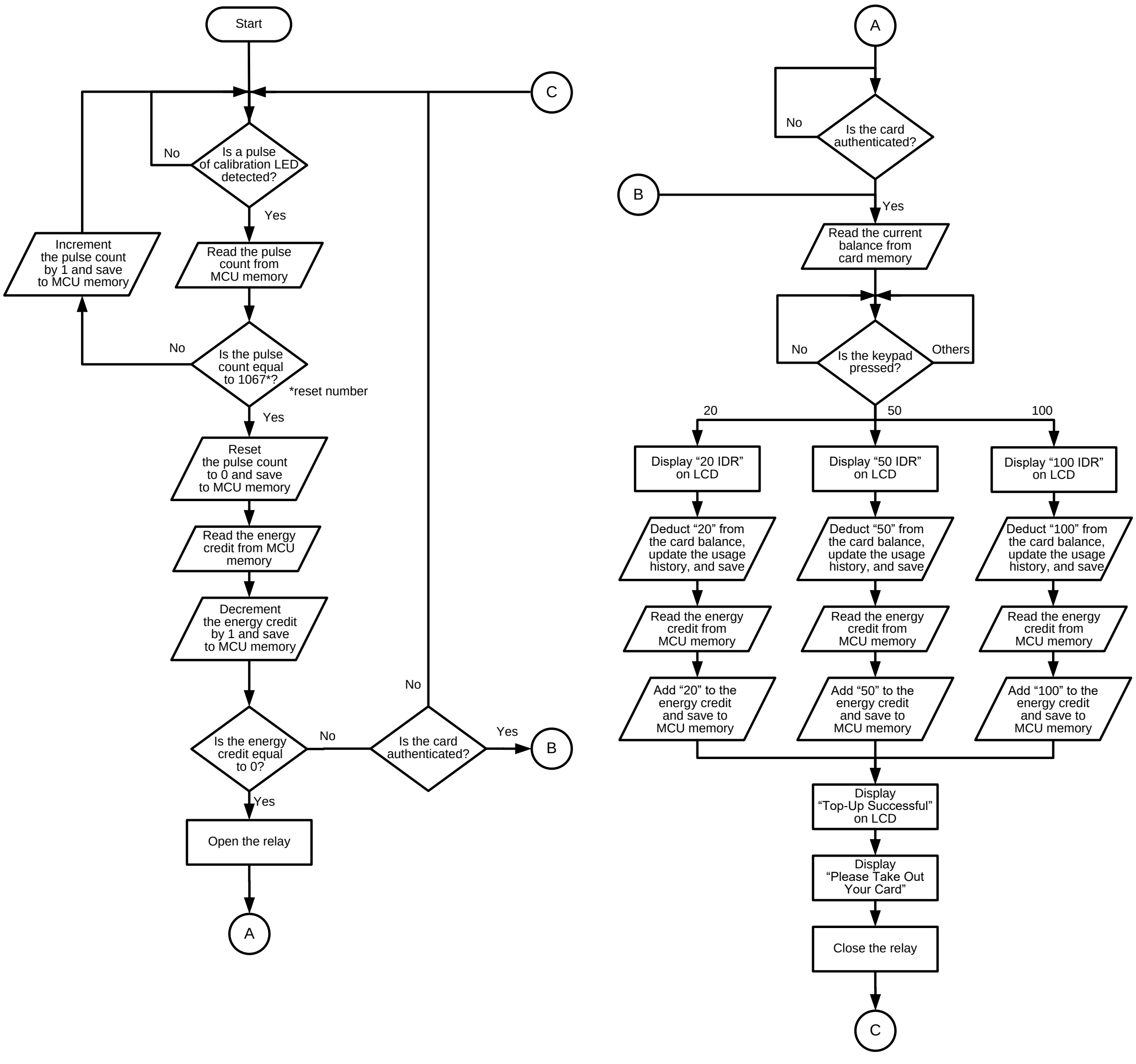


Figure 12. Flowchart of the ETU

The flowchart of the CTU algorithm is presented in Figure 11. If an RFID-card is inserted to the CTU, its authenticity will be first checked. If the card is valid, the memory of the card is read, and the stored card balance is displayed on the LCD. A resident has now the possibility to choose the desired top-up amount among 20,000 IDR, 50,000 IDR, or 100,000 IDR. For the sake of simplicity, from this point onward the amount of card balance and top-up amount will be shortened to the thousands value.

If the keypad is pressed correctly with the number “20”, “50”, or “100”, the selected amount will be added up to the previous card balance, resulting the new card balance. The new card balance and the card’s top-up history are updated and saved to the card’s memory. The new card balance can readily be checked by letting a new cycle start to enable the re-read of the card.

The flowchart of the ETU algorithm is shown in Figure 12. Two main processes are conducted at the

TABLE 2
PULSE DETECTION TEST

Load	Power rating (W)	Number of pulses						Estimation	
		Test, each conducted for 3 minutes					Mean	Pulses/ hour	Power Consumption (W)
		1	2	3	4	5			
Hairdryer	500	70	70	69	71	69	69.8	1,396	436.25
Notebook	65	10	11	9	10	9	9.8	196	61.25

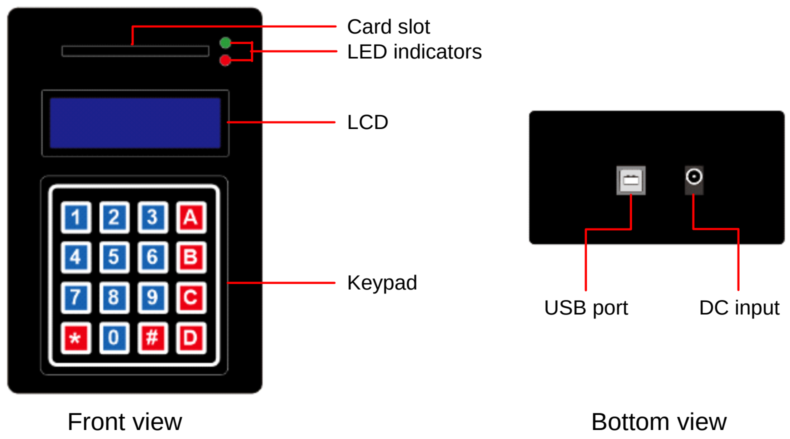


Figure 13. Design of CTU prototype

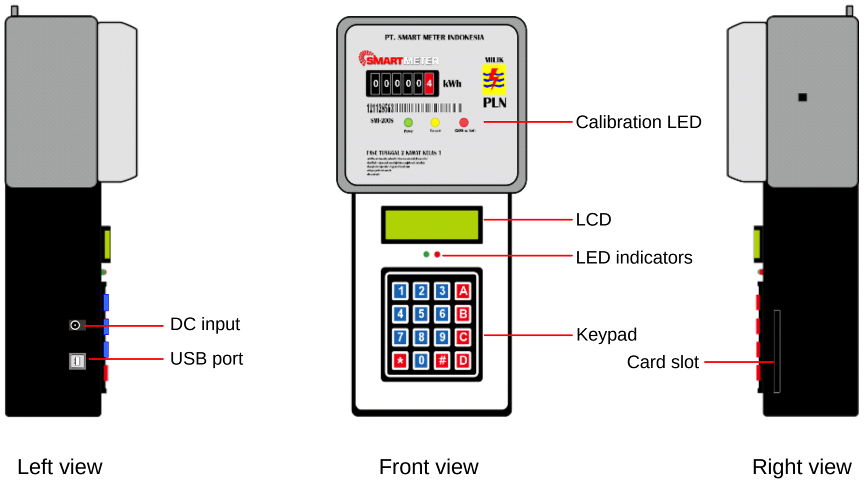


Figure 14. Design of ETU prototype

ETU: *the calibration LED's pulse count* and *the energy credit top-up*. The latest pulse count and the latest energy credit are stored in the memory of Arduino Uno (Microcontroller Unit, MCU). The card's usage history is updated and stored in the card's memory.

In the pulse count process, the pulse count is updated every time a pulse is detected. Thus, the system is completely accurate, it will not miss any pulse count in case of sudden power breakdown. The energy credit is updated every time the price of consumed energy is equal to 1 IDR. In this case, the pulse count also reaches a *reset number*, where the pulse count is reset back to 0.

Let say, the simulated price is 3 IDR for 1 kWh. Since 1 kWh equals 3,200 pulses for the energy meter SMI 200S, a 1 IDR credit will be equivalent to 1/3 of a kWh, or 1,066.7 ≈ 1,067 pulses. This is used as the reset number in the flowchart of the ETU.

In real implementation, any electricity tariff of x IDR (with x in thousand rupiah) for 1 kWh can be converted into a certain reset number. Again, every time the pulse count reaches the reset number, electricity with the cost of 1 IDR is consumed. The pulse count reset number is calculated by the formula

3,200/*x*. As an example, the official base electricity tariff (excluding surcharges) for household customers in mid-2020 is 1.467 IDR [23]. This tariff will be corresponding to a reset number of 2,181.

If the energy credit is equal to 0, then the relay opens the connection to the power line. Only after the energy credit is refilled, the relay will close the connection and the electricity will reach the loads. The pulse count resumes.

In the energy credit top-up process, once the RFID-reader/writer detects an RFID-card, it will be authenticated. If the card is valid, the balance will be read. A resident now can choose whether to top-up the energy credit with the amount of 20 IDR, 50 IDR, or 100 IDR. If the card balance is adequate, the selected amount is processed. This amount is deducted from the card balance and is added to the energy credit. The memory of the card and the memory of the ETU's microcontroller are updated accordingly. The new energy credit is directly shown on the ETU's LCD along with the equivalent electrical energy in kWh.

The memory management of the RFID-card is summarized in Table . The data allocation as listed in the table is stored in hexadecimal number at the first 4 bytes of the corresponding block. This simple way is chosen for the prototyping objective only. Further improvement to include time stamp and data encryption is possible.

G. Prototype Realization

The prototypes of the CTU and the ETU are made in the form of thick plastic boxes. Figure 13 shows the design of the CTU prototype. A card slot is placed above the LCD. An RFID-card is to be inserted in the slot, so that it can be detected by the RFID-reader/writer placed inside the box. One USB port and one DC input connector can be found at the bottom of the box, which belong to the Arduino Uno. Two LED indicators are used to inform the states of the process in CTU. The green LED turns on when a valid RFID-card is authenticated. The red LED turns on when a card is being topped up.

This design of the ETU prototype is presented in Figure 14. The thick plastic box is embedded to the lower part of the SMI 200S energy meter. The card slot is located at the right side of the box, while the USB port and the DC input connector can be found at the left side. Two LED indicators are used to inform the states of the process in ETU. The green LED turns on when the energy credit is available and turns off when exhausted. The red LED turns on when the energy credit is being topped-up. The connections from the ETU to the AC input (from the house owner's energy meter) and to the AC output (to the resident's electricity load) are settled through openings at the bottom side of the box. The power supply for the ETU is taken from the AC input power line, to the burden of the house owner.

H. Prototype Tests

After the prototypes is completely constructed, the prototype of the CTU and the ETU are set to undertake a series of tests.

The first test subject is the energy meter's pulse detection. In this test, the ability of the optocoupler to detect the pulses produced by the energy meter will be observed. Two electrical loads, a hairdryer and a notebook will be connected to the power line and the calibration pulses will be counted both manually by observing the calibration LED of the power meter and automatically by using the optocoupler. The expected success rate for the pulse detection is 100 %, so that the accuracy of the standardized energy meter can be optimally exploited. This first test is by no mean intended to calibrate or measure the accuracy of the SMI 200S power meter. It is a standardized power meter, fulfilling the requirements of a competent certification center of PLN [16].

The second test subject is the top-up process at both the CTU and the ETU. In this test, the functionality of the CTU and the ETU in interaction with the RFID-card and the electricity usage is tested. A top-up scenario is to be applied to the CTU and the ETU. The current balance, the top-up history, and the usage history of the RFID-card will be observed along this test. It is expected that the sequences of balance top-up and balance usage are well recorded in the memory of the RFID-card. Besides, the current credit shown on the ETU's display will also be checked, as it should be updated according to the amount of the top-up. For *the card balance top-up test*, an RFID-card with zero balance is used. Then, the card will be topped up and the change in the card balance and the card balance top-up history are to be observed. For *the energy credit top-up test*, the initial condition is a zero energy credit at the MCU's memory.

The third test subject is the energy credit deduction process. After an energy credit top-up process is completed, the ETU will be operated to serve a hairdryer as a load. The correctness of the energy credit deduction based on the number of counted pulses will be observed and checked. The ETU should be able to count the electricity consumption of the load and deduct the energy credit accordingly.

III. Result and Discussion

A. Test of the Energy Meter's Pulse Detection

The optocoupler, whose input is directly connected to the input of the calibration LED, successfully detects every pulse produced by the energy meter. This 100 % success rate is obtained by choosing the correct sensitivity of the phototransistor. The sensitivity is regulated by connecting the base pin of the optocoupler through a 1 kΩ resistor. Besides, the level of electrical and optical disturbance is very low. The optocoupler is thus proved as a reliable pulse reader. In case of measurement error, as reported in [24], the source is to be searched at the nonlinearity of the transducer. The power rating of the hairdryer is 500 W, while that of the notebook is 65 W. In each test, a load is turned on for 3 minutes as the calibration pulses are counted. The results are presented in Table .

The pulse counts of the ETU via the optocoupler is identical to the author's manual counts by observing the calibration LED of the power meter. From the mean number of pulses for a 3-minute operation, the estimate number of pulses for a 1-hour (*i.e*. 60-minute) operation can be calculated. This is done by multiplying the mean by 20. The estimate power consumption is obtained by dividing the pulses/hour by 3,200, which is the number of pulses equivalent to 1 kWh. Pulse/hour is herewith converted to kWh/hour or kW. Thus, the hairdryer's estimate power consumption is 1396/3200, resulting 0.43625 kW or 436.25 W. For the notebook, 196/3200 = 0.06125 kW = 61.25 W.

Comparing the estimate power consumption and the power rating, one can obtain the value of 87.25 % for the hairdryer and 94.23 % for the notebook. The power consumption is lower than the power rating, which is expected in normal operation. The condition where a load dissipates power higher than its rating must be avoided [25]. Otherwise, it will be overheated and can literally be burned [26].

The difference between the highest and lowest pulse count for both loads is 2 (69 and 71 for the hairdryer, 9 to 11 for the notebook). Considering the higher power rating of the hairdryer, the aforementioned same difference can be inferred from the constant power consumption of the hairdryer, in comparison to the notebook. Although every test takes exactly 3 minutes, the start time of a test also influences the pulse count result. Because the energy usage is also integrated between 2 pulses, it becomes matter whether a pulse just occurred before the test starts or not.

B. Test of the Top-Up Process

Figure 15 shows the initial condition, after the card is inserted to the CTU, for the purpose of the balance top-up. The LCD shows the current balance of 0 IDR. The reading of the card's memory is also shown. Block 34, marked with blue rectangle, shows a "00_{16}" value, which means that the current balance of the card is zero. Block 33, marked with red rectangle, stores a "32_{16}" value or "50_{10}". This means that the last top-up amount of the card is 50 IDR. Furthermore, Block 32, marked with green rectangle, stores a "14_{16}" value, which is "20_{10}" or 20 IDR top-up amount previous to 50 IDR.

Figure 16 shows the final condition, immediately after the card received a top-up in amount of 20 IDR ("14_{16}"). The LCD shows the new current balance of 20 IDR. In the memory of the card, the current balance in Block 34 changes from zero to now "14_{16}". The last top-up amount in Block 33 becomes "14_{16}" which comes from the last top-up that just happened. The previous last top-up amount in Block 32 becomes "32_{16}", which is the previous value of Block 33 before the top-up.

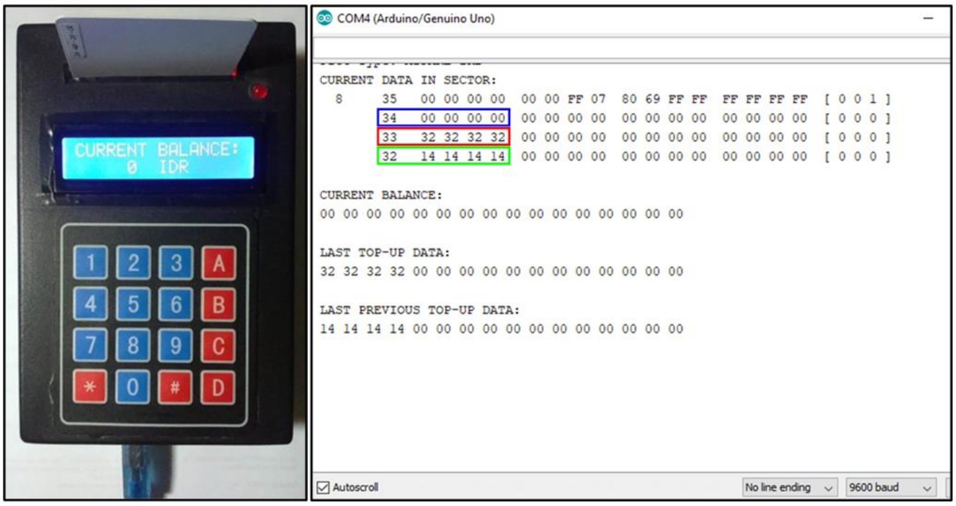


Figure 15. The conditions of the CTU and the RFID-card's memory before the balance top-up

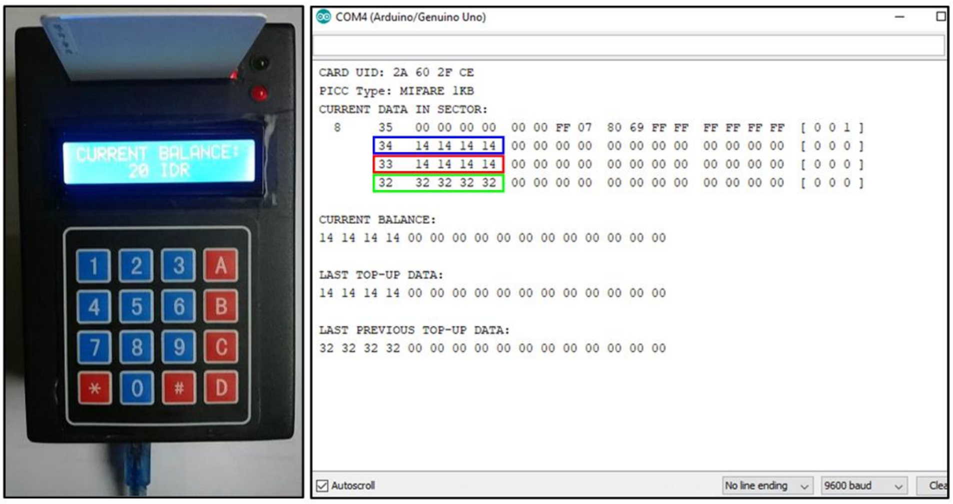


Figure 16. The conditions of the CTU and the RFID-card's memory after the balance top-up

As summary, in every top-up, the data in Block 34 will be updated by adding the current balance with the top-up amount. Then, to update the top-up history, the data from Block 33 is shifted to Block 32, and the top up amount is stored as new data in Block 33. Since the balance is stored in a two-digit hexadecimal number, the maximum balance of a card is therefore limited to 255 IDR.

The condition before the energy credit top-up is shown in Figure 17, where the ETU's LCD shows 0 kWH and 0 IDR. The current card balance can be read from Block 34 (purple rectangle). Thus, the initial balance of the RFID-card is 170 IDR (AA_{16}). The card's usage history can be seen in 3 blocks of Sector 7, which are Block 30 (blue rectangle), 29 (red rectangle), and 28 (green rectangle). It can be deduced that previously the card is used to top-up the ETU with the amounts of 50 IDR (32_{16}), 20 IDR (14_{16}), and 100 IDR (64_{16}), in reverse chronological order.

Now, an energy credit top-up in an amount of 100 IDR (64_{16}) is conducted. Figure 18 shows the conditions when the credit top-up is completed. In this test, the price of 1 kWH is taken to be equal to 3 IDR. Thus, the ETU's LCD shows 33.3 kWh and 100 IDR as the proof that the credit top-up is successful. These values are also stored in the memory of the ETU's microcontroller. The current balance of the card is now only 70 IDR (46_{16}) as can be read from Block 34. The usage history of the card is already updated. The last usage becomes 64_{16} stored in Block 30. The previous value of Block

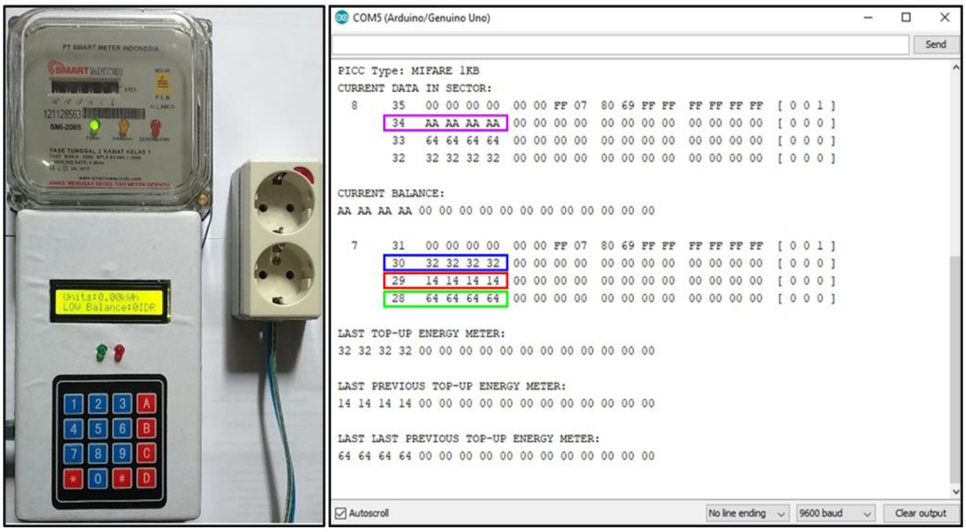


Figure 17. The conditions of the ETU and the RFID-card's memory before the credit top-up

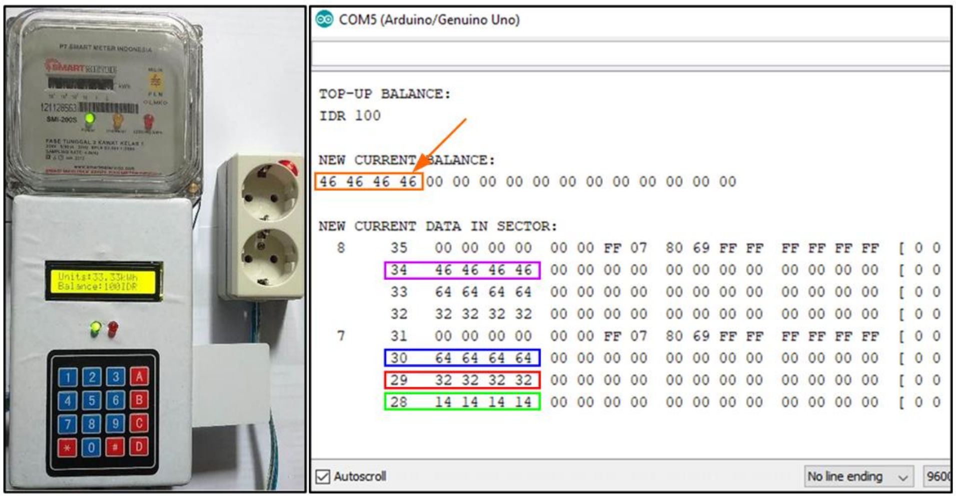
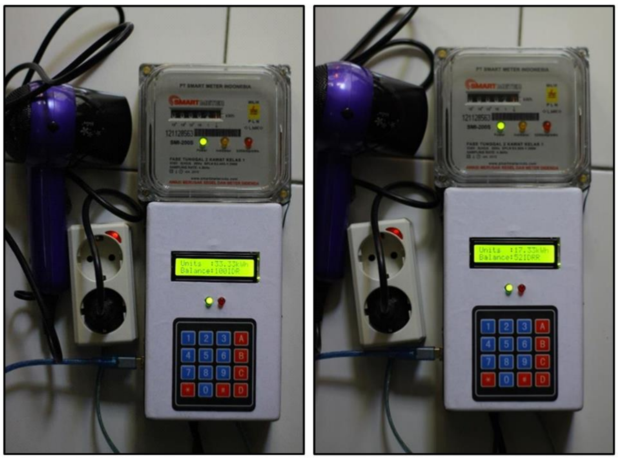


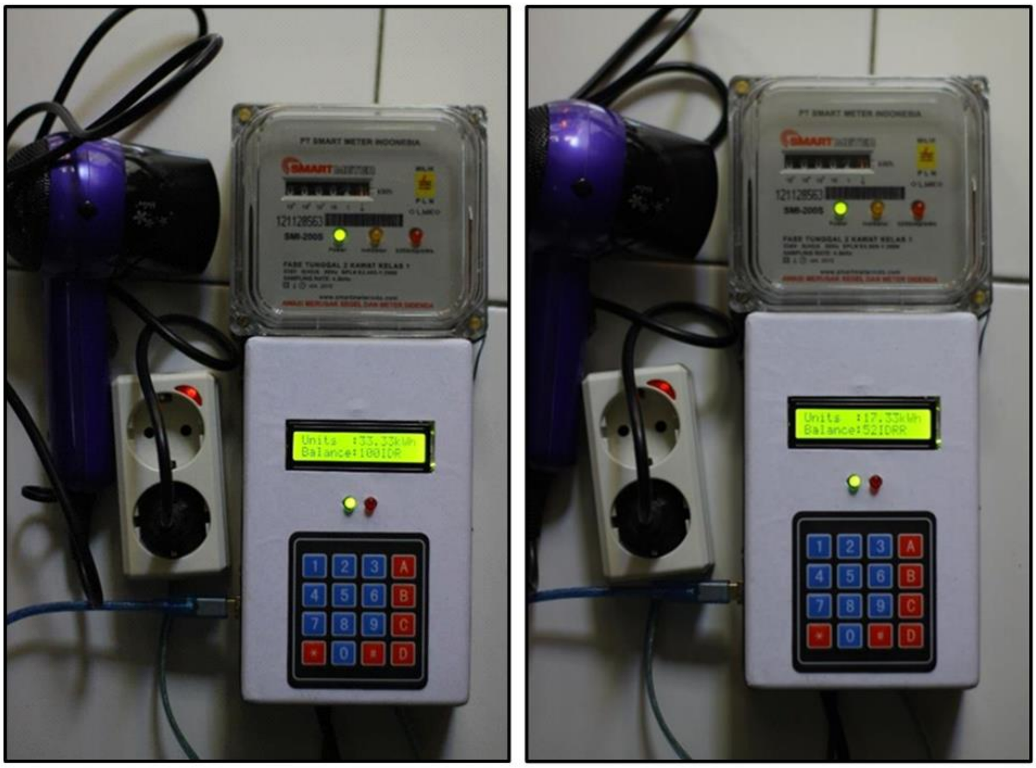
Figure 18. The conditions of the ETU and the RFID-card's memory after the credit top-up



(a) (b)

Figure 19. The operation of ETU and the energy credit deduction,
(a) Initial condition; (b) Final condition

30, which is 32_{16}, is shifted to Block 29. The previous value, which is 14_{16}, is shifted to Block 28.



(a) (b)

Figure 20. The operation of ETU and the energy credit deduction,
(a) Initial condition; (b) Final condition

C. Test of the Energy Credit Deduction Process

At initial condition, the energy credit is 100 IDR, or equivalent to 33.33 kWh. This can be seen in Figure 19(a). In this case, the electricity price is IDR 3 for 1 kWh, corresponding to reset number of 1,067. In this test, however, the reset number is changed to 1 (1 IDR for every 1 pulse), so that the change of energy credit can happen faster. The final condition is presented in Figure 19(b). After an artificial consumption of 48 IDR or 16 kWh, the energy credit left is 52 IDR or 17.33 kWh, as shown on the ETU's LCD.

A closer look to the mechanical register of the SMI 200S in Figure 19(a) and (b) reveals the negligible real energy consumption of the hairdryer. It is far less than 0.1 kWh, since the numbers shown on the register are both 2.1 kWh. The ETU's calculation of the energy consumption can be set back to normal by setting the reset number back to 1,067 to represent the price of 3 IDR/kWh, or any other value as required.

IV. CONCLUSION

An RFID-based payment system for prepaid electricity scheme in rooming houses is proposed in this paper. The house owner purchased the electricity from an electricity company, either prepaid or postpaid, while the room residents buy the electricity in the form of an energy credit to the house owner prepaid. An RFID-card is used to store a balance, as a resident conducts a payment to the house owner. The card balance is later to be used to top-up the energy credit in the resident's room. In case the electricity credit in a certain room is exhausted, the supply to that room is cut off by a relay. A rebuy of the electricity credit is due before the relay closes the power line again. The proposed system frees the house owner from any residents' outstanding electricity bills. The system allows the house owner to keep the house's existing power meter. Besides, flexible power allocation to each room can be done and the required initial installation cost is low.

In the implementation, the system is realized in the form of a card balance top-up unit (CTU) and an energy credit top-up unit (ETU). Every unit is equipped with a microcontroller and an RFID-reader/writer, with both having a 1 kB EEPROM to securely save the card balance, the energy credit, the card's top-up history, and the card's usage history. The CTU is operated by the house owner to top-up the resident's card balance during the payment process. The ETU is used by the resident to monitor and top-up his energy credit. The ETU utilizes a standardized static electronic energy meter that provides a calibration pulse whose counts are related to the energy consumption. This pulse is detected by an optocoupler, which passes it on to a microcontroller. The ETU's microcontroller keeps the record of the count and deducts the energy credit every time the pulse count is equal to a reset number. In this system, the unit price of electricity, in IDR/kWh, can be adjusted flexibly, following the mutual agreement between the house owner and the room resident.

The test result shows that the calibration pulse can be detected with 100 % success rate, identifying two sample electrical loads to consume power equal to 87.25 % and 94.23% of the corresponding power rating. The card balance top-up and the energy credit top-up are conducted successfully. The proposed system is also successfully implemented to measure the electricity usage along with updating the electricity credit by deducting it according to the amount of usage. Improvement of the RFID-card's memory utilization can be done by using more bytes to store the card balance, so that the maximum balance of the card can be higher than currently 255 IDR. Besides, more information regarding card activities can be stored in the memory. Thus, each activity can be identified by the time, the date, and the identity of the CTU or the ETU used. The integration of memory encryption and IoT technology will unleash the full potential of the proposed system.

REFERENCES

[1] Ministry of Energy and Mineral Resources, "PT. PLN Luncurkan Program Listrik Prabayar," 23 January 2008. [Online]. Available: https://www.esdm.go.id. [Accessed 13 May 2020].
[2] Perusahaan Listrik Negara, "2015 Annual Report," 2016. [Online]. Available: https://web.pln.co.id. [Accessed 13 May 2020].
[3] Intan Pratiwi, "2019 PLN Bukukan Kenaikan Penjualan Listrik," *Republika*, 28 January 2017. [Online]. Available: https://republika.co.id. [Accessed 13 May 2020].
[4] Directorate General of Electricity, "Kebijakan Subsidi Listrik Tepat Sasaran Rumah Tangga Daya 900 VA," Ministry of Energy and Mineral Resources of Indonesia, 12 January 2017. [Online]. Available: https://www.esdm.go.id. [Accessed 13 May 2020].
[5] A. K. Yanti and E. Sitompul, "Designing and Prototyping Record System for Machine Usage Time," *Journal of Electrical and Electronics Engineering*, vol. 2, no. 1, pp. 1–6, 2018.
[6] K. Finkenzeller, *Fundamentals and Applications in Contactless Smart Cards, Radio Frequency Identification and Near-Field Communication*, USA: John Wiley & Sons, Third Edition, 2010.
[7] F. Jeneldi, H. Tanudjaja, and Suraidi, "Perancangan dan Realisasi Sistem Monitoring Pulsa Minimum dan Pemberitahuan Kerusakan Pada KWh Meter Prabayar," *TESLA: Jurnal Teknik Elektro*, vol. 20, no. 1, 2019.
[8] R. Teymourzadeh, S. M. Iwan and A. J. A. Abueida, "RFID-based Prepaid Power Meter," 2013 IEEE Student Conference on Research and Developement, Malaysia, 2013.
[9] R. R. A. Siregar, H. Sikumbang, and R. J. Pasaribu, "Model Pengisian Pulsa Listrik Kwh Meter Dengan Smart Card," *JETri Jurnal Ilmiah Teknik Elektro*, vol. 16, no. 1, 2018.
[10] Arduino, *Arduino Uno Data Sheet*. [Online]. Availabe: https://store.arduino.cc. [Accessed 1 October 2019].
[11] F. Toledo, *Smart Metering Handbook*, USA: PennWell Corporation, First Edition, 2010.
[12] A. Belcher, J. Williams, J. Ireland, R. Iuzzolino, M. E. Bierzychudek, R. Dekker, J. Herick, R. Behr, and K. Schaapman, "Towards a Metrology class ADC based on Josephson junction devices," *Journal of Physics: Conference Series*, vol. 1065, p. 052044, 2018.
[13] S. Ashwini, M. S. Sivakumar, and S. J. V. Rani, "Design of linear ramp generator for ADC," 2017 Fourth International Conference on Signal Processing, Communication and Networking (ICSCN), 2017.
[14] Analog Devices, *AD7750 Product-to-Frequency Converter*. [Online]. Availabe: http://www.analog.com. [Accessed 18 May 2020].
[15] P. Daigle, "All-Electronic Power and Energy Meters,"*Analog Dialogue*, vol. 33, no. 2, February 1999.
[16] Perusahaan Listrik Negara, "SPLN D3.005-1:2008 Standar PLN untuk Meter Statik Energi Aktif Fase Tunggal Kelas 1,0," 16 June 2018. [Online]. Available: https://www.coursehero.com. [Accessed 21 May 2020].
[17] Smart Meter Indonesia,"kWH Meter Elektronik," PT. Smart Meter Indonesia. [Online]. Available: https://www.smartmeterindo.com. [Accessed 18 May 2020].
[18] V. D. Hunt, A. Puglia, and M. Puglia, *RFID – A Guide to Radio Frequency Identification*, New York: J. Wiley & Sons, 2007.
[19] NXP Semiconductors N.V., *MFRC522 Data Sheet*, 27 April 2016. [Online]. Available: https://www.nxp.com. [Accessed 1 July 2019].
[20] NXP B.V., *MF1ICS50 Product Data Sheet*, 29 January 2008. [Online]. Available: https://www.nxp.com. [Accessed 1 August, 2019].
[21] Z. Jun, Y. X. Fei, L. M. Lin, and S. Hailin, "Research on LTCC - based Flat Optocoupler Assembly Technology," 19th International Conference on Electronic Packaging Technology (ICEPT), 2018.
[22] Vishay Semiconductors, *4N35 Optocoupler, Phototransistor Output, with Base Connection*, 1 January 2019. [Online]. Available: https://www.vishay.com. [Accessed 1 July 2019].
[23] Perusahaan Listrik Negara, "Aturan tentang Tarif Tenaga Listrik," 2016. [Online]. Available: https://web.pln.co.id. [Accessed 22 May 2020].
[24] D. Suryadi, S. A. Ayufhi, A. F. Suryono, and M. Maimuzar, "Pembuatan Alat Ukur Kecepatan Angin Optocoupler dengan SMS Berbasis Mikrokontroler," *Rotasi*, vol. 21, no. 3, p. 187, 2019.
[25] B. Arto, B. Winarno, and N. A. Hidayatullah, "Rancang Bangun Smart Plug Untuk Sistem Monitoring Dan Proteksi Hubungsingkat Listrik," *Jurnal ELTIKOM*, vol. 3, no. 2, pp. 77–84, 2019.
[26] G. Rizzoni, *Fundamentals of Electrical Engineering*. New York: McGraw-Hill Higher Education, 2009.