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Mobile prepayment system for off-grid solar power plant

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Abstract

Since the 20th century, a smart grid is one of the global trends in energy sector. Through a smart meter which is an essential ingredient of smart grids, the billing system can be applied in the grid. However, most of the commercial billing systems and researches related to smart grids are confined to developed countries where there are sufficient infrastructure and economic support. In this study, the prepayment system for off−grid solar power plant installed in developing countries through mobile banking platform and vouchers is suggested. This system could be applied even in rural area of developing countries with no external network or any other infrastructure. The local database and local network are constructed to build up an independent system in the targeted village. In addition, this study not only presented new concepts, but also practically implemented the system in the Ngurdoto village of Tanzania for 3 months. To implement the system, 250 TZS/kWh was set as the energy price, comparing with energy price of TANESCO (Tanzania Electric Supply Company Limited). Since the introduction of the prepayment system in the off−grid, the payment status has stabilized compared to the application period of the manual billing system.

Keyword: Off−grid system, Micro grid, Prepayment system, Billing system, Electric charging system

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Chapter 1. Introduction

1.1. Study background

Most countries around the world have access to electricity. In Korea, people can use electricity even in rural areas. However, there are still people who are living without electricity in Sub-Saharan Africa and South Asia [1]. Until 2020, more than 500 million people in Africa cannot get access to electricity, especially in rural areas [2]. However, electricity is essential because it leads to mechanization of daily life and increasing the economic level of people [3]. If it is not available to supply electricity from main power grid (grid-extension) due to environmental or economic reasons, an off-grid system could be a good alternative for supplying energy [4]. Therefore, many countries and organizations such as NGOs have actively implemented the off-grid systems in rural areas of Africa.

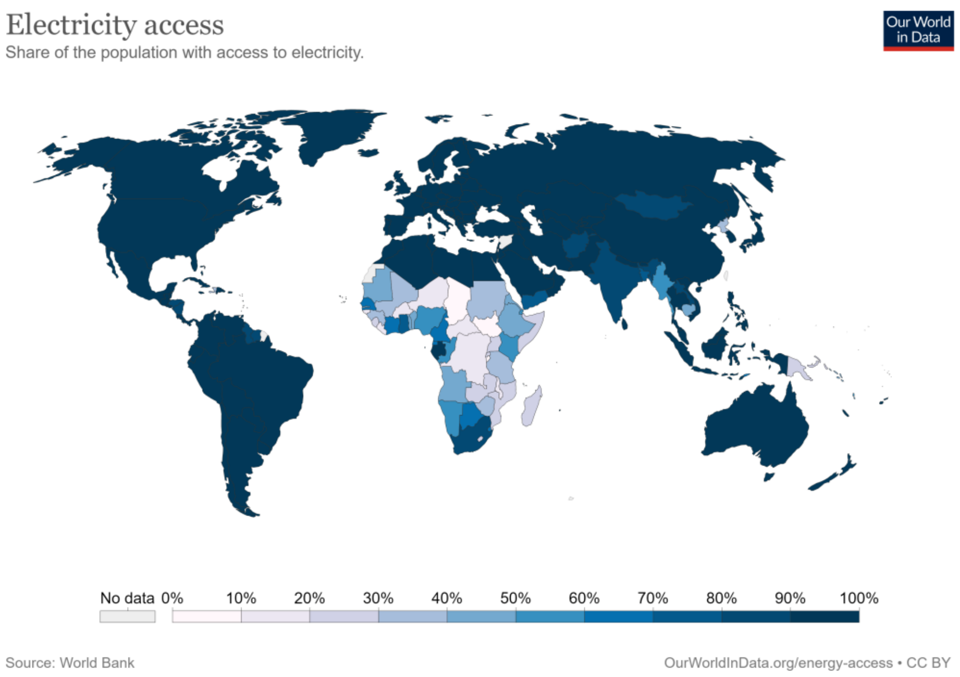

Figure 1. Electricity access in the world (2016) [5]

Along with this trend, one of the global trends in energy sector is a smart grid [6]. Unlike traditional grids, smart grids include two-way communication systems in meters for transmission of the data related to energy. As ICT development progresses, various information of the consumers and the grids could be digitalized and the grids could be remotely controlled to optimize the performance of the generation or transmission system. With smart grid systems, grids can monitor and self-heal themselves, and operation companies managing the grids can apply billing systems for users of grids.

The most basic component of the smart grid is a smart meter. The device, called a smart meter or an advanced metering infrastructure, monitors electricity usages of consumers and transmits data of energy consumptions to data collection units, and receives signals to operate power controlling systems [7]. Through these devices, it is possible not only to apply billing systems for consumers into off-grids, but also to identify consumers' energy usage behaviors [8].

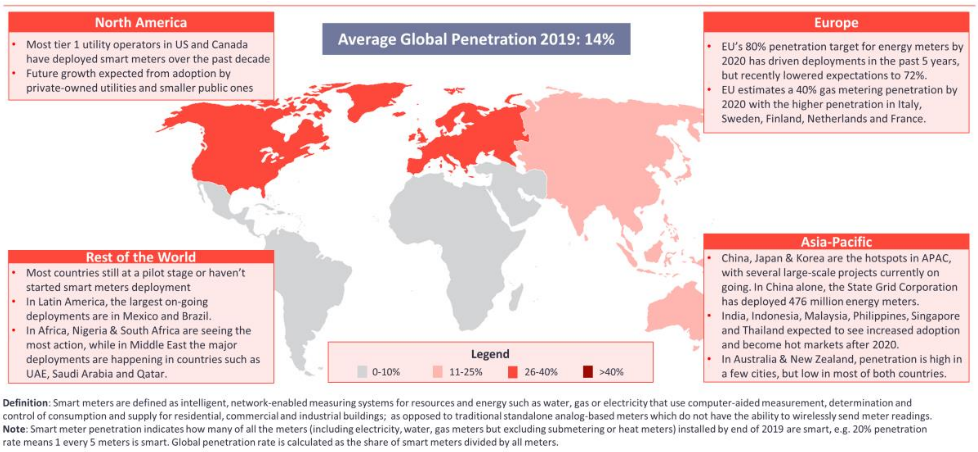

Figure 2. Global smart meter penetration by region in 2019 [9]

1.2. Purpose of research

The functions of smart grids have many advantages and are being utilized in many researches and industries. However, the use of smart grids or smart meters developed to date is limited to specific conditions which have sufficient infrastructures, such as developed countries [10−12]. However, many off−grid plants, not grid−extensions, have been already installed in remote and rural areas of developing countries with environmental or economic problems, and few cases of the above−mentioned smart grid technologies were applied in the off−grids. Because most of the developing countries have insufficient network infrastructures or economic difficulties, it is difficult to implement the smart meters which need networks for communication with a database or a control center. The PowerGen constructed smart grid and payment system for microgrids in small villages of Kenya, but these grids did not have local networks, so that all meters must be installed in one spot (in distribution cabinet). Therefore, its scalability is limited [13].

Smart billing system is an electric charging system for the smart grid. It lets consumers know how much they used electricity and how much they have to pay, using data of smart meters. The billing systems have been installed in smart grids or smart buildings which already possess smart meters. This system automatically operates with little help or control of man. However, for existing off−grid power plants, it is common to use manual billing systems rather than smart billing systems. In the manual billing system, the power plant managers have to visit each household by foot, read the data of the energy consumptions from the meters, set electricity bills on the manual, and receive money from the customers. However, this approach is difficult to maintain for a long time unless external cooperator managements. These situations were observed in the off−grid solar plants installed in rural area of Tanzania by Innovative Design and Integrated Manufacturing laboratory (IDIM) of Seoul National University (SNU) and Innovative Technology and

Energy Center (ITEC). They have constructed three solar power plants to supply electricity to more than 500 people in Tanzania since 2017. In three solar plants, the manual billing and payment systems were applied. One manager was hired for each plant, and they had to visit the households in person to collect electric charges every month. However, one year after applying the manual systems in the grids, the villagers paid anymore and the managers did not administer the solar plants.

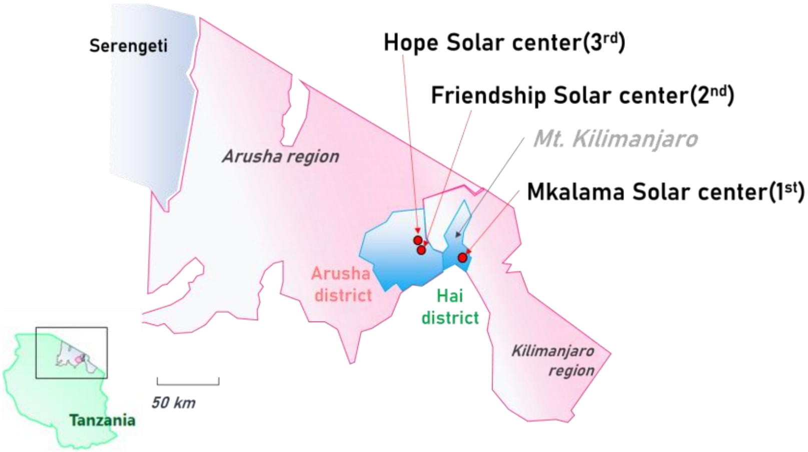

Figure 3. Solar power plants installed by IDIM and ITEC

	(a) Mkalama solar center (1st) Capacity: 9.6 kWp Beneficiary households: 46 Year of construction: 2018
	(b) Friendship solar center (2nd) Capacity: 6.7 kWp Beneficiary households: 42 Year of construction: 2019
	(c) Hope solar center (3rd) Capacity: 6.7 kWp Beneficiary households: 37 Year of construction: 2019

Figure 4. List of ITEC solar power centers

To solve this problem, IDIM develops the automatic smart monitoring system and payment system for the off−grid solar power plants, one of developing countries in Sub−Saharan region. The sites where the developed systems are installed have no sufficient infrastructures such as networks and transports. Additionally, the villagers of the sites have a poor education level.

In this paper, the methodology of the smart monitoring and payment system will be demonstrated and the reaction of the villagers after applying the smart technologies will be shown. This study was supported by International S&T Cooperation Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT.

1.3. Target area

The target sties of this study are rural areas of the developing countries. Tanzania, one of the East African countries located near the equator, was chosen for the study. The eastern side of the country is surrounded by oceans and has a tropical climate. On the other hand, inland is subtropical because it is highland surrounding Mount Kilimanjaro and Meru. November to December and March to May are rainy seasons, so it rains a lot at once [14]. Electricity supply of Tanzania is almost monopolized by the state−run company, named as the Tanzania Electric Supply Company Limited (TANESCO). However only 24% of the mainland receives electricity from TANESCO. In suburban areas of these, only 7% of people get access to electricity. In addition, the market economy system was introduced in Tanzania later than other African countries, so the economy growth is stagnant due to a lack of transportation and communication infrastructure, an insufficient development of information and communications technology (ICT), and unstable power and water supplies for industrial development.

The target village is located in Arusha region, northeast of Tanzania, and its name is Mseseweni. In this area, there is no network supplied by commercial telecom companies so that people cannot use the 3G or LTE which is common technology in the developed countries. In addition, the people of this area have low income and low education level. Because of the geographical features, it is difficult to use public transportations. To enter the village, people must use a motorcycle called pikipiki in Swahili or a private car. For many of these reasons, the village could not receive electricity from TANESCO, a Tanzania public electricity supplier, and some villagers were using private solar home systems (SHS).

IDIM and ITEC installed a 6.7 kW off−grid solar power plant in this village to solve the electricity shortage problem. The grid extension could not access for geographical and economic reasons, so the off−grid solar power plant was chosen for electricity supply. A total of 42 households have got access to electricity by the plant, with 152 people benefiting. The plant has been managed by a community of the village and one man was employed as a manager of the power plant. This plant opened in January 2019 and was named "Friendship Solar Center (2nd plant of iTEC)".

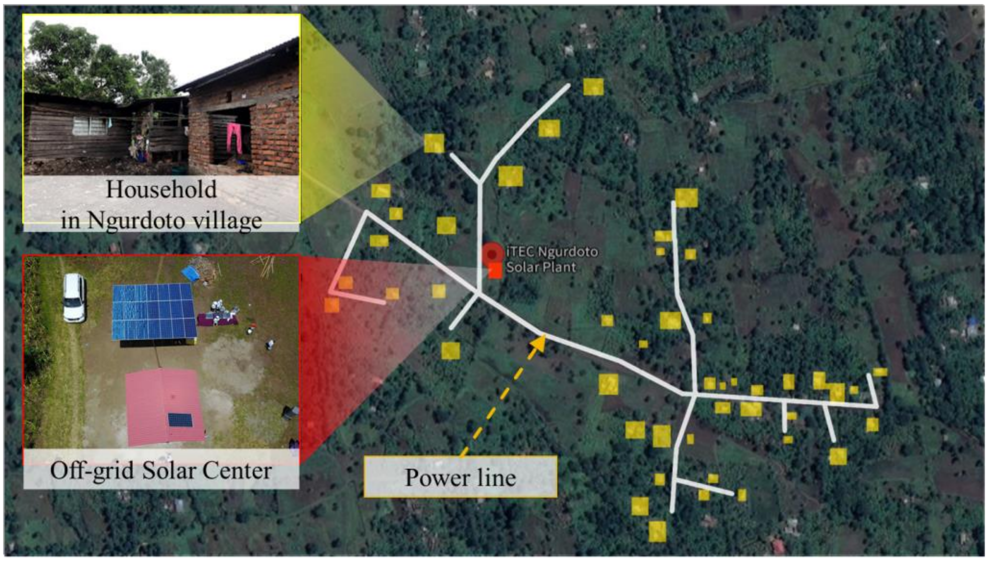

Figure 5. Map of electrified lines in Ngurdoto village (superimposed on an image from Google Maps)

Chapter 2. Smart meter

2.1. Smart metering system

A Smart meter is an advanced meter which measures the energy consumptions of consumers and shares information related to energy in real time, using two-way communication [8, 15]. In addition, smart meters are able to control systems of grids remotely [16]. The smart metering system is a heterogeneous infrastructure which consists of metering devices, communication networks, and data collecting and processing systems [15]. Smart meters are currently used worldwide to monitor power consumption of the households and buildings, especially in Europe and North America [17-20]. The meters which are capable of remote monitoring and controlling enable the deployment of smart buildings and smart grids.

Figure 6. Commercial home digital meter (NTC-A101-050) made by Nuri Flex [21]

2.2. Smart meter in developing countries

Unlike general smart meters used in developed countries, smart meters for developing countries should be designed in consideration of specific environmental and economic conditions in developing countries. For example, smart meters should be designed to communicate with each other even in areas where commercial communication networks are not established and be easy to maintain because rural areas of developing countries are inaccessible to advanced technicians.

In addition, remote monitoring, self-checking and automated management systems are highly important in remote areas, because it is difficult for outside management enterprise to visit these areas. A self-healing technology for off-grid systems installed in the remote sites increase the lifespan of the systems, because it reduces the need for technicians to visit in person.

Electricity theft is also one of the reasons why smart meters are needed in developing countries [22]. Meter tampering, illegal connections, and unpaid bills are the forms of the electricity theft and these cases occurred more frequently in countries where corruption is high level, such as India and Bangladesh [23]. The smart meter monitors electricity flow in real time so that it could be used to detect and prevent the electricity theft.

In this respect, Wang et al. built their own communications network in the village [24]. A LoRa communication module embedded in each smart meter enables the meter to communicate with each other without additional communications networks. The meter installed in each house sends/receives the data to/from a data collector unit through the communication module. In addition, Wang designed a mesh network technology for the rural areas, so it prevents data loss of the smart meters. The smart meter developed in his research is called "SNU-meter. The SNU-meter was utilized for the prepayment system in this study.

2.3. Footprint of the SNU−meter

In the paper of Wang, the version 1 of the SNU−meter was released and it was designed in 2018. The meter contains relays, current sensors, and voltage sensors, which allow to monitor electricity usage of each household and switch on/off supplies of electric power when necessary. Although it has all the basic functions of smart meters, it has poor waterproofing capability and bad durability and inconvenience of manufacturing. In particular, the single meter (single box) is able to collect data from up to four households simultaneously. An Arduino UNO board using open−source software has a role of a main control board so that the unit price of the meter was lower than commercial meters and it is easy for Tanzanian local people to participate in the production and maintenance of the meter. The SNU−meter has been continuously developed after the study of Wang. The upgraded meters and their footprint are presented in this study. The SNU−meter was developed in three versions since 2017. The first version was designed in 2018, the second version in 2019, and the last version in 2020 (Figure 7).

The second version of the SNU−meter had simpler manufacturing process than the previous version by creating a dedicated PCB for the current sensor and the power supplying circuit. In addition, the second version was designed to connect only one house, unlike the previous version which could be joined to four houses per one meter. This is because the second version was installed in a village where each household was located far away from each other, making it difficult to connect one meter to four households together.

In the final version of SNU−meter designed in 2020, the original current sensor was changed and the code was modified to improve accuracy and reliability. In addition, design of the outdoor protection box and the internal fixed components was changed to improve the durability and waterproofness. Furthermore, a LED display was added in the meter so that the villagers could check how much their credits remain. This improving process has been carried out for four years since 2017 based on active feedback from the villagers who have used meters and the technicians who installed the meters and the managers of the solar centers.

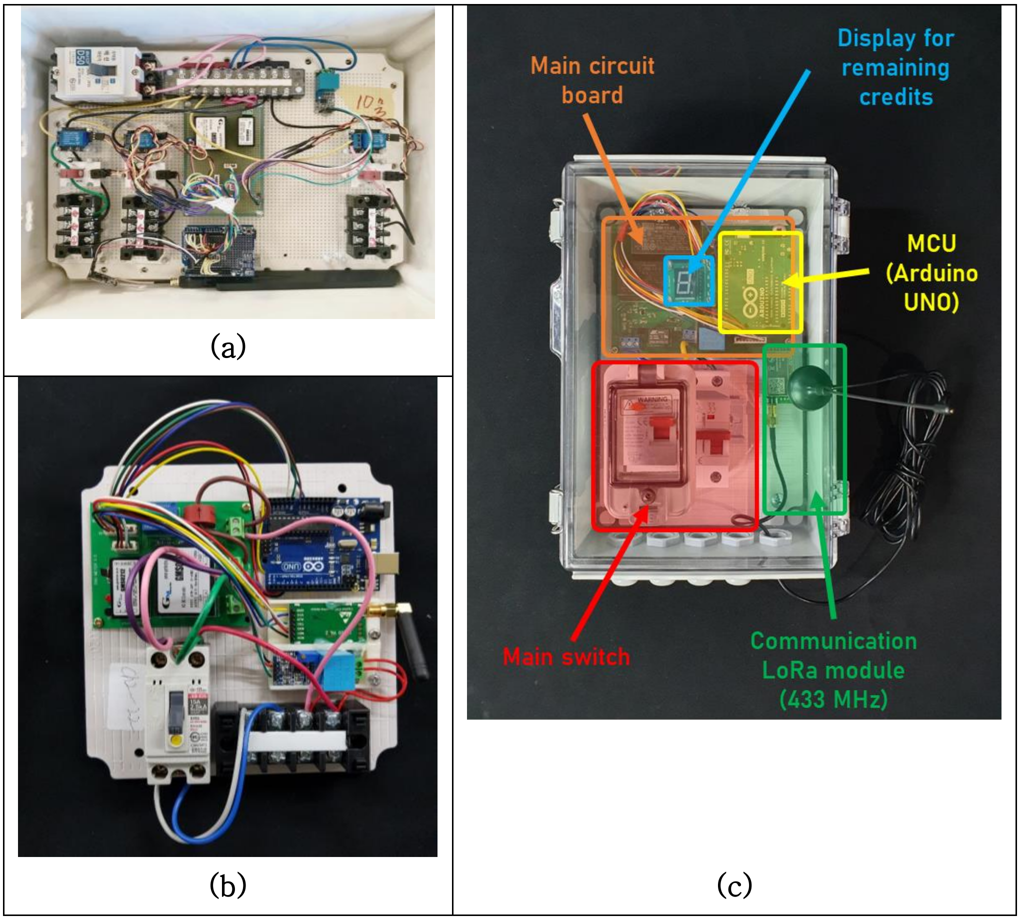

Figure 7. (a) Version 1, (b) version 2, and (c) version 3 of SNU−meter. SNU−meter consists of a switch, a main circuit board, a display, a main control board, and a communication LoRa module (433 MHz)

2.4. Installation of the SNU−meters

The SNU−meters mentioned in this paper were installed in 2019 at Friendship solar center, the second solar center of ITEC. The 42 meters were installed for 42 households which have gotten supply of electricity from the solar center. Since 2019, the meters have been used and monitoring electricity usage of each household and sending all data to a local database located in the solar center.

The most distinctive point of this study is that it aimed to not only develop the functionality of smart meters, but also implement the meters in real sites and be used by customers for many years. In order to implement the meters in a real site, not only conditions set by developers were needed to be considered, but also conditions that developers had not predicted had to be considered. For example, individual life patters of the users and new businesses in the village were unpredictable conditions. In addition, the meter was not installed indoors, but outdoors, so many external environmental conditions had to be considered. In fact, in the early days of invention of the SNU−meter, some external environmental factors caused problems such as corrosion and abrasion and water leak, so improving processes were needed to solve these problems (Figure 8).

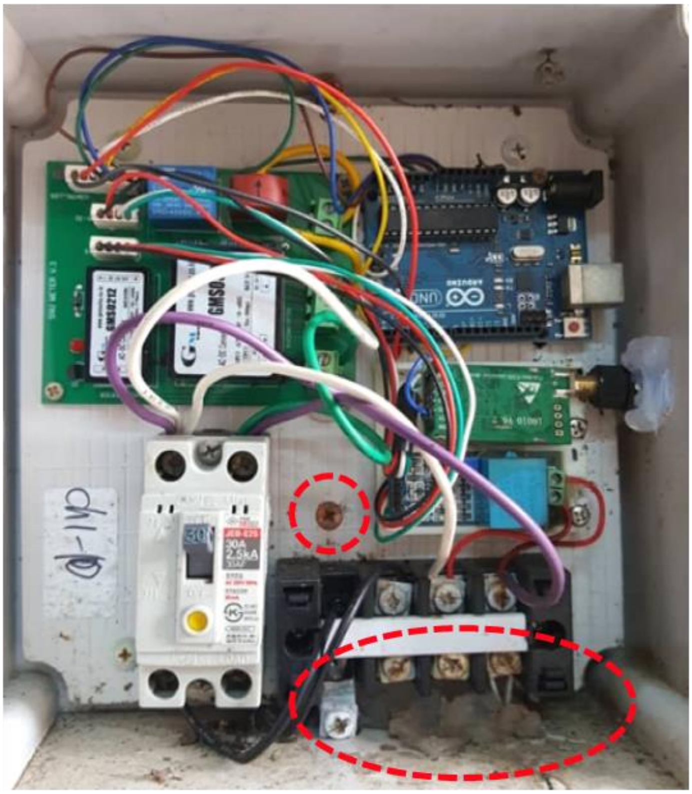

Figure 8. SNU-meter corroded by the water leak (red dotted circle) one and half year after installation

The meters, which were developed in this study and installed in the Friendship power plant of Ngurdoto village, were fixed on the walls of houses or on the poles located closest to households. The location of the installation was adjusted depending on the communication range of the smart meter, because the communication status was affected by obstacles surrounding the households such as hills and trees (Figure 9).

Figure 9. Trees surrounding the households in Ngurdoto village

(a)

(b)

Figure 10. SNU-meter (version 3) installed on (a) a wall of a household and (b) a pole in Ngurdoto village

Figure 11. Technician who is installing a SNU−meter on (a) a wall and (b)a pole in Ngurdoto village

Chapter 3. Smart payment system

3.1. Prepayment system

A prepayment system is unfamiliar in South Korea, which is choosing a post−payment system. However, in developing countries, mobile bill and electricity charges are generally paid based on prepaid systems, because it is difficult to prove a regular income, a bank account, and a permanent address of a potential customer in most of developing countries [25]. In this system, the customers charge the money first as much as they want to use services, and then they can use the services until the charged amount is exhausted. If additional services are needed, then the customers recharge the credits. Since services are only available as much as the amount paid in advance, the regular income or account information of the customer is not required.

In addition, the prepayment billing system helped to detect the suspected frauds, meter tampering and reduce non−technical energy loss [26]. Therefore, the advantages of using the prepayment system in developing countries that have many of these problems are unimpeachable points.

For these reasons, new billing and prepayment method for the off−grids in developing countries are introduced in this study. The villagers who get access to electricity from the Friendship plant charge the money as much as they want to use electricity. This method is similar to the general payment system of mobile payment in Tanzania, so it is easy to use for the villagers. Villagers pay to charge credits in two ways. The first way is to use mobile banking system and the other way is to buy a voucher.

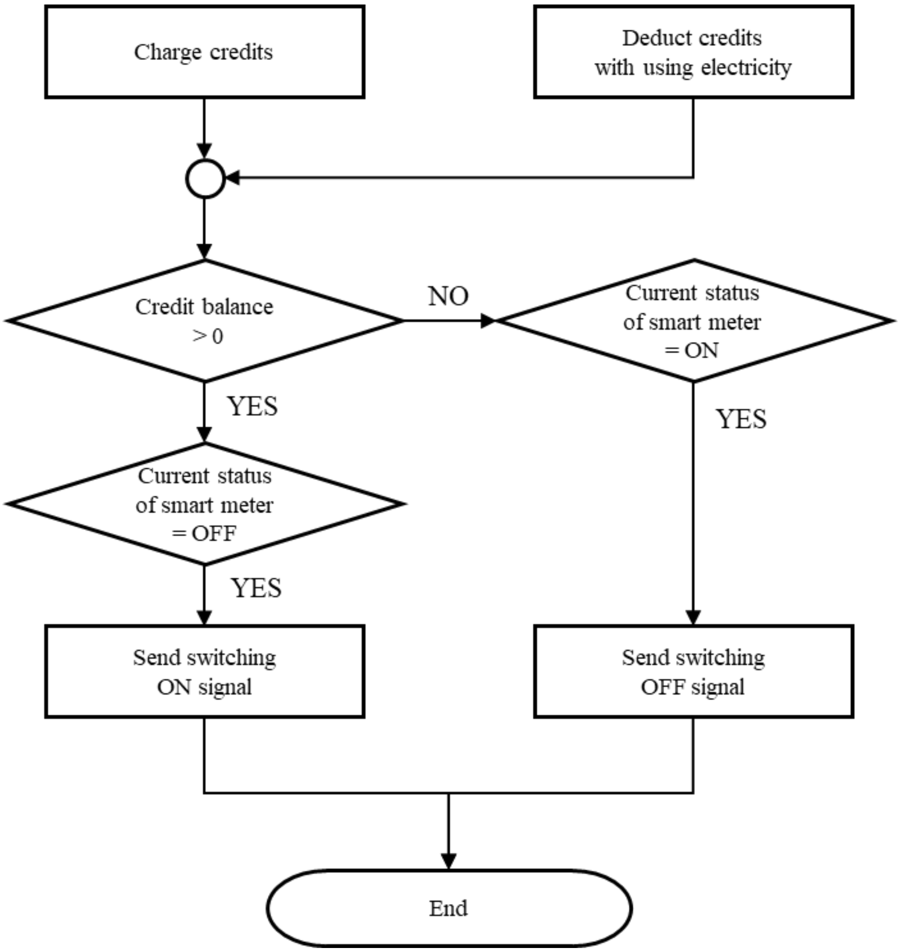

Figure 12. Prepayment system algorithm which controls signals of SNU-meters depending on credit balances saved in a database

3.1.1 Mobile Payment

Successful mobile banking penetration in developing countries has been demonstrated in Africa and South Asia, and Tanzania has the highest rate of registered mobile account users in Africa [27]. M-PESA (M” meaning mobile and “PESA” meaning money in Swahili) is a mobile banking platform used primarily in Kenya [13] and Tanzania. The name of the telecom company who supplies the M-PESA service is Vadacom. Through this platform, people use mobiles to remit money to each other.

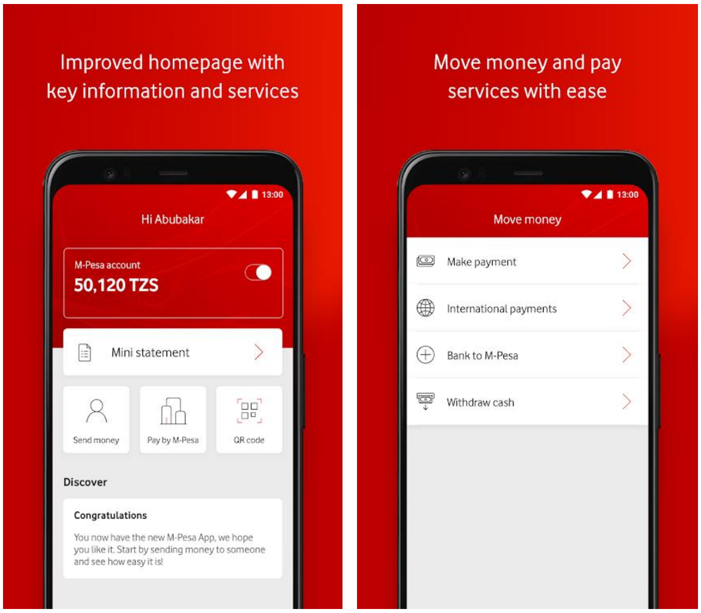

Figure 13. M-PESA Tanzania [28]

Figure 14. Message to a user who remitted 1,000 TZS

The mobile prepayment system developed in this study is linked to the M-PESA platform. When customers want to charge credits for electricity usage, they can remit the money to a public bank account of the village through the M-PESA platform. If the remittance is successful, a confirmation message including information of the remitter, date, and amount of remittance is sent to a GSM module (Figure 15) located at the solar center. In the GSM module, there is a USIM chip using the public bank account of the village, so the module can receive messages from M-PESA. The next step is that the GSM module transmits data, which is included in the message, to the local database. The local database is located in the laptop installed in the solar center. After that, if there is the received information which is matched with user information saved in the database, the credit is charged for the payer (Figure 16).

The GSM module consists of a Keyestudio SIM5320E 3G/GSM/GPS module, a power supply line, and an antenna. The module can use 3G and GSM communication technologies and receive GPS data. However, in this study, the module uses only GSM technology, because it is difficult to use 3G network in the target area. The 3G and GPS are not used in this paper, but these could be used for additional applications for the smart grid later. Supplied power to the module is 5V and a mobile SIM is needed to send and receive text messages from M-PESA.

(a)

(b)

Figure 15. (a) External and (b) internal pictures of GSM module

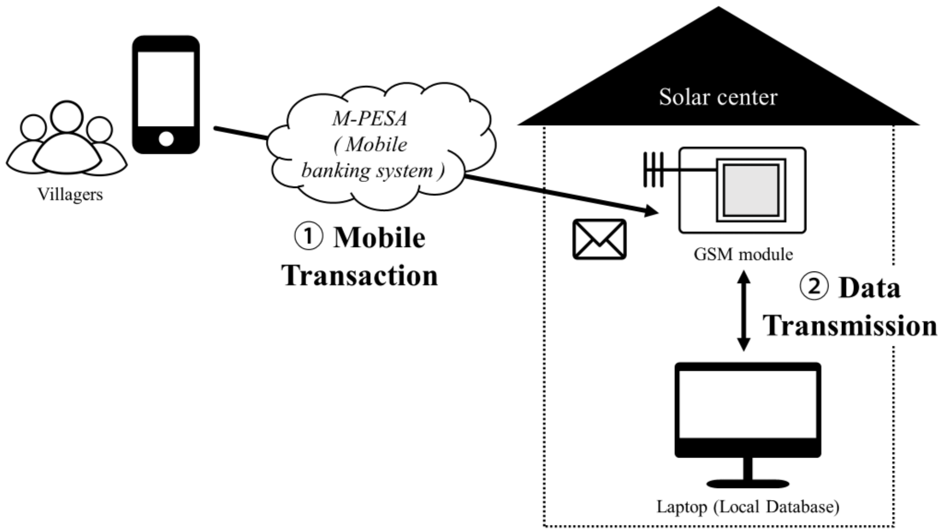

Figure 16. Scheme of the mobile prepayment system through M-PESA

① Mobile Transaction: When customers want to charge credits for electricity usage, they remit money to public bank account of the village through M-PESA mobile banking system. If the remittance is successful, a confirmation message is sent to a GSM module.

② Data Transmission: The GSM module transmits the data included in the message to a local database, such as a phone number of the remitter, date and time, amount of remittance.

To use this method, phone numbers of customers who want to use M−PESA must be stored in the database in advance. Each household can register up to three phone numbers in the database. The credit can be charged only if a phone number of a payer matches stored information in the database.

M−PESA used in the prepayment system is a popular mobile banking platform in Kenya and Tanzania, so the system is accessible to the public. Additionally, the system has the advantage of increasing scalability when adding additional mobile platforms from other mobile companies other than M−PESA in the future (Only M−PESA of Vodacom is used in Friendship solar plant at the moment).

In this prepayment method, it requires only simple programming and a GSM device and a database to apply a commercially available platform such as M−PESA. The biggest advantage of this method is that it increases accessibility for the public using a simple technology.

3.1.2 Prepayment vouchers

A prepayment voucher is a coupon for consumers who want to buy credits by cash. Credit is an indicator of the amount of electric energy that consumers can use, so they can use energy as much as the amount of credits they charge in advance. The voucher contains two types of information. One is a serial number of a voucher and the other is credit amount. The approved serial number is stored in the local database beforehand and the number confirms whether the voucher is officially registered in the system.

In the village, there is an administrator(manager) who sells the vouchers. The villagers(customers) pay cash as much as the amount of credits they want to purchase, and the manager gives the voucher with a serial number. In the solar center located in the center of the village, there are a local database and a device for registering vouchers the villagers bought. The device is called a credit registration device. It consists of a keypad and a display, so it allows customers to input the information of their vouchers, such as the serial numbers and credit amounts. In addition, an MCU of the device is built in to process data and transmit the data to the database. The device can communicate with the laptop using serial bidirectional communication.

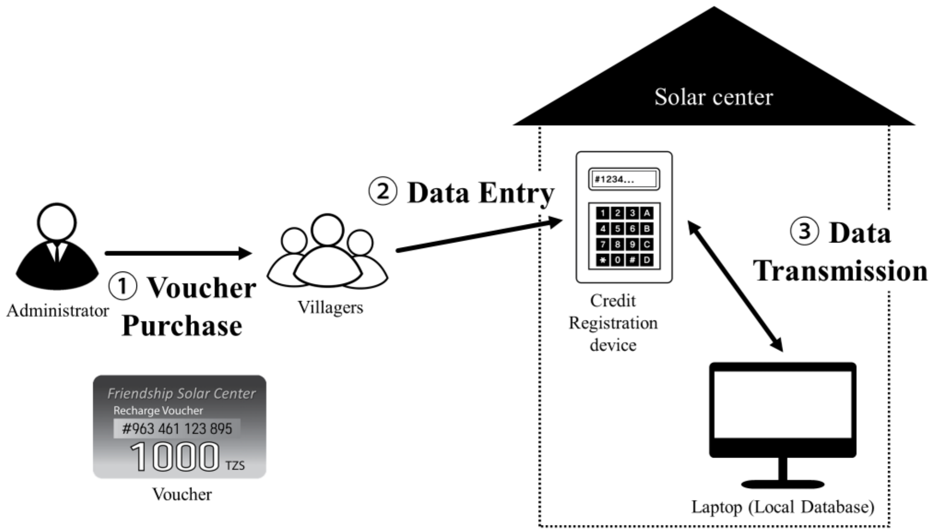

Figure 17. Scheme of how to use prepayment vouchers in the prepayment system

① **Voucher Purchase:** Villagers(customers) pay cash to a administrator as much they want to use. Then the administrator (manager) gives the voucher according to the amount paid by the customers.

② **Data Entry:** The vouchers which the customers took contain serial numbers. When the customers want to charge the credits, they input the serial numbers and their house numbers into a credit registration device. For example, when the house number is 21 and the serial number of the voucher is 1234567890, then user inputs *21*1234567890#. The asterisk (*) is used to separate two numbers.

③ **Data Transmission:** When the credit registration device receives the data input, it transmits the data to a laptop. In the laptop, there is a data processing system which charges the credits for the houses according to the data inputs.

Figure 18. Credit registration module including a keypad and a display

3.2. Communications network

The biggest advantage of the smart prepayment system developed in this study is that it does not require other external infrastructures or networks for system operation. It means when the system is implemented in the field, the system works using only the devices designed in this study, such as SNU-meters, the credit registration device, the GSM module, etc. (Figure 19).

To monitor energy consumptions of households and send control signals to meters from the database, the SNU-meter utilizes a mesh network technology that allows nearby meters to communicate with each other using a communication module embedded in the meter. The SNU-meter does not require the communications network supplied by telecom company, which the most of commercial smart meters require to send data to a central database.

In addition, when the customers pay electric charges, they just go to the solar center and input serial numbers of vouchers they bought into the credit registration device. The credit registration device does not use an external network because it is located inside a local area network. The credit registration device is wired to the database, which means that consumers can use the device to add their credit information directly to the database without going to somewhere outside the village. They do not need to go to banks or stores located outside the village. It is suitable to use for remote areas away from town.

The reason why the off-grid communications network was established in the village is that if external infrastructures and communication networks are used, the stability of the system can collapse because of external problems, not internal problems. For example, an external network may affect the billing system of off-grid plant if the state of internet network supplied by a commercial company is not stable. Another reason is a price. If we use an external network, we have to pay a monthly or annual fee to an telecommunications company. This can be a factor that increases the total amount of maintenance.

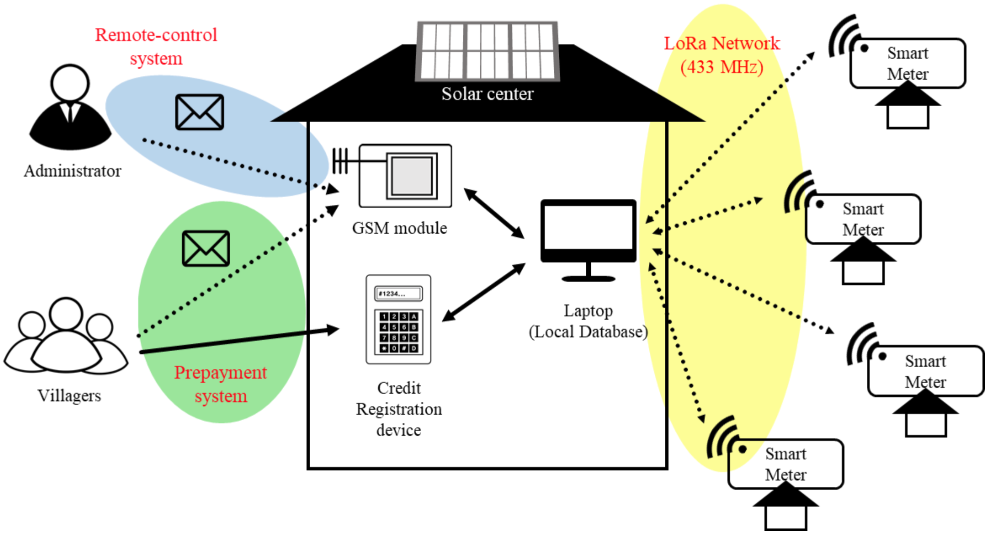

Figure 19. Communication diagram of a remote−control system and a prepayment system and a smart monitoring system

Chapter 4. Results

This work proposes new prepayment system through mobile banking platform and vouchers for off-grid power plant in the rural area of developing countries. The system was implemented in the Ngurdoto village of Tanzania for about 3 months from February 2020. In addition, the smart monitoring system which collects energy consumption data remotely was also installed in the village with the prepayment system. The monitoring system was installed in January 2019, so it has been used for over 2 years. To implement the systems in the village, it was necessary to discuss the electricity tariff and the usage method of systems with the villagers and community of the village. After implementing the systems, the effect of the system on the off-grid solar power plant is analyzed.

4.1 Electricity tariff for off−grid solar power plant

In this study, an electricity tariff for the off−grid power plant is needed to be set up to bill the villagers for electricity usage. The tariff was decided based on the electricity prices of TANESCO. The energy prices of Tanzania have been frozen since 2016 and are shown in Figure 20. The energy price which has been applied for the general villagers is 292 TZS per kWh.

Kundi la Mteja	Aina ya Bei/ Tozo	Uniti	Bei za Sasa	Bei Zilizopendekezwa 2016	Bei Zilizoidhinishwa 2016	% Mabadiliko
D1	Tozo ya kutoa Huduma	TZS/Mwezi	-	-	-	
	Bei ya Nishati (0 - 75 kWh)	TZS/kWh	100	100	100	0.0%
	Bei ya Nishati (Zaidi ya 75 kWh)	TZS/kWh	350	350	350	0.0%
T1	Tozo ya kutoa Huduma	TZS/Mwezi	5,520	-	-	-100.0%
	Bei ya Nishati	TZS/kWh	298	295	292	-2.0%
	Bei ya Mahitaji ya Juu	TZS/kVA/Mwezi	-	-	-	
T2	Tozo ya kutoa Huduma	TZS/Mwezi	14,233	14,233	14,233	
	Bei ya Nishati	TZS/kWh	200	198	195	-2.3%
	Bei ya Mahitaji ya Juu	TZS/kVA/Mwezi	15,004	15,004	15,004	
T3 - MV	Tozo ya kutoa Huduma	TZS/Mwezi	16,769	16,769	16,769	
	Bei ya Nishati	TZS/kWh	159	157	157	-1.5%
	Bei ya Mahitaji ya Juu	TZS/kVA/Mwezi	13,200	13,200	13,200	
T3 - HV	Tozo ya kutoa Huduma	TZS/Mwezi			-	
	Bei ya Nishati	TZS/kWh	156	154	152	-2.4%
	Bei ya Mahitaji ya Juu	TZS/kVA/Mwezi	16,550	16,550	16,550	

Figure 20. Changed electricity prices of TANESCO in 2016 [29]

The electricity tariff for the off-grid solar plant installed by ITEC and SNU compares to the energy price of TANESCO. It was set to 250 TZS/kWh, 42 TZS/kWh less than one of TANESCO, in consultation with the village community and the manager of the solar center and ITEC.

Unit	Energy Price (TANESCO)	Energy Price (SNU-ITEC off-grid)
TZS /kWh	292	250

Figure 21. Energy prices of TANESCO and SNU-ITEC off-grid

From April 2019 to January 2021, a fixed price of 5,000 TZS was applied to each household as electricity charge, regardless of energy consumption. The charges are not changed depending their usage, so they tend to use maximum electricity as much as they want. However, the off-grid system has limited energy production, so the management of energy usage is needed. In addition, the collected money by the charges is used as the maintenance expense of the solar center and the employment of the manger. Therefore, more than a certain amount of money must be collected every month. In Figure 22, the actual collected amount from the customers of Ngurdoto village in 2020 is shown. If all of villagers paid 5,000 TZS, 210,000 TZS (desired amount) should have been collected every month, However, people actually paid less as time went by.

On the other hand, if the prepayment system was applied, people would only be able to use energy as much as they pre-paid. This, in conclusion, could have led to more money being collected. The average monthly energy consumption of Ngurdoto village in 2020 is about 350 kWh (shown in Figure 23). Therefore, when the prepayment system is applied in the village with the energy price of 250 TZS/kWh, about 87,500 TZS will be collected every month.

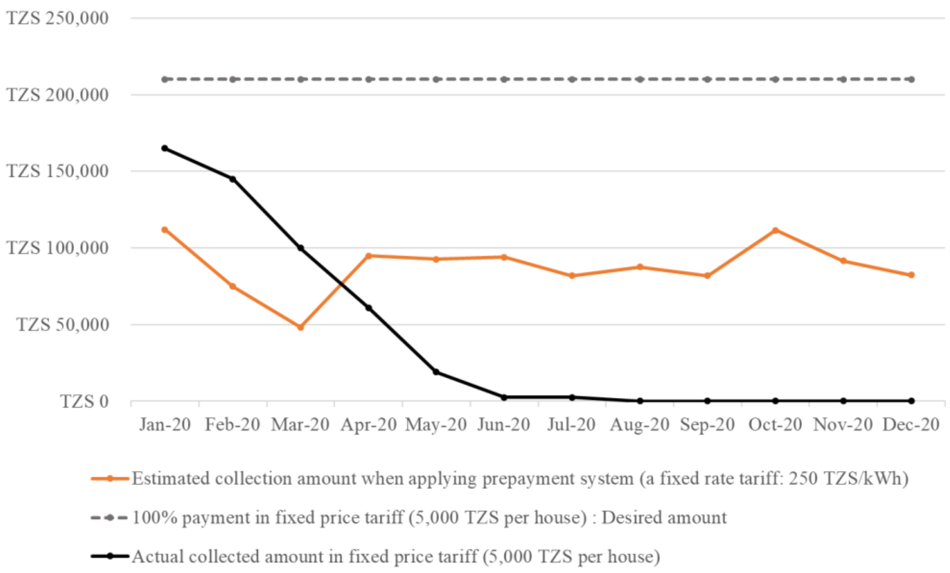

Figure 22. Actual collected amount as the electricity charges in Ngurdoto village (2020) and estimated collection amount if the prepayment system was applied in 2020

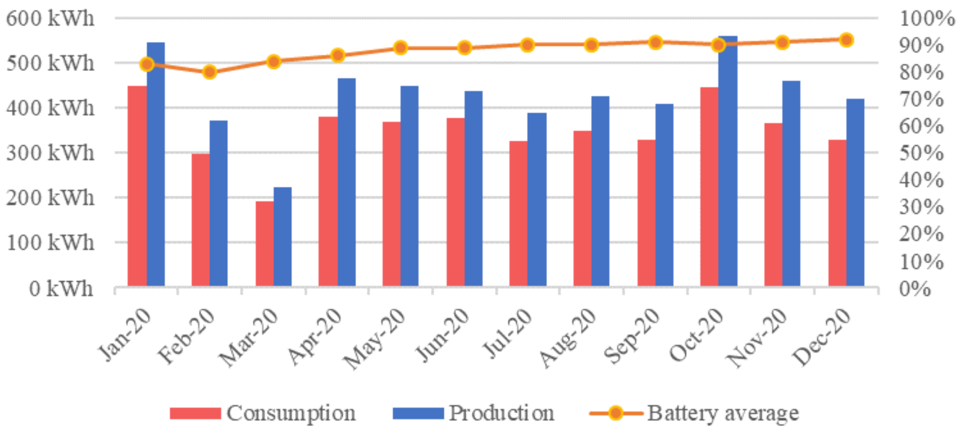

Figure 23. Energy consumption of Ngurdoto village (42 households), production of solar center, and battery state of charge in 2020 (Monthly)

4.2 Energy consumption and credit balance

The prepayment system has been used by the villagers of Ngurdoto village for about 3 months from February 2021. The energy consumption data of each house was saved in the local database. Using this data, we can get the household electricity usage behavior in rural area of Tanzania. Further, the credits which were charged and discharged by the villagers were also recorded in the database. The credit was discharged as much as the usage of electricity, so credit balance is inversely related to energy consumption. The logged data of energy consumption and credit balance in one household which has received electricity from Friendship solar center is shown in Figure 24.

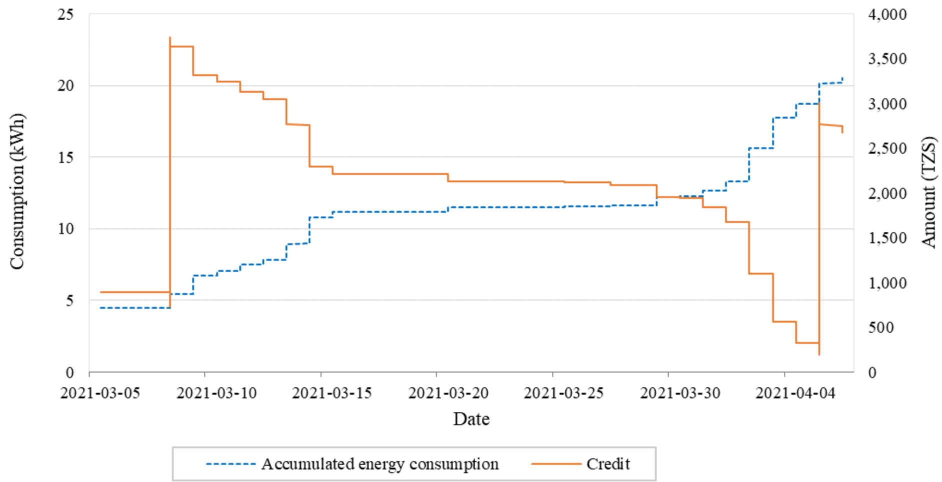

Figure 24. Accumulated energy consumption and credit balance of one household in Ngurdoto village for 1 month

4.3 Electric charges payment status

It is the payment status that shows the most obvious change after applying the developed prepayment system. In the case of the Friendship plant, from April 2019 to January 21, the billing method was operated based on manual system by the manager. The manual system means the manger has to visit each household in person to collect the electric charges. In this method, if there are no people in the house when the manger visits there, then manager cannot get the money. Or even if the user refused to pay, there was nothing the manager could do to them. For these reasons, about one year after the introduction of the manual system, payment has not been done properly before introduction time of prepayment system.

At the end of January 21, the smart billing and prepayment system developed in this study was introduced in the village. It means if the villagers do not pre-pay for their electricity usage, they cannot use the power. Therefore, the villagers must pay the money and the electric chares payment status becomes better than before. Before the introduction of prepayment system, the collected amount was zero, but 3 months after introduction, the amount increased up to 130,000 TZS.

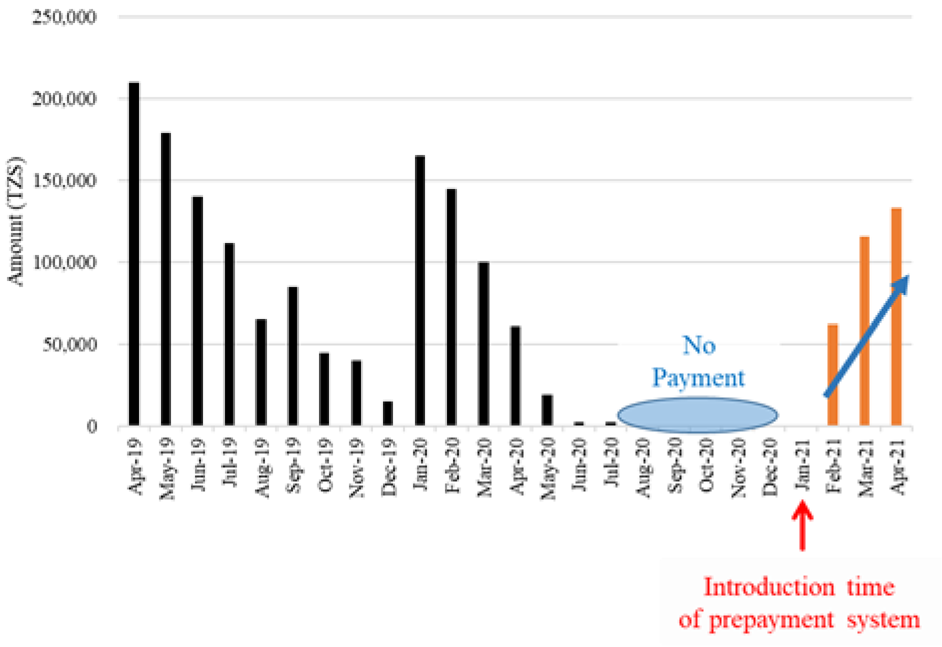

Figure 25. Electric charges payment status in Ngurdoto village (Friendship plant) after introduction of prepayment system

Chapter 5. Conclusion

New prepayment system for off-grid solar power plants was designed to solve the problems of the existing manual billing system. In particular, the remote and rural area of developing counties needed smart monitoring and prepayment systems for the management of off-grids already installed by the governments or NGOs. For the prepayment system presented in this work, an independent local communication system was established so that communication could work in small villages itself, while also preventing villagers from going to banks or stores located outside the village to pay charges. This has the advantage of being applicable in regions with insufficient communication networks and infrastructure, unlike smart meters and payment systems developed in many previous studies. In addition, the mobile banking platform, which is already commercialized in Tanzania, was used to allow villagers to pay for electricity charges. It is meaningful that the system was implemented with only simple programming and one device. The system is expected to have more capabilities in the remote area of developing counties in the future, helping to circulate the economy of small villages.

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Abstract

20세기 이후, 스마트 그리드는 에너지 분야의 세계적인 추세 중 하나이다. 스마트 그리드의 중요한 요소인 스마트 미터는 사용자들의 전기 사용량을 모니터링하고, 전력 제어를 위한 신호들을 송수신 함으로써, 전기료 과금 시스템을 전력 송신망에 적용할 수 있도록 한다. 그러나 스마트그리드와 관련하여 상용화된 스마트 미터들과 과금 시스템들은 대부분 기초적인 인프라와 경제적 지원이 충분한 선진국에서만 사용할 수 있도록 제한되어 있다. 본 연구에서는 모바일 뱅킹 플랫폼과 바우처(voucher)를 활용한 독립형 태양광 발전소용 선결제 과금 시스템을 제안하며, 이 시스템은 외부 네트워크나 기초적인 인프라가 부족한 개발도상국의 오지 지역에서도 구동이 될 수 있다는 장점을 가진다. 이러한 시스템을 구현하기 위해 로컬(local) 데이터베이스와 로컬 네트워크가 탄자니아의 Ngurdoto 마을에 설치되었다. 또한, 본 연구는 새로운 기술을 제안하고 개발했을 뿐만 아니라 실제 현장에서 3개월 동안 마을 사람들이 과금 시스템을 사용하게 함으로써, 실제 사용자들의 데이터들을 수집하였다. 본 연구의 과금 시스템에서는 250 TZS/kWh를 에너지 가격으로 책정하였으며, 이는 탄자니아 전기공급 회사인 TANESCO의 에너지 가격과 비교했을 때 42 TZS/kWh 적은 금액이다. 본 연구를 통해 독립형 발전소에 선결제 과금 시스템이 도입된 이후, 마을 사람들이 지불한 전기료의 총액이 증가하였음이 확인되었다.