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Examining the Smart-Prepaid Metering Systems in Ghana: Implications for Policy Reform

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Abstract:- This study examined Smart-Prepaid Metering System deployed by ECG and NEDCo from the technical point of view. The analysis revealed that smart meters are far advantageous compared to traditional postpaid meters that are error prone- reading errors, generate a lot of system losses, and can be bypassed by power theft. The high losses that utility companies make because of non-payment of bills could be reduced to the barest minimum. The resistance to smart-prepaid meter adoption is due to the high bills consumers are experiencing. The rising bills were caused by the use of energy consuming appliances like electric stove, dryers, washers coupled with rise in tariff. The study recommends mass education using various fora like community engagement and electronic media to teach consumers the added values of the new meters and how to use them efficiently. Also, these meters should installed at all government institutions and private industries that have been persistently defaulting in bill payment.

Keywords:- *Antitheft, Ardduino, GSM, LDR, Overvoltage, RFID, Smart-Prepaid Meters.*

I. INTRODUCTION

The Smart-Prepaid Electricity Meters (SPEM), currently in use in most part of Ghana is a good move by ECG, NEDCo, Enclave Power Company and other stakeholders that are involved. This is due to the fact that smart meters have the ability to remove non-technical losses caused by individuals who manipulate the meters to conceal their true consumption, costing utility companies a significant amount of money (ECG, 2020). It also ensures reliable and effective billing, tracking and monitoring of illegal connections, reduces bill frauds and non-payment of bills, and optimize revenue collection, as well as reduce indebtedness. It gives room for troubleshooting and accessing meter. The British Electricity Authority (2023) posited that smart-prepaid electricity meters reduce aggregate technical, commercial, and collections losses. It enhanced grid visibility and self-healing power of the grid. It lowers cost of power purchased by utility. It helps in peak load management of power (including provision of various options, from control of load of customer to incentives for consumers) (Nepal Electricity Authority (2018). The State Grid Corporation of China (2023) opined smart-prepaid electricity meters improves asset management, and allows for renewable energy integration (e.g. rooftop solar systems)

In terms of consumer, Smart-prepaid electricity meters allow customers to manage their usage and consumption, and advance payments to the utility firm ahead of time (i.e. credit top-ups). Smart-prepaid electricity meters ensure higher-quality electricity supply to clients, whilst reducing the need for voltage stabilizers. It offers opportunity for consumers to save money by shifting demand from peak to off-peak periods as well as more electricity supply options (e.g. renewables) (NEA, 2018). Smart-prepaid electricity meter can monitor usage patterns and identify areas where energy can be conserved by the consumer because of the GSM technology part (Uzair-Rajput et al., 2018). Aloria et al. (2023) added that smart-prepaid meters are user-friendly with transparent interface that enable users to share information with utilities. It regulates accurate view of electricity consumption, ensuring more reliable electricity supply to all consumers, leading to reduced power cuts, and less need for diesel generator sets and inverters (Aloria et al., 2023).

However, the major concern which prompts the need for this research is the consumers frequent complain that these smart-prepaid electricity meters run faster than usual, and their credit get finished quickly. Some indicated that they need education on the smart-prepaid meters so that they can appreciate its use. Many customers also, complain of receiving high bills these days, hence, they prefer old postpaid to the new smart-prepaid meter. It is a fact that old postpaid meters are prone to billing errors resulting from inaccurate manual data entering, whist the new smart-prepaid meters do not make billing errors, consumption information reflect automatically on the utility provider's dashboard for billing. To eradicate the erroneous impression and ensure consumers appreciate the value of smart-prepaid electricity meters and use it efficiently, this study practically model the smart-prepaid electricity meter-how it is built and operationalised with antitheft and overvoltage detection as well as SMS messaging capabilities (i.e. GSM technology) for energy efficiency.

- *Problem Statement*

A rising number of prepaid consumers of ECG and NEDCo are reporting significant anomalies in the readings of their meters, with many finding themselves suddenly burdened with huge deficits in their accounts. This is the problem that necessitates this investigation. Customers are furious about these hikes, which also raise important concerns regarding the NEDCo and ECG's technology infrastructure and billing procedures. For example, 32-year-old Charles Teye, who runs a hospitality business in Accra, described his

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experience: "I paid GH¢400 for a two-bedroom flat that I rent out on Airbnb. I purchased it for a customer. It terminated with a minus GH¢50 three days later. It took place multiple times. The situation caused smart prepaid meter users who buys electricity from me furious and they complained to me bitterly, since they have been monitoring their power usage efficiently and this arbitrary negative charges are beyond their comprehension (Adjei-Njoku, 2024). The most recent transaction that caused a major problem was one where the customer used a prepaid card to purchase GH¢400. Everything was used up in four hours. The customer was upset and felt that I had betrayed him. Only that apartment is designated as having a meter. Early in March 2024, this occurred. Another person expressing anger is Alex Mensah, who runs a "cold store": "My meter showed a negative account balance of GH¢7,800 abruptly, why? What is happening- have you cheated me? This nearly result in a fight between us. It took the intervention of onlookers to separate us. As a result of this, I went to the ECG office, they recommended that I pay it off in instalments but were unable to explain why. This is theft by daylight! How are they going to make us pay for their errors? He declared that pursuing legal action was still an option. These reports don't represent singular occurrences. Similar reports from ECG clients in Ghana reporting sudden negative balances ranging from hundreds to thousands of Ghana Cedis have been flooding social media channels, especially X (previously Twitter) (Adjei-Njoku, 2024). Our devices are being destroyed by the frequent disruptions, power outages, and on-and-offs.

- *Research Questions:*

By what mechanism does smart-prepaid electricity meters ensure energy efficiency in terms of eliminating power thefts, overvoltage and notifying consumer on energy consumption?

II. LITERATURE REVIEW

A. The Concept of Smart-Prepaid Electricity Meters (SPEM)

The ‘Smart-prepaid electricity meters’ have been specifically designed to enhance precision, effectiveness and efficient management of electricity usage; however, the old meters are vulnerable to theft and overload situations. To mitigate the risk of overload, power theft, the current meters incorporate monitoring and control mechanisms that restrict the quantity of electricity that can be utilized at any moment. Also, SPEMs have the capability identify instances of tampering and can notify utility providers of unauthorized actions observed. For clarity the basic types of smart-prepayment meters have been discussed below.

B. Types of Smart-Prepaid Electricity Meters

- *Smart Card Enabled Prepaid Power Meters*

This particular model of smart electricity meters have two key components: (1) smart card and (2) smart-card reader part. Similar to plastic credit cards, smart cards are implanted with several components, including CPU, ROM, and EEPROM, which are built into integrated circuits and constitute the operating system that controls data (Raad et al., 2007). Under this system, consumers are required to recharge their cards according to the number of units they wish to purchase. Subsequently, the card loaded with the unit is inserted into the card reader section which is part of the meter system. Afterwards, the card-reader stores all the units that have been purchased on the smart card. As soon as they begin to use the power, the meter decreases the units in proportion to the amount of electricity used. The device cuts off power when it reaches zero and doesn't restart until it has had another recharge.

- *Smart-Prepaid Electricity Meters based on Radio Frequency Identification (RFID) Technology*

This meter designed with RFID programmed recognizable strategy. RFID tags function by using an antenna and a microchip, also known as an integrated circuit, or IC, to transmit and receive data. Any information that the user desires is written on the RFID reader's microchip. In this case, it is designed and inserted into the meter to enable the consumer to manage his/her power. Thus, in order for the energy meter to supply power, the RFID reader must first read a valid RFID card. An instant text messaging notifying the consumer to recharge electricity unit on the RFID card will be delivered to his or her mobile-cellphone when the unit balance is insufficient or before the electricity is automatically switched off (Teymourzadeh & Abueida, 2018). This meter consists of two sections - a hardware section installed at the consumer’ resident and a software section installed at the utility end to enhance information flow from ECG/NEDCO to the customer vice versa. Afterward, consumers are expected to use the RFID-cards supplied by utility companies like ECG/NEDCO to purchase power through the use of codes on the card. When the customer presents the card to the reader to use the purchased power, the reader recognizes the unique code on the card and begins deducting the amount from the RFID-card in accordance with the unit recharged on the RFID-card. According to Teymourzadeh and Abueida (2018), the consumer must recharge the RFID card once more after using the entire balance.

- *Smart-Prepaid Meter with antitheft and GSM Technology*

The new smart-prepaid electricity meters that ECG is installing in residential facilities to replace the old meters are designed with antitheft and GSM technology to enable customers to buy electricity at their convenience. Thus, you don’t need to go to ECG’s office to buy credit. With your mobile phone, wherever you are, you can buy any amount of electricity units onto your meter. For example, when a consumer buys a credit or recharge unit, a text-message is sent to his/her meter through GSM link as a result of recharge made from the person’s mobile-phone accounts (Patel, 2018). The amount of money (in Ghana cedis) sent to the meter corresponds to specific number of units purchased, which are then deposited in the meter. When the house begins to use the power purchased the meter will deduct the unit until it is depleted and the power supply will cut off automatically. Electricity will resume in the house only upon a recharge (Omijeh & Ighalo, 2013).

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Literature has shown that emergence of smart-prepaid meters result in novel solutions to address energy efficiency-system losses, power thefts and overvoltage issues (Adeoye et al., 2017). These meters are well built to detect thefts, overvoltage management as well as text-messaging option via GSM technology.

With regards to ***energy thefts*** such as by-passing meter to avoid paying for power consumed. In order to address this problem, smart prepay power meters allow users to prepay for the electricity they use. Numerous studies have demonstrated that compared to typical postpaid meters, smart-prepaid meters can successfully prevent power theft, increase cost efficiency, and encourage energy conservation (Marimuthu & Muthukumar, 2016).

Concerning overvoltage, Patel (2018) asserted that overvoltage can damage electrical equipment and endanger consumers. To avoid these situations, smart prepayment meters have overvoltage detection built-in. Latest research on smart-meters showed that overvoltage detection mechanisms in them can successfully lower overvoltage occurrences and increase the power grid's overall reliability (Ciftci et al., 2019). In the work of Ciftci et al. (2019) the invention of smart prepay meters with overvoltage detection have the capability to safeguard electrical appliances from being damaged. The sending of text messages using GSM technology feature of this meters allow for smooth communication between the utility and the consumer. This information flow enable utility companies to rectify overload of grids and ensure efficient and equitable power distribution to all customers in a catchment area (Dike et al., 2015). This implies that the new smart metres with antitheft, overvoltage detection, and instance text-based communication features has led to practical solutions for addressing the problem of high bills if consumers properly monitor their use of power and improves on power conservation, bills will be moderate.

III. METHODOLOGY

According to Alhassan et al. (2019), designing smart-prepaid electricity meters equipped with antitheft, overvoltage detection and SMS messaging functionalities requires meticulously structured approach. This process involves multiple phases, starting with choosing, and installation of suitable and apt-sensors for detecting bypassing and other illegal connections and overvoltage in the design of meter's software as well as the two-way text communication features. From the design stage, a model/prototype-meter is fabricated, thoroughly tried underneath diverse conditions to ensure functionality:- dependability plus precision in terms of performance. Upon successful completion of all testing protocols, the prototype is deployed in a practical environment (i.e. real world-setting) and monitored for some time to gather evidence on its effectiveness (Daras & Asadi, 2019). The appraisal phase involves collecting data on consumption efficiency, incidents of energy thefts, overvoltage occurrences, and SMS message delivery efficacy and response rates (Olukunle et al., 2018). This information is analysed to determine the efficiency of the meters in mitigating power theft, averting overvoltage and facilitating communication with users through SMS. Cost-effectiveness and scalability of the meters are also gaged to determine its potential for widespread implementation in different environment. Studies by Singh et al. (2020) asserted that thoroughly executed methodology is essential for successful design and implementation of smart-prepaid meters with theft detection, overvoltage detection and SMS messaging capabilities, ensuring that the meter operates correctly, performs efficiently under varying conditions, and satisfies the energy consumption and safety needs of consumers (Sumanth et al., 2018). Figure 1 shows the System Architecture of Smart-Prepaid Electricity Meters.

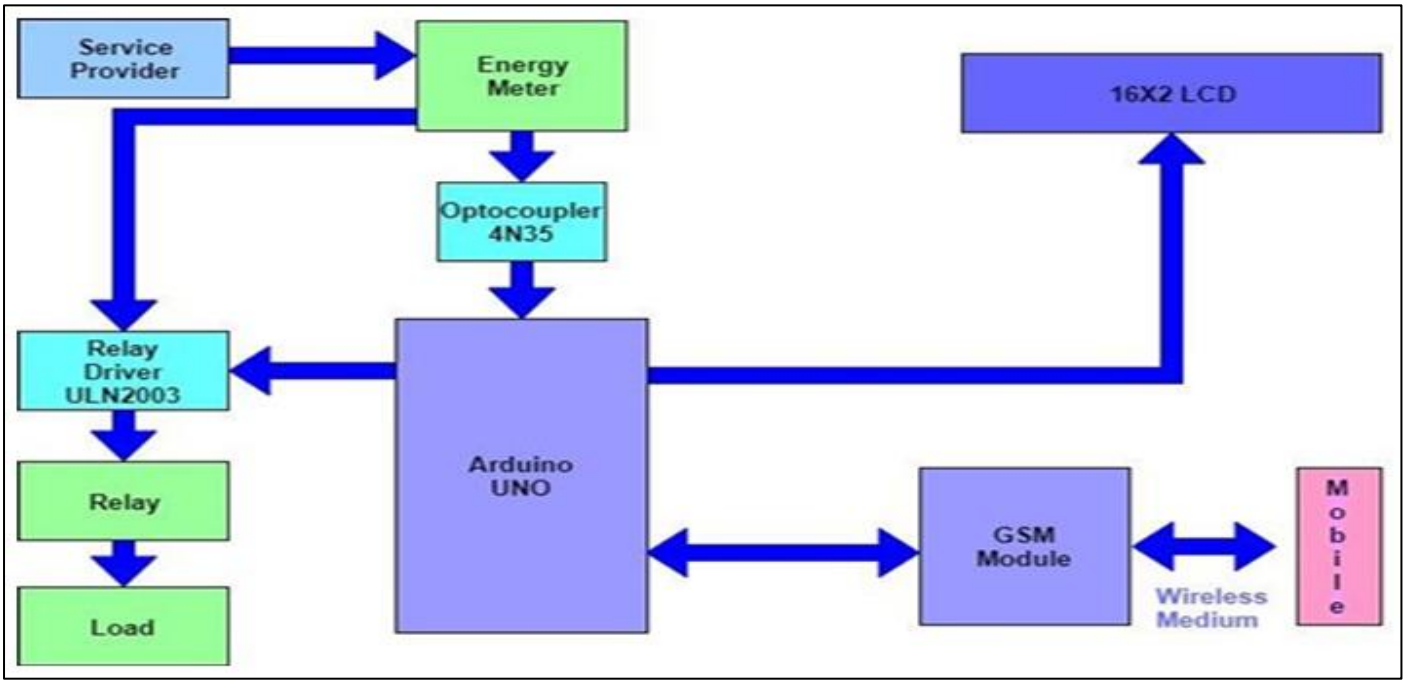

Fig 1 The Architectural Layout of Smart-Prepaid Electricity Meter

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The layout above shows the idea behind prepaid meters. Thus, the distinct, separate hardware components integrated, their connections and information flows path. It can be observed from the layout that the meter is provided by the utilities and electricity is supplied to the load via electromechanical relay that operates under specified condition. In order to achieve the goal of automatically monitoring the consumed electricity, theft and overvoltage detection and taking appropriate action based on the current units available, the meter is attached to an Arduino UNO. Also, the Arduino UNO is connected to the GSM Module in order to send and receive SMS updates to the customer regarding unit depletion, recharge, unit-balance (Rodrigo et al., 2016) and any other information exchange between the consumer and the utility company Samples of the ECG and NEDCo meters are shown below:

Fig 2 Smart Direct Electricity Prepaid Meter

Fig 3 Pole-Mounted Smart Prepaid Meter

➢ *Key Components of the System Defined*

- *Light Dependent Resistors (LDRs):*

LDRs are employed to identify instances of meter manipulation or bypasses. Therefore, any unlawful attempts to cover the meter or change its readings can be identified by keeping an eye on the light levels surrounding it.

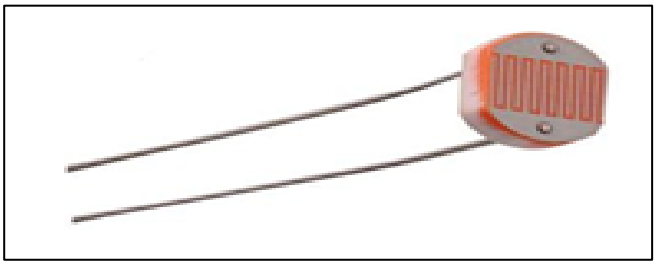

Fig 4 Light Dependent Resistors (LDRs)

- *Arduino-Nanos:*

It is used in prepaid-meters and programmed to monitor power usage and automatically disconnect the supply when the unit purchased is finished. Thus, it helps the meter user recharge units or top-up. This implies customers can recharge units/credits by sending an SMS through mobile application.

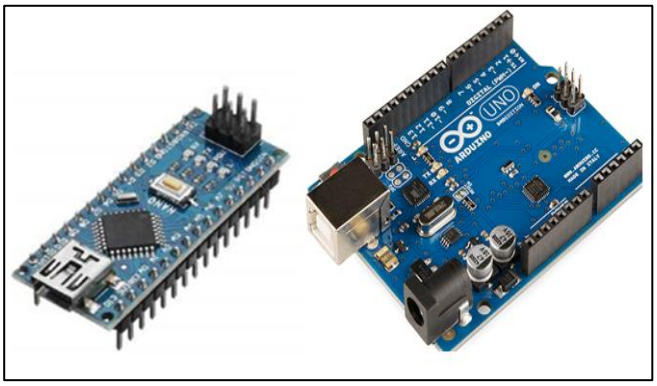

Fig 5 Arduino-Nanos

- *Global System for Mobile Communication (GSM):*

The GSM component integrated into smart prepaid meters are to enable information flow between the utility and consumer. Thus, GSM helps to exchange information between utility and consumers via SMS messages. It also helps to identify energy losses, real-time-data transmission, and electricity metering, remote control, monitoring, alarm and alert notifications.

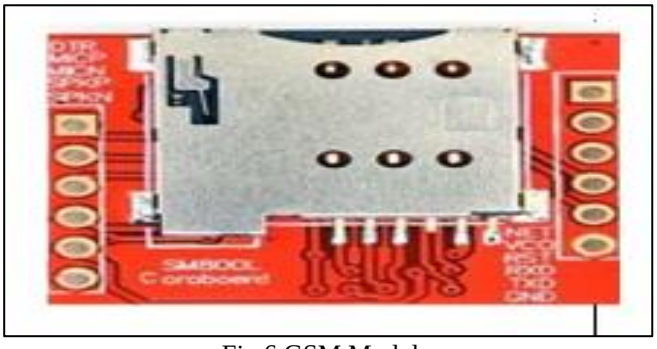

Fig 6 GSM Module

- *Buck Converter:*

In smart prepayment meters, this kind of DC-DC converter is utilized to change a greater voltage to a lower voltage. In order to give the microcontroller and other components a steady and controlled voltage, the buck converter is installed in the power supply section of smart meters.

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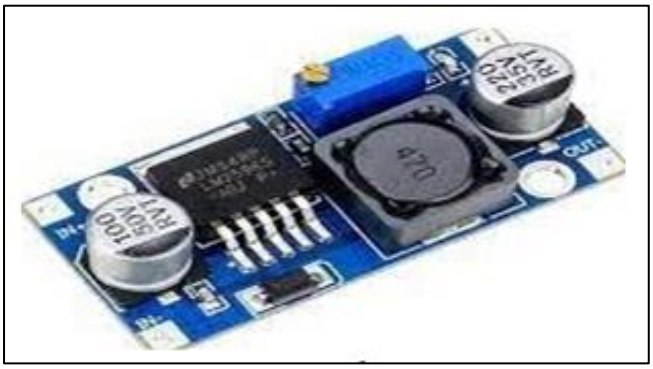

Fig 7 Buck Converter

- *Current Sensor:*

With smart prepayment meters, current (I) sensors are installed in order to gauge the amount of current passing via a load or circuit. The meter can determine how much power is used by the load by measuring the current. It can then transmit this information to a distant server or show it on an LCD screen. This helps in smooth and accurate billing of customers.

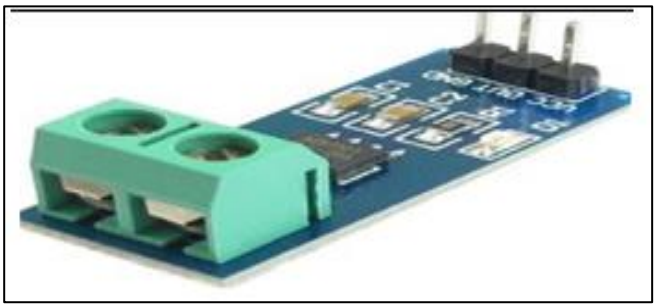

Fig 8 Current Converter

➢ *Circuit Diagram of the New Smart-Prepaid Meter*

Figure 9 provide a circuit pictorial view of the New Smart-Prepaid Meter.

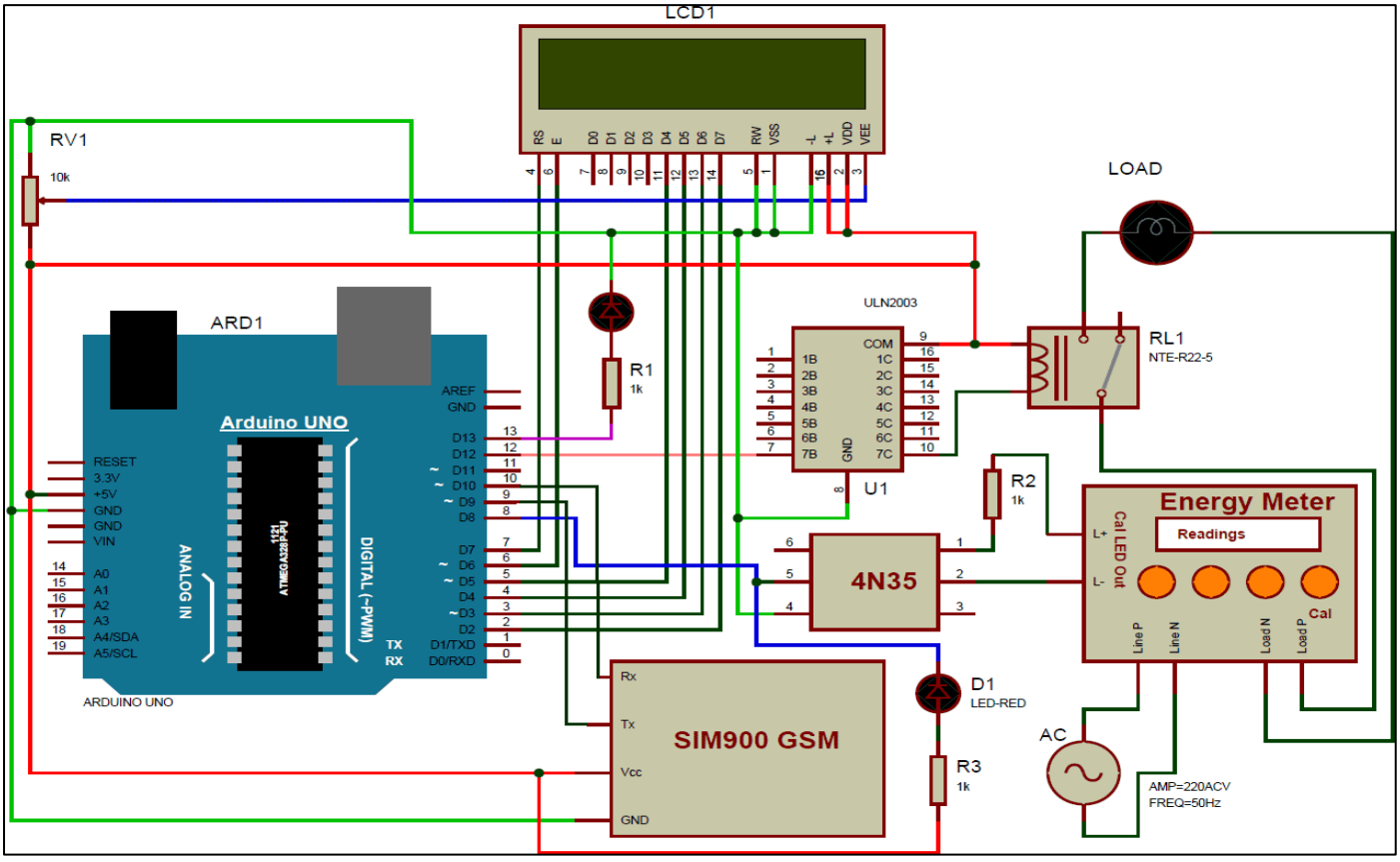

Fig 9 Circuit Diagram of the New Smart-Prepaid Meter

IV. ANALYSIS OF SMART-PREPAID METER WITH GSM TECHNOLOGY

In the Smart-prepaid meter, power is measured with respect to time and is calculated by multiplication of voltage and current signals.

➢ *Mathematically*

$$Current\ (I) = \frac{Voltage\ (V)}{Resistance\ (R)(amps)} = V/R\ (amps)$$

The meter's integrated circuit produces pulses based on actual power consumption. This meter is rated at 3200imp/KWh, meaning that it calculates 1 KWh for 3200 impulses. An LED will blink for each pulse. This LED has an optocoupler attached to it, which will turn on the optocoupler whenever the LED blinks. Since the LED on smart-prepaid meter produces analog signals and Arduino receives digital inputs, so we are unable to connect the LED directly to the Arduino. Thus, the LED on the meter has analog signals, and we are providing the Arduino with digital signals, so we cannot connect the LED directly to the Arduino. To detect

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pulses originating via the meter, the Arduino pin number (D8) is connected to the switching side of the optocoupler. Pin D8 of the Arduino detects a digital 0 when the optocoupler is turned off due to a pulse from the meter. If not, it is in an indeterminate state and is not active. When the pin's status changes from digital 1 to 0, there will be a count 1 to the data. It has an Arduino UNO interfaced GSM module. The RX and TX pins are used for information exchange; the Arduino RX pin is linked to the GSM module TX pin and vice versa.

To connect GSM-module with Arduino, a valid/working SIM-card is inserted into SIM-card-port of GSM-module. All ground-pins GND, are linked together. For this reason relays are used to supply power and serve the purpose for ON/OFF switching. Since Arduino has an ATMEGA328P microprocessor and pins that can produce approximately 25mA, it can't be linked directly to a relay. The microprocessor pins have a high voltage that will "drop" as more current is drawn and a big effective resistance; as the load grows, the voltage will climb. A high pin will be dragged low and a low pin will be pulled high if a pin has a maximum short circuit current, which means that short circuit current has restricted application. Thus, ULN2003 IC or relay driver connects the relay to the Arduino, and Arduino sends ON/OFF commands to the relay driver so that the relay can be turned on or off. Furthermore, the LCD is interfaced with Arduino digital pins (7, 6, 5, 4, 3, 2) so that the consumer can view the amount of units purchased, the number of units left, or the credit balance (Patel, 2018; Rodrigo et al., 2016). Fig. 10 illustrate the flow processes involved in prepaid meter system.

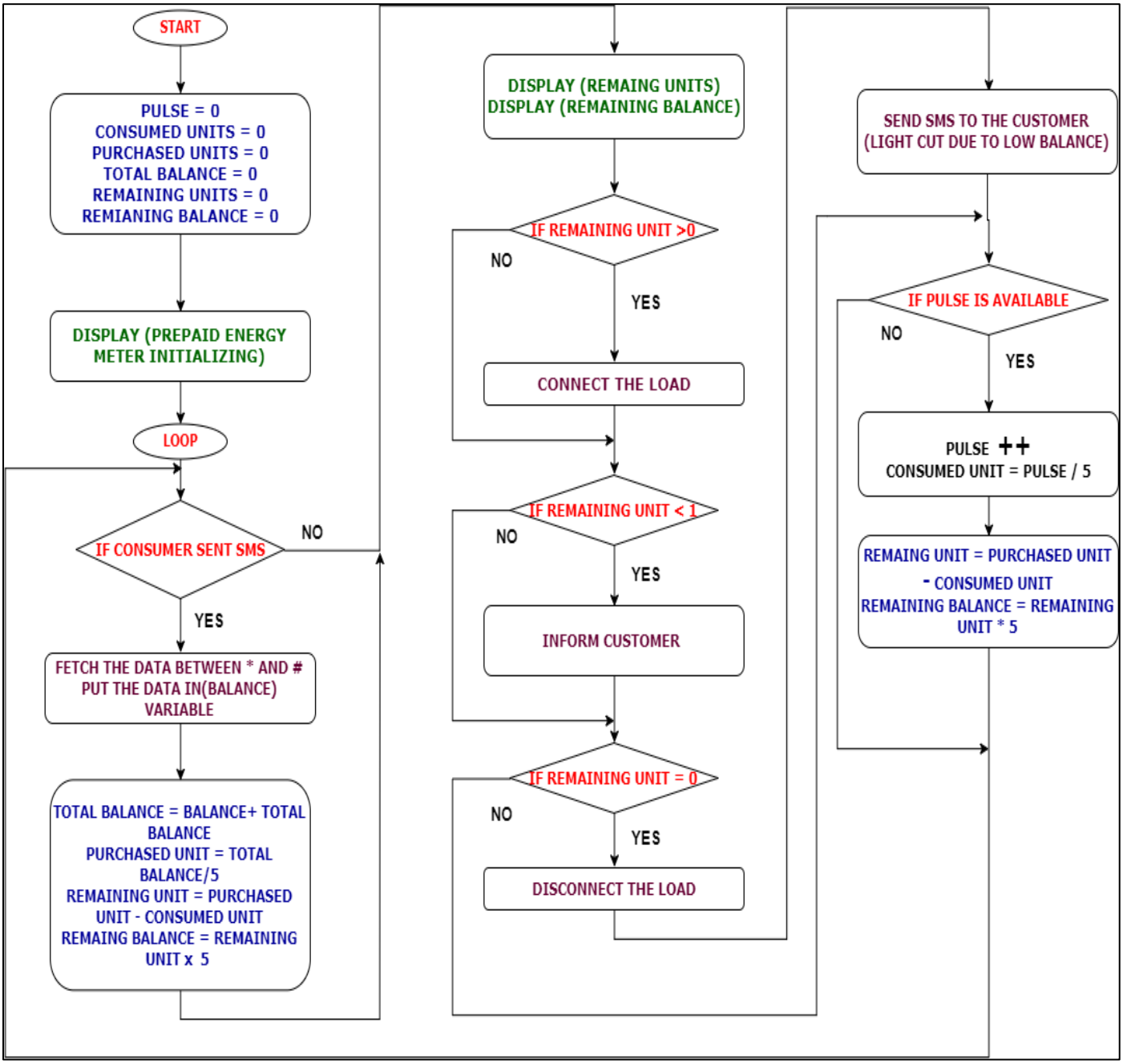

Fig 10 Flow Diagram of Processes Involved in Prepaid Meter System

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In terms of communication with the customer, the microcontroller will display zero units and zero balance as shown in Fig.11 when the meter's balance is zero, as it would be in its inertia, or it may occur when all of the purchased units have been used. At the same time, it will inform the customer regarding no balance by sending an SMS via GSM module as presented in Fig. 12.

Fig 11 Zero Unit and Zero Balance

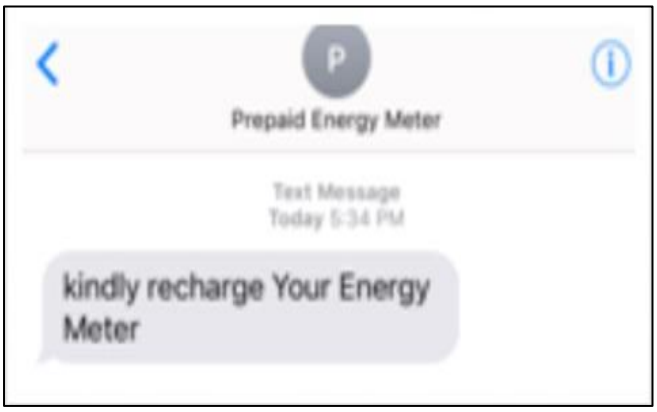

Fig 12 No Balance by Sending an SMS via GSM Module.

On the other hand, if a consumer sends a message to the GSM module in order to recharge his account, the microcontroller (an Arduino UNO) receives that specific data, decodes it, and retrieves the desired amount. The total amount that has been refilled can be seen on the LCD, as illustrated in Fig. 13.

Fig 13 Energy Meter Recharged

Following a systematic procedure, the microcontroller sends an SMS message to the customer informing him/her that connection has been restored, as illustrated in Fig 14, and instructs the load to be connected to the supply automatically once the balance in their account is adequate to do so. This message comes to the customer's phone directly. See Fig. 15, through the GSM.

Fig 14 Recharged Unit and Balance

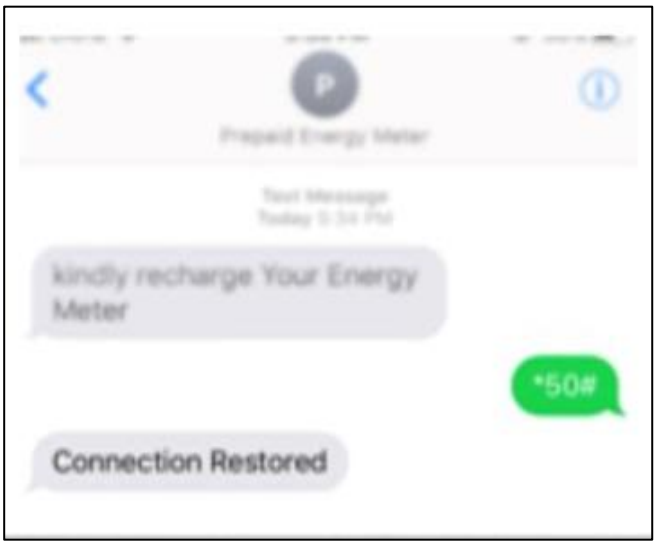

Fig 15 Connection Restored

Also, when the load is switched off by the energy meter because there is not enough balance (Fig. 16). This is followed by text-message from the utility to alert the consumer the reason for the light going off the home. See Fig 17.

Fig 16 Load Cut off due to Insufficient Balance

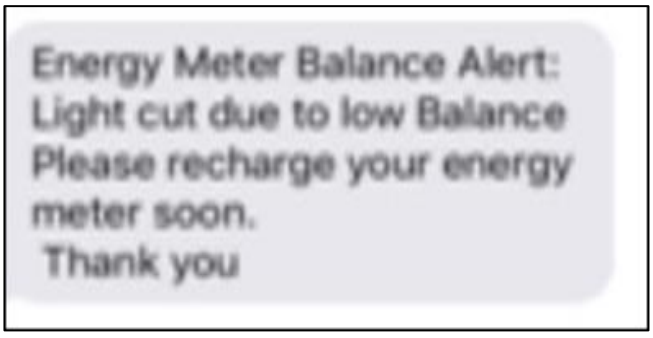

Fig 17 SMS to Informing user Status of Power Connection in the Home

From these illustration, it is certain that the consumer will use as much electricity as the account balance determines. Also, the more appliances a consumer uses at a time determines how fast the current runs out. So, wise use of electricity by the consumer is critical. This is because the microcontroller will issue command to disconnect the load from the supply when the balance in the account drops to zero, meaning there is no longer enough money to keep the load powered. Again, the user is informed about the status of the meter by an SMS and an LCD message regarding the load disconnection. So, when you are using prepaid meter, the more power you use the more prepayments you must make to remain connected.

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V. CONCLUSION AND RECOMMENDATION

New technologies will always be developed, and the power distribution system will continue to evolve. Arduino and GSM based smart-prepaid meters will be enhanced with added feature. Hence, it is imperative to continuously educate consumers on emerging technology so that they can put such technologies like the new meters to good use. Thus, thorough understanding of meters will ensure energy conservation and cost-efficiency (Uzair-Rajput et al., 2018). In this paper single-phase smart-prepared meter for domestic consumers with prepayment billing has been demonstrated using GSM-technology. GSM technology is used to purchase units, and the units are calculated based on power consumption. One highly desirable aspect of this system is its ability to convert ordinary meters into smart prepaid meters via an Arduino and GSM connection (Prepaid Module). This suggest that if ECG and NEDCo strategies properly, the old postpaid meters can be converted into prepaid meters at a lesser cost than the current cost be incurred by government. Within, the current prevailing situation, where the old meters are prone to system losses, metering errors, overvoltage and power thefts, it is prudent to replace all the old meters with the new one across the country, Ghana. Even though the cost involved in the replacement project is high, the use of smart-prepaid meters will yield much dividends in the long run with appropriate maintenance culture.

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