



GSM-Based Prepaid Electricity Energy Meter Using Arduino with Automatic Billing and Load Control

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Abstract: The development is to an advanced metering system that will regulate better electricity consumption. In this paper, GSM Based Prepaid Electricity Energy Meter using Arduino with Automatic Billing and Load Control is presented. With the proposed system, the consumer is able to monitor and control their electricity use in real time and the utility is to maintain timely billing. The meter is integrated with a prepaid recharge system, where the user can reinvest on his/her account through SMS. The system alerts the user that the charge is low using a buzzer if the charge is low. In addition, the system has load control functionality which enables users to switch the power ON or OFF through SMS so as to minimize electric loads effectively. Also, a request message sent to the system will help you to get load status and consumption details. GSM technology is integrated to communicate the user and the meter for a smooth data transfer and real time exchange. Manually reading through meters is minimized, errors are reduced in billing, and a consumer-friendly solution is provided. The proposed system is designed, implemented and the results explored in the research to demonstrate the effectiveness of the system in energy management and encouraging sustainable electricity usage. The paper also specifies existing research gaps and discusses ways to improve energy monitoring systems.

Keywords: GSM module, prepaid electricity meter, Arduino, low balance alert system, automatic billing, load control.

1 Introduction

Since the demand for electricity increases, and needs for efficient energy management, advanced metering systems (AMSS) have been developed in order to enhance the monitoring and control of energy consumption. These traditional postpaid electricity meters are known to delay payment of the bills and sometimes, if payment is not made in time, disconnection might follow. Similarly, these systems depend extensively on manual readings, raising the danger linked with errors and mistakes. Prepaid energy meters have been rolling into popularity as a solution, whereby consumers will only be using the electricity they have prepaid for. The approach prevents billing discrepancies, exploits losses in utility provider's revenue, as well as encourages energy conservation [1-5].

Prepaid metering systems thus enable consumers to know what their electricity usage and balance is, and to ensure that they do not get unexpectedly disconnected or get a bill shock. Nevertheless, traditional prepaid meters compel the consumer to update the balance manually or visit the service centres to recharge. In order to overcome this challenge, the use of GSM (Global System for Mobile Communications) technology in conjunction with prepaid energy meters has developed into a new model of energy management systems that couples the end users with the service providers by way of remote communication. GSM technology uses SMS based communication to automate the billing process, emit low balance alerts, and offers remote load control, hence ensuring an uninterrupted and also successful metering system [6-9].

GSM Based Prepaid Electricity Energy Meter with Automatic Billing and Load Control is proposed that combines prepaid recharge, low balance message, etc. to provide fair judgement experience. Based around the Arduino microcontroller, as control unit, interacting with the GSM module for communication and the energy meter in order to handle the data it provides from the meter. The microcontroller is updated with a new available balance in the microcontroller's memory through a secure SMS sent by the user, and users can recharge their accounts by sending this secure SMS to the system [10-13]. The system triggers a buzzer alert (on a predefined threshold close to the balance) in case it approaches that amount, notifying the user to check the balance to recharge the account. In addition, remote electrical load control is enabled by the system.

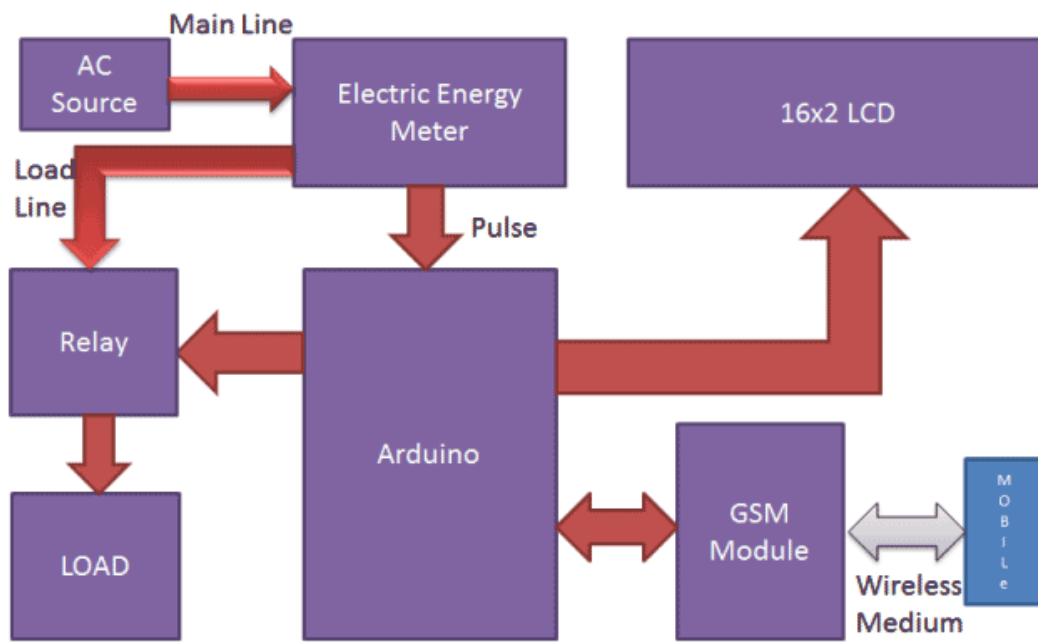


Fig.1: process of prepaid energy meter with automatic billing

With a specific SMS command, users are able to ON or OFF their connected load. It serves the double purpose of allowing the user to dispense with unnecessary energy consumption and greater power consumption control. As a further addition, users are able to query the status of the load and remaining balance through SMS to stay continuously informed of the power consumption. This proposes a user friendly and reliable solution based on a combination of prepaid metering, GSM technology and remote load control. Not only does it eliminate manual intervention, but it also enhances the billing accuracy and adds to a more secured and interactive energy management [14-15].

1.1 Background

Traditionally, edifice meters have been used to monitor power consumption and to create bills because of usage. Nevertheless, postpaid metering system often leads to delayed bill payments and revenue loss in electricity providers. Prepaid energy meters have been introduced to address these challenges; they permit users to prepay for electricity and consume only the amount of electricity they have purchased. Remote communications and data transfer has been added to traditional meters by the addition of GSM technology. With GSM based prepaid energy meters, the consumers can monitor and control their power consumption through SMS which will alleviate the efforts of handling the manual intervention and likewise errors bill. Load control mechanisms are incorporated into the inclusion thus users can easily turn appliances on and off remotely to increase energy efficiency.

For the purpose of developing smart metering system, the use of Arduino microcontrollers is very cost effective and flexible. Arduino based prepaid meters combined with GSM modules offer a good way for monitoring and controlling the electricity usage with reliability and security. The system design combines all the above technologies for the design and development of a smart prepaid energy meter with support for automatic billing as well as load control and real-time communication.

1.2 Problem Statement

It is not usual that there are delayed payment, no real-time monitoring, and inefficiency in managing energy on the traditional electricity billing systems. Postpaid meter users are generally unaware of their consumption level and this unawareness often end up with shock billing and in some cases cut out due to non-payment. Also, manual meter reading and billing bring additional errors and discrepancies in the records of consumption and the delays in updating the billing status. Existing prepaid metering systems, as it were, have been exploited in the course of addressing these issues-to a certain extent, however, they often do not have effective load control mechanisms that allow users to uselessly adjust their electrical loads.

In addressing these challenges, that communication system is proposed as GSM Based Prepaid Electricity Energy Meter Using Arduino with Automatic Billing and Load Control. If you do not recharge your balance within a certain time span, the system will alert the consumers regarding a low balance through buzzer. Recharging the consumers can be easily done via SMS communication and can query load status and make people control

their connected loads remotely. The outcome of the idea is enhanced energy efficiency; reduction in manual errors; and an automated and secure billing process for consumers and service providers with improved energy management and consumer satisfaction in general.

2. Literature Review

The innovative prepaid energy meters provide consumers with an updated method of controlling their energy usage by implementing an enhanced system that supersedes the traditional postpaid metering approach. The billing period enables postpaid systems to measure electricity consumption before generating customer bills at the end of the period [1]. Manual readings of meters combined with delayed payments and possible disconnections result from this operational method. Under prepaid energy metering systems consumers can buy electricity in advance so they can use power only within their purchased amount. A prepaid energy metering system ensures responsible electric power usage because customers only consume energy according to their payments which results in a better managed and sustainable energy management system [2-3].

The primary benefit of prepaid metering systems enables users to track their electricity consumption live and exercise better management of their energy costs. Consumers can easily check their account balance and recharge it based on their needs in order to prevent unforeseen bill increases. Prepaid meters with microcontroller systems determine usage quantities automatically while subtracting balance amounts from the available funds. A notification alert activates from the system once the balance becomes zero causing automatic load disconnection if the customer fails to recharge their account [4].

GSM (Global System for Mobile Communications) technology integration with prepaid energy meters delivers real-time consumer-provider communication through its partnership with the system. GSM technology enables remote SMS functionality which lets users execute critical operations including checking balance and account recharge and electrical load control [5]. GSM-based systems eliminate the need for manual meter readings because the system automatically transmits consumption data as well as account status to utility providers. The system removes reading errors from human operators which results in better accuracy during billing procedures and enhanced energy monitoring transparency [6].

GSM modules play a crucial role in enabling two-way communication between the prepaid meter and the user. Consumers can send specific SMS commands to perform various actions, such as checking the balance, turning the load ON or OFF, and recharging their accounts. The system responds with relevant information or confirmation messages, ensuring that users have complete control over their electricity consumption. Moreover, GSM-based systems can also send automatic alerts to consumers, notifying them of low balance or unusual energy consumption patterns, thereby allowing users to take timely corrective actions [7].

Arduino microcontrollers have emerged as a popular platform for developing smart metering systems due to their affordability, flexibility, and ease of integration with other hardware components. Arduino-based prepaid energy meters are capable of performing multiple tasks such as monitoring energy consumption, managing balance, updating account information, and controlling loads remotely [8]. The Arduino microcontroller acts as the central processing unit that interfaces with the energy meter, GSM module, relay module, and buzzer system to ensure seamless operation of the system. The microcontroller processes data received from the energy meter, calculates energy consumption, and updates the balance accordingly. It also communicates with the GSM module to facilitate SMS-based interactions with users [9].

In addition to managing energy consumption and balance updates, Arduino-based prepaid meters can incorporate additional functionalities such as tamper detection, real-time clock (RTC) integration, and security enhancements. The inclusion of a real-time clock ensures accurate time-stamped data for consumption records and billing, while tamper detection sensors prevent unauthorized attempts to manipulate the system. These features improve the reliability and security of the metering system, ensuring that both consumers and utility providers benefit from a transparent and secure billing process [10].

The important element of present-day smart metering systems consists of load control and monitoring capabilities. The remote load control system enables customers to operate their electrical loads effectively using SMS commands to switch loads ON and OFF. The system feature helps consumers manage their electricity usage during peak times thus minimizing the cost of their overall energy consumption [11]. The implementation of load control functions depends on SMS-controlled relay modules which the GSM module activates or deactivates. Through its processing of the received commands the Arduino microcontroller executes commands for controlling connected loads in real-time [12].

Element control through remote access improves user safety because the system lets consumers cut power from high-power appliances when emergencies happen. A user can avoid potential hazards by using SMS commands to send instructions to the system which disconnects the load while they have forgotten to turn off an appliance. Building load control functionality into energy management systems allows users to plan when they use their appliances thus cutting down energy losses and building an eco-friendly energy system [13].

Conditional automatic energy meter billing and load control management through GSM-based prepaid devices deliver substantial improvements to power management capabilities. The systems benefit consumers and

providers through operational enhancements yet they reduce human errors and help users practice energy responsibility [14]. Prepaid billing systems help consumers receive uninterrupted service since they maintain the required account balance to prevent unwanted bills along with disconnection rates. Users benefit from remote account recharging through SMS as well as automatic alerts for low balance which notify them in advance so they can take necessary steps to prevent interruptions in service [15].

2.1 Research Gaps

- Various pre-installed load control features remain absent from most available prepaid energy meter systems.
- The system lacks immediate message capabilities for power consumption status updates.
- The conventional meter lacks automatic notifications for detecting low balances in power supplies.
- Prepaid energy meters lack proper security systems which protect metering data from unauthorized access.

2.2 Research Objectives

- The research team should create an automated GSM-based system that works as a prepaid meter while also enabling remote load control capabilities.
- Our system will integrate prepayment recharge ability into its automatic billing functions.
- The system should provide instant monitoring alongside automatic alert features for low balance status.
- The meter must establish protected and dependable communication pathways to users.

3. Methodology

An automated prepaid energy management solution features the integration of GSM module, Arduino microcontroller, energy meter, relay module, and buzzer system. This system enables real-time monitoring and load control features as well as balance updates through SMS protocol which improves user capabilities to handle energy consumption effectively. The main programming function of the central processing unit Arduino microcontroller manages all vital operations from data processing through communication and balance oversight and load management tasks.

Through GSM module technology which includes a SIM900 users establish SMS-based interaction with the system for managing communication needs. Users are able to control energy consumption by sending specific SMS commands for checking balance and account recharge and load control. The GSM module receives SMS messages that trigger appropriate instructions delivered to the Arduino microcontroller for execution of the related commands. Real-time communication allows users to control their energy usage and monitor system performance through a system that needs no physical operator involvement.

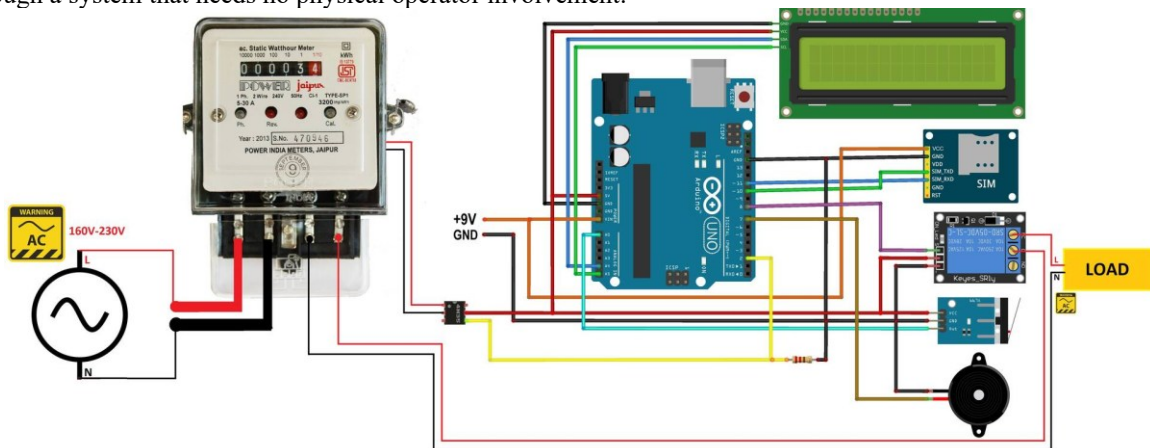


Fig.2: circuit diagram of GSM Based Prepaid Electricity Energy Meter using Arduino with Automatic Billing

Real-time electrical usage measurement occurs through the energy meter and the meter data automatically reach the Arduino microcontroller. When energy consumption occurs, the microcontroller understands how to subtract the needed amount from the prepaid balance. When the system detects that system balance nears zero it will use the buzzer system to deliver an alert which notifies the user they need to recharge. Through audible buzzer alerts the system notifies users about their diminished balance when their account reaches low levels despite their absence from checking SMS notifications.

The relay module serves as an essential control device because it regulates the functional state of electrical loads according to user inputs together with system parameters. A sufficient balance enables the relay to stay in an ON position until the load receives normal operation. The relay operates under two conditions: when the

balance falls short or when the user sends an SMS signal to disable the load then the relay will transition to the OFF position to interrupt power supply. The remote-control features make the system safer through enabling users to maintain their energy loads remotely which prevents wasteful power usage.

The system commences its activities through user-initiated SMS communication that contains a pre-established format for account recharging. The GSM module tells the Arduino microcontroller about SMS messages before sending the request for recharge processing and balance revision operations. Once an account update completes the system activates as the connected load stays online till the balance runs out.

During operation the Arduino maintains continuous observation of the energy meter readings to deduct the related energy costs from the balance. When the system detects the balance drops beneath its defined threshold the buzzer operation starts to notify the user. This warning system provides enough notification so users may conduct account replenishment thus avoiding power disruption. They can check the present load status and remaining balance of their account through SMS communication with the system. Users can receive an SMS from the system containing their present balance and load status information which enables them to take appropriate actions.

The system implements security features which protect against unauthorized modification and unauthorized intrusion. Documented phone numbers function as the exclusive gateway for SMS system commands which guarantees secure system control. The authentication system safeguards the metering system from tampering attempts and protects it from malicious actions.

The operational efficiency of the system increases through real-time updates on load status and account balance sent periodically to the user. The system helps people monitor their power consumption behaviour so they can choose the best practices for energy usage optimization.

The proposed prepaid energy meter powered by GSM integration delivers an efficient and secure user-oriented power management system that utilizes modern technology. The utilization of Arduino microcontrollers combined with GSM communication enables users to exert control over electricity usage and observe account balance and remotely track their loads. Users benefit from better energy consumption and lower costs because the system provides three features: real-time updates, low-balance alerts together with load control capabilities.

4. SMART PREPAID ELECTRICITY METER WITH GSM COMMUNICATION AND REMOTE LOAD MANAGEMENT USING ARDUINO

A prepaid electricity energy meter based on GSM technology powered by Arduino introduces innovative capabilities for automatic billing and load control to smart metering systems. Traditional postpaid electricity meters face limitations which the new approach of GSM-based prepaid electricity meters addresses through an improved management system for energy consumption. The merged prepaid metering system using GSM technology allows both payment and balance management while performing remote load control through messaging functionality to establish a comprehensive service for users and power companies.

The system features prepaid billing as its main strength because customers can make advance payments to their accounts to avoid unpaid bills and disconnection due to non-payment. Consumers who use prepaid energy meters can see their real-time energy usage so they can modify their power consumption by checking their available balance. The system disconnects the load automatically when the available balance is depleted. Prepaid energy meters enable customers to keep to their energy usage within their paid amount thereby preventing excessive electricity bills both for consumers and service providers.

The GSM module exists as the essential component that enables communication links between system users and the system framework. SMS applications enable users to accomplish account recharge while they also query their balance and exercise load control remotely. After receiving the SMS command from the GSM module, the Arduino microcontroller receives through processing updates the account balance. The system re-establishes normal operations after balance update before permitting the load to stay connected until available balance runs out.

Users can enable a low-balance alert system in the system that sends notifications when their account balance reaches predefined warning levels. A buzzer system generates the alert which provides audible notification to users about their charging account requirements. The low-balance alert operates as a vital component which protects from involuntary disconnection by notifying users in advance to perform their necessary recharge. The proactive alerts system both improves user satisfaction levels and helps prevent service breakdowns.

The proposed system depends on its load control functionality for essential operation. Through the system the user can activate remote control of their electrical loads through SMS communication. Consumers maintain control of their loads through this function which enables them to turn them ON or OFF for purposeful energy usage and avoid inefficiency. The system enables users to disconnect a load through SMS commands so they can turn off appliances they forgot while leaving home thus improving energy use efficiency and home safety. The Arduino microcontroller uses the relay module to execute load commands by activating or deactivating electrical devices according to received user instructions.

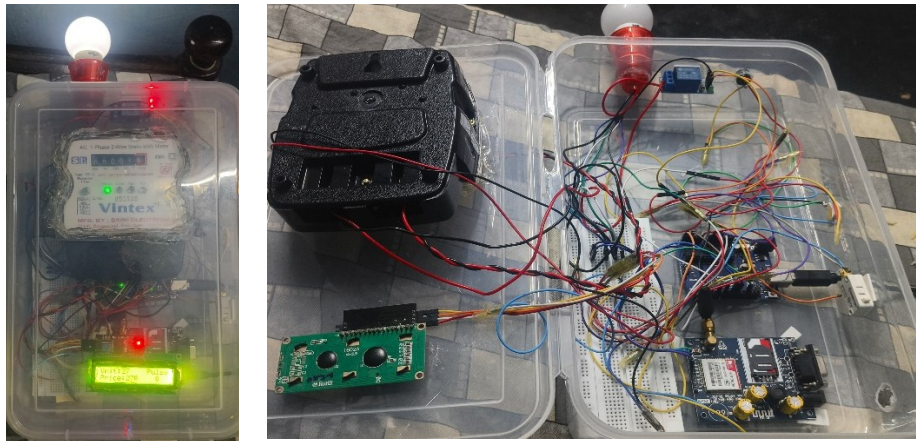
TABLE.1: Features and Functionalities of GSM-Based Prepaid Energy Meter with load control

Feature	Description	Benefits
Prepaid Payment System	Users can recharge the meter in advance to consume energy	Prevent unexpected disconnections
Low balance alert	Send an SMS when the balance reaches a low threshold	Ensure timely recharge prevent cutoff
Zero balance alert	Send an SMS notification when the balance is fully consumed	Notifies the user to recharge immediately
Load control via SMS	Allows load ON/OFF control through SMS commands	Enables remote control of the load
Load Status request	Users can send a command (e.g. Load1 S) to check load status	Confirms whether the load is ON or OFF
Load ON Command	Sending Load1 0 turn the load ON if its off	Ensure remote activation of the load
Load OFF Command	Sending Load1 f turn the load OFF if its ON	Provides load shutdown remotely for safety
Load Details Request	Sending Load1 d gives information about units, price, and power consumption	Provide real-time consumption data
Real-time Monitoring	Display real-time balance, load status, and power consumption	Enables effective usage management

Real-time monitoring and load status inquiry systems provide additional capabilities to improve the system functions. Users transmit SMS inquiries to access real-time data regarding their load conditions coupled with present account balance information. Users gain access to complete system responses that provide them the capability to make knowledgeable choices about their electricity consumption. The system feature supplies useful functionality in handling numerous power loads while delivering live energy measurements which users can access through queries.

5. Results and Discussion

The implementation of the GSM-based prepaid electricity energy meter using Arduino with automatic billing and load control demonstrated significant improvements in energy management and operational efficiency. The system was tested under multiple scenarios to validate its performance, including recharge processing, load control, balance monitoring, and tamper detection.

**Fig.3:** Development of GSM-Based Prepaid Electricity Energy Meter and Load Control

During testing, the system accurately processed recharge requests sent through SMS commands. When the recharge SMS was received, the GSM module successfully transmitted the command to the Arduino microcontroller, which updated the balance accordingly. The system then sent an SMS confirmation to the user, providing details about the updated balance. The balance deduction was consistent with the amount of energy consumed, ensuring accurate and real-time account updates.

The low-balance alert system effectively generated an audible buzzer notification and sent an SMS alert when the balance fell below the predefined threshold. This timely notification allowed users to recharge their accounts before disconnection. In cases where the balance was not replenished, the system automatically disconnected the load to prevent further energy consumption, ensuring that the user consumed only the paid amount.

Load control via SMS commands was also tested extensively. Users were able to turn the load ON and OFF by sending SMS commands such as LOAD ON and LOAD OFF. The system responded promptly by executing the requested action and sending a confirmation message to the user. This remote load control feature proved to be a valuable tool for managing electrical appliances, allowing users to prevent unnecessary power consumption and reduce electricity costs.

The balance inquiry and load status query features provided real-time updates on the account balance and load status. Upon receiving an inquiry SMS, the system accurately retrieved the relevant data and sent an SMS response to the user. This functionality empowered users to monitor their energy usage and make informed decisions about their consumption patterns.

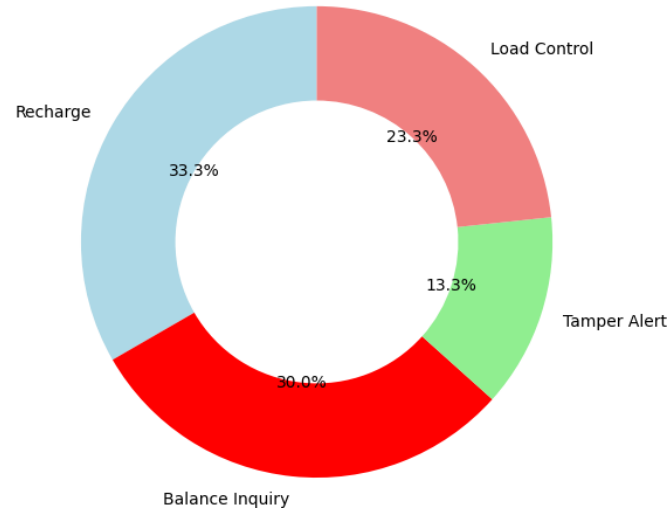


Fig.4: Proportion of Different Operations Performed by the System

The donut chart displays the proportion of various operations performed by the system. It shows which commands were used most frequently, providing a clear overview of system usage.

The system's overall performance was highly reliable, with minimal communication latency and accurate execution of SMS commands. The integration of GSM technology enabled seamless communication between the user and the system, ensuring that operations were carried out without delays. The automated billing process reduced the need for manual intervention, minimizing errors and operational costs.

In summary, the GSM-based prepaid electricity energy meter using Arduino with automatic billing and load control demonstrated robust functionality and efficiency in real-world conditions. The system successfully addressed the challenges associated with traditional postpaid metering systems by introducing prepaid billing, real-time monitoring, and remote load management. This innovative solution not only empowers consumers to manage their energy consumption effectively but also enhances the operational efficiency of utility providers.

Applied and controlled by Arduino microcontrollers the proposed system establishes a dependable system which controls energy consumption monitoring combined with balance updates and also handles load control functionality. Multiple hardware components can be integrated seamlessly into projects by using Arduino which makes it an excellent selection for smart metering systems development. After the microcontroller receives energy data from the meter it adjusts the balance while carrying out directions from GSM module users. The Arduino microcontroller maintains efficient operations and timely execution of all system procedures which improves the entire system reliability.

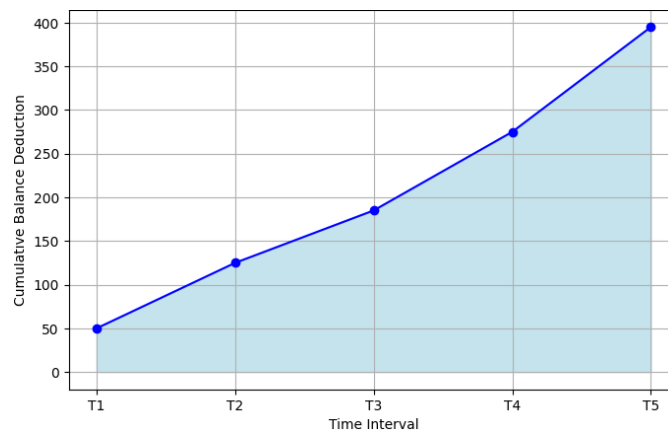


Fig.5: Cumulative Balance Deduction Trend Over Time Intervals

Cumulative Balance Deduction Over Time: This area chart depicts the cumulative balance deduction over time intervals. It visually tracks the increasing balance deductions, helping identify trends and consumption patterns. Any successful prepaid energy metering system must have complete security protocols together with tamper detection capabilities. The system prevents unapproved manipulation through its authentication methods which allow SMS commands to pass through registered telephone numbers only. The system prevents all users except those authorized to operate through an authentication process which performs a dual role of attack prevention and usage safety. The system contains tamper detection sensors which alert operators when unauthorized persons try to modify the meter hardware or circumvent the operational components. The security measure provides an extra protection layer which increases both system reliability and trustworthy operations.

The implemented system provides remarkable economic benefits as its main function. The removal of manual operations in meter reading combined with automatic billing techniques enables utility providers to cut expenses while receiving higher revenue collection rates. Through built-in balance alerts combined with remote control capabilities the system ensures that utility providers receive continuous revenue streams without payment failure or misuse occurrences. The computerized billing system reduces manual oversight which lowers both human mistakes and produces more precise billing results.

6. Conclusion

GSM-based prepaid electricity energy meter developed using Arduino which performs automatic billing functions alongside load control has become an important innovation in energy management systems. This system provides users with a dependable and secure platform that fixes traditional postpaid meter problems through prepaid billing capabilities and instant consumption tracking. The system enables customers who recharge their accounts in advance to receive balance updates and exercise remote control over electrical loads through SMS commands therefore gaining better energy usage control.

The system enables the generation of low-balance notices among its essential features while it disconnects loads automatically upon balance depletion. Users stay aware and disconnected loads are automatically prevented through this system's functionality. Via GSM technology users can maintain hassle-free communication with the system which enables an interactive flexible dashboard to manage their energy use.

The system maintains security through its tampering detection capabilities which verify that only approved users hold access to control the meter. The automatic execution of billing and load control tasks decreases business expenses while getting rid of human errors from manual meter measurements.

A GSM-based prepaid energy meter with automatic billing and load control functions as a sustainable effective and efficient system for contemporary energy management requirements. When deployed it enables better energy resource preservation alongside simplified operations and higher transparency to users and service providers. The system serves as an example for creating high-tech metering systems which will become pervasive in developing advanced and scalable solutions of the future.

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