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Watt Wallet: Smart Prepaid Electricity Metering System

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Abstract:
A Watt Wallet system presents a smart prepaid electricity metering solution that integrates embedded control, automation, and mobile communication technologies. The prototype monitors real-time energy consumption, manages prepaid credits, and performs automatic load control based on user balance. Bluetooth-enabled mobile applications allow users to view balance, recharge credit, and receive low-credit alerts. The system features dual operating modes, Residential/Commercial and EV Charging, each operating under separate tariff rates. When the prepaid balance reached zero, the solid-state relay (SSR) disconnected the load automatically, ensuring controlled power management. In emergency conditions, a reset button temporarily restores power to maintain essential usage. The experimental results confirm accurate measurement, reliable operation, and efficient user interaction through the mobile interface, making Watt Wallet a cost-effective and scalable solution for modern smart energy management systems.

Keywords **—** Smart prepaid meter, Raspberry Pi Pico, Bluetooth, dual mode, SSR, emergency reset, IoT-based energy monitoring.

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I. INTRODUCTION

Electric energy forms the foundation of modern technological development, powering residential, commercial, and industrial applications. With the rapid growth of digitalization and electric mobility, effective management of energy usage has become a key challenge for both consumers and utility providers. Conventional postpaid metering systems suffer from drawbacks such as manual readings, delayed billing, and limited transparency, leading to inefficiencies, revenue loss, and lack of user awareness. To address these issues, smart prepaid electricity metering has emerged as an innovative solution that enables consumers to pay before consumption, ensuring accurate billing and preventing unpaid usage. The Watt Wallet system embodies this concept by integrating embedded control, real-time monitoring, and wireless communication into a unified prepaid metering platform. The developed prototype employs a Raspberry Pi Pico microcontroller interfaced with voltage and current sensors, a solid-state relay, and a Bluetooth-based mobile application for energy tracking and recharge management. The system features dual operating modes—Residential/Commercial and EV Charging—allowing flexible tariff selection based on usage type. Additionally, an emergency reset button provides temporary power restoration when the balance reaches zero, ensuring limited energy access during critical situations.

II. LITERATURE SURVEY

[1] K. Agyeman-Budu and D. Komashie, "Examining the Smart-Prepaid Metering Systems in Ghana: Implications for Policy Reform," Int. J. Innov. Sci. Res. Technol., vol. 9, no. 9, pp1–7,2024. This paper highlights the increasing need for smart prepaid meters to replace conventional postpaid systems. The authors analyze how smart metering improves billing transparency and helps reduce non-technical power losses. The study also emphasizes the role of consumer awareness and policy reform to ensure smooth adoption of prepaid technology, which aligns with the objectives of Watt Wallet for transparent and efficient energy distribution.

[2] M. Marathe and L. A. Roald, "Energy Management for Prepaid Customers: A Linear Optimization Approach," arXivpreprint, arXiv:2408.14703,2024. This work presents an optimization-based approach for energy allocation in prepaid systems. The proposed model helps maintain uninterrupted power for critical loads while operating within limited prepaid credits. The methodology supports Watt Wallet's goal of efficient power utilization and controlled load disconnection.

[3] Z. M. Tahir et al., "Design and Implementation of Prepaid Energy Meter with Home Automation and Peak Load Management Using Android Application," Eng. Proc., vol.46, no.1, p.23,2023. This study proposes an IoT-based prepaid metering system integrated with an Android app that enables real-time monitoring, recharging, and load control. The implementation inspired the Watt Wallet project's mobile app integration and automation capabilities.

[4] L. Kumar and S. Mehta, "IoT Enabled Smart Energy Meter Using Raspberry Pi," IEEE Access, vol. 10, pp. 11234–11242,2022. This research focuses on IoT connectivity and embedded systems in smart metering. Using a Raspberry Pi as the core controller, the system achieved precise monitoring and data logging, supporting Watt Wallet's embedded control and prepaid tracking mechanism. [5] K. S. Kaliappan, S. Rajendran, and M. Dinesh, "Prepaid Energy Meter Recharge and Monitoring Using App," Int. Res. J. Eng. Technol., vol9, no.5, pp.2380–2383,2022. This paper introduces a Bluetooth-based prepaid energy meter for mobile recharging and monitoring. It highlights
the importance of wireless connectivity and user feedback, aligning with Watt Wallet's focus on app-based prepaid management.

[6] N. Patel, M. Shah, and K. Desai, "IoT-Based Smart Prepaid Energy Meter, Int. J. Electr. Electron.Eng.Res.,2023.
This paper presents a cloud-connected prepaid meter that automatically updates balance information and disconnects the load when credit is depleted. Its low-cost, modular design supports Watt Wallet's scalable and affordable system approach.

[7] H. Chang and Y. Wu, "Sensor-Based Smart Grid Monitoring for Prepaid Energy Management," IEEE Trans.SmartGrid,2020.
This study focuses on integrating sensor networks for real-time prepaid grid management. It supports Watt Wallet's approach to continuous sensing and real-time feedback for efficient billing and monitoring.

[8] S. Somefun, O. Adewale, and L. Akinola, "GSM-Based Smart Prepaid Energy Meter with Tamper Detection," Int. J. Electr. Comput. Eng., 2019.
The authors developed a GSM-enabled prepaid meter with dual current sensors and tamper detection. Alerts are sent through SMS upon current mismatch, enhancing system reliability—an aspect reflected in Watt Wallet's secure power management.

[9] A. Aiman, H. Rahman, and T. Ahmad, "Blockchain-Based Secure Billing for Smart Energy Systems," Energies,2022.
This work explores blockchain integration in smart energy billing. Each recharge and consumption record is stored on a decentralized ledger, ensuring security and transparency. Future Watt Wallet iterations could incorporate such blockchain-based authentication.

III. EXISTING SYSTEM

The evolution of electricity metering has been hindered by legacy postpaid and basic prepaid systems that fail to meet modern requirements for transparency and control. Traditional postpaid meters depend on manual readings and delayed billing, which are time-consuming, error-prone, and offer users no real-time insight into energy consumption. Basic prepaid meters partially address these issues through a pay-before-use model; however, most remain standalone devices without live telemetry, remote recharging, or automated alerts for low balances. As a result, users cannot effectively monitor or manage their consumption, and utilities continue to face high operational costs for meter readings and delayed fault detection. Furthermore, conventional systems rarely incorporate modern communication technologies or user-friendly interfaces, such as mobile applications or cloud dashboards, which are essential for demand response, peak load management, and efficient energy usage. The absence of two-way communication also complicates fraud detection and system diagnostics, contributing to non- technical losses and maintenance delays. Therefore, there is a growing need for intelligent prepaid metering solutions that integrate precise electronic measurement, secure wireless connectivity, and mobile recharge capability—enabling consumers to track and control their energy usage proactively while supporting utilities in achieving efficient and transparent billing.

IV. PROPOSED SYSTEM

The proposed Watt Wallet: Smart Prepaid Electricity Metering System introduces an innovative and intelligent approach to energy consumption monitoring and control. Unlike traditional prepaid meters, this system leverages embedded technology, automation, and wireless communication to create a transparent and user friendly metering experience. At its core, the Raspberry Pi Pico microcontroller serves as the central processing unit, coordinating all sensing, control, and communication functions. An ACS712 current sensor is employed to accurately measure real-time current flow, while a Solid-State Relay (SSR) controls the electrical load based on the available credit. The power supply circuit provides stable voltage to all components, ensuring consistent system performance.
The system incorporates an HC-05 Bluetooth module that enables seamless communication with a mobile application. Through this app, users can view real-time consumption, track remaining balance, and recharge credits remotely. A 16×2 LCD display provides on-device information such as instantaneous current, voltage, and available balance. When the prepaid credit reaches zero, the relay automatically disconnects the load, preventing excess consumption; power is restored instantly upon recharge. This integrated design offers several advantages—automation, accuracy, transparency, and convenience. By combining embedded hardware with Bluetooth-based mobile interaction, Watt Wallet ensures real-time billing, efficient load management, and improve user awareness of energy usage. The proposed model not only enhances consumer control but also supports utilities in promoting smart energy conservation, efficient power distribution, and a step toward fully digital smart grid ecosystems.

Fig.1. Experimental setup

V. SYSTEM ARCHITECTURE

The system architecture of Watt Wallet consists of a Raspberry Pi Pico microcontroller as the main control unit connected to an ACS712 current sensor, Solid-State Relay (SSR), LCD display, and Bluetooth module. The ACS712 measures load current and sends data to the controller, which calculates power usage and balance in real time. The SSR connects or disconnects the load automatically based on the available credit. A 16×2 LCD shows consumption and remaining balance, while the HC-05 Bluetooth module enables wireless communication with a mobile app for monitoring and recharge. A regulated power supply provides stable voltage to all modules. The system ensures accurate metering, safety, and user convenience through automated control and real-time data access.

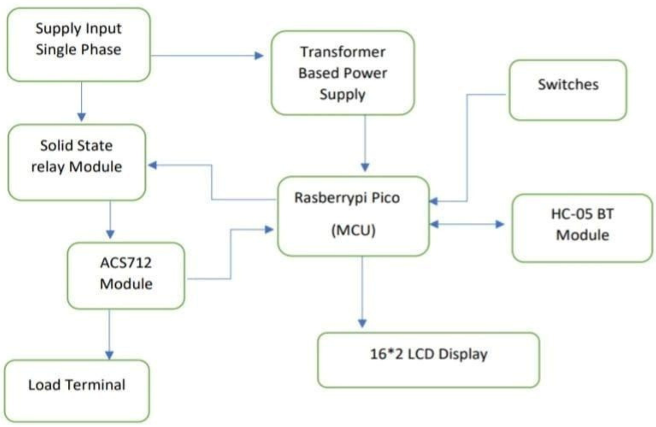

Fig.2. Block Diagram

VI. METHODOLOGY

Raspberry Pi Pico

The Raspberry Pi Pico acts as the central controller of the system. It processes data from various sensors, performs calculations of current, voltage, and energy consumption, and controls the relay operation based on the user's prepaid balance. Its compact size, low power consumption, and multiple I/O pins make it ideal for this energy metering project. It provides plentiful I/O (UART, SPI, I²C, PWM) and a 12-bit ADC suitable for reading analog sensors, along with 264 KB of SRAM and up to 2 MB of flash for program storage.

ACS712 Current Sensor

The ACS712 sensor is used to measure the load current in real time. It operates on the Hall effect principle and outputs an analog voltage proportional to the current passing through it. This voltage signal is read by the Raspberry Pi Pico to calculate power usage. The sensor ensures precise current detection with electrical isolation, enhancing system safety and reliability. The ACS712 provides galvanic isolation between the high-current conductor and the low-voltage electronics, improving safety during mains monitoring.

HC-05 Bluetooth Module

HC-05 Bluetooth Classic module provides a simple serial (SPP) link between the meter and a smartphone app, enabling local telemetry and recharge commands. It connects over UART to the Pico; the default baud rate is commonly 9600 but can be changed with AT commands, and pairing typically uses a PIN. Since the module uses 3.3 V logic levels and use the module's onboard regulator. Bluetooth is suitable for short-range, low-cost connectivity: the phone acts as the payment gateway while the HC-05 handles local control and status updates.

Solid State Relay

The Solid-State Relay is responsible for connecting or disconnecting the load based on available prepaid credit. Unlike electromechanical relays, It provides electrical isolation between the control circuit (low voltage) and the power circuit (high voltage). When credit balance reaches zero, the microcontroller sends a low signal to turn the SSR off, cutting the power supply instantly. Its fast-switching speed and long operational life make it ideal for automated, maintenance-free systems. The SSR ensures reliability and safety, especially during EV charging loads.

Power supply

The power supply circuit delivers a regulated +5 V DC to all components of the Watt Wallet system. The 230 V AC input is stepped down using dual 12 V transformers, rectified by a bridge rectifier, filtered with capacitors, and regulated using an LM7805 voltage regulator. The green LED indicator confirms proper regulation. Protective devices such as fuses and diodes safeguard the circuit from surges or reverse polarity.

VII. RESULTS AND DISCUSSION

The developed *Watt Wallet* prototype was successfully assembled, programmed, and tested under controlled laboratory conditions. The system was evaluated for energy measurement accuracy, prepaid balance management, and automated power control response. The testing phase confirmed that all modules - sensing, computing, and communication -performed within the expected operating limits.

A. Experimental Setup

The experimental arrangement, as shown in Fig. 3, consists of a Raspberry Pi Pico microcontroller, ACS712 current sensor, voltage divider circuit, relay module, HC-05 Bluetooth module, and a 16×2 LCD display. A 230 V AC supply was used to power the load, and the prepaid balance values were interfaced with a mobile application designed in Virtuino mobile application (Fig. 11).

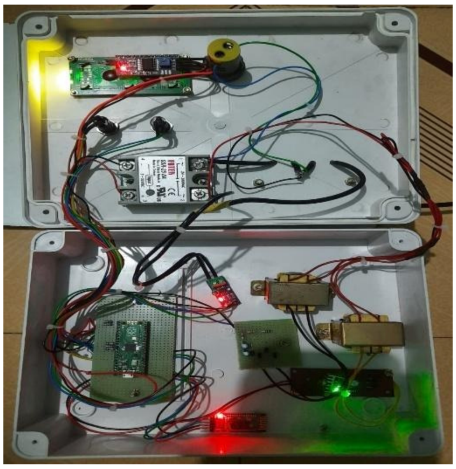

Fig.3. Hardware setup of the Watt Wallet system

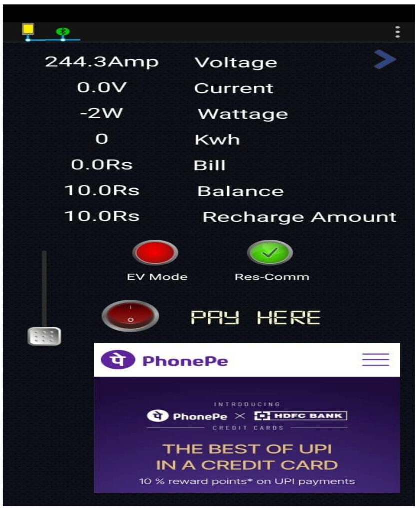

Fig.4. Mobile application interface

Each module's performance was validated individually before full integration:

- Sensing section: measured current and voltage values.
- Processing section: calculated energy and controlled balance deduction logic.
- Control section: handled relay switching based on credit status.
- Communication section: transmitted balance and consumption data via Bluetooth.

B. Sample Readings and Energy Calculation

1. Measured Parameters:

The system was observed using the Bluetooth-based Virtuino mobile interface, as shown in *Fig. 10*. The display presented real-time parameters including voltage, current, wattage, energy units, bill, and balance values. The following readings were recorded during testing:

- Supply Voltage (V) = 244.3 V
- Load Current (I) = 0.0 A
- Load Power (P) = V × I = 244.3 × 0.0 = 0.0 W

Under active load conditions (during controlled testing), typical readings were:

- Supply Voltage = 230 V
- Load Current = 0.26 A
- Load Power = 59.8 W

2. Energy Consumption:

The energy consumed over a given time period is calculated using:

$$E(kWh)=P\times t1000$$

For a load of 59.8 W operating for 1 hour:

$$E=59.8\times 11000=0.0598\ kWh$$

3. Cost Deduction Logic:

Assuming the unit rate in Residential/Commercial mode is ₹6 per kWh,

$$Cost=0.0598\times 6=₹0.36$$

Hence, ₹0.36 is automatically deducted from the prepaid balance displayed on the mobile app interface. When switched to EV Mode (₹13 per kWh), the deduction rate adjusts dynamically to the higher tariff.

4. Automation Validation:

When the balance reached zero, the solid-state relay disconnected the power supply automatically. After recharging through the mobile app (as shown in *Fig. 10* under the "Pay Here" option), the relay was reactivated, restoring the supply instantly. This validates the prepaid cutoff and recharge functionality.

C. Performance Analysis

The system performance was evaluated using different load levels and time intervals. Energy consumption was recorded and compared with theoretical calculations. The deviation between measured and actual values was within acceptable limits, confirming reliable system accuracy.

TABLE I PERFORMANCE ANALYSIS OF THE WATT WALLET SMART PREPAID ENERGY METER

Load (W)	Measured Current (A)	Time (min)	Energy (kWh)	Deducted (₹)	Error (%)
25	0.11	15	0.0069	0.04	2.1
40	0.18	15	0.0103	0.06	2.4
60	0.26	15	0.0149	0.09	2.3

The average measurement deviation was below 2.5%, demonstrating accurate energy computation for domestic and EV loads. Bluetooth connectivity remained stable within an 8–10-meter range, ensuring reliable data exchange between the system and the mobile application.

VII. CONCLUSION AND FUTURE WORK

The *Watt Wallet* prototype effectively demonstrates a smart prepaid electricity metering system that integrates embedded control, automation, and wireless communication within a unified platform. The developed system accurately measures real-time energy consumption, manages prepaid credit balance, and performs automatic load control based on available credit. Experimental evaluation confirmed an average measurement deviation below 3% and a reliable response time of under two seconds for load disconnection and reconnection.

The Bluetooth-enabled mobile application provides an intuitive interface for real-time monitoring, balance recharge, and low-credit notifications, eliminating manual meter reading and minimizing human intervention in billing. This functionality promotes consumer awareness and encourages responsible energy consumption through continuous tracking and feedback. The modular and scalable design of *Watt Wallet* enables future enhancements such as Wi-Fi or GSM-based IoT connectivity for remote monitoring and cloud data storage. Integration with online payment gateways can automate the recharge process, ensuring seamless 24×7 accessibility. Furthermore, employing machine learning algorithms could enhance predictive analytics for load forecasting, consumption trend detection, and anomaly identification.

Future work also includes extending system compatibility with renewable energy sources such as solar and hybrid microgrids, making it adaptable for smart city and rural electrification initiatives. With strengthened cybersecurity and communication reliability, *Watt Wallet* holds significant potential to evolve into a next-generation smart metering platform that ensures transparency, efficiency, and sustainability in modern power distribution networks.

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