

# Design of Smart Electricity Meter System Based on Internet of Things (IoT) Technology

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**Abstract:** With the rapid development of Internet of Things technology, smart home system has become one of the hotspots of research and application. In this context, this paper proposes a smart meter system design scheme based on the Internet of Things technology, aiming to realize the efficient management and use of household electric energy. The system consists of four parts: smart meter, data collection unit, control center and user interface. The smart meter is responsible for real-time monitoring and recording of power usage, and the data collection unit is responsible for sending the collected data to the control center, which analyzes and processes the data, and finally displays the power usage to the user through the user interface and provides energy-saving suggestions. The system uses wireless communication technology to realize the communication between the meter and the data collection unit, and uses cloud computing technology to store and analyze a large amount of data collected to support the remote monitoring, data analysis and fault warning of the use of electric energy. In addition, the design also considers the problem of data security, and adopts encryption technology to ensure the security of data transmission. After testing, the smart meter system can accurately monitor and record the home power consumption, users can remotely view the power consumption report through mobile phones or computers, and the system can also provide energy-saving suggestions according to the power consumption, which helps users save electricity and realize the efficient use of home power.

**Keywords:** Internet of Things technology; Smart meters; wireless communications; Real-time monitoring

## 1. INTRODUCTION

Amid global climate imperatives and "dual carbon" commitments, nations are accelerating the shift from fossil fuels to renewables. Major economies—including the EU (Fit for 55), the U.S. (Inflation Reduction Act), and China (14th Five-Year Plan)—have set aggressive decarbonization targets, driving power systems toward "source-grid-load-storage" interactivity. As smart grid "nerve endings," smart meters are pivotal, enabling bidirectional communication, demand response, and efficient energy allocation. The IEA projects over 70% global household smart meter penetration by 2030, cementing their role in energy digitization [1].

Traditional electromechanical meters suffer from manual reading delays, no user-grid interaction, and inability to capture granular behavior. Modern grids, however, demand real-time monitoring (e.g., for distributed PV, EV charging) and edge intelligence. IoT integrates sensors, LPWANs (NB-IoT/LoRa), and edge computing, transforming meters into intelligent terminals. This leap enables high-fidelity data collection critical for grid precision and user optimization [2].

IoT smart meters face universal hurdles: protocol fragmentation (Zigbee/NB-IoT/LoRa incompatibility), data deluge straining cloud processing, and privacy risks in distributed systems. China, the world's top electricity consumer (>8 trillion kWh/year), urgently needs a tailored yet globally compatible solution. This work addresses these via a multi-protocol gateway, edge-cloud collaboration, and end-to-end encryption. It enhances grid efficiency, empowers users with actionable insights, and offers a replicable model for global decarbonization, aligning with UN SDGs.

## 2. OVERALL DESIGN OF THE SYSTEM

This design constructs an intelligent electric energy meter system based on the STM32 microcontroller, with the STM32

servicing as the core control unit. It integrates multiple functional circuits: a step-down circuit (providing stable 3.3V/5V power supply), a voltage and current acquisition circuit (sampling electrical parameters in real time via voltage division, current transformers, and signal conditioning circuits and transmitting them to the STM32 analog-to-digital converter (ADC)), a relay control circuit (driven by the STM32 general-purpose input/output (GPIO) to manage load on/off states via solid-state relays), and a Wi-Fi module circuit (e.g., ESP8266, communicating with the STM32 via Universal Asynchronous Receiver/Transmitter (UART) to enable remote data upload and command reception). These modules collaboratively achieve real-time current monitoring, fault response, and remote management functions. When internal faults such as overcurrent or voltage exceedance are detected, the system immediately triggers a sound-and-light alarm and uploads fault codes, electrical parameter snapshots, and contextual information to host computer software via the Wi-Fi module to notify users promptly.

Additionally, it supports local human-machine interaction: users input commands via a keypad, which generates electrical signals transmitted to the MCU. The MCU parses these instructions to trigger corresponding functions (e.g., querying status, resetting faults), working in conjunction with a display module to form a "keypad command → MCU processing → hardware response" local closed-loop operation. Ultimately, this design establishes an Internet of Things (IoT)-enabled intelligent electric energy meter solution integrating precise monitoring, intelligent alarming, remote control, and local interaction. The system framework is shown in Figure 1.

## 3. PROJECT DESIGN

### 3.1 STM32f103 chip introduction

The STM32F103 is a high-performance microcontroller belonging to the STM32 series produced by

STMicroelectronics. Based on the ARM Cortex-M3 core, it combines high performance and low power consumption, making it the preferred choice for many embedded systems and intelligent devices. It has a maximum operating frequency of 72MHz, supports up to 128KB of flash memory and 20KB of SRAM, and features excellent storage and processing capabilities. In addition, it is equipped with a variety of peripheral interfaces, such as multiple UART, I2C, and SPI interfaces, as well as a 12-bit analog-to-digital converter (ADC), enabling the STM32F103 to connect and control various sensors and external devices.

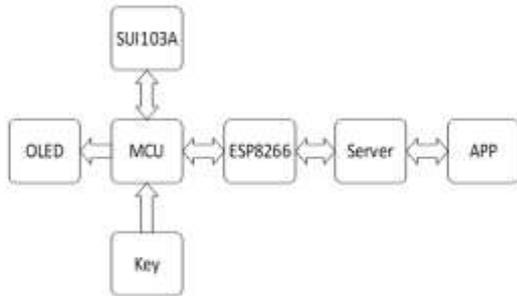


Figure. 1 The overall system framework consists of three modules

### 3.2 ESP8266 Module Introduction

The ESP8266 is a highly integrated Wi-Fi chip characterized by low cost, high integration, and robust networking capabilities, making it particularly suitable for Internet of Things (IoT) application scenarios. As a classic choice for IoT communication modules, its core advantage lies in achieving stable wireless connectivity with an extremely simplified hardware architecture—it can not only collaborate with external microcontrollers via serial interfaces such as UART and SPI but also function independently as a main controller to drive simple applications, significantly reducing the development threshold and cost of IoT projects.

At the hardware level, the ESP8266 integrates a 32-bit Tensilica L106 microprocessor with a maximum clock frequency of 80 MHz, delivering computational performance sufficient for most lightweight IoT tasks. It comes with various memory configurations; common versions are equipped with 512KB to 4MB of SPI flash memory, supporting user program storage and data caching. Boasting abundant interface resources, it features multiple general-purpose input/output (GPIO) pins that support communication protocols such as digital I/O, PWM, I2C, and SPI, enabling flexible expansion of peripherals like sensors and actuators. Additionally, it integrates a UART interface, supporting full-duplex serial communication with other microcontrollers or host computers to facilitate system-level data exchange and debugging. This integrated design of "wireless connectivity + processing performance + abundant interfaces" positions it as an ideal choice for low-cost IoT solutions.

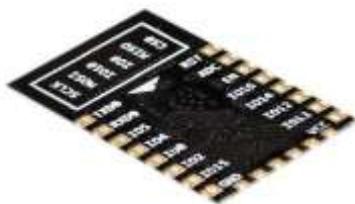


Figure.2 WiFi Function and Circuit Design

### 3.3 SUI-101A AC transducer

The SUI-101A AC transducer is a high-precision alternating current transducer capable of high-fidelity acquisition of multiple electrical parameters, including voltage, current, active power, power factor, frequency, and energy consumption. It features low power consumption, excellent real-time performance, and user-friendly operation, while incorporating high-voltage isolation technology to facilitate safe measurement by isolating high-voltage circuits from low-voltage measurement ends. This design ensures both accuracy in parameter monitoring and safety in practical applications, making it an ideal choice for power system monitoring, industrial automation, and smart metering scenarios requiring reliable electrical data acquisition.

This design is engineered for an operating temperature range of -40°C to 85°C, with a supply voltage of 5V DC  $\pm 0.2V$  and a maximum operating current of 15mA. It supports a maximum measurable AC voltage of 400V and offers selectable maximum measurable current ranges, including 5A, 15A, 30A, 60A, and 100A. In terms of measurement accuracy, the current and voltage transducers achieve Class 0.2 precision, while active power and energy measurements maintain Class 0.5 accuracy. For data transmission, the system adopts a 3.3V TTL serial interface (5V-compatible) and supports intelligent protocol identification for Modbus-RTU or custom lightweight protocols, ensuring efficient and stable data exchange via serial communication.

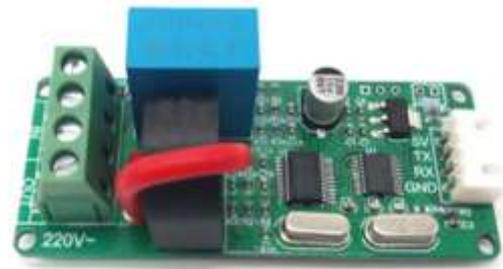


Figure.3 SUI-101A AC Transducer.

## 4. SOFTWARE SYSTEM DESIGN

This system is built around the STM32F103C8T6 core board, with control programs developed using the Keil5 IDE and standard C language. It communicates with the SUI-101A AC transducer via UART2 to acquire electrical parameters (voltage, current, power, etc.), which are stored in memory and displayed on an OLED screen. Data is then transmitted to a remote server via UART3 using an ESP8266 Wi-Fi module.

A dedicated mobile APP can fetch and visualize this server-stored data, while also sending control commands to the server. These commands instruct the MCU to toggle relays, enabling remote on/off control of connected appliances. Local control of appliances is additionally supported via onboard buttons.

The host computer monitoring software is developed using HBuilderX—a lightweight yet powerful front-end integrated development environment (IDE) created by DCloud, tailored for modern front-end development. HBuilderX supports diverse front-end technologies (Vue.js, UniApp, HTML5, CSS, JavaScript, etc.) and integrates plugin-compatible compiler tools to provide flexible development interfaces, simplifying the coding process. For web projects, compiled static files can be directly uploaded to servers or static resource hosting platforms. Notably, HBuilderX incorporates

built-in FTP/SFTP functionality, allowing seamless file uploads to servers directly within the IDE.

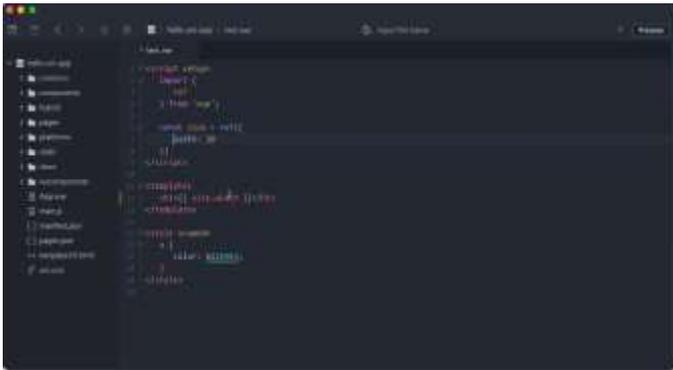


Figure.4 The compilation interface of HBuilderX.

## 5. System Implementation and Debugging

This system realizes functions including voltage and current display, accumulated electricity consumption monitoring, power display, and key control of electrical appliance switching at the local end. The mobile APP displays parameters such as voltage, current, power, frequency, electricity consumption, and appliance switching status transmitted from the local end, while providing control buttons. Functional tests were conducted on all modules. During debugging, due to unstable hardware I<sup>2</sup>C protocol timing of the STM32, software simulation was adopted to ensure stable I<sup>2</sup>C communication. The selected 0.96-inch I<sup>2</sup>C OLED display has no built-in Chinese character library. First, official 51 single-chip microcomputer example code was used to verify basic display functions; then, display logic was debugged using English characters; finally, PCtoLCD2002 was utilized to extract dot matrix data for Chinese characters, achieving Chinese display.

During testing of the voltage and current acquisition module, a space heater was connected, and the relay was controlled via the MCU to turn on the appliance. After the heater operated normally, the MCU sent a data read command {0x55,0x55,0x01,0x02,0x00,0x00,0xAD} via the serial port, parsed the received data, and displayed it on the OLED, verifying the accuracy of data acquisition by the SUI101A module.

Tests on data transmission and control showed that data read by the MCU was forwarded to the mobile APP via the cloud platform. The APP successfully displayed parameters such as voltage and current, and could control the on/off state of electrical appliances through switches.



Figure. 5 Results shown on the screen



Figure.6 Mobile App Operation Interface Screenshot

## 6. Conclusion

The design of an IoT-based smart electricity meter system involves multiple stages, including hardware selection and assembly, software development and debugging, as well as integrated hardware-software debugging. It aims to provide an efficient, reliable, and user-friendly solution for electrical energy measurement and management. Through a comprehensive analysis of the meter's performance evaluation, function implementation, user experience, and potential areas for improvement, the following conclusions are drawn:

The system performs excellently in core functions such as electrical energy measurement accuracy, real-time data processing, overload protection, fault detection, and remote meter reading, meeting the requirements of modern power management. User feedback indicates that the system has received high praise for its ease of use and convenience, particularly in terms of remote operations and electricity fee management. However, there is room for further optimization in the user interface and interaction design, and there is a demand for improved responsiveness in technical support and system maintenance.

The IoT-based smart electricity meter system demonstrates strong potential and broad application prospects. Through continuous technological innovation and integration of user feedback, it is expected to play a more significant role in the field of smart energy management.

## 7. REFERENCES

- [1] Moorthy, V. M., Muthukumar, B. M., Britto Manoj, R. C. S., & Arul Elango. 2024. Design of a Smart Energy Meter and Monitoring System for Industrial and Residential Use Based on the Internet of Things. IEEE .
- [2] Munoz, O., Ruelas, A., & Rosales, P. 2022. Design and Development of an IoT Smart Meter with Load Control for Home Energy Management Systems. Sensors, 22 (19), 7536.
- [3] Moorthy, V. M., Muthukumar, B. M., Britto Manoj, R. C. S., & Arul Elango. 2024. A Secure and Resilient Smart Energy Meter. IEEE Access, 12.
- [4] Ben Dhaou, I. 2023. Design and Implementation of an Internet-of-Things-Enabled Smart Meter and Smart Plug

- for Home-Energy-Management System. *Electronics*, 12 (19), 4041.
- [5] Abdulhakeem, O. O. A., Abdulwaheed, M., & Nasir, F. 2023. Development of Internet of Things Circuitry for Intelligent Interactions of Smart Meters with Users. 2023 2nd International Conference on Multidisciplinary Engineering and Applied Science (ICMEAS). IEEE.
- [6] Haque, M. M. U., Choudhury, Z. H., & Alamgir, F. M. Q. 2019. IoT Based Smart Energy Metering System for Power Consumers. 2019 2nd International Conference on Innovation in Engineering and Technology (ICIET). IEEE.
- [7] Saha, S., Mondal, S., Saha, A., & Purkait, P. 2019. Design and Implementation of IoT Based Smart Energy Meter. 2018 IEEE Applied Signal Processing Conference (ASPCON). IEEE.
- [8] Bilal Shahid, Z. Ahmed, A. Farooqi, R. M. Navid-ur-Rehman. 2012. Design and Implementation of a New Monitoring System for Electrical Energy Consumption with Smart Metering Based on Internet of Things (IoT). Iranian Conference on Smart Grids.
- [9] Choo, Z. R., Leong, H. Y., & Tan, R. H. G. 2022. Design and implementation of IoT-enabled smart single-phase energy meter monitoring system. *Artificial Intelligence and Internet of Things for Renewable Energy Systems*. DeGruyter..