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Design and Improvement of Intelligent IoT Meters and Embedded Operating Systems

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Abstract

This paper primarily discusses the development status of State Grid smart IoT meters and the issues existing in the design and application of embedded operating systems. The text mentions that the low procurement volume of State Grid smart IoT meters has long been a challenge for the electricity meter industry, and analyzes this issue from multiple perspectives. Among these, smart IoT meters employ an embedded operating system platform, but several problems and controversies exist, such as high costs, poor reliability, and low efficiency of general-purpose operating system architectures. Simultaneously, smart IoT meters are also relatively expensive, and the positioning of extended functions is not sufficiently accurate. The text references discussions by industry experts on the design and application issues of embedded operating systems for smart IoT meters. Experts believe that the current embedded operating systems for smart IoT meters do not exhibit much innovation, and the adoption of general-purpose operating system architectures may lead to problems such as low efficiency, inconvenient application, and difficulty in ensuring long-term operational reliability. Furthermore, smart IoT meters are relatively expensive, and the positioning of extended functions is not sufficiently accurate; for instance, the selection of functions such as non-intrusive load identification may not actually be necessary in practical applications. During the discussions, experts also proposed views and recommendations regarding the embedded operating systems for State Grid smart IoT meters. They believe that operating system design should be customized according to the characteristics and requirements of electricity meters, rather than simply adopting general-purpose operating systems. Additionally, operating system reliability and compatibility are also important factors requiring consideration. The text also mentions that discussions on the design and application issues of State Grid smart IoT meter embedded operating systems have been ongoing, and emphasizes the importance of reliability design for smart IoT meter operating systems. Meanwhile, the text also mentions industry experts' discussions and recommendations on the design and application issues

of smart IoT meter embedded operating systems, as well as the importance of reliability design for smart IoT meter operating systems.

Full Text

Design and Improvement of Smart IoT Meters and Embedded Operating Systems

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Abstract

This paper examines the development status of State Grid's smart IoT meters and identifies critical issues in the design and application of their embedded operating systems. The persistently low bidding volume for these meters has emerged as a major challenge for the industry. Key problems include high costs, questionable reliability, and low efficiency resulting from generic operating system architectures. Additionally, the meters' extended functionality lacks precise market positioning, with features such as non-intrusive load identification proving unnecessary for many provincial grid applications. Through extensive industry discussions, experts argue that current embedded operating systems lack innovation and that generic architectures compromise efficiency, usability, and long-term reliability. The paper concludes with recommendations for customizing operating systems to meter-specific requirements and establishing comprehensive reliability and compatibility standards.

Keywords: Smart IoT meters, Embedded operating system

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1. The Challenge of Low Bidding Volume for State Grid Smart IoT Meters

Between 2022 and 2023, the smart IoT meter bidding volume for State Grid remained disappointingly low, representing a persistent obstacle to industry development. Several factors contributed to this situation.

First, the bidding statistics reveal minimal market penetration. In 2020, the inaugural bidding volume was only 19,500 units. This grew to 130,500 units in 2021, and reached 1.374 million units in 2022—yet this figure represents merely 2% of the total annual smart meter procurement (69.74 million units for the 2020 standard). Second, while smart IoT meters represent an innovative next-generation design, particularly with their management modules adopting embedded operating system platforms for the first time, these systems face significant skepticism. Despite claims of stability and freedom from intellectual property concerns, their generic operating system architecture results in relatively low efficiency, inconvenient application development, and unproven long-term reliability. Third, pricing remains prohibitive, with smart IoT meters costing roughly double that of standard 2020-version smart meters. Fourth, the extended functionality lacks precise positioning; for instance, non-intrusive load identification—selected as a primary feature—is not actually essential for provincial grid operations.

Consequently, meter manufacturers urge State Grid to promptly improve the design of both the smart IoT meters and their embedded operating systems to expand bidding volumes and advance the industry.

2. Industry Discussions on Embedded Operating System Design and Application

2.1 Initial Problem Identification (June 2022) On June 2, 2022, the authors' article "Landis+Gyr: Advancing the Next-Generation E360 Smart Meter Series (with IoT Communication Technology)" sparked intense expert discussion regarding domestic smart IoT meter design flaws. Industry specialists identified several critical issues: the high cost and extremely poor reliability of the management chip; lack of innovation in the embedded operating system, which appeared to be merely a derivative of uCOS and Linux; and the inherent unreliability of operating systems with process scheduling and stack overhead, making them unsuitable for electricity meters and demanding power products. Experts emphasized that all operating systems ultimately run programs in RAM, which must be copied from ROM during startup. Since RAM consists of digital flip-flops potentially vulnerable to interference, robust design is essential to prevent anomalies under extreme conditions.

A subsequent discussion on June 7, 2022, questioned whether current embedded operating systems could even be applied to State Grid's 2020-version smart meters. Participants argued that the complex kernel was unnecessary for meter applications, and that meter-specific issues and requirements should be integrated into the operating system itself. Relying solely on system experts to develop specialized operating systems would be problematic. While Yihui's operating system could be used for metering, its efficiency was relatively low. Compatibility issues between any operating system and applications increase design difficulty, requiring comprehensive testing of the entire application environment to ensure proper functionality. The resource allocation between generic operating systems and applications is not an optimized solution; a customized high-frequency, low-cost ARM9 core chip would be more feasible. Concerns were also raised about Linux systems running code in RAM—if RAM anomalies occur, system crashes may result. In contrast, Hanyuan's MOS embedded operating system, derived from bare-metal meter software, was presented as an alternative based on modular meter software systems.

2.2 Technical Specification Analysis (July 2022) On July 9, 2022, the authors published "Interpretation and Discussion on the Development and Application Process of Smart IoT Meter Operating Systems for State Grid," offering perspectives on the "Smart Meter Function and Software Specification (Q/GDW 12180-2021)"—hereafter referred to as the "State Grid 12180 Specification." The specification outlines requirements for management module operating systems and application software, including multi-function capabilities, application software development requirements, generic operating system architecture selection, kernel microcontroller requirements, POSIX standard interfaces, and performance/testing criteria. It also specifies required applications: basic applications, system management programs, security service programs, and extended applications.

However, the specification has notable deficiencies: it fails to define unified management module function codes, does not specify which company's generic operating system product should be selected or address its advantages and problems in smart IoT meter applications, and lacks clarity on process management, memory management, device drivers, file systems, and network systems within the chosen generic operating system. These unspecified technical requirements compel meter enterprises to digest and familiarize themselves with State Grid's selected platform before determining function codes, developing application software, and ensuring proper operation. These ambiguities have triggered significant technical disputes among software experts regarding the operating system design and application.

On July 12, 2022, experts emphasized that smart IoT meter operating system reliability must be considered from a system-wide design perspective. While Hanyuan's MOS operating system has implemented numerous improvements to address reliability issues—such as stack overflow protection and application data protection—these are essentially patches. True reliability requires extensive design efforts in both system and application layers. The fundamental question remains: why not consider reliability and development convenience from a system-level perspective instead of adding complex algorithms to traditional operating systems at high cost? Hanyuan's MOS system achieves all operating system characteristics with the most streamlined architecture, minimalist design, and lowest cost, yet faces skepticism from traditional operating system experts simply because it differs from conventional approaches.

2.3 HarmonyOS and Alternative Solutions (September–December 2022) By September 26, 2022, discussions turned to whether Huawei's HarmonyOS could address practical meter application problems, noting its successful deployment in coal mining and transportation industries. HarmonyOS, officially released on August 9, 2019, is a microkernel-based, full-scenario distributed operating system where only basic scheduling and memory management reside in the microkernel, while file systems are implemented as user-mode daemon processes. Currently applied primarily in mobile phones and IoT devices, its relevance to meters was questioned.

On October 9, 2022, experts identified key pain points for the meter industry from the perspective of electrical research institutes and State Grid: non-uniform standards due to updates, multi-protocol compatibility requirements, inability to maintain software bugs necessitating field replacements, underdeveloped data analysis capabilities post-metering, and lack of strong 话语权 (decision-making power) in device protocols. Recommendations included learning from China Tower's explorations. With the promotion of electricity spot market transactions, new performance requirements emerged. The core function of meters is metering—other functions should extend from this foundation within resource and cost constraints. Function expansion modules can be hardware or software, but the premise is that software extensions must not affect basic metering functions.

On November 29, 2022, experts evaluated domestic meter operating systems: Yihui, Zhixin, Southern Grid Silk Road, and Hanyuan. Zhixin's Hub 4.0, based on Linux, exhibited freezing during testing in circuit breaker products. Hanyuan's team attempted to incorporate MOS advantages into Hub 4.0 but failed due to system complexity. Compared to uCOS and FreeRTOS microkernel systems, Yihui's system has some advantages, but shows clear disadvantages against Hanyuan's MOS, particularly in APP universality across Cortex-M series chips—Hanyuan achieves this while Yihui does not.

The following day, discussions addressed HarmonyOS's meter application potential. Experts noted that HarmonyOS and meters serve different scenarios; Huawei's LiteOS (a lightweight IoT operating system released in 2015, with a 10KB footprint) would be more suitable for meters and switches after secondary development. LiteOS's basic kernel includes tasks, memory, timing, hardware-related functions, IPC communication, and task synchronization, but lacks lightweight processes and microcontroller MPU protection. Meters don't require HarmonyOS's cross-platform capabilities, fancy UI, or high information security. Questions arose about running OpenHarmony on M0 cores, though Toshiba had pioneered ARM Cortex-M0 microcontrollers specifically for smart meters with built-in power calculation engines—a significant innovation demonstrating that meter design could integrate with embedded operating systems.

Experts proposed that OpenHarmony-based meters could be defined as next-generation IoT meters or smart meters, capable of interacting with home devices, enabling demand response, and coordinating with photovoltaics. The architecture would use HPLC for upstream communication and WiFi for home networks, with OpenHarmony using Bluetooth for device authentication and self-networking. However, the fundamental question remained: what kind of embedded operating system truly suits electricity meters? Early research had ported operating systems to meters without mass application. Since meters primarily perform acquisition and control without UI requirements, and connectivity trends favor independent external modules, operating systems seemed unnecessary. Yet if meters are defined as cross-generation devices, the operating system and kernel are distinct—meters may only need the kernel.

2.4 Industry Pain Points and Development Prospects (December 2022) On December 3–4, 2022, discussions focused on whether operating systems could address existing meter pain points. Hanyuan's MOS operating system claims 100% independent intellectual property rights with fully controllable code and comprehensive security mechanisms. However, experts questioned whether operating systems could solve fundamental problems: power equipment requires over a decade of operation without reset—a standard no operating system has yet achieved. If traditional operating systems were applicable, international leaders like Landis+Gyr would have already implemented them. Meter technology is relatively simple, with decade-old designs still in use. The core issues are RAM reliability, low-cost high-reliability design, and lifecycle stability.

The discussion revealed industry concerns about grid industry companies (like Zhixin and Southern Grid Technology) monopolizing system and standard pricing power, forcing technical collaboration and causing many meter enterprises to abandon independent R&D in favor of commercial relationships. Currently, two-thirds of meter manufacturers do not independently develop products; only Dingxin, Westron, Wasion, and Hexing maintain significant R&D investment.

On December 9, 2022, experts discussed OpenHarmony's prospects in power systems. While HarmonyOS suits edge devices like concentrators, TTUs, and DTUs, its 100KB minimum memory requirement exceeds meters' typical 几十 k (several tens of KB) capacity. Nevertheless, OpenHarmony charging piles were under development, with wind power and photovoltaic applications being explored. The OpenHarmony in Power Systems Application and Development White Paper, organized by the China Energy Research Association with participation from State Grid Smart Institute, Southern Grid Digital Research Institute, and Harbin Institute of Technology Power Systems Institute, was noted. Both State Grid and Southern Grid are promoting their own operating systems, but these efforts are not contradictory—OpenHarmony serves as the base layer, with companies building their own distribution versions on top.

Experts argued that China doesn't need numerous competing operating systems, which represents internal friction; instead, collaboration on OpenHarmony is needed. The real challenge is establishing a Chinese embedded software industry certification system with full intellectual property rights. The first HarmonyOS ecosystem charging pile had already passed foundation certification, with expectations for the first OpenHarmony-based smart meter to emerge soon.

2.5 Technical Implementation Considerations Later discussions addressed technical implementation details. Could single-chip solutions meet IR46 standards? OpenHarmony's TrustZone security partitioning theoretically enables single-chip hardware-level data encryption, but operating system isolation cannot support later hardware function additions. The TrustZone approach, available in ARM Cortex-A processors, could isolate spaces, but single-chip solutions cannot address upgrades to non-legal metrology management and IoT functions.

Questions about APP upgrades requiring system resets were answered: resets are unnecessary and do not affect other APPs. However, concerns persisted about RAM requirements surging with APP loading, causing memory overflow risks, and whether complex algorithms introduce new vulnerabilities. While Cortex-M4 processors can support operating systems, lower-end CPUs make OS implementation meaningless. Current State Grid meters predominantly use M0 processors, though Hanyuan's MOS can provide all functions except MPU on such limited resources.

The fundamental challenge remains: who will pay for developing a high-controllability, APP-enabled operating system on low-cost, resource-constrained hardware? And who bears the risk of increased costs and potential management chip failures? While State Grid's OS is reportedly stable and IP-clear, cost, technical specifications, and communication protocol (698) applications await metering system improvements. The key insight is that operating systems aren't mysterious—only the ecosystem is difficult to build.

3. Addressing the Bidding Volume Challenge

As established in Section 1, the 2022 bidding volume remained low due to high prices, inaccurate function positioning, and questionable OS applicability. To increase provincial grid demand, the authors propose repositioning extended functions: all residential users with monthly consumption exceeding 200 kWh should install single-phase smart IoT meters.

3.1 Proposed Application Model Under agreements with local power departments, users would participate in distribution network peak-shaving dispatch or virtual plant projects through their smart IoT meters, receiving economic compensation. This requires installing meters with non-intrusive load identification capabilities for load forecasting, online monitoring, overload alarms, and long-term overload management.

3.2 Projected Impact In 2020, State Grid's peak load reached 820 million kW, with residential users (490 million households) consuming 580 billion kWh annually—14% of total sales. Approximately 89 million residential users consume over 200 kWh monthly and could participate in peak shaving. Assuming 2 kW per household with 8 hours of use, 0.8 kW is dispatchable. This yields a potential peak reduction of 71 million kW (8.8% of State Grid's maximum load)—a significant impact.

3.3 Economic Viability With current single-phase smart IoT meters priced at approximately 600 RMB, and assuming 300 kWh average monthly consumption for target users, power departments recover 14,400 RMB in electricity fees over 8 years. The meter investment represents only 4.1% of this revenue, making it economically viable.

3.4 Projected Bidding Volume Installing smart IoT meters in 89 million households over 8 years requires approximately 11 million units annually—14% of State Grid's baseline annual procurement of 70 million smart meters, representing a substantial market expansion.

References

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Note: Figure translations are in progress. See original paper for figures.

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