Research on Smart Meter Technology Based on Metering Requirements of New-Type Power Systems

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Abstract

This paper primarily discusses the new challenges and transformations facing electricity metering technology and management within the context of new power system development. With the large-scale integration of renewable energy, new power systems must adapt to such changes, and electricity meters, as critical components of power systems, also require corresponding improvements and reforms. The article addresses existing problems and challenges with current electricity meters, including the sharp increase in grid-connected metering points for distributed photovoltaic stations and the need for in-depth research on grid-connected metering solutions for user-side distributed photovoltaic stations. To address these issues, the article proposes several solutions, including the adoption of smart distribution network technology and the advancement of smart electricity meter performance and functionality improvements. Furthermore, the article notes that metering for distributed photovoltaic power generation systems exhibits certain vulnerabilities, such as potential tampering downstream of photovoltaic generation electricity meters. Therefore, intelligent monitoring and analysis solutions must be employed to improve existing metering systems and enhance metering accuracy and reliability. In summary, the large-scale integration of renewable energy will bring a series of challenges and transformations to new power system development. The electricity meter industry must conduct thorough research and actively respond to these challenges to facilitate the smooth development of new power systems.

Full Text

Preamble

Title: 基于新型电力系统计量需求的智能电表技术
Research on Smart Meter Technology Based on the Metering Needs

of New Power Systems

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Abstract: This paper examines the emerging challenges and transformative changes confronting electricity metering technology and management within the evolving framework of new power systems. The large-scale integration of renewable energy sources necessitates fundamental adaptations in power system architecture, requiring commensurate advancements in electricity metering infrastructure. Key challenges identified include the explosive proliferation of grid-connection metering points for distributed photovoltaic (PV) stations and the urgent need for refined metering solutions for user-side distributed PV installations. To address these issues, the paper proposes strategic responses including the deployment of intelligent distribution network technologies and systematic improvements in smart meter performance and functionality. Additionally, the analysis reveals critical vulnerabilities in current distributed PV metering systems, particularly the susceptibility to tampering downstream of generation meters. To mitigate these risks, intelligent monitoring and analytical solutions must be implemented to enhance metering accuracy and reliability. In summary, the large-scale integration of renewable energy will precipitate a series of systemic challenges and transformations. The metering industry must conduct rigorous research and proactively respond to these developments to facilitate the successful evolution of new power systems.

Keywords: new power system, smart meter
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Introduction

On March 15, 2021, the Central Financial and Economic Affairs Commission declared that the 14th Five-Year Plan period represents a critical window for achieving carbon peak, mandating deepened power system reforms and the construction of a new power system with renewable energy as its principal component. This directive will catalyze profound structural transformations across the energy sector, transitioning from high-carbon to deeply low-carbon or zero-carbon power systems, and shifting from deterministic, continuously controllable generation sources to stochastic, intermittently fluctuating sources. Consequently, the new power system must embody four fundamental attributes: extensive interconnectivity, intelligent interaction, flexible adaptability, and secure controllability.

Within the current power system architecture, distribution-level metering directly interfaces with 99% of electricity consumers while simultaneously integrating renewable energy sources. Distribution networks perform the critical function of power delivery and allocation. State Grid is currently advancing intelligent distribution network technologies to enable post-integration monitoring of distributed energy resources, voltage/reactive power management, emergency response and self-healing control, and safety early warning systems. These capabilities aim to enhance power supply reliability while improving power quality, operational management, and economic efficiency.

State Grid's new-generation smart meters—comprising the single/three-phase smart IoT electricity meters and 2020-version smart meters introduced in 2020—are designed to meet the metering requirements of existing power systems (with only a few percent renewable penetration). These meters facilitate power trade settlement and grid technical-economic performance assessment for unidirectional power flows, while offering limited extended functions for distribution and consumption applications. Notably, the smart IoT meter introduces a modular structural design to China for the first time, enabling long-term, demand-driven functional expansion.

In light of these industry opportunities, the metering sector must comprehensively interpret the objectives and characteristics of new power systems, investigate the novel technologies, control mechanisms, and management protocols adopted by new distribution networks to address grid instability and degraded power quality resulting from substantial renewable energy integration, and identify new research imperatives for metering and management reform. This will drive performance improvements, functional expansion, and broader deployment of domestically produced new-generation smart meters to satisfy the metering demands of new power systems.

The following sections elaborate on the new metering challenges and management reforms necessitated by new distribution networks:

1. New Distribution Networks: Explosive Growth in Distributed PV Grid-Connection Metering Points and Enhanced Research on User-Side Metering Solutions

By 2060, national new energy capacity (wind and solar) will reach 5 billion kW, representing 60% of total installed generation capacity (8.33 billion kW)—a 2.27-fold increase from 2020 levels (2.2 billion kW).

1) Forty-Year Projection: 20.8-Fold Growth in Distributed PV Metering Points

In 2020, State Grid's distributed PV cloud network statistics indicated 1.5 million connected distributed PV stations with aggregate capacity of 60 million kW, averaging 40 kW per installation. Within State Grid's service territory, 510 million user consumption metering points existed (including 1.5 million PV grid-connection points), which together with distribution line input/output metering points, accounted for approximately 99% of all system metering points.

By 2060, PV capacity will reach 1.25 billion kW (25% of total new energy capacity). Based on the 40 kW average installation size, State Grid's territory will connect 31.25 million distributed PV grid-connection metering points. This represents a 20.8-fold increase in PV metering points (31.25 million/1.5 million) compared to a 2.13-fold increase in user consumption metering points (1.088 billion/510 million) over the same period.

(Note: The 2060 user consumption metering point projection of 1.088 billion is derived from total societal electricity consumption of 16 trillion kWh and a 2020 per-household annual consumption of 14,700 kWh.)

2) Forty-Year Projection: 9.9-Fold Growth in PV Metering Point Density

In 2020, distributed PV metering points comprised 0.29% of all user consumption metering points (1.5 million/510 million). By 2060, this proportion will reach 2.87% (31.25 million/1.088 billion), representing a 9.9-fold increase in relative density (2.87%/0.29%) alongside the 2.13-fold growth in total consumption points.

3) Enhanced Research on User-Side Distributed PV Metering Schemes

The following analysis is partially excerpted from Jiangsu Changyi Group Corporation's *Discussion on Distributed Power Generation Metering Technology* (August 2014), hereafter "Document A."

Vulnerabilities in Current Metering Architecture

Distributed PV systems comprise PV modules, DC combiners, DC distribution cabinets, grid-connected inverters, AC distribution cabinets, monitoring systems, and environmental sensors. Current grid-connection metering follows State Grid's February 2013 *Notice on Distributed Energy Related Opinions and Specifications*, which provides gateway and generation meters free of charge while explicitly omitting user-side consumption meters. The bidirectional gateway meter handles settlement, while the generation meter records cumulative PV output for subsidy claims.

A critical vulnerability exists downstream of the generation meter, where project owners may tamper with wiring—such as modifying inverter connections or using synchronous devices to inject power upstream—artificially inflating generation meter readings.

Improved Metering Scheme 1 (Document A):
This intelligent monitoring approach employs: (1) real-time recording of DC and AC generation; (2) light intensity sensors generating 24-hour illuminance curves for generation validity analysis; and (3) automatic DC-AC correlation calculations with active threshold-exceeding alerts.

Improved Metering Scheme 2 (Proposed by Authors):
Transform the two-meter system into a three-meter configuration to eliminate vulnerabilities through energy balance verification. The scheme adds a user consumption meter (C) to the existing gateway (A) and generation (B) meters (all recommended as Class 0.5S). The gateway meter periodically collects data from meters B and C to calculate imbalance:

- When C - B = (-A): PV generation exceeds consumption; (-A) represents exported energy
- When C - B = (+A): PV generation is insufficient; (+A) represents imported grid energy

The imbalance rate is calculated as: $[(C - B) \div (\pm A)] \times 100\%$. Rates exceeding 1% trigger active reporting from meter A and on-site investigation.

2. New Distribution Networks: Bidirectional Power Flow from Large-Scale Renewables Driving Enhanced Smart Meter Performance

Large-scale renewable integration subjects distribution networks to stochastic, intermittent bidirectional power flows with high harmonic content, necessitating research into three key performance areas:

1) Gateway Meter Zero-Crossing Metering Characteristics

Bidirectional load zero-crossing detection, compression of metering dead zones, and ultra-low-load accuracy represent novel research frontiers. Rapid, accurate zero-crossing judgment is essential for distributed renewable integration assessment, though unified standards remain absent.

Author Proposals: - At unity power factor, gateway meters require enhanced ultra-low-load sensitivity. Single/three-phase gateway accuracy should be upgraded to Class 0.5S or higher, with starting current reduced to 0.1% of rated value. - At power factor 0.01 across multiple load points, metering error must be controlled within $±$2%.

International Comparison at PF=0.01: 2008 testing by Chongqing Electric Power Metering Center showed Landis+Gyr ZQ three-phase gateway meters achieved $±$0.6% error, while four domestic multi-function meters exhibited $±$10%, indicating uncontrolled zero-crossing errors.

Post-2008, Weisheng's Class 0.1S high-accuracy gateway meter employing phase-error curve compensation achieves $±$1% error at PF=0.01.

Traceability Challenges: China lacked established traceability for PF=0.01 accuracy until 2004, when EMH Corporation's Beijing office provided the K2006 three-phase standard meter test report from Germany's PTB, enabling domestic verification at ultra-low power factors.

2) Dynamic Load Response and Wide Load Range Expansion

Renewable generation exhibits wider load ranges and greater fluctuations. New-generation smart meters provide $ 10×$ wide-load capability; distributed energy applications warrant even broader ranges such as 1(100)A (100× wide-load meters). To ensure flat error curves across this range, error bandwidth (maximum-minimum error difference) must be specified.

Error Bandwidth Recommendations: - Landis+Gyr Class 0.2S ZQ gateway: $±0.05×$ accuracy class bandwidth) - Domestic smart meters: typically 0.6× accuracy class (1.2× bandwidth) - **Proposal:** Domestic PV gateway meters should achieve 0.4× accuracy class (0.8× bandwidth)

3) Harmonic/Interharmonic Metering and Traceability

Harmonic metering research peaked around 2003, shifted to smart meter development after 2009, and faced international challenges by 2020. In 2021, China's new power system initiative provides timely impetus for renewed harmonic/interharmonic and fundamental active power metering research.

International Regulatory Evolution: - Canada (2021): Implemented fundamental active energy settlement; all new meters use fundamental power measurement. The May 2019 international metrology conference in Finland concluded that traditional power triangles become invalid under non-sinusoidal conditions, while IEEE 1459-2010 provides a valid computation framework. Harmonic energy trading is illegal in most Canadian jurisdictions. IR46 requires fundamental-only metering, and IEC 62053-24:2014 standardizes fundamental frequency reactive meters.

Domestic Perspectives: Online discussions reveal expert support for fundamental metering to combat China's uncontrolled harmonic pollution, arguing it would incentivize power quality management and harmonic mitigation device deployment. Some note minimal differences between full-wave and fundamental metering for existing meters, though fundamental+harmonic (absolute value) approaches show larger discrepancies. Fundamental metering represents a compromise reducing both grid revenue losses and user investments in harmonic suppression.

Development Roadmap: State Grid's new-generation meter specifications include harmonic and fundamental metering requirements, but implementation remains unclear. Recommended research includes: - Adopting IEEE 1459-2010 as a national standard for full power computation under harmonic loads - Simulation testing of high-harmonic injection from distribution transformers: recording typical daily generation profiles by climate/region/season, and laboratory simulation of harmonic daily fluctuation curves - Advanced algorithm research: Fourier accuracy depends on discrete integration precision; DFT fails for continuous-spectrum nonlinear loads, requiring new asynchronous sampling algorithms - Performance enhancement: sensitivity and accuracy testing of domestic meters' harmonic/interharmonic and fundamental metering; collaborative development of wide-bandwidth, wide-load, high-accuracy meters - Supplementary testing specifications based on GB/T 17215.302-2013 - Traceability technology development

Traceability Progress: Since 2007, China has developed harmonic power standards (China National Institute of Metrology) and high-accuracy standard meters (Henan Star High-Tech's ST1000, 2010) using novel asynchronous sampling algorithms. Post-market exit of Star High-Tech, current domestic producers of high-accuracy harmonic standard meters require identification. JJG 1106-2015 regulations should be supplemented for new-generation meters under high-harmonic conditions.

3. New Distribution Networks: Virtual Power Plants and Ubiquitous IoT Driving Smart Meter Functional Expansion

New-generation domestic smart meters feature dual-core (metering+management) architecture per IR46 requirements and modular IoT designs enabling demand-driven expansion. Two priority research areas emerge:

1) Virtual Power Plant Integration

Virtual power plants aggregate distributed resources via communication networks under advanced management systems to mitigate renewable fluctuations and provide peak shaving.

- **User Controllable Load Scheme:** Ubiquitous connectivity and submetering identify controllable loads for virtual generation scheduling. In Shanghai, 3,000 commercial buildings' aggregated controllable loads equivalent to a 1,000 MW thermal unit are managed through 24-hour consumption monitoring of lighting, HVAC, elevators, and water heaters.
- **Distributed Source Scheme:** Billing meters monitor/control indoor PV, storage, microgrids, and small generators, feeding data to distribution network virtual power plant platforms for generation scheduling.

2) Expanded Power Quality Monitoring

State Grid's 510 million smart meters constitute the grid's largest sensor network, measuring active/reactive/apparent power, voltage, current, phase, harmonics, and distortion. New distribution networks with substantial nonlinear loads require expanded monitoring and novel management protocols. While distribution dispatch traditionally manages power quality, user-side monitoring (PV, storage, indoor equipment) presents new challenges requiring enhanced meter functions or additional meters. Load control center platforms should aggregate this data for local coordination strategies.

State Grid's 2020 specifications for smart IoT meter power quality modules cover: - **Steady-state:** Voltage/frequency deviation, flicker, harmonics, plus interharmonics - **Transient:** Sag, swell, interruption (differing from national overvoltage standards), plus triggered RMS data

Development and network access testing of these modules should proceed for inclusion in procurement.

3) Active Outage/Restoration Reporting

Traditional low-voltage grid outage management suffered from delayed information and slow response. Since 2017, three active reporting schemes have emerged:

- **Scheme 1 (Suzhou, 2017):** Supercapacitor-enhanced local communication modules with micro-power wireless enable dual-mode (HPLC+wireless) outage reporting via collection terminals to emergency management platforms.
- **Scheme 2 (Jiangsu EPRI):** Voltage drop detection behind meters propagates through network topology, identifying affected users within 30 seconds without individual investigation.
- **Scheme 3 (Zhejiang, 2021):** Dual-core meters with power-loss detection, backup supplies, and Bluetooth modules enable active event reporting via upstream communication channels in both Type I and II concentrator modes.

Evaluation: Active outage/restoration reporting is critical for reliability and should be universal. The Zhejiang scheme's dual-concentrator compatibility and comprehensive functionality make it preferable, though requiring meter redesign. Final selection should be evaluated by State Grid metering management.

Conclusion and Market Outlook

As new-generation smart meters deploy in 2021, they face unprecedented opportunities. The metering requirements from new distribution networks—encompassing distributed PV metering improvements, gateway meter zero-crossing performance, wide-load range expansion, harmonic metering, virtual power plant integration, expanded power quality monitoring, and proactive outage management—align perfectly with the dual-core, modular design architecture of new meters.

In December 2020, the authors projected that starting 2021, State Grid would need to replace 430 million non-IR46-compliant 2009/2013-version meters , requiring 60 million new-generation meters in 2021 alone . Actual 2021 demand has exceeded expectations: the first procurement batch totaled 37.45 million units (46% year-over-year increase), with single-phase, three-phase, and concentrator demand up 50%. Total 2021 procurement may reach 70 million units, indicating strong five-year market prospects for new-generation smart meters.

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