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Research on Smart Meter Communication Technology

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Abstract

Research on smart meter communication technology represents an important research direction in the power sector, encompassing in-depth exploration and technological innovation of smart meter communication systems. With the advancement of smart grids, smart meters serve as critical information interaction nodes between the grid and users, making research and application of their communication technology vital for enhancing grid intelligence and optimizing power resource allocation. The research agenda includes evaluating and improving existing communication technologies to meet the specific requirements of smart meter communication. For instance, narrowband and broadband power line carrier communications, as technological directions that the metering industry can spearhead in research and application, have seen advances in maintenance-free technology, automatic debugging terminals, automatic network configuration instruments, and related areas that constitute current research hotspots. Simultaneously, research and optimization of remote wireless communication systems, along with intelligent terminal development, constitute important facets of smart meter communication technology research. Additionally, such research must address communication protocols, communication security, and data processing. Unified communication protocols enable interconnection and interoperability among different devices, enhancing system compatibility and scalability. Strengthening communication security research ensures secure transmission of power data, preventing data leakage and unauthorized access. Regarding data processing, advanced data analysis technologies enable deep mining of power data to provide robust support for decision-making and operations in the power industry. In summary, smart meter communication technology research is a comprehensive, multi-disciplinary topic requiring continuous tracking of emerging technologies and demand-driven technological innovation and application promotion to advance intelligent development of the power sector.

Full Text

Research on Smart Meter Communication Technology

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Abstract

Research on smart meter communication technology represents a critical direction in the electric power field, involving in-depth exploration and technological innovation of smart meter communication systems. With the development of smart grids, smart meters serve as key information interaction nodes between the grid and users, making research and application of their communication technologies vital for improving grid intelligence levels and optimizing power resource allocation. This research encompasses evaluation and improvement of existing communication technologies to meet the specific requirements of smart meter communication. For instance, narrowband and broadband power line carrier communication—technologies that the meter industry can independently research and apply—are currently hot topics, with advances in maintenance-free technology, automatic debugging terminals, and automatic networking instruments. Meanwhile, research and optimization of remote wireless communication systems and development of intelligent terminals constitute important aspects of smart meter communication technology research. Additionally, this field requires attention to communication protocols, security, and data processing. Unified communication protocols enable interoperability among different devices, enhancing system compatibility and scalability. Strengthening communication security research ensures safe transmission of power data, preventing data leakage and unauthorized access. In data processing, advanced data analysis techniques enable deep mining of power data, providing robust support for decision-making and operations in the power industry. Overall, smart meter communication technology research is a comprehensive topic spanning multiple domains, requiring continuous tracking of new technological developments and innovation tailored to practical needs to promote intelligent development of the power industry.

Keywords: smart meters; communication; low-voltage carrier; AMI

Smart meter communication systems represent an expanded communication domain for the meter industry, encompassing local and remote communication systems with numerous categories and rapid technological updates. Most are public communication methods, with the meter industry focusing on application research, particularly interoperability development. Only narrowband and broadband power line carrier communication can be independently researched and applied by the meter industry, though actual progress remains unsatisfac-

tory.

After nearly two decades of development, remote wireless communication systems for large-consumer smart meters have become relatively mature with simple communication methods, now requiring research on intelligent terminals capable of local response and decision-making. However, for residential users, no comprehensive solution has yet emerged that meets modern information demands with high quality and economic rationality, representing a widespread communication challenge. With rapid growth in smart distribution network construction and distributed power grid integration, research on this problem should be prioritized on the agenda of the meter industry—including communication chip enterprises, system integrators, and power departments—with organized collaborative development.

1. Construction and Application Research of Electricity Information Collection Systems

- 1) The release of the State Grid Corporation's revised enterprise standards for electricity information collection systems, along with new terminal prototype development and submission for inspection, represents another urgent task for meter enterprises.

The new standards comprise 5 categories with 14 volumes: - **Functional specifications:** 1 volume - **Technical specifications:** 3 volumes covering dedicated transformer acquisition terminals, centralized meter reading terminals, and communication units - **Type specifications:** 3 volumes for dedicated transformer acquisition terminals, concentrators, and collectors - **Communication protocols:** 3 volumes covering master station-to-terminal protocols, concentrator local communication module interfaces, and terminal remote communication module interfaces - **Inspection technical specifications:** 4 volumes for system, dedicated transformer terminals, centralized meter reading terminals, and communication unit testing

Key changes in the new standards include: - **Functional specifications:** Added node active reporting functions; automatic maintenance of energy meter communication parameters; system time synchronization schemes; statistics on success rates for different local communication solutions; and acquisition terminal function testing items. - **Type/technical/inspection specifications:** Added Type II concentrator requirements; unified type requirements for Type III dedicated transformer terminals and Type I concentrators; communication unit interchangeability requirements; node active reporting functions; automatic energy meter parameter maintenance; terminal load capacity requirements; remote upgrade security and management requirements; voltage monitoring functions; and radio interference suppression tests. - **Communication protocols:** Added magnetic field anomaly event records; terminal time synchronization event records; concentrator-local communication module interaction processes; and acquisition terminal remote communication module interface protocols.

- 2) The Ningxia Power Grid, building upon its 2012 achievement of full smart meter coverage in urban areas, will become the first in China to achieve full rural smart meter coverage in June of this year, benefiting 1.09 million rural households.
- 3) In application practices:
 - **Shenyang Power Grid** achieved, for the first time in China, the practical requirement of 100% daily automatic meter reading success rate in public transformer districts using broadband carrier and micro-power wireless communication.
 - **Shandong Power Grid**' s electricity information collection system features unique characteristics:
 - Utilizes broadcasting networks for information collection
 - Transforms line loss management from monthly statistics to daily monitoring and analysis, shifting from settlement management to process control
 - Exploits smart meter voltage acquisition functions
 - Integrates with marketing GIS and distribution production systems to establish intelligent fault location and analysis models, enhancing outage monitoring for urban and rural public transformer districts and lines, and improving fault emergency repair services
 - **Shanghai Power Grid** added 13,000 load management terminals to its existing base of 12,500 terminals, achieving full load management for 10kV and above customers.
 - **Shanxi Electric Power Company** implemented GPS-based visualized asset lifecycle management; Mudanjiang smart meters achieved full GPS coverage.
 - **Shanghai Pudong Power Supply Company** applied QR code technology for electricity bill payment.

2. New Progress in Low-Voltage Carrier Communication Technology

- 1) **Maintenance-free technology for narrowband carrier systems** has emerged:
 - Zhejiang Power Grid' s automatic debugging terminals and automatic pairing technology between public transformers and user meters
 - Tianjin Power Grid' s development of smart meter automatic networking instruments
- 2) Collaborative research projects are underway for engineering design of local narrowband carrier systems and high-frequency interference source management.
- 3) **China Electric Power Research Institute** is developing a power line communication method combining power frequency and carrier communication.

- 4) How can State Grid achieve “full coverage” targets in electricity information collection system construction?

3. Micro-Power Wireless Communication Interoperability Solutions Show Promise

- 1) The **IEC 62601** standard (*Industrial Communication Networks—Fieldbus Specifications for WIA-PA Communication Networks*) was developed under the leadership of the Shenyang Institute of Automation, Chinese Academy of Sciences, with WIA-PA communication being piloted in Shenyang’ s power grid.
- 2) Beijing Power Grid has made important progress in micro-power wireless communication interoperability.

4. Should 3G Remote Wireless Communication System Pilot Experience in Rural Power Systems Be Expanded?

- 1) County-level power grids in Shandong’ s Huantai County and other provinces have completed 3G practical application pilots, achieving multi-faceted applications in distribution communication and electricity information collection and transmission.
- 2) Overall solutions to comprehensively address county-level power grid communication needs are being developed.

5. Power Frequency Communication Technology Expands in Rural, Mountainous, and Oil Field Areas

- 1) Wasion Group introduced American power frequency communication system technology.
- 2) Ailangrui Company promotes WPLC wide-area power frequency communication systems.

6. Smart Meter Communication Testing Equipment Forms a New Industry

- 1) Nanjing Zhide Company has become China’ s first professional manufacturer of electricity information collection system testing equipment.
- 2) Qingdao Dongsoft Company developed the SSC1650 narrowband carrier communication chip module based on OFDM, simultaneously launching the SSC1645 micro-power wireless communication chip module based on the new IEEE 802.15.4g standard, along with dedicated power line driver amplifiers ESPA16/ESPA13 and other products.
- 3) Shenzhen Guodian Technology Communication Company (under NARI Group) released China’ s first proprietary broadband power line carrier

communication chips SG5000/SG3000, adopting TDS-OFDM core technology and globally pioneering the use of 2-12MHz mid-band communication. SG5000 is used for concentrators, while SG3000 serves collectors, repeaters, and smart meters.

- 4) Hexing Company offers power line carrier solutions based on IEC 61334 technology:
 - **NCN49599 chip:** Operates in CENELEC A-D bands; baud rate 300-4800bps

7. New Breakthroughs in AMI Project Exports

NARI Group won the bid for Iran' s smart electricity consumption AMI system project.

8. International Trends in Local Communication Methods

- 1) **PRIME Alliance:**
 - PRIME = Powerline Intelligent Metering Evolution (interoperability standard for smart grids and advanced metering systems)
 - Fundamentally defines OSI Layer 1 and Layer 2
 - PRIME standard published as ITU-T G.9904 recommendation and as normative reference in IEEE P1902.2
 - Only Wasion Group from China has joined PRIME
 - PRIME' s FCC band spans 40-490kHz, providing maximum data rates of 980kbps
- 2) **Enel Company:** Sharing experience from AMI system deployment in Italy and Spain:
 - PLC standard formulation for AMI systems requires a complex process taking several years to mature
 - **PRIME:** Iberdrola has just begun large-scale installation of 1 million smart meters
 - **G3-PLC:** ERDF is conducting limited sample trials (2,000 units), still in early stages with large-scale growth expected within 2-3 years
 - **IEEE P1901.2 standard:** Still in trial phase; industry believes large-scale promotion will occur in 2014, though mass deployment normally requires at least 5 years
- 3) **enerv Company:** SOC solutions for smart grid applications:
 - The greatest cost in AMI network implementation is meter removal and replacement
 - Reliable power line network communication requires substantial DSP processing capability to compress data to millisecond-level transmission within brief network stability windows

- enverv' s dual-core PLC engine runs at 2000 MIPS for complex noise suppression
- Ultra-sensitive receivers capture the weakest network signals (up to 160dB attenuation vs. 75-90dB for other PLC suppliers)
- Large-capacity memory enables field upgrades
- **4GPLC vs. G3-PLC comparison:**
 - 4GPLC provides greater coverage
 - Achieves high-sensitivity, low-SNR connections
 - Offers higher transmission rates: 1Mbps
 - Field tests show 180-210kbps across two distribution transformers and 710kbps without transformers
 - Enables ultra-long-distance transmission
 - Provides complete remote upgrade functionality

4) **Wi-SUN Alliance:** Wireless connectivity for smart meters

- In March 2012, IEEE SA Standards Committee approved the IEEE 802.15.4g PHY amendment
- This standard accommodates diverse smart application requirements (gas metering, demand response, distribution automation, etc.)
- Wi-SUN focuses on physical and MAC layers, authentication, certification, and interoperability testing procedures, providing profiles for PHY and MAC specifications
- Huawei has joined the Wi-SUN Alliance

9. Lack of Standards for Local Narrowband Carrier Communication

Local narrowband carrier communication, promoted by State Grid' s marketing department, accounts for 50% of local automatic meter reading residential users (approximately 120 million households) and forms the foundation of electricity information collection systems.

- 1) The newly released State Grid enterprise standards (revised edition) for electricity information collection systems maintain the low requirement of 98% daily automatic meter reading success rate for low-voltage narrowband carrier communication, failing to address long-standing technical bottlenecks.
- 2) There is insufficient monitoring, control, and improvement of factors affecting narrowband carrier communication quality in low-voltage grids, including high-frequency interference sources, channel attenuation (impedance and reflection-induced), and crosstalk signals from public transformer districts.
- 3) Laboratory assessment metrics and testing methods for narrowband carrier module transmission and reception capabilities remain inadequate.
- 4) Lack of unified communication management specifications prevents consistent, correct management of smart meter addresses between master

stations and concentrators through State Grid' s SG186 network.

- 5) Local narrowband carrier system construction primarily uses post-implementation assessment without pre-installation low-voltage grid testing or system routing simulation requirements, lacking engineering design and management methodology specifications.

10. Preliminary Results of Narrowband Carrier System Performance Evaluation Testing System Cooperation Research (2009-2011)

- 1) Relying on three types of public transformer district experimental projects in Chongqing' s low-voltage grid, research on narrowband carrier communication field evaluation technology developed rapid methods for identifying communication failures and differentiating among various chip design solutions.
- 2) Laboratory research completed full-performance testing devices for narrowband carrier communication modules, including two different design schemes from Chongqing Electric Power Research Institute and Wasion Group.
- 3) Narrowband carrier communication routing simulation testing systems were introduced (one each from Chongqing Electric Power Research Institute and Wasion Group) with different design philosophies.

11. Ongoing Multi-Party Cooperation Research on Local Narrowband Carrier Communication System Engineering Design and Application

- 1) **High-quality local narrowband carrier communication system engineering design objectives:**
 - **First step:** For monthly billing and line loss management, local narrowband automatic meter reading systems require 100% daily automatic meter reading success rate.
 - For daily line loss management and remote prepaid management systems: 100% success rate within 2-hour automatic reading cycles.
 - For AMI pilot projects: Bidirectional communication with 100% success rate within 1-hour cycles.
 - Interference suppression requirements for local narrowband automatic meter reading systems.
- 2) **Key preliminary research topics:**
 - Factors affecting narrowband carrier communication quality
 - Calculation formulas, testing methods, and assessment metrics for signal-to-noise ratio at low-voltage grid meter nodes
 - Carrier communication modules:
 - Full-performance practical indicators and testing methods for transmitted signals

- Reception capabilities including chip SNR, reception stability measures, anti-interference capability, and routing adaptability
- Low-voltage grid impedance distribution characteristics and correct testing methods
- Low-voltage grid attenuation distribution characteristics including impedance, reflection, standing waves, copper-aluminum interfaces, and branch-induced attenuation
- Low-voltage grid noise classification, distribution characteristics, and measurement methods
- Communication system routing, relay, and networking capability requirements, algorithms, and evaluation methods
- Communication stability requirements and testing methods
- Power supply performance requirements for carrier modules
- Address consistency protocols and testing between master stations, concentrators, and meters
- Identification, testing, and suppression methods for crosstalk signals in transformer districts
- Three-level application testing method standardization for carrier communication products
- Laboratory full-performance testing and evaluation methods and equipment requirements
- Routing/relay/networking simulation testing systems and equipment
- Field testing system requirements, environmental impact metrics, and evaluation methods
- Standardized design schemes for concentrator, collector, and meter carrier modules including functional specifications, internal logic, hardware/software modular structures, interfaces, protocols, and testing methods
- Calculation formulas for automatic meter reading time in entire transformer districts and measures to achieve 100% success rate targets within 24h/2h/1h
- Assessment metrics and suppression measures for interference with other electrical appliances

12. Future Prospects for Low-Voltage Narrowband Carrier Communication Technology

Recent industry discussions question whether existing narrowband carrier communication technology has limited development space, whether OFDM-based narrowband carrier communication suits bidirectional high-speed requirements, and whether broadband carrier technology has become established, with ITU-T clarifying that home wired networks should adopt one technology across multiple media (telephone lines, power lines, coaxial cables, and Category 5 cables). These discussions reflect the direction of low-voltage carrier communication technology.

- 1) **State Grid's Q/GDW 375.3-2009 Design Guidelines** explicitly state that in low-cost solutions, low-voltage power line carrier, micro-power wireless, and RS-485 communication are viable options. For the foreseeable future, low-voltage narrowband carrier modules will remain State Grid's preferred local communication product in large-scale centralized bidding, with annual investment of approximately 1.5 billion RMB. Current narrowband technology, despite improvements, still offers limited rates (maximum 20kbps), only suitable for billing information transmission under current pricing policies. The key challenge is breaking through technical bottlenecks to create high-quality local automatic meter reading systems. Preliminary expectations suggest existing narrowband technology may remain viable for another 10 years until superior local systems are developed and widely deployed.
- 2) With smart distribution network development and growing demand for bidirectional high-speed local communication, OFDM-based narrowband carrier chip development and application show promising prospects. However, the path from chip development to market dominance will be lengthy. While Chinese universities systematically studied OFDM technology a decade ago, only Wasion Group recently joined Europe's PRIME and G3 alliances, and Dongsoft launched OFDM narrowband chips in 2012. Further industry collaboration is needed to adapt new high-speed narrowband methods to improve poor low-voltage grid carrier communication quality.
- 3) Attention should be paid to expanding applications of domestic micro-power wireless communication technology WIA-PA based on IEC 62601 standards.
- 4) Comprehensive analysis suggests that combining domestic OFDM narrowband carrier communication with domestic micro-power wireless communication may become the overall solution for high-quality local communication.
- 5) Finally, to achieve State Grid's "full coverage" requirements for remote meter reading in remote rural and mountainous areas, medium- and low-voltage grid power frequency communication methods should be studied.

13. Questions Raised by State Grid's Electricity Information Collection System Construction Process Self-Assessment

- 1) **Brief review:** In September 2008, State Grid launched the "Standardization Construction of Metering, Meter Reading, and Billing" project, establishing 12 technical standards for smart meters and 24 for collection terminals. By October 2013, over 173 million smart meters had been installed, covering 173 million users (within State Grid's operational scope exceeding 300 million users).

2) Key technologies:

- **Communication technology:** Power line carrier communication offers convenient installation without rewiring but suffers from poor reliability, real-time performance, and stability. Micro-power wireless communication's transmission distance is significantly affected by obstacles, with severe on-site co-frequency interference. Public wireless network communication has high costs, maintenance timeliness issues, weak signals in some areas, and channel congestion during emergencies. Private wireless 230MHz networks have limited access capacity, base station coverage of only ~30km, and data transmission susceptible to high-rise building blockage. Fiber optic communication requires large initial investment, high costs, difficult wiring, and massive engineering 工作量.
- **Master station application technology:** (Omitted)
- **Smart fee control technology:** Implemented through master station, acquisition terminal, or smart meter fee control. High communication responsiveness requirements necessitate improved real-time performance, reliability, and stability of carrier communication.
- **Electricity information security technology:** (Omitted)

3) Development trends:

- **Communication network access technology:** Requires rich system interfaces, flexible networking, and integrated access for data, voice, and image services to provide secure, reliable channels for information collection and load control.
- **Information sharing and integration technology:** The collection system lacks effective integration with other business systems, requiring improved resource sharing and public service functions.
- **Massive data processing and analysis:** (Omitted)
- **Mobile operation technology:** (Omitted)
- **Three-network convergence-based collection technology:** Research should propose solutions integrating telecommunications, broadcasting, and internet networks to achieve data, voice, and video service convergence, saving communication line investment and operational costs while improving efficiency, reliability, and economy.
- **Smart electricity bidirectional interaction technology:** Utilizes fiber channels and power line carrier channels to collect and analyze electricity information, monitor household equipment, and provide real-time information, alarms, and pricing policies through networked, human-computer interactive platforms, guiding rational electricity use and regulating peak-valley loads.

14. State Grid's 2014 Smart Meter Communication Priorities

1) Collection system expansion and strict project management:

- Complete master station capacity expansion and upgrades; replace old

- load control systems with provincial centralized master stations
- Extend master station coverage to holding and newly integrated county customers
 - Research big data and cloud computing technologies to improve data storage and processing performance
 - Develop data sharing strategies to support online power quality monitoring systems
 - Upgrade master station functions and system architecture for distributed power access and EV charging management
 - Promote power generation side energy data sharing with dispatching and trading systems
 - Strengthen low-voltage user outage monitoring and remote fee control function deployment
 - Develop software upgrade and replacement work plans
 - Complete terminal software testing, upgrades, and voltage monitoring point replacements
- 2) **New remote and local communication technology application research:**
- Provincial companies should implement micro-power wireless communication based on local conditions
 - Conduct research and standard formulation for new 230MHz wireless broadband technology
 - Research low-voltage broadband carrier communication interoperability and complete enterprise technical specifications
 - Conduct pilot applications of low-voltage broadband carrier technology
 - Study public network operator cooperation mechanisms to reduce communication costs
 - Research public network channel information security strategies
 - Promote application of backbone fiber networks and existing distribution fiber resources
- 3) **Bidirectional interactive smart electricity system architecture exploration:**
- Prioritize smart meters with modular compartments for future direct interaction needs
 - Develop technical solutions and equipment selection considering interaction services and fee control business
 - Formulate implementation plans for direct bidirectional interactive smart meter R&D
 - Research information security-based smart meter data interface openness
 - Develop new embedded communication modules supporting bidirectional communication and open gateways
 - Conduct prototype development and pilot verification
 - Formulate and improve technical standards and master station specifications

- Explore integrated data collection technology for electricity, water, gas, and heat meters
- Develop communication protocols supporting bidirectional interaction

15. Reference Experience for Low-Voltage Broadband Carrier Communication Interoperability Research

- 1) **Liaoning Power Real-Time Information Collection System:** On October 12, 2012, the Liaoning Power real-time information collection system—jointly built by NARI Guodian Tong Network Company, Liaoning Electric Power Company, and Shenyang Power Supply Company—was commissioned.

The project conducted mixed networking experiments across six scenarios (dense high-rise residential, villa, old residential, urban-rural fringe, rural, and isolated small settlements) using wireless public networks, private networks, broadband carrier, RS-485, and micro-power wireless to form optimal networking solutions for typical scenarios.

Using broadband wireless private networks as the platform, integrated with power line broadband and micro-power wireless technologies, the project designed three solutions for collection blind spots (broadband carrier + micro-power wireless combination, cascading, and wireless 倒挂), achieving “full coverage, full collection, full fee control” targets. The system installed 318 broadband concentrators and 12,940 broadband collectors, serving 68,699 industrial, commercial, and residential users, with primary collection success rates exceeding 98% and daily periodic collection rates of 100%.

- 2) **China’s First Proprietary Broadband Carrier Chip:** On April 17, 2013, Guodian Technology Communication Company officially released China’s first proprietary broadband power line carrier communication chip at the China International Metering Conference.

Previously, heavy reliance on imported broadband carrier chips and lack of core technology left domestic manufacturers without pricing power, limiting market share due to high costs. The newly released SG5000/SG3000 chips adopt completely proprietary TDS-OFDM core technology, globally pioneering 2-12MHz mid-band power line communication. The chips optimize anti-attenuation, anti-noise, power consumption, and cost, with technical indicators surpassing international mainstream broadband chips. SG5000 serves concentrators while SG3000 serves collectors, repeaters, and meter terminals.

- 3) **China Electric Power Research Institute: “New Generation Power Line Carrier Communication Technology Research and Progress”**

- **Business requirements:** AMR/AMI needs 1.2/20kbps with maximum 1s delay; distribution transformer monitoring needs 4.8kbps; video monitoring needs 1000kbps with maximum 1s delay. Predicted PLC speed

requirements: 100-500kbps for low voltage, 2-4Mbps for medium voltage.

- **New generation PLC:** Cross-band (150kHz-10MHz) frequency self-awareness, adaptive, self-organizing, and cooperative communication technology that integrates advantages of traditional narrowband low-frequency and broadband high-frequency technologies, improving spectrum utilization and communication performance (coverage, speed, stability).
 - **Key technologies:** Cross-band channel characteristics and modeling; frequency cognition technology; PHY/MAC core technology development; wireless network integration; cooperative and subnet interference adjustment; analog front-end technology; cross-band PLC coupling technology.
 - **Preliminary results:** Developed narrowband (30-500kHz) and broadband (0.5-20MHz) PLC test systems; channel and noise characteristic testing; frequency cognition and spectrum aggregation research; Matlab-based system performance simulation; software radio-based point-to-point testing platforms.
- 4) **Shenzhen Guodian Technology Communication Company: “Short-Range Micro-Power Wireless Communication (Interoperability) Standard Analysis and Outlook”**
- **Standard development goal:** Interoperability, compatibility, and interchangeability among different manufacturers’ micro-power wireless communication units.
 - **Compatibility analysis:** The new standard is incompatible with previously deployed State Grid solutions, though existing devices can achieve compatibility through software upgrades. The new standard 预留 s sufficient space for future compatibility and will apply to become an industry or national standard.
- 5) **Conghua Power Supply Bureau (Guangzhou): “Analysis of Narrowband High-Speed Power Line Carrier Communication Development Status”**
- Internationally, PRIME, G3-PLC, and ITU-T’ s G.hnem are open standards using OFDM modulation.
 - **PRIME:** Uses CENELEC-A band (3-95kHz), maximum 130kbps.
 - **G3-PLC:** Supports all narrowband PLC frequency bands specified by CENELEC, ARIB, and FCC (3-500kHz), providing 20-300kbps rates.
 - **ITU-T G.hnem:** Combines PRIME and G3-PLC advantages for interoperability, approved in February 2011 as G.9955/G.9956 for PHY and DLL specifications, supporting all narrowband PLC bands with maximum 1Mbps raw data speed.

16. Preliminary Work on New 230MHz Wireless Broadband (4G) Technology Research

- 1) **Smart Grid Construction with 4G Technology:** Since 2008, State Grid Information & Communication Company has researched 4G applications for power systems through national science and technology projects. In 2011, 230MHz power wireless communication system verification was completed in Haiyan County. In 2012, 4G technology was applied in Hebei, Hunan, and Jiangxi. In 2013, pilot units expanded to eastern Inner Mongolia, Hebei, and other regions. The system provides video transmission at 500kbps over 5km distances, with single-station coverage of 10km.

Challenges: High power consumption, private-public network interconnection security, and signal interception risks require mature solutions. State Grid is researching power wireless virtual private networks.

- 2) **Shenzhen Guodian Technology Communication Company: “New 230MHz Wireless Broadband Communication System”**
The system adopts TD-LTE core technology for power communication networks, performing carrier aggregation on 40 discrete 25kHz channels in the 230MHz band to provide higher bandwidth meeting smart grid requirements, including video transmission capability.

Technical advantages: - **Speed and heartbeat detection:** Spectral efficiency $>2.5\text{bps/Hz}$. With 1MHz bandwidth, single-cell uplink throughput reaches 1.5Mbps, with terminal peak uplink rates of 1.76Mbps. - **Multi-user access:** Single sector supports 1,200 terminals; single base station supports 3,600 wireless terminals. - **Anti-interference performance:** Uses spectrum sensing and cognitive radio technology to coexist with traditional 230MHz radio stations, meeting national radio management committee requirements. - **Coverage:** 3km in urban areas, 30km in rural areas. - **Spectrum adaptability:** TDD duplex mode with adjustable uplink-downlink ratios.

- 3) **China Electric Power Research Institute & State Grid Electric Power Research Institute: “Carrier Aggregation Technology Based on 230MHz Power-Specific Spectrum”** The new 230MHz power wireless broadband private network uses TD-LTE technology, transforming the physical layer of 40 discrete 25kHz channels in State Grid’s authorized 230MHz band through carrier aggregation to provide bandwidth sufficient for smart grid data and video transmission needs.
- 4) **Security Testing:** In early 2014, State Grid Information & Communication Company’s TD-LTE230 system passed security testing organized by State Grid Information & Communication Company and China Electric Power Research Institute. The system’s security architecture effectively prevents fake base station and terminal intrusion, meeting smart grid application security requirements.

Smart meter communication technology research is a key technology for the meter industry' s development, involving multiple communication technologies and applications. As smart grid construction advances, smart meters—as critical components—are receiving increasing attention. Research encompasses local and remote communication systems, narrowband and broadband power line carrier technology development, and communication protocol optimization. Narrowband and broadband carrier communication represents an important direction the meter industry can independently research and apply. With rapid growth in distributed power grid integration, higher requirements are imposed on smart meter communication systems, necessitating solutions to communication challenges and providing modern, high-quality, economically rational comprehensive solutions.

In electricity information collection systems, construction and application research proceed simultaneously, including enterprise standard formulation, terminal prototype development, and new standard content evolution. Regional grids are actively promoting smart meter applications: Ningxia achieved full rural smart meter coverage; Shenyang achieved 100% daily automatic meter reading success in public transformer districts. These practices provide valuable experience and data support.

Low-voltage carrier communication technology has made new progress, including maintenance-free narrowband systems, collaborative research on engineering design and interference management, and new carrier chip module development. However, challenges remain in communication stability, security, and reliability. With rapid IoT and big data development, smart meter communication technology requires continuous innovation to meet new application demands.

In conclusion, smart meter communication technology research is an ongoing process requiring collaborative efforts from the meter industry, chip enterprises, system integrators, and power departments to advance smart grid construction.

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