Research on the Design of a Narrowband Carrier Automatic Meter Reading System

Authors: Zhang Zhen, Zhang Zhen

Date: 2024-02-26T10:57:18+00:00

Abstract

This passage primarily introduces the electricity information collection system construction to be completed by State Grid between 2010 and 2014, with particular focus on the application and challenges of local narrowband carrier communication methods. The article also mentions collaborative research on engineering design and management methodologies for local narrowband carrier automatic meter reading systems, emphasizing that this constitutes a complex public welfare project requiring substantial investment. Early-stage research drew upon experience from performance evaluation systems for low-voltage power line narrowband carrier communication systems and proposed a series of innovative construction strategies. Simultaneously, the article identifies certain missteps in the formulation of State Grid's enterprise standards for electricity information collection systems, such as the failure to prioritize research on technical bottlenecks in local narrowband carrier automatic meter reading systems for residential users, along with various problems and deficiencies within the standards themselves. The text centers on "State Grid electricity information collection system construction" and "application and issues of local narrowband carrier communication methods", while also addressing early-stage research, innovative construction strategies, and standard formulation missteps.

Full Text

Abstract

This paper examines the construction of the electricity information collection system undertaken by the State Grid Corporation of China between 2010 and 2014, with particular attention to the application and challenges of local narrowband carrier communication technologies. The research represents a collaborative effort among Chongqing Electric Power Research Institute, Wasion Group, Qingdao Neusoft Company, and the author to investigate engineering design and management methodologies for local narrowband carrier automatic meter reading systems—a complex, capital-intensive undertaking that directly impacts millions of households. Drawing upon experience from performance evaluation systems for low-voltage power line narrowband carrier communication, this work proposes a series of innovative deployment strategies. Additionally, the paper identifies critical oversights in the development of State Grid's enterprise standards for electricity information collection systems, notably the failure to prioritize research on technical bottlenecks affecting residential narrowband carrier AMR systems, and highlights various deficiencies within these standards.

Keywords: narrowband carrier, automatic meter reading system, engineering design

1. Introduction

Between 2010 and 2014, the State Grid Corporation of China undertook the construction of a comprehensive electricity information collection system, achieving full coverage for 240 million residential customers—91% of its total user base—with daily remote meter reading accounting for 13% of total electricity sales. This initiative represents a massive, complex, and capital-intensive systematic engineering project that directly affects electricity consumption and billing for millions of households. The local narrowband carrier communication approach, championed by the State Grid's marketing department, serves as the foundational component of this system, accounting for 50% of residential users in local automatic meter reading deployments.

In recent years, large-scale deployment of the State Grid's electricity information collection system has proceeded despite communication technology constraints, revealing numerous issues with narrowband carrier communication. From October 2009 to August 2011, the author collaborated with Chongqing Electric Power Research Institute, Wasion Group, and Qingdao Neusoft Company on research concerning performance evaluation systems for low-voltage power line narrowband carrier communication. Building upon this foundation, the team has now pioneered research into engineering design and management methodologies for local narrowband carrier automatic meter reading systems—representing a new challenge at the most fundamental level of electricity information collection system construction with substantial technical difficulty.

2. Preliminary Research

2.1 Learning from Low-Voltage Power Line Narrowband Carrier Communication Performance Evaluation Systems

This research initiative yielded a series of groundbreaking preliminary results. First, leveraging the Chongqing experimental distribution transformer district project, collaborative multi-party research was conducted on field evaluation techniques for narrowband carrier communication systems, producing several demonstrable scientific and technical achievements. These include specifications and selection methodologies for experimental transformer districts, implementation plans and construction projects for evaluation-grade electricity information collection systems, and the development of monitoring and analysis capabilities for communication environment parameters affecting carrier communication quality in low-voltage grids. The research also produced a communication environment monitoring instrument and typical test data reports, along with guidelines for metering asset standardization and low-voltage power line renovation schemes in transformer districts. Additionally, the team developed a comprehensive performance evaluation index system for electricity information collection systems with corresponding typical test data reports, and generated comparative field test data reports for different narrowband carrier modulation schemes.

Second, regarding narrowband carrier electricity meter (narrowband carrier communication module) performance, two distinct technological solutions were developed. The first is a laboratory low-voltage power line carrier communication (point-to-point) test system developed through collaboration between Chongqing Electric Power Research Institute and Xinlian Company. The second is a fully automatic narrowband carrier communication performance test apparatus developed by Wasion Group.

Third, for narrowband carrier communication system routing simulation testing, two different technological approaches were proposed. One features a hardware-based laboratory low-voltage power line carrier communication routing test system developed by Chongqing Electric Power Research Institute and Xinlian Company. The other is a laboratory simulation testing platform for power line carrier communication routing proposed by Wasion Group. It should be noted that Neusoft Company began researching routing algorithms and simulation technologies earlier, accumulating substantial experience and providing advanced NS2 routing simulation documentation. International standards for narrowband carrier communication were also translated as part of this effort.

These preliminary research findings primarily stemmed from innovative development thinking. Based on this foundation, the team summarized and proposed strategies for constructing high-quality local narrowband carrier automatic meter reading systems. The first strategy involves creating experimental distribution transformer districts for performance comparison of local narrowband carrier automatic meter reading systems, developing rapid methods for identifying communication faults and differentiating between various narrowband carrier communication schemes. The second employs reverse thinking to identify factors causing communication failures, addressing all discovered issues through tripartite collaboration among electric power departments, communication chip companies, and system integrators. Specifically, power departments manage interference sources from low-voltage grids and renovate low-voltage power lines; communication chip companies focus on improving routing, relaying, networking technologies, error correction algorithms, and modulation schemes; and system integrators manage anti-interference measures for input/output circuits, transmission/reception levels, and system software development. The third strategy emphasizes starting with laboratory testing of narrowband carrier products, necessitating research on laboratory testing equipment for narrowband carrier electricity meter performance and simulation testing systems for local system communication routing. The fourth highlights the importance of controlling high-frequency interference sources to reduce technical difficulties in routing, relaying, and networking, particularly regarding random noise in low-voltage grids, which requires statistical measurement and recording methods—a research area not yet addressed domestically. The fifth advocates for research into engineering design and management methods for high-quality local narrowband carrier automatic meter reading systems.

2.2 Analysis of Shortcomings in State Grid's Electricity Information Collection System Enterprise Standards

The State Grid electricity information collection system represents a branch of grid marketing operations, encompassing functions such as data acquisition, data management, control, comprehensive analysis, operation and maintenance management, and system interfaces. The formulation of functional specifications for electricity information collection systems primarily referenced standards for large consumer power load management systems and load management terminals, failing to prioritize research on technical bottlenecks affecting local narrowband carrier automatic meter reading systems for residential users.

The system's overarching objective of "full coverage, full acquisition, full fee control" cannot be achieved at a high standard without high-quality local communication quality as a guarantee. Technical issues span multiple layers: six research hotspots at the physical layer, channel coding and medium access control (MAC) at the link layer, networking routing (relaying) methods at the network layer, and communication services and network management at the application layer. The matching degree between carrier communication module output impedance and power line input impedance directly affects signal coupling efficiency.

The Q/GDW375.3-2009 technical specification for electricity information collection system design explicitly states that low-cost solutions may employ low-voltage power line carrier, micropower wireless networks, or RS-485 communication. However, the Q/GDW374.3-2009 communication unit technical specification for electricity information collection systems contains basic requirements for low-voltage power line narrowband carrier communication that are identical to DL/T698-1999 but inconsistent with Q/GDW379.4-2009. The Q/GDW379.4-2009 inspection technical specification for communication units specifies inspection items including communication unit output performance, transmission performance, interface performance, transmission characteristics, and communication protocol consistency—all of which are type test items not performed during factory inspection or arrival acceptance, with no provisions for pre-installation inspection.

Furthermore, Q/GDW379.1-2009 inspection specifications require meter reading accuracy sampling tests for residential users during periods of light electricity load. These standardization oversights obscure the existence of technical bottlenecks in local narrowband carrier communication, resulting in multi-faceted vulnerabilities and low standards in local narrowband carrier automatic meter reading system construction, falling far short of the bidirectional high-speed communication requirements for smart grid and AMI engineering.

2.3 Research Questions from Reference Document "Research Progress on Low-Voltage Power Line Carrier Communication Technology"

Key research directions include two primary approaches to improving power line carrier communication reliability: enhancing point-to-point communication probability and addressing peripheral circuit design, particularly filter circuits that essentially constitute resonant circuit design in narrowband communication. Critical questions remain regarding the establishment of low-voltage power line channel models and transfer functions within the 3KHz-500KHz frequency range. Hot research topics in power line OFDM technology include modulation and demodulation algorithms, spectrum optimization, and channel estimation. Chaos frequency hopping coding systems can achieve low communication error rates at relatively low signal-to-noise ratios. Networking technologies for low-voltage power line communication have proposed cluster routing algorithms, ant colony algorithm-based networking, and network characteristic models. Application technologies for power line carrier modulation chips primarily involve ST's ST75XX series using 2FSK modulation and Intellon's P300/P400 products based on spread spectrum modulation. Standardization efforts for low-voltage narrowband power line communication continue to progress slowly, with difficulties reaching consensus on conducted interference definitions and limits. Future directions include employing intelligent theories and technologies to enhance system resistance, recognition capability, recoverability, and rate adaptability, as well as service-oriented resource control to minimize transmission power and reduce unnecessary EMI impact while ensuring communication quality.

3. Discussion and Verification

3.1 System Engineering Design and Management Objectives; Factors Affecting Narrowband Carrier Communication Quality

Key research contributions include Chongqing Electric Power Research Institute's "Low-Voltage Power Line Carrier Field Evaluation Application Technology" and "Construction of Power Line Carrier Communication Test Environment," Qingdao Neusoft's documentation on BS EN 50065-1:2001+A1:2010 regarding signal transmission on low-voltage electrical installations in the 3KHz-148.5KHz range, Chint Instrumentation's "Basic Research on Carrier Technology Based on Lonworks," and Heilongjiang Electric Power Research Institute's "Low-Voltage Power Line Carrier Communication and Signal Transmission Characteristic Detection Methods."

3.2 Prevention of Residual Current Device Malfunction

Research from China Electric Power Research Institute analyzes the applicability of carrier sense/collision detection mechanisms for low-voltage power line carrier communication.

3.3 Low-Voltage Power Line Impedance Definition, Testing, and Impedance-Time Characteristics

Contributions include Chongqing Electric Power Research Institute's studies on the relationship between carrier communication frequency and impedance in low-voltage distribution networks, research on carrier signal attenuation characteristics, and North China Electric Power University's field measurements and analysis of narrowband carrier communication channel impedance and attenuation characteristics. Additional work from Yunfu Power Supply Bureau examines indoor low-voltage power line channel characteristics.

3.4 Household Appliance High-Frequency Interference Signal Characteristics and Control Measures

Research from Baodi Power Supply Company addresses overcoming high-frequency harmonic effects on carrier communication, while Analog Devices' studies investigate low-voltage power line noise characteristics.

3.5 Low-Voltage Power Line Narrowband Carrier Channel Modeling

Key topics include automatic routing technology based on predictable - persistent CSMA from Heilongjiang Institute of Science and Technology, fully dynamic relaying technology adapting to grid channel conditions from Langjin Company, dynamic networking technology applications from RMS Company, intelligent relaying technology implementations from Hefei University of Technology, and automatic networking algorithms for 10KV power line carrier communication from North China Electric Power University.

3.6 Laboratory Selection Methods for Narrowband Carrier Modules

Research encompasses test system development from Chongqing Electric Power Research Institute, mainstream carrier communication module design and testing from Wasion Group, and power line carrier communication test environment construction from Qingdao Neusoft.

3.7 Routing, Relaying, and Networking Performance Simulation

Simulation approaches include hardware-based routing test systems from Chongqing Electric Power Research Institute and routing test simulation platforms from Wasion Group, complemented by Neusoft's NS2 network simulation software introductions.

3.8 Distribution Transformer District Crosstalk Signal Identification and Testing

3.9 Wiring Quality Requirements for Low-Voltage Power Lines, T-Connections, and Communication Lines

Research includes testing of narrowband carrier signal reflection losses at copper-aluminum joints.

3.10 OFDM Narrowband Carrier Communication Applications

Investigations cover online analyses of OFDM power carrier chip applications, Lonworks-based carrier technology fundamentals from Zhuhai L&G Instrumentation Systems, overviews of Neusoft's 5th-generation carrier systems, and research on semi-blind channel estimation and time-varying channel estimation for low-voltage narrowband power line carrier communication.

3.11 Power Frequency Communication Technology Application Prospects

Research from China Electric Power Research Institute explores multi-channel transmission in distribution networks and power remote meter reading systems capable of crossing transformer districts.

3.12 Automatic Testing Functions for Local Narrowband Carrier Automatic Meter Reading Systems

Zhejiang Electric Power Company pioneered automatic debugging technology for collection terminals, enabling automatic generation of relationships between concentrators, collectors, and customers upon device wiring completion, eliminating complex manual testing. The system automatically updates hierarchical relationships during meter replacement and district reconfiguration processes. Qingdao Neusoft contributed research on meter number search algorithms in power line communication-based meter reading systems.

4. Preliminary Research on System Engineering Design and Management Methods

4.1 Data Collection for Distribution Transformer Districts

Comprehensive data collection should include: total number of residential households and total electricity consumption capacity; building distribution and user counts; quantities and capacities of elevators, water pumps, capacitors, and frequency converters (switching frequencies 40-210KHz); total number and capacity of distribution transformers, including individual transformer capacities; lengths and specifications of overhead lines, T-connections, and cables; reactive power compensation capacity and distribution; electricity meter topology diagrams with inter-meter power line distances; quantities and total capacity of household appliances (switching power supplies operating at 40-120KHz, energy-saving lamps at 50KHz); commercial outlet electricity and equipment capacities; photovoltaic/wind new energy capacities and inverter specifications; and electric vehicle charging station capacities with voltage/current harmonic content.

4.2 Field Surveying

Survey procedures must measure total electricity consumption and distributed power during evening peak and daytime light-load periods. Power line impedance, high-frequency interference signal intensity, and transformer district crosstalk signal strength should be tested under both conditions. The intensity of high-frequency interference injected into the low-voltage grid by sources such as elevators, water pumps, and large household appliances must be quantified. Signal attenuation measurements should be taken at distances of 100m, 200m, 250m, 300m, 350m, 400m, 450m, and 500m from the transformer after injecting standard narrowband carrier signal limits at the transformer outlet. Additional measurements include transmission power distribution for commonly used narrowband carrier modulation frequencies, reflection loss at copper-aluminum joints, and sampling of customer-to-ground coupling capacitance.

4.3 Basic and Extended Testing Items for Narrowband Carrier Modules

Testing must comply with Q/GDW374.3-2009 communication unit specifications, which prioritize the IEC61000-3-8 designated power sector frequency band of 9KHz-95KHz for low-voltage power line narrowband carrier communication. Key parameters include output signal levels 20% below limits, out-of-band conducted disturbance levels 20% above limits, transmission performance, communication success rates, static and dynamic power consumption, and protocol consistency. Extended testing should cover maximum transmission power, signal transmission rates, filter circuit performance, output coupling circuit resonance points, load capacity, reception sensitivity, and noise immunity.

4.4 Local System Design and Simulation

Design objectives vary by application: monthly billing and line loss management requires 24-hour 100% automatic meter reading success; daily line loss and remote prepaid management demands 2-hour 100% success (optimally 1-hour); and AMI pilot projects require 1-hour 100% success. System architecture design must consider power line parameter calculations including impedance-frequency characteristics, narrowband carrier signal attenuation, and high-frequency interference bands and intensity. Based on design targets and routing/relaying/networking performance specifications, minimum transmission rate limits (bps) must be established. Carrier module selection criteria should encompass electromagnetic crosstalk, transmission power, signal strength, reception sensitivity, line location, phase information, and physical link connectivity.

Narrowband carrier interference calculations must derive coupling capacitance-frequency curves based on sampled customer-to-ground capacitance data. Extensive sampling analysis should consider high-frequency signal attenuation within residual current devices to propose limits for customer-to-ground coupling capacitance and leakage current induced by narrowband carrier interference. Laboratory simulation testing should evaluate point-to-point communication under influences including power line impedance-frequency characteristics, transformer district crosstalk, high-frequency noise interference, signal attenuation, and copper-aluminum joint reflection losses. Routing, relaying, and networking performance must be simulated and tested under these influence factors, with algorithm adjustments and design improvements implemented based on local system performance metrics.

4.5 Supplementary Management Measures

Based on design and simulation results, necessary auxiliary management measures may include controlling high-frequency interference sources during automatic meter reading periods and inspecting/improving copper-aluminum joints in power lines, T-connections, and cables.

4.6 Local System Engineering Acceptance

Acceptance testing must verify local system performance metrics and enable visual online monitoring of routing, relaying, and networking processes in the field. Additional tests should measure maximum narrowband carrier signal transmission power and verify other acceptance items including system response to environmental temperature variations.

4.7 Documentation Archiving

All engineering design and management methodologies, including algorithms and software, must be compiled and archived for future reference.

Reference: [1] Zhang Zhen. Research on the design of narrowband carrier automatic meter reading system.