

Research on Large-scale Application of Broadband (Intermediate Frequency) Power Line Carrier Communication Technology

Authors: Zhang Chunhui, Zhang Zhen, Zhang Zhen

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Abstract

This paper primarily introduces the IEEE1901.1 broadband (medium-frequency) power line carrier communication international standard and its application in the State Grid' s electricity information collection system. This standard, released by the China Electric Power Research Institute (CEPRI), fills the gap in international standards for medium-frequency power line carrier communication in the smart grid domain, thereby enhancing China' s international influence and discourse power in the Internet of Things field. Meanwhile, the State Grid emphasizes the development of broadband (medium-frequency) power line carrier communication technology, primarily because narrowband (low-speed) carrier communication methods suffer from slow communication rates and low automatic collection success rates, which have become a technical bottleneck for local communication. This paper also introduces the investment situation in the construction of the State Grid' s electricity information collection system, as well as the electricity information collection requirements that broadband (medium-frequency) carrier communication rates must satisfy.

Full Text

Research on the Large-Scale Application of Broadband (Intermediate Frequency) Power Line Carrier Communication Technology

ZHANG Chunhui¹, ZHANG Zhen²

¹State Grid Shandong Electric Power Company, Jinan, Shandong 250001, China

²Huaneng Jinan Huangtai Power Generation Co., Ltd., Jinan, Shandong 250100, China

Abstract

This paper introduces the IEEE1901.1 international standard for broadband (intermediate frequency) power line carrier communication and its application in the State Grid's power consumption information acquisition system. Published by the China Electric Power Research Institute, this standard fills the gap in international standards for intermediate-frequency power line carrier communication in smart grid applications, thereby enhancing China's international influence and voice in the Internet of Things domain. State Grid's emphasis on developing broadband (intermediate frequency) power line carrier communication technology stems primarily from the limitations of narrowband (low-speed) carrier communication, whose slow communication rates and low automatic acquisition success rates have become technical bottlenecks for local communication. This paper also discusses the investment in State Grid's power consumption information acquisition system construction and the communication rate requirements that broadband (intermediate frequency) carrier technology must satisfy for power consumption information acquisition applications.

Keywords: broadband, power line carrier communication technology, power consumption information acquisition system

Recently, the IEEE1901.1 broadband (intermediate frequency) power line carrier communication international standard was released by the China Electric Power Research Institute, which may trigger updates to the local communication methods in State Grid's power consumption information acquisition system and warrants close attention.

1) IEEE1901.1 International Standard

According to online reports, on May 22, 2018, the IEEE1901.1 standard—*Medium Frequency (Less Than 12 MHz) Power Line Carrier Communication Technology Standard for Smart Grid Applications*—was officially released and implemented. This standard was jointly formulated by the China Electric Power Research Institute, State Grid Information & Telecommunication Industry Group, and other enterprises. Based on State Grid's Q/GDW 11612 *Technical Specification for Interoperability of Low-Voltage Power Line Broadband Carrier Communication*, the standard extensively employs innovative technologies, proposing physical layer communication technical specifications centered on OFDM, dual-binary Turbo coding, and time-frequency diversity copying, as well as data link layer technical specifications represented by channel timing optimization, tree networking, and multi-transformer district network coordination. The release of this standard fills the void in international standards for intermediate-frequency power line carrier communication applications in smart grid fields and enhances China's international influence and voice in the Internet of Things domain. By constructing high-bandwidth, high-reliability, low-latency, and low-cost power line communication networks, the IEEE1901.1

standard supports various application scenarios such as remote automatic meter reading and distribution transformer district monitoring, enabling the effective application of power line carrier communication-based IoT technology in energy internet applications. Furthermore, the standard will promote the development of the entire industry chain, including power line carrier communication chips, communication modules, and intelligent terminals.

2) State Grid' s Development Process for Broadband (Intermediate Frequency) Power Line Carrier Communication Technology

State Grid' s emphasis on developing broadband (intermediate frequency) power line carrier communication technology arises from critical limitations in existing systems. From 2010 to 2017, State Grid constructed its power consumption information acquisition system, covering 430 million households with 99% coverage and representing a massive investment of approximately 51 billion yuan in equipment and user engineering. Among these systems, 70% adopted narrowband (low-speed) power line carrier communication technology for local communication. After years of operation, the narrowband approach has proven inadequate, with slow communication rates and low automatic acquisition success rates. In some residential communities, single-phase meters could not be read even after 24 hours, creating a persistent technical bottleneck for local communication. Consequently, State Grid has prioritized the practical application of broadband (intermediate frequency) power line carrier communication as a key new technology development project, leveraging the 资源优势 of ubiquitous power line infrastructure.

According to communication traffic forecasts proposed by experts from the China Electric Power Research Institute, broadband (intermediate frequency) carrier communication rates must meet the following power consumption information acquisition requirements: AMR/AMI communication rates of 1.2/20 kbps, load management at 10 kbps, distribution automation, alarm management, and distributed generation (DG) all at 10 kbps, and distribution video monitoring requiring 1 Mbps, along with other new video communication demands for distribution networks.

In July 2012, State Grid launched the “Key Technology Research on New Generation Intelligent Power Line Carrier Communication” project. This intelligent PLC features cross-band capability (150 kHz-10 MHz), frequency self-awareness, self-adaptation, self-networking, and coordinated communication functions. The project was led by the China Electric Power Research Institute, with participation from State Grid Communication Company and NARI Group. By November 2014, the project passed acceptance, and its intelligent PLC system underwent actual testing and verification on medium- and low-voltage power lines in Shaoxing and Changchun power grids.

In July 2014, during the technical exchange meeting for the *Research on Full Performance of Imported High-End Electrical Energy Meters* organized by the

authors, Huawei HiSilicon introduced its independently designed Hi3911 broadband (intermediate frequency) carrier chip, operating in the 2-12 MHz band with communication rates of 200 kbps to 14 Mbps. This suggests that Huawei HiSilicon's intermediate-frequency carrier chip was launched even earlier. In October 2014, State Grid held a seminar on low-voltage power line broadband carrier communication technical standards, proposing initial drafts for broadband carrier communication unit technical specifications, testing specifications, and communication protocols. The following month, at the power line carrier communication new standards and new products technical exchange meeting organized by the authors, international and domestic broadband and OFDM narrowband carrier communication technologies were extensively discussed.

In 2015, Huawei HiSilicon shared the physical layer and communication protocols of its intermediate-frequency carrier chip within State Grid's broadband carrier communication technical enterprise standards. Under the premise of a unified physical layer, various broadband carrier chip manufacturers independently developed upper-layer applications. In 2016, at the discussion meeting on current hot issues in the electricity meter industry organized by the authors, Chongqing Electric Power Research Institute introduced field test results of broadband carrier communication interoperability in large public transformer districts (approximately 700 households). In 2017, Jiangsu Electric Power Research Institute completed interoperability testing of broadband carrier modules, verifying their performance under complex field conditions including overhead lines, pre-installed cables, urban, and rural environments. Also in 2017, Chongqing University of Posts and Telecommunications and Chongqing Electric Power Research Institute proposed in their paper *Implementation of Broadband Power Line Impulse Noise Based on System Generator* that implementing a Class A noise generator based on FPGA would facilitate evaluation and testing of broadband PLC product anti-noise performance.

In 2017, State Grid released the *Technical Specification for Interoperability of Low-Voltage Power Line Broadband Carrier Communication (Q/GDW 11612-2016)*, which consists of six parts: general principles, technical requirements, testing methods, physical layer and communication protocols, link layer and communication protocols, and application layer technical requirements. In May 2018, the China Electric Power Research Institute published the *Medium Frequency (Less Than 12 MHz) Power Line Carrier Communication Technology Standard for Smart Grid Applications (IEEE1901.1)*.

3) Qingdao Eastsoft Company: Launch of IEEE1901.1-Compliant Broadband (Intermediate Frequency) Carrier Communication Chip

According to online reports, "IEEE Released New Carrier Standard, Eastsoft Carrier Chip Obtains International Passport," Eastsoft has launched a new intermediate-frequency carrier chip model: Eastsoft SSC1667. Currently, at least one million chips are in network use, with continuous deepening application and features such as supercapacitor power outage reporting and auto-

matic transformer district identification. The design performance of Eastsoft's SSC1667 broadband (intermediate frequency) carrier communication chip includes: 40nm Flash process technology, highly integrated SoC chip with built-in Flash and low peripheral costs; OFDM orthogonal frequency division multiplexing modulation technology; communication rate of 6 MHz; communication band of 0.7 MHz-12 MHz; lower power consumption (static 0.7W/dynamic 1W); support for both new and existing State Grid broadband interoperability standards with band switching capability; and support for 4 frequency bands and 6 modes (specific standards and bands omitted).

4) Technical Challenges and Disputes in Intermediate-Frequency Power Line Carrier Communication

China's achievement in developing the IEEE1901.1 international standard represents a breakthrough in international standard formulation for power line carrier communication technology. Internationally, the early research focus for broadband (high frequency: 2 MHz and above) power line carrier communication standards was smart home networks, later expanding to meet communication demands for home digital multimedia, video, audio, data, and intelligent energy control. In this domain, the Home Plug Alliance proposed broadband power line carrier communication technical standards relatively early and comprehensively, with some standards subsequently converted into IEEE international standards: Home Plug 1.0 (2001) with maximum data rates of 14 Mbps, primarily for home network applications and also used for low-voltage broadband access; Home Plug 1.0-Turbo (2004) increasing maximum rates to 85 Mbps; Home Plug AV (2005) operating in the 1.8-25 MHz band with maximum rates of 200 Mbps for video, audio, and data transmission; and Home Plug Green PHY (2006) designed for embedded smart energy and automation applications in homes and buildings, interoperable with IEEE1901/Home Plug AV protocols while reducing data rates to low speed (10 Mbps), lowering power consumption by 80%, and reducing costs with broad home coverage capabilities.

For narrowband (low frequency: 500 kHz and below) OFDM power line carrier communication standards, the PRIME Alliance was established in 2011, releasing the G3-PLC standard, with ITU's G9955 and IEEE P1901.2 both compatible with the G3-PLC physical layer. In 2014, ITU G9903 released an updated version. These narrowband communication standards, using OFDM low-frequency narrowband carrier communication technology, have rapidly emerged with advantages of higher transmission rates and flexible frequency bands, primarily used for automatic meter reading management and smart home networks in the 10 kHz-500 kHz band with data transmission rates of 20 kbps-150 kbps.

This context reveals two key points: (a1) Internationally, there has long been no international standard for intermediate-frequency (150 kHz-12 MHz) power line carrier communication methods suitable for smart grid power consumption information acquisition; (a2) Domestically, since State Grid proposed the construction of a power user electricity consumption information acquisition system

in 2009, multi-faceted cooperative research has been conducted on intermediate-frequency (below 12 MHz) power line carrier communication technology for smart grid applications. The IEEE1901.1 international standard is based on years of domestic cooperative innovation and systematic research achievements, including intermediate-frequency carrier chip development, field broadband carrier communication interference performance testing, broadband carrier communication interoperability discussions, and broadband carrier communication standard formulation.

From an application perspective, what are the technical difficulties and disputes in intermediate-frequency (below 12 MHz) power line carrier communication? The delayed introduction of an international standard for smart grid applications likely stems from key technical challenges and controversies. Based on comprehensive analysis from the 2014 Qingdao power line carrier communication new standards/new products technical exchange meeting and the 2016 Chongqing electricity meter industry development hot issues discussion meeting, the authors propose three major difficulties and disputes in intermediate-frequency power line carrier communication application development:

First, bidirectional high-frequency interference in intermediate-frequency power line carrier communication. Online reports indicate that in June 2013, ITU-R (International Telecommunication Union Radiocommunication Sector) published *The Impact of Power Line Communication Systems on Radio Communication Systems Operating Below 80 MHz (ITU-R SM.2158-3 Report)*, which questioned power line carrier communication methods (Note: SM series refers to spectrum management. Currently, no domestic comments on the ITU-R SM.2158-3 report have been seen).

Second, the severity of impact from distribution network pre-installed cables and reactive power compensation devices on intermediate-frequency power line carrier communication, and the rationality assessment of improvement measures. Field measurements have shown that when concentrators are installed before reactive power compensation devices (on the power source side), automatic meter reading success rates are extremely low or even impossible.

Third, broadband carrier communication interoperability issues. Although domestic broadband carrier chip manufacturers have unified the physical layer and communication protocols of their intermediate-frequency carrier chips, network path selection and relay functions remain different, resulting in unsatisfactory interoperability effects in actual field networking and meter reading applications.

Regarding these difficulties and disputes, State Grid's metering department has organized unified field testing and analysis, proposing some improvement measures. However, few reports on this topic have been published in journals or online. The IEEE1901.1 international standard proposes physical layer and data link layer technical specifications for intermediate-frequency (below 12 MHz) power line carrier communication networks, with extensive innovative technologies that improve communication signal (bit, frame) transmission quality and

data transmission performance. Subsequently, there is intention to continue cooperative development of network layer and other layer technical specifications for intermediate-frequency carrier communication networks, expecting to unify deep-level communication technologies in networking, routing algorithms, data transmission, and interoperability to significantly improve power consumption information acquisition rates and automatic acquisition success rates, thereby resolving application challenges caused by intermediate-frequency carrier communication quality issues.

Additionally, the authors propose that another important standard needs to be jointly researched and formulated: the technical specification for intermediate-frequency power line carrier communication channel monitoring and management. Suggestions for formulating this technical specification are described in section 5). High-quality intermediate-frequency power line carrier communication can only be achieved by combining technical performance development of intermediate-frequency carrier communication networks with channel monitoring and management measures to effectively resolve these three application challenges.

Attention should also be paid to the technical performance of intermediate-frequency carrier communication chips, with testing and certification conducted according to the IEEE1901.1 standard. It is understood that relevant laboratories have been established domestically for this purpose, marking a first in the electricity meter carrier communication field. Regarding carrier module pricing, current intermediate-frequency carrier modules are still more expensive than narrowband (low-speed) carrier modules, which will affect large-scale promotion and application. However, as application volumes continue to grow, prices can be expected to reach reasonable levels.

5) Recommendations for Formulating Domestic Intermediate-Frequency Power Line Carrier Communication Channel Monitoring and Management Technical Specifications

Internationally, the EN50065 standard *Signaling on Low-Voltage Electrical Installations in the Frequency Range 3 kHz to 148.5 kHz* includes: Part 1 (general requirements, frequency bands, and electromagnetic disturbances), Part 2-1 (immunity requirements for equipment operating in residential, commercial, and light-industrial environments in the 95 kHz-148.5 kHz band), Part 2-2 (immunity for industrial environments), Part 2-3 (immunity for equipment operated by electricity suppliers and distributors in the 3 kHz-95 kHz band), Part 4-1 through 4-6 (various specifications for low-voltage decoupling filters), and Part 7.

For domestic formulation of intermediate-frequency power line carrier communication channel monitoring and management technical specifications, reference can be made to the EN50065 series standards, combined with characteristics of intermediate-frequency power line carrier communication. The specifica-

tions should cover: intermediate-frequency bands and bidirectional electromagnetic disturbance limits; intermediate-frequency carrier signal attenuation and signal-to-noise ratio measurement, concentrator site survey; bidirectional high-frequency interference monitoring; anti-conduction and radiation interference requirements for various application environments; testing and handling solutions for the impact of pre-installed cables and reactive power compensation equipment on intermediate-frequency carrier communication; co-frequency interference testing and improvement methods; various decoupling filters; equipment impedance; bidirectional communication and gateway technical specifications; and other relevant aspects.

References

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Author Biographies

ZHANG Chunhui (male, born 1938) is engaged in research on electrical energy metering technology.

Corresponding Author: ZHANG Zhen (born 1977) is engaged in research on electrical energy metering technology. Email: 721047546@qq.com

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

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