Research on the Evolution of Chinese Multifunction Meter Technology

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Abstract

This paper discusses in depth the technical evolution of domestic multifunctional electricity meters. With the rapid development of the domestic power market and continuous technological innovation, domestic multifunctional electricity meters have experienced transformation from simple billing to complex multifunctional capabilities, and from single applications to a wide range of fields. This transformation has not only driven rapid development of electricity meter technology but also met increasing power demands and management requirements. This paper expounds the concept of multifunctional meters, the working principle and algorithm of digital multipliers, the initiation and evolution of multifunctional electricity meter standards, and the initiation and evolution of domestic multifunctional electricity meter products. Although domestic independent production of multifunctional meters has made great achievements in performance, reliability and key process technologies still need improvement. In addition, the development of communication technology provides new opportunities for the progress of electricity meter technology. The application of new technology provides more convenient and efficient ways for data transmission and remote management of electricity meters. Domestic multifunctional electricity meters have made remarkable achievements in technology evolution and application expansion, but they still face some challenges and opportunities. In the future, with continuous development of the power market and promotion of smart grid construction, domestic multifunctional electricity meters need to continue strengthening technological innovation and product research and development, and improve product reliability and competitiveness, in order to meet higher application needs and market requirements.

Full Text

Research on the Evolution of Domestic Multi-Function Meter Technology

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Abstract: This paper provides an in-depth examination of the technical evolution of domestic multi-function electricity meters. Driven by the rapid development of China' s power market and continuous technological innovation, domestic multi-function meters have undergone a transformation from simple billing devices to complex multi-functional instruments, expanding from single applications to broad fields of use. This evolution has not only propelled rapid advancement in electricity meter technology but also addressed growing demands for power management and operational requirements. The paper elaborates on the concept of multi-function meters, the working principles and algorithms of digital multipliers, the initiation and evolution of multi-function electricity meter standards, and the development of domestic multi-function meter products. While domestically produced multi-function meters have achieved significant performance improvements, reliability and key process technologies still require enhancement. Additionally, the development of communication technology presents new opportunities for meter technology advancement, providing more convenient and efficient methods for data transmission and remote management.

Domestic multi-function electricity meters have made remarkable achievements in technological evolution and application expansion, yet they still face challenges and opportunities. With the continuous development of the power market and the promotion of smart grid construction, domestic multi-function meters must continue to strengthen technological innovation and product research and development to improve product reliability and competitiveness, thereby meeting higher application demands and market requirements.

Keywords: Multi-function meter; Chinese chart classification number: TM933.4; Data processing unit; Analog multiplier

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0 Introduction

In modern power systems, multi-function electricity meters play a vital role. They serve not only as fundamental tools for system operation monitoring but also as essential instruments for achieving energy management, economic accounting, and energy conservation and emission reduction goals. These meters

monitor and record key parameters such as voltage, current, active power, reactive power, and power factor in real time, providing accurate data support for power system monitoring and management. Through analysis of this data, power operators can understand system operation status, identify and address potential problems promptly, and ensure stable power system operation.

Multi-function meters provide detailed electricity consumption data that assists power users and enterprises in energy management and economic accounting. By analyzing power consumption patterns, users can identify energy waste points, formulate energy-saving measures, and reduce energy costs. Simultaneously, this data supports electricity market transactions and settlements, providing strong guarantees for fair and transparent market operation. Multi-function meters also provide data support for energy conservation and emission reduction initiatives by enabling analysis of power system energy consumption and environmental impact, optimizing system operation modes, reducing emissions and pollution, and achieving green, low-carbon power supply.

Currently, there is no unified international standard for multi-function electricity meters worldwide. In China, since 1992, the concept, application requirements, standards, and products of multi-function electricity meters have been introduced, improved, and gradually completed.

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1. Concept of Multi-Function Meter

The concept of multi-function meters was first published in March 1995 in the second part of the "Technical Report on Power Metering Measurement Technology of East China Power Grid" : "Improve time-sharing metering technology, steadily develop multi-function meter."

1.1 Multi-Function Meter Concept

The report states: "The development of electronic technology has created the foundation for multi-function electricity meters. In addition to time-sharing measurement, the multi-function electricity meter generally also includes demand measurement and load control, load survey representative daily load curve and other functions, simplifying the user measurement point meter, facilitating data collection, and should be promoted."

1.2 The Process of Writing the Report

In 1992, the Technical Committee of East China Electric Power Administration established a research group to draft the report, composed of 14 experts from the East China Electric Power Administration bureau and its provincial power grids. In 1993, the subject materials were completed successively. In 1994, Zeng Naihong of East China Electric Power Administration Bureau searched and wrote the first draft, printed it, and finalized the report.

1.3 Comments on This Article

In the initiation and development of domestic multi-function meters, the former Electric Power Department of the Ministry of Energy and the East China Electric Power Administration paved the way and achieved significant results in promoting the development of domestic high-end electricity meters. They issued China's first regional power grid power metering modernization technology report, proposed the development and application of domestic multi-function meters, and organized the drafting of the first domestic multi-function meter mechanical standard and power standard, providing a basis for the development and application of domestic multi-function meter products.

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2. Working Principle and Algorithm of Electric Energy Meter Using Digital Multiplier

The main content of this section is extracted from "Key Technology of Dynamic Power Measurement of New Power System" by China Electric Research Institute.

2.1 Working Principle of Electric Energy Meter Using Digital Multiplier

Metering method of active electric energy: Circuit (AC voltage sampling → analog-to-digital converter → current sampling → ADC → high pass filter HPF circuit) → parallel digital filter LPF → correction → integral → digital frequency conversion → pulse output → active energy.

Metering method of reactive electric energy: After parallel connection with active power metering circuit → ADC → HPF circuit, then connect to Hilbert filter → digital multiplier → LPF → correction → integration → digital frequency conversion → pulse output → reactive power.

2.2 Power Algorithm of Digital Multiplier

Time domain: Point product and numerical integration algorithm; Walsh overlapping algorithm; weighted average algorithm and window function convolution algorithm.
Frequency domain: (Window interpolation) DFT algorithm; FFT algorithm.
Time and frequency domain: Wavelet transform; estimation spectral S transform; modern intelligent algorithm.

The above algorithms can calculate electrical parameters: active power/power; reactive power/power; apparent power/power; voltage and current effective value and fundamental wave frequency.

2.3 Typical Case of Electric Energy Meter Integration Algorithm

This is an excerpt from the 2010 Weisheng "The Application of Newton-Cotes Integral Algorithm in Electric Energy Metering." The DTSD341-MA1-type high-accuracy power metering adopts a high-order integral algorithm. For signals containing up to n harmonics, to accurately calculate signal power, effective value and other parameters, the sampling of the n harmonic signal must include more than 3 points, meaning the sampling frequency must ensure more than 3n points per fundamental wave cycle. To improve accuracy of dot product signal algorithm, higher-order integration algorithms can be used. The Newton-Cotes algorithm is a practical and easily realized algorithm. The Newton-Cotes algorithm of n order has at least n times algebraic accuracy.

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3. Onset and Evolution of Multi-Function Electricity Meter Standards

The technical requirements for electricity meter accuracy and function definitions in multi-function energy meter standards reflect the technical development level of domestic multi-function meters in different periods. The multi-function table, being the most complex in function, can be divided into two categories: basic functions and extended functions.

After summarizing and analyzing seven standards of multi-function meter, smart electricity meter and new generation smart electricity meter (excluding the standard of intelligent Internet electricity meter), the State Grid standard Q/GDW 1354-2013 "Functional Specification for Smart Electricity Meters" has the most complete functions and forward-looking design, and can serve as a reference level for comparing different standards. Its functions are divided into two categories: Category 1 data/information/software output function (including general multi-function meter/smart meter output function and special smart meter output function) and Category 2 internal data/information/software formation and processing function.

3.1 Reference Level: Q/GDW 1354-2013 "Functional Specification for Smart Electricity Meters" (Released March 2013)

Definition of smart electricity meter: Composed of measurement unit, data processing unit, communication unit, etc., with electrical energy measurement, information storage and processing, real-time monitoring, automatic control, information interaction and other functions.

Types of electricity meters: Static electricity meter.

Accuracy: Electricity meters can be divided into four levels: 0.2S, 0.5S, 1 and 2.

Functions:

Category 1 basic functions (30 items, 119 detailed rules):

- **General output function of data/information/software (14 items, 58 detailed rules):**
  1. Measurement of one-way or two-way total active electric power and phase electric power, one-way or four-quadrant total reactive power (does not use phase active power to calculate total active power).
  2. Measurement of combined active electric energy and combined reactive electric energy.
  3. Time-sharing active energy and reactive electric energy measurement.
  4. Maximum demand measurement (5 detailed rules).
  5. Clock and time calibration (5 detailed rules).
  6. Event record (22 detailed rules).
  7. Communication requirements (8 detailed rules).
  8. Communication mode type (5 detailed rules: RS485, infrared communication, carrier communication, public network communication, micro-power wireless communication).
  9. Signal output (3 detailed rules: pulse output, multi-function signal output, control output).
  10. Data storage (4 detailed rules).
  11. Freezing (6 detailed rules: regular freezing, instantaneous freezing, daily freezing, agreed freezing, hour freezing, frozen content).
  12. Display (8 detailed rules).
  13. Grid operation parameters monitoring (4 detailed rules).
  14. Security protection (3 detailed rules: zero, programming, parameter setting).
- **Special output function for smart meter (9 items, 37 detailed rules):**
  1. Cost control function (14 detailed rules).
  2. Load record (3 detailed rules).
  3. Ladder electricity price (5 detailed rules).
  4. Power failure meter reading (2 detailed rules).
  5. Protect electricity function (5 detailed rules).
  6. Alarm (3 detailed rules).
  7. Auxiliary power supply (3 detailed rules).
  8. Safety certification (2 detailed rules).
  9. Load switch misaction detection function.

Category 2 internal data/information/software formation and processing function (7 items, 24 detailed rules): 1. Data/information/software formation function. 2. Data/information/software processing function. 3. Rate and time period (4 detailed rules). 4. Zero clearing (2 rules: electricity meter zero, demand zero). 5. Demand measurement (5 detailed rules). 6. Clock and school time (5 detailed rules). 7. Event record (22 detailed rules).

Category 2 extended function: (None).

Comments on this article: The general data/information/software output

function of Q/GDW 1354-2013 standard summarizes nearly 20 years of development and application experience of domestic such electricity meters, and complies with new demands of metering technology in smart grid development. Its main characteristics include: new types of electric energy metering demands are proposed, including active and reactive total power and active phase electric energy, combining active and reactive power, programming combination reactive power, time-sharing active and reactive electric energy. The clock circuit and timing method are proposed. Five types of event records are put forward (22 rules): abnormal power supply work (6 rules), abnormal power grid operation (6 rules), electricity meter work record (5 rules), anti-theft function (3 rules), event reporting and recording (2 rules). Five types of communication modes are clearly defined: RS485, infrared communication, public network communication, carrier communication, micro-power wireless communication.

The following describes the rise and evolution of multi-function meter, smart meter and new generation smart meter standards from 1995 to 2020.

3.2 JB/T 7656-95: First Domestic Mechanical Line Standard (Released March 1995)

Definition: A meter composed of measuring unit and data processing unit, which can complete multiple billing methods, load management and long-distance data transmission functions.

Meter type: According to working principle, divided into mechanical electronic multi-function meter and electronic multi-function meter.

Accuracy: Active power is 0.2, 0.5 and 1.0; reactive power is 2.0.

Functions:

Category 1 basic functions (12 items, 30 rules): - Type 1 data/information/software (general) output function (6 items, 25 rules): 1. Electric energy metering function: receiving total active and/or reactive power energy from the system; metering total active and/or total reactive power energy to the system. 2. Measurement of peak, valley, and peacetime section of active and/or reactive power division (1 detailed rule). 3. Time interval demand measurement: demand measurement mode can be interval or slip, with slip interval of 1min-15min (3 rules). 4. Preset data with external or internal attached programmer (7 rules). 5. Monitoring function (9 detailed rules). 6. Data transmission (5 detailed rules).

Category 2 internal data/information/software formation and processing function (6 items, 5 detailed rules): 1. Data/information/software formation function. 2. Data/information/software processing function. 3. Time period control function (3 detailed rules). 4. Display (2 detailed rules). 5. Automatic reset zero function (can also be manually reset zero). 6. Crash automatic recovery and program self-check function.

Category 2 extended function (10 items): Reading of active and reactive power during voltage transformer and fault checking, event recording, and 10 functions including measuring V^2h and I^2h.

Comments on this article: The JB/T 7656-95 standard reflects the design level of domestic multi-function electricity meters in the 1990s. In 1995, induction meters continued to dominate the domestic meter market; electronic meters had been used in batches; multi-function meters were in the low-volume trial phase.

Class 3 multiplier: 1. Induction electricity meter uses multiplier based on rotating magnetic field principle. 2. Electronic electricity meter with analog multiplier adopts time-split multiplier. 3. Electronic electricity meter with digital multiplier usually uses multiplier with point product and numerical integration algorithm.

The measurement error below 5% basic current is not assessed. No 0.2S, 0.5S accuracy level requirements. Software requirements are preliminary, only proposing crash automatic recovery and program self-check function.

Drafting unit: Electric Power Department of the Ministry of Energy, East China Electric Power Joint Company and East China Branch of Electricity Consumption and Electricity Saving Committee of China Society of Electrical Engineering.

Main drafters: Huang Shouhai, Chen Li, Zeng Naihong and 6 other experts.

3.3 DL/T 614-1997: Power Line Standard (Released May 1997)

Definition of multi-function electricity meter: Composed of measurement unit and data processing unit, in addition to measuring active (reactive) electric energy, also has two or more functions such as time-sharing, measurement demand, and can display, store and output data.

Meter type: According to working principle, divided into electromechanical multi-function meter and electronic multi-function meter.

Accuracy: 0.2, 0.5, 1, 2 and 3.

Functions: (Omitted)

Comments on this article: The DL/T 614-1997 standard added some new technical requirements to JB/T 7656-95. However, the two standards were released only two years apart, with few new requirements. For reactive power measurement, it estimated using only sine wave 90° phase shift circuit. Functional requirements were put forward. Accuracy added level 3 for reactive power.

Compared with Q/GDW 1354-2013, JB/T 7656-95 standard has rare functions: only one rule for data/information/software output function type; not mentioned: active power combination measurement, programming combination reactive power measurement, clock circuit and timing, event recording, anti-theft

function, power meter software comparison function, load switch misaction detection, intelligent items, fundamental wave active energy, harmonic active energy metering.

Extended functions: Communication function expansion, daily load curve record, measurement of electric energy loss, copper loss, load monitoring function, bar code number function.

Centralized unit: Technical Committee of Standardization of Electricity Measurement of the Ministry of Electric Power Industry.

Main drafters: Huang Shouhai, Wu Shijin, Yao Wenkui and 5 other experts.

3.4 GB/T 17215.301-2007: First National Standard (Released October 2007)

Definition: Multi-function watt-hour meter composed of single measurement mechanism, data processing unit, communication interface and other functional components enclosed in a case. In addition to measuring and displaying active power and reactive power, also has two or more functions such as time-sharing measurement, maximum demand measurement, and can store and output data.

Meter type: Static meter.

Accuracy: Active power: 0.2S, 0.5S, 1 and 2; reactive power: 2 and 3.

Functions:

Category 1 basic functions (12 items, 36 rules): 1. Bidirectional or unidirectional active electrical energy measurement and total four-quadrant reactive energy measurement. 2. Measurement of active energy and reactive energy of each rate. 3. Maximum demand measurement function (5 detailed rules). 4. Clock setting. 5. Event recording function (9 detailed rules). 6. Measuring output device (4 detailed rules: pulse output sequence, photoelectric test output, work indicator, etc.).

Category 2 extended function (9 items): Prepaid; calculating 11 functions including apparent power, loss, copper loss or other required parameters.

Comments on this article: In 2005, the total output of domestic electronic meters surpassed induction meters for the first time; subsequently, electronic meters dominated the domestic market. The release of national standard GB/T 17215.301-2007 reflects the domestic multi-function table technology development level over 10 years.

The multi-function table definition is more comprehensive. Accuracy includes levels 0.2S, 0.5S. Measurement assessment starts from 1% basic current. General output function of data/information/software adds event recording rules (9 articles); proposes data communication technical requirements and communication protocol; but does not mention: active/reactive power combination measurement, programming combination reactive power measurement, clock circuit

requirements, three communication modes (carrier communication, public network communication, micro-power wireless communication), anti-magnetic field interference, and comparison function of electricity meter software.

Extended feature: Represents the prepaid feature.

Standard centralized unit: National Standardization Technical Instrument Electrical Committee.

Main drafters: Xu Min, Wang Zhaohong, Xu Heping and 17 experts.

3.5 DL/T 614-2007: Updated Power Line Standard (Released December 2007)

Multi-function table definition: Same as DL/T 614-1997.

Meter type: Static meter.

Accuracy: Divided into four grades: 0.2S, 0.5S, 1 and 2.

Functions:

Category 1 basic functions (16 items, 51 detailed rules): - General output function of data/information/software (8 items, 28 rules): 1. Metering one-way or two-way active electric energy, one-way or four-quadrant reactive electric energy. 2. Measurement of multiple period active and reactive electric energy. 3. Demand measurement (6 detailed rules). 4. Event records (9 detailed rules). 5. Communication interface type (2 rules: communication interface, infrared communication). 6. Communication interface requirements (6 detailed rules). 7. Pulse output (3 detailed rules). 8. Power grid operation parameter measurement (2 detailed rules).

Category 2 internal data/information/software formation and processing functions (8 items, 23 detailed rules): 1. Data/information/software formation function. 2. Data/information/software processing function. 3. Calendar, rate, time period (2 detailed rules). 4. Measurement data storage function (3 detailed rules). 5. Freeze (3 detailed rules). 6. Clear zero out (2 detailed rules). 7. Display (8 detailed rules). 8. Software requirements (5 rules: manufacturers application software, software is not allowed after factory remote and on-site upgrade update, etc.).

Category 2 extended function (5 items): Metering and visual electric energy; harmonic voltage and current monitoring; calculation of loss and copper loss; and wireless fiber, Bluetooth optical communication mode.

Comments on this article: Compared with previously released multi-function table mechanical lines, power lines and national standards, the technical requirements of DL/T 614-2007 standard can basically cover: event recording, energy measurement, demand measurement, communication requirements, grid operation parameter monitoring, pulse output; data/information/software formation and processing functions: rate, data

storage, freezing, zero clearance, display are relatively complete, and electric meter software is not allowed to upgrade after delivery; but does not mention: active power combination measurement, programming combination reactive power measurement, clock circuit requirements, three types of communication (carrier communication, public network communication, micro-power wireless communication), anti-magnetic field interference power theft function, comparison function of electricity meter software.

Extended functions: Mention harmonic voltage and current monitoring; optical fiber, Bluetooth, wireless communication applications.

3.6 Q/GDW 354-2009: First State Grid Standard (Released September 2009)

Definition of smart electricity meter: Same as previous State Grid standard Q/GDW Functional Specification.

Meter type: Static meter.

Accuracy: 0.2S, 0.5S, 1, 2 four levels.

Functions:

Category 1 basic functions (25 items, 85 detailed rules): - Data/information/software output function (18 items, 65 detailed rules): - General output function (11 items, 40 detailed rules): 1. Forward and reverse total active power and phased active power and four quadrant total reactive power measurement (does not use phased active power arithmetic addition method to calculate total active power). 2. Combined active power and combined reactive power electric energy metering. 3. Time-sharing active energy and reactive electric energy measurement (2 detailed rules). 4. Demand measurement (4 detailed rules). 5. Clock circuit and school time (5 detailed rules). 6. Event record (15 detailed rules). 7. Communication requirements (2 detailed rules). 8. Communication mode type (4 detailed rules: RS485, infrared communication, carrier communication, public network communication). 9. Signal output (3 detailed rules: pulse output, multi-function signal output, control output). 10. Power grid operation parameters monitoring (2 detailed rules). 11. Security protection (2 detailed rules: programming, reading table operation).

- Special output function for smart meter (7 items, 25 detailed rules):
  1. Fee control function (11 detailed rules).
  2. Load record (3 detailed rules).
  3. Ladder electricity price.
  4. Power failure meter reading (2 detailed rules).
  5. Alarm (4 detailed rules).

Category 2 internal data/information/software formation and processing functions (7 items, 20 detailed rules): 1. Data/information/software

formation function. 2. Data/information/software processing function. 3. Rate and time period (4 detailed rules). 4. Zero clearing (2 rules: electricity meter zero, demand zero). 5. Data storage (2 detailed rules). 6. Freezing (5 rules: regular freezing, instantaneous freezing, daily freezing, agreed freezing, hour freezing). 7. Display (7 detailed rules).

Category 2 extended function: (None).

Comments on this article: The development and application from domestic multi-function meter to smart electricity meter represents a new leap in domestic electricity meter technology development. State Grid launched Q/GDW 354-2009 "Functional Specification for Smart Electricity Meters," which plays a connecting role in the evolution of China' s multi-function meter standards.

Compared with the previous power standard DL/T 614-2007, Q/GDW 354-2009 standard is more advanced, proposing active power combination measurement, clock circuit measurement, increasing event recording rules, network communication, carrier communication mode; load record, ladder electricity price, power failure meter reading, safety authentication function, etc.

Compared with the subsequent Q/GDW 1354-2013 standard, Q/GDW 354-2009 standard is less advanced, not mentioning: programming combination reactive power metering, micro-power wireless communication, anti-magnetic field interference theft function, meter software comparison function, load switch misaction detection, intelligent items, fundamental wave active energy, harmonic active energy metering.

3.7 Q/GDW 1354-2020: State Grid Standard (Released August 2020)

The State Grid Smart Meter (2020 edition) is a new generation of smart meters. The four specifications of the General Technical Specification for Smart Electricity Meters (2020 Edition) respectively quote the relevant IR 46 international requirements of measurement proposal of active power meters.

Definition of smart electricity meter: Same as Q/GDW 1354-2013 Functional Specification of Smart Electricity Meter.

Meter type: Static meter.

Accuracy: Active power measurement: B, C, D; reactive power measurement: 2.

Functions:

Category 1 basic functions: - Data/information/software output function: - Basically same as Q/GDW 1354-2013 standard (12 items): measuring total active and reactive power, combined power, time-sharing power, phase separation power, demand measurement, clock and timing, communication requirements, communication mode type, signal output, constant magnetic field monitoring, power meter software comparison function. - Different functions: - Event record:

26 detailed rules, adding 4 detailed rules (clock fault record, metering chip fault record, electricity meter change current abnormal record, etc.). - Power grid operation parameters monitoring: 7 rules, adding 3 rules (three-phase electricity meter to provide beyond limit monitoring function, etc.).

- Dedicated (smart meter) output function:
  - Basically same as Q/GDW 1354-2013 standard (7 items): cost control function, ladder electricity price, power failure meter reading, power protection function, alarm, auxiliary power supply, load switch misoperation detection.

Category 2 internal data/information/software formation and processing functions: - Basically same as Q/GDW 1354-2013 standard (4 items): data/information/software formation, processing function, rate and time period, and display function. - Different functions: - Zero clearing: 3 rules, adding 1 rule (event zero). - Freezing: 10 rules, adding 4 rules (minute freeze, ladder settlement freeze, monthly freeze, settlement freeze). - Deleted function: data storage.

Category 2 extended function: (None).

Comments on this article: The 2020 version of Q/GDW 1354-2013 standard includes: 12 data/information/software general output functions, 7 special output functions, 4 internal data/information/software formation and processing functions; 4 functions added; 3 functions deleted. After 7 years of application, Q/GDW 1354-2013 "Smart Electricity Meter Function Specification" functions are still applicable, with 76% retained.

The biggest change in the 2020 smart meter function specification is accuracy: active power measurement uses grades B, C, D; reactive power measurement uses level 2. Here, the representation method of IR 46 international measurement proposal of active energy meter still adopts the representation method of IEC meter standard, which complicates the detection of active and reactive power. At the same time, no new functions are proposed for the development and application of fundamental and harmonic active power metering of intelligent electricity meter projects.

3.8 Latest Standard: Q/GDW 12180-2021 "Intelligent Internet of Things Energy Meter Function and Software Specification" (Issued January 2022)

In January 2022, State Grid issued Q/GDW 12180-2021 "Specification for Intelligent Internet of Things Power Meter Function and Software." However, 2022 is the second year of the first batch bidding, which only accounts for 2.1% of the total equipment of the same batch. Meanwhile, there are some disputes about the application of intelligent meter, mainly: high meter price; extended function is optional; the first use of embedded general operating system is not practical; some special requirements of electricity meter require the development

of embedded special operating system.

In view of the above situation, this article will temporarily not discuss the State Grid Q/GDW 12180-2021 "Intelligent Internet of Things Energy Meter Function and Software Specification."

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4. Evolution of Domestic Multi-Function Electricity Meter Products

Domestic multi-function meters have undergone 30 years of development from 1992 to 2021, evolving through five generations of product technology: mechanical and electronic multi-function meter, analog multiplier multi-function meter, digital multiplier (four types) multi-function meter, smart meter, and new generation smart electricity meter.

The evaluation of technical performance of multi-function meters mainly covers: multi-function table structure, new measurement technology, accuracy, and multi-function/intelligence level.

4.1 1992: Shanghai Electric Meter Factory DSD 8, 0.5 Class Three-Phase Three-Wire Multi-Function Meter

In 1992, Shanghai Electric Meter Factory launched the first independently designed electronic-level mechanical multi-function meter DSD 8, 0.5 class three-phase three-wire multi-function meter.

Multi-function meter structure: Composed of induction base meter, infrared photoelectric sensor and electronic multi-function recorder.

Multiplier: Uses power multiplier based on rotating magnetic field principle.

Multi-functions: Total active power metering; time-sharing energy metering; maximum demand of slip type; magnetic suction infrared interval or strong communication; anti-interference function; self-test function.

Comments on this article: Mechanical and electronic multi-function meter is the first generation of multi-function meter in China, which realizes multi-function based on active power and electric energy measurement. Because there is no basic technology of reactive power measurement, multi-function is limited.

4.2 August 1994: Weisheng DSSD331/DTSD341-Type 0.5S Class Three-Phase Electronic Multi-Function Meter Using Digital Multiplier

In August 1994, Weisheng first developed the DSSD331-type/DTSD341-type 0.5S class three-phase electronic multi-function meter using digital multiplier.

Multi-function meter structure: All-electronic multi-function meter composed of voltage sensor (PT), current sensor (CT), analog-to-digital converter (A/D), microcomputer special chip, and display (LED).

Digital multiplier: In the microcomputer special chip, digital current and voltage instantaneous values undergo various judgment, processing and operation.

Multi-functions: - Forward and reverse active power, perceptual/capacitive reactive power and four-quadrant reactive power. - Time-sharing metering of active and reactive electric energy. - Maximum demand for active and reactive power. - Monitoring of power grid active power, reactive power, voltage, current, power factor and frequency. - Load curve record. - Two independent simultaneous RS485 interfaces, adsorption infrared interface. - 4-way empty contact pulse auxiliary terminal output. - Event record of 8 classes. - Self-diagnosis function and fault alarm function. - Voltage and current harmonic analysis function, up to 21 harmonics.

Product identification: In the same year, the new electricity meter passed the ministerial appraisal under the auspices of the Basic Equipment Department of the former Machinery Department. Director of the appraisal committee: Professor Fei Zhengsheng. Experts attending the appraisal meeting from the electric power department included Qu Tao, Chen Li, Zong Jianhua.

Conclusion: Product performance and structure reach the advanced level of similar products in the early 1990s, and are in the leading position of similar products in China.

Comments on this article: Weisheng is the first to launch multi-function meter using digital multiplier. The digital multiplier multi-function meter represents the first class of the third generation of domestic multi-function meters. Through microcomputer periodic sampling of chip waveforms, multi-functional operation can be performed, including power grid voltage, current, phase angle, active power, reactive power, apparent power, frequency, harmonic content, etc.

Initially, digital multiplier applied only to low-level multi-function meters. Later, by improving sampling rate and calculation accuracy, it could be applied to 0.1S class multi-function meters and standard electricity meters for power grid. Now, digital multiplier multi-function meters, with advantages of easy multi-function implementation, low cost, and short product development cycle, have become the mainstream of domestic multi-function meters.

However, the A/D sampling software of digital multiplier is non-real-time and has significant drawbacks. For aperiodic and unstable signals and scenarios with high harmonic content, active power cannot be accurately calculated. At the same time, even if hardware of different manufacturers' products is the same, actual quality and performance level may differ significantly, mainly because manufacturers' software capabilities cannot be assessed by a unified standard.

4.3 December 1995: Ningbo Photoelectric Factory DSSF22A-X/DTSF22A-X 1-Level Electronic Three-Phase Four-Wire Intelligent Multi-Function Meter with Integrated Circuit

In December 1995, Ningbo Photoelectric Factory launched the DSSF22A-X/DTSF22A-X, 1-level electronic three-phase four-wire intelligent multi-function meter with integrated circuit.

Multi-function meter structure: Multi-function meter adopts special integrated circuit.

Analog multiplier: In 1991, Ningbo Photoelectric Factory commissioned 771 Institute of China Aerospace Academy to design small-scale metering special integrated circuit, using time-split multiplier principle and double integral V/F conversion.

Multi-functions: - Accurate measurement of active power, reactive power, active power demand, reactive power demand, power factor, prepaid payment and 4 rates. - Overload and over-preset power alarm and automatic power off. - Phase loss alarm record. - Automatic meter reading. - Operation of card insertion and pulling realizes information transmission between user's electricity meter and electricity sales management system of power supply department. - Various software and hardware anti-interference measures.

Comments on this article: Ningbo Photoelectric Factory launched electronic multi-function meter using divided multiplier integrated circuit earlier in China. The multi-function meter using analog multiplier represents the second generation of domestic multi-function meters.

The time-split multiplier plays a very important role in active power metering technology. With 0.005% measurement accuracy, it is the standard electricity meter for distortion of voltage and current signals; the harmonic power measurement value of split multiplier is consistent with theoretical calculation result.

In 1973, Jiangxi Electric Power Experimental Research Institute first developed PS-4 single-phase electronic standard electricity meter in China, using time-split multiplier principle.

However, time-split multiplier is only used in active power measurement. As a multi-function meter, its reactive power measurement and other functions are important components, which need to be supplemented with alternative phase shift circuit or A/D sampling scheme to produce reactive power measurement, making functions complicated. Therefore, currently the market share of multi-function meters using analog multiplier is not large.

4.4 2002: Nanjing Bluestar Electric Power Instrument Research Institute 0.5S Class Full Digital Stationary Multi-Function Meter

In 2002, Nanjing Bluestar Electric Power Instrument Research Institute launched the 0.5S class full digital stationary multi-function meter.

Multi-function meter structure: Composed of full digital CS5460A-type measurement chip (integrated A/D, voltage reference, operation and discharge, DSP and digital interface), digital signal operation, digital filtering, digital quantity correction, digital adjustment unit, etc., without any physical adjustment element.

Digital multiplier: The CS5460A chip adopts new generation analog-to-digital conversion technology and DSP digital signal processor.

Multi-functions: - Active and reactive electric energy metering. - Phase electric energy metering. - Voltage, current effective value, instantaneous value, power, power factor. - Full digital compensation, including phase compensation, without external devices. - Realize treatment of measured cross variable range, and make nonlinear compensation for wider measurement range and transformer. - Clock backup using lithium battery with storage life of more than 20 years.

Comments on this article: Nanjing Bluestar launched the full digital multi-function meter, representing the second type of third-generation domestic multi-function meter using digital metering chips. Its full digital characteristics: measurement accuracy, anti-interference capability, and reliability quality have been greatly improved.

Nanjing Bluestar, founded around 1980, is mainly engaged in power instruments, electric instrument data acquisition devices, software development, marketing and import/export business.

It is estimated that from 2002 to 2008, Bluestar' s full digital electronic multi-function meter products sold well, mainly supplying short-term OEM demand for multi-function meter transformation of large induction meter enterprises, and short-term labeling needs of emerging electronic meter enterprises with insufficient multi-function meter development capacity.

4.5 2002: Weisheng 0.2S/0.5S Class Electronic Multi-Function Meter with Harmonic Metering Function

In 2002, Weisheng first developed 0.2S/0.5S class electronic multi-function meter with harmonic metering function in China.

Multi-function meter structure: Adopts internationally popular high-end electricity meter design scheme: metering DSP + management MCU hardware scheme.

Harmonic analysis and measurement principle: Current and voltage of each phase are sampled and digitally processed by 16-bit A/D and DSP high-speed processors. Through corresponding digital calculation, DSP transforms current and voltage signals with 256-point FFT transformation in real time, which can provide current, voltage and harmonic components from 2nd to 49th order. Harmonic amplitude accuracy is 2%, phase accuracy is $±$1-2°. DSP completes electrical parameter measurement, electric energy accumulation, har-

monic analysis, fundamental wave electric power, and harmonic electric energy calculation; metering data is exchanged with management MCU; management part adopts display, data statistics, storage, communication, meter function selection, and initialization data setting.

Multi-functions: - Total active power time-of-service metering. - Combined reactive electric energy metering. - Vacation settlement across month. - Maximum demand amount calculation. - Measurement of voltage, current, and power. - Harmonic electric energy metering (3 optional modes): 1. Based on fundamental wave measurement: total active electric energy = fundamental wave active electric energy. Active power energy metering is 0.5S class. 2. Based on digital multiplier: total active electric power = fundamental wave active electric energy + total harmonic active electric energy. Active power energy metering is 0.2S class. 3. Based on Fourier transform: total active power = fundamental wave active power + absolute value of total harmonic energy. Active power measurement is 0.5S class. - Transformer loss compensation. - Correction and compensation of external PT, CT ratio difference and angular difference. - Communication interface: 2 independent RS485 interfaces, 1 adsorbed infrared and far-infrared interface. - Load record. - Event record. - Test output. - Alarm function. - Self-diagnosis and recovery function.

Comments on this article: Weisheng first launched 0.2S/0.5S level all-electronic multi-function meter with harmonic metering function in China, representing the third class of third-generation domestic multi-function meters (measurement DSP + management MCU) high-end scheme.

Application prospects of different measurement methods: - The second measurement mode based on digital multiplier, with 0.2S active power measurement level, is adapted to billing applications under current electricity price policy. - The first mode based on fundamental wave measurement, with 0.5S active power measurement, has been officially implemented in Canada. Domestically, it needs support from national electricity price policy. - The third harmonic measurement mode based on FFT, with 0.5S active power measurement, is difficult to implement temporarily as the administrative department has not yet issued penalties for harmonic source users.

4.6 2010: Weisheng 0.1S Class Settlement Pass Multi-Function Meter

In 2010, Weisheng first launched the 0.1S class settlement pass multi-function meter in China.

Multi-function meter structure: - Pass table: Mainly composed of I/V conversion circuit (CT), V/V conversion circuit (resistance partial pressure), analog-to-digital converter (A/D) with independent voltage reference, and then to metering DSP. - Key components selected from international high-reliability brands: German VAC high permeability current transformer, VISHAY high precision column resistance, American 18-channel 24-bit high precision analog-to-digital converter (A/D) with 12.8k sampling rate, ADI high performance

external voltage reference chip and high speed DSP metering chip, using multi-layer PCB with analog-digital separation. The overall measurement scheme has high accuracy, high stability, high reliability, and long life characteristics.

High-precision design: - Applies Newton-Cotes high-order integration algorithm, fast power and power current resolution technology, and hardware phase matching technology to achieve high accuracy measurement under dynamic load. - Factory active power metering accuracy controlled at less than $±$0.04%; reactive power metering is grade 0.5S. - Impact of ambient temperature, power factor, frequency, and load current fluctuation on measurement accuracy can be ignored. - Measurement accuracy is less than 0.1%.

Multi-functions: - Forward active energy metering (reverse metering for reference only). - Four-quadrant reactive electric energy metering. - Two combinations of reactive power metering, which can be arbitrarily combined by four-quadrant reactive electric power. - Time-sharing active power quantity and reactive power quantity. - Calculate maximum demand of active power and reactive power by time-sharing. - Up to 12 rates, two sets of main and secondary periods, clock double backup. - 6 types of data load curve records can be set, with capacity of 20M bytes. - Dual RS485 interface; adsorption/far infrared communication interface; 100M adaptive Ethernet interface, supporting UDP/TCP remote meter reading (DL/T 645-2007 or user custom protocol). - Rich power grid event records storage, self-inspection and error correction functions. - Double-backup. - 4-way empty contact power pulse and LED power pulse output. - Large screen with wide view LCD display.

Product identification: In December 2010, the scientific and technological appraisal meeting of "Research and Development of 0.1S Level Key Technology of Power Meter" organized by Hunan Science and Technology Department was held in Weisheng Science and Technology Park.

Appraisal opinion: "This achievement has a number of independent intellectual property rights, and the key technology has reached international advanced level. It is suggested to develop finalized products and realize industrialization as soon as possible."

Comments on this article: Weisheng launched 0.1S class high-accuracy settlement pass multi-function meter, representing the third generation of domestic multi-function meters using high-end metering algorithm, filling the gap of high-end domestic products and exceeding the highest level of 2011 IEC electricity meter standard 0.2S. Currently, the 0.1S class pass table has been in stable and reliable operation for more than 10 years at regional power grids, provincial power grids, power plants and electrified railways with frequent load changes. The 0.1S class pass table has passed EU MID certification and DLMS certification, and has been applied in many countries.

In 2018, Langier released information at Shandong Institute of Electricity Research Institute: Langier is developing a new generation of E860 series higher precision settlement threshold table. The E860 series 3-core electricity meter,

its accuracy meets the 0.1S level requirements of IEC standard, and has more advanced anti-theft capability in software and hardware. It is understood that in mid-2023, Langier will release E860 series 0.1S level meter to the international market. The domestic electricity meter industry should pay special attention to secondary information, focusing on factory control error, requirements of fundamental wave and harmonic active power metering, reverse metering accuracy, etc.

4.7 2013: State Grid 2013 Version Smart Electricity Meter

In 2013, State Grid launched the 2013 version of State Grid standard smart electricity meter. This smart meter is the second smart meter after the 2009 standard smart meter of State Grid. The design and production of smart meter standards, grid access testing, product bidding and acceptance are provided by grid metering and material departments.

Structure and design technology of smart meters:

Structural design: According to Q/GDW 1356-2013 "Specification for Three-Phase Intelligent Power Meters"and Q/GDW 1355-2013 "Specification for Single-Phase Intelligent Power Meters,"the structural design includes: electricity meter parameters, display, indicator light, power failure display, installation size appearance structure, material and process requirements.

Technical design: According to Q/GDW 1827-2013 "Technical Specification for Three-Phase Intelligent Electricity Meters" and Q/GDW 1364-2013 "Technical Specifications for Single-Phase Intelligent Electricity Meters," the technical design includes: specification requirements, environmental conditions, mechanical and structural requirements, accuracy requirements, electrical requirements, insulation performance, electromagnetic compatibility requirements, reliability requirements, data security requirements, software requirements, packaging requirements, communication module interchangeability requirements.

Special chip for electric energy metering: Currently, there are four types of special chips: three-phase energy metering chip, three-phase multi-function metering chip, single-phase energy metering chip, single-phase energy meter SOC chip.

In China, Shanghai Juquan, Shanghai Beilin, Fudan Microelectronics, Shenzhen Xinhai occupy most of the domestic market; foreign manufacturers ADI, TDK, Atemel, Cirrus Logic occupy part of the domestic market.

Typical cases: - **Shanghai Bell:** BL6513C three-phase active power metering chip based on digital signal processor with input dynamic range of 3000:1; nonlinear error less than 0.1%; static power consumption of chip is 25 mW; measures forward and reverse active power. - **Shanghai Juquan:** ATT7022E/26E/28E series high-precision, multi-function three-phase electric energy metering chip based on digital signal processor, with second-order integrated Sigma-Delta

ADC, reference voltage, digital signal processing circuit, and built-in temperature sensor. Input dynamic range is 5000:1, nonlinear error less than 0.1%. Measures active power, reactive power, apparent power, active power and reactive power of each phase, and can also measure current, voltage, effective value, phase angle, power factor, frequency and other parameters of each phase. Can accurately measure 41 harmonic active, reactive, apparent power. - **ADI company:** ADI' s ADE7868, ADE7878, ADE7858, ADE7854 high precision electric energy metering IC can provide 0.2% accuracy of active and reactive power measurement in dynamic range of 3000:1. Can also measure reactive power and active power with accuracy of 0.1%. One chip has fundamental wave electric energy measurement function.

Multi-functions: According to Q/GDW 1354-2013 "Functional Specification for Smart Power Meters" and Q/GDW 1365-2013 "Technical Specification for Security Certification of Smart Power Meters," the 2013 version of State Grid standard smart meter has relatively complete functions (detailed functions omitted).

Comments on this article: State Grid 2013 version of standard smart meter is the third generation of domestic second-type multi-function meter using digital metering chips. After the 2009 version of standard smart meter operated for 1-3 years, many meter failures reflected serious product quality problems. To address this, the Marketing Department of State Grid issued the Notice on Rectifying and Strengthening Quality Management of Smart Meters, and organized formulation of technical specifications for main components of smart meters (13 items). Subsequently, the 2013 version of smart meter standard was developed.

The 2013 version of standard smart meter products added new requirements: constant magnetic field protection, power frequency magnetic field protection, power work limit potential, temperature, communication module interface with load capacity, interchangeability, meter communication module, improved smart meter software comparison function, meter measurement stability, reliability, power theft prevention capability, communication module connectivity capability, and meter failure rate was greatly reduced. However, no new functions were proposed for the development and application of fundamental and harmonic active power metering of intelligent electric meters.

4.8 2020: State Grid 2020 Version Smart Meter—New Generation Smart Meter

The 2020 version of State Grid standard smart meter is developed on the basis of the 2013 version, citing key requirements of IR 46 active power meter international measurement proposal.

Structural design of smart electricity meters: According to the standard' s "three-phase intelligent watt-hour meter technical specification" and "single-phase intelligent watt-hour meter technical specification,"the 2020 version smart meter structure design includes: specifications, display, shape indicator, power

outage display, structure and installation size, materials and process requirements. The current specification is expressed using minimum current Imin, turning current Itr, and maximum current Imax.

Technical design of smart electricity meters: According to State Grid standard "General Technical Specification for Intelligent Electricity Meters (2020 Edition)," the technical design includes: 1. Accuracy level: active power measurement uses A, B, C, D; reactive power measurement uses 2. 2. Current specification: minimum current Imin, turning current Itr, maximum current Imax. 3. Ambient condition. 4. Mechanical and structural requirements. 5. Accuracy requirements: - Factory error expressed by basic maximum allowable error. - Timing accuracy with detailed rules requirements. - Impact quantity referencing IR 46 standard requirements. 6. Voltage and current test: harmonic-square wave test in voltage and current circuit; harmonic-spike wave waveform test; harmonic/pulse string triggered in current circuit; odd harmonic-90 degrees phase-triggered waveform test circuit. 7. Interference impact test: citing multiple electromagnetic compatibility test items (omitted). 8. Electrical performance requirements. 9. Insulating property. 10. Reliability requirements. 11. Data security requirements. 12. Software requirements. 13. Packing requirement. 14. Interchangeability requirements for communication modules.

IR 46 International measurement proposal of active power meter and IEC meter standard: - Accuracy representation method: maximum allowable error, basic maximum allowable error, and maximum allowable error deviation. - Traceability of errors: The data change process from initial inherent error, inherent error, anomaly (fault) to major anomaly (fault) should be traceable. - Accuracy level: A, B, C, D, covering wide range of changes including reference quantity, influence quantity and interference quantity. - Current working range representation: starting current Ist, minimum current Imin, turning current Itr, and maximum current Imax. Specific accuracy calculation methods from Ist to Imin are provided. - Accuracy composition: including basic maximum allowable error, allowable error of influence quantity, and allowable influence of interference. For first interference amount, interference level, allowable influence and electricity meter error deviation limit are proposed. - Combined error estimation. - Metering characteristic protection: hardware separation and software separation of electricity meters.

Multi-functions: According to functional specification requirements of State Grid smart meter (2020 version), the 2020 version smart meter products have more complete functions (detailed functions omitted).

Comments on this article: State Grid 2020 version of standard smart meter is the third generation of domestic multi-function meters using digital metering chips. The main feature of the 2020 version is the first demonstration of IR 46 standard on domestic smart meters, focusing on measurement accuracy and measurement performance protection requirements of IR 46. In recent years, IR 46 standard has become important content and basis for formulation of smart meter national metrological verification regulations. However, IR 46 standard

has limitations. Currently, only the international measurement proposal for active power meters, while reactive power measurement test of multi-function meters needs to follow IEC meter standard, which is complicated.

Epilogue

Reviewing the emergence and evolution history of domestic multi-function meters (smart meters, new generation smart meters), we can see that after 30 years of development, the domestic multi-function meter industry has undergone profound changes:

- **Domestic multi-function meter type:** From mechanical and electronic multi-function meter in 1992, through electronic multi-function meter and smart electricity meter, to new generation smart electricity meter in 2020.
- **Design function of multi-function meter:** From JB/T 7656-95 multi-function electricity meter standard with 12 basic functions and 30 rules, to Q/GDW 1354-2013 "Smart Power Meter Function Specification" with 30 basic functions and 119 rules.
- **Accuracy of multi-function meter:** Developed from active power metering level 1 in 1992 to level 0.1S in 2010 (using digital multiplier).
- **2020 version of State Grid smart meter** first cited key requirements of IR 46 active power meter on domestic electricity meter.

Reviewing the development process of domestic multi-function meters, the electricity meter industry should bear in mind the achievements of the following units in development exploration and guidance:

- **East China Electric Power Administration:** In 1995, issued the first electric power measurement modernization technology report of East China Power Grid, and organized drafting of the first mechanical and power standards for multi-function meters.
- **Jiangxi Electric Power Experimental Research Institute:** In 1973, first developed PS-4 single-phase electronic standard electricity meter in China using time-split multiplier principle.
- **Ningbo Photoelectronics Plant:** Later developed electronic multi-function meter with special integrated circuit for the first time in China.
- **Weisheng:** In 1994, first launched multi-function meter using digital multiplier (microcomputer chip) in China. In 2002, first developed 0.2S class electronic multi-function meter with harmonic metering function in China. In 2010, first launched 0.1S class high-accuracy settlement pass electricity meter in China.
- **China Electric Power Research Institute:** In 2013, led Weisheng, Linyang and other electricity meter enterprises to jointly launch the 2013 version of State Grid standard smart electricity meter.

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