Research on remote calibration and online monitoring system of electric energy metering device

Lu Yang\(^1\), Dingqu Zhang, Guoying Lin, Qiang Song, Qingliang Meng, Feng Pan and Chang Liu

Metrology Center of Guangdong Power Grid Co., Ltd., Guangzhou 510080, China

\(^1\)E-mail: yanglu910715@126.com

Abstract. This paper introduced research on remote calibration and online monitoring system of the gateway electric energy metering device. The function combined with composition of the station's remote calibration-monitoring device and the master station management platform are emphasized. The system integrated the ways of multi-channel synchronous remote calibration, multi-dimensional monitoring, intelligent switching of detection and calibration loop, self-test of detection unit and so on into the complete set, cooperated with the master station management platform, to realize remote calibration, online monitoring, fault diagnosis and state evaluation of the gateway electric energy metering device. The system innovatively adopts a multi-channel synchronous remote calibration method to realize intelligent switching of detection and calibration loops. Through multi-dimensional data detection and state evaluation algorithms, it is possible to more comprehensively detect device status and achieve fault diagnosis. In addition, the system has high stability, accuracy and flexibility. The research plays an important role in reducing the operation-maintenance costs of the gateway electric energy metering device, guaranteeing the safety of operators and improving the level of operation and management, which ensures the accuracy of gateway energy metering and the fairness of both parties in power trade.

1. Introduction

The gateway electric energy metering device is an important tool to ensure accurate metering, accurate trade settlement, fair and equitable transactions. It is mainly used for various gates between generation, transmission, distribution and electricity [1, 2]. However, there are many problems in the operation and management of the traditional gateway energy metering device. First, the calibration of the gateway energy metering device uses a traditional on-site periodic approach. Due to the large number of devices involved, work efficiency is difficult to improve. Secondly, the traditional calibration method cannot monitor the condition of the equipment, and it is difficult to evaluate the accuracy and reliability of the metering device in time. In addition, the fault of the energy metering device of the gateway often occurs between the two calibrations. Since the fault cannot be found and diagnosed in real time, it is difficult to correct the electric power billing. At last, the operation management of the gate energy metering device is still not standardized [3], which does not meet the concept and requirements of lean management in the enterprise. In order to solve these problems, many researchers have conducted research on remote calibration and online monitoring of the gateway energy metering device. The remote calibration and online monitoring device will be developed on the basis of the traditional operation and management mode of the gateway electric energy metering device. The on-site periodic calibration will be replaced by the remote calibration method, and the operation status of
the device can be grasped at any time through online monitoring. The operating status of the devices will be readily available through online monitoring. Hao Junfeng [4] systematically introduces the design of the remote calibration system of the multi-function electric energy meter, and makes a detailed analysis of the remote calibration technology. Shandong Zibo Power Supply Company has put the remote calibration and monitoring system of electric energy metering device into use. The system realizes the measurement of admittance and voltage drop of the metering loop and the device error through remote command control, which changes the mode of on-site operation and reduces the threat of high-voltage operation to workers [5]. The remote calibration system of the electric energy metering device developed by the State Grid Shandong Electric Power Company Electric Power Research Institute has the function of remote calibration, which can realize real-time monitoring, automatic analysis, interaction and sharing of electric energy data [6]. Albu M.M. [7] states many advantages of remote verification, such as efficiency, security, etc. However, the remote calibration monitoring system mentioned above still has shortcomings in remote calibration and traceability, monitoring dimension and effectiveness, deep mining of multi-dimensional data, so it is difficult to promote and apply.

This paper mainly introduces the structure, composition and functions of the remote calibration and online monitoring system. The system includes remote calibration and monitoring device, communication network and management system. The system innovatively adopts a multi-channel synchronous remote calibration method to realize intelligent switching of detection and calibration loops. Through multi-dimensional data detection and state evaluation algorithms, it is possible to more comprehensively detect device status and achieve fault diagnosis. The algorithm realizes the innovation and breakthrough of the remote calibration and online monitoring technology of the gateway electric energy metering device. In addition, the system has high stability, accuracy and flexibility.

2. Overview of remote calibration and online monitoring system
The remote calibration and online monitoring system is mainly composed of station's remote calibration and monitoring device, data communication network and master station management system. The system structure is shown in Figure 1. As shown in Figure 1, the remote verification and monitoring device mainly includes multi-channel analog collector, Potential Transformer (PT) detection module, Current Transformer (CT) detection module, integrated processing unit, standard power source and other functional units. It is used for local calibration and data acquisition of the gateway energy metering device, self-test of detection unit, etc. The data communication network includes a local communication network and a remote communication network, and mainly adopts RS485, optical fiber, broadband carrier, Ethernet, etc.. It is responsible for data communication among local modules and between the local device and the primary station management platform. The primary station management system mainly includes remote calibration control, multi-dimensional data collection management and application, intelligent analysis and other functional modules, which are used for remote calibration device command control and multi-dimensional data deep mining. The hardware and software of each component cooperate with each other to realize the remote calibration and online monitoring function of the gateway electric energy metering device.

3. Station's remote calibration and monitoring device
At present, most remote calibration devices adopt the calibration mode of “standard energy meter + secondary circuit switching”, which can only check the gate energy meter of one gateway point at a time. There is also the risk of open circuit of CT secondary circuit during loop switching. In order to solve the problems above, we have innovatively adopted the “one main model + multiple sub-models” structural model in the station’s remote calibration and monitoring device (as shown in Figure 2). The main model is an integrated processing unit, which is responsible for multi-channel synchronous control, data acquisition and processing, and uplink and downlink communication. The sub-model is an acquisition and calibration module configured at each gateway point, including a multi-channel
analog collector, a PT detection module, and a CT detection module. It is responsible for completing the electric energy meter calibration, the PT secondary voltage drop test, and the transformer secondary load test, clock test, and multidimensional data collection. This model can realize “point-to-point” test, which can collect multi-dimensional monitoring data such as PT, CT, junction box and power meter. It realizes multi-channel synchronous acquisition through centralized control of integrated processing unit, which has the advantages of wide coverage, high efficiency and low risk. In addition, the multi-channel analog collector has a “test/self-test mode” switching function, and with 0.02-level high-precision standard power source, it can realize the traceability of standard units in the sub-model.

![Figure 1. Structure of remote calibration and online monitoring system.](image)

3.1. Multi-channel analog collector

The multi-channel analog collector is one of the core function modules of the whole device, and is composed of a sensing unit, an electrical connection and switching unit, a high-precision synchronous sampling unit, a communication unit, a timing and clock synchronization unit, a pulse input and output unit, and an intelligent main control unit (as shown in Figure 3).

It is equipped with 0.01 high-stability wide-temperature non-inductive transformer for current sampling, built-in high-precision A/D acquisition circuit (AD7608) and CPU processing unit (BF609), communication unit, clock circuit and other components. The acquisition accuracy is 0.02%, the clock timing accuracy is higher than 1ms, and the synchronization accuracy is higher than 1us.

The multi-channel analog collector has functions such as data acquisition, error test and data processing, which can replace the traditional joint junction box. The specific functions are as follows:
3.1.1. **Data collection.** Phase voltage, current, frequency, power, power factor and other data can be collected by the synchronous sampling high-precision ADC inside the module. The current sampling adopts 0.01-level through-core transformer, which does not affect the secondary metering loop. The AC sampling instantaneous value, electric energy data, clock time, clock battery voltage status and other data of the electric energy meter can be collected through the 485 interface. The phase synchronous voltage sampling data with time stamp in the PT detection module can be collected by the wideband carrier to realize the PT secondary voltage drop calculation. At the same time, the instantaneous amount data in the PT detection module and the CT detection module can be collected, as well as the real-time clock and the clock battery status.

![Figure 2. Configuration structure of remote calibration and online monitoring device.](image)

3.1.2. **Error test.** Two active and reactive input pulse circuits are internally configured to simultaneously achieve active and reactive pulse access measurements of the primary and secondary energy meters. With the AC sampling data, the error test and error comparison of the main and secondary energy meters can also be realized. The ADC sampling signal connected to the multi-channel analog collector can be switched to the standard source by the "check/self-test" mode switching and the instruction of the integrated processing unit. The integrated processing unit controls the output value of the standard source, and realizes the online self-calibration of the multi-channel analog collector through the internally configured active and reactive pulse output circuits.

3.1.3. **Data processing.** The synchronous acquisition data of the PT detection module and the multi-channel analog collector are processed and analyzed to obtain the pressure drop and the angular difference at both ends of the PT secondary side, that is, the test function for the PT secondary voltage drop. The AC sampling data of the PT detection module is collected and analyzed to realize the function of PT secondary load monitoring. Through the analysis of the AC sampling data of the CT detection module and the AC sampling data corresponding to the multi-channel analog collector, the function of discriminating the secondary circuit faults such as the CT loop disconnection and the loop shunt is realized.
3.1.4. Clock synchronization. By receiving the high-precision clock of the integrated processing unit and timing the internal clocks of the energy meter, PT, and CT monitoring module, the timing can also be achieved. The timing accuracy above is 1ms.

The collector realizes the precise synchronization of the integrated processing unit, multi-channel analog collector and PT detection module by using the E2E principle. The clock synchronization is realized by the reserved clock synchronization pulse port and its accuracy is 2us.

3.1.5. Communication. The communication mode with the integrated processing unit is the Ethernet or broadband carrier mode. The communication mode with the PT and CT detection modules is a broadband carrier, and the communication with the CT monitoring module is forwarded by the PT monitoring module. The communication method with the electric energy meter is RS485, and supports the communication protocol of DL/T 645 2007, DLMS and the like.

3.2. PT detection module
The PT detection module is based on the embedded platform BF609, and is equipped with high-precision A/D sampling circuits, CPU processing units, communication units, clock circuits and other components. The specific functions are as follows:

3.2.1. PT secondary voltage drop measurement. The voltage synchronization sampling on both sides of the PT secondary circuit can be realized by the clock synchronization between the PT detection module and the multi-channel analog collector. The voltage signal is uploaded to the multi-channel
analog collector through the broadband carrier for PT secondary voltage drop calculation. The calculation formula is as shown in Equation (1):

\[ \varepsilon_{\Delta U} = \sqrt{f^2 + (0.0291\delta)^2} \% \] (1)

Where, \( \varepsilon_{\Delta U} \) is the relative value percentage of the secondary voltage drop, \( f \) is the voltage drop in phase component (\%), and \( \delta \) is the voltage drop quadrature component (\').

3.2.2. PT secondary load measurement. The phase-voltage, current, frequency, power factor and other data are collected by the high-precision A/D sampling circuit inside the module to calculate PT secondary load. The calculation principle is as follows: obtain the vector ratio between the secondary circuit and voltage, that is, the equivalent admittance \( Y \) of the loop, and convert it into the volt-ampere value of the actual load on the secondary loop of the PT according to \( S = U^2 \times Y \).

3.2.3. Online self-calibration. The ADC sampling signal connected to the multi-channel analog collector can be switched to the standard source by the "check/self-test" mode switching and the instruction of the integrated processing unit to realize the function of online self-calibration.

3.2.4. Time alignment and synchronization. The detection module can complete its own time alignment by receiving the instruction of the integrated processing unit with an accuracy of 1 ms. By using the E2E principle and wideband carrier, the clocks of the integrated processing unit, the multi-channel analog collector and the PT detection module can be accurately synchronized with an accuracy of 1 us. In addition, a clock synchronization pulse port and a GPS/Beidou time alignment module are reserved as a supplement to clock synchronization.

3.3. CT detection module
The hardware configuration of the CT detection module is similar to the PT detection module. The 0.1-level high-stability wide-temperature non-inductive transformer is used to collect current, which can ensure the reliability of the measurement itself without affecting the original metering circuit. The specific functions are as follows:

3.3.1. CT secondary load measurement. The phase-voltage, current, frequency, power factor and other data are collected by the high-precision A/D sampling circuit inside the module to calculate CT secondary load. The calculation principle is as follows: obtain the vector ratio between the secondary voltage and circuit that is, the equivalent impedance \( Z \) of the loop, and convert it into the volt-ampere value of the actual load on the secondary loop of the CT according to \( S = I^2 \times Z \).

3.3.2. Admittance measurement through inter-frequency signal. The admittance measurement by the inter-frequency signal [8] uses the signal injection method. The high-frequency signal with the frequency different from power frequency and its harmonic frequency is amplified and injected into the CT secondary circuit, and measured in the loop, which can detect the faults such as the CT loop disconnection and the loop shunt [9].

3.4. Integrated processing unit
The integrated processing unit is designed based on the ST90B industrial-grade computer. The other peripheral function modules adopt BF609 for modular design. The two communicate with each other using RS232 mode, as shown in Figure 4.

3.4.1. Data collection. The collected data includes: synchronous digital sampling value of PT/CT detection module, real-time clock, secondary side AC sampling value of multi-channel analog collector, electric energy meter error, collector clock, AC sampling value of electric energy meter, electric energy, electric energy meter clock, etc. These are the sources of multidimensional data.
3.4.2. Control and monitoring. The integrated processing unit receives the remote control operation instruction of the main station, controls the multi-channel analog collector, the PT and CT detection module, the relay, the standard power source, etc. to perform various operations such as online calibration and self-test, and analyzes and processes the multi-dimensional collected data. It can realize error monitoring, fault monitoring, and status monitoring.

![Figure 4. Structure of integrated processor.](image)

3.4.3. Time alignment and synchronization. The GPS module and high-stability crystal are internally configured, and the synchronous clock source of the substation can be optimally received through intelligent decision to ensure the reliability of local time. The integrated processing unit can time synchronize the multi-channel analog collector through the optical pulse output port with an accuracy of 0.1us. It can also use the RS485 interface to clock the electric energy meter and the multi-channel analog collector with an accuracy of at least 1ms. In addition, the integrated processing unit is provided with a clock verification function for detecting clock anomalies and running errors of the self, the intelligent module, the electric energy meter, and automatically timing the time before a certain error threshold.

3.5. Summary
The integrated processing unit, the multi-channel analog collector, the PT detection module and the CT detection module cooperate with each other, supplemented by the intelligent switching module and the clock synchronization timing module, which together constitute the main body of the remote calibration and online monitoring device. It lays the physical foundation for remote calibration and online monitoring systems.

4. Master station management platform
The main station management platform is designed in a multi-layered architecture, which is divided into a transport layer, a monitoring service layer and a presentation layer, as shown in Figure 5. Specifically, the presentation layer adopts the B/S architecture of the Microsoft ASP.NET platform, and the monitoring service layer and the transport layer adopt the VC architecture. The ASP.NET platform has the simplicity of task execution, the manageability of configuration information, the
scalability and usability of applications, the customization and extensibility of code components, etc. The VC architecture can improve the communication efficiency between the server and the site, and ensure the reliability and stability of the system operation.

The main station management platform is divided into three parts: data storage, business logic interface and user interaction. Specifically, data storage includes collection and control of remote calibration and online monitoring data and instructions, storage and processing of database data, and the like. The business logic interfaces mainly include a remote monitoring interface, a user management interface, a fault assessment interface, a statistical report interface, and a remote upgrade interface. The main functions of user interaction include user login, remote calibration, status monitoring (including curve table, historical data record, real-time status, etc.), health assessment, fault location, remote diagnosis, statistical report, online upgrade, etc.

4.1. Data acquisition and storage
The data acquisition module adopts the design scheme of independent operation in the background, and it runs automatically without interruption for 7*24 hours without manual intervention. The communication between the data acquisition module and the remote site uses a 1024-bit RSA encryption algorithm to ensure the security of data collection and transmission. Even if the data is maliciously intercepted during transmission, the data cannot be cracked.

The collected data is stored in a generic MySql database. The MySql database is highly efficient, reliable, complete, and self-synchronizing. It is the preferred tool for data control in related fields. In terms of data storage capacity, it has hundreds of millions of levels of data storage, and supports high-speed concurrent data reading and writing and system subsequent expansion.

4.2. Remote verification and real-time monitoring
The system administrator or operator can send instructions through a simple operation, remotely calibrate the running gateway energy metering device via the in-station detection device, and return the calibration data to the master station management platform for further analysis and processing.

Figure 5. Software layered architecture of master station management platform.
The platform analyzes the real-time status data of the energy meter, transformer and secondary circuit stored in the database, and presents the data and analysis results in various ways such as images, tables and curves, so as to conveniently check the operating status of the energy metering devices at the gates of each station. In addition, users can also view various types of statistical reports automatically generated based on historical data, so that system decision makers can timely grasp the activity information, operating status, and current problems of each gate of the grid.

4.3. Fault diagnosis and status assessment
Fault diagnosis and state assessment are the deep application of multi-dimensional monitoring data. According to the test and monitoring data, the faults in the operation process of the gateway energy metering device are discovered and diagnosed, and the operating state is evaluated to realize the stop loss through pre-judgment [10]. This part of the content is one of the main functions of the main station management platform, and it is a supplement and innovation to the remote calibration and online monitoring of the gateway energy metering device.

4.3.1. Fault diagnosis. The fault diagnosis of the gateway energy metering device is mainly divided into three parts: PT secondary loop fault diagnosis, CT secondary loop fault diagnosis and energy meter fault diagnosis [11].

Fault diagnosis and location of PT secondary loop and CT secondary loop are realized by analyzing test data, multi-dimensional monitoring data, and fixed data such as transformer parameters, energy meter parameters, and metering methods, using rule-based reasoning. The types of faults that can be diagnosed mainly include loss of pressure, undervoltage, overvoltage, PT secondary voltage drop error overrun, voltage fluctuation overrun, voltage phase anomaly, outflow, shunt, overcurrent, current phase anomaly, etc.

The fault diagnosis of electric energy meter firstly builds a decision tree model for the machine learning algorithm, then fits the model data according to the fault characterization and the fault result, and finally diagnoses and locates the electric energy meter according to the model obtained by the machine training. Types of faults that can be diagnosed include error overrun, abnormal liquid crystal display, poor current column contact, battery undervoltage, meter stop, etc.

The fault diagnosis module of the software management platform basically covers the typical faults of the gateway energy metering device. It can quickly find the fault location of the substation, display the alarm information by means of a text list or a geographical map, so that the manager can quickly dispatch the relevant staff to handle the fault and avoid the loss expansion.

4.3.2. State Assessment. The state evaluation of the gateway energy metering device is mainly divided into four parts: PT state evaluation, CT state evaluation, energy meter state evaluation, and secondary loop state evaluation [12]. Each part of the content analyzes the respective state assessment indicators, establishes an appropriate state assessment model, and finally forms a “unit-total” integrated state assessment system. The status assessment method is as follows:

(1) Set up a hierarchical model of state indicators.

(2) Scoring each status indicator. The non-linear mathematical scoring model was used to quantitatively evaluate the status indicators, and the expert evaluation method was used to qualitatively evaluate the status indicators.

(3) Calculate the initial state evaluation vector of each state indicator. The fuzzy state theory [13] and the grey theory are used to cluster the quantitative state indicators and the qualitative state indicators to obtain the initial state evaluation vector.

(4) Calculate the final state evaluation vector for each state indicator. The improved analytic hierarchy process is used to determine the state weight vector of each indicator. The initial state evaluation vector is modified by the weighted average model to obtain the final state evaluation vector according to the principle of maximum membership degree.
The status evaluation results are divided into five levels: “excellent”, “good”, “general”, “poor” and “very poor”, which can provide a prerequisite for fault warning, status management, and inspection strategy adjustment of the gateway energy metering device.

4.4. Summary
The main station management platform realizes the remote verification and online monitoring function of the gateway energy metering device through the data acquisition of the substation device, through remote control and data processing, and extends the fault detection and status evaluation to serve as the remote calibration and the "brain" of the online monitoring system.

5. Conclusions
This paper introduces the remote calibration and online monitoring system of the gateway energy metering device in detail, and elaborates the structure and function of the remote calibration and monitoring device and the main station management platform. The system innovatively adopts a multi-channel synchronous remote calibration method to realize intelligent switching of detection and calibration loops. Through multi-dimensional data detection and state evaluation algorithms, it is possible to more comprehensively detect device status and achieve fault diagnosis, which provides a solution for the safe, accurate and reliable operation of the gateway energy metering device. Compared with other similar systems, it is more functional and has made breakthroughs in remote calibration and traceability, monitoring dimension and effectiveness, and multi-dimensional data depth application. Clock synchronization and timing functions, high-precision measurement devices, and software and hardware co-operation also make the system have good stability, accuracy and flexibility. The system plays an important role in reducing the operation and maintenance cost of the gate energy metering device, ensuring the safety of operators and improving the operation and management level of the gate, ensuring the accuracy of the gate measurement and the fairness and fairness of both parties.

Acknowledgements
This work is supported by the Science and Technology Project of China Southern Power Grid Co., Ltd. (Project Name: Key Technology Research on Remote Calibration and State Assessment of Gateway Electric Energy Metering Device, Project No.: GDKJXM20162188).

References
[1] Wang Rui and Yu Haibo 2016 Failure Risk Assessment Method of electric energy meter based on state evaluation China Int. Conf. on Electricity Distribution (Xi’an, China) 2016 1-5
[2] Rosario M, Claudio D C, Gaetano F and Subhas C M 2017 A smart power monitor energy flow in Smart grids: the role of advanced sensing and IoT in the electric grid of the future IEEE Sensors Journal 17 7828-7837
[3] Tang Yi 2012 The design and implementation of electric energy metering device remote calibration and monitoring system Chengdu: University of Electronic Science and Technology of China
[4] Hao Junfeng 2012 Remote verification and monitoring system for electric energy measuring device study Baoding: North China Electric Power University
[5] Hao Wei 2015 Research of remote monitoring system of electric energy measuring device calibration Baoding: North China Electric Power University
[6] Zhang Zhongyao, Zhang Xiaodong, Yang Jian, et al. 2016 A New Remote Calibration System of Electric Energy Metering Device SHANDONG DIANLI JISHU 43 47
[7] Albu M M, Ferrero A, Mihai F and Salicone S 2005 Remote calibration using mobile, multiagent technology IEEE Transactions on Instrumentation and Measurement 54 24-30
[8] Yan Meng 2015 Exploration for monitoring system of electric energy metering device Heilongjiang: Harbin Institute of Technology
[9] Xiao Yong and Zhou Shangli 2010 Design and implementation of intelligent detection method
for secondary side circuit fault of current transformer. *Power System Protection and Control* **38**, 115

[10] Lu Jianhao, Nie Yixiong, Wen Shengke, et al. 2017 Operation status evaluation methods for energy metering devices based on AHP. *Electrical Measurement & Instrumentation* **54**, 81

[11] Shen Li, Peng Xiang and Li Lihua 2017 Design of the pre-device for the online inspection and fault diagnosis in gateway electrical energy metering device. *Electrical Measurement & Instrumentation* **54**, 102

[12] Du Weihua, Cao Yi and Li Da 2013 Application of status assessment technique in the gateway electric power metering device management. *East China Electric Power* **41**, 2107

[13] Cui Li, Lu Wenwei, Ge Le, et al. 2016 Precise calculation of the actual strength of transmission tower material actual strength based on rough fuzzy set. *Electrical Measurement & Instrumentation* **53**, 101