

Analysis of Present State of the Digital Power Meter Field Calibration Technology

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Abstract: As one of the most important measurement equipment of the intelligent substation, digital electric energy meter fundamentally resolved the technical bottleneck of traditional substation. During the operation process, measurement accuracy and reliability are related to the safe and stable operation of power system. Based on the literatures related to the digital electric energy meter, this paper introduced the concept of digital meter, analyzed the error sources, and summarized its development status and the existing calibration method. The paper studied the calibration system based on IEC61850-9 and provided an accurate and safe application method for digital electric energy meter.

1 Introduction

Compared with the traditional electric energy meter, working principle and interface mode of digital electric energy meter have been changed fundamentally. Nowadays, most people have inherited the ideas of traditional instrument measurement, calibration parameters, calibration method, provision of technical indicators and so on^[1], which has demanded new requirements for the calibration of the digital power meter.

As an electric energy transmission and consumption metering device, electric energy meter has gone through more than one hundred years of history. Its development has experienced induction type (mechanical), pulse type (electromechanical) electric energy meter and electronic energy meter etc^[2]. In 1880, the world's first electric energy meter was born. Through continuous improvement, in nineteenth century the inductive power meter manufacturing theory was proposed and had since been widely used for its advantages of simple manufacturing, good reliability and low cost etc. With the updated requirements of the power management modernization, pulse electric energy meter came to the market with the accuracy of 2.0, 1.0 and highest 0.5. In 1976, electronic power meter prototype appeared in Japan. Following the development of electronic devices, especially the electric energy metering chip, the performance of electronic energy meter was improved greatly, and gradually replaced the ordinary induction meter.

Nowadays, with the advancements of intelligent substation^[3] digitized standards, its corresponding technology, and the continuous development of the

digital and network measurement mode, digital multifunctional electric meter based on IEC61850 has been widely used and become the development trend of the smart grid. Because there is no single standard of digital electric energy meter calibration, 347 digital substations all over the country that use digital electric energy meter are operating without complete test or the measuring accuracy cannot be guaranteed. This paper provided a variety of ideas for realizing high precision in the current verification technology.

2 Overview of Digital Electric Energy Meter

Digital electric energy meter uses digital interface, optical fiber interface, data interface etc. and the high speed optical fiber Ethernet are used in the physical layer and link layer. The electric current and voltage signals are digitized by digital substation fore-end electromagnetic or electronic transformer, and the digital signal is transmitted to the merging unit (equivalent to the analog signal processing and A/D converter) by the optical fiber. The merging unit outputs normative digital signal frame which is based on the IEC61850 standard. Digital power meter can figure out electric energy parameter by receiving this digital signal frame. The digital electric energy meter is a pure digital signal processing equipment or an IT equipment. It requires that the equipment is reliable, the algorithm is scientific and the calculation error is minimized.

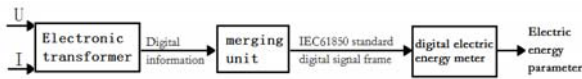


Fig1. Digital substation electrical energy measurement principle diagram

The digital substation electric energy metering device is comprised with an electronic type voltage, current transformer, combining unit (which plays a role of protocol conversion and time synchronization), digital electric energy meter and total station sampling synchronous clock as well as the connecting cable^[4]. Compared with the traditional electric energy meter, digital substation metering device's current and voltage digital signal should guarantee the synchronization to ensure the accurate measurement. So it is necessary to design a new calibration device to replace the traditional electric energy meter calibration instrument. The device must have the following basic functions: first of all, it should be equipped with an optical fiber Ethernet interface; secondly, the link layer needs to have the ability to adapt to different standards; and thirdly, it should have the function of calculating the power. Most important thing is to have the function of preserving historical data for follow-up, and the detection system should also be able to receive the meter pulse signal to do some error analysis.

Considering the measurement structure principle, digital electric energy meter can be divided into two categories^[5]: digital electric energy meter based on single chip microcomputer (MCU) and digital signal processor (DSP). DSP chip is 32 bit register with a very high clock rate and very rich signal processing optimized instruction set with its operational speed on "instruction level". The other category is based on the special electric energy metering chip, which has a strong anti-interference capability and good measurement accuracy. But the development cost is high and its flexibility is low because it is too dependent on the multi functions of the electric energy metering chip. The hardware frame of digital electric energy meter is more stable and the data processing is the key to realize the wide application of the digital electric energy meter. In other words, how to reform the electric energy meter and realize the high precision measurement relies on how to overcome the difficulty of electric energy parameter measurement algorithm.

Referring to the problems that occurred during the application of digital electric energy meter, research shows that the following points should be considered for high-precision: the measurement accuracy of the digital electric energy meter in the multi unit data packets, the measurement accuracy in different sampling ratio, the measurement accuracy at 0.01% Packet-loss Ratio, and the digital electric energy meter should keep the same level of accuracy when change the voltage and current specifications.

3 Analysis of electric energy meter error formation

3.1 Error formation of traditional electric energy meter

The error of the traditional measurement system is mainly from aspects such as Holzer component, shunt circuit, voltage divider circuit, TV and TA. The error characteristics curve of A/D preamplifier and A/D converter under different temperature, different load or power factors are nonlinear^[6]. For example, Figure 2 is the error characteristic curve of the inductive electric energy meter under voltage change, in which $\mu = U/U_e$. The relative error γ_u represents the voltage influence, The induction watt-hour meter is composed of the electromagnetic element, the rotating element and the brake component. In reality, the turntable is affected by the driving torque and braking torque that is proportional to the load power. It is also affected by the inhibition torque, parasitic torque, friction torque and torque compensation. The influence of the turntable displacement, will directly affect the basic error of the electric energy meter.

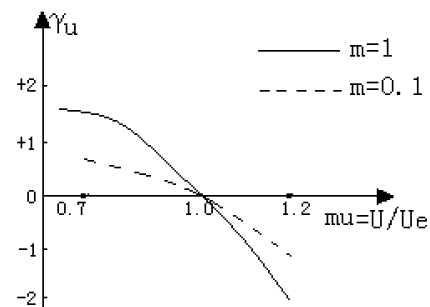


Figure 2. Voltage error characteristic diagram of induction type electric energy meter

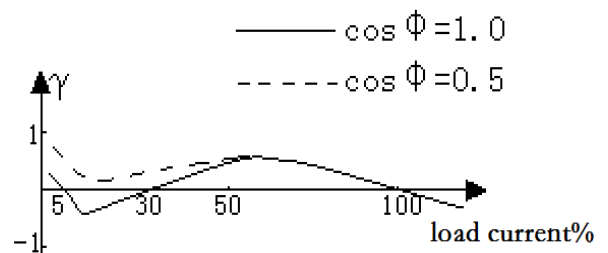


Figure 3. Load characteristic curve diagram of induction type electric energy meter

In the same way, the error characteristic curve of the induction watt-hour meter is nonlinear when load changes. In Figure 3, the electric energy meter working characteristic is unstable when the load current is less than 5%, The influences are from the friction torque, self-induced dynamic torque, the current magnet nonlinear error and nonlinear error changes when the load current is from 5 to 100 percent. Due to its different principle of electronic energy meter^[7], the load characteristic curve is a straight line as shown in

Figure 4.

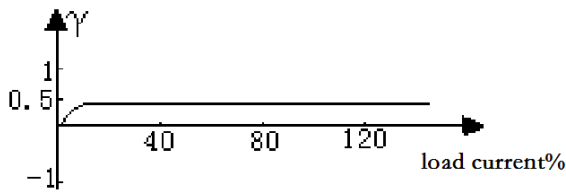


Fig4. Load characteristic curve diagram of Electronic energy meter

3.2 Error formation of the digital electric energy meter

In the digital electric energy meter, there is no start, running concept and overload limit. Small current or no current state does not affect the electrical energy measurement. Different from the traditional analog electronic energy meter, there is no impacting factor such as signal transformation, A/D conversion, sampling and synchronization that caused by the equipment itself. Changes in voltage, frequency fluctuations, three-phase imbalance, noise and other external signal impact also do not influence the digital electric energy meter. In theory, the digital electric energy meter is just a mathematical operation with no error. The actual error may be caused by three factors. The first is the abnormal phenomena due to the loss of frames and packet during the process of sending the packet, which will affect the meter's work function and reliability. It will not change the internal program (algorithm) so that the measurement performance is not impacted. Second, is the error caused by the difference between the electric energy pulse output and the actual electric energy accumulation^[8]. Lastly, is the error caused by the floating point operation or the truncation error^[9] which is the computer system inherent error. But in the digital substation, the sampling data error caused by the limit of the IEC61850 protocol is more suitable to be considered as the error of electronic transformers. In fact, in the field of electronic transformer, it is one part of the error and it is not reasonable to repeat the calculation. As for the tremble during the process of analog signal harmonic, noise and digital signal transmission, it is the error factor of mutual inductance and the combination unit. Even being disposed by the electric energy meter, it still belongs to the category of the algorithm error.

4 Research status and methods of electric energy meter

Overseas researches on electric energy meter testing technology have started very early, and a lot of relevant technical solutions for the measurement device state detection have been proposed. But there is no any related international or western standards to follow. In

the field of digital electric energy meter, there still lacks of authoritative research results.

Domestic calibration technology is relatively weak. It was not until the mid-1980s, China began to develop field calibration instrument. The rapid expansion of market demand greatly stimulated the enthusiasm of domestic field calibration instrument research. In a short span of less than twenty years, China's field calibration apparatus has experienced three stages of development. The first stage is mechanical pointer type instrument, the second stage is digital instrument, and the third stage is intelligent instrument. With the continuous development of the digital process, many research institutions, universities and manufacturers have launched the exploration and research on the measurement system of digital electric energy. For different concepts and applications, a number of different digital electric energy meter calibration methods are proposed: digital power source and standard digital electric energy meter method, standard digital power source method, and analog power source and analog standard electric energy meter method.

4.1 Digital power source and standard digital electric energy meter method

Principles of digital power source and standard digital electric energy meter method are shown in Figure 5. The digital power source and network equipment should be stable and reliable. The accuracy grades of standard digital electric energy meter should be two steps higher than the verified digital electric energy meter. It also requires that the standard digital electric energy meter must pass the energy value.

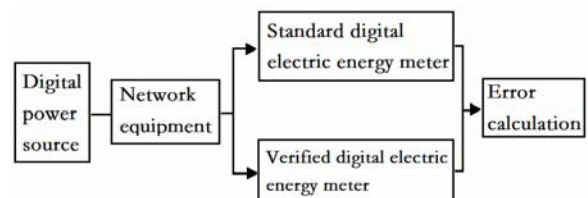


Figure 5. Principle block diagram of digital power source and standard digital power meter method

A number of scientific institutions and universities, such as Chinese Academy of Metrology, have proposed calibration methods based on the principles above. State Grid Hubei Electric Power Research Institute's Shen Li^[7] et al. have designed a scheme of test device. It is able to simulate and test the meter accuracy when network packet is abnormal which provides a new design idea for the laboratory test of the digital electric energy meter. Zhejiang Electric Power Test Research Institute developed a digital electric energy meter detection device based on the digital power source and standard digital electric energy meter method^[10]. In its unique design, the digital channels can be configured, primary and secondary pulse constants are optional, the IEC61850 related parameters can be configured; uses

both of 220V and 110V AC auxiliary power supply, and with single mode, multi-mode etc. This device can solve the problem of standard digital power source output with only one way, and also solve the problem of a network interface that cannot be connected to both single and multimode optical converters.

4.2 Standard digital power source method

Jiangsu Electric Power Research Institute, Nanjing Automation Co. Ltd, China Institute of Metrology and several institutions put forward the so-called standard digital power source method. Different from the China Institute of Metrology which obtain the standard electric energy value through the way of receiving line with IEC61850-9-1/2 communication protocol standards packet and then unpacking, the Nanjing Automation Co. Ltd obtains the standard electric energy value through direct calculation.

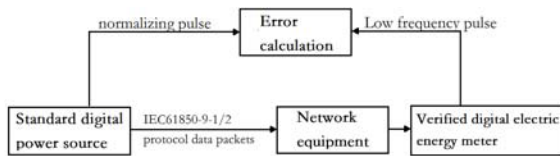


Figure 6. Principle block diagram of standard digital power method

4.3 Analog power source and analog standard electric energy meter method

Guangdong Electric Power Scientific Research Institute and other institutions have proposed a method based on the analog power source. The principle is to use three-phase power source output analog voltage and current signal directly to the standard analog meter, and after sampling and communication protocol conversion, analog voltage and current signal are provided to the verified digital electric energy meter and standard digital electric energy meter. The error of the digital electric energy meter can be obtained by comparing the electric energy value of standard digital electric energy meter and the verified electric energy meter.

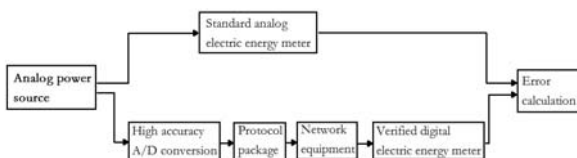


Figure 7. Principle block diagram of analog power source and standard analog power meter method

The first two methods are using the digital frequency direct synthesis technology to generate a sine wave signal. This method can set up the output sine wave amplitude, phase, frequency and channel number. Standard digital power source method can also test the error that caused by the error rate and the algorithm of the digital electric energy meter. But the

calculated current and voltage values generated by the standard digital power source are not directly traceable to the standard analog values. The third method have better flexibility since it generates digital signal through high precision A/D conversion equipment acquisition of analog power source voltage current signal and then packaged.

4.4 Other related research results

In research on the field environment for test technology to simulate the merging unit, Wasion Group digital electric energy meter checking device first proposed the merging unit measurement technology, which can simulate the maximum three units in on-site inspection environment, support maximum of 50 channel sampling data and GMRP networking^[11], and realize multi-fiber access port digital electric energy meter calibration^[12].

On the electric energy meter error characteristic and the digital electric energy measurement traceability method^[13], the Sichuan Electric Power Research Institute and the Tsinghua University have been working together to construct a kind of "input type digital standard power meter" which can output two types of digital parameters.

Zhejiang Han Pu Electric Power Technology Co. Ltd has designed a digital power meter calibration device based on embedded platform^[14]. The device can realize the function of analog voltage and current collection, digital power output, and all kinds of electric energy calculation, display, storage etc. It can also provide the function of MMS communication to complete the calibration of the electric energy meter.

Sichuan Electric Power Science Research Institute^[15] developed a digital power meter with DSP as the core to support the IEC61850 protocol. It was an electric energy meter with integration of the meter and its power source realized the test of positive reverse and active reactive power. Based on their design, experts and scholars are able to continue to develop and optimize the power meter test function.

5 Research of digital power meter calibration system based on IEC61850 protocol

In recent years, based on the electronic transformer's good linear relationship with the measurement value, the wide measurement range, and the magnetic saturation is not a problem, output sampling data packets can be done with standard format. While the traditional power meter cannot receive the digital signal, the digital electric meter is coming into play.

In this paper, a portable digital electric energy meter calibrator is tested and verified in the laboratory and on-the-spot. It can effectively solve the problem of field calibration of digital electric energy meter with high accuracy and efficiency. The calibrator includes

hardware and software platform. The main function of the hardware platform is that through the way of real-time receiving, to convert the standard channel merging unit's digital output and the electric energy meter pulse output into the corresponding electrical signal, and transmitted them to the software platform for analysis and calculation through the signal processing unit frame.

The software platform for digital power meter is shown in Figure 8.

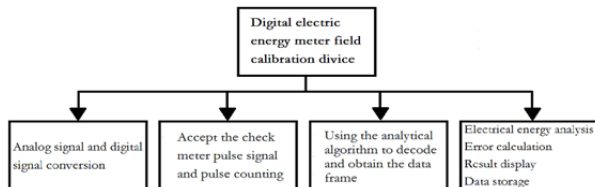


Figure 8. Digital electric energy meter field calibration software platform

Its main functions are summarized here. First, is the data frame decoding of the merging unit's digital output, which can obtain its voltage and current signal and then perform the standard channel power calculation. The data frame of the merging unit output is generally in the 61850-9-2 IEC frame format. The software platform needs to receive the data of the merging unit in real time so that it can carry out the frame decoding accurately; Second, is to receive the pulse of the verified meter and analyze the corresponding electric energy. Finally, the software platform will compare the standard channel and the electric energy meter calibration data to get the error value and the results will be displayed in real time which can be stored as needed.

There are two key points of this research. First, the data acquisition and transmission system of the field digital electric energy meter is divided into the standard channel merging unit data acquisition^[16] and the verified electric energy meter pulse output acquisition. Because it is compatible with the current mainstream synchronous mode and can achieve higher synchronization accuracy, the synchronization error between the standard and the check channel can be controlled within 0.01%. Second^[17], based on high precision and multifunction clock synchronization method research, it can realize clock synchronization by taking advantage of the substation clock, and keep high precision synchronization by using its high frequency crystal oscillator clock. It is of great significance to the promotion of the digital electric energy meter technology development and the power grid's intelligent level.

Through the research of this project, we can develop a portable calibration device that can carry out real-time verification of digital electric energy meter, not only guarantee the instrument's accuracy and reliability but also improve the accuracy of the current channel and the voltage channel to the 0.05 levels. This work has an important theoretical and practical

significance in regulating the economic benefit evaluation index of electric power industry and promoting the standardization and intelligence of the entire network.

6 Concluding remarks

The new generation of intelligent substation is in the direction of large-scale and practical applications. Meanwhile, ensuring the accuracy of the digital electric energy meter has great economic and social benefits to the substation construction. Study the existing research results is essential to the science and development in this area. . This paper provided a variety of design ideas for experts and scholars through the analysis on the digital power meter error form factor. The work summarized and analyzed the development status of existing methods and introduced digital electric energy meter calibration system based on the IEC61850-9 protocol.

Acknowledgement

This work was supported by Natural Science Fund of Hubei Province (grant number 2015CFB219) and Foundation of Education Department of Hubei Province (grant number B2015245).

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