Research and Analysis on Evaluation Methods of Electrical Performance of Smart Energy Meters

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Abstract. Based on the technical specifications of smart meters, the electrical performance evaluation methods of single-phase smart meters are studied, and the accuracy, stability and safety of smart meters are analyzed and studied through specific data verification. Analysis the basic characteristics of the electrical performance of the smart energy meter, and evaluate the electrical performance based on the basic characteristics. Collect the specific working characteristic data of the intelligent electric energy meter, accurately measure the parameters of the intelligent electric energy meter, and analysis the electrical performance. Analysis the influence of the harmonic components of the power system on the measurement of the electric energy meter, study the power consumption of the smart electric energy meter, and the accuracy and stability of the operation.

Keywords: Single phase smart meter, Electrical performance, Evaluation method.

1. Introduction
As a good medium for smart electricity service interaction, smart energy meters are one of the important links of smart grid data collection. The accuracy of their measurement and the stability of operation are getting more and more attention. Smart electric energy meter is one of the basic equipment for data collection in smart electricity service. It is responsible for collecting raw electric energy data, transmitting electric energy information and measuring electric energy. It is the basis for integrating electric energy information and optimizing data analysis. With the huge demand for smart energy meters, governments and enterprises are establishing related policies and standards for smart energy meters.

As an important part of the smart grid, smart energy meters are attracting more and more attention all over the world. The interactive two-way communication between smart energy meters is characterized by automatic management of the meters, which can automatically process, transmit and use metering data. Smart energy meters support services that improve energy management systems and energy utilization efficiency, and can provide timely and valuable information for participants, electricity users, and energy consumers in smart metering systems. Smart energy meters have functions such as remote reading of data, distributed power access, remote control of power, detection
of illegal power usage, interoperability of service equipment, detection of power quality, and interactivity of information communication. The application of smart energy meters in the power grid and its absolute superiority in the process of power distribution measurement.

As an important part of the unified and strong smart grid, smart electricity services are directly facing the whole society and all power customers. It is the main way to understand the unified and strong smart grid and understand its construction results. It has a very important position in the construction of domestic smart grids. And role. The development of smart meters faces various problems and challenges. In the future power market applications, smart meters have unique advantages.

2. Electric principle and combination of smart meter

Smart energy meter is a kind of intelligent meter, with communication technology and microprocessor application as the core. It has the characteristics of data processing, automatic measurement, two-way communication and extended functions. It can realize remote power failure, multiple electricity price billing, and real-time data. Interactive, two-way metering, monitoring power quality, remote and local communication, meter data and other functions. The electrical working principle of the smart electric energy meter is shown in Figure 1.

![Figure 1. Electrical working principal diagram of smart energy meter.](image-url)

The power supply of the smart electric energy meter includes two parts: AC power supply and battery power supply. The 220V AC high voltage of the grid can be transformed through a transformer, after being rectified by a bridge circuit, and filtered by a filter circuit composed of capacitors, and a voltage stabilizer composed of a diode circuit the circuit stabilizes voltage and converts high-voltage AC power into DC low-voltage. The smart electric meter needs to be electrically isolated from the external AC grid. The battery maintains the basic functions of the smart electric meter's display and clock during a power failure.

The smart electric energy meter uses a single-chip microcomputer as the central processing system, which is composed of a central processing unit, arithmetic unit, controller, input/output port, read-only memory, read-write memory, etc., to complete the data collection, processing, storage, and display of the smart electric energy meter. Communication and other functions. The main communication methods used by electric energy meters include bus communication, wireless transmission, power line carrier transmission, and bus interface. The communication capability of the smart energy meter determines the normal operation of the automatic meter reading system.

The intelligent electric energy meter needs to sample and process the voltage signal and current signal in the circuit under test. The voltage is sampled by the resistor divider, and the current is sampled by measuring the voltage value generated by the current flowing through the shunt. The sampled discrete voltage and current data analog quantity is converted into digital quantity through the
analog-digital converter, and sent to the central processing system for processing, analysis and calculation.

The electric energy metering unit is the core of the smart electric energy meter, which integrates scattered electronic components into an overall device. A single function is integrated into a multifunctional metering chip, which reduces the cost, volume, and function of the smart energy meter.

3. Analysis of the impact of the electrical performance of smart meters
The electrical performance of a smart energy meter refers to the reliability, controllability, stability, sensitivity, and anti-interference performance of the energy meter. Technical specifications, mechanical performance, adaptation to the environment, functional requirements, electrical performance, anti-interference, and reliability are all important index requirements for electrical performance analysis and management of smart meters.

① The influence of power supply voltage on smart meters
The power supply voltage impact test mainly evaluates the performance of the electric energy meter under different voltage conditions. The error of the smart electric energy meter should be within the allowable range under the conditions of different power factors within the working range of the rated voltage. When the working voltage has a short-term sudden change, the error change of the electric energy meter should be within the allowable variation range. Regardless of whether it is powered by AC power or switched to battery-powered mode, the electric energy meter should be able to ensure the accuracy of its measurement. The voltage working range of the smart meter is shown in Table 1, where UN is the rated voltage value.

Table 1. Classification of smart meter working range.

| Smart meter working voltage | Voltage parameter |
|----------------------------|-------------------|
| Rated working range        | 0.9UN-1.1UN       |
| Expand the scope of work   | 0.8UN-1.2UN       |
| Limit working range        | 0.0UN-1.2UN       |

Similarly, the smart meter should maintain the normal working ability of the meter in the event of high voltage and sudden power failure and switch to battery power.

② The impact of pulse voltage on smart meters
The pulse voltage requires the electric energy meter to have better insulation performance under the impact of the pulse voltage. The pulse voltage is a non-periodic transient voltage that rises quickly to a peak value and then slowly drops to zero. The electric energy meter should be able to withstand the pulse voltage test between line to ground and line to line. The smart electric energy meter cannot appear flashover, rupture discharge or breakdown.

③ The impact of overcurrent on smart meters
The short-term overcurrent impact test mainly assesses the performance of the electric energy meter after a short-term large current impact. When the electric energy meter is overcurrent for a short time, it should be ensured that the electric energy meter should not be damaged and can work normally, and the error change should not exceed 1.0%.

④ The impact of temperature rise on smart meters
The temperature rise mainly refers to the degree of influence of the internal heating of the smart electric energy meter on the performance of the intelligent electric energy meter under the normal maximum load condition. The temperature rises of the internal structure of the smart energy meter and the temperature rise of the environment should not reach the temperature that affects the normal operation of the energy meter.

⑤ The impact of insulation performance on smart meters
Insulation performance is an important test to ensure reliable operation and safe operation of electric energy meters. Insulation requirements are mainly reflected in the insulation level of the electric energy meter, the insulation defect of the electric energy meter, and the ability to measure overvoltage. The insulation performance determines the operating condition and integrity of the electric energy meter, and determines whether it can continue to be put into operation.

The impact of harmonics on smart meters

The harmonic components of the power grid not only affect the power supply quality of the power system, but also interfere with the normal operation of various power equipment such as communication equipment and measuring instruments. The influence of harmonics poses a certain threat to the safe operation of the power grid and reduces the accuracy and reliability of electric energy measurement. Similarly, harmonics will also affect the accuracy and stability of smart meter measurement. A good smart meter should maintain good accuracy and operating status under the influence of harmonics.

4. Analysis of the influence of harmonics on the performance of smart meters

Due to the asymmetry of the load, a negative sequence component is generated in the power supply system. The volatility of the load causes the voltage of the power supply system to fluctuate. The nonlinearity of the load will also produce high-order harmonics in the power supply system. When harmonics, negative sequence components, and fluctuating voltages enter the grid, they not only cause the quality of power supply to decline, but also cause serious harm to the power system. The mathematical model method is used to study and analyze the load harmonic current. The content rate of the fundamental wave and each harmonic of the load current is shown in Table 2.

| Harmonic order | Harmonic content | Harmonic order | Harmonic content | Harmonic order | Harmonic content | Harmonic order | Harmonic content |
|----------------|-----------------|----------------|-----------------|----------------|-----------------|----------------|-----------------|
| 0              | 0               | 5              | 12.4            | 10             | 0               | 15             | 5.1             |
| 1              | 100             | 6              | 0               | 11             | 6.2             | 16             | 0               |
| 2              | 0               | 7              | 9.1             | 12             | 0               | 17             | 4.3             |
| 3              | 20.2            | 8              | 0               | 13             | 5.6             | 18             | 0               |
| 4              | 0               | 9              | 7.3             | 14             | 0               | 19             | 4.7             |

The error limit of the smart energy meter is within 60% of the allowable error limit in accordance with the "Electronic Energy Meter Verification Regulations". It is determined that the measurement error of the energy meter under harmonic conditions is greater than the measurement error when the fundamental wave changes. 0.06, it can be determined that the harmonics have a certain influence on the normal measurement of the electric energy meter. Use 220V, 10A multiple electric energy meters as experimental sample meters to detect the interference and influence of harmonics on the electrical performance of smart meters.

When voltage $u(t)$ and current $i(t)$ contain fundamental wave and multiple harmonic components, both voltage $u(t)$ and current $i(t)$ can be expressed as the superposition of fundamental wave and each harmonic component.

$$u(t) = U_1 \left[ \cos(\omega t - \theta_u) + k_i \cos(\omega t - \theta_i) \right]$$  \hspace{1cm} (1)

$$i(t) = I_1 \left[ \cos(\omega t - \theta_i) + k_i \cos(\omega t - \theta_i) \right]$$  \hspace{1cm} (2)
When there is harmonic power in the power grid, the influence on the measurement of electric energy meters is studied from the two aspects of harmonic order and harmonic power content. That is to analyze the two situations where the harmonic power content is different and the same and the harmonic order is different.

When the harmonic order is the same and the harmonic power content changes, the analysis of the \( N \)-th harmonic at the initial phase angle is 0°, and the voltage and current content rate is variable \( X \). The voltage and current of the energy meter can be expressed as:

\[
\begin{align*}
    u(t) &= U_1 \left[ \cos(2\pi f \cdot t) + X \cos(N \cdot 2\pi f \cdot t) \right] \\
    i(t) &= I_1 \left[ \cos(2\pi f \cdot t) + X \cos(N \cdot 2\pi f \cdot t) \right]
\end{align*}
\]

In the formula, \( f \) is the frequency of the public network, with a value of 50 Hz.

When the harmonic power content is the same and the harmonic order changes, the voltage and current content rate is a fixed value \( M \) and the initial phase angle is 0°, the voltage and current of the variable \( i \)-th harmonic input to the electric energy meter can be expressed as:

\[
\begin{align*}
    u(t) &= U_1 \left[ \cos(2\pi f \cdot t) + M \cos(i \cdot 2\pi f \cdot t) \right] \\
    i(t) &= I_1 \left[ \cos(2\pi f \cdot t) + M \cos(i \cdot 2\pi f \cdot t) \right]
\end{align*}
\]

The fundamental wave power supply is used to superimpose odd harmonics to simulate the harmonic characteristics of the load, analyze the degree of influence of the harmonic conditions on the accuracy of electric energy measurement, and explore whether the accuracy of harmonic measurement meets the requirements of relevant regulations.

The fundamental wave is superimposed on the odd harmonics, and the voltage and current contents are 5%, 10%, 15%, 20%, 25%, and 30% respectively. The fundamental wave error and measurement error of the 6 electric energy meters to be tested are shown in the table 3 shown.

| Meter   | Energy meter 1 | Energy meter 2 | Energy meter 3 | Energy meter 4 | Energy meter 5 | Energy meter 6 |
|---------|----------------|----------------|----------------|----------------|----------------|----------------|
| Fundamental wave | 0.10          | 0.10           | 0.00           | -0.06          | 0.02           | 0.04           |
| 5%      | 0.12           | 0.10           | 0.00           | -0.06          | 0.00           | 0.06           |
| 10%     | 0.12           | 0.12           | 0.02           | -0.08          | -0.02          | 0.10           |
| 15%     | 0.12           | 0.14           | 0.02           | -0.12          | -0.04          | 0.14           |
| 20%     | 0.12           | 0.14           | 0.04           | -0.14          | -0.06          | 0.16           |
| 25%     | 0.12           | 0.16           | 0.04           | -0.16          | -0.06          | 0.18           |
| 30%     | 0.12           | 0.16           | 0.04           | -0.18          | -0.08          | 0.20           |

It can be observed and analyzed from the table that after the odd harmonics are applied to the electric energy meter, the measurement error range of the electric meter 1, the electric meter 2, and the electric meter 3 does not exceed 0.06, and the error change of the electric energy measurement is small. The metering errors of meter 4, meter 5, and meter 6 have changed greatly, and the measurement error exceeds 0.06 when compared with the fundamental wave. The greater the harmonic power content, the greater the measurement error of the electric energy meter. When the harmonic content of the electric
energy meter 6 is 15%, the measurement error is already 0.1 different from the fundamental wave, and the measurement accuracy of the electric energy meter is seriously affected.

When the voltage harmonic content is unchanged, only the harmonic current content is changed, when the odd harmonic current content added to the electric energy meter is 5%, 10%, 15%, 20%, 25%, 30%, the energy meter the measurement error and fundamental wave error at this time are shown in Table 4.

| Meter       | Energy meter 1 | Energy meter 2 | Energy meter 3 | Energy meter 4 | Energy meter 5 | Energy meter 6 |
|-------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Fundamental wave | 0.10           | 0.10           | 0.00           | -0.06          | 0.02           | 0.04           |
| 5%          | 0.10           | 0.10           | 0.00           | -0.06          | 0.00           | 0.04           |
| 10%         | 0.10           | 0.12           | 0.00           | -0.06          | 0.00           | 0.06           |
| 15%         | 0.10           | 0.12           | 0.02           | -0.08          | -0.02          | 0.08           |
| 20%         | 0.10           | 0.12           | 0.02           | -0.08          | -0.02          | 0.10           |
| 25%         | 0.10           | 0.12           | 0.04           | -0.10          | -0.04          | 0.12           |
| 30%         | 0.10           | 0.12           | 0.04           | -0.10          | -0.06          | 0.14           |

The harmonic voltage content is small. When only the harmonic current content changes, the generated harmonic power is small. The measurement error of the electric energy meter is much lower than the influence of the harmonic voltage and the harmonic current content on the electric energy meter. The measurement error changes of meter 1, meter 2, meter 3, and meter 4 are basically within the allowable range, and harmonics have little effect on electric energy measurement. When the harmonic content of the electric meter 5 and the electric meter 6 are 30% and 25%, the error data has been different from the fundamental wave by more than 0.06, and the electric energy meter is not accurate.

Harmonic voltage and harmonic current content change, electric energy meter measurement error curve, and harmonic voltage unchanged and harmonic current change, electric energy meter measurement error curve is shown in Figure 2 and Figure 3 respectively.

![Figure 2](image_url)
Figure 3. Harmonic voltage does not change, current changes, the meter error curve.

When the harmonic current content of the electric energy meter 6 is 15%, the error value has changed by more than 0.06 compared with the fundamental wave. In the process of verifying the electric energy meter, the harmonic content of the current harmonic content of more than 150% must be tested for its influence on the measurement error of the electric energy meter. There are differences in the harmonic measurement error of different electric energy meters. Some electric energy meter measurement errors vary greatly with harmonic power. When using electric energy meters with serious harmonic influence, the influence of harmonics on electric energy meter measurement errors cannot be ignored.

5. Conclusions
As a good medium for smart grid interaction, smart energy meters play an irreplaceable role in the construction of smart grids. As an important part of the smart grid, smart energy meters are attracting more and more attention all over the world. Smart energy meters have great advantages in metering and management, with low metering costs, high energy efficiency, and remote control to fully meet consumer needs. However, attention should be paid to the influence of harmonics on the electrical performance of the energy meter when using the energy meter. When choosing smart energy meters for different harmonic sources, it is necessary to detect the measurement errors of the energy meters under the corresponding harmonic conditions. Measure the measurement error of the electric energy meter, and determine whether the harmonics affect the measurement accuracy of the electric energy meter, so as to ensure the accurate operation of the smart electric energy meter.

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