Integration and Test Methods of Energy-saving Electronic 10kV Metering Device

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ABSTRACT: Designed in this paper, the energy-saving electronic 10kV metering device is composed of electronic voltage transformer, electronic current transformer, electronic metering terminal and communication terminal. Electronic transformers and metering terminal are no longer designed and tested independently. Based on the principle of minimum overall error of 10kV electricity metering device, the partial pressure ratio of 10kV volt-age divider network, the ratio of electronic current transformer and current-voltage conversion, the influence of the stray capacitance generated after electronic transformer and metering terminal are packaged in the circuit breaker box, should be coordinated in integrated design consideration, based on input range and calibration capability of measurement chip. And the 10kV metering device is tested with integration method. This article describes the device structures and calibrating methods. The test results show that the active power accuracy class of the device designed in this paper is 0.5, and that reactive power accuracy class is 2.0. The developed device with low power consumption advantages and three-phase four-wire connection mode, resolved line loss problem due to the unbalanced load.

KEYWORD: 10kV measurement; electronic voltage transformer; electronic current transformer; integration; error uncertainty

1 INTRODUCTION

In China, the transformer uses three-phase three-wire connection mode in high-voltage (HV) side while using three-phase four-wire connection mode in low-voltage side in the condition of 10kV high voltage wire using neutral non-effective grounding. The traditional electromagnetic 10kV metering devices are installed in HV side, using the three-phase three-wire measurement model. The electric energy results are accurate relatively in the condition of three-phase balance load (BU Zhengliang et al., 2006). However, in the case of three-phase unbalance, metering electric energy and user's energy consumption are not equal, that will lead to inaccurate measurement, even active power is not measured. Users may steal power through a three-phase three wire measurement model of the vulnerability. And due to the serious imbalance of the line load, there will be a serious loss.

The developed device using three-phase four-wire connection mode can measure the full information (current, voltage) of three-phase on line. The measurement can be carried out without leakage phase, and micro electricity consumption can be metered. Accordingly, the device can measure the power energy more accurately and has the function of anti-stealing electric energy.

Energy-saving electronic 10kV metering device consists of electronic transformers, metering terminal and communication terminal. Low power current transformer and resistor divider voltage transformer outputting the weak analog voltage signal proportioned with the primary current and voltage, can connect with metering terminal seamlessly. Electronic transformer almost does not consume energy, but also can save a large amount of iron and copper, with light weight, low power consumption, advantages of energy-saving and loss reduction, in line with the national energy-saving emission reduction and green environmental protection requirements (LI Jiuhu et al. 2007).

This paper introduces methods of integration error testing and uncertainty evaluation and the seamless integration between electronic transformers and metering terminal which is the way to improve the measurement accuracy of the device.

2 SYSTEM COMPOSITION

In this context, the main elements of energy-saving electronic 10kV metering device, depicted in the

block diagram of Fig.1, include: electronic transformers, electronic metering terminal and communication terminal. By use of electronic voltage transformer and current transformer, the device transferred high voltage and large current signal into little volt voltage signals and mill amperes current signals which were sent directly to the measurement terminal for data processing. And the energy parameters obtained were transmitted by RS485 to the communication terminal finally. The electronic transformers and metering terminal were packed in the circuit breaker box hanged on the top of the pole for anti-stealing electric energy. And the communication terminal used for meter reading staff and users to check the data was put in the bottom of the pole. Simultaneously, the communication terminal has the function of the local power parameters displaying and remote data transmission. The device using a 50MΩ HV resistance between with phase and ground, did not affect the connection mode of 10kV system.
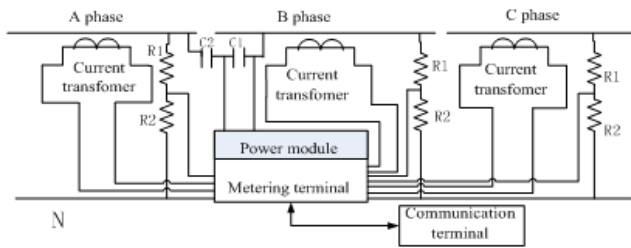

Figure 1. Block diagram for metering device system

2.1 *Metering Terminal*

The metering terminal shown as Fig.2, consisted of the following sections: pre-processing circuit, ADE7878, MCU, ferroelectric memory, RS232/485, real time clock (RC) and power module, etc. The metering terminal calculated power parameters, then transmitted data to display terminal. ADE7878 can calibrate the phase and amplitude offset of electronic transformer within a certain range.
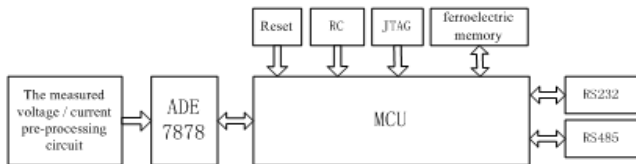

Figure 2. Block diagram for metering terminal

The high voltage and large current signals from 10kV high-voltage grid were converted by the pre-processing circuit into mV, mA level signals transmitted to ADE7878. The data were processed and stored in internal registers of ADE7878, The LPC2368 microcontroller could read current, voltage, power, electric energy and other data via the serial port. RS232 was used to automatic calibration of the device and RS485 was for remote meter reading.

2.2 *HV Energy Supply Module*

The design of HV energy supply module uses the principle of capacitive voltage divider. The line voltage instead of phase voltage as supply ensured that the accuracy of the phase voltage measurement is not affected.

By selecting the proper capacitance value, the voltage divider output was controlled within 83V~154.2V with the 10kV voltage fluctuation range 7~13kV, because the measurement terminal voltage input range was 80V~265V. The pressure value of the high voltage capacitor is chosen as 50kV, which meted the 42kV requirement of 10kV equipment.

3 INTEGRATED DESIGN METHOD

The so-called integrated design method means that electronic transformers and metering terminal are no longer designed independently, tested independently. Based on the principle of minimum overall error of 10kV electricity metering device, the partial pressure ratio of 10kV voltage divider network, the ratio of electronic current transformer and current-voltage conversion, the influence of the stray capacitance generated after electronic transformer and metering terminal are packaged in the circuit breaker box, should be coordinated in integrated design consideration, based on input range and calibration capability of measurement chip. The calibration flow chart of the ADE7878 gain registers and offset registers is shown in Fig. 3.
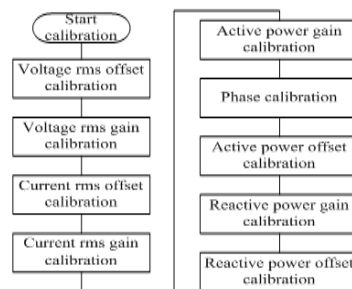

Figure 3. Calibration flow chart

4 INTEGRATION TESTING ERROR AND UNCERTAINTY ANALYSIS

4.1 *Independent Test*

In this context, the technical indicators of energy-saving electronic 10kV metering device are: voltage:3*5.77kV,   current:5~500A,   frequency:

(50±2.5) Hz, power: < 6W, voltage accuracy class: 0.2, current accuracy class: 0.2S, active power accuracy class: 0.5, reactive power accuracy class: 2.0.

According to IEC60044-7/8, the evaluation of electronic transformers was completed in Xi'an High Voltage Apparatus Research Institute in 2013. And voltage measurement accuracy class is 0.2, the current measurement accuracy class is 0.2S. Specific testing projects include the followings: accuracy test, the accuracy of the temperature-cycle test, power-frequency voltage withstand of primary side test, partial discharge measurement, rated lightning-impulse test, truncated lightning impulse test, short-time current tests, ECT temperature-rise test and experiment on the relationship between accuracy and frequency. Electronic voltage transformer rated output is 2V. Electronic current transformer rated output is 10mA which is converted to the rated voltage output 4V after 1/10000 precision resistors.

The terminal measurement accuracy test using the comparison method was completed in Baoding, Hebei Province, the metrology Supervision Bureau. Calibration device is the CL303 programmable three-phase power source whose signal (100V/5A) were connected with the measurement terminal through 1/10000 precision class metering transformers. The standard meter is CL311V2 three-phase multi-function meter whose accuracy class is 0.05. Then, the output of calibration device was set to the rated voltage. The output current was adjusted to 0.2Ib, 1.0Ib, 4.0Ib in turn. The output power factor was adjusted to 1.0, 0.5L, 0.8C. The electric Energy measurement accuracy of the test measurement terminal was obtained by comparing the active energy pulses output of the test meter and the standard meter. The experimental results show that the error of the test measurement terminal reaches the design requirements in this article.

4.2 *Integration Test Approach*

According to the basic principles of the International Electrotechnical Commission (IEC) : The error of all instrumentation and measuring devices must be actual measurement. Without measurement, the error just based on other measurements and calculated error voltage, current and power factor reference combination, cannot be used as the basis for evaluating the basic error of the device (Wei, J. et al .2014). Assuming the accuracy rating of the current transformers, voltage transformers and meter are 0.2, integrated permissible error of metering device is estimated to be 0.7%. Now the defect of using this estimation method is: current transformers are working in a HV side, and tested in low voltage; combination transformer is working in the state of three-phase, but only tested in single phase (Zhang fuzhou et al. 2014). So the metering device should

be calibrated integrally and uncertainty should be assessed entirely. Verification platform for testing in this paper is shown as Fig.4.
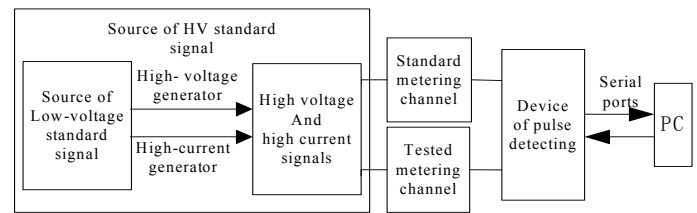

Figure 4. Verification platform diagram

4.3 *Uncertainty Evaluation of Testing Error*

In standard channel system, the accuracy rating of standard voltage transformer and current transformer are class 0.01, and the accuracy rating of standard meter is 0.1. The data of Table 1 is active error which tested under the condition of different power factor and current which is set respectively 100%,50%,20%,10%,5% of the rated current(Ib). When the current is 100% of the rated current(Ib), the data of the reactive error is 0.063 and 0.220 respectively under the condition of the power factor 1.0 and 0.5L.

Table 1. Active error

Ib% cosφ	100% [%]	50% [%]	20% [%]	10% [%]	5% [%]
1.0	0.0143	0.0096	0.0266	0.0419	0.0936
0.8C	0.148	0.1372	0.1307	0.1497	0.2009
0.5L	-0.3276	-0.2884	-0.1784	-0.1394	-0.0316

5 CALCULATION AND ANALYSIS OF CALIBRATION DEVICE UNCERTAINTY

Uncertainty Evaluation methods include Class A, Class B uncertainty, standard uncertainty and expanded uncertainty.

Class A uncertainty U(r01): Uncertainty of each component can be described by the standard deviation S which used a limitednumber of experimental standard deviation S calculated by

Bessel formula: $S = \sqrt{\dfrac{\sum_{i=1}^{n}(x-\bar{x})^2}{n-1}}$.

Table 2. Relative error

Ib% Times	100% [%]	50% [%]	20% [%]	10% [%]	5% [%]
1	-0.344	-0.291	-0.298	-0.289	-0.309
2	-0.329	-0.275	-0.288	-0.277	-0.318
3	-0.313	-0.287	-0.301	-0.294	-0.305
4	-0.329	-0.292	-0.303	-0.279	-0.310

5	-0.329	-0.274	-0.299	-0.288	-0.307
6	-0.329	-0.292	-0.311	-0.298	-0.311
7	-0.313	-0.297	-0.304	-0.302	-0.307
8	-0.317	-0.288	-0.299	-0.279	-0.324
9	-0.329	-0.288	-0.294	-0.292	-0.316
10	-0.344	-0.292	-0.302	-0.288	-0.312
x	-0.328	-0.288	-0.300	-0.289	-0.312
S	-0.0110	-0.0075	-0.0099	-0.0084	-0.0059

As shown in Table 2, the data are error data, average value and experimental standard deviation measured under the condition of $\cos\varphi=0.5L$, rated voltage and current which is set respectively 100%, 50%, 20%, 10%, 5% of the rated current(Ib).

Standard deviation of the synthetic samples:

$$S_P = \sqrt{\frac{\sum_m S^2}{m}} = 0.0087\%$$

Sandard uncertainty:

$$U_{(r01)} = S_P / \sqrt{n} = 0.0028\%$$

Class B uncertainty U(r02): $U_{(r02)} = \sqrt{\sum_{j=1}^{n} (c_j u_j)^2}$

Firstly, the distribution coefficient kj of each component and the sensitivity coefficient cj were obtained. And then Class B Uncertainty were calculated. The uncertainty components of the standard electric energy meter error and voltage and current transformer error are uniformly distributed. And the value of the distribution coefficient kj is $\sqrt{3}$, the value of the sensitivity coefficients cj is 1. The error terms of Class B uncertainty were shown in Table 3:

Table 3. Uncertainty errors of class B

NO.	Source of uncertainty	bj*	kj*	cj*	uj=bj/kj(%)
1	rr*	0.1%	$\sqrt{3}$	1	0.0577
2	fTV*	0.01%	$\sqrt{3}$	1	0.0058
3	fTA*	0.01%	$\sqrt{3}$	1	0.0058

*b_j represents Error limit; k_j represents distribution coefficient; c_j represents sensitivity coefficient r_r represents Standard meter error; f_{TV} represents Standard voltage transformer error; f_{TA}

$$U_{(r02)} = \sqrt{U_1^2 + U_2^2 + U_3^2} = 0.0583\%$$

represents Standard current transformer error.

Standard uncertainty:

Combined standard uncertainty U_C :

$$U_C = \sqrt{U_{(r01)}^2 + U_{(r02)}^2} = 0.0584\%$$

Expanded uncertainty U: $U = KU_C$

Coefficient K is the confidence factor, also known as the inclusion factor. In the standard device of the electric energy meter, the value of K was generally taken 2 and confidence rate (P) was 95% . So the value of Expanded uncertainty is:
U=2 * 0.0584%=0.1168%.

The best estimate of error ($\overline{\varepsilon_r}$) can be calculated by relative error:

$\overline{\varepsilon_r} =$ (0.328%+0.288%+0.300%+0.289%+0.312%) ÷5=0.3034%.

The energy relative error (ε_r) is represented by synthetic error (ε_r): $\varepsilon_r = (0.3034 \pm 0.0584)\%$.

The energy relative error (ε_r) can be indicated by expanded uncertainty: $\varepsilon_r = (0.3034 \pm 0.1168)\%$.

6 SUMMARY

The developed device using three-phase four-wire connection mode has the advantages of energy saving, materials saving and small size and anti-stealing electric energy. The measurement accuracy of the device was improved by using the seamless integration methods and the integrated verification methods. The metering device in the paper was tested by the integrated verification platform of Power supply Company metering chamber in Tangshan City. And measurement results show that energy-saving electronic 10kV metering device meets the design requirements of active power accuracy class: 0.5 and reactive power accuracy class: 2.0.

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