Automatic Sensing and Measuring Technique for Power Metering

Yang Feili*
Zheng Ke, Cheng Yingying, Guo Xun, Zhang Yuting
Marketing Service Center, State Grid Chongqing Electric Power Company, Chongqing, China 401123
Email: yfl1234@cq.sgcc.com.cn

Abstract: The growing demand for electricity has set higher requirements for the sensing and measurement system of smart distribution network. Therefore, a new state monitoring technology for power metering is proposed based on automatic sensing and measuring technique to improve power metering. Firstly, the influence of various physical conditions and natural environment is analyzed on power metering equipment. Then, internal detection is used to detect the operation state of the equipment. Secondly, DC (direct current) magnetic bias is detected by self-excited fluxgate. Furthermore, the working condition of the secondary circuit is tested by the secondary circuit current measurement method. Finally, the narrowband Internet of Things technology is adopted to conduct data communication with the terminal platform. The research results show that compared with the traditional online operation state detection and management system of smart distribution network, the innovative state monitoring technology can additionally monitor the temperature, DC magnetic bias and secondary circuit of the distribution network. This shows that improved monitoring technology based on automatic sensing and measuring technique can monitor the important state of the distribution network to reduce the risks caused by the inability to detect potential problems and improve the performance of the distribution network. The optimized state metering technology makes an example for the improvement of automatic sensing and measuring technique of the metering equipment of smart distribution network nationwide.

1. Introduction
In the current society, electric power system has become the core part of people's production and life, driving the development and progress of human civilization. And power metering is an important part of the whole grid system, which is related to the social development and scientific and technological progress of mankind in future [1]. However, due to the traditional manual inspection for power grid equipment maintenance, this method is easy to cause casualties and damage to power grid equipment, and the efficiency is low. Depending on the manual method and experience is gradually unable to meet the future requirements for lean operation and maintenance of smart grid. Therefore, it is necessary to find a new technical means to replace manual operation and maintenance of power equipment.

DC magnetic bias is excited by the saturation magnetization characteristic of the transformer core. The DC flowing from the winding is converted into part of the transformer excitation current. DC biases the transformer core and changes the transformer's operating point. The core of the working field of the original magnetization curve moves to the magnetic saturation field. Thus the total excitation current changes to a peak wave which in turn raises the vibration of the transformer [2].
This paper first introduces the physical state such as temperature, electromagnetic state such as DC magnetic bias and secondary circuit fault, and then analyzes the influence of these factors on power metering, and then designs the power metering method to avoid these influences, and puts forward a monitoring scheme detecting the equipment’s operating state combined with the Internet of Things. Finally, the principle of the treatment scheme detecting these adverse effects is verified by practical application, which provides theoretical guidance for subsequent theoretical research and improvement.

2. Principle of improvement of automatic sensing and measuring technique based on power metering

2.1 Influencing factors of operating state

(1) Temperature

Temperature can greatly affect the operating state of power metering equipment, and its stability and accuracy, especially precision metering equipment. Temperature can affect test accuracy of voltage and current sensors. The current equipment mainly uses the principle of magnetic potential balance to measure the state of the power grid [3]. The following formula 1 is the expression of the operating principle of the equipment.

\[
E = -n \frac{d\phi}{dt} = -\mu_0 S \frac{N}{l} \frac{di}{dt}
\]

\(\phi\) in the upper formula is the coil main flux of the mutual inductor. \(E\) indicates the induced electromotive force of the secondary winding. \(\mu_0\) indicates permeability, \(S\) the sectional area of the coil, and \(N\) the number of turns density of the coil. The formula for coil turns density is as follows:

\[
n = \frac{N}{l}
\]

In formula 2 above, \(N\) indicates the number of turns of the coil, and \(l\) indicates the length of the coil.

The mutual inductor \(E\), the sectional area of the coil \(S\) and turns density \(n\) has a certain linear relationship. The change of the surrounding temperature will cause the volume and shape of the coil to change, and the \(n\) and \(S\) to change. Therefore, the output of the mutual inductor becomes inaccurate and unstable, resulting in errors in the output results.

(2) DC magnetic bias phenomenon

The phenomenon of DC magnetic bias refers to that the DC magnetic flux will be coupled into the main magnetic flux of the mutual inductor, and the AC (alternating current) and DC magnetic flux will be superimposed on the main magnetic flux, so that the saturation of the half-wave core of the mutual inductor in the direction of DC magnetic flux increases, and the sum saturation in the opposite direction decreases, causing the waveform of the positive and negative half waves of the excitation current becoming unsymmetrical. When the additional DC is 2% greater than the mutual inductor rating, the accuracy of the metering equipment will be greatly affected, resulting in an overall negative offset of the coincidence error, thus making the measured data smaller [4].

(3) Secondary circuit

The main power metering module of power grid is composed of mutual inductor, secondary circuit and electric energy meter. Figure 1 below is a schematic of a simple secondary circuit.
The main influencing factors of secondary circuit are aging connecting pieces, gaps of device, poor contact, etc., which will lead to open circuit of mutual inductor. When this happens, not only the accuracy and stability of metering equipment may be affected, but also safety accidents such as fire will be caused in serious cases [5].

2.2 Operating state monitoring

Figure 2 below is a schematic diagram of the monitoring system structure of grid metering equipment.

![Diagram](image.png)

**Figure 1 Circuit diagram for simple secondary circuit**

The operational control core of the monitoring system was MCU, which detected temperature, DC magnetic bias and secondary circuit state respectively, and used narrowband Internet of Things for data transmission.

1) Principle of temperature monitoring

The temperature sensor was used to measure the temperature. The main temperature sensor was Pt100 type, which can be used for temperature measurement under extreme high and low temperatures. Its stability was good, linearity high, and feedback timely. The main principle is that temperature affects the resistance of the sensor [6]. The temperature measuring bridge is shown in Figure 3 below.

![Diagram](image.png)

**Figure 2 Schematic Diagram of Monitoring System Structure of Grid Metering Equipment**

...
Figure 3 Temperature measuring bridge

The $U_{oo}$ in the figure represents the power supply of the bridge, and assuming $R_1=R_2=R$, $U_0$ represents the output voltage, the following formula 3 is the calculation formula of $U_0$. Formula 4 is the resistance value calculation formula for $R_T$.

\[
U_0 = \left( \frac{R}{R+R_3} - \frac{R}{R+R_T} \right) U_{oo}
\]  
(3)

\[
R_T = \frac{R_3 U_{oo} + (R + R_3) U_0}{R U_{oo} - (R + R_3) R}
\]  
(4)

Under the normal temperature of 0-100°C, the resistance value change is linearly proportional to the temperature change, and the relation of quadratic function appears in the extreme temperature -40-0°C. Formula 5 below is the relation of normal temperature and formula 6 is the relation of extreme temperature.

\[
R_T = 100 + 0.385T
\]  
(5)

\[
R_T = -6 \times 10^{-5} T^2 + 0.396T + 100
\]  
(6)

(2) Principle of DC magnetic bias measurement

Figure 4 below is a detection tool fluxgate circuit.
The magnetic core portion of the fluxgate coil above used a high flux-rate material, with its excitation winding represented as W1 and both together formed a nonlinear inductance to sense the magnetic field variation within the magnetic core. When the magnetic field changed, the inductance changed [7].

(3) Principle of secondary circuit test

The secondary circuit is the electrical circuit for monitoring, controlling, adjusting and protecting the primary equipment, which is composed of the secondary equipment connected to each other. It is used to control, protect, adjust, measure and monitor the operating conditions of each parameter and each element in the primary circuit. The circuits used to monitor the electrical connections made by measuring meters, control operation signals, relay protection and automatic devices are all called secondary circuits or called secondary wiring. If leakage or theft occurs, the terminal of the meter will be short-circuited and the current will be reduced. Figure 5 below is the equivalent circuit diagram of the secondary circuit.

U2 in the figure above represents the input voltage, the number of coil turns at the input end N1, the current $i_1$, the secondary circuit as the output end, the number of coil turns N2, the induced current $i_2$,
and the induced voltage $U_2$. It is represented by the following formulas 7 and 8.

\[ i_L = i_m + i_{1L} \quad (7) \]
\[ i_{1L} = \frac{-N_2}{N_1} i_2 \quad (8) \]

$i_m$ in the formula above indicates the required excitation current. $i_{1L}$ represents the partial load current of $i_1$, to compensate for various effects on secondary circuit transformers. $i_m$ generally does not change with the use of appliances and $i_1$ is related to the size of $i_2$. If there is a problem with the mutual inductor, $i_2$ becomes 0, $i_1$ is equal to $i_m$, and $i_{1L}$ is minimum. So if the input voltage changes, there is a problem with the mutual inductor secondary circuit.

2.3 State information transmission

(1) State information transmission network

Narrow Band Internet of Things network (NB-IoT) is used to transmit power metering data. Cellular network is an architecture mode of mobile communication hardware. It is called cellular network because the communication distribution between its network base stations presents hexagonal shape. The main modules of NB-IoT are: monitoring terminal, NB-IoT base station, core network, cloud platform, power supply facilities, etc. Figure 6 below shows the power metering Narrow Band Internet of Things facility [8].

Figure 6 Power metering Narrow Band Internet of Things facility

2.4 Experimental configuration

The temperature measurement experiment was simulated with the incubator with the accuracy of 0.1°C. The temperature was measured every 10 degrees centigrade between -20 and -70 degrees centigrade, and each temperature was measured three times. DC detection test used its own fluxgate sensor for testing, using alternating current of different current values. In the case of the same primary side current $I_1$, the secondary circuit currents $I_{1L}$ and $I_2$ under normal and abnormal conditions were detected.

3. Empirical Analysis of Automatic Sensing and Measuring Technique

3.1 Temperature experiment

The test results are shown in figure 7 below.
Since the fluctuation of the three experimental data in the figure above was very small, and the difference with the set temperature each time was very small, the vast majority of the temperature deviation was within 0.1°C, which may be related to the error of the measurement together. Therefore, the deviation of the actual data was very small, so it was completely negligible. Therefore, the temperature measurement technology was considered effective and the accuracy rate was high.

3.2 DC test
Figure 8 below is a diagram showing the variation relationship between voltage U and DC I of sampling resistance at different AC.
It can be seen from the above figure that the sensitivity was not good when the current \( I \) was small, and its change was linear when the current \( I \) was between 2-8 A, and the sensitivity change rate decreased when the current \( I \) exceeded 8 A. In addition, when the AC current ampere increased, the curve was offset, resulting in the minute difference distortion between the feedback current and the primary AC. Moreover, the primary AC current cannot be completely eliminated, so it can have an impact on the DC detection.

3.3 Secondary circuit measurement

The measurement results of secondary circuit are shown in Table 1 below.

| Status   | I1L | I2  |
|----------|-----|-----|
| Normal   | 1.31| 1.31|
| Un normal| 1.29| 0.08|

As shown in the table above, the experimental measurement was carried out when the primary side current \( I_1 = 0 \) A, a square wave model of 20 kHz being applied to the circuit. When various faults occurred in the secondary circuit, the passing current \( I_2 \) of the sampling resistance was far from the value of the current \( I_{1L} \) of the other circuit. Therefore, the measuring technique can be judged to be correct and the experiment was successful.

4. Conclusion

In this paper, an internal detection method is proposed to detect the operation state of the electric meter, and the influence of various physical conditions and natural environment on the power metering equipment is analyzed. The DC magnetic bias was detected by the self-excited fluxgate, and the operation state of the secondary circuit was analyzed by the secondary circuit current measurement method, and finally the data communication with the terminal platform was carried out by the narrow-band Internet of Things technology. It is shown that the new automatic sensing and measuring technique for power metering proposed in this paper can automatically monitor and measure the power metering equipment to detect the potential danger, reduce the corresponding danger and improve the transmission network performance.

Although this study basically achieved the originally expected research goal and obtained some valuable research conclusions, there are still many deficiencies in the research work, and the conclusions may be limited by two factors: (1) the detection means of power metering equipment is limited today. (2) Large amounts of actual measurement data could not be obtained to facilitate practical comparison with numerical simulation studies. That also points the way for our future research. In the future, we will focus mainly on the above two aspects: (1) further searching for effective power metering equipment detection means; (2) further contact with more power industries to learn more about the actual situation and get lots of measured data.

About the author

Yang Feili, Male, 1987, Han, master's degree, senior engineer, marketing service center of State Grid Chongqing Electric Power Company, main research direction: Research on sensing and measurement related technology, engaged in research on new technology of measurement equipment. 18680887087@163.com

Zheng Ke, Male, 1975, master's degree, senior engineer, marketing service center of State Grid Chongqing Electric Power Company, main research direction: reliability research of electric energy meter, engaged in new technology research of metering equipment.

Cheng Yingying, Female, 1975, master's degree, senior engineer, marketing service center of State Grid Chongqing Electric Power Company, main research direction: Research on new technology of measurement management and measurement equipment.
Guo Xun, Male, 1983, bachelor degree, assistant engineer, marketing service center of State Grid Chongqing Electric Power Company, main research direction: engaged in the detection and research of electric energy metering equipment

Zhang Yuting, Female, 1987, bachelor, assistant engineer, marketing service center of Chongqing Electric Power Company of State Grid, mainly research direction: Research on related technology of sensing and measurement, engaged in new technology research of measuring equipment

References

[1] Koskela J, Rautiainen A, Kallioharju K, et al. Effect of the Electricity Metering Interval on the Profitability of Domestic Grid - Connected PV Systems and BESSs [J]. International Review of Electrical Engineering, 2020, 15 (2). pp. 164-165.

[2] Feng Jun. Suppression of DC Magnetic Bias in Transformers under Complex Operating Conditions [J]. Electrical applications, 2018, 37 (2). pp. 100-105.

[3] Tima S, Vuillermet Y, Friedrich A, et al. Angle Sensing Using Differential Magnetic Measurement And A Back Bias Magnet [J]. Journal of Japan Foundry Engineering Society, 2018, 9 (4). pp. 71-76.

[4] Sun Bing, Yu Yongjun, Qi Xiaoxiao, et al. Key Site Assessment of DC Magnetic Bias Distribution Based On Network Connectivity Analysis [J]. High voltage technology, 2020, 46 (3). pp.231-240.

[5] Jiang Peng, Zhang Ping. Factors Affecting Thermal Response Time of Pt100 Temperature Sensor [J]. Science and Technology and Innovation, 2018, 1 (2). pp. 49-50.

[6] Muhlethaler J, Biela J, Kolar J W, et al. Core Losses Under the DC Bias Condition Based on Steinmetz Parameters [J]. IEEE Trans Power Electronics, 2017, 27 (2). pp. 2430-2437.

[7] Yao Qinghua, Dong Linhui. Research and Analysis of Secondary Circuit Delay Detection Method in Modern Intelligent Substation [J]. Power system protection and control, 2018, 46 (23). pp.188-192.

[8] Hong Jiazhen. Low-rate NB-IoT communication technology status and development trend [J]. Electronic World, 2018, 544 (10). pp. 44-45.