Study on Anti-electricity Theft Based on Electricity Comparative Method

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Abstract Electricity stealing not only makes great economic losses, but also threatens the order and security of power supply seriously. This paper starts from electricity theft, and puts forward an anti-electricity theft design based on electricity comparative method. According to programming realization and simulation test by MATLAB, we verify the feasibility and effectiveness of the design. The anti-electricity theft design can be applied to demotic users and middle/small-sized enterprises to reduce loss from electricity theft.

Keywords: *anti-electricity theft, electricity comparative method, electric quantity gauge*

1. Introduction

Power is an important energy for human's survival and development, so good order of power supply is significant for power system operation and development. However, since the beginning of opening-up reform, in particular the establishment of economy of manufacturing, electricity stealing has become more prominent. According to statistics, due to electricity-stealing, Chinese annual economic loss is up to 20 billion Yuan [1]. With the development of science and technology, means of electricity-stealing becomes more sophisticated, and is of high technology content and hidden function, which leads to enormous difficulties to deal with various acts of electricity stealing. Electricity stealing acts will not only bring economic losses to the state and the power sector, interfering with normal supply order, but also cause fire, destroy power supply units and cause widespread power outage, threatening power grids and public security [2,3]. Therefore, it is imperative to crack down electricity stealing activities.

Although the means of electricity stealing is diverse, their basic principle is changing the metering of electric energy [4,5], which can change the metering of voltage, current and power factor. As long as any one of these is changed, it can make power meter turn slowly, stop or even reverse. Changing the structure of electric meter itself can also make a slow turn so as to achieve the goal of stealing electricity. In order to prevent electricity-stealing, power enterprise has taken variety of measures, and has made some effectiveness. But problem still exists , which mainly includes [6,7]: (1) using dedicated measuring cabinet and sealing, but general seal is easy to copy and recover after opening; (2) using anti-stolen electric power meter, it's mainly for single-phase meters .But its anti-electricity theft function is not comprehensive; (3) using high installation of power meter, which installs power meter several meters high , but it also cause troubles when reading and replacing meter; (4) using high voltage power meter, which makes theft hard to get access, but also causes inconvenience to the daily maintenance for staff.

To sum up, although there are a variety of anti-electricity theft measures, shortcomings and inconvenience, such as great limitations and high cost are still existed due to an increasingly specialized, high-tech, and hidden electricity-stealing behavior. Therefore, in view of recent various hidden electricity-stealing ways, this paper puts forward an anti-electricity theft design based on electricity comparative method. First of all, this paper introduces electricity comparative method .Then this paper makes specific anti-electricity theft policy based on the electricity comparative method .Finally, based on instance analysis, the paper verifies the rationality and effectiveness of the method so as to provide a reference for the design and application of anti-electricity theft.

2. The Basic Principle of Electricity Comparative Method

Electricity comparative method is a common way to test single-phase meter's error. It is usually used to determine whether the relative error of detection meter is qualified. Its power calculation formula is as follow:

$$\begin{cases} u = \sqrt{2}U \sin wt \\ i = \sqrt{2}I \sin(wt - \theta) \end{cases} \quad (1)$$

In the formula: U is effective value of AC voltage; I is current valid value; θ is power factor angle.

The measured power is:

$$p = ui = 2UI \sin wt \cdot \sin(wt - \theta)$$
$$= UI \cos \theta \cdot (1 - \cos 2wt) - UI \sin \theta \sin 2wt \qquad (2)$$

Its average is:

$$p = UI \cos \theta \qquad (3)$$

We can get active energy during time T:

$$W = T \cdot UI \cos \theta \qquad (4)$$

Electricity comparative method is typically carried out in the following ways about single-phase active power meter.

(1)Watt second method

Under rated power, we can use standard meter to measure the time which is taken by tested meter to accumulate energy, and constant power is multiplied to get measured energy values. According to comparing with measured energy valued and power values accumulated by testing meter we can determine the relative error. Error is calculated as follows:

$$\gamma = \frac{W - P \cdot t}{P \cdot t} \cdot 100\% + \gamma_w \qquad (5)$$

In the formula: γ_w is standard meter or measuring device's inherent system error (%). When there is no need to correct, $\gamma_w = 0$; P is a constant power value(W); t is standard tags measured time(s); W is the power value measured by tested meter(J).

(2)The standard method

Within a particular period of time t(s), we write down cumulative energy tested by standard meter and tested meter and the relative error of the meter can be calculated by the following formula:

$$\gamma = \frac{W' - W}{W} \cdot 100\% + \gamma_0 \qquad (6)$$

In the formula: γ_0 is inherent system error of standard meter (%), When there is no need to correct, $\gamma_0 = 0$; W' is the power value displayed by tested meter(J); W is the energy value displayed by standard meter (J).

The comparative quantity of the two methods above are energy values, but one way uses time as constant value , another uses power as constant value. Their purpose is to calculate power value which is suitable for comparison. Therefore, this paper puts forward an anti-electricity theft design based on electricity comparative method.

3. Study on the Anti-electricity Theft Method Based on Electricity Comparative Method

According to the electricity comparative method, in order to identify electricity-stealing behavior, we need to compare the benchmark measurement data with the measurement data of electric quantity. In this paper, the data of relay protection equipment of line protection circuit is used to access to voltage, current and power factor directly, or we install the power factor meter between the protection circuit and the measurement circuit to collect the voltage, current and power factor, etc.

directly. We calculate the standard electric quantity for a period of time and compare with the electric quantity of the measuring circuit, which can identify electricity-stealing behavior effectively.

Aiming at possible error in measurement, this paper uses electric quantity instead of time as standard, and sets the basic measurement threshold of electric quantity. We compare electric quantity when electric increment measured from protecting side reach to threshold. Using electricity as the threshold for measurement, it can not only control the error which is generated by the difference between electricity consumption in peak and valley time with a group of users, but also avoid tedious time steps and enhance the practicability of the method. Anti-electricity theft method based on electricity comparative method is shown in Figure 1.
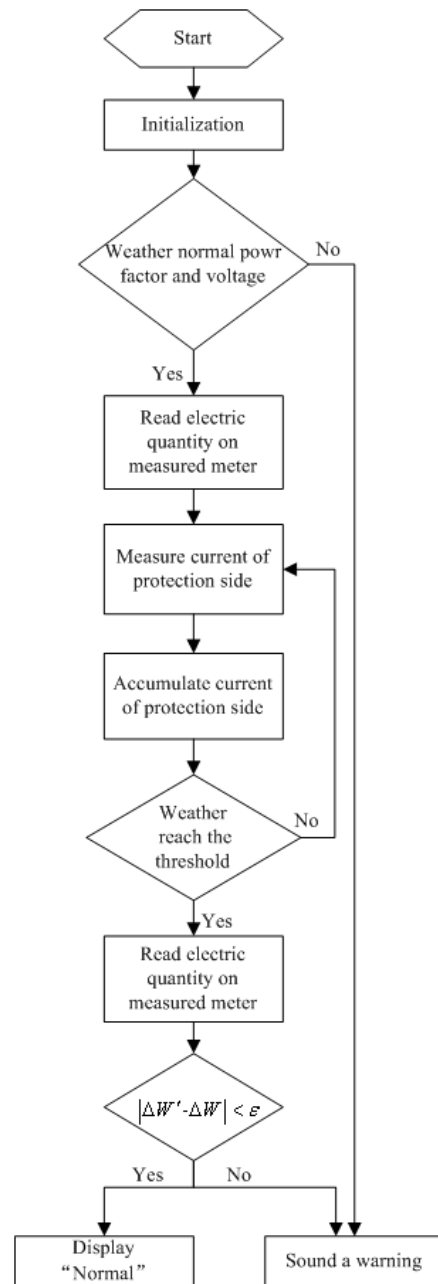

Figure 1. Anti-electricity theft method based on electricity comparative method

As shown in Figure 1. First, we should set basic measured threshold value of electric quantity ΔW as the

threshold for electricity comparative method; second, we should check the operation condition of circuit, including voltage and power factor; third, we record the electric quantity of users' energy meter and calculate the sum of electric increment $\sum W$ on protection side at the same time. When $\sum W = \Delta W$, we record the electrical energy meter of the users again. The difference value between the two records is electric quantity during the period time.

Finally, we compare the power consumption of electric meter measurement on user side ($\Delta W'$) with ΔW. If $|\Delta W' - \Delta W| < \varepsilon$, The electricity-stealing could happen and the method issues warning.

Among them, the core of this method is the part of measurement and comparison, it mainly includes:

(1) Voltage comparison. During the stable operation of power system, voltage fluctuation is small, so it can be regarded as a constant value when the electric quantity is calculated. If the voltage Vp measured on protection side is normal at this time, it can be used as the input value of the voltage to calculate power. When the voltage of the protection side is less than the allowable minimum value, undervoltage warning is issued.

(2) Power factor comparison. Power system is required to maintain a high level when power system is stable operation. Therefore, it can be considered as a constant value when calculating the electric quantity. If the $\cos\varphi$ measured on protection side meet the requirement, it can be used in electric quantity calculating. When the power factor of the protection side is less than the minimum allowable value, warning is issued.

(3) Electric quantity comparison. The electric quantity comparison is the core of the electricity comparative method, and the comparison method used in this paper is as follows:

$$\frac{W_p - W}{W_p} < B \qquad (7)$$

In the formula:

① $W_p = \sum W = \sum \Delta t V_p I_p \cos\varphi$ is electric quantity measured by protection side, Δt is current sampling period, V_P is protecting side voltage, I_p is real-time measured current, $\cos\varphi$ is the power factor of protection side. Protection side voltage V_P and the power factor $\cos\varphi$ are constant value, and because the user side load will change from time to time, which means I_P is real-time change and needs real-time measurement.

②W is electric quantity on measuring side. $W = W_2 - W_1$, W_1, W_2 are first and second electric quantity measured by measuring side respectively. W_1, W_2 are needed to distinguish peak and valley time to prevent from misjudgment. If the first is peak time, the second is valley time, the measurement is invalid;

③B is electric quantity allowable overproof ratio, when electric quantity overproof ratio is less than B, user is judged to be normal; when the electric quantity overproof ratio greater than B, user is judged to be suspected electricity stealing. An electricity stealing warning is issued and the method increases the frequency of testing to determine the fraudulent use of electricity, the paper set $B = 0.05$.

④The electric quantity threshold $\Delta W = W_0$, W_0 is setting electric quantity. Its value is determined by the user

calculated load. According to the current measurement interval, the total measurement time is not less than 5 minutes. Under normal circumstances, in the user's daily load curve, peak load is generally no more than the computational load of 2 times [12]. In the supreme power condition, we need to ensure adequate measurement time, so the conversion ration from calculated load to setting electric quantity is 0.2. Considering the present electric energy meter accuracy is 0.01kWh, and the error of this method should not exceed 1%, therefore, the minimum electric quantity of the set is not less than 1.

In conclusion, the set value of electric quantity is:

$$W_0 = 0.2 P_{ca} + 1 \qquad (8)$$

In the formula: P_{ca} is calculated load of user. It determines the required total electric quantity of different users in a certain period when comparing electric quantity.

4. Test and Analysis

According to the proposed anti-electricity theft method, this paper establishes a simulation environment to verify the method, the dynamic input current of simulation system is as follows:

$$I' = 2 + 1.5\sin(0.003t + \varphi_1) + 0.1\sin(20t + \varphi_2) \qquad (9)$$

In the formula: The φ_1 and φ_2 are random phases, range is from 0 to 2π; 2 is current reference value; first sine function is used to simulate the change of current in different time periods; the second sine is used to simulate current fluctuations.

Test uses the control variate method to test each function. During normal operation, the voltage is 220V, power factor is 0.9. In order to shorten the running time of the program to improve the efficiency of the test, this paper does not consider the matching of calculated load and actual power, the user calculated load is set to 0.4kW. This paper uses M file in MATLAB to realize the method.

Simulation test scheme is as follows:

(1) Turn down voltage/power factor, run program and observe the output of the voltage when voltage is too low.

①Under voltage condition
Input voltage is set to 190V, display is:

Current voltage value (V):190.00
Current power factor: 0.900
Average current (A):0.640
Peak current (A):0.727
Calculating electric quantity (KWh):1.09
Measuring electric quantity (KWh):1.08
Time used (s): 10
Electric quantity overproof ratio: 0.014
Voltage is too low!

②Low power factor condition
Input power factor is set to 0.75, display is:

Current voltage value (V):220.00
Current power factor: 0.750
Average current (A):0.899
Peak current (A):0.987
Calculating electric quantity (KWh):1.11
Measuring electric quantity (KWh):1.09
Time used (s): 7
Electric quantity overproof ratio: 0.018
Power factor is too low!

Figure 2. The simulation output of scheme (1)

It can be seen from Figure 2 that the method can detect effectively and issue a low voltage/low power factor warning when the undervoltage or low power factor condition happens.

(2) Simulate normal/electricity-stealing condition, run the program and observe the output.

①Normal condition

The input voltage is 220V, power factor is 0.9, and the program is run 5 times, and the output is as follows:

Table 1. Normal condition output display

Measurement times	1	2	3	4	5
Voltage value (V)	220.00				
Power factor	0.900				
Average current (A)	3.078	0.899	1.645	0.787	0.583
Peak current (A)	3.134	0.987	1.700	0.882	0.683
Calculating electric quantity (KWh)	1.22	1.25	1.30	1.09	1.15
Measuring electric quantity (KWh)	1.22	1.22	1.28	1.09	1.15
Time used (s)	2	7	4	7	10
Super power ratio	0.001	0.018	0.021	-0.003	0.003
Result	Normal electric quantity.				

②Simulation of electricity-stealing

When electricity-stealing happen, measuring electric quantity reduce. We assume that the electric quantity loss percentage is 30%, run the program. The results are as follows:

Table 2. The output of electricity stealing simulation

Measurement times	1	2	3	4	5
Voltage value (V)	220.00				
Power factor	0.900				
Average current (A)	1.645	3.287	0.583	2.739	0.767
Peak current (A)	1.700	3.339	0.683	2.798	0.851
Calculating electric quantity (KWh)	1.30	1.30	1.15	1.63	1.22
Measuring electric quantity (KWh)	0.89	0.90	0.80	1.12	0.83
Time used (s)	4	2	10	3	8
Super power ratio	0.315	0.307	0.302	0.309	0.319
Result	Electric quantity abnormity!				

In order to verify the results, the simulation outputs under normal condition and electricity-stealing condition are as follows:

①Normal condition:

Current voltage value (V):220.00
Current power factor: 0.900
Average current (A):1.418
Peak current (A):3.264
Calculating electric quantity (KWh):286.05
Measuring electric quantity (KWh):286.01
Time used (s): 1019
Super power ratio: 0.002
      Normal electric quantity

②Electricity-stealing condition:

Current voltage value (V):220.00
Current power factor: 0.900
Average current (A):2.103
Peak current (A):3.429
Calculating electric quantity (KWh):286.46
Measuring electric quantity (KWh):200.52
Time used (s): 688
Super power ratio: 0.300
    Electric quantity abnormity!

Figure 3. The output under normal and electricity stealing condition

From Figure 3, we can see, the method can make effective judgment on electricity stealing behavior and make alarm to the possible stealing behavior.

To sum up, we know that: the anti-electricity theft method can make a reasonable judgment on electricity stealing behavior, and can give alarm when the system runs in abnormal way, which increase the stability of power system operation and catch the electricity stealing behavior timely. The test result verifies the feasibility and effectiveness of anti-electricity theft method in this paper.

5. Conclusion

In this paper, anti-electricity theft based on electricity comparative method can identify the electricity stealing behavior effectively and give the alarm to ensure the stability and efficiency of power system, also the electric stealing quantity can be estimated by the output of the method. The method is concise, economic and flexible, it has good application prospect in anti-electricity theft of community, self-employment venture and middle/small-sized enterprise. At the same time, although the method is designed for single-phase electric energy meter, the same design thought with phase sequence detection can also be used in three-phase network anti-electricity theft system. However, because this method does not consider the line

loss and other problems, it is not suitable for high voltage network and large power consuming unit.

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