Evaluation of Smart Meters Based on Fault Excitation

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Abstract: Based on the research of fault incentive technology of smart meters, the characteristic quantities which cause the fault of smart meters were explored, the fault incentive test of smart meters were developed and the state evaluation technology of smart meters under multi-factor fault incentive were studied in this paper. Through the research in this paper, it will help to eliminate the potential quality hazards, provide technical support for the promotion and application, improve relevant standards of smart meters, enhance the quality control capability of power companies for smart meters, bring better power services to power users and fully support the construction of industrial Internet and ubiquitous power Internet of things.

1. INTRODUCTION

As the most basic metering equipment for smart grid, smart meters should not only ensure accurate metering in use, but also can collect complete information for acquisition system. At the same time, smart meters are the energy entrance of enterprises and families as the end of smart grid marketing business, power consumption information and energy distribution, which can also sense the change of load. Under the current situation of construction of the ubiquitous Internet of Things, through the integration of new technologies such as the Internet of Things (IOT), big data and other emerging technologies, smart meters can be used to expand new businesses and help construct the energy Internet as well as ensure safe and economic operation of the grid. While if there are faults in smart meters during operation, that will lead to inaccurate measurement, functional failure and even bring some potential safety hazards. Therefore, it is necessary to evaluate the status of smart meters after fault excitation. Through the research of fault incentive technology of smart meters, the characteristic quantities combination causing the fault is explored, fault incentive test is developed and the state evaluation technology of smart meters under multi-factor fault incentive is studied in this paper, which are helpful for early detection of potential quality hazards of smart meters, bring better electricity service, and fully support the construction of ubiquitous power Internet of things.

Supported by the faults of smart meters on the spot, six typical faults, including metering fault, display fault, control fault, clock battery fault, power unit fault and communication fault are chose as the main analysis objects. By exploring the causes of various faults, the main characteristic parameters causing the fault, such as electrical stress, temperature, humidity and sunshine radiation are combined to excite faults. Harmonic test, load switch tolerance test, sunshine radiation test, voltage response test and strengthened aging test are selected to carry out single stress or combined stress on the samples of smart meter respectively AHP and grey relational degree methods are applied to evaluate the state of smart meters after incentive[1]. Due to the limitation of the length of the article, this paper will focus on strengthening aging test operated under high temperature, high humidity and over-voltage excitation conditions, which is taking electrical stress, temperature and humidity these typical excitation into consideration. Through the corresponding performance indicators after test, it can be used as the basis for comprehensive state evaluation of smart meters.
2. STRENGTHENED AGING TEST OF SMART METERS

Forty-two single-phase smart meters from A to G totally seven manufacturers with an equal distribution were selected as samples. Before the fault excitation experiment, the LCD screen and the clock battery are checked and the basic error test is carried out with rated voltage and current \((U_n = 220V, I_b = 5A)\) at room temperature and humidity. The performance of each meter is normal and the error range is within -0.1% to 0.2%, which is far less than 2% of the meter error limit. In the begin of the test, samples are put into the temperature and normal humidity test box at 85°C, 85% RH. And these meters are connected in parallel charged with voltage of 1.2 \(U_n\). Every 100 hours rest in the test box, samples will be placed at room temperature and normal humidity to check the performance, the experiment lasts 500 hours totally\(^2\).

3. EVALUATION INDEX OF SMART METERS

3.1 Selection of evaluation data

In order to evaluate the state of smart meters after excitation, the subject combines the different faults of smart meters after excitation test with the consideration of the importance of the performance indicators of the meter by the relevant experts. The basic errors, start-up, latency, LCD screen, power consumption sudden change, clock battery, load switches, communications and so on are considered. These test data and results are used as the state evaluation index of smart meters after fault excitation. The features selected in this subject are shown in Table 1 below. The selection of feature quantities is not limited to the items listed in the table. Specific evaluation indexes can be supplemented and adjusted according to the fault excitation test.

Among the performance indicators listed, the basic error value is a quantitative index and the data are obtained at different load under different power factors. In order to conduct a unified comprehensive evaluation, this paper uses the principal component analysis method to reduce the dimension of multiple error data \(^{[5-7]}\).

| Table 1. Evaluation index of power meter quality under fault excitation |
|---------------------------------------------------------------|
| metering | LCD screen | Clock battery | Change of power | Load switch | Communication |
|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| Basic error, starting, latency | Display normal or not | Dead or not | Change hard or not | Rejection misoperation | Dead or not |

3.2 Obtaining indicators weight based on Analytic Hierarchy Process

As the quantitative data obtained from the basic error test and the qualitative results given by LCD screen, clock battery and electric power change, the analytic hierarchy process (AHP) which combines the qualitative and quantitative indicators is selected to give the weight of indicators. Taking a layer A as an example, the judgment matrix is \(A = (a_{ij})_{m\times n}\) where \(a_{ij}\) denotes the relative importance of element \(i\) and element \(j\) to the target, \(a_{ij} > 0, a_{ii} = 1, a_{ji} = 1/a_{ij}\). The calculation steps of the analytic hierarchy process are listed below.

1. The elements of judgment matrix \(A\) are normalized by columns, and \(B = (b_{ij})_{m\times n}\) is obtained.

\[
b_{ij} = \frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}}, (i, j = 1, 2, ..., n)
\]

2. The elements in matrix \(B\) are added by rows to get the vector 

\[
c_i = \sum_{j=1}^{n} b_{ij}, (i, j = 1, 2, ..., n)
\]

3. Normalizing vector \(C\) to get eigenvectors 

\[
w = \left(w_1, w_2, \ldots, w_n\right)^T, \text{ where}
\]
\[ w_i = \frac{c_i}{\sum_{i=1}^{n} c_i}, (i = 1,2,\ldots,n) \]  
(3)

Finding maximum eigenroot \[ \lambda_{\text{max}} \]

\[ \lambda_{\text{max}} = \frac{1}{n} \sum_{i=1}^{n} (\mathbf{A} \mathbf{w}_i) \]  
(4)

3.3 State evaluation of smart meters based on grey correlation degree method

In the actual use of grey relational analysis, the data often do not have the same measurement conditions. In order to compare better, the data must be standardized before the grey correlation degree analysis. Assuming that there are \( n \) influencing factors and \( m \) sequences are involved in the comparison, the standardization formula is as follows:

\[ x_i(k) = \frac{x_i(k) - \min x_i(k)}{\max x_i(k) - \min x_i(k)} \]  
(5)

The grey correlation model used to evaluate the performance of smart meters is as follows:

\[ \mathbf{R} = \mathbf{E} \times \mathbf{W} \]  
(6)

\( \mathbf{R} \) is the comprehensive evaluation result vector of the evaluated object; \( \mathbf{W} \) is the weight vector of the evaluation index; \( \mathbf{E} \) is the evaluation matrix of each index. Suppose there are \( m \) evaluation objects and \( n \) evaluation indexes. \( \mathbf{R} = (r_{01}, r_{02}, \ldots, r_{0n}) \), \( \mathbf{W} = (w_1, w_2, \ldots, w_n) \) and \( \mathbf{E} = \begin{bmatrix} \xi_{n0}(1) & \xi_{n0}(2) & \cdots & \xi_{n0}(m) \\ \xi_{10}(1) & \xi_{10}(2) & \cdots & \xi_{10}(m) \\ \xi_{20}(1) & \xi_{20}(2) & \cdots & \xi_{20}(m) \\ \vdots & \vdots & \ddots & \vdots \\ \xi_{n0}(1) & \xi_{n0}(2) & \cdots & \xi_{n0}(m) \end{bmatrix} \), \( \xi_{ij}(j) \) is the correlation coefficient between the \( j \)th evaluation index and the reference index of the \( i \)th evaluation object, \( \rho \in (0,1) \). \( x_i = (x_{i0}, x_{i1}, \ldots, x_{in}) \) is reference matrix. According to the value of the correlation degree obtained, the evaluation samples can be sorted. The correlation degree is between 0 and 1, the bigger correlation degree is, the better performance of the samples is.

\[ \xi_{ij}(k) = \frac{\Delta_{\text{min}} + \rho \Delta_{\text{max}}}{\Delta_{(i,j)} + \rho \Delta_{\text{max}}} \]  
(7)

\[ \Delta_{\text{max}} = \max \max_{j} |x_i(k) - x_j(k)| \]  
(8)

\[ \Delta_{\text{min}} = \min \min_{j} |x_i(k) - x_j(k)| \]  
(9)

4. EXAMPLES OF EVALUATION

In this section, total 12 samples from 4 typical smart meter manufacturers are selected to carry out strengthened aging test.

4.1 Basic performance of samples

Due to the influence of temperature, humidity and overvoltage, the error of metering unit are over-tolerance or can’t accumulate power, LCD screen fades or misses parts of display contents and clock battery unit failures. However, there is no abrupt change of electric quantity, abnormal action of load switch or abnormal communication, so these performances are normal.

4.2 State evaluation of smart meters

The performance of samples are listed in Table 2. No. G-7 meter can’t be measured so there is no error data. Considering that actual 2.0 single-phase meters requires 1% error limit in practice, and the value of 1 meets the data normalization processing requirements, so the indicator of this sample is defined 1. If the error exceeds the limit value, the index is also 1.

As for the qualitative performance indicators such as starting, latency and clock battery, if the performance is normal, the index is 0, or the index is 1. Besides, for LCD screen, because of the
existence of different degrees of screen damage, it’s defined that if the screen has no abnormality, the indicator is 0, if the screen is damaged hardly, the indicator is 1. However, the screen of No.A-5 samples fades but can display normally after connecting electricity, so the indicator is defined as 0.5; the screen of No.B-6 samples fades but can display normally, so the indicator is defined as 0.3; the screen of No.F-3 samples has some cracks but can display, so the indicator is defined as 0.7.

Because the basic error test is carried out under different load points and different power factors, there are many error data points in each sample table. Based on the principal component analysis method and SPSS software,[8] the basic error indicators after weighted processing as listed in Table 3.

Strengthening aging test has no effect on the load switch, communication function and electric quantity metering, so these three indicators are ignored when giving the weight. In addition, except for those smart meters which can’t be measured, the starting and latent tests results of the other meters are normal. The basic error, starting and latent tests all characterize the metering performance of the smart meters, so only the test data of basic error test are selected as the characteristics and judgment indicator. The weight value of the indicators under strengthening aging test is listed in Tab.4 and the normalized weights of each index are shown in the Table 5.

### Table 2. Malfunction of smart meters after excitation

| No. | A-3 | A-5 | A-7 | B-3 | B-6 | B-7 | F-3 | F-5 | F-7 | G-4 | G-5 | G-7 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Basic error | normal | normal | normal | normal | normal | normal | normal | normal | normal | normal | normal | dead |
| LCD screen | dead | fades, display | normal | fades, display | normal | Cracks, display | normal | normal | dark & dead | normal | normal | dark & dead |
| Clock battery | dead | dead | normal | normal | normal | normal | normal | normal | normal | normal | normal | normal | normal |

### Table 3. Error after weighting

| No. | A-3 | A-5 | A-7 | B-3 | B-6 | B-7 |
|-----|-----|-----|-----|-----|-----|-----|
| Basic error | 0.0611 | 0.0851 | 0.0794 | 0.0686 | 0.0836 | 0.0725 |
| No. | F-3 | F-5 | F-7 | G-4 | G-5 | G-7 |
| error | 0.0886 | 0.0822 | 0.0751 | 0.0649 | 0.0802 | - |

### Table 4. Analytic Hierarchy Process scoring results

| Basic error | LCD screen | Clock battery |
|-------------|------------|---------------|
| Basic error | 1          | 3             | 5             |
| LCD screen  | 1/3        | 1             | 3             |
| Clock battery | 1/5      | 1/3           | 1             |

### Table 5. Index weight

| Basic error | LCD screen | Clock battery |
|-------------|------------|---------------|
| 0.63        | 0.26       | 0.11          |

According to the grey correlation degree evaluation method, combined with the weight listed above, the correlation degree values of various samples can be obtained. The correlation coefficient of the samples and the scoring results are shown in Figure 1 below. The larger the relational degree is, the better the performance of the samples is.
Comparing the scoring results and the list of sample performance indicators, it can be seen that, the error of all samples have little difference except for the No. G-7 meter. Relatively, the difference of LCD screen and clock battery indicators are bigger, so the impact on state evaluation is relatively greater. No. B-3, F-7, G-5 and F-5 smart meters have no problems in LCD screen and clock battery after fault excitation, but there are only basic error difference, so these meters scored better in the evaluation. No. G-7 meters can’t measure error, and the weight of error indicators is relatively large in all evaluation. Besides, LCD screen becomes black and can’t display, so No. G-7 meters obtains the lowest score and the performance is the worst. Through the above analysis, it can be seen that the evaluation results obtained by this algorithm are consistent with the actual situation, and the evaluation method is effective.

5. CONCLUSIONS AND PROSPECTS

In this paper, the typical fault excitation schemes of smart meters are preliminarily explored and the state evaluation method for meters based on fault excitation is proposed. The incentive test carried out has positive practical significance for stimulating potential faults and reducing faults of running smart meters. The evaluation method adopted combines the qualitative and quantitative performance indicators and gives a quantitative evaluation result of each samples, which provides effective support for the establishment of the evaluation system of smart meters. Due to the limitation of research time and the length of this article, more sample data are needed to support the validation of the subject evaluation method, and the comprehensiveness of the whole evaluation system needs to be improved. In the follow-up, the evaluation index can be supplemented and improved and this state evaluation method can be compiled into software in the future.

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