Failure Modes and Effects Analysis for Domestic Electric Energy Meter Using In-Service Data

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Abstract. Field operation data for domestic electric energy meters are valuable for both manufactures and users, from this point of view, the main failure modes, failure numbers, installed time, and lifetime were analysed based on in-service data. The result could provide a reference for maintenance and reliability improvements.

1. Introduction
State Grid Corporation of China proposed a large program to establish a strong intelligent grid. the quality and reliability of intelligent electrical meter is not only related to electrical safety of tens of thousands homes, but also have severe impacts on the reliable operation of national intelligent grid. Because field environment of the electric energy meter is complex, considering the effects of temperature and humidity changes, thunder and lightning, power system fluctuation, and electromagnetic interference, the risk of the electric energy meter failure is increased accompany with the long-term operation [1]. When State Grid bought electric energy meters through open tender, they identified that the average lifetime of electric energy meter should be not below 10 years under specified working conditions, and also pointed out that the relevant lower limits value of “m1” is 2.19×10⁴h[2].

Reliability test is an important method to investigate product reliability, and relevant reliability standards, such as JB/T50070-2002 Reliability Requirements and Reliability Compliance Test for electric energy meter, were published. The limitation is that long testing time, at least 1360h, is needed when 43 electric energy meters were put in a test. Testing time could be shorten by improving testing stress [3]. Luo Ranran (2013) investigated reliability of electric energy meters, combining accelerated life test, and accelerated degradation testing and reliability prediction based on component stress [4]. Bao Jin (2014) pointed out that high accelerated life test was a quick and efficient method to test the potential failure of electric energy meter at the research stage. Physical analysis of failure must be conducted before conducting high accelerated stress test to make sure the consistent of failure mechanism [5]. Accelerated life test generally is carried out on basic components, and we need to ensure the failure mechanism is not to be changed. Statistical analysis on the reliability of electric energy meter based on field failure/lifetime data could reflect reliability level of product. However, little relevant search results could be found, except Li yuxuan (2012) analyzed the failure model and
impact of single-phase intelligent electrical meter. Comprehensive analysis of failure records generated in the operation process could help to improve product reliability, but scarce data can be collected and applied to support reliability study for new developed electric energy meters [6]. This is the motivation of our research to conduct failure statistical analysis based on in-service data.

2. Description and Identification for In-Service Data of Domestic Electric Energy Meter

In-Service data were collected from two provinces in China, one is located in the south of China and denoted as F province, which is characteristic as high temperature, high humidity, and salt mist. The other is in the north of China and denoted as H province, which is famous for its low temperature in winter.

The intelligent electric energy meters were inspected at a certain time-point during its operation, the failure records for fault meters were collected from Jan. 2015 to Dec. and generated from 461 places for F province and from 24 places for H province. 2015. The numbers of the meters were shown in Table 1.

| Table 1. The number of meters |
|-----------------------------|
|                            | quantity |
|                            | F Province | H Province |
| Single phase               | 231224     | 5191       |
| Three phases               | 22719      | 1281       |
| total                      | 253943     | 6472       |

All the failures were classified into four modes according to failure reasons, which were equipment quality, performance quality, outer factors, and natural hazard. In terms of the intrinsic quality, the equipment quality further divided into several elements for meters from F and H provinces listed in Table 2 and Table 3 separately.

| Table 2. Failure modes of equipment quality for meters from F province |
|---------------------------------------------------------------------|
| No. | failure modes                  | No. | failure modes                  | No. | failure modes                  | No. | failure modes                  |
|-----|--------------------------------|-----|--------------------------------|-----|--------------------------------|-----|--------------------------------|
| 1   | 232 interface damage           | 9   | Capacitor damage               | 17  | Failure of Leapyear switch    | 25  | Wireless module corruption    |
| 2   | 485 interface damage           | 10  | Solder joint short circuit     | 18  | Time conversion damage         | 26  | Error excess                   |
| 3   | data Automatic Clear           | 11  | Infrared interface damage      | 19  | Clock failure                  | 27  | Display unit fault             |
| 4   | foreign matter in the meter    | 12  | Metering chip damage           | 20  | Clock chip damage              | 28  | Rosin joint                    |
| 5   | unstart                        | 13  | Relay damage                   | 21  | System halted                  | 29  | Instrument transformer damage  |
| 6   | Memory loss                    | 14  | Crystral damage                | 22  | Stop go                        | 30  | Carrier module damage          |
| 7   | Out of battery                 | 15  | Pulse interface damage         | 23  | Communication protocol conformance | 31  | Combined error tolerance      |
| 8   | Power data mutation            | 16  | Shunt running                  | 24  | Physical abuse                 |     |                                |

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### Table 3. Failure modes of equipment quality for meters from H province

| No. | failure modes         | No. | failure modes         | No. | failure modes         |
|-----|-----------------------|-----|-----------------------|-----|-----------------------|
| 1   | 485 interface damage  | 4   | Physical abuse        | 7   | Display unit fault    |
| 2   | Solder joint short circuit | 5   | Wireless module corruption | 8   | Carrier module damage |
| 3   | Metering chip damage  | 6   | Error excess          | 9   | other                 |

Three types of users were identified in the record, which were Industrial users, commercial users, and residential users. The number of each type were shown in Table 4. It’s clear to see that a large number of users was not identified.

### Table 4. Types and number of users

| User types   | single-phase meters users | single-phase meters users |
|--------------|---------------------------|---------------------------|
|              | F Province | H Province | F Province | H Province |
| Industrial users | ——         | 12         | 44        | 178        |
| commercial users  | 21254     | 2687       | 66        | 19         |
| residential users | 1604      | 589        | 136       | 439        |
| blank          | 208366    | 1903       | 22473     | 591        |

3. **Statistic Analysis of In-Service Data**

Inspect data were recorded from Jan.2015 to Dec.2015, and the failure numbers during one month were simply computed and were presented in Fig.1.
In terms of the Entry-into-service time, the inspected meter’s installed date were collected and shown in Table 5.

Table 5. installed time of inspected meters

| Time       | Installed date for three-phase meters | Installed date for single-phase meters |
|------------|--------------------------------------|----------------------------------------|
|            | F Province | H Province | F Province | H Province |
| Before 2000| ———        | 10         | ———        | 2          |
| 2000       | ———        | 3          | 0          | 20         |
| 2001       | ———        | 10         | 0          | 6          |
| 2002       | ———        | 10         | 1          | 8          |
| 2003       | ———        | 16         | 0          | 3          |
| 2004       | 1          | 13         | 6          | 17         |
| 2005       | 1          | 7          | 4          | 14         |
| 2006       | 1          | 13         | 0          | 4          |
| 2007       | 3          | 9          | 5          | 6          |
| 2008       | 15         | 31         | 11         | 39         |
| 2009       | 35         | 182        | 4          | 2290       |
| 2010       | 82         | 273        | 775        | 367        |
| 2011       | 809        | 167        | 26692      | 488        |
| 2012       | 1280       | 161        | 124425     | 906        |
| 2013       | 17252      | 97         | 50273      | 376        |
| 2014       | 2642       | 164        | 23983      | 436        |
| 2015       | 598        | 105        | 5043       | 190        |
| blank      | ———        | 10         | ———        | 12         |

After indentification of failure modes in the catalogy of equipment quality, the failure number in each failure mode were further given, as listed in Table 6 and Table 7 seperately considering two different provinces.
Table 6. Failure number for each failure modes from F province

| No. | failure modes              | Failure number | No. | failure modes              | Failure number |
|-----|----------------------------|----------------|-----|----------------------------|----------------|
|     | three-phase meters | single-phase meters |     | three-phase meters | single-phase meters |
| 1   | 232 interface damage     | 3              | 17  | Failure of Leapyear switch | 2              |
| 2   | 485 interface damage     | 116            | 18  | Time conversion damage    | 3              |
| 3   | data Automatic Clear     | 3              | 19  | Clock failure             | 541            |
| 4   | foreign matter in the meter | 8             | 20  | Clock chip damage         | 85             |
| 5   | unstart                  | 46             | 21  | System halted             | 94             |
| 6   | Memory loss              | 7              | 22  | Stop go                   | 137            |
| 7   | Out of battery           | 1597           | 23  | Communication protocol conformance | 6              |
| 8   | Power data mutation      | 29             | 24  | Physical abuse            | 1406           |
| 9   | Capacitor damage         | 8              | 25  | Wireless module corruption | 106            |
| 10  | Solder joint short circuit | 174         | 26  | Error excess              | 27             |
| 11  | Infrared interface damage | 181           | 27  | Display unit fault        | 1319           |
| 12  | Metering chip damage     | 57             | 28  | Rosin joint               | 50             |
| 13  | Relay damage             | 33             | 29  | Instrument transformer damage | 16             |
| 14  | Crystall damage          | 6              | 30  | Carrier module damage     | 584            |
| 15  | Pulse interface damage   | 6              | 31  | Combined error tolerance  | 16             |
| 16  | Shunt running            | 40             | 126 |                           |                |

Table 7. Failure number for each failure modes from H province

| No. | failure modes              | Failure number | No. | failure modes              | Failure number |
|-----|----------------------------|----------------|-----|----------------------------|----------------|
|     | three-phase meters | single-phase meters |     | three-phase meters | single-phase meters |
| 1   | 485 interface damage     | 30             | 6   | Error excess               | 6              |
| 2   | Solder joint short circuit | 2             | 7   | Display unit fault         | 2              |
| 3   | Metering chip damage     | 12             | 8   | Carrier module damage      | 14             |
| 4   | Physical abuse            | 43             | 9   | Other                       | 1106           |
| 5   | Wireless module corruption | 1             | 10  |                            |                |
The lifetime of all the inspected meters are shown in Fig.2. It is clear to see that the operation time of most of Single-phase and Three-phase meters are shorter than 2500 days from H province, meanwhile, the operation time for most of meters are no more than 2000 days for F province.

4. Conclusion
This paper conduct failure modes analysis and statistical analysis based on in-service data. Domestic Electric Energy Meter in-service data are described and identified, some basic information including failure modes and main users were provide. For further, certain statistic analysis on failure numbers, installed time, and lifetime were conducted. The main contribution of this paper was to provide basic statistic reference in terms of domestic electric energy meters field operation data, which could be useful for further analysis on maintenance and reliability improvements.

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