Reliability Prediction Approaches For Domestic Intelligent Electric Energy Meter Based on IEC62380

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Abstract. The reliability of intelligent electric energy meter is a crucial issue considering its large scale application and safety of national intelligent grid. This paper developed a procedure of reliability prediction for domestic intelligent electric energy meter according to IEC62380, especially to identify the determination of model parameters combining domestic working conditions. A case study was provided to show the effectiveness and validation.

1. Introduction

There is an increasing demand for smart energy meters in terms of strong smart grid proposed by State Corporation of China. Intelligent electrical meter's quality and reliability not only relates to the electrical safety of tens of thousands homes, but also have severe impacts on the reliable operation of national intelligent grid. In order to assure reliable and stable operation, it is necessary the meters are able to withstand harsh environmental conditions. Therefore, four experimental base have been establishing at four distinguished climate environment places. In addition, the average lifetime of electric energy meter should be not below 10 years under specified working conditions was identified when state grid bought electric energy meters.

Reliability prediction for electric products at the design stage are mainly based on components reliability information, related prediction methods include component stress method, component counting method, failure physical analysis method, similar prediction method, score prediction method, reliability block diagram method, and Monte Carlo method, One of which named component stress method is recommended by State Grid Corporation. At present, the handbooks of reliability prediction for electronic products are MIL-HDBK-217F, GJB/Z299C, SN29500, IEC/TR62380, FIDES, and SR-332[1]. MIL-HDBK-217 an GJB/Z299C were mainly applied to military products and equipment, SN29500, FIDES, and SR-332 were proposed by companies, and provided component reliability database, while the predict results were with low precision, regardless of confidence intervals were provided 1 SR-332 [2]. From the study objects point of view, IEC 62380 provided a general method for civil electric products reliability prediction, which is suited to reliability forecasting for smart electric meters. However, the models provided in which is complicated, and could be used for general electric products. In order to improve the engineering practice, reliability prediction methods are needed to be simplified and tailed for intelligent energy meters, which is the motivation of this research.
Extensive studies paid attention to reliability prediction. Ju Hanji (2013) forecasted reliability of smart electric energy meter based on components information [3]. Li Xiangfeng (2010) discussed reliability prediction of intelligent electric energy meter based on IEC62059 standard [4]. Wu Hongbo (2011) predicted the reliability of electronic electric energy meter considering discontinuous operation [5]. Shu Zhan (2012) incorporated the analytic hierarchy process, deflection subtraction method, and triangular fuzzy to evaluate smart electric energy meters [6]. Yuan Jincan (2013) pointed out that Telcordia SR-332 was the most practical prediction handbook for the reliability prediction, which also analyzed the influence of temperature stress and electrical stress on the reliability [7]. SR-332 provided the estimation method of point evaluation and standard deviation of component [8]. However, few papers focused on the application of IEC62380.

2. Electric Energy Meter Reliability and IEC62380

2.1. Electric Energy Meter

To take a single phase cost-control intelligent electric energy meter as an example. Its main functions include metering performance, multi-rate function, step power quantity function, account day unloading, event recording, data storage, freeze function, loading control, cost control function, timer function, infrared communication, and other functions[9]. The operation principle can be seen in Fig. 1.

![Operation Principle](image)

Fig.1 Operation Principle

This electric energy meter could be regarded as a series system with 6 function modules according to its operation principle, shown in Fig. 2.

![Reliability Model of electric energy meter](image)

Fig.2 Reliability Model of electric energy meter

Assume the series system consists of $n$ units, and the $i$th ($i=1,\ldots,n$) unit is composed of $n_i$ components with series relationship. And also assume the failure rate of $i$th ($i=1,\ldots,n$) unit is, and $\lambda_i$ the failure rate of $j$th ($j=1,\ldots,n_i$) component in $i$th unit is $\lambda_{ij}$. Then the system failure rate model can be shown

$$\lambda_s = \sum_{i=1}^{n} \lambda_i = \sum_{i=1}^{n} \sum_{j=1}^{n_i} \lambda_{ij}$$

(1)
From this point of view, the key issue is to predict component reliability. If all the failure rate of components are forecasted according to IEC 62380, then the reliability of a meter is computed.

2.2. EC 62380 Standard

① Reliability database

The reliability database in this handbook comprises failure rates and life expectancy. Failure rates are assumed to be constant either for an unlimited period of operation or for limited periods.

② Influence factors

A base failure rate value for a component was provided based on a number of operational and environmental factors. The component failure rate depends on base failure rate and influencing factors. The influence factors are as below, a) Factors giving the influence of temperature, such as St and SW; b) Factors giving the influence of special stresses, such as utilization factor Su for thermistors, Zenger diodes, SA for Aluminum liquid electrolyte capacitors, SY for relays, and factor Si for connectors. The identification methods of all these influence factors are discussed in terms of the engineering background of smart electric energy meter.

③ Mission profile

Component in-service conditions should be incorporated in estimation and calculation of smart electric energy meter reliability. A mission profile was applied in several homogeneous working phases on the basis of a typical year of use. This is distinguished from other prediction methods. Three phases are defined as below for meters:

- On/Off working phases with various average outside temperatures seen by meters;
- Permanent-working phases with various average outside temperature swings seen by Meters;
- Storage or dormant phase’s mode with various average outside temperature swings seen by meters.

3. Failure Rate Prediction for Electronic Components

3.1. Components in Intelligent Electric Energy Meter

Types of components used in smart electric energy meter are identified according to IEC62380, delivering 21 kinds of components listed in Table 1.

| No. | Types                                      | Sub-Types                  |
|-----|--------------------------------------------|-----------------------------|
| 1   | Equipped printed circuit boards and hybrid circuits | equipped printed circuit board |
| 2   | Integrated circuits                         | Integrated circuits         |
| 3   | Diodes and thermistors, transistors, opt couplers | Low power diodes           |
|     |                                             | Low power transistors       |
|     |                                             | Opt couplers                |
| 4   | Optoelectronics                             | Light emitting diodes diode |
|     |                                             | photodiodes                 |
| 5   | Capacitors and thermistors                  | Fixed ceramic dielectric capacitors-Class I |
|     |                                             | Fixed ceramic dielectric capacitors-Class II |
|     |                                             | Aluminum, non-solid electrolyte capacitors |
| 6   | Resistors and potentiometers                | Fixed, low dissipation film resistors |
|     |                                             | Fixed, low dissipation surface mounting resistors and resistive array |
| 7   | Inductors and transformers                  | Inductors and transformers  |
| 9   | Relays                                     | Electromechanical relays    |
| 10  | Switches and keyboards                      | Switches and keyboards      |
| 11  | Connectors                                 | Connectors for PCBs and related sockets |
| 12  | Solid State Lamps                           | Displays                    |
|     |                                             | Solid state lamps           |
| 13  | Protection devices                          | Thermostats                 |
|     |                                             | Varistors                   |
| 14  | Energy devices, thermal management devices, disk drive | Primary batteries          |
3.2. Mission Profile Configuration

The mission profile should be identified according to field conditions of meters. Here, two main operation modes are considered, and the profile is shown in Fig. 3.

![Fig. 3 mission profile of meters](image)

The parameters of various working modes are defined as below:

- \( y \) — the number of phases, \( y = 1, 2 \);
- \( (t_{\text{ae}})_{i} \) — average outside ambient temperature surrounding the meter, during the \( i \)th phase of the mission profile;
- \( (t_{\text{ac}})_{i} \) — average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled;
- \( \tau_{i} \) — annual ratio of times for the PCB, in permanent working mode with supply, and at the \( (t_{\text{ac}})_{i} \) temperature;
- \( \tau_{\text{on}} \) — total annual ratio of time for the PCB, in permanent working mode with supply, \( \tau_{\text{on}} = \sum \tau_{i} \);
- \( \tau_{\text{off}} \) — total annual ratio of time for the PCB, in non-working or storage/dormant modes \( (\tau_{\text{on}} + \tau_{\text{off}} = 1) \);
- \( n_{i} \) — annual number of thermal cycles seen by the components of the PCB, corresponding to the \( i \)th phase of the mission profile with an average swing \( \Delta T_{i} \);
- \( \Delta T_{i} \) — average swing of the thermal variation seen by the components of the PCB, corresponding to the \( i \)th phase of the mission profile.

3.3. Failure Rate Prediction Models

1. The failure rate model for equipped printed circuit board is

\[
\lambda_{p} = 5.1 \times 10^{-3} \pi_{i} \left[ N_{i} \sqrt{1 + \frac{N_{i}}{S}} + N_{p} \cdot \frac{1 + 0.1 \sqrt{S}}{3} \pi_{e} \right] \times \left( 1 + 3.1 \times 10^{-3} \times \sum_{i=1}^{\pi_{i}} [(\pi_{is}) \times (\Delta T_{i})^{0.68}] \right)
\]

2. The failure rate model for Integrated circuits is

\[
\lambda = \left\{ \lambda_{i} \times N \times e^{-0.35a} + \lambda_{0} \right\} \times \left\{ \sum_{i=1}^{\pi_{i}} [(\pi_{is}) \times \tau_{i}] \right\} + \left\{ 2.75 \times 10^{-3} \times \pi_{i} \times \sum_{i=1}^{\pi_{i}} [(\pi_{is}) \times (\Delta T_{i})^{0.68}] \times \lambda_{0} \right\} \times F_{It}
\]

3. The failure rate model for Low power diodes is
The failure rate model for Low power transistors is

\[ \lambda = \left( \pi_i \times \lambda_0 \right) \times \left( \frac{1}{r_{on} + r_{off}} \right) + 2.75 \times 10^{-3} \times \sum_{i=1}^{y} (\pi_i) \times (\Delta T_i)^{0.68} \times \lambda_0 + \{ \pi_\text{on} \times \lambda_\text{EOS} \} \cdot \text{Fit} \]  

(4)

The failure rate model for Optocouplers is

\[ \lambda = \left[ 2.2 \times \pi_i \times \left( \frac{1}{r_{on} + r_{off}} \right) \right] + 2.75 \times 10^{-3} \times \sum_{i=1}^{y} (\pi_i) \times (\Delta T_i)^{0.68} \times \lambda_0 + \{ \pi_\text{on} \times \lambda_\text{EOS} \} \cdot \text{Fit} \]  

(5)

The failure rate model for Light emitting diodes diode is

\[ \lambda = \lambda_0 \times \pi_i \times 10^{-9} / h \]  

(7)

The failure rate model for photodiodes is

\[ \lambda = \lambda_0 \times \pi_i \times 10^{-9} / h \]  

(8)

The failure rate model for dielectric capacitors is

\[ \lambda = \pi_{\text{Type-I}} \left( \frac{1}{r_{on} + r_{off}} \right) \times \pi_{\text{Type-II}} \times \left( \sum_{i=1}^{y} (\pi_i) \times (\Delta T_i)^{0.68} \right) \times \text{Fit} \]  

(9)

Table 2. Parameters for dielectric capacitors

| Type | Parameter 1 | Parameter 2 |
|------|-------------|-------------|
| Fixed ceramic dielectric capacitors–Class I | 0.05 | 3.3×10^{-3} |
| Fixed ceramic dielectric capacitors–Class II | 0.15 | 3.3×10^{-3} |
| Aluminum, non-solid electrolyte capacitors | 1.3 | 1.4×10^{-3} |

The failure rate model for resistors is

\[ \lambda = \pi_{\text{Type-I}} \left( \frac{1}{r_{on} + r_{off}} \right) \times \pi_{\text{Type-II}} \times \left( \sum_{i=1}^{y} (\pi_i) \times (\Delta T_i)^{0.68} \right) \times \text{Fit} \]  

(10)

Table 3. Parameters for resistors

| Parameter 1 | Parameter 2 |
|-------------|-------------|
| Fixed, low dissipation film resistors | 0.1 | 1.4×10^{-3} |
| Fixed, low dissipation surface mounting resistors and resistive array | 0.01 | 3.3×10^{-3} |
The failure rate model for Inductors and transformers is

$$
\lambda = \lambda_0 \times \left[ \frac{\pi_c \times \pi_T \times \pi_p \times \pi_s \times \pi_T \times \pi_c \times \{1 + 1.27 \times 10^{-3} \times \left[ \sum_{i=1}^{j} (\pi_e) \times (\Delta T_i)^{0.68} \right] \}}{\pi_{on} + \pi_{off}} \right] + 7 \times 10^{-3} \times \left[ \sum_{i=1}^{j} (\pi_e) \times (\Delta T_i)^{0.68} \right] \cdot Fit
$$

The failure rate model for electromechanical relays is

$$
\lambda = 1.5 \times \pi_c \times \pi_T \times \pi_p \times \pi_s \times \{1 + 1.27 \times 10^{-3} \times \left[ \sum_{i=1}^{j} (\pi_e) \times (\Delta T_i)^{0.68} \right] \} \cdot Fit
$$

The failure rate model for Switches and keyboards is

$$
\lambda = \lambda_0 \times N \times \left[ 1 + 2.7 \times 10^{-3} \times \left[ \sum_{i=1}^{j} (\pi_e) \times (\Delta T_i)^{0.68} \right] \right] \cdot Fit
$$

The failure rate model for Connectors for PCBs and related sockets is

$$
\lambda = \lambda_0 \times \pi_c \times \pi_T \times \pi_p \times \pi_c \times \pi_{M} \times \pi_s \times \left[ 1 + 2.7 \times 10^{-3} \times \sum_{i=1}^{j} (\pi_e) \times (\Delta T_i)^{0.68} \right] \cdot FIT
$$

The failure rate model for Displays is

$$
\lambda = \lambda_0 \times \{1 + 2.5 \times 10^{-3} \times \sum_{i=1}^{j} (\pi_e) \times (\Delta T_i)^{0.68} \} \cdot Fit
$$

The failure rate model for Solid state lamps is

$$
\lambda = 2 \times \{1 + 2.7 \times 10^{-3} \times \sum_{i=1}^{j} (\pi_e) \times (\Delta T_i)^{0.68} \} \cdot Fit
$$

The failure rate model for Thermistors and Varistors is

$$
\lambda = (\lambda_0 \times \pi_c \times \pi_{M}) \cdot Fit
$$

Table 4. Parameters for Thermistors and Varistors

|          | $\lambda_0$ (Fit) | $\pi_i$ |
|----------|------------------|--------|
| Thermistors | 5                | 1      |
| Varistors  | 1                | 1      |

The failure rate model for Primary batteries is

$$
\lambda = \lambda_0 \cdot Fit
$$
Table 5. Parameters for Primary batteries

| Types of battery       | λ₀ (Fit) |
|------------------------|----------|
| Primary battery        |          |
| Ni-Cd battery          | 100      |
| Li-Lon battery         | 150      |

4. Case Study
Intelligent electric energy meter named FM3318 was selected to conduct reliability prediction, totally about 168 components were used in this meter. The electronic components in power modular is listed in Table 6 as an example.

Table 6. Component list of power modular

| Footprint | Designator | Description | Quantity |
|-----------|------------|-------------|----------|
| B-CR1/2AA | BT1        | ER14250 3.6V| 1        |
| 0603C     | C10, C25, C44, C46, C51, C54, C60, C64 | CC0603KRX7R9BB104(50V/0.1uF) | 8        |
| 35v1000 yxf | C45       | WL1V108M12025PL180(35V/1000μF) | 1        |
| RB.1/2   | C47        | WF1E107M6L011PC480(25V/100μF) | 1        |
| YXF25V/470U | C48      | WF1A477M0811MP280(10V/470μF) | 1        |
| 0805     | C49        | GRM21BR61A106KE19L (0805-10V-X5R-106±10%) | 1        |
| YXF25V/470U | C55      | WL1E477M10016PA18P(25V/470μF) | 1        |
| 1206     | C59        | CC1206KKX5R8BB106(25V/10μF) | 1        |
| YXF25V/470U | C62      | WL1C477M1012MPA180(16V/470μF) | 1        |
| 0022-SOIC4(2.7)(4.9×7.0) | D3      | MB6S-TR(600V,0.8A) | 1        |
| M7       | D6, D9, D19 | M7(GOOD) | 3        |
| TP4      | D7         | LTV-816S-TP(TA1)-D3-TX2Cu | 1        |
| M7       | D12        | SS14(GOOD-ARK) | 1        |
| CHOKE CR43 | L1        | CW45-120K(A70627016) | 1        |
| 0603r    | R19        | RC0603FR-07110KL (110kΩ 1%) | 1        |
| 0603r    | R20        | RC0603FR-078K2L (8.2KΩ 1%) | 1        |
| 0603r    | R21        | RC0603JR-07300KL (300kΩ 5%) | 1        |
| 0805     | R68, R69, R70, R71 | RC0805JR-07470KL (470kΩ 5%) | 4        |
| REMING   | RT1        | MZ21-05AR(200-400)Ω | 1        |
| YM       | RV1        | MYG3-20K420 | 1        |
| DT-3-817 | T1         | WSD-DX-ZB | 1        |
| MK06A    | U4         | MP2451 DT-LF-Z | 1        |
| SOT-89   | U7, U8, U9 | 78L05G-AB3-R(UTC SOT89 100mA) | 3        |
The details of components could be found in datasheets, then the components failure rate was predicted. In order to give a case to show the methodology of forecasting failure rate, the installed place is selected Shandong Province, the climate information could be found in website of Meteorological Bureau, and the mission profile is prepared in Table 7.

### Table 7. Mission profile configuration

| module | Continue working mode | On/off working mode | Storage mode |
|--------|------------------------|---------------------|--------------|
|        | Phase 1th | Phase 2th | τ₁ | τ₂ | n₁ | Δ T₁ | n₂ | Δ T₂ | n₃ | Δ T₃ | n₄ | Δ T₄ |
| Power module | 10 | 12/24 | 20 | 12/24 | 1 | 0 | 365 | 10 |

The failure rate prediction values are shown in Table 8.

### Table 8. Failure rate of power module

| No | components | Part No | Working failure rate λ (Fit) |
|----|------------|--------|------------------------------|
| 1  | CC0603KRX7R9BB104(50V/0.1uF) | C10 | 0.1126 |
| 2  | C100 | C11 |
| 3  | C44 | C45 |
| 4  | C46 | C47 |
| 5  | C51 | C52 |
| 6  | C54 | C55 |
| 7  | C60 | C61 |
| 8  | C64 | C65 |
| 9  | GRM21BR61A106KE19L (0805-10V-X5R-106±10%) | C49 | 0.1126 |
| 10 | CC1206KKX5R8BB106(25V/10uF) | C59 | 0.1126 |
| 11 | W1V108M1205PL180(35V/1000uF) | C45 | 2.4235 |
| 12 | WF1E107M6L01PC480(25V/100uF) | C17 | 2.4235 |
| 13 | WF1A477M0811MPF280(10V/470uF) | C48 | 2.4235 |
| 14 | W1C477M1012MPA180(16V/470uF) | C62 | 2.4235 |
| 15 | W1E477M10016PA18P(25V/470uF) | C55 | 2.4235 |
| 16 | M7(GOOD) | D6 | 2.1144 |
| 17 | D9 | D10 |
| 18 | D19 | D20 |
| 19 | SS14(GOOD-ARK) | D12 | 2.1164 |
| 20 | MB0S-TR(600V,0.8A) | D3 | 7.8129 |
| 21 | RC0603FR-07110KL (110kΩ 1%) | R19 | 0.0213 |
| 22 | RC0603FR-078K2L (8.2KΩ 1%) | R20 | 0.0212 |
| 23 | RC0603JR-07300KL (300kΩ 5%) | R21 | 0.0212 |
| 24 | RC0805JR-07470KL (470kΩ 5%) | R68 | 17.0412 |
| 25 | R69 | R70 |
| 26 | R71 | R72 |
| 27 | LTV-816S-TP(TA1)-D3-TXCu | D7 | 58.6672 |
| 28 | MZ21-05AR(200~400)Ω | RT1 | 45 |
| 29 | MYG3-20K420 | RV1 | 41 |
| 30 | CW45-120K(A70627016) | L1 | 0.7325 |
| 31 | WSD-DX-ZB | T1 | 11.8935 |
| 32 | ER14250 3.6V | BT1 | 150 |
| 33 | MP2451DT-LF-Z | U4 | 18.9624 |
| 34 | 78L05G-AB3-R(UTC SOT89 100mA) | U7 | 18.9929 |
| 35 | U8 | U9 |
| 36 | Failure rate | | 480.9788 |

Further, the failure rate of smart electric energy meter is forecasted, shown in Table 9.
Table 9. Failure rate for meters

| modular            | Failure rate (Fit) | MTBF(year) |
|--------------------|--------------------|------------|
| ① power module    | 480.9788           | 130.2      |
| ② measurement module | 340.6392          | 95.7       |
| ③ control module  | 687                | 80.4       |
| ④ Display module  | 191.7458           | 595.3      |
| ⑤ Communication module | 139.294         | 819.5      |
| ⑥ Storage module  | 27.8806            | 4094.4     |
| ⑦ Security module | 14.2253            | 8024.8     |
| Meter              | 1881.7637          | 60.66397   |

5. Conclusion
This paper provided a method for reliability prediction for domestic electric energy meter based on IEC 62380. The identification of model parameters were discussed based on domestic working conditions, the main advantage is that the prediction results are more precise and reasonable the results using GJB299. Further investigation should focus on the collection of components and systems reliability information and management of support chain.

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