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 calve 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 I 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, defection 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.

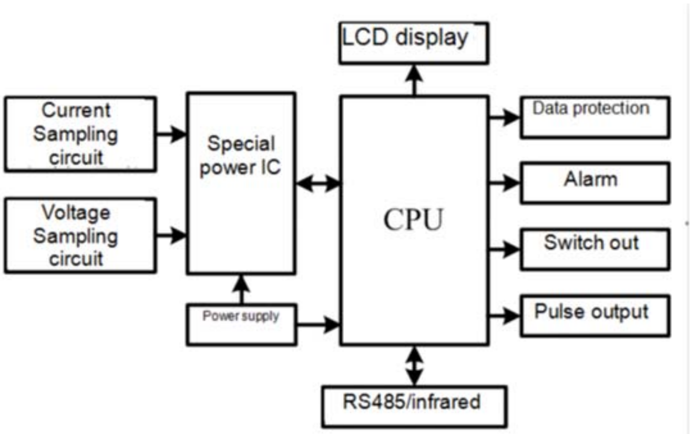

Fig.1 Operation Principle

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

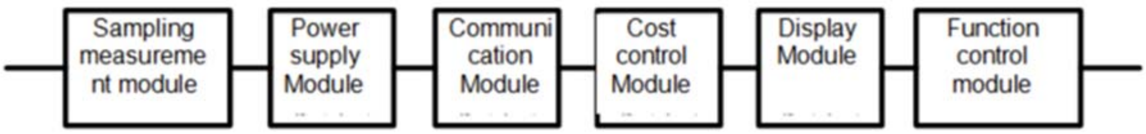

Fig.2 Reliability Model of electric energy meter

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

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

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.

Table 1. Types of components used in meters according to IEC TR 62380

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	Thermistors
		Varistors
14	Energy devices, thermal management devices, disk drive	Primary batteries

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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.

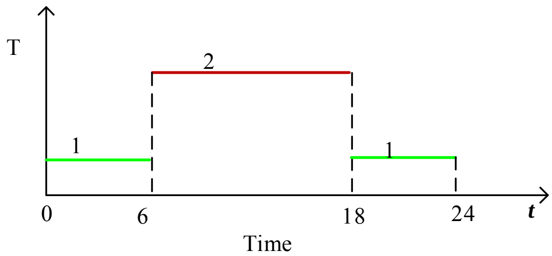

Fig.3 mission profile of meters

The parameters of various working modes are defined as below:

y——the number of phases, y=1,2;

$(t_{ae})_i$——average outside ambient temperature surrounding the meter, during the ith phase of the mission profile;

$(t_{ac})_i$——average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled;

τ_i——annual ratio of times for the PCB, in permanent working mode with supply, and at the (tac)I temperature;

τ_{on}——total annual ratio of time for the PCB, in permanent working mode with supply, $\tau_{on}=\sum\tau_i$;

τ_{off}——total annual ratio of time for the PCB, in non-working or storage/dormant modes($\tau_{on}+\tau_{off}=1$).

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 ΔT_i

ΔT_i——average swing of the thermal variation seen by the components of the PCB, corresponding to the ith phase of the mission profile.

3.3. Failure Rate Prediction Models

① The failure rate model for equipped printed circuit board is

$$\lambda_B=5.1\times10^{-3}\pi_t\pi_c\left[N_t\sqrt{1+\frac{N_t}{S}}+N_P.\frac{1+0.1\sqrt{S}}{3}\pi_L\right]\times\left(1+3.1\times10^{-3}\times\sum_{i=1}^{z}[(\pi_n)_i\times(\Delta T_i)^{0.68}]\right)\quad(2)$$

② The failure rate model for Integrated circuits is

$$\lambda=\left[\left\{\lambda_1\times N\times e^{-0.35a}+\lambda_2\right\}\times\left\{\frac{\sum_{i=1}^{y}(\pi_t)_i\times\tau_i}{\tau_{on}+\tau_{off}}\right\}+\left\{2.75\times10^{-3}\times\pi_\alpha\times\sum_{i=1}^{z}[(\pi_n)_i\times(\Delta T_i)^{0.68}]\times\lambda_3\right\}+\left\{\pi_I\times\lambda_{EOS}\right\}\right]\times Fit\quad(3)$$

③ The failure rate model for Low power diodes is

$$\lambda=[\{\pi_{\mathrm{U}}\times\lambda_0\}\times\{\frac{\sum_{i=1}^{y}[(\pi_t)_i\times\tau_i]}{\tau_{\mathrm{on}}+\tau_{\mathrm{off}}}\}+\{2.75\times10^{-3}\times\sum_{i=1}^{z}[(\pi_n)_i\times(\Delta T_i)^{0.68}]\times\lambda_{\mathrm{B}}\}+\{\pi_{\mathrm{I}}\times\lambda_{\mathrm{EOS}}\}]\cdot\mathrm{Fit} \quad (4)$$

④ The failure rate model for Low power transistors is

$$\lambda=[\{\pi_{\mathrm{S}}\times\lambda_0\}\times\{\frac{\sum_{i=1}^{y}[(\pi_t)_i\times\tau_i]}{\tau_{\mathrm{on}}+\tau_{\mathrm{off}}}\}+\{2.75\times10^{-3}\times\sum_{i=1}^{z}[(\pi_n)_i\times(\Delta T_i)^{0.68}]\times\lambda_{\mathrm{B}}\}+\{\pi_{\mathrm{I}}\times\lambda_{\mathrm{EOS}}\}]\cdot\mathrm{Fit} \quad (5)$$

⑤The failure rate model for Optocouplers is

$$\lambda=[\{2.2\times\pi_{\mathrm{S}}\}\times\{\frac{\sum_{i=1}^{y}[(\pi_t)_i\times\tau_i]}{\tau_{\mathrm{on}}+\tau_{\mathrm{off}}}\}+\{2.75\times10^{-3}\times\sum_{i=1}^{z}[(\pi_n)_i\times(\Delta T_i)^{0.68}]\times\lambda_{\mathrm{B}}\}+\{\pi_{\mathrm{I}}\times\lambda_{\mathrm{EOS}}\}]\cdot\mathrm{Fit} \quad (6)$$

⑥The failure rate model for Light emitting diodes diode is

$$\lambda=\lambda_0\times\pi_t\times10^{-9}/h \quad (7)$$

⑦The failure rate model for photodiodes is

$$\lambda=\lambda_0\times\pi_t\times10^{-9}/h \quad (8)$$

⑧The failure rate model for dielectric capacitors is

$$\lambda=\pi_{Type-\mathrm{I}}\{[\frac{\sum_{i=1}^{y}(\pi_t)_i\times\tau_i}{\tau_{on}+\tau_{off}}]\times\pi_A+\pi_{Type-\mathrm{II}}\times[\sum_{i=1}^{j}(\pi_n)_i\times(\Delta T_i)^{0.68}]\}\times Fit \quad (9)$$

Table 2. Parameters for dielectric capacitors

	$\pi_{\mathrm{Type-I}}$	$\pi_{\mathrm{Type-II}}$
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}

⑨The failure rate model for resistors is

$$\lambda=\pi_{Type-\mathrm{I}}\{[\frac{\sum_{i=1}^{y}(\pi_t)_i\times\tau_i}{\tau_{on}+\tau_{off}}]\times\pi_N+\pi_{Type-\mathrm{II}}\times[\sum_{i=1}^{j}(\pi_n)_i\times(\Delta T_i)^{0.68}]\}\times Fit \quad (10)$$

Table 3. Parameters for resistors

	$\pi_{\mathrm{Type-I}}$	$\pi_{\mathrm{Type-II}}$
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}

⑩The failure rate model for Inductors and transformers is

$$\lambda=\lambda_0\times\{[\frac{\sum_{i=1}^{y}[(\pi_t)_i\times\tau_i]}{\tau_{\text{on}}+\tau_{\text{off}}}]+7\times10^{-3}\times\{\sum_{i=1}^{j}[(\pi_n)_i\times(\Delta T_i)^{0.68}]\}\}\cdot Fit \tag{11}$$

⑪The failure rate model for electromechanical relays is

$$\lambda=1.5\times\pi_t\times\pi_T\times\pi_p\times\pi_Y\times\pi_C\times\{1+1.27\times10^{-3}\times[\sum_{i=1}^{j}(\pi_n)_i\times(\Delta T_i)^{0.68}]\}\cdot Fit \tag{12}$$

⑫The failure rate model for Switches and keyboards is

$$\lambda=\lambda_0\times N\times\{1+2.7\times10^{-3}\times[\sum_{i=1}^{j}(\pi_n)_i\times(\Delta T_i)^{0.68}]\}\cdot Fit \tag{13}$$

⑬The failure rate model for Connectors for PCBs and related sockets is

$$\lambda=\lambda_0\times\pi_{\text{t}}\times\pi_{\text{C}}\times\pi_{\text{M}}\times\pi_{\text{i}}\times\left(1+2.7\times10^{-3}\times\sum_{i=1}^{z}[(\pi_n)_i\times(\Delta T_i)^{0.68}]\right)\times FIT \tag{14}$$

⑭The failure rate model for Displays is

$$\lambda=\lambda_0\times\{1+2.5\times10^{-3}\times[\sum_{i=1}^{j}(\pi_n)_i\times(\Delta T_i)^{0.68}]\}\cdot Fit \tag{15}$$

⑮The failure rate model for Solid state lamps is

$$\lambda=2\times\{1+2.7\times10^{-3}\times[\sum_{i=1}^{j}(\pi_n)_i\times(\Delta T_i)^{0.68}]\}\cdot Fit \tag{16}$$

⑯The failure rate model for Thermistors and Varistors is

$$\lambda=(\lambda_0+\pi_I\times\lambda_{EOS})\times\text{Fit} \tag{17}$$

Table 4. Parameters for Thermistors and Varistors

	λ_0 (Fit)	π_I
Thermistors	5	1
Varistors	1	1

⑰The failure rate model for Primary batteries is

$$\lambda=\lambda_0\times\text{Fit} \tag{18}$$

Table 5. Parameters for Primary batteries

Types of battery		λ_0 (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/1000uF)	1
RB.1/.2	C47	WF1E107M6L011PC480(25V/100uF)	1
YXF25V/470U	C48	WF1A477M0811MPF280(10V/470uF)	1
0805	C49	GRM21BR61A106KE19L (0805-10V-X5R-106±10%)	1
YXF25V/470U	C55	WL1E477M10016PA18P(25V/470uF)	1
1206	C59	CC1206KKX5R8BB106(25V/10uF)	1
YXF25V/470U	C62	WL1C477M1012MPA180(16V/470uF)	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-TXCu	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	MP2451DT-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		τ_{on}	τ_{off}	n_1	ΔT_1						
	$(t_{ae})_1$	τ_1	$(t_{ae})_2$	τ_2					n_2	ΔT_2	n_3	ΔT_3	n_4	ΔT_4
Power module	10	12/24	20	12/24	1	0	365	10						

The failure rate prediction values are shown in Table8.

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		C25	0.1126
3		C44	0.1126
4		C46	0.1126
5		C51	0.1126
6		C54	0.1126
7		C60	0.1126
8		C64	0.1126
9	GRM21BR61A106KE19L (0805-10V-X5R-106±10%)	C49	0.1126
10	CC1206KKX5R8BB106(25V/10uF)	C59	0.1126
11	WL1V108M12025PL180(35V/1000uF)	C45	2.4235
12	WF1E107M6L011PC480(25V/100uF)	C17	2.4235
13	WF1A477M0811MPF280(10V/470uF)	C48	2.4235
14	WL1C477M1012MPA180(16V/470uF)	C62	2.4235
15	WL1E477M10016PA18P(25V/470uF)	C55	2.4235
16	M7(GOOD)	D6	2.1144
17		D9	2.1144
18		D19	2.1144
19	SS14(GOOD-ARK)	D12	2.1164
20	MB6S-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	17.0412
26		R70	17.0412
27		R71	17.0412
28	LTV-816S-TP(TA1)-D3-TXCu	D7	58.6672
29	MZ21-05AR(200~400)Ω	RT1	45
30	MYG3-20K420	RV1	41
31	CW45-120K(A70627016)	L1	0.7325
32	WSD-DX-ZB	T1	11.8935
33	ER14250 3.6V	BT1	150
34	MP2451DT-LF-Z	U4	18.9624
35	78L05G-AB3-R(UTC SOT89 100mA)	U7	18.9929
36		U8	18.9929
37		U9	18.9929
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)
①power module	480.9788	130.2
②measurement module	340.6392	95.7
③control module	687	80.4
④Display module	191.7458	595.3
⑤Communication module	139.294	819.5
⑥Storage module	27.8806	4094.4
⑦security 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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