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Dynamic Error Testing of Electricity Meter Based on Distorted m-sequence Dynamic Test Signal

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***Abstract* – The complex random characteristics of smart grid lead to large dynamic errors of static electricity meters in electrical energy metering. According to the typical intrinsic characteristics of large power dynamic loads (LPDL), this paper firstly proposes a distorted m-sequence dynamic test (DmDT) signal model to reflect the characteristics. In addition, a likelihood function indirect testing method is also proposed to solve the problems of both static electricity meter dynamic error testing and dynamic reference electrical energy traceability. Then, a dynamic error testing system is also built for verifying the likelihood function indirect testing method under different DmDT signal conditions and the dynamic error testing results are given out. Experimental results show that the DmDT signal and the likelihood function indirect testing method are effective for dynamic error testing of static electricity meters. At last, the measurement uncertainty of the dynamic error testing system is better than 0.04% (coverage factor *k*=2).**

Keywords* – *Dynamic error, Static electricity meter, Dynamic load, Test signal

I. INTRODUCTION

During past ten years, smart gird has developed rapidly and has been affected by renewable energy sources (RES) and large power dynamic loads (LPDL). In this complex dynamic situation, electricity meters present large dynamic errors when metering the electrical energy [1]. For these reason, the electricity meters are required to have excellent dynamic error characteristics to ensure accurate electrical energy metering. Therefore, under complex random conditions, the dynamic error testing method of electricity meters is a new challenging problem in the field of electrical energy metering.

During the past decades, the metrological characterization of electricity meters has been intensively investigated. The IEC 62052-11 standard has stipulated five nonsinusoidal test signals for characterizing the errors of static electricity meters [2]. After that, different nonsinusoidal test signals have been proposed to calibrate electricity meters [3]. However, in real word, dynamic load currents often accompanied with dynamic random fluctuations. Therefore, the electricity meters, which are tested under the above steady-state test signal conditions, often come out with significant errors and exceed their error limits in the complex dynamic fluctuation situations.

Recently, the dynamic test signal modeling has been investigated for dynamic error testing of electricity meters. An amplitude modulation test signal model and a direct comparison method have been proposed, the uncertainty is 3% [4]. An on-off-keying (OOK) dynamic test signal model has been proposed and on-off ratio indirect method has been presented, the uncertainty is 0.38% (*k*=2) [1]. However, the proposed dynamic test signals are deterministic and used to evaluate meter dynamic errors caused by amplitude cyclical fluctuation of dynamic load current, but not suitable to evaluate the electricity meter errors caused by the random typical intrinsic characteristics of dynamic load current.

Motivated from all these considerations, in this paper, we establish a three-phase distorted m-sequence dynamic test (DmDT) signal to reflect typical intrinsic characteristics of LPDL. Meanwhile, for testing the dynamic error of electricity meter, we propose a novel likelihood function indirect testing method, which is validated by experiments. The uncertainty evaluation is also provided.

II. DISTORTED M-SEQUENCE DYNAMIC TEST SIGNAL MODELLING

A. Typical Intrinsic Characteristic of LPDL

Until now, the characteristic analysis of dynamic loads has focused on the load profiles at macroscopic time scales, such as daily, weekly, monthly and yearly profiles. In this paper, by sampling instantaneous current and power waveforms of electric arc furnace and high speed electrified railway from point of common coupling (PCC), we analyze the typical intrinsic characteristics in the range of 0~3200 second of LPDL. Meanwhile, we summarize the typical intrinsic characteristics in Table 1. These characteristics are main factors that determine the dynamic errors of electricity meters.

Table 1. Typical intrinsic characteristics of LPDL.

Load voltage	
1	Nearly steady-state
2	Harmonic distortion
Load current and active power	
1	Amplitude cyclically change
2	Harmonic distortion
3	Amplitude random fluctuation in cyclical period
4	Amplitude aysmtotic Gaussian distribution

B. Distorted m-sequence dynamic test signal model

According to IEC 62052-11, the distorted steady-state test voltage $u_k^s(t)$ and current $i_k^s(t)$ are given as follows

$$u_k^s(t) = U_k\left[\sum_{n_1=1}^{L_k} A_{kn_1}\sin\left(n_1\omega_1 t + \phi_{kn_1}\right)\right] \tag{1}$$

$$i_k^s(t) = I_k\left[\sum_{n_2=1}^{l_k} B_{kn_2}\sin\left(n_2\omega_1 t + \varphi_{kn_2}\right)\right] \tag{2}$$

where $k = a,b,c$ represents the A-phase, B-phase and C-phase. U_k and I_k are the fundamental amplitudes of voltage and current. n_1 and n_2 are the harmonic orders of voltage and current. A_{kn_1} and B_{kn_2} are the relative amplitudes of harmonic components to fundamental amplitudes, $A_{kn_1} = B_{kn_2}$ =1. ω_1 is the angular frequency and $\omega_1 = 2\pi f_1$, f_1 is the fundamental frequency and f_1 =50Hz. T is the fundamental period and $T = 1/f_1$. ϕ_{kn_1} and φ_{kn_2} are the phase angles of harmonic components.

In the fundamental period of voltage and current, we define a series of rectangular window function as

$$g_n(t) = \begin{cases} 1, t \in \left[t_0 + (n-1)T, t_0 + nT\right] \\ 0, t \notin \left[t_0 + (n-1)T, t_0 + nT\right] \end{cases} \quad n = 1,2,\cdots,N \tag{3}$$

where t_0 is signal zero crossing time. We truncate $u_k^s(t)$ and $i_k^s(t)$ by the window functions in every period T

$$u_{kn}^s(t) = u_k^s(t)g_n(t) = U_k\left[\sum_{n_1=1}^{L_k} A_{kn_1}\sin\left(n_1\omega_1 t + \phi_{kn_1}\right)\right]g_n(t) \tag{4}$$

$$i_{kn}^s(t) = i_k^s(t)g_n(t) = I_k\left[\sum_{n_2=1}^{l_k} B_{kn_2}\sin\left(n_2\omega_1 t + \varphi_{kn_2}\right)\right]g_n(t) \tag{5}$$

Therefore, we define function vectors of distorted steady-state test voltage and current as

$$\mathbf{u}_k^s = \left[u_{k0}^s(t), u_{k1}^s(t), \cdots, u_{kN}^s(t)\right] \tag{6}$$

$$\mathbf{I}_k^s = \left[i_{k0}^s(t), i_{k1}^s(t), \cdots, i_{kN}^s(t)\right] \tag{7}$$

The m-sequences are binary {0,1} pseudorandom sequences with the following characteristics [5]:

1) Amplitude random fluctuation in cyclical period.

2) Amplitude cyclically change at macroscopic time.

3) Asymptotic Gaussian distribution of run-length.

It is worth noticing that the m-sequences have the similar characteristics of the load current and active power. Therefore, in order to obtain a dynamic test signal, we define $\mathbf{I}^m$ as modulation operator

$$\mathbf{I}^m = \left[m(1), m(2), \cdots, m(N)\right] \tag{8}$$

By the vector operation of $\mathbf{I}_k^s$ and $\mathbf{I}^m$, we can obtain the distorted m-sequence dynamic test current vector as

$$\begin{aligned}\mathbf{I}_k^d = \mathbf{I}^m \odot \mathbf{I}_k^s &= \left[m(1), m(2), \cdots, m(N)\right] \odot \left[i_{k0}^s(t), i_{k1}^s(t), \cdots, i_{kN}^s(t)\right] \\ &= \left[m(1)i_{k0}^s(t), m(2)i_{k1}^s(t), \cdots, m(N)i_{kN}^s(t)\right]\end{aligned} \tag{9}$$

where ‘$\odot$’ denotes the Hadamard multiplication. (9) is the structured parameter model of DmDT current. By defining a matrix $\mathbf{E}' = [1,1,\cdots,1]_{N\times 1}^{\mathrm{T}}$, we can give the continuous time function of DmDT current $i_k^d(t)$ as

$$i_k^d(t) = \mathbf{I}_k^d\mathbf{E}' = \sum_{n=1}^{N} m(n)i_{kn}^s(t) = \sum_{n=1}^{N} i_{kn}^d(t) \tag{10}$$

Similarly, the distorted dynamic test power vector can be expressed as the Hadamard multiplication of $\mathbf{u}_k^s$ and $\mathbf{I}_k^d$

$$\begin{aligned}\mathbf{p}_k^d = \mathbf{u}_k^s \odot \mathbf{I}_k^d &= \left[u_{k1}^s(t), u_{k2}^s(t), \cdots, u_{kN}^s(t)\right] \odot \left[i_{k0}^d(t), i_{k1}^d(t), \cdots, i_{kN}^d(t)\right] \\ &= \left[m(1)u_{k1}^s(t)i_{k0}^s(t), m(2)u_{k2}^s(t)i_{k1}^s(t), \cdots, m(N)u_{kN}^s(t)i_{kN}^s(t)\right]\end{aligned} \tag{11}$$

The continuous time function of DmDT power signal can be restored by the inner multiplication of $\mathbf{u}_k^s$ and $\mathbf{I}_k^d$ as

$$p_k^d(t) = \left\langle \mathbf{u}_k^s, \mathbf{I}_k^d \right\rangle = \sum_{n=1}^{N} m(n)u_{kn}^s(t)i_{kn}^s(t) \tag{12}$$

The above (6), (9) and (11) give the structured parameter models of DmDT signals, the (1), (10) and (12) comprise the continuous time functions of DmDT signals.

III. DYNAMIC ERROR INDIRECT TESTING METHOD OF ELECTRICITY METER

A. Likelihood function indirect testing algorithm

Under DmDT signal condition, the dynamic error testing process of meter under testing (MUT) is shown in Fig. 1. The gate signal controls the time interval of DmDT power. During the testing process, the length of m-sequence is N_1. The accumulated dynamic electrical energy in every fundamental period is E_0 while $m(n) = 1$, on the contrary, the electrical energy is zero while $m(n) = 0$. Therefore, the dynamic reference electrical energy sequence can be expressed as

$$E_X(n) = m(n)E_0 \quad n = 1,2,\cdots,N_1 \tag{13}$$

According to the (14), the dynamic reference electrical energy sent to MUT is

$$E_{X0}(N_1) = \sum_{n=1}^{N_1} E_X(n) = \sum_{n=1}^{N_1} m(n)E_0 \tag{14}$$

The dynamic reference electrical energy is related to the total number of $m(n) = 1$. Therefore, we define a likelihood function of $m(n) = 1$ as

Definition 1. Likelihood function of $m(n) = 1$ for $p_k^d(t)$

$$L\left(p_k^d(t) \mid m(n) = 1\right) = p\left(m(n) = 1 \mid p_k^d(t)\right) = \frac{\sum_{n=1}^{N_1}\left(m(n) = 1\right)}{N_1} \tag{15}$$

On the contrary, different from the MUT, a standard meter is operated under steady-state condition, which can be considered as $m(n) = 1$ in every fundamental period. Therefore, the steady-state reference electrical energy measured by standard meter is

$$E_{S0}(N_1) = \sum_{n=1}^{N_1} E_0 = E_0 N_1 \tag{16}$$

Substituting the (15) and (16) into (14), the relationship of $E_{X0}(N_1)$ and $E_{S0}(N_1)$ is given as

$$\begin{aligned} E_{X0}(N_1) &= \sum_{n=1}^{N_1} m(n) E_0 = \frac{\sum_{n=1}^{N_1}(m(n)=1)}{N_1} E_0 N_1 \\ &= L\left(p_k^d(t) \mid m(n)=1\right) E_{S0}(N_1) \end{aligned} \tag{17}$$

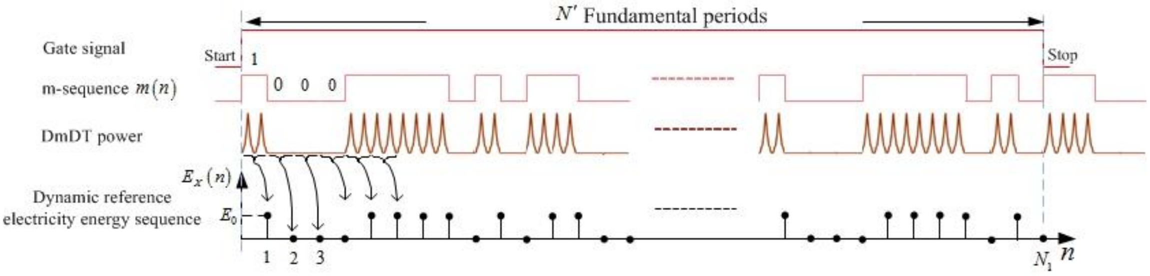

Fig. 1.Dynamic error testing process of MUT

It can be seen clearly from (17), the dynamic reference electrical energy $E_{X0}(N_1)$ can be traced to the steady-state reference electrical energy $E_{S0}(N_1)$. Assume that the actual dynamic electrical energy measured by MUT is $E_x(N_1)$. Accordingly, under DmDT signal condition, the dynamic error of MUT can be calculated as

$$e = \frac{E_x(N_1) - E_{X0}(N_1)}{E_{X0}(N_1)} \times 100\% \tag{18}$$

B. Dynamic error testing system

Based on the DmDT signal model, the dynamic error testing system is designed as shown in Fig. 2. The testing system consists of the electrical power standard (three-phase steady-state power source), standard meter, HE5025 dynamic error testing device and MUTs. The three-phase distorted steady-state test voltage $u_k^s(t)$ and current $i_k^s(t)$ are output from the electrical power standard, the steady-state reference electrical energy is obtained from standard meter. HE5025 dynamic error testing device is developed to generate the DmDT signal, which is sent to the MUTs. Meanwhile, the HE5025 also calculate and display the dynamic errors of MUTs.

IV. RESULTS AND DISCUSSIONS

A. Experiment of DmDT signal

Based on the Fig. 2, in experimental environment, a dynamic error testing system is built and the equipments in the system are listed in Table 2.The generation of the proposed DmDT signal is validated by experiments. Taking the peaked waveform stipulated in IEC 62052-11 as an example, the three-phase DmDT signals with peaked waveform are shown in Fig. 3.

B. Dynamic error testing experiments of MUTs

A series dynamic error testing experiments of MUT ① with class 1.0 is carried out under different DmDT signal conditions. The RMS of test voltage is 3×220V and the level of m-sequence in DmDT signal is 12 with 24 frequency division. Six types of test signals are generated and the power factor is 1.0. The standard meter constant is 50000imp/Wh and the constant of MUT ① is 400imp/kWh. The results are reported in Table 3.

With the distorted steady-state test signal, the steady-state error of MUT ① is -0.02%. However, when the test signals are the five types of DmDT signals, the MUT ① shows obvious dynamic errors. The results illustrate that the DmDT signal model and the likelihood function indirect testing algorithm are effectiveness for dynamic error testing of electricity meters.

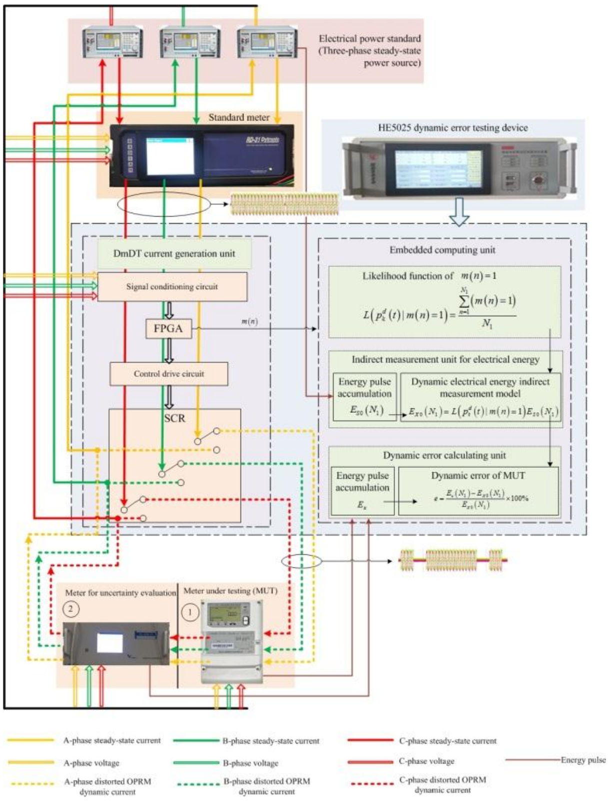

Fig. 2. Schematic of dynamic error testing system.

Table 2. Equipments for dynamic error testing.

Equipment	Type
Electrical power standard	Fluke 6100A
Standard meter	RD 31
Meter under testing ①	Three-phase four-wire electricity meter
Meter for uncertainty evaluation ②	Three-phase four-wire harmonic standard electricity meter

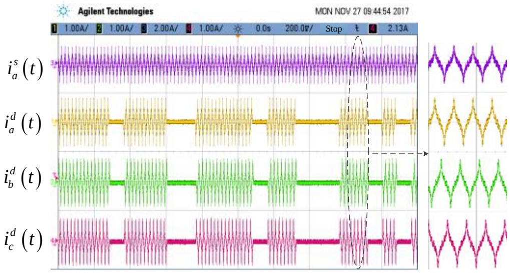

Fig. 3. DmDT current with peaked waveform.

Table 3. Dynamic errors of MUT ① with different DmDT signals.

Test signal	Steady-state reference electrical energy (Wh) E_{S0}	Dynamic reference electrical energy (Wh) E_{X0}	Measured dynamic electrical energy of MUT ① (Wh) E_x	Error (%) e
Distorted steady-state test current (RMS of test current=3×5A)	10.00208	10.00208	10.00000	-0.02
	10.00214	10.00214	10.00000	-0.02
	10.00206	10.00206	10.00000	-0.02
DmDT signal with fundamental waveform (RMS of test current=3×5A)	1897.687	953.482	900.000	-5.61
	1895.958	952.168	900.000	-5.48
	1887.080	947.326	900.000	-5.00
DmDT signal with quariform waveform (RMS of test current=3×5A)	1892.630	951.726	900.000	-5.43
	1889.888	950.247	900.000	-5.29
	1907.777	950.878	900.000	-5.35
DmDT signal with peaked waveform (RMS of test current =3×3A)	1135.751	571.714	540.000	-5.55
	1139.700	573.350	540.000	-5.82
	1138.685	573.608	540.000	-5.86
DmDT signal with pulse waveform (RMS of test current=3×2A)	760.091	383.442	360.000	-6.11
	765.323	382.357	360.000	-5.85
	769.138	384.842	360.000	-6.46
DmDT signal with multi zero crossing current waveform (RMS of test current=3×2A)	765.479	385.156	360.000	-6.53
	765.552	384.331	360.000	-6.33
	766.904	383.943	360.000	-6.24

C. Uncertainty evaluation

According to the ISO GUM (guide to the uncertainty expression in measurement), the uncertainty of dynamic error testing system is evaluated as shown in Table 4.

Table 4. Uncertainty of dynamic error testing system.

Source of uncertainty	Symbol	Type	Uncertainty (%)
Repeatability of testing	u_{A1}	*A*	0.0013
Electrical power standard	u_{B1}	*B*	0.0136
Switching power loss	u_{B2}	*B*	0.0133
Testing algorithm	u_{B3}	*B*	0.0041
Combined uncertainty	/	/	0.0195
Expanded uncertainty (*k*=2)	/	/	0.0390

Under the condition of DmDT signal, the uncertainty of dynamic error testing system is 0.04% (*k*=2).

V. CONCLUSIONS

In this paper, a DmDT signal model is proposed to reflect the typical intrinsic characteristics of LPDL. Meanwhile, a likelihood function indirect dynamic error testing method of static electricity meter is proposed. In addition, a dynamic error testing system is built for generating the DmDT signal and testing the dynamic error of electricity meters. Experimental results verify the effectiveness of the DmDT signal model and the likelihood function indirect testing algorithm. The uncertainty of the dynamic error testing system is 0.04%.

VI. ACKNOWLEDGMENT

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REFERENCES

[1] Wang, X, Chen, J. et al., *OOK power model based dynamic error testing for smart electricity meter*, Measurement Science and Technology, vol 28, no. 2, 2017, 025015.

[2] Electricity metering equipment (a.c.) general requirements, tests and test conditions-part 11: Metering equipment IEC EN 62052-11, Mar 2003.

[3] Gallo, D, Landi, A. et al., *A new methodological approach to quality assurance of energy meters under nonsinusoidal conditions*, IEEE Transaction on Instrumentation and Measurement, vol 56, no. 5, Oct 2007, pp. 1694-1702.

[4] Lu, Z and Eddy, S, *A proposal for verifying the performance specifications of certain functions of smart meters in distribution power line networks*, Proc. of Conf. on Precision Electromagnetic Measurements(CPEM) IEEE, Daejeon, June 13-18, 2010, pp. 271-272.

[5] Cohn, M and Lempel, A, *On fast m-sequence transforms*, IEEE Transaction on Information Theory, vol 23, no. 1, Jan 1977, pp. 135-137.