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Analysis of the Frame Loss Influence on the Digital Input Electricity Meters

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Abstract. Currently, verification regulation and related technical specifications about digital input electricity meter are being drawn up. In order to provide reference information for the technical specifications in relevant technical standards and strengthen quality control for digital input electricity meters, based on the previous research on the test projects of digital input electricity meter, the paper analysed the random frame-loss influence on the meter. The theoretical analysis and experimental tests showed that a 0.01% frame-drop rate had no effect on the metering performance. With the growing of the frame loss rate, the tested meters have different cutoff frame loss rate. The cutoff frame loss rate is far higher than 0.01%.

1 Introduction

With the construction of smart substation, digital input electricity meters were widely used. The national verification regulation about digital input electricity meter is in the process of being drawn up. Currently, the national recommended standard and the State Grid Corporation enterprise standards about digital meter have been released. But some technical index of digital input electricity meter follows the related electronic meter parameters [1, 2], which is difficult to control the quality of digital input electricity meter.

There have been studies on metering performance and test projects of digital input electricity meter [3]. How different algorithms affect the meters metering performance has also been analysed [4]. However, when the digital meter is in the field operating condition, the drop of data frames may happen, whose influence on the meters' metering performance has not been studied. Though there is a regulation that the meters' metering performance should not be influenced when the frame loss rate or frame drop rate is 0.01% [1], whether this index is appropriate needs to be researched. In this article, the influence of drop frames was analysed theoretically and experimentally. Also the experiment results were analysed.

2 Theoretical analysis

In the smart substation, the voltage and current can be sampled by the electronic transformer and the sampled data would be transmitted to the merging unit in the FT3 packets [5, 6]. The merging unit transforms the FT3 packets to IEC 61850-9-2 frames which contain the voltage and current sampled data [7, 8]. Then the frames will be sent to the meters through networking or point-to-point way. In the networking way, applying the Ethernet switches create a complicated and changing circumstance under the actual operation condition. External disturbance and network congestion can make some resource (like switch buffer, network bandwidth, and intelligent electronic device) not meet requirements, which may result in message delay. If the time delay exceeds intolerable staying time, the message will be dropped and then lead to frames loss. In addition, electromagnetic interference in power system will influence signal processing and signal transmission, which bring about byte error. If a communication failure occurs, frames loss may also occur in the data transmission process.

The instantaneous values of voltage u and current i can be supposed to be:

$$u = \sqrt{2} \times V \cos(\omega t) \tag{1}$$

$$i = \sqrt{2} \times I \cos(\omega t) \tag{2}$$

where V and I represent the effective value of the voltage and current, ω represents angular frequency.

The active power P can be defined as [9-10]:

$$P = \frac{1}{T}\int_0^T uidt \tag{3}$$

When the sum of dot product algorithm was chose, after the discretization of u and i, if N sampling points were taken from each cycle and n cycles were used to calculate the single-phase active power [11], there was:

$$P = \frac{1}{nN}\sum_{k=0}^{k=nN-1}[\sqrt{2}V\cos(\frac{2\pi k}{N})][\sqrt{2}I\cos(\frac{2\pi k}{N})] \tag{4}$$

where the k should be an integer.

When the packet loss occurred, retroactive interpolation of electric power energy was banned by the metrological law, so the loss data should be considered as zero. In this way, when the loss of packet occurred in the n computing cycles, the effective value of voltage V_l, current I_l, and active power P_l were as follows:

$$V_l = \sqrt{\frac{1}{nN}\sum_{k=0,\, k\neq j}^{k=nN-1}[\sqrt{2}V\cos(\frac{2\pi k}{N})]^2} \tag{5}$$

$$I_l = \sqrt{\frac{1}{nN}\sum_{k=0,k\neq j}^{k=nN-1}[\sqrt{2}I\cos(\frac{2\pi k}{N})]^2} \tag{6}$$

$$P_l = \frac{1}{nN}\sum_{k=0,k\neq j}^{k=nN-1}[\sqrt{2}V\cos(\frac{2\pi k}{N})][\sqrt{2}I\cos(\frac{2\pi k}{N})] \tag{7}$$

The error of active power ε_p in n cycles, which was caused by the loss of one packet, was as followed:

$$\varepsilon_p = \frac{P_l - P}{P}\times 100\% = -\frac{1}{nN}[\cos(\frac{4\pi j}{N}) + 1]\times 100\% \tag{8}$$

From (8), the error which was caused by the packet loss was always negative. The error of single-phase power which was caused by the packet loss was not constant, and changed with the changing of loss packet number j, sampling points N, and period n which were used to calculate the power.

When n equalled 50 and N equalled 80, we used MATLAB to calculate the active power and metering error within 1 second. The error curve was showed in Fig. 1.

From the curve, we could see that when the frame loss rate was $1/N$, the maximum sum of dot product algorithm metering error ε within N dots was:

$$\varepsilon = -\frac{2}{N}\times 100\% \tag{9}$$

When n was a constant, the error of active power changed with a period of $N/2f$ where f was the frequency of the voltage.

Conclusion could be known by the simulation that the error would be -0.05% when the biggest point was abandoned in the calculation and 10 cycles with 80 points per cycle was used. If the interpolation algorithm could be used for the losing points, the error would be the product of interpolation algorithm error ε_{insert} and ε. The error of the effective value, which was caused by the losing point, could be ignored, if the interpolation algorithm was excellent. Generally, the accuracy of the divalent algebraic precision of interpolation algorithm ε_{insert} could be 10^{-5} orders.

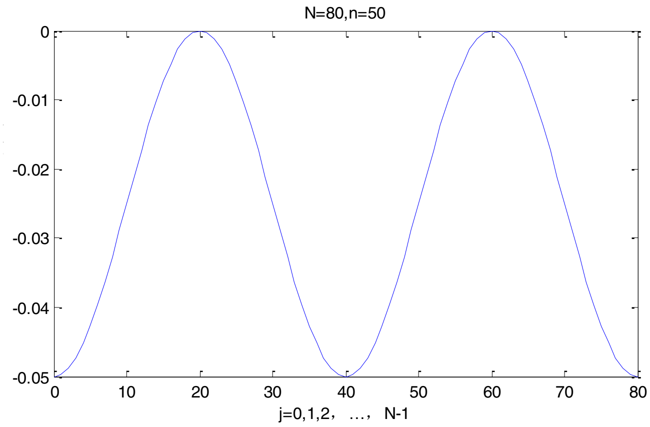

Figure 1. The active power error curve with frames loss

3 Experiment conditions and results

In this paper, the digital meters from C, W and L manufacturing enterprises were used as the tested meters. There were two meters from each manufacturer, which were numbered as C7395, C7394, W2310, W2303, L1 and L2. The measure uncertainty of the digital source output was 0.01% (k=2). Standard digital power source mode of the calibration system was used. The primary side reference voltage was 220kV, and the current was 600A. The rated voltage of meter was 3×57.7V, and the rated current were 3×1.5(6) A or 3×0.3(1.2) A. In the test, the second side reference voltage was 57.7V, and the current of C meters was 1.2A, while the one of L meters was 1.5A. The norms of tested meters are showed in Table 1. The reference condition and allowable variation in the experiment are showed in Table 2.

Table 1. The number and the norms of tested meters.

Number	Nominal Voltage and Current
C7394 C7395	U: 57.7V, I: 0.3(1.2)A
W2310 W2303	*U*: 57.7V, *I*: 1.5(6)A
L1 L2	*U*: 57.7V, *I*: 1.5(6)A

Table 2. Reference condition and allowable variation.

Reference condition	Value	Allowable variation

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Reference temperature	20°C	±1°C
Relative humidity	50%	±15%
Sampling rate	4kHz	/

The test applied virtual calibration method. The mode of virtual calibration outputted IEC 61850-9-2 frames to a digital input electricity meter. The digital input electricity meter accumulated electric energy and then output electric energy pulses to the pulse input port of digital input electricity meter calibrator. In the test, the IEC 61850-9-2 frames were generated by the calibrator itself and it did not need analog power source. The calibrator outputted data frames through optical fiber and received electric energy pulses from RS485 interface of the digital input electricity meter. The error of the digital input electricity meter can be calculated by comparing the information in data frames to the electric energy pulses. The different cases of frame loss could be set in the digital input electricity meter calibrator. The schematic diagram of digital input electricity meters experimental setup is illustrated in Fig. 2. The testing site for digital input electricity meters experiment is showed in Fig. 3. The pictures of human-computer interface of the calibrator are showed in Fig. 4.

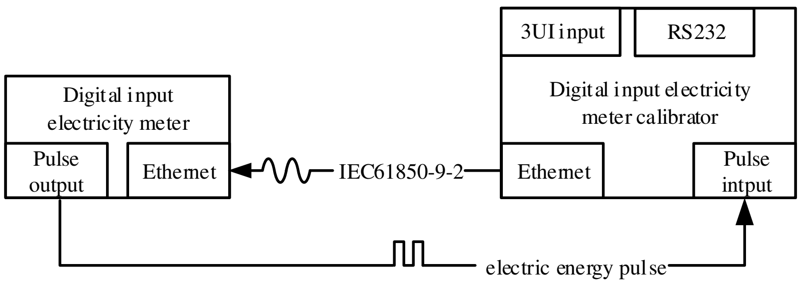

Figure 2. Schematic diagram of digital input electricity meters experimental setup

Figure 3. Standard digital power source and the meter being tested

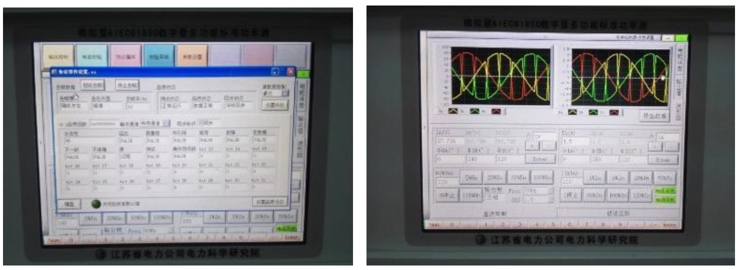

Figure **4.** Random frame-drop function of the standard digital power source

In the test, the standard energy values were calculated with no dropped frames, and the power factor was 1.0. Cut off rate of frame loss was defined in the test. It means that when the rate was higher than the cut off frame loss rate, the meter stopped calculating or could not calculate correctly.

During the experiment, the loss rate were increased from 0.01% to the cutoff loss rate. It can be noticed that when the frame loss rate was lower than 10%, the metering error and standard derivation of all the tested meters were not influenced at all. The experiment results are illustrated in Table 3.

For W meters, the error was about 0.05% when the loss rate was 10% and -0.29% when the loss rate was 66%.

For C meters, the display of the electrical parameters was zero, while the cut off loss rate was greater than 10%.

For L meters, the meter could not work, while the loss rate was greater than 66%. If the loss rate was lower than 66%, the L meters could calculate correctly and the metering performance was not influenced.

Table 3. Experiment results.

Measured value	Frame loss rate (0.01%~10%)					
	W2303	W2310	C7394	C7395	L1	L2
Mean (%)	0.0143	0.0142	-0.0020	-0.0023	-0.0007	-0.0003
S (%)	0.0002	0.0003	0.0063	0.0058	0.0062	0.0029
Cut off loss rate	67%		10%		66%	

4 Conclusion

The optical fiber was used in SV and GOOSE transmission, which required high transmission reliability in intelligent substation. So the rate of frame loss should be zero. Also the metering devices should identify the loss of data packets and the digital integrity required by the 'Q/GDW 393 Intelligent Substation Design Guidelines'. In the 'GB/T 17215.303-2013', the 5.5.8.3 clause requires that in the reference condition and the rate of frame loss should not exceed 0.01%, the metering accuracy should meet the corresponding accuracy requirements. The test results of the above meters could meet this requirement. But the requirement of error with frame loss is meaningless, as it is like the analysis of metering error in the status of current or voltage loss by the traditional electronic meters.

Another clause in the 'GB/T 17215.303-2013' should be followed when the loss of packet occurred. It could be described as follows: the digital electricity meter should record the events of the abnormal sampled value. When the bigger packets loss rate occurred, the meter should record the events and report the event to the back group or send out a warning. Then technicians would remove faults and resume the communication as soon as possible to avoid the leakage of power. The test results showed that the above meters of three types could do interpolation calculation accurately. There was no alarm of frame loss, so it should be suggested to add the alarm function of abnormal frame events other than the metering accuracy requirement with frame loss.

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