

## Sampling Data Identification In Smart Grid

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**KEYWORD:** abnormal sampling data; real identification; linear interpolation

**ABSTRACT:** The real-time identification of sampling data can avoid incorrect action of protection and monitoring device. It is difficult to distinguish abnormal sampling data and electric parameters in system failure for single sampling points. The existence of second derivative of electrical quantity in power system is proved firstly; the error between the adjacent remainder of Lagrange Linear Interpolation is deduced secondly; and the error threshold are given last. This method has the strong real-time processing capability and suitable for all kinds of relay protection and real-time systems such as measurement and control device.

### INTRODUCTION

With the construction of smart substation and intelligent transformation of the traditional substation, electronic transformer and merging unit are used more and more widely.

These sample data could easily be shared for installations (Xiao Shiwu et al. 2000). The substation works in a complex electromagnetism place and there is much disturbance, so it is likely to result in abnormal sampling data. The real-time identification of sampling data can avoid incorrect action of protection and monitoring device by abnormal sampling data.

It is difficult to distinguish abnormal sampling data and electric parameters in system failure for single sampling points.

The main bad data identifying for power system has long focused on the convergence of the sampling data in the power system state estimation (Wang Zhou et al. 2001). Researching on whether sampling data is normal is still insufficient.

Some atypical abnormal data could hardly be observed because of roughly quantitative of threshold in paper (Zou Junxiong et al. 2001). It is difficult to adapt to the continuous abnormal data detection based on wavelet transform because of large amount of calculation in paper.

Based on second derivative, judgment method of sampling data is presented and proved by linear interpolation. The abnormal samples data could be judged under the condition delay of three sample point. This method could be used for all kinds of protection and measurement-control device.

### Analysis of remainder of Lagrange Linear Interpolation about electrical quantities

In power system, current and voltage are indicated as following expression:

$$f(t) = \sum A_k \sin(k\omega t + q_k) e^{-t/T_k} + B e^{-t/T_0} \quad (1)$$

$k$  is the harmonic frequency, can be an integer and non-integer;  $A_k$  is  $k$ -harmonic amplitude,  $T_k$  is the decay time constant;  $\omega$  is the angular frequency of the power frequency;  $B$  is the amplitude of decaying aperiodic component,  $T_0$  is the decay time constant of  $B$ .

When the system is running normally, it could be regard as only fundamental component contained. The amplitude of harmonic components and the decaying aperiodic component are 0.  $f(t)$  is the smooth and derivable sine curve with second derivative. When the system failure occurs, voltage and current will be redistributed. Due to different fault point, different jump of electric quantity will arise, which will lead to discontinuity point of wave curves. But  $f(t)$  is still piecewise continuous as a curve of time. It can be easily found that the first derivative of  $f(t)$  is also piecewise continuous. By the analysis above, in addition to discontinuity point, electrical quantities is second derivative in power system.

$$f''(t) = \sum A_k \left[ (k\omega)^2 + \left( \frac{1}{T_k} \right)^2 \right] \sin(k\omega t + q_k - 2d_k) e^{-t/T_k} + \frac{B}{T_0^2} e^{-t/T_0} \quad d_k = \arctan(1 / k\omega T_k) \quad (2)$$

For four consecutive sampling of point electric parameters ,x1, x2, x3, x4, the sampling instant is  $t, t+\Delta t, t+2\Delta t$  and  $t+3\Delta t$  respectively ( $\Delta t$  as the sampling interval).

Using the Lagrange interpolation polynomial,  $x'_2$  can be observed by  $x_1$  and  $x_3$ ;  $x'_3$  can be observed by  $x_2$  and  $x_4$ . Formula as follows:

$$x'_2 = x_1 + \frac{x_3 - x_1}{2\Delta t} \Delta t = \frac{1}{2}(x_1 + x_3) \quad (3)$$

$$x'_3 = x_2 + \frac{x_4 - x_2}{2\Delta t} \Delta t = \frac{1}{2}(x_2 + x_4) \quad (4)$$

If the four sampling data is normal,  $f(t)$  is second derivative in  $(x_1, x_4)$  .

Based on Lagrange interpolation, the remainder of interpolation in points of  $x_2$  and  $x_3$  is represented as follows:

$$R(x_2) = x_2 - x'_2 = \frac{f''(e)}{2!} (t + \Delta t - t)(t + \Delta t - t - 2\Delta t) = -\frac{1}{2}(\Delta t)^2 f''(e_1) \quad e_1 \in (t, t + 2\Delta t) \quad (5)$$

$$R(x_3) = x_3 - x'_3 = \frac{f''(e)}{2!} (t + 2\Delta t - t - \Delta t)(t + 2\Delta t - t - 3\Delta t) = -\frac{1}{2}(\Delta t)^2 f''(e_2) \quad e_2 \in (t + \Delta t, t + 3\Delta t) \quad (6)$$

The numerical values of  $R(x_2)$  and  $R(x_3)$  are small and approximately the same, The  $f(t)$  is not second derivative in  $(x_1, x_4)$  , when the four points are abnormal sampling point.

### Layout of text The recognition of abnormal sampling data

The results show that the error between the adjacent remainder of Lagrange Linear Interpolation  $|R(x_2) - R(x_3)|$  is very small when the four points are normal sampling point. When the four points are abnormal sampling point,  $|R(x_2) - R(x_3)|$  is bigger. As follows is the condition that four consecutive sampling points are normal

$$|R(x_2) - R(x_3)| < m \quad (7)$$

$\mu$  is the threshold of the error between the adjacent remainder of Lagrange Linear Interpolation in derivable curve.

Set  $p_k = A_k / A_1$  is the ratio between  $k$  order harmonic amplitudes and fundamental voltage amplitude. If we choose  $m_1 = \sum p_k k^3$  as reliable coefficient, then

$$m = \frac{3}{2} m_1 A_1 (\Delta t \omega)^3 \quad (8)$$

The expression of  $\mu$  has parameters:  $\Delta t$ 、 $\omega$ 、 $m_1$  and  $A_1$ .  $\omega$  is the angular frequency of the power frequency;  $\Delta t$  is the sampling interval ; The sampling frequency of smart substation  $f_s = 4\text{kHz}$ , corresponding  $\Delta t = 0.00025\text{s}$ .

And considering that the three harmonics is relatively large in the system,  $m_1$  is based on 30% of three harmonic to calculation

$$m_1 = 1 + 0.3 \times 3^3 \approx 9 \quad (9)$$

So,

$$m = \frac{3}{2} m_1 A_1 (\Delta t \omega)^3 = 1.5 \times 9 \times (100\pi \times 0.00025)^3 A_1 = 0.0065 A_1 \quad (10)$$

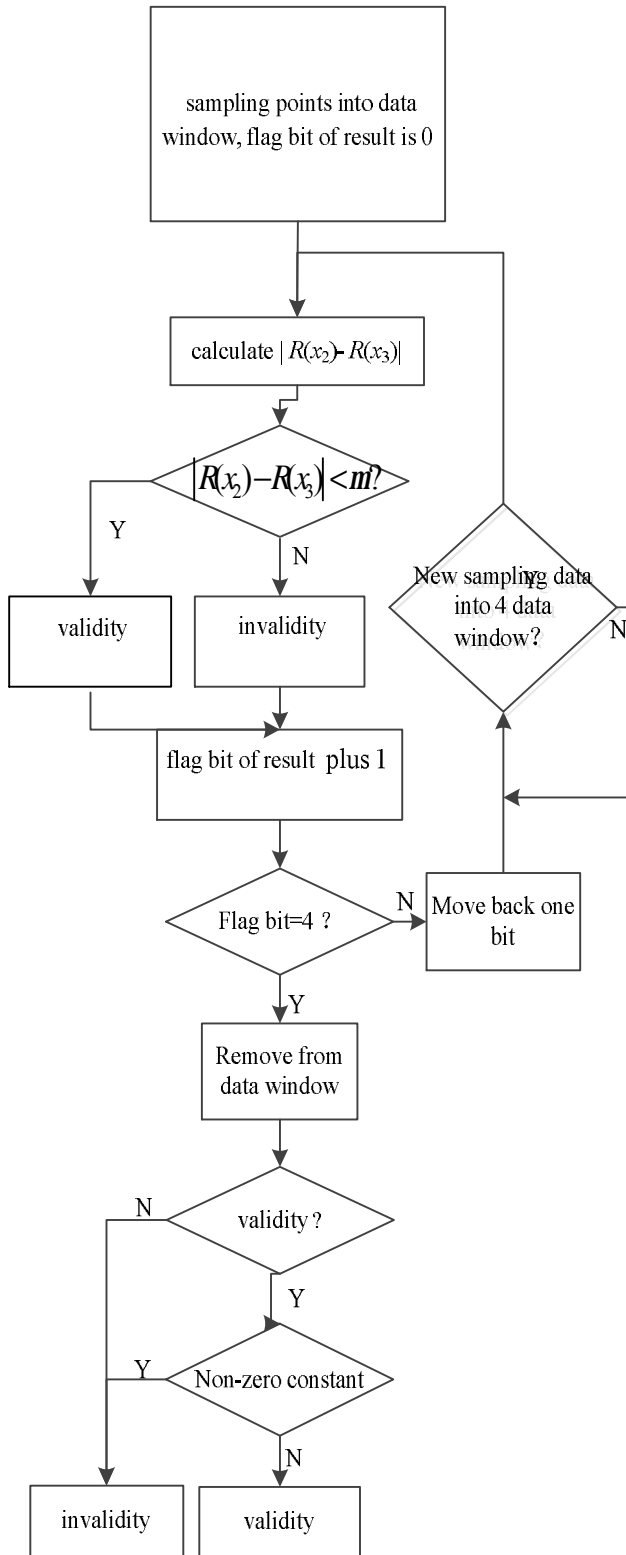


Figure 1. process diagram of discriminance .

According to the characteristics of periodical voltage and current, when the sampling data in a certain period of time (a quarter cycle) keeps a non-zero value, sampling circuit is unusual, and sampling data is invalid.

After setting  $\mu$ , therefore, if the sampling values not a zero constant, effectiveness can be determine by the following way: for any of four consecutive sampling points, if error of remainder of interpolation in the second and the third point meets the requirements of Formula, they are all normal samples dates.

Otherwise, there are at least one invalid sampling data. After a sampling point entering the data window, if  $|R(x_2) - R(x_3)| < \mu$ , The four sampling points in data window would be considered effective, setting flag bit of result 0; otherwise, result would not be acceptable, setting flag bit of result is 1; Then, each point data in the data window was moved back and new sampling point would be moved in, recycling process of the relationship between  $|R(x_2) - R(x_3)|$  and  $\mu$  made our determination. In this way, each sample point from moving in to remove in the data window, would attend four effective judgment. The process diagram is shown in Figure 1.

If the sampling point in four judgments has been considered to be normal and its values are not for nonzero constant, then the sampling data is valid data.

For any normal data, if four judgments are at least once judged as normal, the sampling points was eventually considered to be normal.

### Simulation verification

In this paper, an example from current sampling in faults of a high voltage line was studied, and it was shown that the proposed method was feasible. High-voltage lines with series capacitor compensation and Shunt Reactor is 330 kv and 250 km, fault-current under three-phase short-circuiting:  $i(t) = \sqrt{2} \times 392 \times \sin(\omega t - 71^\circ) + \sqrt{2} \times 99 \times \sin(96^\circ) e^{-34t} + \sqrt{2} \times 496 \times \cos(68t + 52^\circ) e^{-29t} - \sqrt{2} \times 15 \times \cos(1760t) e^{-24t}$  A, the waveform is shown in figure 2.

In normal working, load current is 50A,  $A_1$  can be set 20 times as large as normal load current 1000A, sampling frequency  $f_s = 4\text{kHz}$ , and  $m_1 = 9$ , the threshold of error between remainder of Lagrange linear interpolation in second derivative curve is  $\mu = 1.5m_1A_1(\Delta t\omega)^3 = 6.5404\text{A}$ .

Separated by a period of sampling points, ie, stacking random value for one to three point, then, sample data was considered by the proposed method in our paper. The simulation results are shown in Figure 3 and Figure 4. The sampling data for invalid data is 1.

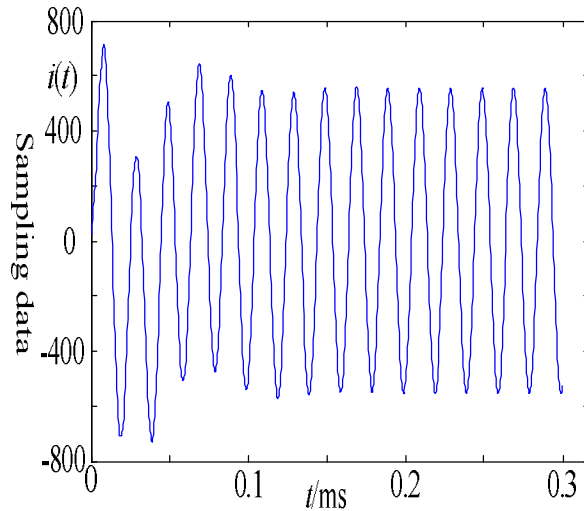


Figure 2 Original waveform figure to sampling

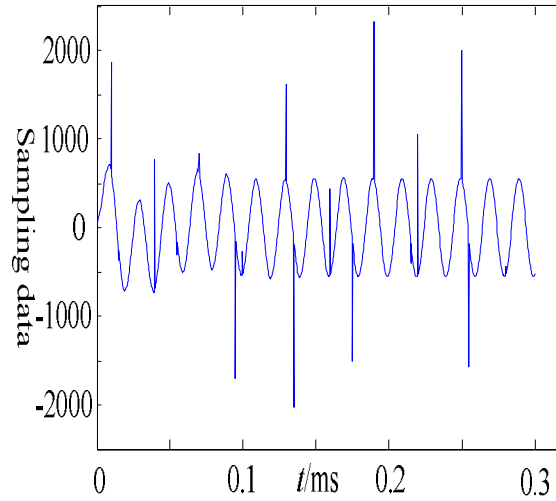


Figure 3 simulation diagram of stacking (noisy data sampling waveform graph after stacking noisy data)

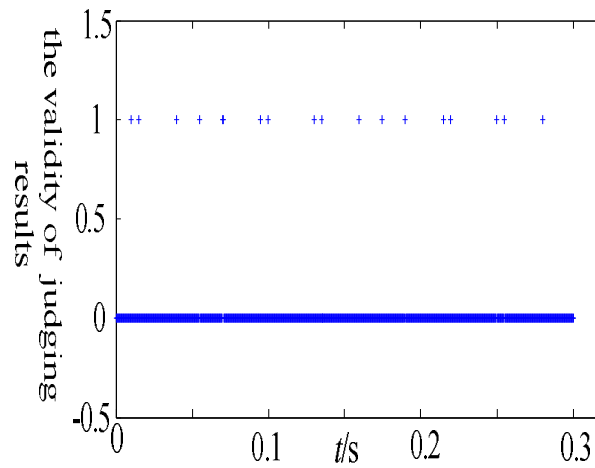


Figure 4 simulation diagram of stacking noisy data(the validity of judging results)

## Conclusion

This paper presented a real-time estimation scheme about validity of sampling data based on linear interpolation.

The method is accurate and reliable. Even small abnormal disturbance could be detected. Abnormal sampling data could be detected regardless of a single or multiple consecutive abnormal sampling data. This method has the strong real-time processing capability and suitable for all kinds of relay protection and real-time systems such as measurement and control device.

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