A Research on Implementing GPS to Synchronize Sampling in a Disturbed Phase Difference's High-precision Measure System for Insulation Testing

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Keywords: GPS; PPS Pulse; synchronizing sample; Dielectric loss; Orthogonal algorithm.

Abstract. It's been widely used that Synchronize data Sampling with GPS clock. But, the precision should be improved when it's used for dielectric loss test in a substation. In this article, it's studied that a portable testing system which based on high-precision sampling synchronously with GPS and wireless. It's introduced about the theory, design of hardware and software, error of synchronizing sampling. The cause for orthogonal algorithm's error is analyzed, and a reformative algorithm is proposed to improve the precision. The algorithm's influence and synchronize performance were studied with comparison. The system's performance was tested. It shows the system can measure phase difference with very high precision, and the error is less than 0.05%, which can be used for relative dielectric loss measurement.

Introduction

The Global Positioning System（GPS） has been widely used since birth. Because GPS contained precise clock time and frequency information can be published on space satellite GPS system. In addition to GPS navigation, positioning, measurement, GPS can used in precise time or frequency control of laboratory services for many projects.

Geographically widespread power system equipment, so when the GPS synchronization technology award in the power system has been widely used.

Computer power system protection, monitoring, fault location, phase measurement, would require accurate time control and synchronization control. Different application methods need different time accuracy requirements. Network mode correct local network. The exchange of information of time coordinate can achieve the accuracy of 1ms. But some data accuracy is not enough in the regional of collection or measurement applications. High voltage insulation test equipment is an important test project in the power systems. Among them, the realization of the live line measurement of dielectric loss can grasp the insulated equipment to improve reliability. Dielectric loss measurement, the need for high-precision measurement phase.

GPS can provide an error of less than 1μs high-precision clock. Therefore, the GPS as a common time base of various devices can achieve high-precision synchronous sampling[1~5]. This paper deeply study GPS synchronization communication technology and insulating live detection technology. Through hardware and software design and algorithm improvement, high-precision acquisition devices distributed in the region synchronous acquisition and measurement technology phase. So phase measurement accuracy can achieve $\pm 2'$ and measurement accuracy of dielectric loss tan δ can achieve $\pm 0.05\%$. It fully meet the requirements to carry out live tests capacitance equipment.

Phase difference measurement methods

Dielectric loss factor (tan) is an important performance index of high-voltage electrical equipment insulation.

The measurements in dielectric of voltage and current of phase α_U, α_I can obtain dielectric loss tanδ according to the formula(1). Oiled paper insulation dielectric loss of normal value range from 0.1% to 0.8%.

$$\tan\delta=\tan(\pi/2-(\alpha_I-\alpha_U)) \quad (1)$$

Measuring the phase difference for a more wide-area applications, the above two methods do not apply. Measurement method using time synchronization, two separate measuring means, at the same time t_0 for data acquisition I_A, I_B, respectively, with respect to the time t_0 calculated the phase φ_A, φ_B, and then calculate the final phase difference α from equation (2):

$$\alpha=\varphi_A-\varphi_B \quad (2)$$

The method is required to communicate with the network. But also time-synchronized high, highly stable hardware and software required synergy and internal clock. Time synchronization performance and ultimately affect the performance of phase measurements. In this paper, GPS time synchronization technology to achieve high-precision measurement phase measurement of dielectric loss.

Phase algorithm analysis

Calculating the relative dielectric loss needs to calculate the phase. The phase of the merits of the algorithm will directly affect the final result. Numerical methods for the main phase include harmonic analysis method, Fourier transform, orthogonal algorithm[9]. This paper uses orthogonal algorithm. Orthogonal algorithm has a large number of small sample data computation, high stability multi-cycle measurement data. We can overcome the short-term advantages for the current wave disturbance. But conventional orthogonal algorithm error is still large. It need for further improvements to apply to high-precision measurement phase.

calculation of phase and amplitude numerical on orthogonal algorithm

Each acquisition module to obtain current waveform i(t). Current waveform include the direct current component, fundamental wave of angular frequency ω and higher harmonic (based on odd harmonics with 3,5,7 ...), from equation (5):

$$i(t)=I_0+I_1\sin(\omega t+\alpha_1)+I_3\sin(3\omega t+\alpha_3) \quad (5)$$

When conventional orthogonal algorithm standard wave $\sin\omega_0 t$ and $\cos\omega_0 t$ on angular frequency $\omega(\omega_0=\omega)$, respectively multiplied with i(t), the calculation integral of K on the whole cycle, the alternating component of the score is 0, straight component k1, k2 directly proportional to cosα、sinα, which can further calculate the phase and amplitude I.

When making method of orthogonal numerical, it handle in accordance with the following manner:

In the current sampling rate f_s sampling sequence of N samples:

$$I(i)=\{I_1,I_2,I_3,\ldots,I_N\}\text{ , where } i=0\ldots N \quad (6)$$

Then k1, k2 integral value is calculated as:

$$k_1=\sum_{i=0}^{N-1}\frac{1}{2f_s}\left[I_i\sin(\omega_0\frac{i}{f_s})+I_{i+1}\sin(\omega_0\frac{i+1}{f_s})\right] \quad (7)$$

$$k_2=\sum_{i=0}^{N-1}\frac{1}{2f_s}\left[I_i\cos(\omega_0\frac{i}{f_s})+I_{i+1}\cos(\omega_0\frac{i+1}{f_s})\right] \quad (8)$$

Above formula: N for K cycle of sampling points, f_s for Sampling rate, ω_0 for standard wave angular frequency.

$$I=\sqrt{k_1^2+k_2^2} \quad (9)$$

$$\alpha = \begin{cases} \tan^{-1}\frac{k_2}{k_1}, 当k_1 \geq 0时 \\ \pi - \tan^{-1}\frac{k_2}{k_1}, 当k_1 < 0时 \end{cases} \quad (10)$$

Each collection terminal according to formula (9), (10) to calculate the current amplitude I_n, I_x, phase α_n, α_x. According to equation (3), (4), calculate the relative value of dielectric loss tanΔ*d* and capacitance ratio Cx/Cn ultimately by the control computer.

Analysis and improvement of numerical algorithms

When *w* ≠*w*, in order to simplify the analysis, only consider the impact on the fundamental, the phase is calculated as follows:

$$\alpha' = \tan^{-1}\frac{k_2}{k_1} = \tan^{-1}\left[\tan(\alpha_1 + \frac{\Delta\omega K T_0}{2}) + \tan(\alpha_1 + \frac{\Delta\omega K T_0}{2})\frac{\Delta\omega}{\omega_0}\right] \quad (11)$$

Where: $\Delta w = w - w_0$, *w* for measured signal angular frequency, w_0 for standard wave angular frequency, $w_0 = 2\pi f_0$, a' for the calculation of phase; a_1 is the signal of the fundamental phase; T_0 is a standard wave period, $T_0 = 1/f_0$.

The relative dielectric loss of phase difference calculation error is:

$$\Delta\alpha = \Delta\alpha_{Ix} - \Delta\alpha_{In} \quad (12)$$

Reducing measurement error angular frequency *w* , it can significantly improve the accuracy of phase measurement. This article uses the high order low pass digital filter sampling data pretreatment in order to improve the accuracy of frequency measurement algorithm.

Test Data

Improved algorithm comparison test

When phase two is large, it can reflect the computational performance of Orthogonal algorithm. To test the algorithm, according to equation (1), (2) measurement of dielectric loss, that is a difference of about 90° measuring voltage U, current I phase difference calculation of dielectric loss. Standard dielectric loss is 0.31%, continuous measurement data 15, the test results shown in Fig1.

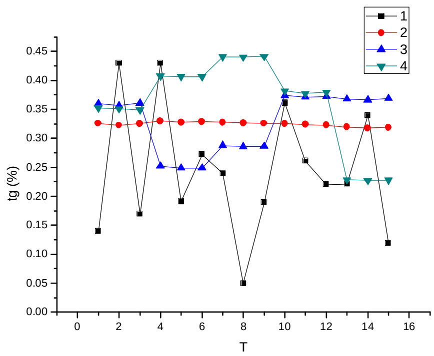

Figure1 Diagram of comparison for improved algorithm performance

Curve 1 is a conventional orthogonal algorithms, data fluctuations from 0.05% to 0.45%; Curve 2 is the second iteration of orthogonal improved algorithm, the results obtained by the same angular frequency. Curve 3 is calculated using the results of the respective angular frequency obtained. Curve 4 is the same angular frequency but phase-shifting algorithm uses the results obtained. Curve 3,4 fluctuations are larger. Curve 2 orthogonal algorithm improvements achieved fairly good results.

synchronization effect comparison test

The dielectric loss 0.25% of the sample testing compare PPS second pulse synchronization and wireless communications. Table 1 data show that under PPS synchronous mode. The data is stable and high dielectric loss, the maximum error of ＜0.025%. Synchronous mode wireless communication error is large. the maximum error ＜0.8%, much greater than the measured value itself. Less than the difference between the capacitance in both synchronous mode.

Table 1 Data comparison for PPS pulse synchronization model and wireless synchronization model

synchronization method	Ix(mA)	In(mA)	tanδ(%)	Cx/Cn
PPS second pulse synchronization	10.02276	24.07748	0.26455	2.402281
	10.02451	24.08193	0.265694	2.402304
	10.00229	24.02912	0.266839	2.402362
	10.00089	24.02526	0.271512	2.402312
	10.01875	24.06784	0.270844	2.40228
wireless communications	10.01236	24.04547	1.034455	2.402286
	10.01432	24.05345	0.745694	2.402297
	10.00325	24.06554	0.263676	2.402314
	10.00242	24.05345	0.571522	2.402301
	10.01356	24.05643	0.264844	2.402288

Conclusion

By use GPS PPS achieving second pulse synchronous acquisition within the region, this design achieve high-precision measurement phase. It carried out improvements the dielectric loss for high voltage equipment insulation test in the following areas:

(1) PPS second pulse direct hardware control mode start Σ-Δ type AD data acquisition and software flow control the timing of synergy is to achieve high-precision data acquisition synchronization.

(2) This paper improve orthogonal algorithm and the repeatability and stability of the data greatly. It reduce the phase difference calculation error.

(3) Test data show good performance synchronous measurement system, the relative dielectric loss measurement error <0.05%. It fully meet the dielectric loss insulation test precision requirements.

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