Online school frequency and time service of high precision clock based on the generalized regression model of GPS

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Abstract

In order to improve accuracy and stability of GPS wide area time service, this paper established generalized regression model of clock based on the different characteristics of GPS clock and crystal clock, and estimated crystal frequency by generalized least squares (GLS) method. Algorithm corrected the error caused by measurement value frequency drifting in the existing regression model, thereby realizing accurate estimation when crystal frequency drifting is large or interval of measurement value is long. Based on that, time service of pulse per second that is synchronous with coordinated universal time (UTC) was generated. Through phrase compensation algorithm, the phrase difference between the generated pulse per second and pulse per second GPS was corrected to realize accurate time service, thereby providing accurate time scale for wide area measurement and fault location and meeting the online wide area time service requirements of power system monitoring system.

Keywords: GPS, generalized regression model, high precision; least square method

1 Introduction

To a large extent, the development of technologies, like wide area measurement and fault location of power system, depends on the innovation of wide area time service technology. It is quiet important to label accurate wide area time label for sampled data using wide area time service technology [1]. GPS can provide all-whether time service all over the world, with biggest coverage area and highest accuracy. Moreover, it is not limited by geography and climate and convenient to receive. In the electrical power system synchronization phasor criteria published in 1998, IEEE power system relay protection recommended the implementation model of GPS in the synchronization phasor measurement. After that, an increasing number of experts pay attention to and study the wide area time service in the power system supervision field based on GPS. In article Key Technology in Beidou/GPS High-Precision Time Service Scheme for Smart Grid Construction [2], Zhao Dongyan, Yuan Yidong, Shi Lei and Zhang Haifeng put forward the three-mode dual channel and high-precision time service which can be used for smart power grid construction based on Beidou first generation system, Beidou second generation system and GPS system. The scheme has effectively guaranteed the accuracy of smart power grid cut time benchmark. In article Development of a Clock Synchronization Device Based on GPS and IEEE-1588 Protocol [3], Zhuang Yufei, Huang Qi and Jing Shi developed a kind of clock synchronization device using FPGA technology. The device can simultaneously experience IEEE-1588 and receive the second synchronous signal sent by GPD and IRIG-B code, which guarantees the accuracy and reliability of synchronous clock and meet the requirement of power system wide area measurement to synchronous clock. In article A New Time Provider for Wide-area Power System Stabilizer Control Engineering [4], Liu Zhixiong, et al discussed the requirements of time synchronization in wide area PSS control system. Aiming at the time synchronization application of PM U Server and control end, they put forward the clock generator which combines UPS time service and CPU time stamp counter (TSC), which is easy, reliable and of high accuracy. Experiment showed that this method could effectively provide the real time clock that meets the application of wide area PSS control engineer.

This paper concentrated on the online frequency correction and time service scheme of generalized regression model based on GPS. The existing research also showed that the time service scheme based on GPS and crystal oscillator can enhance GPS time accuracy, which also guaranteed the time service accuracy of GPS. However, all of schemes mentioned above neglected the frequency changes among measurement values. In other word, the counted value of crystal oscillator within certain period of time was served as the time value directly, which neglected the time deviation caused by crystal oscillator frequency drift during this period of time, and the model veracity also decreased. Therefore, this paper reconstructed the complementary clock regression model, and provided the scheme of high-accurate clock online frequency correction and time service.

2 Plan design for online frequency adjustment and time service of high precision clock

Structure of online frequency and time service of high precision clock designed is shown in figure 1:

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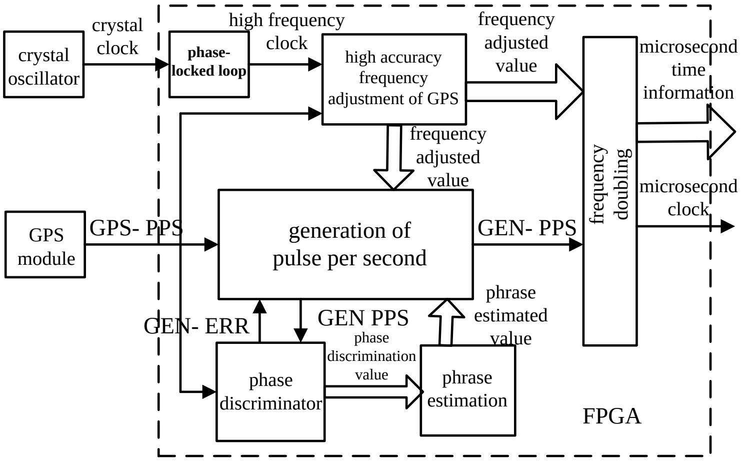

FIGURE 1 Structure diagram of online frequency adjustment and time service of high precision clock

In figure 1, online frequency adjustment and time service function of high precision clock is realized on FPGA platform. Crystal clock (50 MHz) is transformed into high frequency clock (250 MHz) through digital phase locked loop frequency doubling. Specific content of steps are as follows:

(1) Frequency adjustment. High accuracy frequency adjustment module estimates the accurate frequency of the current high frequency clock and realizes frequency adjustment through measuring high frequency clock count value of pulse per second GPS_ PPS when GPS is effective.

(2) Time service. Pulse per second generation module generates new pulse per second GEN_PPS according to frequency adjusted value and phrase estimation difference to realize time service function; phrase discriminator tracks the phrase difference of GPS_PPS and GEN_PPS, and phrase estimation module estimates time difference between GEN_PPS and coordinated universal time (UTC) and then feedback to pulse per second generation module for adjustment.

(3) Frequency doubling. Frequency doubling module performs frequency doubling on GEN_PPS to 1 MHz according to frequency adjusted value to realize microsecond level clock output.

3 Online frequency adjustment of high accuracy clock

3.1 GPS AND CRYSTAL CLOCK MODEL

Assessment of clock frequency generally includes accuracy and stability. Accuracy refers to the deviation degree of practical frequency and nominal value and stability refers to the fierce degree of random change of output frequency.

Crystal clock will be affected by component burn-in, environmental temperature and short-term disturbance. Among them, component burn-in is the irreversible tendency change and temperature drifting is reversible periodic change. Generally, random disturbance of crystal oscillator can be ignored since it is small. Therefore, crystal clock has high stability and accuracy can be affected by time and environment. GPS time output is affected by ephemeris change, satellite clock error, conduction error and receiver error. The amount of satellite meet the requirement and clock error basically meet normal distribution. In addition, GPS has no accumulated error in long term operation; therefore, it has high accuracy.

Thus it can be seen that GPS clock and crystal clock has complementary frequency characteristics. Adjusting crystal clock by GPS clock can improve accuracy and stability. Frequency measurement of complementary clock is shown in figure 2.

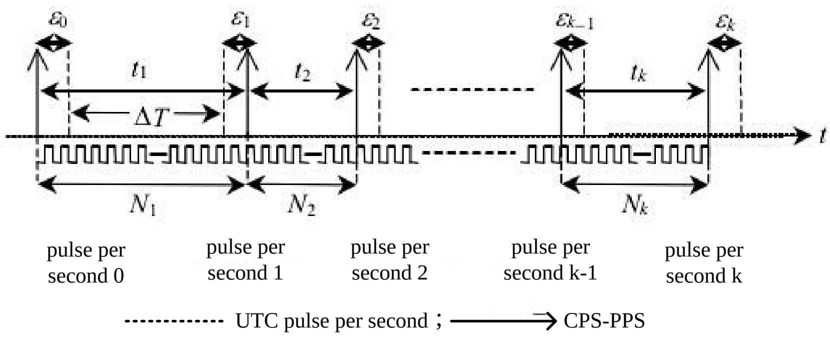

FIGURE 2 Frequency measurement of complementary clock

3.2 GLS ESTIMATION OF COMPLEMENTARY CLOCK MODEL

Least squares estimation, put forward by Gaussian in 1975, is the most widely used optimization algorithm at present. Its algorithm is simple without knowing the statistical information of the estimated subject and measurement value [5]. In generalized regression model, because noise sequence has no characteristics of white noise, although ordinary least square estimation algorithm has unbiasedness and consistency in specific condition, the result is no longer effective estimation. In order to solve the problem, GLS estimation based on relaxation iteration algorithm is introduced into whitening filter. After making preprocessing on data, related noise is transformed into white noise, and then ordinary least square method is adopted for obtaining model parameter. Steps for applying GLS on complementary clock model are as follows:

3.2.1 Suppose model order is n. Use N+n to input xk and output yk. GLS estimation is performed according to the following model.

$$a(z^{-1})y_k = b(z^{-1})x_k + v_k \tag{1}$$

$$\theta = [\hat{a}_n, \hat{a}_{n-1}, ..., \hat{a}_1, \hat{b}_n, \hat{b}_{n-1}, ..., \hat{b}_1]^T = (\Phi^T \Phi)^{-1} \Phi^T y \tag{2}$$

$$\Phi = \begin{bmatrix} -y_n \cdots -y_1 & x_n \cdots x_1 \\ -y_{n+1} \cdots -y_2 & x_{n+1} \cdots x_2 \\ \vdots & \\ -y_{n+N-1} \cdots -y_N & x_{n+N-1} \cdots x_N \end{bmatrix} \tag{3}$$

$$y = [y_{n+1}, y_{n+2}, ..., y_{n+N}]^T \tag{4}$$

3.2.2 Calculate residual sequence {ek}.

$$e_k = \hat{a}(z^{-1})y_k - \hat{b}(z^{-1})x_k \tag{5}$$

3.2.3 Suppose there is white noise sequence $\{\gamma_k\}$ *making the equation true*

$$e = \Omega c + \gamma \tag{6}$$

$$\Omega = \begin{bmatrix} -e_n & -e_{n-1} \cdots -e_{n-m+1} \\ -e_{n+1} & -e_n \cdots -e_{n-m+2} \\ \vdots & \\ -e_{n+N-1} & -e_{n+N-2} \cdots -e_{n+N-m} \end{bmatrix} \tag{7}$$

$$e = [e_{n+1}, e_{n+2}, ..., e_{n+N}]^T \tag{8}$$

$$c = [c_m, c_{m-1}, ..., c_1]^T \tag{9}$$

$$\gamma = [\gamma_{n+1}, \gamma_{n+2}, ..., \gamma_{n+N}]^T \tag{10}$$

Least square estimation of that model can be obtained, as follows.

$$c = (\Omega^T \Omega)^{-1} \Omega^T e \tag{11}$$

3.2.4 Update input and output value.

$$\hat{y}_k = y_k + c_m y_{k-1} + ... + c_1 y_{k-m} \tag{12}$$

$$\hat{x}_k = x_k + c_m x_{k-1} + ... + c_1 x_{k-m} \tag{13}$$

3.2.5 Substitute formula (16)- (18) into update data $\hat{x}_k$ *and* $\hat{y}_k$*, thus to estimate model parameter* $\hat{\theta}$ *again.*

3.2.6 Test whether parameter $\hat{\theta}$ *meet the requirement. If not, then return to step 2); if it is, then use* $\hat{\theta}$ *to estimate deterministic trend* $\hat{y}_k$ *and frequency estimated value.*

$$a(z^{-1})\tilde{y}_k = b(z^{-1})x_k \tag{14}$$

$$\hat{f}_k = e^{\tilde{y}_k} \tag{15}$$

In formula, $\hat{f}_k$ is crystal frequency estimated value.

Online frequency adjustment procedure of high accuracy clock can be designed using complementary clock model and GLS estimation algorithm mentioned above, as shown in figure 3:

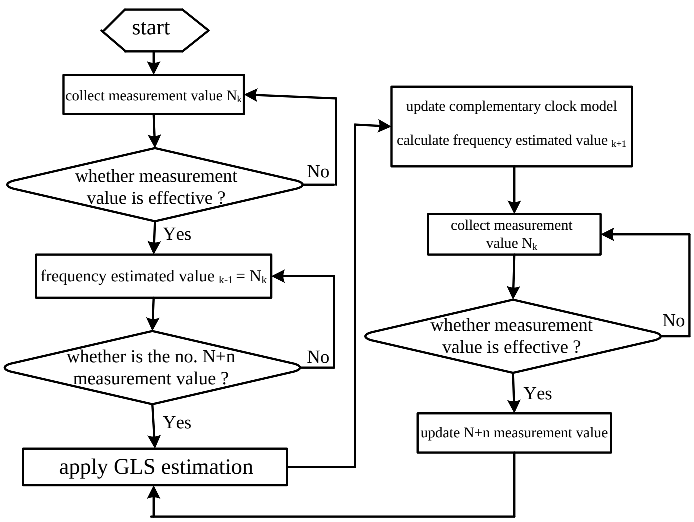

FIGURE 3 Flow chart of online frequency adjustment of high precision clock

4 Accurate adjustment design of pulse per second phrase of time service

After obtaining the accurate frequency of crystal clock by clock frequency adjustment based on GPS, crystal clock can generate pulse signal GEN_PPS that is synchronous with pulse per second UTC. At that moment, time sequence of pulse per second UTC, GPS_PPS and GEN_PPS are shown in figure 4. Suppose estimated value of crystal frequency is ideal value, then the generated pulse per second GEN_PPS and pulse per second UTC are completely synchronous. Since pulse per second UTC is invisible, GEN_PPS is bound to have phrase difference with pulse per second UTC during generation. In order to eliminate that phrase difference, phrase discriminator is used to record phrase difference sequence {qk}. Then we can obtain the following relationship:

$$q_1 + q_2 + ... + q_T = Ta + (\varepsilon_1 + \varepsilon_2 + ...\varepsilon_T) \quad (16)$$

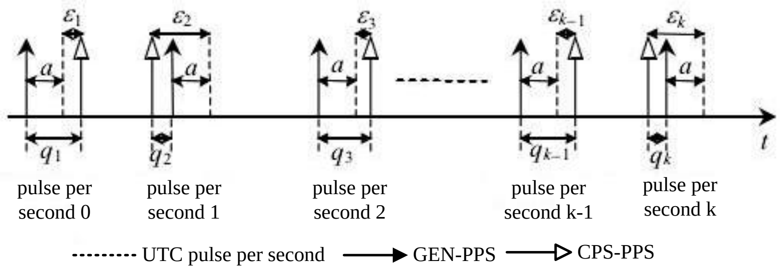

FIGURE 4 Time sequence figure of 3 kinds of pulse per second

It is known that GPS clock error sequence $\{\varepsilon_k\}$ is white noise that meet normal distribution $N(0,\sigma^2)$. Therefore, when T is big enough, then formula (16) can be transformed into

$$q_1 + q_2 + ... + q_T \approx Ta \Rightarrow a \approx (q_1 + q_2 + ...q_T)/T \quad (17)$$

Value of phrase error a can be obtained via formula (17). In the ideal condition, initial phrase error only needs one time of adjustment. In practice, tiny frequency estimation error can accumulate to large phrase error in long-term operation, since crystal frequency estimated value can not be completely accurate. Therefore, phrase error adjustment only performs at intervals, in order to endure the time service accuracy of generated pulse per second. The implementation flow is shown in figure 5:

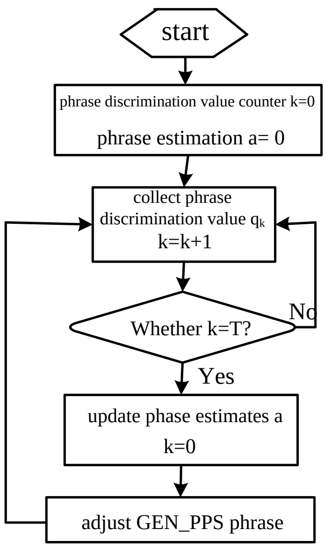

FIGURE 5 Flow chart of phrase error estimation

5 Conclusion

At present, some important fields such as power system, communication system, and industrial automation system all depend on synchronous clock to perform real time scheduling and control. These applications requires higher on the consistency and accuracy of clock in distribution system [6-7]. Aiming at the problems above, many scholars perform a large amount of researches, and also propose several valuable solutions [8-10]. Wide area time service plan implemented on FPGA platform was designed in this paper. This paper analyzed the accurate adjustment of pulse per second phrase of online frequency adjustment and time service of clock and designed accurate complementary clock model through analysis of characteristics of GPS clock and crystal clock. In addition, the requirement of that model conforming to generalized regression model was deduced, and frequency estimation recursive flow based on GLS was given. Aiming at accurate adjustment algorithm of pulse per second phrase, online implementation flow based on phrase adjustment algorithm was given. Experimental result proved that, frequency estimated value obtained by that algorithm has high accuracy of GPS clock, and its stability is also superior than GPS clock. The generated pulse per second and pulse per second UTC have good synchronism. After processing by phrase adjustment algorithm, phrase error between them was effectively eliminated, which meet the request of accurate wide area time service of power system?

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