TELKOMNIKA, Vol. 11, No. 6, June 2013, pp. 3172 ~ 3177
e-ISSN: 2087-278X

Study on Frequency Control Based on WTTP Frequency Detection Method

Zhanfeng Ying*, Yunyun Chen, Junji Wu
Nanjing University of Science & Technology, Nanjing, Jiangsu, 210094, China
Corresponding author, e-mail:yingzhanfeng@163.com, cyy19870104@yahoo.cn, wjj807@126.com

Abstract

For improving the precision of power system frequency control under the condition of noise and harmonic interference, a new power system frequency control algorithm is proposed based on WTTP frequency detection method, which is a combination of wavelet transform and three-point frequency detection method. Fundamental component can be extracted from distorted signal by wavelet transform under asynchronous sampling, and then three-point frequency detection method is used to detect fundamental component frequency. For improving the detection precision, error mathematics mechanism of three-point frequency detection method is analyzed and error mitigation method is proposed. Even though there is noise and harmonic interference in feedback loop, power system frequency can be controlled accurately and stably by applying WTTP frequency detection method to power system frequency control. Simulation results demonstrate the feasibility of algorithm.

Keywords: *noise and harmonic interference, wavelet transform, three-point frequency detection method, frequency control, frequency singularity*

1. Introduction

Power system frequency is an important characteristic parameter of power network signals and it can reflect supply and demand balance of active power. Abnormal frequency fluctuation will bring serious economic loss to user, even lead to power system instability and large area blackout when frequency fluctuates seriously. So power system frequency stability is an important condition in power system safe operation.

The important premise of frequency control is the frequency can be detected in high precision. The three-point frequency detection method [1-3] in the software algorithm of frequency detection has recently been widely used in engineering because of its simple principle and low computational complexity. But it requires that signal to be measured is distortionless sinusoidal signal. The frequency detection result error will be obvious if signal distorts. The influence of noise and harmonic to algorithm can be eliminated by using prefilter or harmonic detection algorithm, but filter will increase cost and it is uneasy to adjust filter's filtering characteristics. And other harmonic detection algorithms, such as DFT, FFT and instantaneous reactive power, are not suitable for three-point frequency detection method to detect frequency because these algorithms are established based on synchronized AC sampling. Wavelet transform theory [4-7] has recently developed widely. It can extract fundamental wave of signal under unsynchronized AC sampling. But at this time, some errors which called wavelet reconstruction errors probably exist in the reconstructed fundamental[8]. It can be easily found that if the three-point frequency detection method can mitigate wavelet reconstruction and noise errors, the fundamental wave frequency can be detected under combination with wavelet transform and three-point frequency detection method.

This paper proposes a new frequency detection method which named WTTP frequency detection method by combination of wavelet transform and three-point frequency detection method. For improving the detection precision, error mathematics mechanism of three-point frequency detection method is analyzed and error mitigation method is proposed. By applying WTTP frequency detection method to the power system frequency control, the frequency can be

Received January 16, 2013; Revised April 2, 2013; Accepted April 18, 2013

controlled accurately and stably even though there is noise and harmonic interference in feedback loop.

2. Wavelet Transform Theory

A assumed signal $f(t) \in L^2(R)$ can be expressed as $f(t) = \sum_k a_j(k)\phi_{j,k}(t) + \sum_j \sum_k d_j(k)\psi_{j,k}(t)$, where $\phi_{j,k}(t)$ is scaling function, $\psi_{j,k}(t)$ is wavelet function, and $\phi_{j,k}(t)$ and $\psi_{j,k}(t)$ are respectively standard orthonormal basis of scale space V_j and wavelet space W_j. The relationships between V_j and W_j are shown as $V_0 \supset V_1 \supset V_2 \ldots\ldots \supset V_j$ and $V_0 = V_1 \oplus W_1 = V_2 \oplus W_2 \oplus W_1 = \ldots = V_j \oplus W_j \oplus \ldots \oplus W_1$.

$a_j(k)$ and $d_j(k)$ can be solved fast using Mallat algorithm as follows:

$$a_{j+1}(k) = a_j(n) * h(-n)\big|_{n=2k} = a_j(n) * \tilde{h}(n)\big|_{n=2k}$$

$$d_{j+1}(k) = a_j(n) * g(-n)\big|_{n=2k} = a_j(n) * \tilde{g}(n)\big|_{n=2k}$$

where, $\tilde{h}(n)$ and $\tilde{g}(n)$ are respectively regarded as low-pass and high-pass analysis filter coefficient, they are complementary filter, and $\tilde{h}(n) = h(-n)$, $\tilde{g}(n) = g(-n)$. It is easy to found that $a_{j+1}(k)$ and $d_{j+1}(k)$ can be obtained by second decimation after the convolution of $a_j(k)$ to low-pass and high-pass filter. $a_{j+1}(k)$ and $d_{j+1}(k)$ respectively represent low frequency information and high frequency information of $f(t)$ in V_j. So wavelet decomposition process is equivalent to twice decomposition process of signal frequency band in V_j. That means, approximate coefficient $a_j(k)$ can be considered to represent only fundamental wave information when wavelet decomposition reaches the specific layer.

3. WTTP Frequency Detection Method

Derivation of WTTP Frequency Detection Method. Suppose that distortionless power network signal is $u(t) = U\sin(2\pi ft - \phi)$, where, f is real frequency of signal. With sampling frequency f_s, $u(t)$ is sampled. In the sample sequence, three sampling points that are respectively u_i, u_{i+m}, u_{i+2m}, are selected by equal time interval m/f_s. In order to distinguish from other sampling points, here u_i, u_{i+m}, u_{i+2m} are called detection points. Then m can be considered to be sampling period interval number of neighboring detection points. Suppose that $\theta = \omega m/f_s = 2\pi mf/f_s$, then $f = \theta f_s/(2\pi m)$. According to triangular transformation, $\theta = \arccos((u_i + u_{i+2m})/(2u_{i+m}))$ is obtained. So Eq. 1 can be obtained as follows:

$$f = \arccos((u_i + u_{i+2m})/(2u_{i+m}))\, f_s/(2\pi m). \tag{1}$$

where, u_{i+m} can't be zero, or Equation 1 has no meaning. The above frequency detection method is called three-point frequency detection method.

The three-point frequency detection method requires that the signal to be detected is of high precision and distortionless fundamental sine signal. If there is harmonic in the signal to be detected, the wavelet transform can be used to extract fundamental component firstly. And then, the frequency can be detected by using three-point frequency detection method. This new frequency detection method can be named WTTP frequency detection method.

Algorithm Error Mechanism. There are two reasons that cause some errors probably exist in the three detection points involved in calculation in three-point frequency detection method. The first reason is some errors called wavelet reconstruction errors probably exist in the reconstructed fundamental under asynchronous sampling. And the second is some noise may exist in the signal to be detected. The detection points error will influence the algorithm precision seriously, so the error mechanism is significance to research.

Suppose that a curve $y = f(x)$, y occurs error Δy when x occurs small error. Δy is approximate written to be $|\Delta y| \approx |y^{'}||\Delta x|$ according to the solving method for first derivative.

So, $|\Delta y|$ can be approximately expressed as product of $|y^{'}|$ and $|\Delta x|$. $|\Delta x|$ is generally small, so $|\Delta y|$ is determined by $|y^{'}|$ to a great extent. Then Equation 2 can be obtained according to Equation 1 as follows.

$$|y^{'}| = \left| f_s \big/ \left(2\pi mf \sin\left(2\pi mf / f_s\right)\right)\right|. \tag{2}$$

So the absolute value of $y^{'}$ is affected by f and m. If detection points occur error, frequency detection result error is closely related to real signal frequency and detection points' interval.

Error Mitigation Method. After error mechanism of WTTP frequency detection method is analysed, error can be mitigated. Algorithm result error is minimum when $|f_s / (2\pi m \sin(2\pi mf / f_s))|$ is minimum. But f is the variable to be measured, it is difficult to accurately calculate $|y^{'}|$. It is fortunate that power frequency of power network has small fluctuation in general case, and its fluctuation range is about $49Hz \sim 50Hz$. So the range of m and the optimal value of m can be estimated based on this range. The inverse cosine function range is $[0, \pi]$, so $0 \le 2\pi mf / f_s \le \pi$ can be obtained as follows according to Equation 1. Because maximum f is $51Hz$ and $m \ge 1$, the range of m can be written to be Equation 3 as follows.

$$1 \le m \le f_s / 102 \tag{3}$$

Equation 2 can be converted into $|y^{'}| = f_s \big/ \left(2\pi mf \sin\left(2\pi mf / f_s\right)\right)$ according to Equation 3. The relation curve between $|y^{'}|$ and m when f are respectively $49Hz$, $50Hz$ and $51Hz$ is shown in Figure 1. It is known that $|y^{'}|$ decreases radically and largely at first, then increases slowly and smally. So, a minimum point must exist in the $|y^{'}|$ in the range of m. The minimum value of $|y^{'}|$ can be solved by solving nonlinear equation which is Equation 4 as follows.

$$-f_s\left[\sin(2\pi mf / f_s) + 2\pi mf \cos(2\pi mf / f_s) / f_s\right] \big/ \left(2\pi f m^2 \sin^2(2\pi mf / f_s)\right) = 0 \tag{4}$$

It is difficult to get analytical solution of m, but its high precision approximate solution can be gotten by Newton Iteration Method. The round value of approximate solution is optimal m value which ensures algorithm precision. The optimal m value gotten by iteration under the condition that $f_s = 3.2KHz$ and f is respectively $49Hz$, $50Hz$ and $51Hz$ which is shown in Table. 1. It is known that the m value differs little when fluctuation of f is little, so $m = 20$ is approximately selected as the optimal value.

In the case of known f_s, above solving process to m can be completely calculated before frequency detection. Frequency result error can also be mitigated in the maximum degree by using the optimal m value when detection points occur some error. This has great significance.

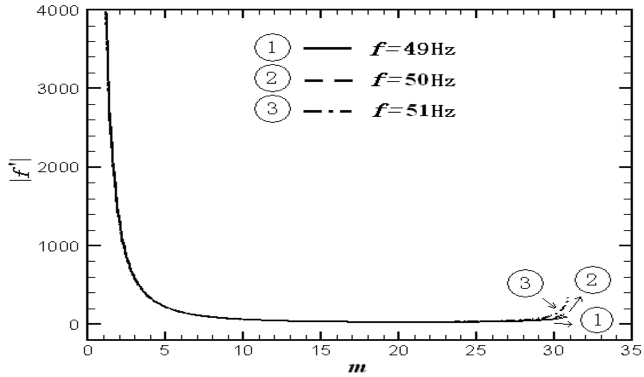

Figure 1. The Relation Curve Between $|y'|$ and m

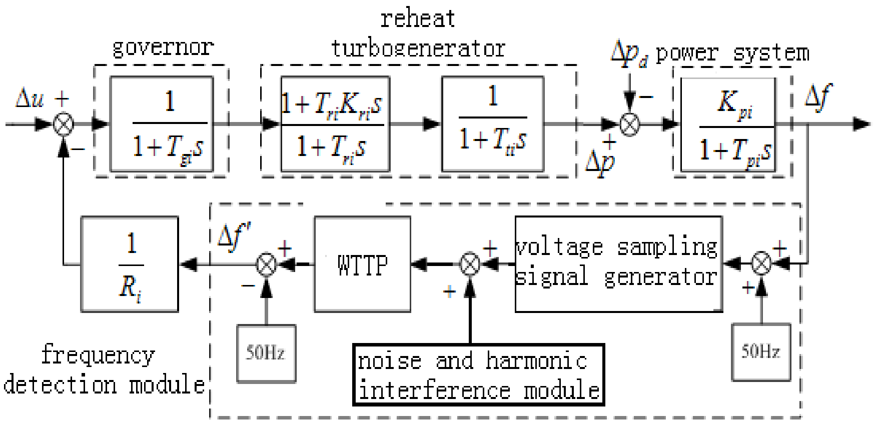

Figure 2. The Control Model of Power Frequency

Table 1. The m value when $f = 49Hz, 50Hz, 51Hz$

frequency(Hz)	m (approximate solution)	m (round value)
49	21.086	21
50	20.664	20
51	20.259	20

4. Control Model of Power Frequency

Basic task of power frequency control is adjusting generator speed. Power system is complicated nonlinear system and only occurs smaller load change, so linear model is often used to represent system dynamic characteristics. Therefore, without considering the governor dead time, this paper constructs the power frequency control model whose feedback loop adds WTTP frequency detection module for researching the influence of noise and harmonic to frequency control. The power frequency control model is shown in Figure 2.

In the model, power frequency is $50Hz$, Δu is system control variable quantity, Δf is real-time frequency error, and Δp_d is system load disturbance in Figure 2. Power system gain $K_{pi} = 120Hz/pu$, power system time constant $T_{pi} = 20s$, reheater gain $K_{ri} = 0.5$, reheater time constant $T_{ri} = 10s$, turbogenerator time constant $T_{ti} = 0.3s$, governor time constant $T_{gi} = 0.08s$, governor speed adjustment coefficient $R_i = 2.4s$. Above all parameters come from the literature [9]. A group $f_s = 3.2KHz$ of voltage sampling signal is constructed according to real-time power frequency $f = \Delta f + 50$ and expression $u(t) = U_m\sqrt{2}\sin(2\pi ft - \phi)$ in the voltage sampling signal generator, in which the voltage virtual value U_m and phase φ can be self set. The noise and harmonic interference module is used to add noise and harmonic into $u(t)$. WTTP module detect frequency using WTTP frequency detection method and it is written with Embedded Function in Matlab. $\Delta f^{'}$ is feedback frequency error.

5. Instance Simulation

Now simulation is carried out to Figure 2. Δp_d is zero, Δu is step signal, and signal power sent out from noise and harmonic generator is $\delta = 15dbw$. Frequency control results when there are no noise and harmonic in feedback loop are shown in Figure 3. Frequency control results when noise and harmonic exist in feedback loop and m is respectively 5, 10, 20, 29 are shown in Figure 4-7.

After comparing Figure 3 with Figure 6, it can be found that the two frequency control curves are basically similar, and there is only minimal steady-state error after system is steady in Figure 6. That is because frequency detection precision is high when m is optimal interval value and power frequency can be controlled accurately and stably even there are noise and harmonic interference in feedback loop. However, As Figure7, there may be large steady-state error when m is not the optimal value. As Figure 4 and Figure 5, the precision of frequency control decreases seriously and the frequency control curve occur in large fluctuation. So, WTTP frequency detection method in this paper can effectively improve the stability and accuracy under the condition of noise and harmonic interference.

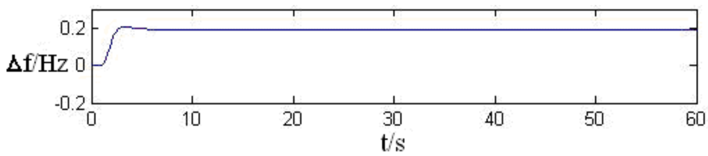

Figure 3. The Frequency Control Result No Noise And Harmonic

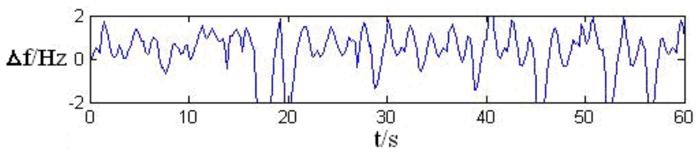

Figure 4. The Frequency Control Result When $m = 5$

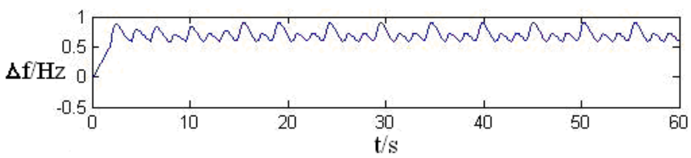

Figure 5. The Frequency Control Result When $m = 10$

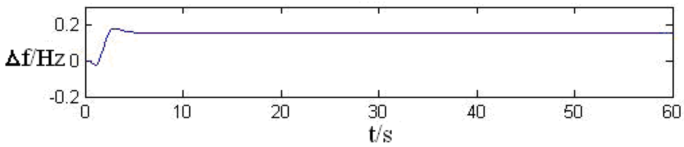

Figure 6. The Frequency Control Result When $m = 20$

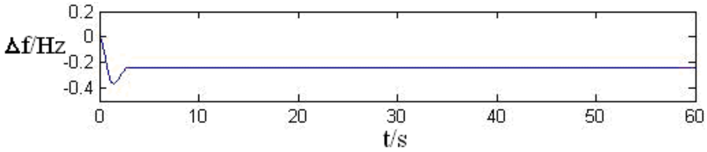

Figure 7. The Frequency Control Result When $m = 29$

6. Conclusion

After using error mitigation method, the frequency can be detected in high precision from distorted signal by combination of wavelet transform and three-point frequency detection method. Based on the high precision detection results, power frequency can be controlled accurately and stably even there are noise and harmonic interference in feedback loop.

References

[1] SY Xue, SX Yang. Accurate and Fast Frequency Tracking for Power System Signals. *IEEE International Conference on Systems, Man and Cybernetics, Montreal*. 2007; 2754-2759.

[2] R Aghazadeh, H Lesani, M Sanaye-Pasand, B Ganji. *New technique for frequency and amplitude estimation of power system signals.* IEE Proc. Gener. Transm. Distrib. 2005; 152: 435-440.

[3] HN Hong, XM Li. Three-point arithmetic for amendment AC sampling of fundamental wave frequency in power system. *High Voltage Engineering*. 2006; 32: 139-141. In Chinese.

[4] ZG Wang, SS Shi, D Wang. *A new harmonic analyzer based on Wavelet and virtual instrument*. International Conference on Intelligent Human-Machine Systems and Cybernetics. Hangzhou. 2009; 1: 253-255.

[5] S Sangeethapriya, M Prabhakar. *Harmonic Detection using Wavelet Transform*. Proceedings of International Joint Conference on Neural Networks. Montreal. 2005; 4: 2228-2231.

[6] C Jaipradidtham, V Kinnares. Discrete Wavelet Transform-Signal Processing for Harmonic Analysis of Electromagnetic Transients in 500 kV Single Circuit Transmission System. *IEEE International Symposium on Communications and Information Technology.* 2005; 1: 574-577.

[7] MY Xiao, HL Xiao. *The harmonic detection based on wavelet transform and FFT for electric arc furnaces*. Proceedings of the 2009 International Conference on Wavelet Analysis and Pattern Recognition. Baoding. 2009; 408- 412.

[8] XF Wang, KJ Xu. Fundamental wave extraction and frequency measurement based on wavelet transform*. Chinese Journal of Scientific Instrument*. 2005; 26: 146-151.

[9] Z. Li, L. H. Mou, W. H. Yang. Load frequency control identification using wavelet neural networks in power system. *RELAY*. 34(9): 34- 44.