分布式同步采集系统实质是一个同步数据采集和分析系统。该系统通过采集设备同步采集监测单元的数据信息，传输到计算机存储设备上；上位分析软件通过建模对监测单元的状态进行分析。

如图 6 所示，系统采用 IEEE 1588 协议实现数据采集同步，该系统主要由 IEEE 1588 时钟同步服务器、支 持 IEEE 1588 协议的采样模块、支持 IEEE 1588 协议的工业交换机，以及数据采集与分析服务器构成。

支持 IEEE 1588 采样模块每 1s 与时钟同步服务器进行一次同步，达到微秒级同步精度。数据采集与分析服务器用于控制和协调系统的工作，并实现对采样数据进行分析、处理、显示和存储等功能。

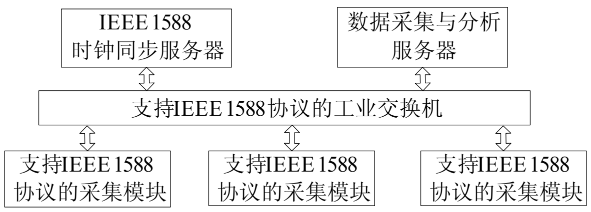

Fig. 6 The diagram of the distributed bridge structure monitoring system

图 6 分布式同步采集系统框图

4 实验及其结果

本系统同步采样的精度取决于各从时钟与时钟同步服务器精度[5]。

首先测试系统中的所有采样模块都与时钟同步服务器同步。由数据采集与分析服务器发送一条报文当作测试请求报文，该报文以组播方式发送，时钟同步服务器和采集模块接收到测试请求报文后，打上各自的本地时间戳放入测试响应报文中，然后向数据采集与分析服务器返回测试响应报文，数据采集与分析服务器收到测试响应报文后取出时间戳，采集模块与主时钟之间的时间戳的差便是要测试的时间同步偏差。考虑到设备本身存在硬件性能、软件性能的差异，即他们本身存在的反应速度差会给测试精度带来误差，为了减少误差，提高测试结果的准确精度，可以在测试之前先求出两者之间的反应速度偏差作为测试结果的修正值。测试偏差减去测试修正值得到时间同步精度。具体的流程如图 7 所示。对 6 个采样模块的测量结果如表 1 所示，该系统的时间同步精度优于 1μs。

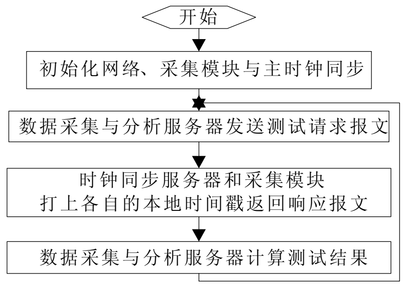

Fig. 7 The synchronous testing flow

图 7 同步测试流程图

5 结语

IEEE 1588 以太网精确时间同步技术能够在网内实现小于 1uS 的时钟抖动，这为分布式同步数据采集铺平了道路。同时 IEEE 1588 在设计时就特别考虑到尽量减少资源需求，对内存和 CPU 没有特殊要求，工作时只需要很少的带宽和监控，而且支持冗余主时钟，自动选取最佳时钟，可以在降低成本的同时可靠高效地为构建分布式同步采集系统服务。先期的研究成果表明 IEEE 1588 毫无疑问地会在分布式同步采集系统中取得巨大的成功。

但是由于 IEEE 1588 技术现推出的时间尚短，还有一些地方需要完善和修正。虽然它对透明网络可提供很好的定时同步，但仍未克服经过路由器等具有不确定性网络的定时，作为一种新兴的技术它尚未得到足够的实际应用。

References (参考文献)

[1] John C.Eidson, White Paper 1—the app location of IEEE 1588 to test and measurement system s[Z].December 20 th,2005.

[2] John C.Eidson, IEEE 1588 TM Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems[Z],2002.

[3] Utilization of Modern Switching Technology in EtherNet/ IP Networks,Anatoly Moldovansky, RTL IA 2002, 1st Int'l Work-shop on Real Time LANS in the Internet Age[Z]. Technical University of Vienna,Austria, June 18, 2002

[4] Evaluation of Timing Characteristics of Industrial Ethernet Networks Synchronized by means of IEEE 1588

[5] John C.Eidson , The Application of IEEE 1588 to Test and Measurement Systems , 2005,1

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The Hopf Bifurcation Phenomenon in Low Frequency Oscillation

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Abstract: LFO (Low Frequency Oscillation) is a main aspect that affects power system stability. In this paper, the inherent reason that causes LFO is discussed, with Hopf bifurcation theory, it is analyzed that the nonlinear singularity phenomenon happens near the critical points in a single-infinite power system of four-rank model. The study indicates that because of the Hopf bifurcation, singularity phenomenon in the power system happens near the critical points, which affects the stable bound.

Key words: LFO, Hopf bifurcation, nonlinear, singularity, stability

1 Introduction

When little disturbance occurs in power system, relative swing sometimes happens between the generator rotors, and the power of transmission lines will oscillate correspondingly, which leads to power being not transmitted abnormally, if the system damp is not enough, the system will lose dynamic stability, oscillation continuously between the rotors will happen. The oscillating frequency is low (about 0.2-2.5 Hz), called LFO (Low Frequency Oscillation). LFO occurred in foreign power system in 1950s, in china LFO is observed on the weak connecting line from Guangdong to Jiulong in 1979, thereafter the phenomenon appeared in power systems such as Hunan and Hubei, etc.

In general, it is considered that physical hypostasis of LFO is that the generator shafts swing as a rigid body, when the system damp torque is negative, amplitude increasing LFO occurs. In recent years, along with in-depth study about power system stability, it is discovered that besides negative damp causing LFO, singular phenomenon such as nonlinearity and chaos exits. The phenomenon is due to the nonlinearity of the system itself, which usually behaved differently from usual oscillation. In the mid 1980s, Abed and Varaiya firstly put forward the nonlinear singularity phenomena in power system, they pointed out that the phenomenon is caused by Hopf bifurcation[1]. And erenow，through studying Commonwealth Edison power system located in Chicago, the literature [2] had found the oscillation appeared near the imaginary axis of the linearization system model. In the article, without being pointed out straightforward, it is indicated strongly that the oscillation is the result of bifurcation. In1993, it is opened out in literature [3] that the amplitude increasing oscillation will ceased under approximately periodical little disturbance in quasi-infinite system.

According to the system model, the method to study power system LFO is classified into two: one is the little disturbance method based on linearized dynamic equation, the other is time domain simulation and bifurcation theory based on nonlinearity dynamic equation. The little disturbance method (eigenvalue analysis method) based on linearized dynamic equation has been an important method to study LFO for a long time. According to the theory, if only a pair of eigenvalues of the power system exist, whose real part is positive, and imaginary part is 0.4-0.5 π rad, and is strongly correlative with δ 、ω of the generators , the LFO with increasing amplitude will occurred. But in fact, since the power system is a nonlinear system, considering all nonlinear characteristic, nonexclusive solution , turning point and bifurcation point , singularity phenomenon will occurred near the imaginary axis of the system, i.e. near imaginary axis, even if all the eigenvalues of the system are located on the left of imaginary axis, LFO increasing amplitude resulted from bifurcation because of nonlinearity is likely to occur; on the contrary , even if a pair of conjugate eigenvalues are located on the right region near the imaginary axis, it is possible that the oscillation with increasing amplitude turns into stable and nonlinear oscillation owing to bifurcation. In essence ,the stability is different from Lyapunov stability , the latter is to study the system stability through changing its original condition, but if bifurcation is considered, the system topology configuration is changed, which represents a kind of 'jump' or ' saltation' of the system state .

2 Bifurcation Theory

Bifurcation phenomenon exists universally, which is an important characteristic of nonlinear system, it exists in various domain such as mathematics, physics, chemistry, economics, sociology, etc. for example, the phenomenon such as exclusive solution in mathematics, phase transition in physics, static and dynamical stability lost in engineering, domino effect in economics, periodical oscillation in electronics, dynamical stability analysis in power system, etc. all the foregoing phenomenon can be studied with bifurcation [4] [5] [6].

2.1 The Definition of Bifurcation

When the response of dynamical system transits from one kind to another, the phenomenon connecting the two responses is called bifurcation [5]. Strict and universal definition for bifurcation is as follows:

Definition suppose M is n dimension flow, consider the system defined on M

$$\frac{dx}{dt} = f(x, t, \varphi(x,t)) \quad (1)$$

$\varphi \in \Phi$, Φ is a class function, thereon measurement is defined, it can be a vector, or an operator (for infinite dimension). Solution space of equation (1) is marked as: $X=\{x(t);x(t) \in M\}$, equivalence class is introduced, namely $X=E_1 \cup E_2 \cup \cdots$, the equivalence class is not intersectant each other. (namely $E_i \cap E_j=\Phi$, when $i \neq j$) .

If exist $\varphi_0(x,t) \in \Phi$, for any $\varepsilon>0$, exist $\varphi_1, \varphi_2 \in \Phi$ satisfying $|\varphi_1-\varphi_0|<\varepsilon$ and $|\varphi_2-\varphi_0|<\varepsilon$

The solution of equations (2)

$$\begin{aligned} \frac{dx_1}{dt} &= f(x_1, t, \varphi_1(x_1, t)) \\ \frac{dx_2}{dt} &= f(x_2, t, \varphi_2(x_2, t)) \end{aligned} \quad (2)$$

$x_1(t)$, $x_2(t)$ belongs to respectively equivalent class, then $\varphi_0(x,t)$ is regards as a bifurcation point of the system of equation (1).

2.2 Hopf Bifurcation

In system denoted by equation (1), when $\varphi(x, t)=\mu$, the single parameter system will be found:

$$\dot{X} = F(X, \mu) \quad (3)$$

Here $X \in R_n$ is state variable, $\mu \in R$ is system parameter (control parameter).

Expand equation (3) at equilibrium point:

$$\dot{X} = AX + \hat{F}(X, \mu) \quad (4)$$

The solution $X(0, \mu)$ satisfying $F(X, \mu)=0$ is called the equilibrium state solution of equation (3), it is the final state of equation (1).

It is pointed out in bifurcation theory , for matrix A of equation (4) , when there is any eigenvalue with nonzero real part, equation (3) and (4) is topologically identical near the equilibrium point, singularity phenomenon occurs where zero eigenvalue of (μ) exists. If when $\mu=\mu_c$, $A(\mu)$ has zero eigenvalue through imaginary axis, static bifurcation will occur, which is called saddle bifurcation; If when $\mu=\mu_c$, $A(\mu)$ has a pair of conjugate eigenvalue through the imaginary axis, the bifurcation from equilibrium state to periodical solution will occur, which is called Hopf bifurcation.

According to Hopf bifurcation theory, It is known that if the curvature coefficient $\beta_2>0$, near the critical point, the system will suddenly get into nonlinear oscillation of unstable orbit from tending to be Lyapunov stable, which is called subcritical bifurcation; if $\beta_2<0$, near the critical point, the system will suddenly get into nonlinear oscillation (oscillation with equivalent amplitude) of the orbit being stable from being Lyapunov stable, which is called supercritical bifurcation. When the subcritical bifurcation occurs, if the crossing condition $\alpha(\mu_c)>0$, the bifurcation will occurs on the left of critical point; otherwise the bifurcation will occurs on the right of critical point. When supercritical bifurcation occurs, if the crossing condition $\alpha(\mu_c)>0$, the bifurcation will occur on the right of critical point, otherwise it will occur on the left critical point[4].

As far as the method to calculate the curvature coefficient β_2, for the system of two dimension (n=2), its easy to calculate β_2, the method is introduced in the literature [3], and for multidimensional system (n>2), the multidimensional nonlinear space must be simplified into low dimension flow, and the low dimensional flow reduced dimension must keep its original topological structure, namely its

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all original nonlinear characteristic can be kept. There are a few reductive means, such as centre flow theory, Lyapunov-Schmit method, etc. The centre flow theory is one of the most important methods [7], which is used to calculated β_2 in the article.

3 An Example for a Single Infinite System

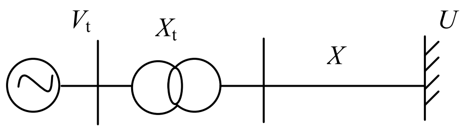

Figure1 a single-infinite power

In figure.1, capacitor and resistance of the line is ignored, voltage of the infinite system is $\dot{U}=1\angle 0$. The transfer function of the voltage self-regulation system adopting thyristor fast excitation $-\Delta F_{fd}/V_t= K_e/(1+T_e)$, K_e and T_e are respectively equivalent amplifying multiple and time constant of the excitation system, V_t is the outputting voltage of the generator. the system differential equation is [8]:

$$\begin{aligned} &\dot{\delta}=\omega_0(\omega-) \\ &\dot{\omega}=[P_m-P_e-D(\omega-)]/M \\ &\dot{E}_q'=(E_{fd}-E_q)/T_{d0}' \\ &\dot{E}_{fd}=(-E_{fd}-K_eV_t+K_eV_{t0}+E_{fd0})/T_e \end{aligned} \qquad (5)$$

The linearized differential equation is as follows:

$$\dot{X}=AX, \quad X=(\Delta\delta \quad \Delta\omega \quad \Delta E_q \quad \Delta E_{fd})^T \qquad (6)$$

The system parameter is:

x_d=0.982, x_d'=0.344, $x_e=x_t+x$=0.504, $x_{d\Sigma}=x_{q\Sigma}$=1.486, $X_{d\Sigma}'$=0.848, T_{d0}'=5.0, M=10, D=0.75, T_e=0.4, δ=49

The amplifying multiple is as control parameter μ of the system, the dynamic action near the critical point can be analyzed with Hopf bifurcation theory.

Firstly, $\mu_c=K_e$=39.41086 is calculated at the critical point , here system eigenvalues are {0±j5.886204, -1.462736±j3.367631}, by means of centre flow theory, the curvature coefficient β_2 and crossing condition $\alpha'(\mu)$ are calculated, according to Hopf bifurcarion theory, near the critical point, subcritical bifurcation occurs on the left of the critical point, the conclusion is: because of subcritical bifurcation occurs, in the neighborhood of $\mu<\mu_c$ ($K_e<K_{ec}$), the system dynamic response behaves singularity, namely even when the eigenvalue is still on the left of imaginary axes, the system is unstable, oscillation with increasing amplitude occurs. It can be validated with the step by step method.

Taking the input mechanical power ΔP_m as disturbing parameter, obviously at the equilibrium point P_m=1 (ΔP_m=0), if $K_e<K_{ec}$, the system eigenvalues are all on the left part of s plane, and the system is stable. After the little disturbance is introduced, let the system transit to balanceable state P_m=1.05, calculate equation (5) and (6), the curves is shown as figure 2 and figure 3.

It is shown in figure 2 and figure 3 that, when the little disturbance is introduced, if $K_e<K_{ec}$, the increasing amplitude LFO occurs in the nonlinear system, and the corresponding linear system is declined.

It is indicated by further analysis that, even if the operating parameter of the studied system is changed, the characteristic of subcritical bifurcation is unchangeable (shown in table 1).

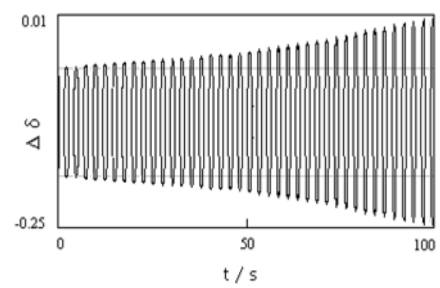

Figure 2 when Ke=39, the solution curve of equation (5)

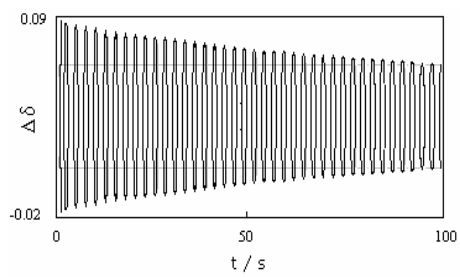

Figure 3 when Ke=39, the solution of equation(6)

Table 1. Ke is control parameter, Te=0.01,the calculation result with different δ (unit: degree)

δ	Kec	β	α´(μ)
20	55.0076	0.13378	0.076817
40	13.4897	0.10802	0.00927
60	8.25854	0.07278	0.00596
80	4.91799	0.06469	0.00084