

QPSK Signal Detection Based on Two Duffing Oscillator

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Abstract. Due to great noise interference and strong signal attenuation in low voltage power line, two Duffing oscillator methods is proposed to detect QPSK carrier signal. At the same time, after analyzing the law of system solution of Duffing Oscillator, the algorithm of difference distribution of system solution is proposed to identify phase transition, which can greatly decrease calculation. The experiment shows that two Duffing oscillator methods can detect the phase of QPSK signal accurately and obtain good detection effect in low SNR.

Keywords: Two Duffing Oscillator; QPSK; phase transition identification;

1. Introduction

Low voltage power line communication transmits digital messages in low voltage distribution networks, and the communication channel is very bad because of linking user end and complicated load environment, such as strong noise interference and large signal attenuation^[1]. Traditional methods are hard to detect signal accurately. Weak signal detection based on chaos Oscillator is a new method recently^[2-6]. Chaos Oscillator is very sensitive to weak signal and has strong immunity against noise. The key of this detection technology is phase transition identification. The methods of phase transition identification have Lyapunov exponent method^[7]、Floquet exponent method^[7]、Two-oscillator-difference chaotic identification^[8]、image recognition^[9] and so on. But these methods have complicated algorithms、large calculation、poor real-time.

This paper firstly shows that two Duffing Oscillator detects the phase of QPSK carrier signal. Secondly, this paper proposes a new kind of algorithm of difference distribution of system solution to identify phase transition. The numerical simulation and experimental test show that this method can obtain good effect in low SNR.

2. Two Duffing Oscillator Detection Principles

Duffing-Holmes equation is studied adequately in Chaos Oscillator weak signal detection field. The equation is:

$$\begin{cases} \dot{x} = y \\ \dot{y} + \xi y - x + x^3 = f \cos \omega t \end{cases} \quad (1)$$

where ξ is damping ratio, $f \cos \omega t$ is the periodic driving force. When amplitude f of the periodic driving force increases from 0, system will go through reappearing orbit、period-doubling bifurcation、Chaotic state、Large-scale periodic state. Phase diagram is usually used to study motion state of system. Figure 1 shows phase diagram of Chaotic state and Large-scale periodic state.

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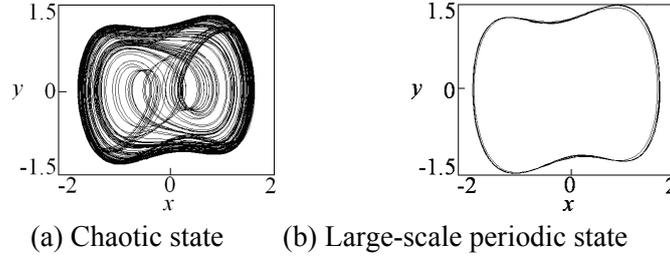


Figure 1. Phase diagram

Duffing Oscillator is very sensitive to amplitude f of the periodic driving force. When Duffing Oscillator is in chaotic state, weak change of amplitude f will cause system to transform from chaotic state to Large-scale periodic state, which is phase transition.

Fixing the periodic driving force, adding QPSK carrier signal that has the same frequency as the periodic driving force, two Duffing Oscillator carrier signal detection equation is:

$$\begin{cases} \dot{x}_1 = y_1 \\ y_1 + \zeta y_1 - x_1 + x_1^3 = f \cos \omega t + S \\ \dot{x}_2 = y_2 \\ y_2 + \zeta y_2 - x_2 + x_2^3 = f \cos(\omega t - \pi/2) + S \end{cases} \quad (2)$$

where S is QPSK carrier signal, which is described with $a \cos(\omega t + \tau)$. the phase τ of QPSK signal will cause the first and second Duffing Oscillator into different states, and the phase τ of QPSK can be identified by two Duffing Oscillator states. The detection rule is the following TABLE 1:

Table 1. Detection rule of the phase τ of QPSK signal

First Oscillator	Second oscillator	the phase τ
Large-scale periodic	Chaos	$(0, \pi/2)$
Chaos	Chaos	$(\pi/2, \pi)$
Chaos	Large-scale periodic	$(\pi, 3\pi/2)$
Large-scale periodic	Large-scale periodic	$(3\pi/2, 2\pi)$

So the key of two Duffing Oscillator detection methods is phase transition identification that is state identification. But at present identification algorithm have large calculation 、 poor real-time.

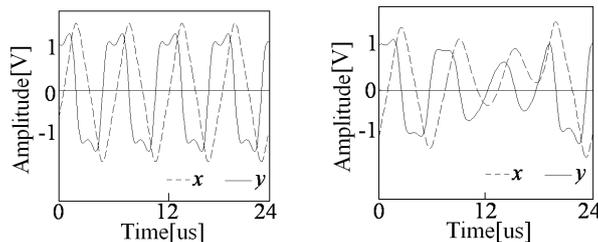
3. Difference Distribution Algorithm

This section analyzes system solution x and y of Duffing Oscillator, discovering rules of its phase variation, proposing a new kind of algorithm of difference distribution of system solution to identify phase transition.

3.1 Variation Rules of System Solution

Parameter setting: $\zeta=0.6$, $\omega=1$, $f=0.983$, $a=0.01$, using 4 order runge kuta method to solve system solution x and y , obtaining the following rules:

System solution x and y is periodicity and have constant phase relationship in Large-scale periodic state; system solution x and y is random variation, as shown in Figure 2.



(a) Large-scale periodic state (b) Chaotic state

Figure 2. Time domain wave of system solution x , y

Taking difference of system solution x and y every carrier signal period $T=2\pi/\omega$, difference is defined as Z :

$$Z = x(nT + \theta) - y(nT + \theta) \quad n = 0, 1, 2, \dots \quad (3)$$

where θ is any initial time in the equation. Figure 3 is distribution map of difference Z , difference Z is a line and show stable distribution in Large-scale periodic state, difference Z is random distribution in Chaotic state.

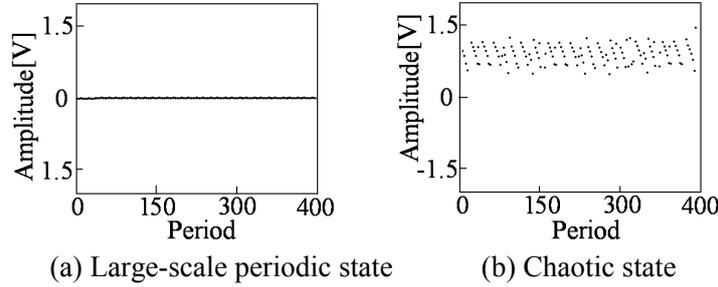


Figure 3. Distribution of difference Z

According to the above rules, difference Z of system solution x and y is used to identify phase transition.

3.2 Algorithm realization

Use standard deviation of difference Z to analyze stable degree quantitatively in practical detection.

- 1) Identify phase transition in certain time: take mean value of current and front $N-1$ difference Z .

$$A = \frac{1}{N} \sum_{i=1}^N Z_i \quad (4)$$

- 2) And then take standard deviation $\sigma(Z)$ of N difference Z , which represents stable degree of N difference Z :

$$\sigma(Z) = \sqrt{\frac{1}{N-1} \sum_{i=1}^N (Z_i - A)^2} \quad (5)$$

- 3) Set up threshold, if less than threshold, and then identify system in Large-scale periodic state, conversely in Chaotic state.

4. Experiment Research

For verifying detection ability of the method, two Duffing Oscillator is used to detect QPSK carrier signal in power line. The power line model is shown in Figure 4, into which background noise and impulse noise is added by Agilent 33220A signal generator.

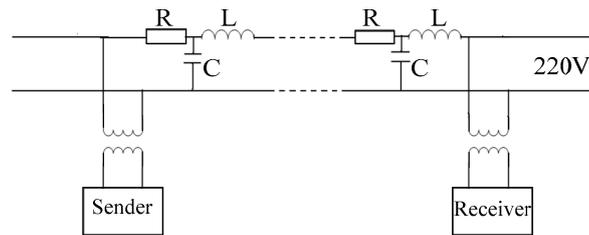


Figure 4. The power line model

4.1 Background noise

Power spectral density of background noise in power line is low relatively and keeps on constant in several minutes and even several hours. QPSK carrier signal is added into background noise, SNR achieve -20 dB, amplitude of QPSK carrier signal is 0.01 v, frequency is 120 k, phase is $7\pi/4$, $3\pi/4$, $\pi/4$, $3\pi/4$ which represent digital signal, the detection process is shown in Figure 5.

When SNR is -20 dB, QPSK carrier signal is submerged by noise, as shown in Figure 5(a). Standard deviation $\sigma(Z)$ of the first and second oscillators are shown in Figure 5(b),(c). According to the detection rule in Table 1, the phase of QPSK can be detected.

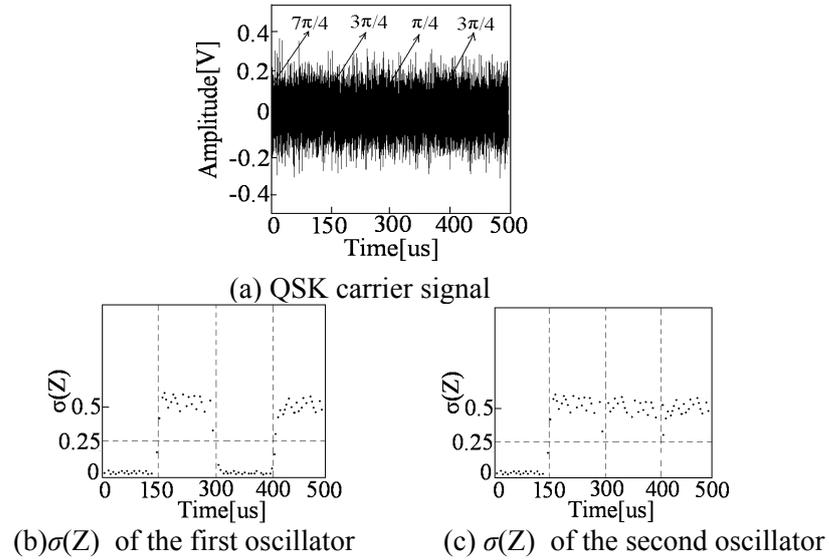


Figure 5. The detection process

Traditional filtering method, spectrum method could detect weak signal in SNR -10 dB^[6], this method can detect phase of weak signal in SNR -20 dB.

4.2 Impulse noise

Impulse noise in power line has strong time variation and power spectral density is high, which will easily lead to bit misjudge and sudden error. Impulse noise has three kinds, such as Figure 6、7 and TABLE 2: (1) Impulse noise of similar damping. (2) Impulse noise of continuous shock. (3) Switch impulse noise.

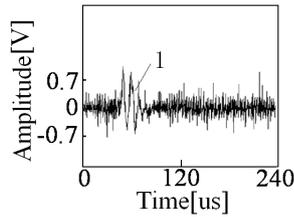


Figure 6. The first kind of impulse noise

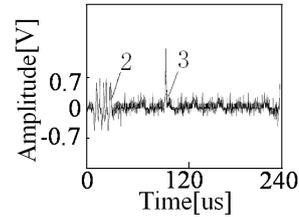


Figure 7. The second third kinds of impulse noise

TABLE 2. Three kinds of impulse noise

taype	time/us	peak value/v	unit
Impulse noise 1	30	1.2	3~4
Impulse noise 2	16	0.6	5~7
Impulse noise 3	5	2.1	1~3

The three kinds of impulse noise are added into QPSK carrier signal. When Duffing Oscillator detects QPSK carrier signal with impulse noise, the three kinds of impulse noise might cause Duffing Oscillator to fluctuate weakly.

Many experiments show that impulse noise has little interference for chaotic state. The first、third kind of impulse noise have interference for Large-scale periodic state, but if choose a suitable threshold, phase transition can be still identified.

5. Conclusion

Two Duffing Oscillator is very sensitive to QPSK carrier signal and can inhibit background noise and impulse noise and can detect phase of carrier signal in lower SNR. After Analyzing variation rules of system solution x and y of Duffing Oscillator, this paper proposes a kind of algorithm of difference distribution, which needs less computation than other methods, to identify phase transition and this algorithm is more suitable for engineering application.

6. References

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