The Method of Realizing IPLL with Software

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Abstract: The concept of Phase-locked loop is earliest described in the 1820’s. In the late 1970 s, the theory of phase locked loop was given good description, but because of the difficulty of hardware implementation of a phase-locked loop, phase-locked loop, until a long time, was not widely used. In the 1970’s, with the rapidly development of integrated circuit (IC), PLL was widely used in modern communication system. Since then, the phase-locked loop had made great progress, and it was transferred from the earlier only used in field of high precision equipment to the all kinds of electronic products used in the consumer. Due to the rapid development of power system, power system signal analysis is more and more important. In this paper, according to the characteristics of the virtual radio technology and the basic principle of phase-locked loop to build software phase-locked loop, through the analysis of the improved phase-locked loop (IPLL), designed IPLL by way of the software. In this paper, based on the MATLAB simulation, the above analysis shows that the software phase-locked loop can be extracted grid signal, frequency, amplitude and phase of fundamental wave information for demand. Copyright © 2014 IFSA Publishing, S. L.

Keywords: Software phase-locked loop, Improved phase-locked loop, Simulation, Amplitude extraction.

1. Introduction

First proposed the concept of a phase-locked loop was in the 1820’s, in the absence of the effect of Doppler shift showing, and the emergence of the phase-locked loop had promoted the development of the coherent communication system. It was a kind of technology using feedback control principle of frequency and phase synchronization [2-7]. The development of Phase-locked loop (PLL) was an important significance for the progress of communication technology and motor servo control system in the past 30 years. More and more modular and integrated phase-locked loop was the development direction of phase locking technology [5-13]. Therefore, the experts expected that it would help the development of communication systems which would become more reliable and practical. At the same time, it has played a very important role in promoting the development of higher accuracy reliability of the servo control system, such as in machine tool servo automatic control. In the late 1970 s, there is the proper description of theory of phase locked loop, but because of the difficulty of hardware implementation of a phase-locked loop phase-locked loop until a long time are not widely used. In the 1970 s, with the rapid development of integrated circuit (IC), PLL is widely used in modern communication system. Since then, the phase-locked loop has made great progress, and only used in field of high precision equipment in earlier were transferred to the all kinds of electronic products used
by consumer. It made modern electronic system greatly improve in the performance and reliability, especially as a very important role in electronic devices which had in common with the PLL. In the 1870 s, researchers majored in the field of power control research realized synchronous motor speed control system by phase-locked loop. Since then, through using phase-locked loop, the phase locked servo system (PLS) in the field of AC and DC motor servo mechanism have got rapid development. In the past 10 years, rapid development of high performance digital integrated circuit and microprocessor need of the appearing of the PLL of digital technology, and it made new type of controller in the field of dc servo system and ac servo system. With the PLS function, which contained PLS was easy to convenient control [14-17].

In the frequent using virtual radio today, people began to focus on how to implement the function of PLL through the software. Although compared with analog phase locked loop and digital phase locked loop, its basic principle were in common, but in mathematical modeling, implementation method, parameter design had a larger difference. Because of the traditional form hardware circuit design which phase-locked loop in software gets rid of, the PPL in software has the advantages of simple structure, flexible parameter design, and it is not affected by the characteristics of voltage, temperature, and the environment. And its frequency is adjustable by programming, and it is easy to construct high order loop filter, etc. As the development of the communication technology and the chip of Development Board, phase-locked loop in software will have more extensive application prospect.

In the power system, the neutral point grounding or via arc suppression coil, resistance of system, called the small current grounding system, such as the power system of power plants, substations, hydropower station and chemical industry, large corporations. The most common fault in small current grounding system is single phase grounding. Single-phase earth fault occurs, the small current grounding system all over the ground with capacitance circuit will be zero sequence current through, but because of the zero sequence current is small, and there is a great deal of dispersion, it is difficult to select grounding line; If there is the arc suppression coil in system, it is more difficult to select grounding line; If there is the arc suppression coil in system, it is more difficult to select grounding line. The single-phase grounding grounding current is small, so according to the provisions of the rules of safe operation in power system, when the single-phase earth fault occurred, the system can continue to run 1 to 2 hours, but the fault of line is relatively higher voltage than the voltage of normal line, if not handled in time, it is easy to develop into two phase short circuit, arc grounding overvoltage can also cause the whole system over normal voltage. Be badly in need of the existence of small current line selection device at this moment, there are multiple ways of small current line selection, such as application of advanced phase-locked loop to extract 5 harmonics in power grid [1-7].

2. The Summary of Phase-locked Loop

What we called the PLL, in fact, is the phase lock loop (PLL). Phase-locked loop is usually consists of three parts, namely, phase discriminator, loop filter and the voltage-controlled oscillator (VCO).

Phase-locked loop can be used to realize the output and input phase synchronization. When the input signal is zero, the output of the loop filter is zero. At this point, the voltage-controlled oscillator output its inherent frequency. If the input signal is named FR, input and output signal input the phase discriminator and if the input signal frequency and output signal is different, the phase discriminator will output signals of phase error voltage which is proportional to the voltage-controlled oscillator frequency, and it will repass loop filter to filter, forming the control voltage named UC. The UC will make the change the frequency of voltage-controlled oscillator named FV, and the frequency of the output of the VCO is close to the frequency of input signal, finally make the FV equal to FR, and the loop is locked. After entering the locked loop once, the output signal and the input signal will have a fixed stationary phase [1].

3. Improved Phase-locked loop (IPLL)

3.1. Improved Phase-locked Loop (IPLL) Basic Structure

With the rapid development of power system, power system signal analysis is more and more important. Based on the classic phase-locked loop, the literature [1], this paper proposes a modified phase-locked loop (IPLL), modified phase-locked loop can extracted the amplitude and waveform of whichever sine wave in a set of mixed signal. In the literature [1], with control theory, IPLL mathematical model are analyzed in detail, and based on the Matlab/Simulink, IPLL function are simulated. It shows that the structure can extraction the frequency, amplitude and phase of fundamental wave of grid signal. And compared with PLL in the widely used in the power system, it reduces the αβ transformation and DQ transformation, and strengthens the function of tracking signal amplitude, for power system signal analysis providing a new way of thinking.

3.2. The Basic Working of IPLL

IPLL is consists of four parts:

1) Input part is a subtracter, and what the input signal, named Ui, minus feedback signal, named y, is e, and e is the input of multiplier 1 in the part of
Phase adjustment and multiplier 2 in the part of amplitude adjustment.

2) Phase adjustment part consists of multiplier 1 (phase discriminator), loop filter named F(s), voltage-controlled oscillator. Signal e and the VCO is inputted in a multiplier 1, which output is the input part of the loop filter, which output is the input of the voltage controlled oscillator, and the above parts implement a feedback loop phase control section.

3) Amplitude adjustment part includes multiplier 2, 3 and the controller of the integral. Signal e and Uo2 are inputted in the part of multiplier 2, which output is the input of integral circuit, which output value is expressed as A (extraction signal’s amplitude) and which output and the output of VCO are inputted multiplier 3. The output of the part of amplitude adjusting is named y.

4) Output part consists of two parts: one is the output of the voltage-controlled oscillator which is tracking the different phase between input signals named φ, and the other is the output of multiplier 3 which is in extraction of the amplitude information fundamental wave signal.

Literature [1] is verified IPLL, when the input signal occurs voltage surge or phase jump or frequency changes, even in the case of the pollution of harmonic, still can extract the information of the input sine wave signal phase, frequency and amplitude information, even restoring fundamental information from the pollution of harmonic. Theoretical analysis results showed that there are second order phase and first-order amplitude adjustment in IPLL, and when the input signal occurs acceleration rates jump or phase ramp up or phase and amplitude step change, IPLL can accurately track the information of amplitude, phase and frequency of the input signal. Simulation proves that, similar to the above changes in the power grid voltage such as the surge or plunged of voltage, phase jump, frequency change or harmonic pollution, IPLL can realize the function, and can separate fundamental wave and harmonic signals. We can adjust the proportion of the circuit by changing the phase coefficient and the parameters of the loop filter to achieve rapid phase tracking speed. Amplitude tracking speed can adjust by changing the amplitude coefficient.

4. The Method of Realizing IPLL with Software

4.1. The Ultimate Principle

PLL in the form of software does not needing hardware maintenance comparing with the traditional form, and its failure analysis is simple, and it adapts to the needs of current in the power system microcomputer control. Just a series of procedures, it can realize IPLL function. At the same time the software implemented IPLL function can adapt to face more widely, can adjusted in many places according to update some program. It also has the advantages of simple structure, flexible parameter design, programming track frequency adjustable, easy to construct high order loop filter, etc. As the development of the communication technology and the chip of Development Board, software phase-locked loop will get more and more important status in power system analysis.

Now we have the mathematical model of IPLL block diagram and the institutions, and we can make it through transfer function of IPLL including parts in the form of software. In the first we should know about the transfer function of the system. By a linear system feature of the relationship between the input and output, with a function to described, is the transfer function of the system. The transfer function of the system and the system differential equations of motion are related. After the system determines, the transfer function of the have determined that it does not change with the size of the input.

The transfer function is mainly used in three aspects.

1. It can conclude that the output of the system or response.
   The system transfer function is named H(s), and the input of system is named I(s), and the output of the system response is named Y(s), which can be inferred by H(s) multiplying by the I(s) to calculate.

2. The analysis of the influence of system parameters change on the system.
   By the method of root locus method, closed loop control system can analysis the effects of the system of the open loop gain changing on zero pole on the zero pole distribution of closed-loop transfer function.

3. Used to design control system.
   Directly by the system open-loop transfer function to carry on the design, use the root locus method. The frequency response is designed by frequency response method. Through the transfer function, we can get the discrete model to program by MATLAB. Here in this paper, we give an example to show how to design the loop filter and how to implement the function of IPLL by software.

4.2. The Implement of the Filter Function by Software

Designing a 1 kHz filter steps are as follows:
   By the input expression of the MATLAB, ‘tf’, the transfer function can be inputted into the MATLAB.
   Input ‘h=tf([1/1000/2/pi,1])’ in the operation box.
   MATLAB calculate the transfer function, and we can get the continuous domain expression:
   \[ h = \frac{1}{0.0001591s + 1}, \]

Next we use the function of ‘c2d’ to make the ‘h’ discretization,
The type of sampling frequency is 100 kHz, ‘zoh’ for sampling way. It provide five sampling methods in MATLAB, including ‘zoh’, ‘foh’, ‘imp’, ‘tustin’ and ‘prewarp’.

We can get the result:

\[
hd = \frac{0.0609}{z - 0.9391}
\]  

(2)

Input ‘bode (hd)’ in the operation box.

We can see from the Fig. 1 that there is a -3 dB attenuation in the frequency of 6.24 kHz. Reaching the cutoff frequency, it indicates that the discrete transfer function can realize the function of filter, so as to prove that you can through the transfer function of the device at discrete domain (Z domain).

When there's a parameter Z domain, then the parameters of the Z domain can be transformed into difference equations. Through the discrete transfer function (2), for example, the input sequence is named \( x(n) \), so it is \( y(n) \) for the output sequence, and we can get the transfer function:

\[
y(n) = 0.0609 * x(n-1) + 0.9391 * y(n-1)
\]  

(3)

where \( y(n) \) and \( x(n) \) are the time series.

C language program programmable for:

```c
float loopf(float x)
{
    static float x_z,y_z;
    float y;
    y=0.0609*x_z+0.9391*y_z;
    y_z=y;
    x_z=x;
    return y;
}
```

4.3. Realizing the Function of IPLL in Discrete Domain Based on MATLAB

First, we can use Simulink construct IPLL model, as shown in Fig. 2. The loop filter (Discret Transfer Fcn), integrator (Discrete Transfer Fcn1) by the way, using MATLAB 'c2d 'function of built-in functions from the continuous time domain, are transferred into Discrete Z domain.

![Fig. 1. The phase and frequency of transfer function of ‘hd’.

Fig. 2. Discrete model.](image-url)
To input three different frequency sine waves is used to simulate the fundamental wave and harmonic of power system. At the same time, the difference of between functions IPLL software and hardware is software system need sampling on the outside world to analyze the data. So we adjust three sampling time of different frequency sine wave in 0.001 seconds.

Their frequency and amplitude in the Table 1.

<table>
<thead>
<tr>
<th>No.</th>
<th>U (V)</th>
<th>F (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>380</td>
<td>50</td>
</tr>
<tr>
<td>2.</td>
<td>20</td>
<td>150</td>
</tr>
<tr>
<td>3.</td>
<td>60</td>
<td>250</td>
</tr>
</tbody>
</table>

Maximum frequency is 250 Hz, which the cycle is 0.004 seconds and the system of sampling time is 0.001 seconds, so a signal can be sampled more than 2 times in a cycle, which meet the sampling theorem that the signal can be restored. After the operation, click on the amplitude and the oscilloscope respectively wave signal oscilloscope, Fig. 3.

In Fig. 3, we can see that amplitude eventually stabilized at 380, consistent with the fundamental wave signal, and it can be concluded that wave signal amplitude can be extracted by the discrete IPLL. From Fig. 4, as a result of sampling, the sampling frequency is 1 KHz, five times the harmonic in a cycle can be sampling four times, from Fig. 6, it can be seen that the amplitude is 58 and the frequency is 250 Hz, and we can be sure that it is five times the harmonic signal, which proved that the discrete IPLL can complete the extraction of the harmonic signal.

We can see in Fig. 3 that amplitude eventually stabilized at 380, consistent with the fundamental wave signal, and it can be concluded that wave signal amplitude can be extracted by the discrete IPLL. From Fig. 4, as a result of sampling, the sampling frequency is 1 KHz, so the image shows the square wave signal, but we can infer the signal cycle is 50 Hz and the amplitude is 380, and it can be concluded that wave signal can be extracted.

Changed in parameters, IPLL can extract arbitrary signals from a mixed signal, such as the extract of five times the harmonic. After the operation, we observe the amplitude oscilloscope and fundamental wave signal oscilloscope.
5. Conclusion

Through the above analysis, we can found that we, through the IPLL discrete model, can extract any signal waveform and the amplitude of signal from a mixed signal. According to the transfer function of discrete model of Z domain, we can get a set of formula, which can realize the function of IPLL in C language. Ultimately we achieve the goal of realizing the function of IPLL by software.

References


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