Research and Design of Intelligent Electric Power Quality Detection System Based on VI

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***Abstract*—Electric power quality problem has become an important problem in modern society, which effects industrial production and product quality, etc. So, we urgently need monitor and analyze electric power parameter to solve electric power quality problem. In this paper, we design a kind of electric power parameter detection system based on visual instrument (VI) technology, etc. System uses voltage/currency transformer module and signal processor module to realize electric power network analog signal conversion. System adopts multiplexing technology, which solves multi data acquisition card (DAQ) using complexity problem as well as saving cost. In addition, system software adopts method of wavelet resolution analysis combining with FFT, which solving FFT disadvantage in analyzing non-steady distortion signal. System is applied to harmonic monitor, voltage fluctuation and flicker monitor, etc. This paper mainly introduces system's structure, algorithm simulation, part of hardware and software design in detail. Through experiment, monitor error of harmonic wave's *THD*% is 0.01%, and amplitude wave's frequency and amplitude of voltage flicker is respectively less than 0.01Hz and 0.005V, which obtains accuracy result in high monitor precision as expectation.**

***Index Terms*—visual instrument, DAQ, FFT, harmonic monitor, voltage fluctuation and flicker, wavelet analysis, Matlab+LabVIEW**

I. INTRODUCTION

With the development of power electric system, especially introduced of power electronic equipment, power system harmonic harm is serious increasing. On production of industrial and mining enterprises, etc, power quality is necessary. To assure equipment reliable operation, we need detect voltage, currency, and their state of power network, etc in real time. Traditional detection equipment depends artificial to complete, but there are many more problems: one is field circumstance is poor, especially, under middle or high voltage condition, which is not suitable to work in long term; the other is that artificial style has larger error, and data static, processor both require amount of time and work. In addition, present detection equipment can not completely detach field. So, design a kind of convenient and simple detection style has very important significance. With the increasing of electric component precision, speed, and reliability, it provides base to realize high character method and in real-time control. [1]

This system adopts technologies of data acquisition multiplexing, VI, PC, and new algorithm of wavelet multi-resolution, etc, which an intelligent power network detection system is carried out.

II. SYSTEM STRUCTURE AND WORK PRINCIPLE

Intelligent electric power quality detection system is mainly composed of two parts, which is PC system installing VI software LabVIEW8.5+Matlab and data acquisition system. Because PC system input signal is small voltage signal after processed by transformer and process module transforming from three phase voltage/currency. According to waiting signal detection method demand, when monitor voltage phase, power factor, etc, which needs adopt synchronization collection style, it is to say, we need synchronization sample to two phase voltage or voltage-currency. If we make six groups signal amplify, filter and transmit to data acquisition module, which needs data acquisition module at least has six groups synchronization sampling channel. But normal synchronization DAQ only has four groups synchronization sampling channel, which needs two card and increases synchronization controlling problem between two cards, and brings cost and technology complex problem by this kind of style. So, system adopts multiplexing technology to solve this problem. Overall structure of system design is shown as Fig. 1.

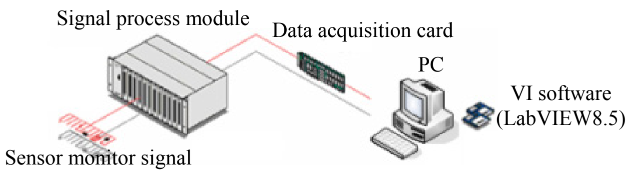

Figure 1. Overall structure of system design

III. SYSTEM HARDWARE DESIGN

Six groups of electric power parameter of electric power system two channel groups output through double channel 16 groups/double 8 group analog switch AD7507, and then it is amplified, low-passing filtered and transmitted to DAQ. So, we only need one card to fulfill system signal collection requirement, which not only reduces cost, but also simplifies technology schema. To increase monitor system generality, we design multi-range automatic control circuit, which makes system automatically range shifting to meet monitored value changing according DAQ A/D transfer's factors of voltage change limit value, monitor precision and resolution, etc.

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System completes field electric power system detection in real time, and processes field collection data through PC Computer adopts normal industry control computer. System PC can realize displaying and alarming through analyzing and processing receiving data. Because paper coverage is limit, so we introduce some important parts.

A. Transformer Circuit

System adopts voltage transformer SPT204A and other circuit to consist voltage signal collection module. SPT204A is a precision current transformer of mA level in fact. Because of size technology it usually adopts voltage transformer of current type. And its rated transformation ratio is 1, input rated current is 2mA, input voltage can't add to primary coil in use, we need to serial into limit currency resistance, which makes voltage signal transform into currency signal of mA level. Secondary output mA level currency signal is transformed into voltage signal by amplifier I/V transferring. Amplifier uses good character chip LM118, which can easy to reach higher precision and stability. Transformer works at approximate zero load state, which has many advantages such as broad dynamic range, high precision, and good linearity, etc. Voltage signal collection circuit is shown as Fig. 2.

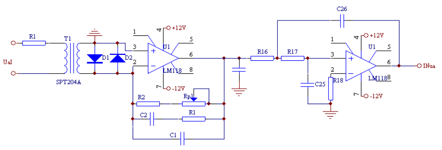

Figure 2. Voltage transformer circuit

System uses currency transformer STC254AK and other circuit to compose currency transformer module. Circuit principle is basic same as voltage transformer without introducing. In addition, in system designing, we should notice transformer has homonymy and synonym end, input signal should synonym end connects LM118 reversed phase end, which can assure amplifier signal same with detection signal. Otherwise it is reversed phase. [2]

B. Multi-channel Selection Switcht

System adopts America AD .co production 16 channel/double 8 channel, low leakage, CMOS analog multiplexer AD7507, which makes sensor module output in two channel voltage signal, and then realize subsequent process of amplify and filter. AD7507 logic true value table is shown as Table I.

TABLE I.
LOGIC TRUE VALUE TABLE

A2	A1	A0	EN	On-off switch
×	×	×	0	NONE
0	0	0	1	1&9
0	0	1	1	2&10
0	1	0	1	3&11
0	1	1	1	4&12
1	0	0	1	5&13
1	0	1	1	6&14
1	1	0	1	7&15
1	1	1	1	8&16

From Table I we can see, each group of chip outputs corresponding one group of input, it can control *U*a, *U*b, *U*c, *I*a, *I*b and *I*c signal in double channel acquisition by three channel selection ports and a enable port, so, we need four control signal of *D*0, *D*1, *D*2 and *D*3 form DAQ. Circuit principle is shown as Fig. 3. [3]

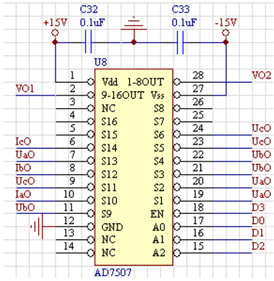

Figure 3. Multi-channel selection switch circuit

C. DAQ Selectiont

Because this projection monitor task is simpler without multi-module trigger problem, monitor signal is low frequency, and has more requirements of EMI, etc. So, thinking about hardware cost and realization complexity, we adopt data acquisition module based on PCI bus, and plug DAQ directly into PC PCI bus, which realizes field data collected and processed as controlled object by PC. This system adopts ADLINK .co DAQ-2010 4 channel synchronization DAQ, which has 14 bit A/D resolution; maximum sampling frequency can reach 2MHz. According GB of electric network quality, A level instrument frequency monitor range is 0~2500Hz, which is 50 times of sampling maximum time harmonic signal's frequency. From Nyquist sampling method we can see, if DAQ's maximum sampling frequency is more than 5 kHz, it can reach system requirement. This DAQ-2010 can completely meet electric power quality Ath level monitor requirement of three phase voltage, currency.

In addition, ADLINK .co not only provides DAQ-2010 driving program, which can assure DAQ to realize all function well in LabVIEW platform, but also provides part of VI function, which makes user program by calling these functions in LabVIEW circumstance.

IV. SYSTEM SOFTWARE DESIGN

Software design of system adopts modularization program structure. PC program control software uses LabVIEW+Matlab, and adopts LabSQL[4] connecting with database to design. Software system adopts modular design, which divides into some relative independent function module, and arranges suitable enter and exit port parameters. We mainly introduce electric power quality monitor method of harmonic, voltage fluctuation and flicker, etc. In harmonic monitor, we use FFT combining wavelet multi-resolution monitor method, which can realize harmonic monitor when signal has mutation. In voltage fluctuation and flicker monitor, we use synchronization square monitor algorithm with multi-resolution monitor method, which can realize analysis without low-passing filter. We mainly introduce part of method and theory in use.

A. LabSQL Connecting With Database

This system selects LabSQL connects with database, principle of LabSQL connecting with database is shown as Fig. 4. Using LabSQL can realize data transmission between application program and database.

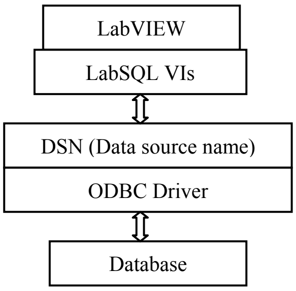

Figure 4. Frame diagram flow of LabSQL connecting with database

To avoid user error operation because no using authority, we design login and check functions module, etc. Login program uses LabVIEW to design. User information includes user name, password, authority, login times, and last time login time, etc. Database "用户.mdb" use Microsoft Access to build. Among them, we design a "用户" table to storage user information, which design structure is shown as Table II.

TABLE II.
DATABASE USER TABLE

用户: 表

字段名称	数据类型
编号	自动编号
用户	文本
密码	数字
权限	文本
最后登录时间	文本
登录次数	数字

B. FFT

At present, harmonic monitor method is DFT and FFT. DFT computational complexity is proportional to square of transform length *N*. When harmonic analysis, in order to assure calculation precision, *N* is a big number value, so, computational complexity is greatly. FFT is fast speed algorithm of DFT, which can improve 1~2 magnitude in DFT operation efficient. So, it has broad application in harmonic analysis. [5] Its way is shown as below: at first, calculate basic wave, real and imaginary parts of each harmonic, then calculate its amplitude and phase, and each harmonic containing amount and harmonic total amount. As voltage value for example, if we use FFT algorithm to get real and imaginary of *K* times harmonic (k=2, 3…40) is $U_r(k)$ and $U_i(k)$, then *K* times harmonic voltage amplitude $U(k)$ is shown as formula (1):

$$U(k)=\sqrt{U_r^2(k)+U_i^2(k)} \tag{1}$$

Phase of *K* times' harmonic voltage is as (2):

$$\theta(k)=arctg\frac{U_r(k)}{U_i(k)} \tag{2}$$

Correspondingly, we can get harmonic containing amount by using some times harmonic amplitude corresponding to basic amplitude percentage. *K* times' harmonic containing amount is shown as (3): [6]

$$HRU(k)=\frac{U(k)}{U(1)}\times 100\% \tag{3}$$

Total harmonic distortion (*THD*) is total containing amount reflecting harmonic, which can calculate by below formula is shown as formula (4):

$$THD=\frac{\sqrt{\sum_{k=2}^{40}U_k^2}}{U_1}\times 100\% \tag{4}$$

Though FFT has character of fast speed, high precision, etc, this method has two sides of error, it is leakage error when sample period is asynchrony with signal period, and frequency aliasing error as sample frequency is less than biggest signal frequency twice. Leakage error has found some ways to solve, such as adding window technology, and interpolation technology, etc. But, at aliasing error aspect, normally, we adopt adding low-passing filter behind sampling, which can filter higher of Nyquist frequency component. But, FFT on harmonic monitor is suggested wave is stable and period. In fact, harmonic signal would have catastrophe point, integral action of Fourier transform smoothing unstable signal catastrophe, which can make Fourier algorithm effect is not ideal at unstable harmonic monitor, such as signal catastrophe, transient distortion, short time harmonic, etc.

C. Multi-resolution Wavelet Analysis Algorithm

When sampling frequency of signal that waiting to be analyzed is satisfied with the sampling theory of Nyquist, normalization frequency band is restrained between -π and +π. So we can use parts of low frequency 0~π/2 and high frequency 2/π~π. They are decomposed by ideal low-pass filter *H*0 and high-pass filter *H1*, which is corresponding to signal general picture and detail. The two groups of output must be orthogonal because the frequency band cannot associate with, and that the width of frequency band is halved, so the information would not lose if we use sample rate in half. Sample rate of band-pass signal is decided by its width of band but its upper limit of frequency. The analogous process can be carried out to every part of low frequency signal after decomposing. That is to say, output signal is decomposed into a general approach part of low frequency and a detail of high frequency part in each level decomposing, and output sample rate of each level can divide into half. So the original signal $s(n)$ is decomposed in multi-resolution.

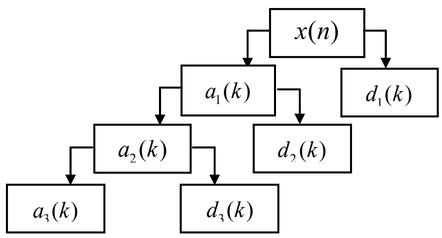

Figure 5. Multi-resolution wavelet decomposition

Fig. 5 takes on an operation as: $x(n)=a3(k)+ d3(k)+ d2(k)+d1(k)$. *S* is original analysis signal. $d1(k)$, $a1(k)$, $d2(k)$, $a2(k)$, $d3(k)$ and $a3(k)$ are high and low frequency of each layer's decomposition. If we want decompose any more, the method is same. The ultimately intention is that construct an orthogonal wavelet base in a frequency band, which highly approach in $L^2(R)$ dimensional. These orthogonal wavelet bases in different frequency resources are equal as band-pass filter of different bandwidth. The low frequency signal is decomposed constantly in multi-resolution analysis, which makes frequency resolution become higher and higher.

Based on the theory of multi-resolution analysis, Mallat presents a fast algorithm of wavelet decomposition and reconstruct—Mallat. [7] The initial value is show as below:

$$c_n^{\,j-1} = \sum_i a_{i-2n} c_i^{\,j} \quad d_n^{\,j-1} = \sum_i b_{i-2n} c_i^{\,j}$$

Output is c^{N-M} and $d^j (N-M \le j \le n)$.

N is signal decomposition level of analysis signal $f(x)$, f_n is discrete sample value of analysis signal $f(x)$, c_n^j and d_n^j are modulus of low frequency and high frequency. a_n and b_n are decomposition list of low frequency and high frequency, which is decided by scale function $\Phi(x)$ and wavelet function $\Psi(x)$. The detail of each signal frequency band can be observed through focusing signal scale based on multi-resolution Mallat arithmetic. [8]

D. FFT Combining Wavelet Transform

Ideal harmonic analysis algorithm should be not only getting each times stable harmonic accuracy frequency, amplitude, and phase but also monitor small change, such as transient harmonic, and transient catastrophe. So, single to use Fourier algorithm or wavelet transform algorithm also make perfect harmonic analysis, so, this paper combines the two algorithm to realize harmonic monitor and analysis.

Before we adopt FFT to carry out harmonic analysis, we firstly monitor if unstable interference signal has or not, if it has, we will filter it at first. Because Fourier transform has limited in time domain, so, it can not analyze unstable distorted wave. But, wavelet transform has good time domain locality, which can process transient signal and make up Fourier transform shortcoming. As well as provide better basic to FFT. When monitor catastrophe point by using mode maximum and singularity detection method. Harmonic monitor principle is shown as Fig. 6. [9]

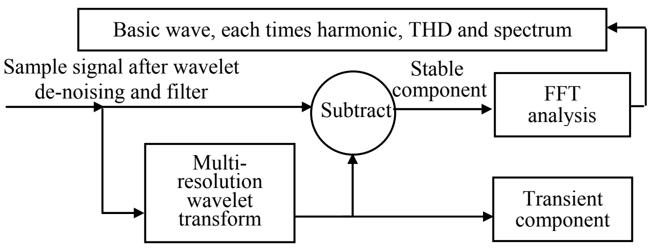

Figure 6. Flow diagram of combining wavelet transform with FFT

From upon diagram we can see, this kind of harmonic monitor and analysis algorithm adds multi-resolution wavelet transform algorithm before FFT algorithm, which is the key of this method and its function is: ①analyzing signal transient component; ②correction-compensation initial signal, which reduces FFT error because of transient component, and improve spectrum analysis precision.

E. Voltage Flicker Synchronization Square Algorithm

Voltage flicker of electric net voltage can be seen that a carrier wave, which composed of power frequency voltage in sinusoidal, is changed amplitude modulation by a frequency 0.5Hz~35Hz signal. Electric net voltage changing usually causes voltage flicker. So electric net voltage fluctuation and flicker signal $u(t)$ can use be expressed as formula (5):

$$u(t) = V_m[1 + m\sin(\Omega t)]\sin(w_0 t) \tag{5}$$

In formula (3-3), V_m is voltage amplitude of power frequency, w_0 is angle frequency of power frequency carrier wave, m is voltage amplitude of amplitude modulation wave/ carrier wave voltage (modulation parameter), and $m \le 1$, $m\cos(\Omega t)$ is flicker voltage, and Ω is angle frequency of amplitude modulation voltage.

The envelope signal of voltage flicker $m\sin(\Omega t)$ includes its amplitude and frequency information. The signal will be decomposed into a series of sinusoidal signals' sum by using wavelet multi-resolution signal decomposition method, which constituted by groups of sub-band filters, and each component compares to a kind of corresponding frequency sinusoidal signal. Wavelet analysis approaches original signal in different resolution, and projection component has a certain bandwidth with time-domain resolution. Through replacing traditional low-pass filter of synchronization radio-detector by sub-band filter, we cannot only measure envelope signal of voltage fluctuation with non-distorted, but also precisely monitor the start time and amplitude of voltage flicker.

This paper introduces a method with adopting IEC commendatory of square monitor [10] and combining wavelet analysis in allusion to the stable or unstable voltage flicker signal. After experiment, this method is a better way. Its measurement principle diagram is shown as Fig. 7.

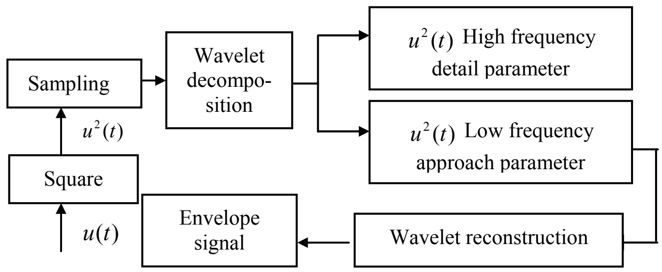

Figure 7. Wavelet transforms measurement

According to square measurement method, we can gain envelope signal of $u(t)$ from $u^2(t)$ low frequency approach parameter when make modulation wave voltage to square based on wavelet reconstruction. Formula derivation process is shown as below formula (6):

$$u^2(t) = A^2(1 + 2m\sin\Omega t + m^2\sin^2\Omega t)\sin^2\omega t$$

$$= \frac{A^2}{2}(1+\frac{m^2}{2}) + A^2 m \sin\Omega t - \frac{A^2}{2}(1+\frac{m^2}{2})\cos 2\omega t - \frac{A^2}{4} m^2 \cos 2\Omega t$$
$$-\frac{A^2}{2} m^2 \sin(2\omega+\Omega)t + \frac{A^2}{2} m \sin(2\omega-\Omega)t$$
$$+\frac{A^2}{8} m^2 \cos 2(\omega+\Omega)t + \frac{A^2}{8} m^2 \cos 2(\omega-\Omega)t \quad (6)$$

From formula (6) we can see, modulation wave voltage quadratic term has not only DC component, but also frequency component, such as Ω , 2Ω , $2\omega_0$, $2(\omega_0 \pm \Omega)$, $2\omega_0 \pm \Omega$. We analyze time-frequency of $u^2(t)$ by using Mallat wavelet decomposition arithmetic. [11] Its process is corresponding to a decomposition process of a series of sub-band. Considering actual modulation index m is far from 1, multiple component of amplitude modulation wave voltage is far from amplitude of amplitude modulation wave, so we can neglect it. Thereby, we can realize demodulation after wavelet transforming, and obtain near weighting amplitude modulation voltage $u^{'}(t)$, which is shown as formula (7)

$$u^{'}(t) \approx m V_m^2 \sin\Omega t \quad (7)$$

V. Simulation Analysis

A. Mutation Point Analysis and Compensation

In order to verify this algorithm accuracy, we suggest signal: $x(t) = \sin 100\pi t + 0.3\sin(200\pi t + 15^\circ) + 0.15\sin(400\pi t + 30^\circ) + 0.1\sin(600\pi t + 30^\circ) + 0.01\sin(1200\pi t + 60^\circ)$ $+p(t)$ cos($3200\pi t$). From signal, signal basic wave frequency is 50Hz, amplitude is 1, and containing amplitude of 0.3, frequency of 100Hz 2 times harmonic; amplitude of 0.15, frequency of 200Hz 4 times harmonic; amplitude of 0.1, frequency of 400Hz 6 times harmonic; and amplitude is 0.01, frequency of 600Hz 12 times harmonic component.. In addition, structure a mutation signal $p(t)$, signal produce a unstable cosine shrinkage pulse signal at 0.015s, constant width is 0.000625s, $p(t)$ signal is structured through segment function. Suggesting we sample signal as frequency 6.4 kHz, so pulse is between 96 and 100 sample pot in theory. Through Matlab simulation to initial signal, Initial signal simulation wave is shown as Fig. 8.

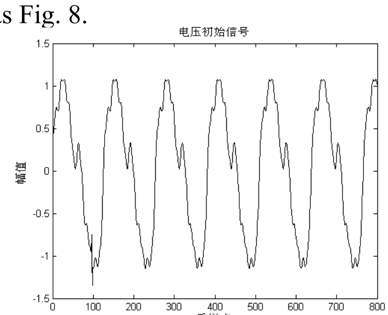

Figure 8. Initial signal simulation diagram.

According to signal $x(t)$, its basic frequency f is 50Hz, sample frequency f_s is 6.4kHz, from formula (3-5), we can get N=5. So, after making 5 layers wavelet multi-resolution decomposition, we can get $a5$, which is basic wave component range. Each times' harmonic respectively is distributed at high frequency band d1 and $d2$. Frequency band division is shown as Fig. 9.

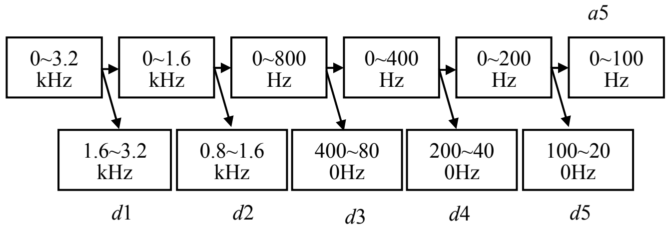

Figure 9. Dividing of signal y frequency band.

According to multi-resolution analysis layer, we make signal $x(t)$ db24 wavelet decomposition, and extract this two layers high frequency detail $d1$, $d2$ and its neighbor d3. According to d1 (or d2) confirming transient disturbance continue time segment, without disturbance, d1 value is minimal, 0.00000 or 0.00001, and we make mode maximum value [13] monitor to judge if there is mutation and confirm disturbance time, limited value is mode average 10 times, and we can obtain disturbance appear between 96 and 100 point, and its continue time ΔT we can get by ways as:

$$\Delta T = \frac{1}{6400} \times (100-96) = 0.000625s \cdot$$

From calculation, this transient signal time is shortest, (ΔT<0.67ms, more than 30 times harmonic frequency), we can judge this signal is disturbance signal, and this disturbance signal frequency f can be calculated by:

$$f = \frac{1}{\Delta T} = \frac{1}{0.000625} = 1600Hz \cdot$$

According to f value and Fig. 9 sub-frequency band division we can see, f is at 0.8 kHz~1.6 kHz and 1.6 kHz~3.2 kHz. So, at sampling point between 96 and 100 time segment, we reconstruct 1 and 2 layers high frequency signal, which will get initial signal unstable component, it is total distortion component. Matlab simulation wave is shown as Fig. 10.

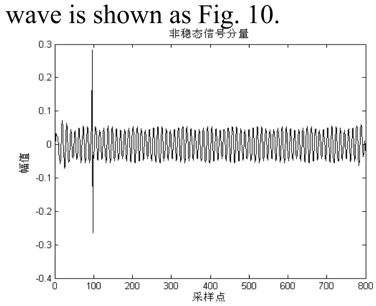

Figure 10. Total distortion component(unstable signal component).

Through compensating initial signal, using initial signal subtract total distortion component after wavelet reconstruction, which will realize compensation to initial signal and get stable component. Fig. 11 is stable signal component after compensation.

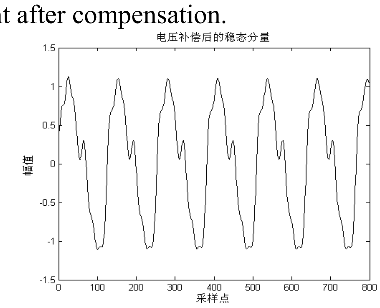

Figure 11. Stable signal component after voltage compensation)

B. Harmonic Analysis

Because wavelet analysis is base on multi-resolution signal processing theory, different scale corresponds with different time and frequency resolution. That is to say, different frequency component of original signal can be separated through wavelet decomposition to realize detection and tracking of the harmonic. In electric power system, original signal fundamental wave frequency is 50Hz and effectively decomposition to it can obtain sub-band ($0 \sim f_s / 2^j$) whose frequency range contains 50Hz. Therefore, fundamental wave can be separated from various harmonic. In power system, harmonic's order, produced actually by the voltage or current of network, mostly may be $2K+1$. In given simulation algorithm, original current signal construct harmonic of 1, 3, 5, 7 orders and expression is: $x(t)$=sin(wt)+sin(3wt+3)/3+sin (5wt+5)/5+sin(7wt+7)/7, w=100π. According to sampling theorem, the sampling frequency of discrete signals can't be lower two times than the highest frequency. The sampling frequency is fs=50×512=25600 =25.6 kHz and carry on 7 levels decomposition to original signals by choosing the db24 as wavelet function.

In original signals, only fundamental wave frequency is between 0Hz and 100Hz. Therefore, we can obtain fundamental wave component by means of the reconstruction of $a_7(k)$ and simultaneously attain the end of fundamental wave detection. The transforming results of scale 1 to 7 are sub-band $d1$~$d7$, and respectively indicate the harmonic of continuous frequency. The reconstructed images through different wavelet coefficient decomposing are as shown in Fig. 12.

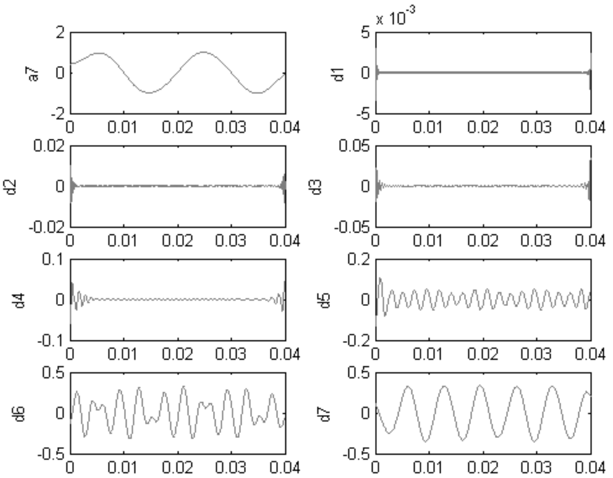

Figure 12. Reconstructed of various wavelet resolution coefficients

From simulation results of sub-band $a7$, we can figure out the amplitude value of fundamental wave component to be 0.9931V and the effective value to be 0.7023V. The relative error of the effective values is 0.67%. Therefore, this method can realize the separation of fundamental wave. In addition, because wavelet db24 is un-symmetry, therefore, the excursion of frequency's phase appears between the fundamental wave component, which detected and the original fundamental component. It is shown as Fig. 13.

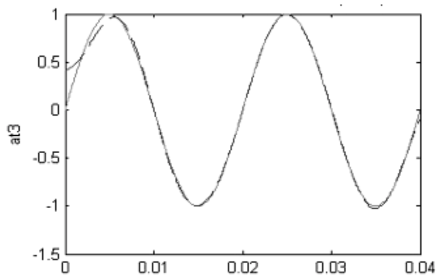

Figure 13. Ideal fundamental wave (broken line) and real fundamental wave (real line)

The original signal can be decomposed into the fundamental wave $a7$ and sub-harmonics $d1$, $d2$, $d3$, $d4$, $d5$, $d6$, and $d7$ through wavelet transform. The frequency of sub-band signals respectively is 445.64Hz, 276.72Hz, 150.00Hz, 50Hz, and the result is consistent with Table 1. It can be seem that wavelet transform has good localization characteristic in time domain and frequency domain as well and it is suitable for harmonic analysis of electric power system. The real-time harmonic tracking mainly aims at obtaining the trend of harmonic. The relative error of amplitude and phase may not demand too much. By choosing suitable wavelet, the wavelet transform can effectively track the changing trend of harmonic. It is shown as Fig. 14.

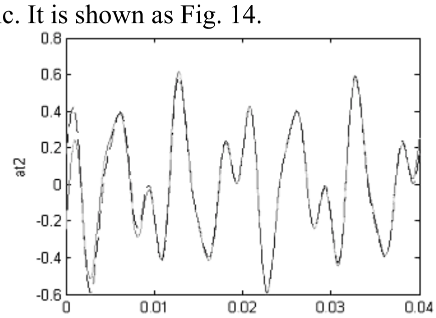

Figure 14. Ideal harmonic (broken line) and real harmonic (real line)

C. Voltage Fluctuation and Flickers

Steelmaking arc furnace is main equipment causing electric voltage fluctuation and flicker, and each frequency sub-value of amplitude is inversely proportional to frequency. Now we analyze arc furnace voltage flicker signal by wavelet analysis tools of simulation software Matlab. We suggest electric voltage flicker signal expression causing by steelmaking arc furnace as formula (8):

$$u(t) = V_{\mathrm{m}}[1 + m\sin\Omega t]\sin(wt) \tag{8}$$

From formula (8), Vm=1V, Ω=6πrad/s, w=314πrad/s. when 0.1875s≤t≤1.875s, m=0.05. On Matlab simulation experiment, at first, we make initial signal $u(t)$ squaring, get signal $s(t)$, then get 8000 sample point of $s(t)$ by 3.2kHz sample frequency, and then select Daubechies wavelet db24, decompose signal into multi-layer wavelet decomposition and reconstruction.

High frequency $d1$ and $d2$ is after wavelet transform and reconstruction. Model maximum position is mutation point position. It is shown as Fig. 15. In which, abscissa is time, unit is s, ordinate is voltage amplitude, and unit is

V. The following wave diagram abscissa and ordinate is same.

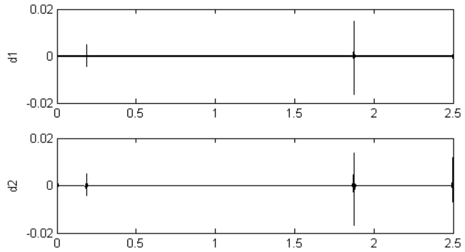

Figure 15. Reconstruction high frequency signal $d1$ and $d2$.

From Fig. 15 we can see, two position of mutation point respectively at $t_1 \approx 0.20$s and $t_2 \approx 1.85$s, modulus maximum of position t_2 obvious larger than t_1, which express singular degree of t_2 is higher than t_1, simulation experiment shows that mutation position and singular degree are uniform with initial signal. Low frequency $a6$ is voltage flicker signal envelope after wavelet transform reconstruction. It is shown as Fig. 16.

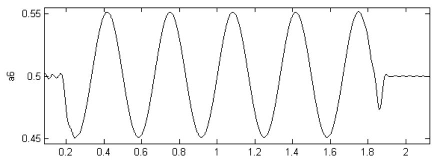

Figure 16. Reconstruction low frequency signal $a6$

From Fig. 16 we can see, voltage flicker signal initial time t_1 is at position 0.2s and end time t_2 position is at 1.85s, which is uniform with theory value 0.1875s and 1.875s, and in Fig. 15, transient signal shows as slope form at position t_1, and position t_2 shows as spike signal, which is uniform to mutation ambiguity degree in conclusion1. From it we can see, by selecting suitable wavelet, orthogonal wavelet decomposition algorithm can effectively recognize signal position of catastrophe point and singular degree.

To verify wavelet reconstruction accuracy of sub-band signal, we suppose $a(t)$=0.1sin(Ωt)+0.03sin(3Ωt)+0.02sin (5Ωt), from Ω=6πrad/s, we can see, flicker signal includes three amplitude wave of 3Hz, 9Hz, and 15Hz, and theoretical amplitude respectively is 0.1, 0.03 and 0.02. From multi-resolution Mallat algorithm, each sub-band frequency range is shown as Table III.

TABLE III.
SUB-BAND FREQUENCY RANGE

Scale(j)	Reconstruction signal	Frequency band (Hz)
1	$d1$	800~1600
2	$d2$	400~800
3	$d3$	200~400
4	$d4$	100~200
5	$d5$	50~100
6	$d6$	25~50
6	$a6$	0~50
7	$d7$	12.5~25
7	$a7$	0~25
8	$d8$	6.25~12.5
10	$d10$	1.5625~3.125

VI. SIMULATION ANALYSIS

For easy to realize human-computer interaction function, we adopt visual instrument technology to design upper PC voltage flicker observe panel. According to wavelet decomposition and reconstruction method, we mix LabVIEW and Matlab to realize flicker monitor by calling Matlab script node in LabVIEW [14]. Through setting wavelet decomposition limit frequency value, we can make signal decomposed into enough bigger scale, which can make program automatic judge wavelet layer number, and get all amplitude modulation wave voltage signal of carrier wave.

A. Harmonic Monitor

Upper PC detection system receives lower PC transmitting data, and memories into EXCEL format file. Through read power network sample data files, where, we introduce software program method as harmonic detection for example. System uses wavelet transform and FFT analysis algorism to realize harmonic analysis. Matlab [15] wavelet analysis tool box function is perfect. So, we use Matlab program language to realize wavelet analysis. And adopt Matlab+LabVIEW mixed program technology, which make harmonic analysis Matlab program harmonic.m use at LabVIEW[16][17]program call. Voltage steady state component after wavelet decomposing is sent into function FFT.vi port X, FFT result is obtained at port FFT{X} after program running. To make wave display control X axis calibration correspond to time, we add Bundle data packer node: first item is wave initial position x_0, where valuation 0, express display from point. Secondary item is step length Δx, where is obtained by system sample frequency/sample point. The third item is frequency analysis result shaping array. The three items are sent into display control after packing.

A phase voltage as example, its harmonic analysis front panel measurement result is shown as Fig. 17.

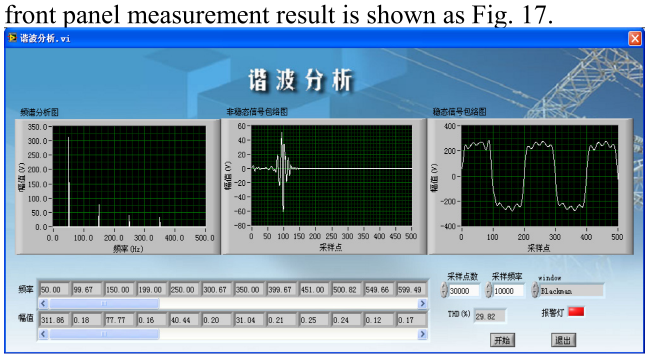

Figure 17. Harmonic analysis front panel

Ideal THD% calculation formula is shown as:

$$THD\% = \frac{\sqrt{77.77^2+40.44^2+31.11^2}}{312} \times 100\% = 29.83\%$$

From Fig. 17 we can see, THD% of monitor value is 29.82%, which obtains accurate measurement result in little monitor error.

B. Voltage Fluctuation and Flicker

We also use LabVIEW combining Matlab to complete voltage fluctuation and flicker monitor. In theory, three kinds of amplitude wave signal locate at $d7$, $d8$ and $d10$

after wavelet transform reconstruction, we use 10 level reconstruction. Sub-band *d*7, *d*8, and *d*10 simulation result is shown as Fig. 18.

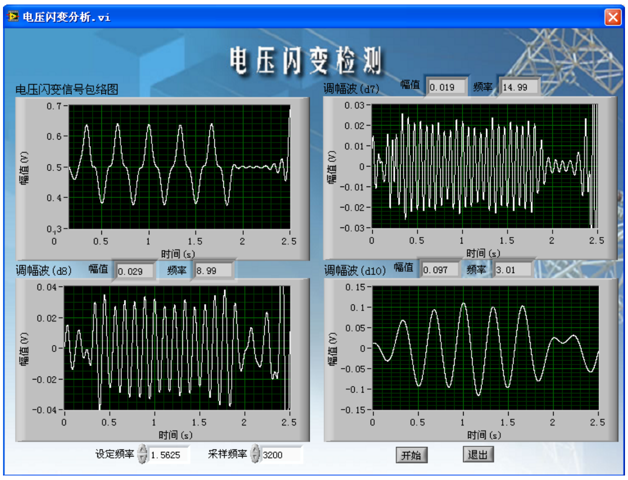

Figure 18. LabVIEW front panel running result

From Fig. 18 we can get each wavelet reconstruction sub-band frequency and amplitude after taking single frequency measurement function of LabVIEW function tools. It is shown as Table IV.

TABLE IV.
RECONSTRUCTION RESULTS

Sub-band	Frequency(Hz)	Error(Hz)	Amplitude(V)	Error(V)
d10	3.01	0.01	0.097	-0.003
d8	8.99	-0.01	0.029	-0.001
d7	14.99	-0.01	0.019	-0.001

From three sub value of suggestion voltage $a(t)$, which theoretical amplitude are respectively 0.1V, 0.03V and 0.05V. Signal basic wave, three times, and five times harmonic wave sub-value amplitude are respectively 0.097V, 0.029V, and 0.019V, frequency are respectively 3.01Hz, 8.99Hz, and 14.99Hz. Corresponding frequency and amplitude monitor error are shown as Table III, which is verified algorithm's accuracy in smaller monitor error.

VII. CONCLUSION

System changes traditional electric power parameter measurement style based on hardware as core through VI technology, which completely adopts PC's strong functions of calculation, display, and storage, etc.

System uses module of voltage/currency transformer, multiplexing switch, etc, which realizes electric power network signal detection. Software design of detection module, data display module, alarming module, report form drawing module, etc are done by control software of Matlab+LabVIEW8.5 [18] System hardware has many advantages of sample structure, higher measurement precision, convenient extension, and easy to realize electric power parameter monitor, etc. System software uses wavelet multi-resolution analysis method, etc in monitor error of harmonic wave's *THD*% is 0.01%, and amplitude wave's frequency and amplitude of voltage flicker is respectively less than 0.01Hz and 0.005V, which realizes high precision electric power parameters measurement.

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