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EXPERIMENTAL STUDY OF ON-LINE ARC FAULT DETECTION SYSTEM BASED ON LABWINDOWS/CVI

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ABSTRACT

Arc fault is one of the primary reasons that cause electrical fire. In power supply line, if arc fault occurs, the currents can not make protective equipments act, the arc fault can not be found easily, so electrical fire comes into being. Based on LabWindows/CVI, experimental studied the on-line arc fault detection system. AT89S51 Single Chip Microcomputer is used as lower computer, based on LabWindows/CVI, the upper computer program uses multithreading technology to detect and analyze the current signal. By arc fault detection algorithm, the system judges whether there has arc fault . The algorithm judges whether there has arc fault through detect if there has periodicity singularity points. The experiments show that this detection method of arc fault can detect arc fault in power supply circuits exactly and efficaciously.

Keywords: *Arc Fault, LabWindows/CVI, On-line Detection; Multithreads, Periodicity Singularity Point*

1. INTRODUCTION

With rapid economic development, the fire caused the property loss increases with the same pace of GDP. According to the researched by World Fire Statistics Centre (WFSC) and European Communities (EC), if the economic loss caused by fire account for 1% of GDP, the loss of the entire fire will account for more than 20% of GDP[1]. In recent years, the incidence of fire is increasing in China. From 1997 to 2004, electrical fire occurred more than 220 thousand, the casualties exceeded to 9 thousand and the property loss went beyond 35 billion[2]. So study on the detection of electrical fire has very positive significance.

In low voltage power circuits, there are some reasons that cause arc fault, such as electrical leakage, grounding, and bad contact, etc. The arc fault current can not make protective equipments action, the arc fault continuously burning, cause the electrical fire and huge damages.[3-5]

Scholars at home and abroad all devote to the study of the arc fault's characteristic. The foreign scholars first set up the mathematical model of arc (L.NieMayr, J .P.Novak and A.D.Stokes), then in subsequent studies, research the voltage and current waveforms' characteristic of arc fault in the circuits[6], and design the devices which can cut off the arc fault [7-9]. But most of these mathematical models which they built are based on the statistical data's empirical formulae, can not solve the arc fault's actual physical characteristics in the low voltage apparatus. Regard the arc fault as the major reason of the electrical fire and set up special programs to research, domestic scholars did not give adequate attention, the studies of the arc's detection mostly focus on electric arc furnace, high-voltage electrical apparatus and arc-welding, etc [10-12]. For these reasons, based on the experiment research and theoretical analysis, studied the characteristic of arc fault and designed the arc fault on-line detection system.

2. EXPERIMENT STUDY OF THE ARC FAULT'S CHARACTERISTIC

In order to achieve the effective method to detect the arc fault from its characteristic, established a simulative experiment flat of arc fault. The flat is composed by alternating pure power (220V, 50Hz), current sensor, digital filter and a pair of model electrodes to simulate the arc's discharge. Separately selected aluminum and copper as the arc's discharge model electrode and the model electrodes' interval can be changed arbitrarily. The digital filter is TipPiescope-HS801, it has the function of automatic data acquisition, curve show

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and data storage. The sample frequency of the digital filter is 10 KHz to meet the demand of precision.

The course of experiment is:

1) The normal current waveform's acquirement. First add the load, observe the digital filter, note the current waveform when the circuit normal work, conserve the data.

2) The arc fault current waveform's acquirement. It has two stages, the one is arc's generation, the other is arc's reignition. First change the interval of the simulation electrodes, gain the stable arc, observe the digital filter, note the waveform and conserve the data, then close the simulation electrodes completely, in this time no arc comes into being, gain the current waveform when the circuit back to normal.

The waveforms which we gained are showed in Fig.1. Waveform 1 is normal current waveform, waveform 2 is arc current waveform, T1 is the waveform when the arc comes into being, T2 is the waveform when the arc back to normal.

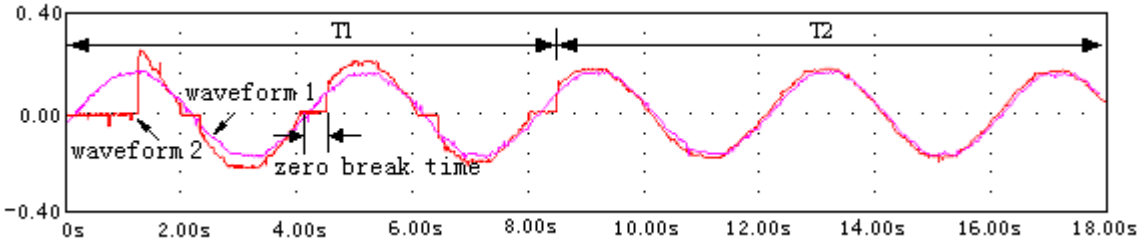

Figure 1: Arc current waveform compare with normal current waveform

Analyze the arc current waveform from Figure 1, we can know that:

1) when the arc stable combustion, the current waveform is very similar to the normal current waveform, so the arc current value is very close to the normal current value, it is the real reason of why the circuit protective equipments can not cut off the arc easily.

2) At the course of T1, the arc current instantaneous value has a particular region. At this region, the current value is close to zero. This region is usually regarded as zero off time[13]. The reason of the form of zero off time is: After the arc's continuously burning, when the current is coming to the zero, because the electric field strength cannot keep the arc continuous discharge, the current between the electrodes decrease to zero rapidly. When the two electrode voltage gradually rises, the electric intensity between the electrodes intensify, under the action of afterheat, air gap breakdown between electrodes to form arc, the air-gap between the electrodes is breakthrough and form arc, the electric current value increase rapidly and form the abrupt signal.

3) At the arc continuously burning course, accompanied with electric current periodically pass through the zero, the zero-off phenomena periodically appear.

According to these primary characteristics, experimental studied the arc fault on-line detection system based on the wavelets singularity signal's detection theory. The system through detect the currents' periodical singularity point to judge whether the existence of the arc or not in the power supply circuit [14], use AT89S51 single chip as the core of lower computer to detect the current signal, use LabWindows/CVI as upper computer's program flat to develop the synthetic judgment programs, realized the arc fault's on-line detection.

3. THE DESIGN OF THE ARC FAULT SIGNAL'S SAMPLE CIRCUIT

(1)The Basis of The Design of Hardware Circuit

According to the experiment, we discover that when the arc comes into being in the power supply circuit, the zero-off phenomenon usually maintain more than 1ms. According to the Nyquist sampling theorem, in order to reflect the signal characteristic correctly, the sample circuit's sample interval must less than the 1/2 zero break time. In order to reflect the course of arc's produce and extinguish, the system's sample frequency is set to 10KHz. Select the Hall current sensor as the detection component; the AD976A as A/D translation chip, its conversion accuracy can reach the 16 bits; the AT89S51 single

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chip as the low computer to compose the arc fault signal's sample circuit.

The arc fault on-line detection system showed in Fig.2. After current signal extracted from current sensor, the sample signal is gained and through preamplifier circuit, the sample signal is amplified. Through low-pass filter, the high frequency interference signal is filtered and through A/D translation circuit, the analog sample signal is transformed into the digital signal. Then the digital sample signal is sent to the sample maintain circuit waiting to the AT89S51 signal chip's read. AT89S51 control multiple-way switch, select the signals to the signal chip. Signal is designed as the long-range signal and through signal chip serial port sent to upper computer. The transport protocol between the signal chip and upper computer is RS485.

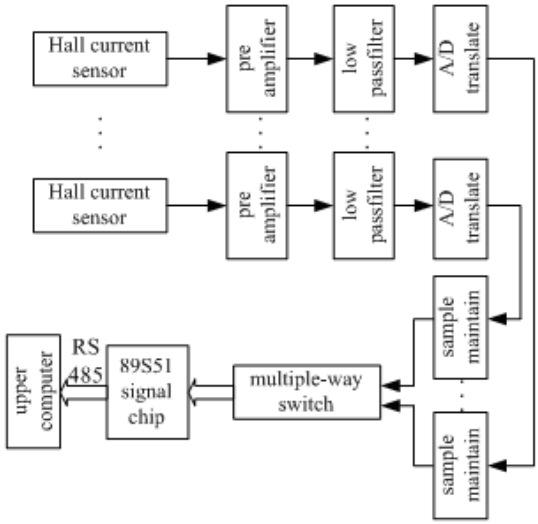

Figure 2: Frame of on-line arc fault detection system

(2)The Key Techniques of Low Computer Program Design

The low computer program design mainly includes A/D conversion program, serial port transmission procedure and watchdog program, etc. The serial port transmission procedure and watchdog program should be paid more attention.

(a) The Key Techniques of Serial Port Data Transmission Procedure:

The upper computer is developed by LabWindows/CVI, but the LabWindows/CVI can only read the character data. In order to optimize the upper computer program further, reduce the upper computer program's run time, increase the upper computer program's readability, the low computer's data is designed as the character data. But there has another problem: use assembly language to realize data type conversion is very difficult, so we use C Language to write the low computer program.

In C Language, suppose 'a' is a signed shaping data, use the command 'b=(char)a' compulsively transform 'a' to character data and use the command 'c=(int)b' return 'b' to shaping data 'a', that is 'c=a'. but the point we must pay attention is: 32 bits PC computer can only realize data conversion from -128~+127, the 8 bits AT89S51 can only realize data conversion from -32~+31, but AD976A's conversion accuracy is 16 bits, its output data range from -32768~+32767, which beyond the data range of the command '(char)a' and '(int)b' in 8 bit signal chip. So when translate the data, split the data which waited to transmit into the 'units', 'decimals', 'hundreds', 'kilobits', 'myriabits' (merge the 'sign bits' into 'myriabits'), and set the 'flag bits' correspondingly. The upper computer recombines these data depend on the situation.

(b) The Key Techniques of Watchdog Program[15][16]:

In order to avoid the system halt caused by the program's lossing and the endless loop, the watchdog program should be used in system's sample circuit to ensure the system's reliability. the watchdog module is integrated in AT89S51, but the watchdog module must be activated. The program to activate watchdog is:

```
int a6=DBYTE[0xA6];
        //define storage unit A6H//
a6=0x1e;
        // startup watchdog, first input 1E//
a6=0xe1;            //then input E1//
```

Because AT89S51 only has 14 bit enumerator, the dog should be feed every 16383 cycles, and the time is fixed, can not be changed. If the crystal oscillator frequency is 12M, the dog should be feed every 16 ms. So the watch dog timer should be in the program of data send interrupt program.

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4. THE UPPER COMPUTER LABWINDOWS /CVI PROGRAM DESIGN

The upper computer program---"the on-line arc fault detection system" developed by the monitor and control software of LabWindows/CVI. LabWindows/CVI is a suit of software development platform, it is face to monitor and control area, developed by the National Instruments Company. The ANSI C is its core, it affords a perfect software development environment for developer to build the detection system, automatic measurement environment, and data sample system and process monitor system.

Upper computer system is composed by main interface, on-line detection interface, data analysis interface. The main interface's main task is accomplish the 6 points' detection, display the 6 detection points' working position, once arc fault formed, alarm in time. On-line detection interface can instantly reflect the detail information of the points' current waveform, current virtual value, fault situation, etc; and can design the detection points' sample precision, software shift, filtering way, filtering frequency, wavelet type, wavelet threshold value, etc. Data analysis interface is to detailed analyze the past signal, and reveal the wavelet function and scale function of data arc detection algorithm.

(1) The Use of Multithreading Technology

The multithreading program is the program which has at lest two threads to execute programs at the same time. When user command the operation system to execute a particular program, the operation system build a main thread, in the same time, operation system need to build one or more than one subsidiary threads other than the main threads. Multiple threads can avoid block, decrease the interaction between running course and user interface, and make the best use of multiple processor.

The main programs in upper program are serial port data program, data pretreatment program, data analysis program, etc. systems build two subsidiary threads other than main thread. The main thread's task is each interface's display, switch, exit; one of subsidiary thread's task is read serial port data, display the detecting type; the other of subsidiary thread's task is data pretreatment and data analysis.

LabWindows/CVI afford the thread pools and asynchronous timers, we can select the thread pools to build subsidiary threads according to the need. Use the function:

'CmtScheduleThreadPool- Function( )' to build two subsidiary threads;

Before the system exit, use the function:

'CmtWaitForThreadPoolFunctionCompletion()' to compulsive finish, and through the function:

'CmtReleaseThreadPoolFunctionID( )' to release the resource which is occupied by subsidiary threads. Every subsidiary thread would produce a corresponding thread call-back function. The program which works under every thread should write in the corresponding thread call-back function.

(2) The Design of Serial Port Data Read Program

LabWindows/CVI afford serial port function base. Program the serial port, first use the function

'OpenComConfig( )' to open and to initialize the COM1 port, than receive the data, close the COM1 port before the program end.

LabWindows/CVI afford an important serial function:

'InstallComCallback( )', it set a call-back function for the appointed serial port. This call-back function can reflect the different situation of serial port. The system's setting is: when serial port receives each data, it would start up serial port data receiving function. In the receiving function, first compute the length of data which the serial port received, then open a data area of char type with the same size to store data, at last, use function:

'ComRd( )' to read the serial port data.

After the data reading finished, must use function:

'CloseCom( )' to close the serial port

(3) The Design of Data Pretreatment Program

The upper program recompose the data which is carried by AT89S51, revert the real values based on A/D conversion precision, eliminate the noisy signal according to the need.

(a) Data Recompose: The system set a sign character 'flag' to note the number of received data. Through judge the value of 'flag', make sure the data belongs to which bits, the 'units', 'decimals', 'hundreds', 'kilobits' or 'myriabits'. For the more, system store a data file every 2000 sample data points, so every time the 'flag=1999', the data file store once, and 'flag=0', to recalculate.

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(b) Data Revert: According to the output scope of AD976 and the input scope of current sensor, the formulation of data reverts is:

$$signal[i] = ontimesignal[i] \cdot 40.0 / 65535.0 \quad (1)$$

$ontimesignal[i]$ --- the result of data recompose

$signal[i]$ --- the real signal after revert

(c) Elimination of Noisy: In order to eliminate the possible noise at the process of data transmission, can use software to filter the received data. LabWindows/CVI affords a variety of filters, such as Butterworth filter, chebyshev filter, etc. Butterworth filter is selected as the software filter. 'Bw_LPF()' is the low-pass Butterworth filter, 'Bw_HPF()' is the high-pass Butterworth filter. Set a numerical control 'Numeric1' at the user interface, user can change the filter frequency through change the Numeric1's value.

(3) The Design of Arc Fault Detection Algorithm Program

When AC arc continuously burning, the phenomena of periodical zero-off is reflected as the periodical singular point in the signal. So the essence of arc fault detection is to detect the periodical singular point of the current signal.

System transform the collected current data based on binary wavelet group by group, select the orthogonal quadratic spline wavelet as wavelet function, select cellular algorithm as wavelet transformation. Based on the quality of the signal singular point's dimension transmit, each group need three times' wavelet transform. Analyze each wavelet transform's high-frequency signal, find model's maximum value. If in the high-frequency signal of the three times' wavelet transform, the model's maximum value located within the limit area, we regard this model's maximum value as the signal's singular point. In the experiments, if the sample frequency is 10KHz, the arc burn constantly and the space of the two singular points is 100 ± 15, at the same time the arc's burning time is the half of power frequency periods, which is 0.01s. If the signal's singular points display the periodic distribution, we regard that the arc fault in the power supply circuit comes into being.

When we program the signal's wavelet transform, set a parameter i to compute the number of convolute of signal and filters. If $i \le 3$, then go next, if $i > 3$, then output the last high frequency coefficient of wavelet transform. The wavelet transform's flow chart showed in Figure 3. Use the wavelet cellular algorithm to realize the wavelet transform in LabWindows/CVI, benefited from the convolution function which afforded by LabWindows/CVI:

'Conolve(double x[],int n, double y[], int m, double cxy[])'

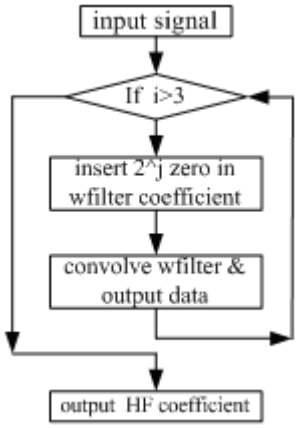

Figure 3: Flowchart of wavelet transformation

Based on the above methods, we designed the algorithm of arc fault's detection, fused it into the on-line arc fault detection system and realized the on-line arc fault detection. The working image of on-line detection interface of arc fault on-line detection system showed in Figure 4.

5. CONCLUSION

This project researched the voltage and current waveforms' characteristic of arc fault through experiments. When the arc fault formed in the circuit, there has the periodical zero-off phenomenon in current, the phenomenon is represented as periodical singularity point in signal processing, so proposed the periodical singularity point's detection algorithm. This algorithm use the wavelet transform's singularity detection to judge whether there has the periodical singularity point in the current, then to judge if the arc fault comes into being. The arc fault detection circuit realized the 6 current signals' on-line detection and data transmission. The upper computer developed the data analysis system based on LabWindows/CVI, using the multithreading technology, the subsidiary threads can finish the data pretreatment and data analysis, the arc fault detection algorithm in the system can be rapidly realized in this way. The

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experiments showed that the on-line arc fault detection system is the very important part in electrical fire early warning system, can on-line detect the power supply circuit effectively, if the arc fault comes into being, can alarm timely and accurately.

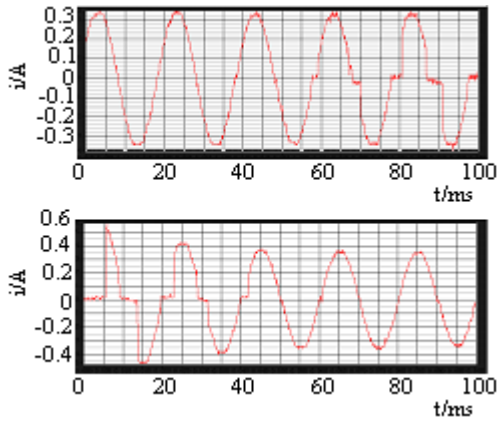

Figure 4: On-line arc fault detection

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