Journal of Theoretical and Applied Information Technology
30th November 2012. Vol. 45 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

FEATURE EXTRACTION FROM SERIES LOW-VOLTAGE ARC FAULT

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ABSTRACT

220V/50Hz residential circuit was taken as application object. Series arc fault experiment platform was built with reference to the domestic existing research results and the United States UL1699 standards. Arc current and arc voltage were collected. High order harmonic ratio analysis method for wire's current was proposed. Through the variation condition analysis for high order harmonic ratio of wire's current data in parallel multi-load circuit, the variation characteristics, for high order harmonic ratio caused by arc fault, was summed up. Research results show that: if a non-linear load was connected to the circuit's load in parallel, when this two loads were in stable operation at the same time, high order harmonic ratio of wire's current increased. If a linear load was connected to the circuit's load in parallel, high order harmonic ratio of wire's current did not significantly change. When arc fault occurred in parallel load circuit, high order harmonic ratio of wire's current appeared to rise sharply, and it is not stable, in fierce fluctuation.

Keywords: *Electrical Fire, Arc Fault, High Order Harmonic Ratio, Harmonic Analysis, Feature Extraction*

1. INTRODUCTION

With the rapid development of electrical technology, residential electrification is becoming more and higher, however, the threat of electrical fire on people's life and property safety is getting more and more. The United States Fire Administration(USFA) statistics shows: there were 67800 residential fires caused by arc fault in American in 2006, 485 people killed, more than 2300 people injured, direct property loss of $0.868 billion [1]. Electrical fire, caused by residential wire's fault, is two times as much as that caused by electrical equipment's fault. Further more, arc fault is one of the primary causes of electrical fires [1],[2]. In China, electrical fire, caused by arc fault, accounted for 51% in total fires during 2005~2009 year, and the direct economic loss accounted for 36% in total fire losses. Arc fault is one of the main causes of Chinese building electrical fires [3].

Because of arc's concealment and high risk, developed countries such as Europe and America have exploited 120V/60Hz arc fault circuit interrupter(AFCI).In 1999, America exploited a AFCI, forced installing AFCI through legal measures in 2008, and has received remarkable results in electrical fire prevention. Japan forced the use of high-quality electrical fire detector in 1978, so that electrical fire down to fire 2%. Chinese research has just started, Shenyang Fire Research Institute of the Ministry of Public Security will develop 220V/50Hz arc fault detection standard. The present theoretical study mainly focuses on arc modeling, arc detection and arc fault identification etc. Because of the complexity of arc fault, current methods have many limitations: first of all, arc fault location is random, so the arc voltage can not be measured directly, and the theory based on arc voltage is difficult to be used for the actual detecting system; Secondly, the circuit load has many types, so it is not possible to measure every load's characteristic curve, when there are several loads in parallel in circuit, characteristic will change; Finally, the arc fault current is very weak, lost in a variety of electrical noise, because of the time averaging effect of frequency domain analysis method, short arc fault is difficult to stand out, simple statistical parameters are difficult to detect various types of arc fault.

The typical household loads are similar to arc fault in characteristics. Therefore, in order to effectively achieve accurate arc fault detecting, a feature vector must be found to reflect different arc essence maximization, at the same time, to filter similar common background and interference. In this paper, 220V/50Hz residential circuit was taken as application object, series arc fault experiment platform was built with reference to the United

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States UL1699 standards. Arc current and arc voltage were collected. High order harmonic ratio analysis method for wire's current was proposed. Through the variation condition analysis for high order harmonic ratio of wire's current data in parallel multi-load circuit, the variation characteristics of higher order harmonic ratio, caused by arc fault, was summed up. This paper provides theory and technology foundation to construct arc fault feature vector, to realize quick capturing and recognition of arc fault, to solve the key technology of electrical fire prevention. In recent years, many experts and scholars have begun to pay attention to the research of arc fault detecting method, but the research work is still at the beginning stage. So, it is very important and meaningful to research arc fault deeply, and exploit an AFCI, suitable for China's electrical characteristics.

2. LOW-VOLTAGE ARC FAULT TEST

Series arc fault experiment platform was built with reference to the domestic existing research results and the United States UL1699 standards. The experiment platform can be used to collect series arc fault experimental data and test the developed arcing fault detection device. The UL1699 standards are AFCI safety standards, testing AFCI's safety performance [4], [5]. The standards include carbonized path arc ignition experiment. As shown in Fig.1, The arc generator can be used to test tripping performance of AFCI. In the experiment, arc generator and load are in series, and the arc generator generates arc. In this paper, series arc fault experiment platform was designed according to the testing theory, its schematic diagram is shown as in Fig.1.

The circuit uses 220V, 50Hz as power supply. In the circuit, arc generator and typical household appliances (such as light bulb, vacuum cleaner, dimmer and so on)are in series. Load is connected to the circuit through load socket. Every socket has an independent switch control for a single load experiment and also parallel several loads experiment. Experimental signals are obtained through signal detecting circuit, which includes a current transformer, a voltage transformer and DAQ data acquisition system. The current transformer is used for sensing the current signal, and the voltage transformer is used for sensing the voltage of arc generator.

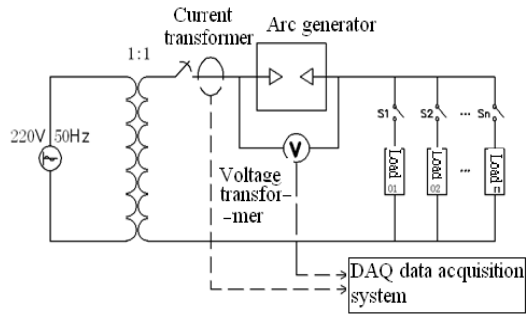

Figure 1: Schematic Diagram Of Series Arc Fault Experiment Platform

3. HIGH ORDER HARMONIC RATIO CHARACTERISTICS ANALYSIS

3.1 High Order Harmonic Ratio

Harmonic ratio is defined as following: the mean square of h-order harmonic component, contained in Periodic AC components, divide the mean square of fundamental component. It's expression is as following:

$$HRI_h = \frac{I_h}{I_1} \times 100\% \qquad (1)$$

Where, I_h is the mean square of h-order harmonic current, I_1 is the mean square of fundamental component. Mean square is defined within the specified time T_0, its expression is as following:

$$I_h = \sqrt{\frac{x_{h1}^2 + x_{h2}^2 + \cdots + x_{hM}^2}{M}} \quad h = 0, \pm1, \pm2, ... \qquad (2)$$

Where, x_h is harmonic h, M is the total number of signal discrete points.

The previous analysis indicated that, harmonic ratio of harmonics 3, 5, 7, 9 of wire's current increased when arc fault occurred. However, because of the smaller increase, it is unreliable to take harmonic ratio's variation of one of the harmonics 3, 5, 7, 9 as detecting standard of arc fault. So, We tentatively put forward the sum of harmonic ratio of harmonics 3, 5, 7, 9, abbreviated as high order harmonic ratio(HR). Its formula expression is shown as (3).

$$HR = \frac{I_3 + I_5 + I_7 + I_9}{I_1} \times 100\% \qquad (3)$$

When arc fault occurs, the HR's variation will be more obvious. In this paper, we analyzed current high order harmonic ratio(HR) when arc fault occurred in different load circuit , and gather statistics of the variation characteristics.

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3.2 Analysis For Circuit's Data Of Single Load

There is a difficulty for arc fault diagnosis. It is that many characteristics of arc fault are very close to that of some nonlinear loads. Nonlinear electrical load is one of the main causes of leading to arc fault detection and AFCI's error judgment[6],[7]. Wire's current high order harmonic ratio were observed, for linear light bulb load and nonlinear vacuum cleaner load respectively. Wire's current high order harmonic ratio were analyzed, for load in normal operation state and arc fault occurring respectively. The analysis results are shown as in Fig.2.

Firstly, when light bulb was in normal operation, wire's current high order harmonic ratio was smaller, and the mean value was 5% stability. Afterwards, when arc fault occurred, high order harmonic ratio increased sharply, and the mean value increased to 20%, increased by 15%. Therefore, when arc fault occurred, wire's current high order harmonic ratio changed unstably, fierce fluctuating.

Because vacuum cleaner is driven by high speed motor, it is a harmonic source. Firstly, when vacuum cleaner was in normal operation, wire's current high order harmonic ratio was bigger than above light bulb', and the mean value was 21% stability. Afterwards, when arc fault occurred, high order harmonic ratio increased sharply, and the mean value increased to 43%, increased by more than up to 15%, fierce fluctuating. Therefore, whether linear and nonlinear loads, when it is in normal operation state, wire's current high order harmonic ratio varies from each other, but when arc fault occurs, wire's current high order harmonic ratio rises sharply and fierce fluctuating.

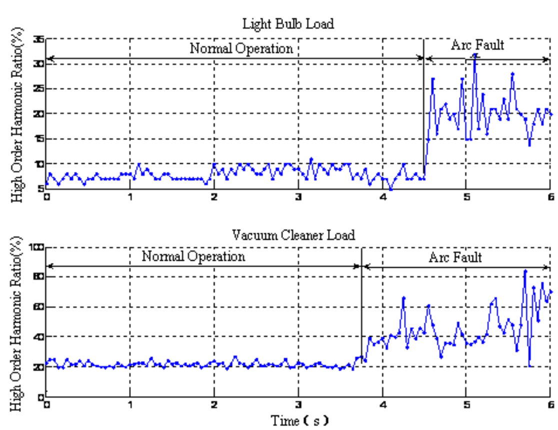

Figure 2: High Order Harmonic Ratio Analysis For Arc Fault Of Single Load

3.3 Analysis For Vacuum Cleaner In Low Speed

The speed regulator of vacuum cleaner can cause wire's current waveform's distortion[8], and then cause high order harmonic ratio increasing. Therefore, wire's current high order harmonic ratio was analyzed for vacuum cleaner in different speed and arc fault respectively. The analysis results are shown as in Fig.3.

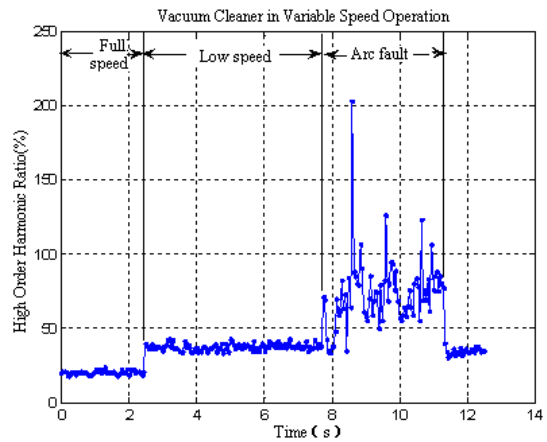

Figure 3: High Order Harmonic Ratio Analysis For Arc Fault Of Vacuum Cleaner In Variable Speed

Firstly, when vacuum cleaner was running at full speed, speed regulator was not working, and the mean value of high order harmonic ratio was around 21% stability. Afterwards, When the running speed of vacuum cleaner was changed suddenly, making it in low speed, the speed regulator was in working state, so wire's current high order harmonic ratio increased, and the mean value rose from 21% to around 38%. Speed changing size was directly related to the changing size of high order harmonic ratio. When the vacuum cleaner was in stable operation again , high order harmonic ratio entered into another stable state. In addition, when arc fault occurred, wire's current high order harmonic ratio increased sharply, fierce fluctuating. And the mean value increased to 72%, increased by more than up to 15%. Therefore, changing load's state can cause wire's current high order harmonic ratio changing, but the change can be stable again as the load in stable operation again. Furthermore, Regardless of load's speed in circuit, when arc fault occurred, wire's current high order harmonic ratio increased sharply and fierce fluctuating.

3.4 Analysis For Parallel Loads

As for parallel multi-loads running simultaneously, there are the following kinds of parallels, as shown in table 1.

Journal of Theoretical and Applied Information Technology
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ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Table I. Parallel Load Experiment Scheme

Scheme	Load combination
Scheme 1	Light bulb + dimmer load
Scheme 2	Vacuum cleaner +dimmer load
Scheme 3	Vacuum cleaner + Light bulb
Scheme 4	Light bulb + dimmer load + vacuum cleaner

Scheme 1: Dimmer was in parallel with light bulb, and it was mainly used for analyzing variation condition of wire's current high order harmonic ratio when a nonlinear load was parallel connected into linear load circuit. The research results are shown as in Fig.4.

Firstly, when a dimmer load was parallel incorporated into the light bulb, high order harmonic ratio increased relative to the bulb light running alone in circuit, and the mean value rose from original less than 10% to15%. In the rising process, when the dimmer was in opening moment, high order harmonic ratio was fluctuant. Afterwards, when the dimmer was in stable operation, the current high order harmonic ratio was in a steady state. Besides, when arc fault occurred, high order harmonic ratio increased sharply, fierce fluctuating , the mean value was more than up to 45%. In addition, when a nonlinear load was parallel connected into circuit, wire's current high order harmonic ratio increased in part, but its change process was stable, and after loads' stable operation, wire's current high order harmonic ratio was also stable in a certain range. Therefore, when a nonlinear load was parallel connected into circuit, wire's current high order harmonic ratio changed relatively stable, however, when arc fault occurred, wire's current high order harmonic ratio rose sharply, fierce fluctuating.

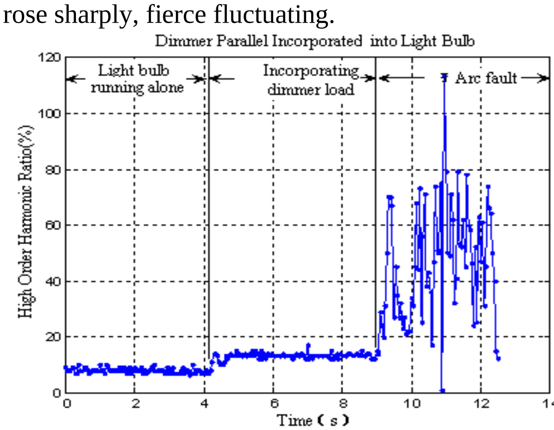

Figure 4: High Order Harmonic Ratio Analysis Of Arc Fault For Light Bulb Parallel With Dimmer

Scheme 2: Vacuum cleaner was in parallel with dimmer load, and it was mainly used for analyzing variation condition of wire's current high order harmonic ratio when a nonlinear load was parallel connected into the nonlinear load circuit. When the two nonlinear loads run at the same time, we adjusted the device of nonlinear dimmer load manually, and observed the variation condition of high order harmonic ratio, comparative with that when arc fault occurred .The research results are shown as in Fig.5.

Firstly, the vacuum cleaner was open, in stable operation, and the mean value of wire's current high order harmonic ratio was 21% stability. Afterwards, when a dimmer load was parallel incorporated into the vacuum cleaner, adjusted slowly, high order harmonic ratio also appeared a slow transition process. With the stop of adjusting, its final mean value was 25% stability. Finally, with rotating the screw of arc generator device, arc fault occurred, wire's current high order harmonic ratio increased sharply, fierce fluctuating, and the mean value was more than up to 45%. Therefore, when a nonlinear load was parallel connected into another nonlinear load, and then adjusted manually, wire's current high order harmonic ratio changed smaller than that caused by arc fault.

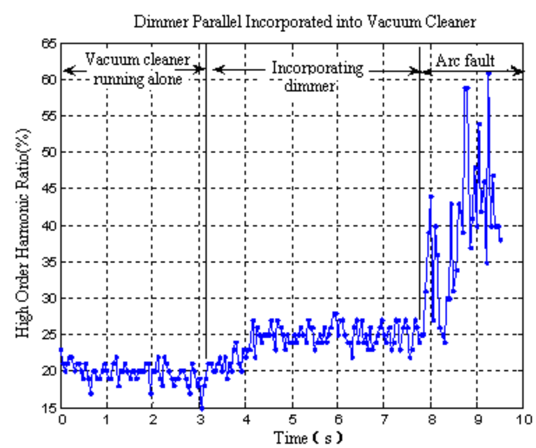

Figure 5: High Order Harmonic Ratio Analysis Of Arc Fault For Dimmer Parallel With Vacuum Cleaner

Scheme 3: When light bulb was parallel incorporated into vacuum cleaner circuit, the circuit power became larger than that of vacuum cleaner running alone[9],[10],and it was mainly used for analyzing the impact of power on wire's current high order harmonic ratio. The research results are shown as in Fig.6.

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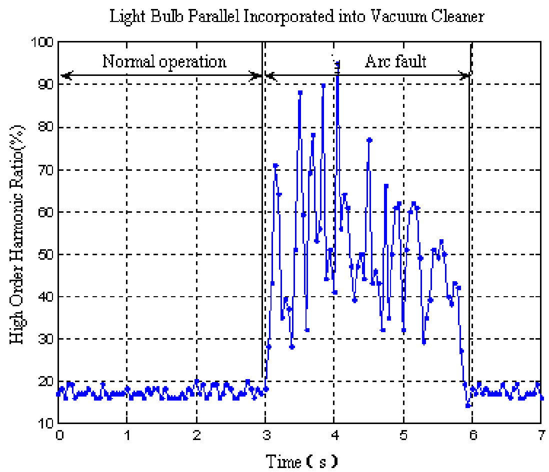

Figure 6: High Order Harmonic Ratio Analysis Of Arc Fault For Light Bulb Parallel With Vacuum Cleaner

Firstly, when vacuum cleaner was in stable operation, a 1000W light bulb was parallel incorporated into it. Because light bulb is a linear load, wire's current high order harmonic ratio did not change appreciably. Then, let the arc generator generated arc fault, high order harmonic ratio increased sharply, fierce fluctuating. Therefore, the impact of power on wire's current high order harmonic ratio was relatively little.

Scheme 4: Scheme 4 was a supplement for the above three schemes, it was mainly used for analyzing variation condition of wire's current high order harmonic ratio when three kinds of loads was parallel connected into circuit at the same time. The research results are shown as in Fig.7.

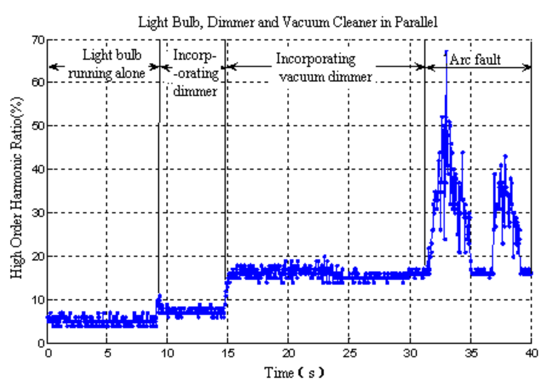

Figure 7: High Order Harmonic Ratio Analysis Of Arc Fault For Light Bulb, Dimmer And Vacuum Cleaner In Parallel

Firstly, when there was only light bulb running in the circuit, the mean value of wire's current high order harmonic ratio was 7% stability. Afterwards, when a dimmer load was parallel incorporated into the light bulb circuit, at the beginning, the mean value appeared to fluctuate. After the dimmer was in stable operation, the mean value of wire's current high order harmonic ratio was 9% stability. Then, when a vacuum cleaner was parallel incorporated into the circuit, the mean value of wire's current high order harmonic ratio increased, eventually stabilizing at around 18%. At the beginning, the mean value also appeared in a small range of fluctuation. When the vacuum cleaner was in stable operation, its mean value was stabilized. Finally, with adjusting electrode spacing, arc fault occurred, and wire's current high order harmonic ratio increased sharply, fierce fluctuating.

4. CONCLUSION AND FUTURE WORK

In this paper, under the condition of power frequency, according to the United States UL1699 standards, we did low-voltage arc fault experiments. We collected wire's current data, and analyzed the experimental data deeply, variation conditions of wire's current high order harmonic ratio for different loads' circuits, and also summed up the variation characteristics of wire's current high order harmonic ratio. The obtained conclusions are as following.

For linear load circuit, wire's current high order harmonic ratio was very small, stable in a certain range. When arc fault occurred, wire's current high order harmonic ratio increased significantly, fierce fluctuating. For nonlinear load circuit, wire's current high order harmonic ratio was larger, also stable in a certain range. When arc fault occurred, wire's current high order harmonic ratio also increased significantly, fierce fluctuating. Adjusting the speed regulator of nonlinear load, changing nonlinear load's operation state (such as changing speed), wire's current high order harmonic ratio for low speed state was larger than that of high speed state, but both stable in a certain range. From high speed to low speed, wire's current high order harmonic ratio changed smoothly ,not volatility.

As for parallel circuit, when a nonlinear load was parallel incorporated into a linear load, after two loads' stability simultaneously, wire's current high order harmonic ratio increased, relative to that of a single linear load running alone in circuit. During the incorporating process, wire's current high order harmonic ratio was fluctuant. However, when two loads were in stable operation, the current high order harmonic ratio was in a steady state.

When a linear load was parallel incorporated into circuit, wire's current high order harmonic ratio did not change appreciably. However, when the arc generator generated arc fault, wire's current high

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

order harmonic ratio increased sharply, fierce fluctuating.

Regardless of any parallel loads circuit, when arc fault occurred, wire's current high order harmonic ratio increased sharply, and the mean value increased by more than 15%, fierce fluctuating.

Currently, more and more fires caused by arc fault occur. In this case, designing an AFCI to prevent fires caused by arc fault has become an important prerequisite for electrical fire safety. In future works, we will further complete our work and exploit other important issues. According to wire's current high order harmonic ratio characteristic analysis, we will design a arc fault detection scheme. Taking the experimental data as samples, we will analyze the detecting effect of detection scheme. Finally, considering the detecting effect, detecting signal, detecting time and other factors, we will design a AFCI. In addition, combining with the actual circuit, we will verify the designed AFCI. We hope this methodology could break the restriction of traditional method and provide more space for virtual arc fault feature extraction and AFCI designing.

ACKNOWLEDGEMENTS

We thank associated professor Jianhong Yang and graduate student Xiaomei Wu for their numerous discussions concerning this work, and the reviewers for their detailed comments. This work in this paper was supported by the National Natural Science Foundation of China(cultivating project) under grant No.JB-ZR1102, the Natural Science Foundation of Fujian Province of China under grant No.2010J01294 and University-industry Cooperation Science Technology Major project of Fujian Province of China under grant No.2012H6101.

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