Detection and Analysis of Series Arc Discharge in Indoor Wiring Systems

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Abstract: In this paper, we simulated series arc on electric heaters, vacuum cleaners and incandescent lamps controlled by a dimmer to analyze the characteristics of series arc that causes electric fires. A high pass filter (HPF) was designed to detect arc signal only. The HPF consists of 2-stage coupling capacitors and detection impedance, and its low cut-off frequency of -3 dB was estimated to 3 kHz. By using the HPF, we could detect high frequency components included in AC voltage and discriminate series arc signals on most types of loads used in low-voltage indoor wiring systems.

Key-Words: Series arc, Electric fires, Electric heater, Vacuum cleaner, Incandescent lamp, Dimmer, High pass filter, Low cut-off frequency

1 Introduction

Electric fires rapidly increase as the use of more low-voltage electric appliances.

According to the 2005 Statistical Analysis of Electrical Disasters, 30.9 % of all fires in Korea were attributable to fires by electrical failures, the highest among all the causes. The survey further revealed that 68.8 % of them were originated from by a short circuit with arcing or leakage current [1].

In particular, it was analyzed that most electric fires take place at residential buildings in densely populated areas in the afternoon from five to seven.

To reduce these electrical fires, various different technologies have been actively studied, including those for high speed breaker and detection of leakage current and arcing. Before the electrical fires, parallel or series arcing phenomena occur on indoor wiring systems.

Parallel arcing occurs when power lines short. It can be instantly detected by a current transformer and disconnected by a breaker as transient currents several times of rated currents flow in several milliseconds.

Series arcing occurs at loose terminations or device connections where electrical resistance increases when loads are connected. As series arcing has a little energy unlike parallel arcing, it does not make damage wiring or insulation materials rapidly but generates heat locally or tracking [2].

Further, as it occurs continuously, it carbonates insulation materials with thermal stress to form a conduction route, eventually causing a fire in a secondary breakdown. Compare to parallel arcing, series arcing does not trip the breaker as its arc current is limited by the load impedance and affected by its characteristic. Therefore, it is necessary to develop circuits and technologies to detect series arcing on indoor wiring system more effectively [3-6].

In this paper, we simulated series arcing on electric heaters, vacuum cleaners and incandescent lamps controlled by a dimmer to analyze the characteristics of series arcing that causes electric fires. And a High-pass filter (HPF) was designed to detect voltage signals under series arcing state. By the HPF, we could detect high frequency components only, excluding power frequency.

2 Experimental apparatus and Configuration

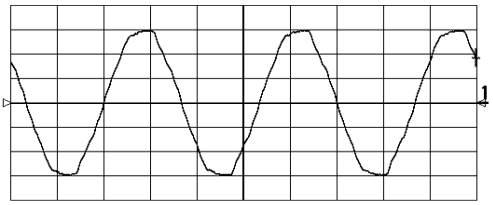
We fabricated and applied an arc generator specified in UL1699 as shown in Figure 1 to simulate series arcing in indoor wiring systems [7].

Carbon and brass electrodes were used for the simulation of series arcing on deteriorated outlets or connectors.

Figure 2 shows the comparison voltage waveforms between the normal state and series arcing with 100 W incandescent lamp. Arc voltage includes little high frequency elements.

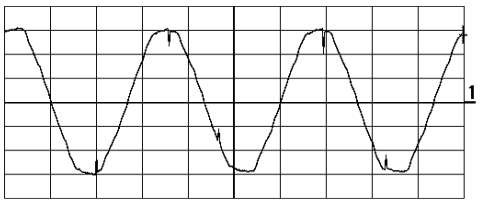
Fig.1 Photograph of the arc generator

It makes difficult to derive arc frequency component from the voltage waveform as the high frequency waves generated in a very little compared to the power frequency.



[100V/div, 5ms/div]

(a) Normal state



[100V/div, 5ms/div]

(b) Series arc state

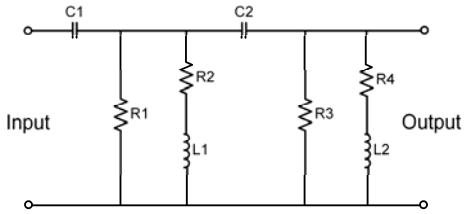
Fig.2 Comparison of voltage waveforms between normal and series arc state

In this study, therefore, we designed a quadruple HPF shown in Figure 3 to detect high frequency arc signals only by eliminating power frequency component.

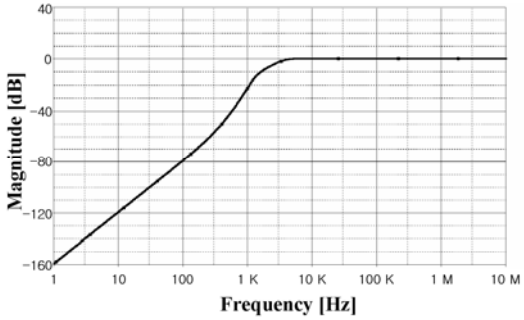
The HPF consists of 2-stage coupling capacitors and detection impedance. Frequency response of the HPF was analyzed by sinusoidal voltage and the low cut-off frequency of -3 dB was estimated to 3 kHz. Using the HPF, we can attenuate 60 Hz by 80 dB and detect series arc components of several kHz over as it is.

The experimental apparatus was shown in Figure 4. AC 220 V source, the arc generator and load were connected in series. The HPF for arc frequency detection was installed at the AC source considering the adaptability to indoor wiring systems.

Incandescent lamps, Electric heaters, and vacuum cleaners were used as the test loads to simulate series arc phenomena. Also, we analyzed the influence on series arcing of incandescent lamps controlled by a dimmer.



(a) Circuit



(b) Frequency response

Fig.3 Configuration and its frequency response of the HPF

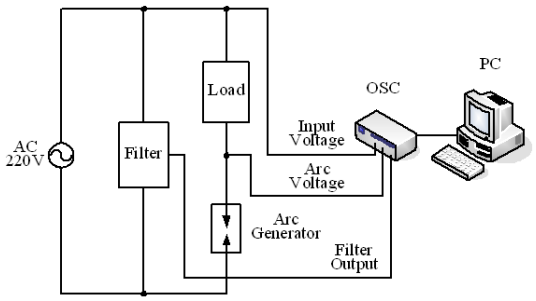


Fig.4 Configuration of the experimental apparatus

3 Experimental Results and Discussion

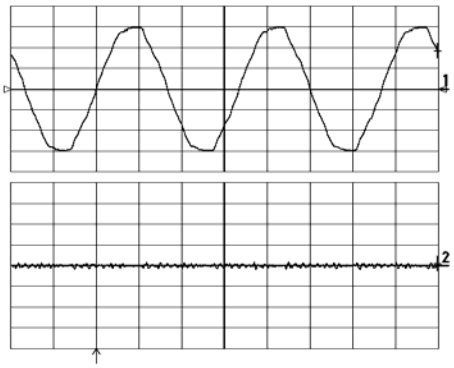
It is necessary to derive the difference between the normal state and arc discharge to detect series arc. High frequency components may generate in normal state as well depending on load characteristics, so we need to acquire parameters that discriminate series arc signals from high frequency elements under loads.

Figure 5 shows the AC voltage waveforms and output signals of the HPF at time of normal and series arc state with 1,000 W electrical heater as a resistive load.

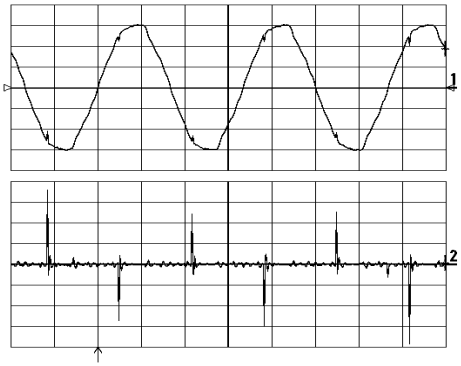
Figure 5(a) shows AC voltage waveform of normal state without arcing where no signal is detected in HPF output.

When series arcing occurs, high frequency components are included in AC voltage at 50° phase. The filter output periodically shows high frequency components and its peak was 70V. In such case, it is difficult to discriminate series arc signals even if the voltage waveform is analyzed by fast fourier transform (FFT)

However, we can discriminate series arc components sufficiently by measurement of high frequency only using the HPF.



Ch.1 : AC voltage [100V/div, 5ms]
Ch.2 : HPF output voltage [20V/div, 5ms]
(a) Normal state



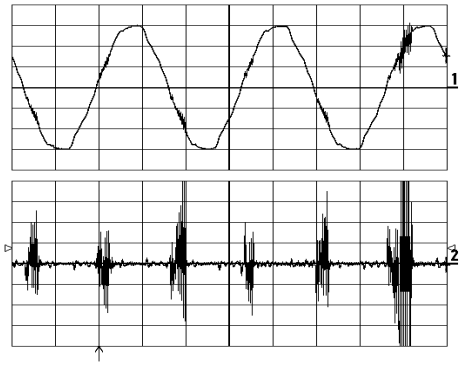
Ch.1 : AC voltage [100V/div, 5ms]
Ch.2 : HPF output voltage [20V/div, 5ms]
(b) Series arc state

Fig.5 Comparison of AC voltage and HPF output on an electric heater

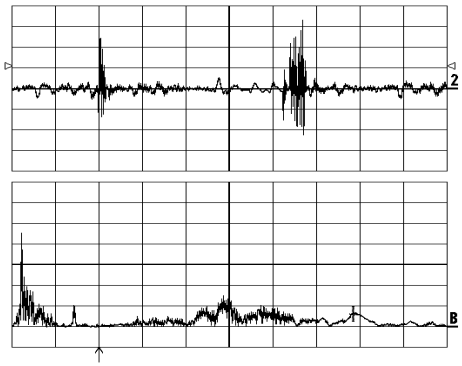
Figure 6 shows the AC voltage waveform, HPF output and its FFT when series arcing is simulated with an inductive load of 1,300 W vacuum cleaner that is controlled by an inverter.

No high frequency element was detected in a normal state even when the vacuum cleaner is controlled by inverter, but more high frequency components are included in the AC voltage waveform when series arcing occurs unlike the resistance load shown in Figure 5 and 80 V or higher was measured in HPF output.

This is a phenomenon caused by large current change rate in inductive load. The voltage frequency of the series arcing is distributed in ranges of 1~3 kHz and 20~30 kHz as shown in Figure 5(b). We can detect series arcing by analyzing the HPF output signal or the FFT of the AC voltage waveform.



Ch.1 : AC voltage [100V/div, 5ms]
Ch.2 : HPF output voltage [20V/div, 5ms]
(a) Series arc state



Ch.2 : HPF output voltage [10V/div, 2ms]
Ch.B : FFT result [200mV/div, 5kHz]
(b) FFT

Fig.6 AC voltage waveform and its FFT result on a vacuum cleaner

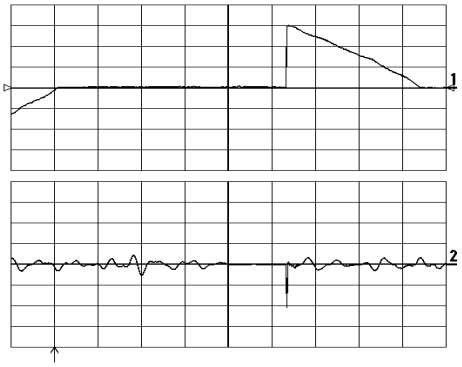
Meanwhile, incandescent lamp as resistive load shows series arc characteristics identical to those of electrical heater. When phase controlled, current chopping generates high frequency components even in normal state.

To discriminate this from those generated by series arcing, we need to analyze the AC voltage waveform and high frequency components detected at the time when incandescent lamp is phase controlled.

In this study, we compared the characteristics

between the normal and series arc state using a 100 W incandescent lamp as load.

Figure 7 shows the AC voltage waveform and HPF output signal when the incandescent lamp is phase controlled by triggering at 130°. When the AC voltage is cut by phase control, single pulse is detected at the same firing angle in HPF output.
It is necessary to analyze the HPF output as it varies depending on the firing angle.



Ch.1 : AC voltage [100V/div, 1ms]
Ch.2 : HPF output voltage [10V/div, 1ms]

Fig.7 Typical AC voltage waveform and HPF output when incandescence lamps are controlled by a dimmer

The HPF output is shown in Figure 8 depending on different firing angles. The peak output voltage was detected at phase of 60°. We simulated series arcing at firing angle 60° where the peak voltage shows was detected.

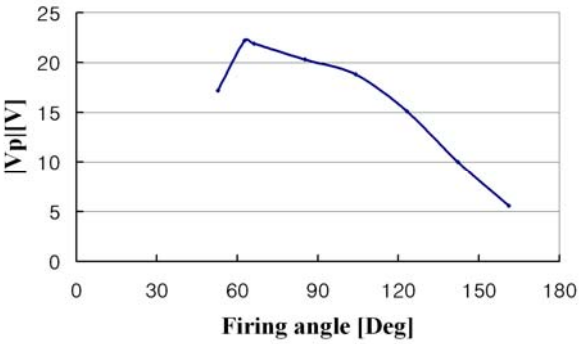
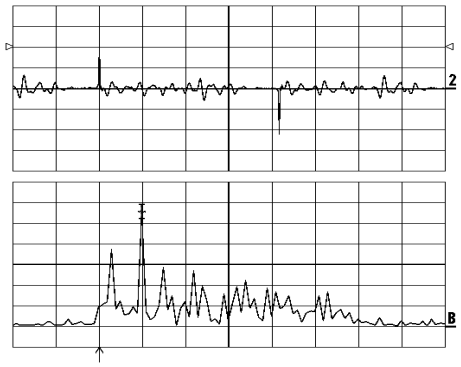


Fig.8 Magnitude of HPF output voltage as a function of firing angle

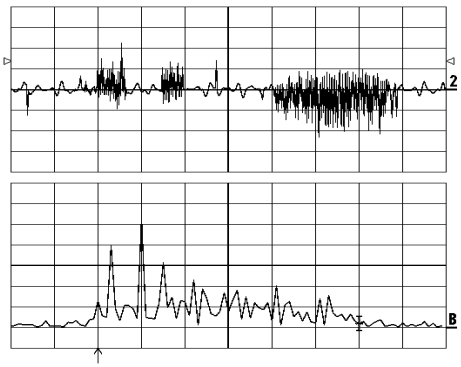
As shown in Figure 9, the HPF output can be clearly distinguished between the normal and series arc stage but the FFT frequency spectrum shows similar trends. There were lots of studies so far related to series arc detection in phase controlled loads.

However, it was difficult to discriminate the normal and the series arc state as they attempted to detect series arc signals by analyzing the FFT of AC voltage waveforms.
As demonstrated in our experiment discussed above, however, we can clearly distinguish the normal and series arc state in indoor wiring systems by detecting the high frequency components included in AC voltage using the HPF on AC source side.



Ch.2 : HPF output voltage [10V/div, 2ms]
Ch.B : FFT result [200mV/div, 0.5kHz]

(a) Normal state



Ch.2 : HPF output voltage [10V/div, 2ms]
Ch.B : FFT result [200mV/div, 0.5kHz]

(b) Series arc state

Fig.9 Comparison of HPF output and its FFT results on an incandescent lamp controlled by a dimmer

4 Conclusions

In this paper, we simulated series arc phenomena under such loads as incandescent lamp, vacuum cleaner and phase controlled lamp to discriminate series arc signals that ignite electric fires in residential low-voltage indoor wiring systems.

To detect high frequency components included in AC voltage when series arcing occurs, we designed a HPF with low cut-off frequency of 3 kHz.
It was difficult to detect series arc signals in resistive load like electric heater by analyzing the AC voltage

only as little high frequency components included in the AC voltage.

However, we could detect series arc components using output signal of the HPF designed in this paper.

More high frequency components were measured under an inductive load like vacuum cleaner controlled by an inverter, and the output voltage of the HPF was higher than that of series arcing under a resistive load.

In case, we can discriminate series arc signals by the FFT of voltage waveform and/or the measurement of the HPF output voltage.

Under incandescent lamps controlled by a dimmer, single pulses were measured constantly even in normal operation. In case, we can detect series arcing by measurement of the peak of HPF output voltage or it's integral.

ACKNOWLEDGEMENT

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