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A Study on Mash-up Analysis Algorithm for Electrical Hazard Risk Factor

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Abstract: This study, presents a technology of predicting electrical accidents (Precursor Prediction) by applying a mash-up analysis algorithm, a core technology for Autonomous Electrical Safety Management System (AESMS) of multi-unit dwellings. In order to develop a mash-up analysis algorithm, this study conducted an integrated analysis on separately-controlled electrical safety management factors such as voltage, current, leakage current and arc occurrence. For an integrated management of those factors, a mash-up DAQ board was designed and each management factor's data was measured using the designed board, its performance was verified by analyzing the measured waveforms. The mash-up analysis algorithm gauges the electrical safety rating by summing the weights of individual electrical safety management factors for some of the factors, however, this study suggests a different way of calculation that considers the incidence rate (e.g., time). The mash-up analysis algorithm proposed in this study can be used for implementation of AESMS to ensure electrical safety of multi-unit dwellings. The mash-up analysis technology enables predication/prevention of electrical disasters and is likely to be utilized as the basic technology for introducing AESMS. Going forward, verifying weights of electrical safety data presented in this study will be required and a field data analysis will also be needed to validate the efficiency of the weights. In order to analyze the field data under a range of conditions, it will be necessary to construct a standardized model of the multi-unit dwellings and to implement a server for monitoring/data collection.

Key words: Electrical safety, mash-up analysis, AESMS, electrical fire prediction, standardized model, Korea

INTRODUCTION

General houses are classified as general purpose electrical facilities and their electric safety states are regularly checked up according to electric utility act. On the other hand, large-scale multi-dwellings such as apartments are still classified as private electrical facilities and are not entitled to legal safety management services. According to the statistics released by the Ministry of Public Safety and Security (MPSS), 916 deaths and 74 injuries occurred in apartment buildings in 2016 (http://www.nfds.go.kr). Even if apartment houses are load systems with various load patterns they are exposed to risks of electric disasters in the blind spot of electric safety management services.

Besides with a rising energy dependence on electricity (i.e., rising use of electric power), the potential risks of disasters such as electric fires have increased. Recent advancements in ICT have led to development of an internet-based electrical disaster prevention technology, yet, it is still in its infant stage-mere monitoring of electricity usage and electricity status information (Narayana *et al*., 2016).

Electrical safety status monitoring requires real-time measurement and analysis of electrical safety management factors such as voltage, current, leakage current, arc and efficiency. Legacy electrical safety devices usually adopt a technology that detects and blocks single factors such as over current, leakage current and arc fault.

Such single-factor information, a management factor corresponding to each protection device 1:1 has a limitation to be utilized as data for effective prevention of electric disasters. In addition to this as single-factor information is operated in an environment where interoperability is not ensured, it is bound to have a risk of information loss.

In order to solve these problems, autonomous electric safety management technologies capable of coping with electricity usage environment should be developed and applied to apartment houses to ensure safety.

For this reason, this study presents a mash-up analysis algorithm for analyzing electrical hazards and demonstrates an autonomic electrical safety management technology that can handle effectiveness and scalability.

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MATERIALS AND METHODS

Analysis of protection device: Protection devices for electrical safety include Molded Case Circuit Breakers (MCCBs), Earth Leakage Breakers (ELBs) and arc breakers. MCCBs are employed as the main circuit breakers in the households and ELBs are used as the branch circuit breakers. While MCCBs prevent electric fire that may be caused by short circuits or overcurrent, ELBs are supposed to avert electric fire and/or electric shock caused by short circuits, overload and leakage current.

Legacy electrical safety protection devices are designed to prevent electrical fire and electric shock accidents by monitoring short circuits, overload, arc and current leakage. The issue with those devices, however is that they occasionally have false operations even during normal operations of facilities, causing user inconveniences. As the protection devices are supposed to only detect short circuits, overcurrent, current leakage, arc, etc., identifying what exactly caused operation of the devices and predicting potential disasters (precursor prediction) are all impossible. Table 1 shows the comparison between the legacy protection system and the future protection system.

Electrical safety protection devices in the future need to work in a different way by analyzing the precursor prediction of electrical hazard for protection purposes. To that end a new protective device for both protection and prevention will be necessary, developing such a protective device requires a predictive electric disaster analysis technique based on the analysis of electric safety management factors. Using the predictive electric disaster analysis technique, a model suitable for multi-unit dwellings needs to be developed in order to better cope with different patterns of electric use.

Design of aesms infrastructure: AESMS is a new convergent electrical safety management technology that enables prevention of electrical disasters as well as power outages. By applying AESMS to multi-unit dwellings with a relatively-vulnerable safety management structure, an autonomous recognition/handling of the situation is possible, securing the safety against electric disasters. AESMS should be developed into a standard-based interoperable system as well as an infrastructure-based interconnection technology to overcome the limitations of existing stand-alone devices and facility technologies (Suguna and Nandhini, 2016; Channe *et al*., 2015).

To develop an interoperable standard technology, a system framework considering a phased-integrated autonomous electrical safety management should be

Table 1: Comparison of electrical safety protection device characteristics

Legacy device	Future device
Protection device	Prevention device
Management of risk factor	Precursor prediction
(Short circuit, overload, leakage, etc.)	(Protection+prevention)
Malfunction tripping	Autonomous electric management system
Analysis technique	Analysis technique
Phenomenon analysis	Risk factor analysis
	Analysis electrical disaster precursor

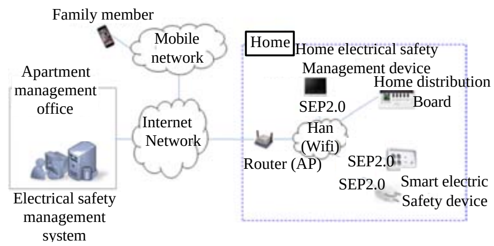

Fig. 1: Schematic diagram of AESMS infrastructure model

designed. Figure 1 shows a conceptual diagram of infrastructure technology of AESMS for developing an interoperable standard technology.

The concept of AESMS technology the load states displayed in smart outlets, smart plugs, distribution boards, etc. are exchanged through communications with home electric safety management device the home electric safety management device then exchanges information on the electricity use and safety with the apartment management system while analyzing the precursor of electric accidents and sending the state information either to the family members or electric safety manager.

The core of AESMS is state-based electric disaster prevention technology. The load and wiring conditions should be monitored to analyze the status quo of electrical equipment; the state monitoring factors include voltage, current and leakage current. In order to ensure standard-based interoperability, a standard data profile for the electric hazard prevention system should be designed (Suguna and Nandhini, 2016; Channe *et al*., 2015).

Designing a standard data profile for state-based electrical hazard prevention system requires application of the electric disaster precursor analysis technology to smart home distribution panels or home electrical safety management devices refer to the AESMS infrastructure illustrated in Fig. 2. The electric disaster precursor analysis technology was developed on the basis of mash-up analysis on electric safety management factors such as voltage, current, leakage current and arc.

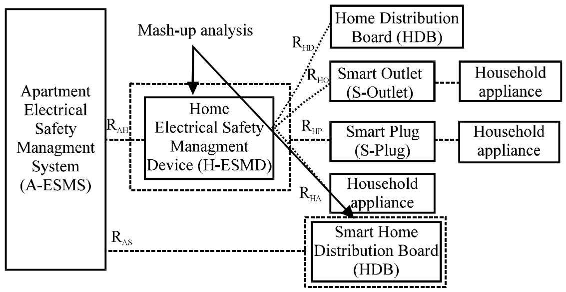

Fig. 2: Scenario of mash-up analysis technology for AESMS

RESULTS AND DISCUSSION

Electrical fire prediction analysis technique: In order to develop a required mash-up analysis technology, analyzing the precursory phenomenon according to the types of electric disasters in each electric facility is necessary.

Each type of electric accident can be defined as follows: overcurrent is a phenomenon that occurs when the rated current of a circuit breaker, a wire or a product is exceeded an electric fire may occur when the heat generated by electric current flow is larger than the heat protection. Leakage current is a current that flows to the areas other than the designated circuit and generally refers to the current flowing between the lines or into the ground through the inside and the surface of the insulator, leakage current may lead to electric shock accidents and the heat generated in the path of leakage current may cause fire. Partial disconnection means that part of the wire is not completely disconnected; the increased resistance of the half-disconnected area generating local heat may cause fire and it is accompanied by arc. Arc is an electrical discharge phenomenon between two or more conductors, the arc discharge is converted into heat, destroying the insulation of electric wires and igniting nearby combustibles a cause of fire. Arc can be divided into a series arc and a parallel arc according to the discharge path.

Figure 3 is a schematic representation of major precursor phenomena by over-current, short-circuit, partial disconnection, arc and other electric accidents. When an electrical accident arises, changes in current and voltage waveforms, temperature rise, electromagnetic wave emissions, elastic wave emissions and light emissions occur. In such a case, abnormal signals distinguished from the normal ones exhibit unique characteristics in the current waveform rather than the voltage. Therefore, the analysis of the electric accident precursor prediction shall be conducted by examining abnormal signals caused by a change of the current waveforms, overcurrent, leakage current, partial disconnection and arc troubles. In particular, it is necessary to consider the correlation between faults according to the characteristics of the electrical disaster, in which several signals are generated at the same time. Through development of a correlation analysis algorithm, it is possible to detect abnormal signals before electric fire occurs and to prevent electrical disasters.

Development of mash-up analysis technology: The mash-up data collection system was designed as in Fig. 4 to analyze the electric disaster precursor phenomena. It basically detects the voltage and load current using Current Transformer (CT). Zero Current Transformer (ZCT) is also used to identify the video current (leakage current) and to analyze the electric disaster phenomena. First, the levels of voltage and current are analyzed to detect overvoltage and overcurrent beyond the reference values and then whether or not the leakage current exceeds the reference value is monitored. Load current data are used to detect arc faults and signals such as load current shoulder, current change rate (Di/dt) and quasi peak are analyzed to detect a harmful arc.

Among the mash-up data, voltage, current and leakage current are detected through the sensor. To detect resistive leakage current and harmful arc, however the following analysis algorithm should be applied.

In order to calculate the resistive leakage current, the voltage and leakage current data are used as follows. The instantaneous value (v) of the reference voltage can be obtained as in Eq. 1:

$$v = \sqrt{2}V\sin(\omega t) \tag{1}$$

Where:
V = The RMS value of the power supply voltage
ω = $2\pi f$, f is the power frequency

If the composite leakage current (lg) of the electric line to be measured is a sine wave, the instantaneous value (igo) of the combined leakage current can be obtained as in Eq. 2:

$$igo = \sqrt{2}Igo\ \sin(\omega t+\theta) \tag{2}$$

where, θ represents the phase difference between the power Voltage (V) and the composite leakage current. In this way, the composite leakage current is divided into the resistive component and capacitive component and the vector sum of both components (from each vector

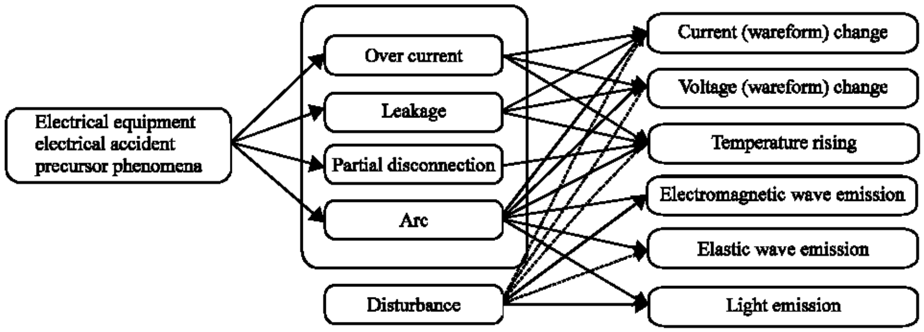

Fig. 3: Diagram of correlation for electrical disaster precursor phenomena

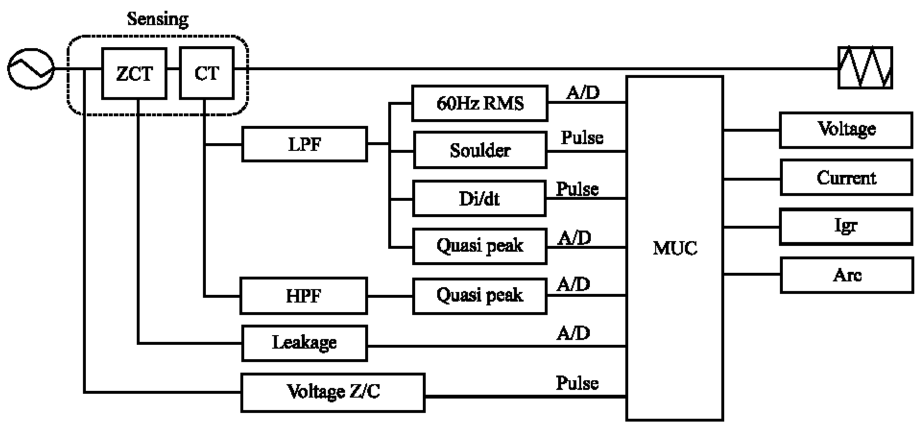

Fig. 4: Schematic diagram of mash-up DAQ board

diagram) becomes the composite leakage current. Therefore, the resistive leakage current and the capacitive leakage current can be expressed by Eq. 3:

$$Igr = Igo \cos\theta, Igc = Igo \sin\theta \tag{3}$$

The resistive leakage current is detected by calculating the phase difference and leakage current of the reference voltage. For this, the reference phase of the voltage is detected by sensing the zero-crossing of the voltage as in Fig. 4 and then the leakage current and the phase difference are detected (Kim *et al*., 2009).

Since, the RMS of the current changes in harmful arc detection, this study applied the Discrete Fourier Transform (DFT) method in the frequency domain and an algorithm to compare and detect the RMS increase/decrease of the current in the time domain.

In general, N(ea) of samples are considered Discrete Fourier Transform (DFT) coefficients and S (n), the DFT coefficients is a series of N points. DFT of the N (ea) of digital signals can be obtained as in Eq. 4 (Smith and Nair, 2009; Lee *et al*., 2012):

$$S(n)=\sum_{n=0}^{N-1} S(n)e^{-\frac{2j\omega t}{N}n},(0 \le n \le N\text{-}1) \tag{4}$$

When the value of N corresponding to the number of repeating cycles in Eq. 4 increases, the volume of data used for calculation keeps rising. To prevent unlimited increase of the data volume, the odd and even harmonics need to be limited to be up to the 4th. In such a case, the odd harmonics, even harmonics and RMS are used as the detection criteria as shown in Eq. 5 and 6:

$$h_{odd}=\sum_{n=1}^{4} h_{2n+1}=h_3+h_5+h_7+h_9 \tag{5}$$

$$h_{even}=\sum_{n=1}^{4} h_{2n}= h_2+h_4+h_6+h_8 \tag{6}$$

The average values of the harmonics obtained from Eq. 5 and 6 are compared with the previous two-cycle earlier average values and when the maximum value of arc is reached, the output is 1 if there is 10% or more gap between the RMS of the load current and previous two-cycle earlier value, then the output is 1. Accordingly, when the RMS of the load current and output of the odd/even harmonics are detected as 1, it is regarded as harmful arc (Lim *et al*., 2014).

In addition, since harmful arc is detected as a broadband signal, from low to high frequency, quasi-peak

Fig. 5: Schematic diagram of mash-up DAQ board

that is usually used in electromagnetic wave analysis is examined to find the presence of harmful arc. That is, an algorithm to distinguish normal arc and harmful arc by selecting and comparing the same pulse values appearing in arc detection algorithm and quasi-peak analysis was used.

Figure 5 shows a designed DAQ board of the mash-up collection system illustrated in Fig. 4. With this board, each major precursor phenomenon of electrical disaster was measured

Figure 6-8 show the measured waveforms of the main precursor phenomenon of each electric disaster using a mash-up collector. Figure 6 shows the input voltage and the load current, green waveforms demonstrate the amplitude of voltage and current and the voltage reference phase (yellow waveforms) is used to detect resistive leakage current. Figure 7 shows the resistive leakage current (Igr) and the capacitive leakage current (Igc) for the voltage reference phase. In relation to the voltage reference phase (yellow-colored) the green leakage current shows the same phase in the case of Igr and in the case of Igc, it is detected in the phase difference of 90°. Figure 8 shows the arc occurrence by analyzing the current waveform; the green waveform of (a) is in a continuous high state and does not detect harmful arc while (b) shows the harmful arc is detected in a pulse form, from high to low when it occurs.

"Mash-up" originally means development of a new service by mixing different services. As shown in Fig. 6-8, a new electrical safety management factor was derived through an integrated analysis of conventional management factors which are used for discrete services only. In order to analyze the information of existing voltage, current, leakage current and arc and to derive a new management factor, analyzing each management factor should be done first (Patel *et al*., 2010).

The normal, caution and warning phases for voltage, current and leakage current are defined in Table 2. The levels of voltage, current and leakage current are referenced to the International Electrotechnical

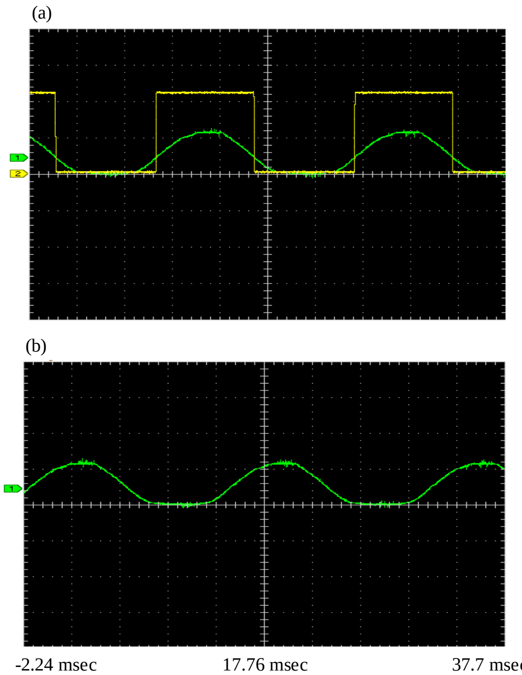

Fig. 6: Measurement of voltage and current for mash-up daq board: a) voltage amplitude and phase reference; b) current amplitude

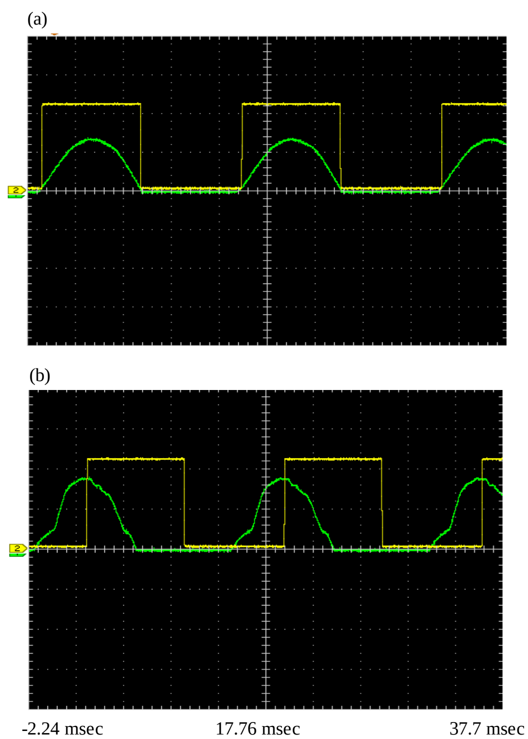

Fig. 7: Measurement of igr and igc for mash-up DAQ board: a) Igr for resistive; b) Igc for capacitive

Table 2: Classification of electrical safety management factor

Class	Voltage	Load current	Resistive leakage current	Arc frequency
Normal (N)	±13 V or less	80% or less	1 mA or les	Once/sec (or less)
Caution (C)	±10% or less	110% or less	3mA or less	3 times/sec (or less)
Warning (W)	Over±10%	Over 110%	Over 3 mA	<3 times/sec
ID	V_{class}	I_{class}	Igr_{class}	ARC_{freq}

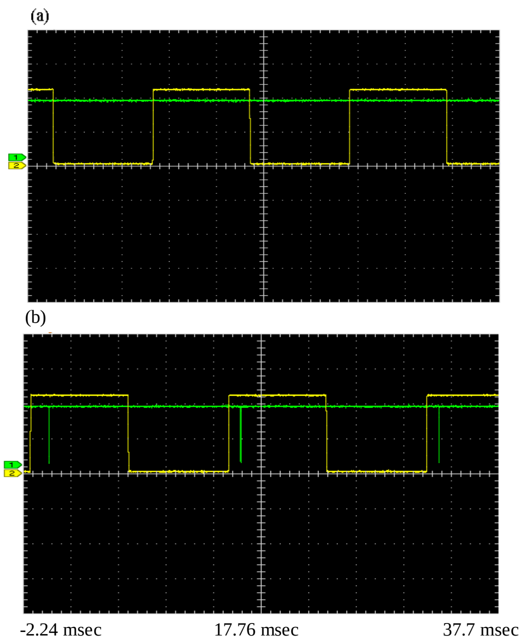

Fig. 8: Measurement of arc fault for mash-up DAQ board: a) normal; b) arc fault detection

Commission (IEC) Standards and electrical equipment technical standards and “AC 220 V, 30 A” which is the electrical equipment used in apartment houses was used as the reference rating.

For each management factor shown in Table 2, two types of the safety level calculation algorithm are defined: one for the user and the other for the administrator. The user alarm algorithm was derived by using load current, resistive leakage current and arc occurrence (Eq. 7) and the administrator alarm algorithm using the voltage, resistive leakage current and arcing occurrence (Eq. 8). While load current can be used as information for after-sales services for the product used by the user as load, rather than the administrator, voltage and leakage current can be utilized for electric safety inspection by the administrator, rather than the user.

$$CLASS_{user} = V_{class}\times F_v + I_{class}\times F_I + Igr_{class}\times F_{Igr} + ARC_{freq}\times F_{arc} \quad (7)$$

$$CLASS_{admin} = V_{class}\times F_v + I_{class}\times F_I + Igr_{class}\times F_{Igr} + ARC_{freq}\times F_{arc} \quad (8)$$

Table 3: Weight for type of electrical safety management factor

Class	F_v	F_I	F_{Igr}	F_{arc}
User	0.1	0.4	0.2	0.3
Admin	0.2	0.1	0.4	0.3

Table 3 shows the weights of each factor. The user and administrator ratings are calculated as the sum of the weighted items for Normal (N = 100), Caution (C = 50) and Warning (W = 0) classes.

According to the electrical safety grade calculation of the user and the administrator, the result is classified into one of the four grades, A (more than 90 points), B (70 points or more), C (50 points or more) and D (50 points or less). “A” is defined as normal, “B” is indicated as “Caution” and C and D are defined as those requiring an immediate safety inspection. The concept of time was adopted for the state of “B” if “B” state continues for a certain period of time, the system is designed to give a warning to the administrator so that he or she can take a necessary action through a thorough inspection.

CONCLUSION

This study developed a mash-up analysis algorithm that enables implementation of an integrated new service using discretely-managed data such as current, leakage current and arc. The mash-up analysis algorithm is a technology that integrates existing electrical safety management factors and determines the safety rating of electrical facilities of multi-unit dwellings by applying weights for each type. With the mash-up technology applied for overcoming the limitations of existing electric safety protection devices, autonomous electric safety management can be realized. Introduction of AESMS is expected to contribute to reduction of electrical disasters in electrically-vulnerable apartment houses. The mash-up analysis technology is considered essential for prevention of electric disasters through prediction, a totally different approach from conventional post-accident actions.

In this study, the electrical safety management factors were derived through analysis of electric disaster precursor phenomena and the system’s performance was verified using a self-designed mash-up DAQ board. The mash-up analysis technology proposed in this study calculates the safety rating using the sum of weights for electrical safety data with this proposed technique, the electric accident precursor prediction and efficient management of electric facilities will be realized. The mash-up algorithm can be utilized for development of a new protection and for apartment houses as an appropriate model by applying it to ICT-based electric safety management system.

RECOMMENDATIONS

Further studies on the weighting of the electrical safety data presented in this study will be needed in the future. Determining more effective weights by analyzing the field data on the multi-unit dwellings and experimental data on accident conditions is required. It is also necessary to develop a monitoring system based on the user or administrator interface and to apply it to the field for management after determining the weights.

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