TEST Engineering & Management

November-December 2019
ISSN: 0193-4120 Page No. 189 – 198

Development of the IoT-Based Home Condition Monitoring System for the Estimation of Abnormal Location and the Evaluation of Electrical Safety grade

Seung-Taek Lim[1], Ki-Yeon Lee[1], Dong-Woo Kim[1], Young-Bae Lim[1], In-Ho Ryu[*2]

[1] *Electrical Safety Research Institute, Electrical Safety Corporation,Wanju 55365, Republic of Korea*

[*2] *Department of IT Applied System Engineering, Chonbuk National University, Jeonju, 54896, Korea*

jstyim@kesco.or.kr[1], lkycj@kesco.or.kr[1],
klove@kesco.or.kr[1],tree@kesco.or.kr[1],toto00@jbnu.ac.kr[*2]

Article Info
Volume 81
Page Number: 189 - 198
Publication Issue:
November-December 2019

Abstract

Background/Objectives: Generally, multi-family residential does not carry out a periodic inspection although the electrical installation for general use conducted periodic inspection every one to four years. Accordingly, the houses that did not conduct the periodic inspection are exposed to electric dangers like fire and electric shock. So, the IoT-based monitoring system is developed to reduce the electrical accident.

Methods/Statistical analysis: The fire and electric shock statistics were analyzed to evaluate the electrical safe score and the algorithm for estimating the abnormal location is introduced. To conform the monitoring system, the experiment consisted of the smart panel board and outlet was conducted.

Findings: Although some electric devices are operated on the IoT, most devices supply services confirming it's operating status and power usage, not a services estimating the abnormal condition and electrical safety grade. By providing the abnormal location with electrical safety grade, the user and manager can take an action to prevent an accident aforetime.

Improvements/Applications: By using an abnormal condition monitoring system of the electrical installation based on IoT devices, the electrical dangers due to the absence of electrical periodic inspection can be reduced in multi-family residential.

Article History
Article Received: *3 January 2019*
Revised: *25 March 2019*
Accepted: *28 July 2019*
Publication: *22 November 2019*

Keywords: *Abnormal location, Electrical safety grade, Home condition monitoring system, IoT, Smart outlet, Smart panel board*

I. Introduction

Under Article 2, Paragraph 18 and Article 66 of the Electricity Business Act of Korea, electrical installations of 75 kW or less are divided into electrical installations for general use, and it is required to periodically conduct an electric safety inspection. The periodic inspection is conducted every 3 years for general housing, 2 years for manufacturing facilities, 2 years for facilities used by many people such as hospitals, and 1 to 4 years for other facilities. On the other hand, the facilities with a capacity of 75kW or more should be classified as electrical installations for private use. An electricity safety supervisor should be selected according to Article 73 of Electricity Business Act, and electrical safety inspections should be carried out by oneself. However, electrical safety management is possible for the power reception facilities, but it is virtually impossible to inspect each generation. In particular, as the number of apartment units has increased due to the increase in the number of single-person households, the blind spot of electrical safety has been increasing [1-3].

The overcurrent circuit breaker and the leakage circuit breaker, which are used as general protection devices for household electrical equipment, detect the magnitude of the current and the magnitude of the combined leakage current, respectively, to shut off the power lines.In some cases, an arc breaker or an arc alarm is installed to protect the power line and household when an arc occurs in the power system. In the case of the mostleakage circuit breaker, the operation is performed on the combined leakage current of the resistive leakage current and the capacitive leakage current. However, the actual electrical hazards are resistive leakage currents, not capacitive leakage currents. Some leakage circuit breakers use a technique of distinguishing resistive leakage currents with capacitive leakage currents and shutting down the power line. However, there are many electric fires and electric shock accidents even though the current overcurrent breaker, the leakage circuit breaker, and the arc breaker are installed, and it is hard to find a countermeasure for prevention [4-8].

As a solution to this problem, IoT-based household appliances have been introduced and it shows whether or not the equipment is abnormal in real-time. In the existing IoT-based facility, the event occurrence and the amplitude of the detected element can be confirmed, but the load status and the abnormal location estimation can not be confirmed. So, it is impossible for user or safety manager to solve the cause of the trouble. Besides, even though the household electrical appliances and lighting products used as loads should be required to obtain product safety certifications to prevent accidents caused by products, but since it can cause the electrical accident due to illegal products or defective products which are used in long-term, a minimum detection method is required [9-13].

Therefore, in this paper, we have developed a system to monitor the electrical safety status of the power line and load in the home and house system. For this purpose, IoT technology such as smart panel board and smart outlet was developed, and IoT-based home condition monitoring system, which provides abnormal location estimation and electrical safety grade, was developed based on data such as leakage current, load power factor, load power factor change-rate and so on. Especially, in this paper, the home condition monitoring systemare described based on leakage current. Through this, it is possible to detect the abnormal of the load and the user can recognize the electric accident beforehand and confirm the location of the event through the change of the load condition. Therefore, we expect to contribute to electrical safety through the promptactions and precautions.

November-December 2019
ISSN: 0193-4120 Page No. 189 – 198

II. Overview of Home Condition Monitoring System

IoT-based Home Facility Abnormal Condition Monitoring System

IoT-based homefacility abnormal condition monitoring system is largely composed of a smart outlet, smart panel board, access device (public platform), and manager server.Smart outlets transform non-IoT home appliances into IoT-based load devices. In smart outlets and smart panel boards, voltage (V), current (I), total leakage current (Igo), resistive leakage current (Igr), and power factor (PF), Arc, etc., is transmitted to the manager server through the access device together with the ID of the smart device.The public platform of the access device analyzes the abnormal element and the abnormal location based on the received status information and provides the electrical safety grade with event notifications to users and managers along with the operation of the protective devices of the smart panel boards and smart outlets. Besides, it is possible to control the ON / OFF operation of the smart panel board and smart outlet according to the user's needs. Figure 1 shows the overall schematic diagram conceptually illustrating the process of the home condition monitoring system.

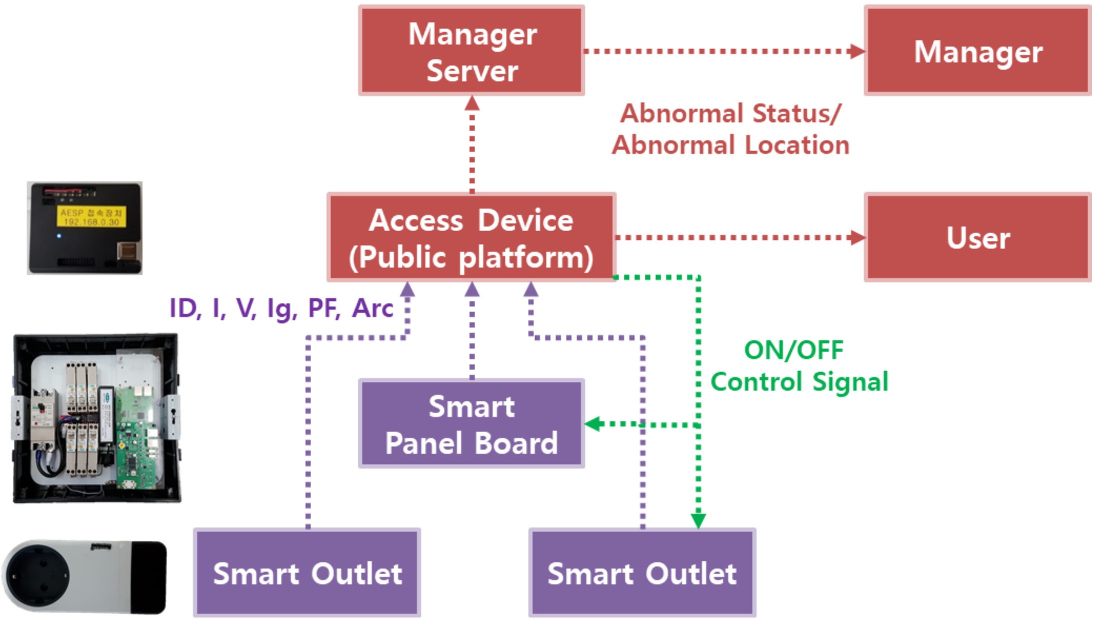

Figure 1. Concept configuration of the autonomous electrical safety management techniques

Event Criteria

Table 1 shows the criteria threshold for each event of leakage current (Igo, Igr), over current, arc, overvoltage, blackout, and power factor, which are home condition monitoring system's safety factor composed of the smart outlet and smart panel board. It was prepared with reference to 'Electrical Equipment Technical Standards and Judgment Standards' [2].The access device that receives the electrical safety element status information from the IoT-based devices (smart outlets and the smart panel board) performs the estimation of the abnormal condition of the power lines and load through the public platform's data-based analysis and finally presents the electrical safety grade.In this way, abnormal-based alarms can be provided to induce user and manager action, such as replacement of the power devices and wiring checks. It can also detect changes in rating to prevent accidents from illegal products or load accident that can

November-December 2019
ISSN: 0193-4120 Page No. 189 – 198

occur over long periods.

Table 1: Criteria Threshold for Monitoring Factor of Electrical Accident Event

Monitoring Factor	Event	Threshold
Leakage Current	Caution	(Igr)More than 4.0mA
		(Igo) More than 16.0mA
	Warning	(Igr)More than 8.0mA
		(Igo) More than 20.0mA
	Dangerous	30.0mA or more
Over Current	Caution	90% at the rated current 2 min. or more
	Warning	100% at the rated current 2 min. or more
	Dangerous	120% at the rated current 2 min. or more
Arc Fault	Caution	Arc warning
	Dangerous	Arc cutoff
Over Voltage	Warning	More than 242V
Blackout	Warning	190V or less
Power Factor	Caution	(smart outlet) 0.8 or less
		(smart panel board) 0.7 or less
	Dangerous	0.5 or less

AbnormalLocation Estimation

IoT-based home condition monitoring system provides an estimation of the abnormal location through data analysis of public platformusing the data provided from smart outlets and smart panel boards.Through this, users and managers can check whether the load or power line is abnormal, and it is possible to solve the trouble quickly so that it can provide electrical safety, convenience, and prevention of electric accidents.

Figure 2 shows the abnormal location estimation algorithm for leakage current.Depending on whether the branch circuit breaker leakage current value (Igo_CB_B) of the smart panel board and the smart outlet leakage current value (Igo_SO_i) connected to the load exceed the reference value ($ref1, ref2$), it determines the abnormal condition of load side, branch side, etc. and provides the event alarm to the user and manager.

Even though the branch CB leakage current value (Igo_CB_B) and smart outlet leakage current value(Igo_SO_i) do not exceed the reference values ($ref1, ref2$) respectively, if the difference between the branch CB leakage current value (Igo_CB_B) and the sum of the smart outlet leakage current ($\sum Igo\_SO_i$) are significantly different, it is determined that there is an abnormal condition in the power line according to the Kirchhoff's law.Accordingly, the event alarm is provided according to whether the subtraction between the branch CB leakage current and a sum of the smart outlet leakage current ($Igo\_CB_B - \sum Igo\_SO_i$) exceeds the reference value ($ref3$). If the reference value ($ref3$) is exceeded, it is determined as an abnormal event somewhere in the power line.

If the leakage current is detected at the branch CB and not detected at the smart outlet, it is determined that the branch line is abnormal and the manager's check is required. Since the leakage current measured in the smart outlet should always be measured in the branch breaker, if the leakage current is detected in the smart outlet without detecting the leakage current in the branch breaker, it is determined that the branch breaker itself is abnormal and needs to be checked. The abnormal location estimations according to the events of the branch CBs and smart outlets are shown in Table 2.

In this paper, an only abnormal location estimation about leakage current is included.

November-December 2019
ISSN: 0193-4120 Page No. 189 – 198

The abnormal location about other monitoring factors have similar algorithms but are not contained in this paper.

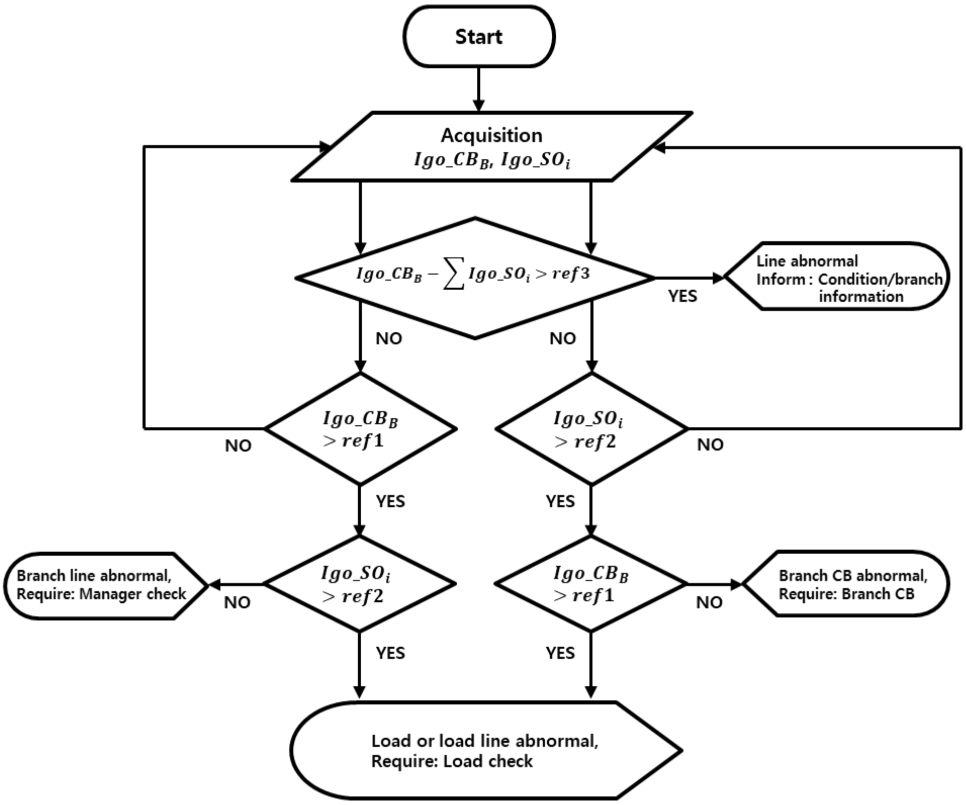

Figure 2. Algorithm ofAbnormal condition estimation flow chart using the leakage current

Table 2: Criteria Threshold for monitoring factor of electrical accident event

No.	Branch ELB	Smart Outlet	Abnormal Location Estimation
1	Leakage Detect	Leakage Detect	Load or Load Line
2	Leakage Detect	Normal	Branch line
3	Normal	Leakage Detect	Branch CB

Determine Electrical Safety Grade

As mentioned above, the home condition monitoring system provides the electrical safety grade along with the abnormal location estimation through data analysis of the public platform of access device and the grade is assessed through the statistics base.

Table 3: Casualty statistics by type of electric shock (2017)

Type	Charging part direct contact	Leakage	Electrostatic induction	Flash over	Arc	ETC	Total
Death (person)	13	6	-	-	-	-	19
Injury (person)	294	27	6	1	168	7	513
Total (person)	307	33	6	11	168	7	532
Ratio (%)	57.7	6.2	1.1	2.1	31.6	1.3	100

Table 4: Electric fire statistics by ignition type of the electrical fire(2017)

Type	Short by insulation aging	Short by tracking	Short by pressure damage	Turn to turn fault	Unidentified short	Over load	leakage	Poor contact	Half disconnection	ETC	Total
Electrical (case)	1,995	854	505	88	2,091	754	301	795	174	454	8,011
Ratio (%)	24.9	10.7	6.3	1.1	26.1	9.4	3.7	9.9	2.2	5.7	100

Tables 3 and 4 show the casualties by type of electric shock accidents in 2017 and the electric fire statistics by ignition type of fire. In statistical data of Table 3, the electric shock caused by direct contact with the charging parts occupies the largest as 57.7% in Korea.Since the direct contact with charging parts is caused by the user's carelessness, except for this, it appears that it causes many casualties in the order of arc, leakage, flashover.Therefore, this type should be concerned as an important factor when the electrical safety grade is evaluated. The overcurrent based fire accidents, like short circuit and overload, take a share of around 80% of electric fires in Korea and the arc-based fires accidents, poor contact and fires due to leakage current are the main reason in Table 4. Therefore, the factors related to over current and arc should be assessedhigher risk elements than other element [4].

The electrical safety grade was evaluated by scores for smart outlets, the smart panel board and the access device, and the score for each factor was calculated based on the influenced range and the statistical data in Tables 3 and 4. Table 5 shows the scores by events.As mentioned above, the over currents and leakages with a high risk of fire and electric shock were given higher scores than those resulting from over voltages and blackouts.Also, the smart panel board with a wide influence range of events was given a higher risk score than those of the smart outlets with a small influence range.Since the blackout of the smart outlet means that the load is removed, a zero point is assigned.

Table 5: Electrical safety grade according to event element

		Safe	Caution	Warning	Dangerous
Power panel board	Over voltage	0	-	5	-
	Blackout	0	-	5	-
	Over current	0	2	10	20
	Leakage current	0	2	10	20
	Arc	0	2	10	-
	PF	0	2	10	-
outlet	Over voltage	0	-	1	-
	Blackout	0	-	0	-
	Over current	0	1	5	10
	Leakage current	0	1	5	10
	Arc	0	1	5	-
	PF	0	1	5	-
Merging platform	Rate of change(PF)	0	1	5	-

November-December 2019
ISSN: 0193-4120 Page No. 189 – 198

	Rate of change(overcurrent)	0	-	5	-

A home safety monitoring system evaluates the final score by adding each factors score evaluated based on Table 5. The factors' gradeis evaluated as Safe, Caution, Warning and Dangerous according to score and the safety grade is distinguished as colors (green, yellow, red, black). Finally, the public platform assesses the electrical safety grade of the entire system based on Table 6 and this grade is provided to the user and the manager.

Table 6: Score of the electrical safety grade

	Electrical Safety Grade	
	Safe	≤ 1
2≤	Caution	< 10
10≤	Warning	< 20
20≤	Dangerous	

Construction of the HomeCondition monitoring system

The home safety monitoring system's user page is shown in Figure 3. The screen shows the following functions such as measurement information of branch and load, branch and load status, event status, electrical safety grade and so on.

① Electrical safety data (branch/load)

② Event display screen

③ Event/Data tab

④ Electrical safety grade

⑤ Select safety factor and display time

⑥ Data display screen

Electrical safety data show the real-time monitoring of branch and load side and when the event occurred, the event display screen and electrical safety grade are changed with alarm.The Event tab shows the entire lists of the events and specific information and the Data tab shows the past monitoring factors of smart outlet and panel board, as shown in figure 3(b).

Figure 3.Configuration of the abnormal condition monitoring system of the electrical installation

(a) The home safety monitoring system's user page (b)Data tab for the past data

III. Utility of the IoT-based HomeCondition Monitoring System

Experiment Configuration

The experiment was constructed as shown in figure 4 to confirm the estimation of abnormal location and the evaluation of the electrical safety grade of the home condition monitoring system. An experiment including a smart panel board having a main circuit breaker (MCB) and six branch circuit breakers and two smart outlets (S.O.) from the branch#2 were constructed.The resistive leakage current (Igr)

November-December 2019
ISSN: 0193-4120 Page No. 189 – 198

application test was performed to confirm the analysis of the monitoring system for the six cases as shown in Table 7.

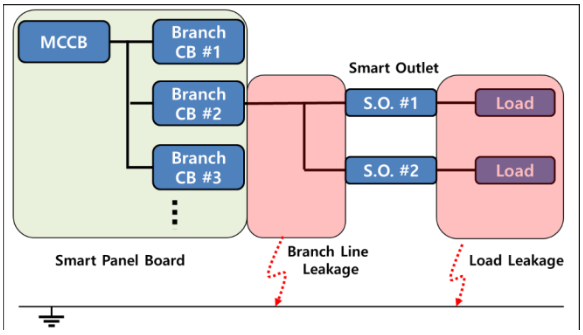

Figure 4.Configuration of Test bed for the abnormal condition monitoring system of the electrical installation

Table 7: Experiment condition for Leakage current (Igr) to confirm the analysis of the monitoring system

	Test leakage current [mA]			
Case	S.O.#1	S.O.#2	Branch line	Expected electrical safety grade
1	0 (Safe)	0 (Safe)	0 (Safe)	Safe
2	0 (Safe)	0 (Safe)	5 (Caution)	Caution
3	5 (Caution)	5 (Caution)	0 (Safe)	Caution
4	5 (Caution)	5 (Caution)	5 (Caution)	Caution
5	5 (Caution)	0 (Safe)	10 (Warning)	Warning
6	5 (Caution)	5 (Caution)	10 (Warning)	Warning

Experiment results

Figure 6 (a) shows the experiment result for Case1 without applying leakage current. As both the branch CB and the outlet loads are normal, the safety score is 0, indicating Safe grade on the event display screen and electrical safety grade.

Figure 6 (b) shows the experimentresult for Case2in which the leakage current of 5 mA is applied to the branch line not the load side. As the branch CB is abnormal even though the smart outlet load side is normal, it is shown that the branch line#2 changes to caution on the event display screen andthe safety score is 2, indicating Caution grade.

Figure 6 (c) shows the experiment resultfor Case3in which the leakage current of each 5 mA is applied to the SO#1 and SO#2 not the branch side. As the two smart outlets are abnormal, it is shown that the SO#1 and SO#2 change to caution on the event display screen and the safety score is 2, indicating Caution grade.In this case, the electrical safety grade indicates the Caution grade even if the actual leakage current passing the branch line is 10 mA, which this value corresponds to the Warning grade.However, the Warning event in the branch CB is not desirable because the actual abnormal location caused by leakage current is the load side.Therefore, it can be seen that the Safety grade is displayed on the branch and the Caution grade is displayed on the two outlets, through the public platform's data analysis of the figure 2 algorithm.

Figure 6 (d) shows the experimentresult for Case4in which the leakage current of each 5 mA is applied to the two outlets and branch #2. As the two smart outlets and branch side are abnormal, it is shown that the SO#1, SO#2, branch line #2 change to Caution on the event display screen and the safety score is 4, indicating Caution grade.In this case, the electrical safety grade indicates the Caution grade even if the actual leakage current passing the branch line is 15 mA, which this value corresponds to the Warning grade.As the leakage current occurred in the branch is 5 mA, it can be seen that the Caution grade is displayed on the branch through the public platform's data analysis.

Figure 6 (e) shows the experimentresult for Case5in which the leakage current of 5 mA is applied to the SO#1 and the leakage current of 10 mA is applied to branch #2. It is shown that the SO#1, branch line#2 change to Caution and Warning, respectively, on the event display screen and the safety score is 11, indicating

Warning grade.

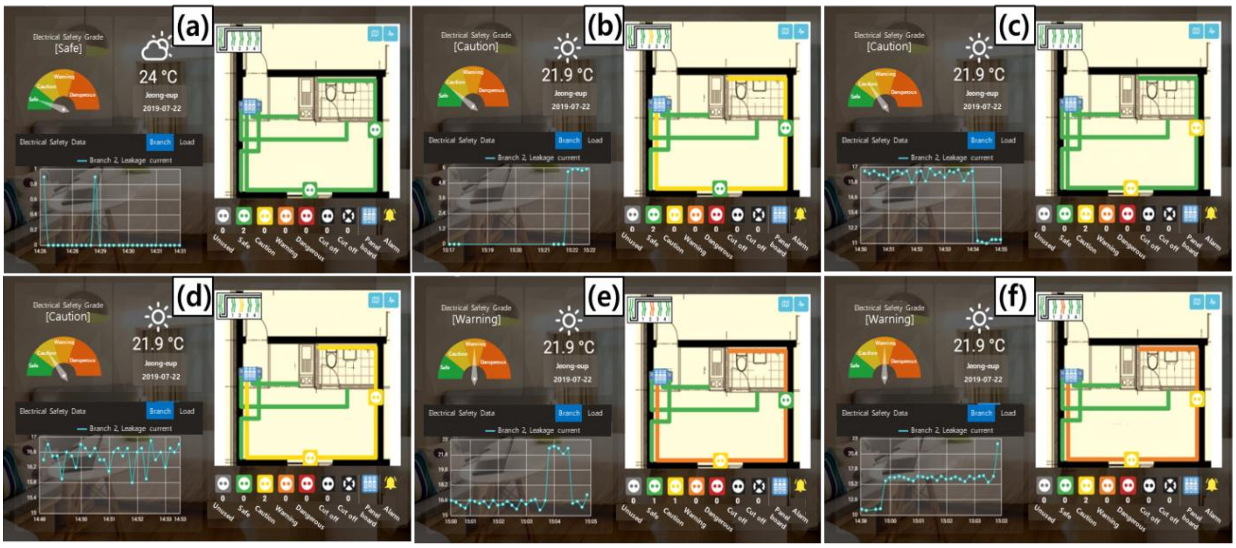

Figure 5. Screen of the abnormal condition monitoring system of the electrical installation (a) Case1 (b) Case2 (c) Case3 (d) Case4 (e) Case5 (f) Case6

Figure 6 (f) shows the experimentresult for Case6in which the leakage current of 5 mA is applied to the two outlets and the leakage current of 10 mA is applied to branch #2. It is shown that the SO#1, SO#2, and branch line#2 change to Caution and Warning, respectively, on the event display screen and the safety score is 12, indicating Warning grade.In this case, the electrical safety grade indicates the Caution grade even if the actual leakage current passing the branch line is 20 mA, which this value corresponds to the Dangerous grade. As the leakage current occurred in the branch is 10 mA, it can be seen that the Caution grade is displayed on the branch through the figure 2 algorithm.

IV. Conclusion

In this paper, a study was conducted to secure electrical safety for individual households where electrical safety inspections have not been carried out regularly. For this purpose, the IoT - based household facilities such as smart panel board and smart outlet have been developed and abnormal location estimation and electrical safety grade service model has been proposed. When an event such as leakage current or overvoltage occurred, it is possible to determine the cause and abnormal location, which was difficult to judge previously, through the analysis on the public platform. By providing the event alarm, abnormal location and electrical safety grade, the user and electric safety manager can be aware of the electrical safety of the home. Through the developed monitoring system,it can contribute to the reduction of electrical disaster by eliminating the electrical hazards in advance.

V. Acknowledgment

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning(KETEP) and the Ministry of Trade, Industry & Energy of the Republic of Korea(No. 20151210000050)

References

[1] Electric Utility ACT, Ministry of Trade,

TEST Engineering & Management
November-December 2019
ISSN: 0193-4120 Page No. 189 – 198

Industry and Energy, http://elaw.klri.re.kr

[2] Lee KY, Moon HW, Kim DW, Lim YB, Ryu IH. A study on the development of an autonomous electrical safety management service using an IoT-based smart outlet.International Journal of Electrical Engineering Education.2019Jan. DOI:10.1177/00207 20918822753.

[3] Ku JH. A Study on Evaluation Plan of Fire Safety Performance for Public Building. Journal of the Korea Convergence Society. 2019 Apr;10(4):25-32

[4] A Statistical Analysis on the Electrical Accident, Korea Electrical Safety Corporation, http://www.esps.or.kr

[5] IEC, IEC 62606 : General requirements for arc fault detection devices 2013.

[6] Venkat NR, akshit M, Shayideep S, Internet of Things-Architecture and Enabling Technologies, International Journal of computer Technology & Applications 2016; 7(6); 798-804

[7] Lim YB, Kim DW, Park WG, Lee HK, Cho SW. A Study on the Prediction Method of Electrical Accident Using MFCC and Change Rate. Journal of Korean Insitute of Intelligent Systems. 2018 Jan;28(2):114-121.

[8] Baik SH, Lee HJ, Lim SY, Huh JD.Managing mechanism for service compatibility and interaction issues in context-aware ubiquitous home. IEEE Transactions on Consumer Electronics, 2005 Jul;51(2). DOI:10.1109/TCE.2005.1467996

[9] A Study on IoT Technology and New Home IoT Service Models [master's thesis]. Gwangju (Chonnam): Chonnam National University, Gwangju; 2016.

[10] Lee KY, Moon HW, Kim DW, Lim YB, Choi JS. A Study on Arc Fault Detection Algorithm Based on Mash-up Analysis Technique. Transactions of the Korean Institute of Electrical Engineers.2017 June:66(6):995-1000. DOI:10.5370/KIEE.2017.66.6.995

[11] Kim JH. A Study on ESS-based Clean Energy, Smart Home IoT Platform. Journal of The Korea Institute of Electronic Communication Sciences. 2018;13(1):147-152

[12] G. Kesavan, P. Sanjeevi and P. Viswanathan. A 24 hour IoT framework for monitoring and managing home automation, 2016 International Conference on Inventive Computation Technologies, 2016 Aug. DOI:10.1109/INVENTIVE.2016.782320 5

[13] Abdur RN, Raffaele G. IoT and cloud convergence: Opportunities and challenges. 2014 IEEE World Forum on Internet of Things (WF-IoT). 2014 Mar. DOI:10.1109/WF-IoT.2014.6803194