An Analysis of the Relationship between Elevator Emergency(Entrapment) and Situation Measurement of Sag/Interruptions at the Switchboard

Gi-Hyun Kim* · Young-Bae Lim · Seok-Myung Bai · Jae-Chul Kim** · Hee-Tae Lee

Abstract

This study researched the mutual relationship between elevator emergencies(sudden stops, entrapment) and power quality such as voltage interruptions or sags. To analyze the power quality at the elevator switchboard of an apartment, the on-line power quality(sag, swell, and interruption, etc.) were measured and error messages(under voltage error, etc.) in the elevator control room were researched. Also the performance and susceptibility for stops were evaluated and stated through the testing of three pieces of simulated test equipment with an EN12016(2004) standard setting and the magnitude and duration data of the measured sag or interruption. This paper will use these data in the analysis of the mutual relationship between power quality and elevator emergencies.

Key Words : Elevator, Power Quality, Sag, Interruption, Kept within elevator

1. Abstract

Every year, damage from natural disasters such as lightning strikes and forest fires has an impact on the overall industrial economy.

These natural disasters, in particular lightning strikes, cause increasing damage to every product which uses electricity by causing power outages or drops in voltage.

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The number of elevators upon which we closely rely in many areas of our daily life amounted to 324,426 on June 30th, 2006. Fifty-five percent of these are currently utilized in apartment buildings.

The number of elevator accidents causing casualties or loss of human life is increasing steadily; these accidents can cause death, serious injury, and light injury, according to the degree of damage incurred.

Based solely on the data investigated and recorded over a recent 10 year period(1995~2004), an average of 20 accidents resulting in casualties took place. The average number of the victims totaled more than 40 per year.

However, by including those accidents that do not get reported, the number of victims may rise significantly.

Potential accidents such as stops, jumps, sudden stops, and errors in floor display that can cause feelings of uneasiness in passengers and accidents resulting in injury are also reported to occur around 6 times a year per elevator[1].

The purpose of this paper is to study how much relationship there is between such moving accidents and accidents of entrapment in apartment housing have to power quality impacts such as interruptions, sags, swells, harmonics, and surges. To achieve this goal, the power quality in the elevator switchboard apartment was measured and elevators that are usually installed in the field were built, the susceptibility to power quality of which was tested to analyze the mutual relationship to elevator entrapment.

To this end, a real-time power quality measuring system from the elevator control board was installed on-site, which enabled the measuring of voltage above a certain amount. The accidents of errors and breakdowns caused thereby were then investigated.

Three models of elevator that have recently become popular for installation were also built to test the properties of movement and the susceptibility of the elevating facility according to the level and duration data pertaining to sags and interruption, which data were used to analyze the mutual relation with the stop accidents.

2. Main Discourse/Issues

2.1 Causes of voltage sag in apartment buildings

Voltage-sag is defined as a 'Dip' by the IEC and as a 'Sag' by the IEEE. Table 1 shows the magnitude and duration for Sags, Swells and Interruptions as defined in IEEE Std 1159. For this study, the duration of the waveform measured on-site was defined as being less than 60 cycles (1 sec). In electric power systems, a sag is caused in situations such as: In cases when a breakdown is caused by a lightning strike and/or forest fire, the broken line is separated from the system with a high-speed breaker in order to minimize damage to the facility or to keep the disturbance in the system to a minimum. While the breakdown problem is being removed, an instantaneous voltage drop occurs in the part of the line connected to the system. Also, a sag waveform can occur in the connecting line due to the property of the arrester when inductive lightning, which is a momentary abnormal voltage caused by a lightning strike, occurs, and the arrester begins operating to eject the following current[5-6]. From the data which analyzes the contents of the 2005 "Report on the analysis of power supply facility breakdown and preventative measures" presented by the Korea Electric Power Corporation, the number of momentary power failures caused by lightning strikes among natural disasters increased in the year 2004 as compared to the situation in 2003[2]. For the purposes of this study, it was confirmed that domestic damage in Korea caused by temporary or momentary power failure due to lightning disaster was on the rise as every year passed.

Table 1. IEEE Standards for Sags, Swells, Interruptions

Categories			Duration time	Magnitude
Short Duration Variation	Instantaneous	Sag	0.5~30cycle	0.1~0.9[pu]
		Swell	0.5~30cycle	1.1~1.8[pu]
	Momentary	Interruption	0.5cycle~3s	<0.1[pu]
		Sag	30cycle~3s	0.1~0.9[pu]
		Swell	30cycle~3s	1.1~1.8[pu]
	Temporary	Interruption	3s~1min	<0.1[pu]
		Sag	3s~1min	0.1~0.9[pu]
		Swell	3s~1min	1.1~1.8[pu]

Some of the causes for momentary power failures, such as instantaneous power failures induced by re-closing time as a re-closer operates, and those induced by the ripple effect of a power failure to nearby network lines, can lead to a sag in apartment elevator switches. In electric power systems, if first line earth fault, second line earth fault and/or a three-phase 3 short circuit accidents occur, the impact on nearby line of the network can cause an instantaneous drop in voltage(i.e., sag). While the point of accident is separated from the system and the breakdown problem is being removed, an instantaneous voltage drop(i.e., sag) occurs in nearby network lines.

2.2 Measurement of power quality input into elevators

2.2.1 On-line measurement system of power quality

To balance the regions, measurement equipment was installed in elevators with the specifications shown in Table 2 in 2 locations in Seoul and 1 location each in Cheonan and Chuncheon. In most elevator power systems in apartment buildings, elevator power is supplied by a power transformer. Usually, 1 to 3 elevators operate for each Main Circuit Breaker per switchboard.

One example was as follows: One elevator power system installed on-site supplies power to 11 elevators and other electric equipment such as the drain pump, using 3 motors with a 750[kVA] capacity for lighting and 1 motor with a capacity of 350[kVA] for power supply purposes.

Fig. 1 represents an on-line measurement system of power quality from secondary panel boards of elevators. There is usually a great deal of difficulty in measuring and analyzing abnormal power quality on-site or the desired waveform. The possibility of such a measurement is small because there is no knowing when the waveform that one would hope to measure will happen.

Table 2. The place of installation and motor capacity

Place of installation	Manufacturing Company	Year of installation	Motor capacity
Toegye Dong, Chuncheon	Company A	1999. 09	13[kW]
Baekseok-Dong, Cheonan	Company B	2002. 11	9.5[kW]
Gwanak-Gu, Seoul	Company C	2001. 12	13[kW]
Dongdaemun-Gu, Seoul	Company D	1999. 10	15[kW]

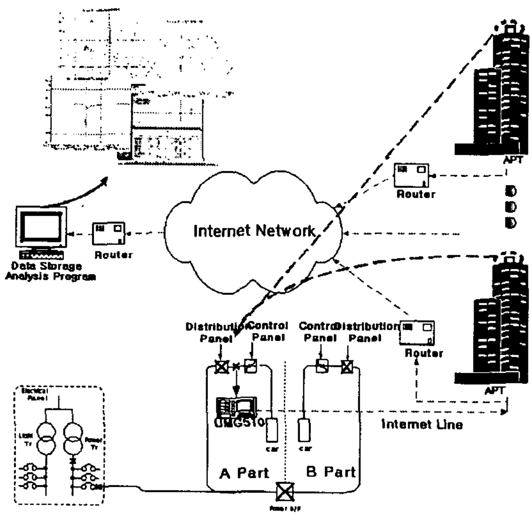

Fig. 1. On-Line measurement system of elevator power quality

2.2.2 Measurement and analysis of the waveform of sags and interruptions

When an instantaneous power failure(i.e., interruption), an instantaneous voltage drop(i.e., sag) or a power failure occur, they are recorded as a low-tension error, a stop, etc., in the fault record of the elevator[4]. Accidents of standardized floor movement and accidents entrapment are possible in accordance with the duration and magnitude of these occurrences.

In cases of permanent a power failure, power for the elevators is supplied by an emergency electric generator. However, in some inverters the disparity between the signal of the door sensor and that of the door switch prevents the elevator from operating, which leads to an extended state of closure and, therefore, results in being trapped within the elevator. Thus, there are complex factors which can cause this entrapment[3-4]. The factors that influence this are instantaneous power failures(i.e., interruptions), instantaneous voltage drops(i.e., sags), and power failure s in general, for each of which the state of power quality was measured for the areas featured in Table 2.

Tables 3 and 4 show the data on the event time, magnitude and duration of sag measured on-site. On 5th August 2006 and 19th August, when the occurrence of sags was measured, the data from the Korea Metrological Administration showed that heavy rain and lightning strikes occurred within the area of measurement. While the sags probably did not occur at all the instances of lightning activity, it is our judgment that because of the impact the lightning has on the system, a sag occurs in nearby loaded facilities[5]. In cases where a sag waveform flows into the panel board and such natural disasters as lightning and forest fires have caused a breakdown in the system connected to an apartment building, the line that broke down is separated from the system with a high-speed breaker in order to minimize damage to the facility or to keep the disturbance to the system to a minimum. While this breakdown is being removed, instantaneous voltage drops occur in the line of the network connected to the system. Figs. 2 and 3 show the waveform of instantaneous voltage drops(i.e., sag) measured in the place(s) of installation, defined as a waveform of virtual/effective value.

Fig. 5 shows the values of the magnitude and duration of the sags, interruptions and swells measured in 4 locations in one year. The causes for the occurrences of sag waveforms measured in the power input of elevator were identified. It was found that these causes included not only those mentioned in Section 2.1 of this paper but also the fact that a partial sag can occur when the elevator is running, due to the characteristics of elevator operation(this usually happens at 90[%]). Also, note that in Fig. 5 it is indicated that a sag occurred in each state in the cases when a sag and an interruption happened simultaneously in the bi-state and three-phases, which makes them more in actual count than the number of actual sag and interruption occurrence. Of course, even when sags occur simultaneously, the impact of the sag on elevators differ greatly, depending on the magnitude and duration for each state and on whether the state is connected to the power from the elevator control board. The swell was measured at approximately 110[%] to 112[%], internal division, and neither abnormalities nor errors were observed in the corresponding voltage level.

Table 3. Sag Magnitude, event time and duration by measured

Minimum value([V])	Average value([V])	Line of accident	Event time	Duration (ms)
169.019	184.407	L1	06. 8. 5 9:04:22 PM '660	131[ms]
171.0	186.917	L2	06. 8. 5 9:04:22 PM '660	131[ms]
73.374	155.048	L3	06. 8. 5 9:04:22 PM '660	131[ms]

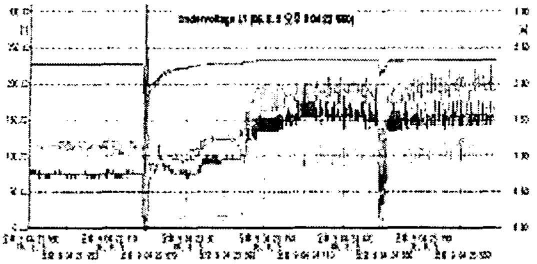

Fig. 2. Sag waveform(131[ms]) measured on 5th August

Table 4. Sag Magnitude, event time and duration by measured

Minimum value([V])	Average value([V])	Line of accident	Event time	Duration ([ms])
156.246	160.223	L2	06. 8. 19 4:06:43 AM '076	368[ms]
85.811	120.636	L3	06. 8. 19 4:06:43 AM'080	368[ms]
180.381	182.487	L1	06. 8. 19 4:06:43 AM'166	270[ms]

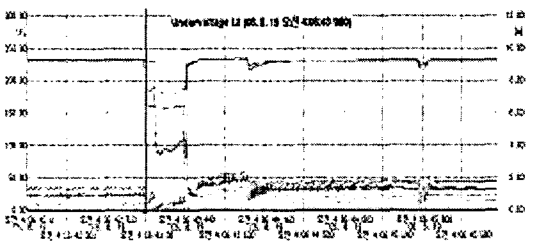

Fig. 3. Sag waveform(368[ms]) measured on 19th August

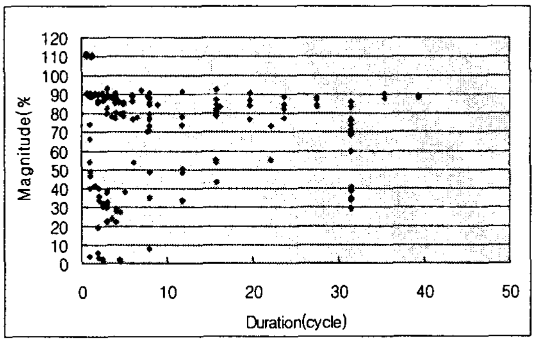

Fig. 5. Magnitude and duration of measuring sag and interruption over one year

3. The Evaluation of movement characteristics and susceptibility to sag and interruption in an elevator

In order to select a representational model for testing elevator equipment, the VVVF method was chosen as the control method. Afterwards, three models that are have been installed often in apartment buildings in recent times(2005) with the same specification that are described in Table 5 were selected for production. These were installed according to the organization of the test equipment in EN12016[9]. To test the configuration of the equipment for the elevators, load controllers, each of the [average] weight of one passenger, were additionally installed to achieve the same effect as real-life elevator operations. Load capacity was controlled depending on the characteristics of the company that made the elevator, and the test was carried out while the elevator was operating normally.

Table 5. Selected elevator testing equipment

model	mode	capacity	speed /velocity
O model	Rope elevator for passenger	550[kg]/for 8 passengers	90[m/min]
O model	rope elevator for passenger	1000[kg]/for 15 passengers	60[m/min]
O model	rope elevator for passenger	1000[kg]/for 15 passengers	60[m/min]

Fig. 6 shows the testing impression equipment, an elevator control board and the scene of the test, whose purpose is to confirm the important voltage change of the control board, according to the voltage susceptibility test.

It is common to make the part that enters the control board a single-phase power outlet of

380[V], and to transform the power into the needed voltage through a TR(i.e., transformer). There are, of course, some elevators that achieve the necessary control power by receiving a three-phase power and being transformed through a three-phase TR.

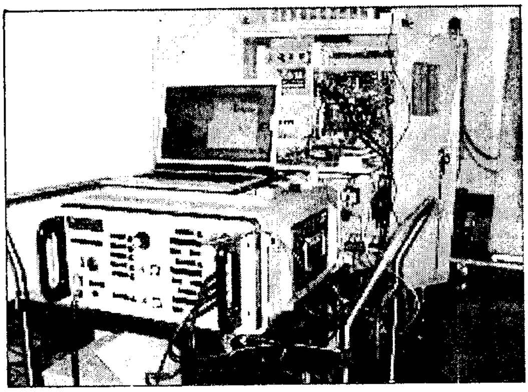

Fig. 6. Voltage susceptibility test of elevator

3.1 Test Methods and the Results for the Company A Elevator

The test condition for Company A elevator: In the state of both normal and idle operations of the elevator, the conditions for testing and analysis consisted of the repetition of automatic movement between the 1st and the 5th floors. In order to confirm the voltage alterations in important parts at the control board according to the power quality impression level of Company A, the changes in the SMPS AC 220[V] input, the DC 24[V] Limit S/W power, the DC 5[V] PCB Control power, the DC 10[V] Encoder power, and the DC 15[V] Gate power were checked, which enabled us to identify the characteristics of movement for the elevator. With elevators made by Company A, when the sag and interruption impressed, the elevator stopped, moved to the key floor, and finally either opened or closed the door, or remained stopped, according to the level and duration of the impression. The characteristics of movement of the Company A elevator involved receiving a 380[V] '1'state(L1-L3) current from the control power of three-phase power, going through a TR to change the voltage into 220[V] and transforming from SMPS the necessary mode of power. Therefore, with the inflow of a sag and/or interruption, among the control power the M/C(magnetic contactor) operates power in a 220[V] line. The M/C has among its properties the tendency to be switched On/Off by a SR(Safety Line Relay) which is in turn controlled by 110[V], and thus is sensitive to sags and interruptions.

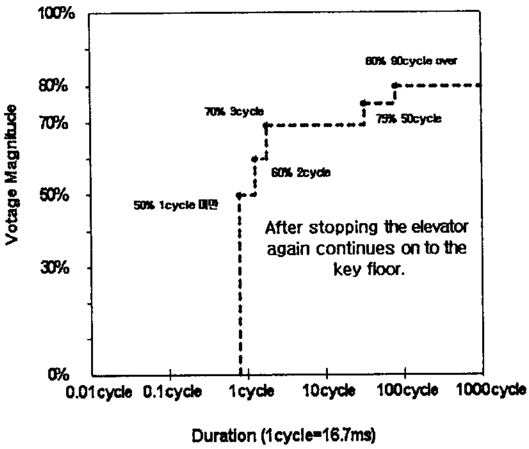

Fig. 7. ITIC curve of the voltage susceptibility of the Company A elevator

As can be observed in the ITIC(Information Technology Industry Council) curve, which confirms the movement characteristics of the Company A elevator according to the voltage level and duration as shown in Fig. 7, the elevator mostly displays characteristics such as stoppages and movement to the key floor at less than 70[%] and more than 3 cycles. Thus in the cases where the waveform of the sag and interruption measured on site impresses on the control power line, it may be assumed that many accidents of stoppage and movement to the key floor are likely to occur.

3.2 Test Methods and the Results for the Company B Elevator

The test conditions of Company B elevator were that: In the state of normal and idle elevator operation, the conditions for testing and analysis consisted of a repetition of automatic movement between the 1st and the 15th floors.

In order to confirm the voltage alterations in important sections at the control board according to the power quality impression level of Company B, the following were assessed: the changes in the Secondary AC 220[V] TR, the DC 24[V] control power, the DC 110[V] Safety Line, and the DC 5[V] PCB Control power, which enabled the identification of the movement characteristics of the elevator. In elevators made by Company B, when sags and interruptions impressed, the elevator stopped, moved to the key floor, and finally opened or closed the door, or remained in stopped, according to the level and duration of the impression.

The movement characteristics of the Company An elevator involved receiving 380[V] from the control power going through the '1'state transformer and transforming the necessary form of power from 220[V] and SMPS.

With the inflow of a sag and/or interruption, among the control power the M/C(magnetic contactor) controls the power via a 220[V] line. The M/C may be switched On/Off by the MCA which is in turn controlled by DC 24[V] and thus receives less impact from a sag and interruption.

As can be seen in Fig. 8, the elevator operates normally for a voltage drop of less than 50[%] (L1-L3 : 190[V]).

In the event of a sag impression, there is no distinguishing from waveforms measured in the main sections of the control board between the elevator stopping in the midst of movement and moving to the key floor and that of the elevator operating in normally.

It may be said, then, that depending on the duration and magnitude of the sag, the abnormal voltage flows in. When low tension(less than 50[%]) flows in continuously(lasting longer than 90 cycles) at one point in time the M/C, which is composed of coils, becomes open to the energy level.

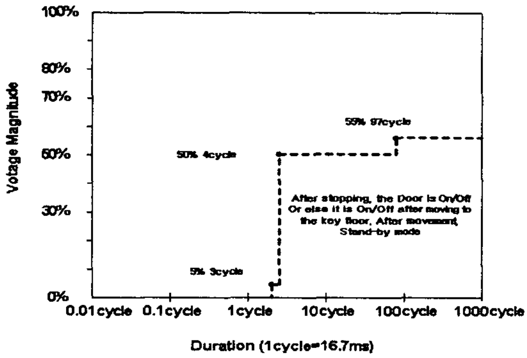

Fig. 8. ITIC curve of voltage susceptibility of Company B

3.3 Test methods and the Results for the Company C elevator

The test condition of the Company C elevator was: In the state of the normal operation of the elevator and with a 50[%] full load impression, the conditions for testing and analysis consisted of a repetition of automatic movement between the 1st and the 15th floors. In order to confirm the voltage alterations in the important sections at the control board according to the power quality impression level of Company C, the following were checked: the changes in the SMPS AC 110[V] input, the AC 110[V] Gate SMPS input, the DC 110[V] M/C input, the DC 15[V] Encoder, and the DC 15[V] Hall CT, which enabled the identification of the movement characteristics of the elevator.

For the elevator made by Company C, when a sag or interruption impressed, the elevator stopped at the nearest floor, opened/closed the door, and went back to normally operations. It was also observed that when the voltage was restored to a normal level after a power failure, a '1'-state power failure in more than 2 Cycles or a 30[%] Sag inflow over more than 90 Cycles, the elevator stopped moving and the floor signal disappeared. The elevator moved to the nearest floor post-restoration and the door opened/closed and finally maintained a standby state.

In this case the elevator went back to normal operations when the passenger pushed Hold button or the Door button. The movement characteristics of Company C involved receiving three-phase 380[V] from the control power, which goes through a TR to transform into 110[V], and also transforms the necessary power from SMPS to 1-state and three-phase. Therefore, with the inflow of a sag or interruption, the control power controlled by M/C is also controlled by DC 110[V] and thus is under less influence from sags and interruptions. Also, the power supply is three-phase and is transformed into the necessary form of power to be used. All of these factors add up to the judgment that Company C elevators have a strong susceptibility to '1'-state, bi-state, three-phase sags and interruptions caused by external factors.

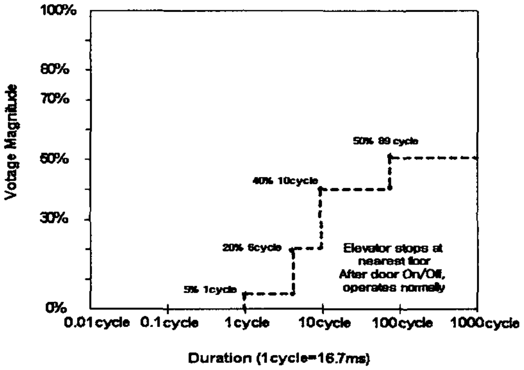

Fig. 9. ITIC curve of voltage susceptibility of Company C

4. Conclusion

Elevator-related accidents are reported year after year, including those with injury and death and those of entrapment. This has to do with the number of installed elevators and that the total number of elevators in retention is increasing every year.

This study chose to analyze the performance of elevator operation depending on changes in power quality, which may be related to elevator accidents such as entrapment. Through testing, the movement characteristics of elevators were analyzed according to the circuit composition of the elevator control board. Through these tests and analyses, it was confirmed that susceptibility differed from one kind of elevator to another, depending on the control system of AC and DC, and control by M/C of the elevator motors. Also confirmed was the existence of differences in safety of elevator movement in terms of sag and interruption, which depended on whether '1'-state or three-phase power is supplied to the control panel. When a sag was lasted for more than 90 cycles(1.5 sec), stoppage or similar phenomena occurred although the situation differed from company to company. The conclusion of this study is that, even with the movement characteristics differing from company to company, the identification and definition of the section where normal operations must happen, in terms of sag, is necessary. Once the boundaries of that section are established, normal operation should be able to be maintained without stopping inside those boundaries. This definition will reduce anxiety about accidents of movement to key floors and being trapped within an elevator caused by sags above a certain level and reduce general mistrust of elevators. The contents of this paper will provide data for presenting preventative measures for electric disturbances based on elevator EMS susceptibility tests and fact-finding field missions.

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