SEISMIC ASSESSMENT OF MEDIUM AND HIGH VOLTAGE POWER SUBSTATION EQUIPMENTS

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ABSTRACT :

Power electric substations are key elements of power supply systems. Equipments of the power substations have been the most vulnerable components within the power supply systems in past earthquakes. Damage to substation equipments will cause disoperation of whole substation, and then, widespread power disruptions. This paper develops methods for seismic assessment of medium- and high-voltage power substation equipments. In this paper, data of seismic performance of equipments within fifty-eight medium- and high-voltage substations, as the most vulnerable substations, in past major earthquakes in a few countries are collected. The selected equipments are power transformer, live-tank circuit breaker, dead-tank circuit breaker, disconnect switch, current transformer, potential transformer, bus-bar system, lightning arrester, wave trap, and capacitive coupling voltage transformer. In last part of the paper, a damage ratio curve for the medium and high voltage substations is proposed. The obtained results for damage analyses of the equipments indicate that the live-tank circuit breakers by 32.3% are the most vulnerable equipment and dead-tank circuit breakers by 2.5% have the best seismic performance. Current transformers, bus-bar systems, potential transformers, and power transformers are the other vulnerable equipments respectively.

KEYWORDS: Power substation, Seismic assessment, Medium voltage, High voltage, Substation equipment

1. INTRODUCTION

A power supply system is composed of four sub-systems: power generators, transmission grid, power substations and distribution grid. Supplied power to be useful in a home or business, when it comes off the transmission grid and is stepped-down to the distribution grid. This may happen in several phases. The place, where the conversion from "transmission" to "distribution" occurs, is in a power substation. A power substation typically does three jobs as follows:

- It has transformers that step transmission voltages (in the tens or hundreds of thousands of volts range) down to distribution voltages (typically less than 20 kV).
- It has a "bus-bar" that can split the distribution power off in multiple directions.
- It often has circuit breakers and disconnect switches so that the substation could be disconnected from the transmission grid or distribution lines can be disconnected from the substation when necessary.

A high or medium voltage substation is used in a transmission grid but a low voltage substation is employed in a distribution grid. Several large structural systems exist within the substation, each contributing to the overall functionality of the substation. Most of the substation equipments have poor seismic performance. Recent seismic events, such as the 1971 San Fernando (US), 1986 North Palm Springs (US), 1989 Loma Prieta (US), 1990 North of Iran, 1992 Landers (US), 1994 Northridge (US), 1995 Kobe, 1999 Izmit (Turkey), 2001 El Salvador, 2003 Bam (Iran), 2004 Niigata (Japan), 2004 Indian Ocean, 2006 West of Iran and 2006 Java (Indonesia) earthquakes demonstrated the vulnerability of substation components to ground shaking. Failures commonly occurred in support structures of conductors, anchorage of power transformers, bushings, insulator poles, circuit breakers, and disconnect switches. Figures 1-4 show examples of damages to substation equipments in the 2004 Niigata Ken Chūetsu earthquake in Japan (JSCE/JGS, 2004). These damages occurred while mostly of power substations in Japan during last decades, especially after the Kobe 1995 earthquake, have been strengthened against earthquake. Japan Electric Association in 1985, for first time, developed a Guideline titled as "Earthquake resistant design guideline for electric facilities in power substation", which was revised in 1999 (JEAG 5003-1999).

Power substations based on functionality are classified in three types as follows:

- Transmission substations (voltage and current increase or decrease)
- Distribution substations (voltage decrease and current increase)
- Switchyards (no change in voltage and current)

Also based on voltage level they are categorized in three class, which are:

- Low-voltage: less than 150 kV
- Medium-voltage: between 150 kV and 350 kV
- High-voltage: 350 kV and above

In this paper, seismic performance of medium- and high-voltage power substation equipments are discussed.

Figure 1 Lightning arresters of all three-phases were broken in Nagaoka Sub. (JSCE, 2004)

Figure 2 Oil leakage from joint between transformer and condenser in Minami Nagaoka Sub. (JSCE, 2004)

Figure 3 Failure of condenser in Nagaoka sub. (JSCE, 2004)

Figure 4 Extrusion of gasket and oil leakage in bushing of 154 kV transformer in Uonuma Sub. (JSCE, 2004)

2. DATA GATHERING

In this research, at first damages to the power systems in 43 earthquakes, from the 1923 Kanto earthquake(Japan) to the 2006 Java earthquake(Indonesia) are investigated, which hundreds of power substations had been suffered damage. Unfortunately exact information like as ground acceleration at substation site, description of damages, exact number of damaged equipments, voltage level of equipments and etc. in mostly of reports are not reported. Due to these data limitations, just enough data of 58 medium- and high-voltage substations (as the most vulnerable substations) are found, which are used in this paper. Due to volume consuming of this paper, it is not possible to list all specifications of these substations and also all references which are more than 80 references but it could be referred to Chapter 2 of (Bastami, 2007) to view list the mostly of the references. Operation of a power substation is function of equipments operation within the substation such as power transformer, disconnect switch, live-tank circuit breaker, current transformer, bus-bar and etc. A substation, based on its functionality, may include some or all the equipments. All important equipments within a standard substation are listed below:

- Power transformer
- Live-tank circuit breaker
- Dead-tank circuit breaker
- Disconnect switches
- Current transformer
- Potential transformer
- Bus-bar system
- Lightning arrester
- Wave trap
- Capacitive coupling voltage transformer

In this research all the above equipments are taken into account.

3. PERFORMANCE OF SUBSTATION EQUIPMENTS IN PAST EARTHQUAKES

3.1 Performance of Equipments

In this section, results for seismic performance of the abovementioned equipments are presented. Percentage of damage for each equipment is defined as ratio of number of damaged equipments to total number of that equipment. Figures 5-14 depict percentage of damaged equipments in medium- and high-voltage substations respectively. The figures indicate vulnerability of all equipments within medium- or high-voltage power substations.

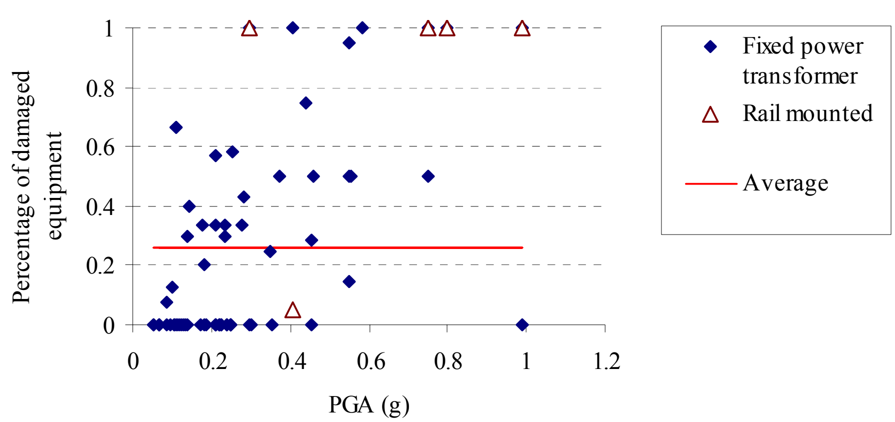

Figure 5 Percentage of damaged power transformers in medium- and high-voltage substations

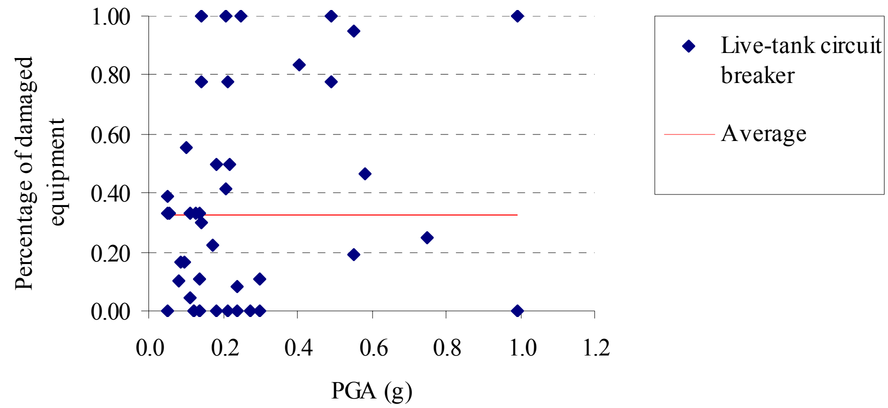

Figure 6 Percentage of damaged live-tank circuit breakers in medium- and high- voltage substations

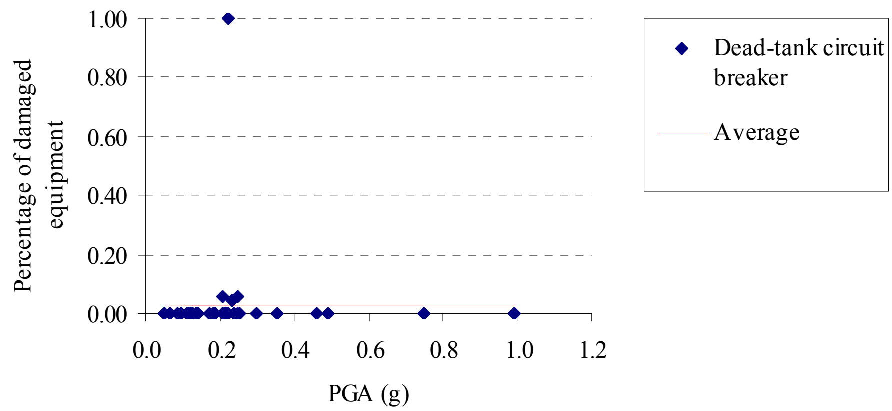

Figure 7 Percentage of damaged dead-tank circuit breakers in medium- and high- voltage substations

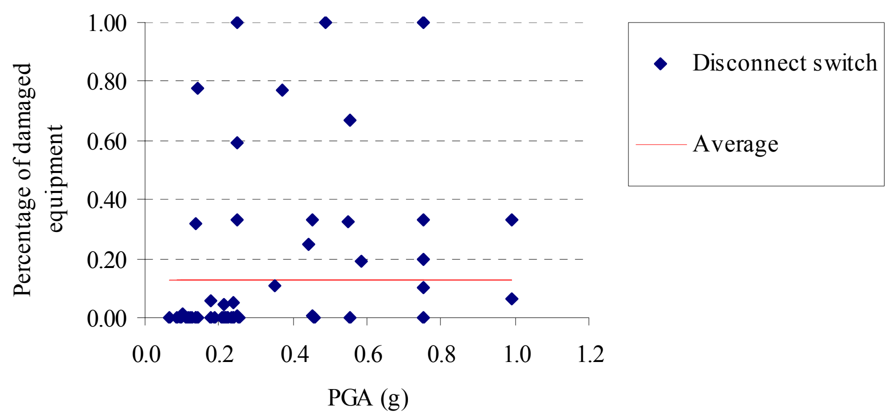

Figure 8 Percentage of damaged disconnect switches in medium- and high- voltage substations

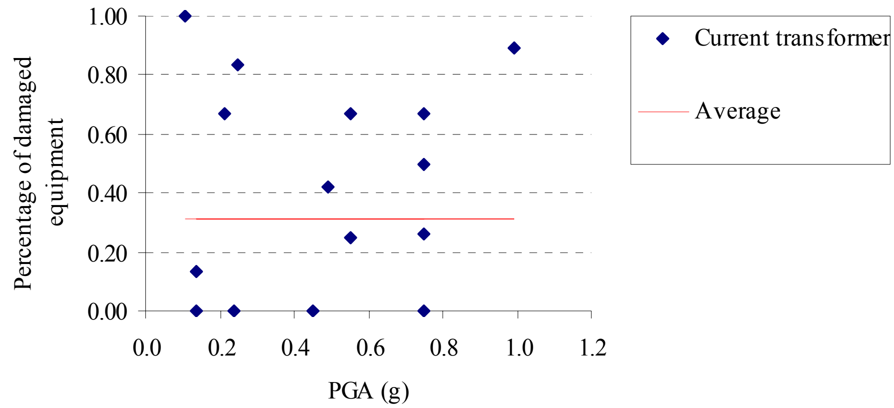

Figure 9 Percentage of damaged current transformers in medium- and high-voltage substations

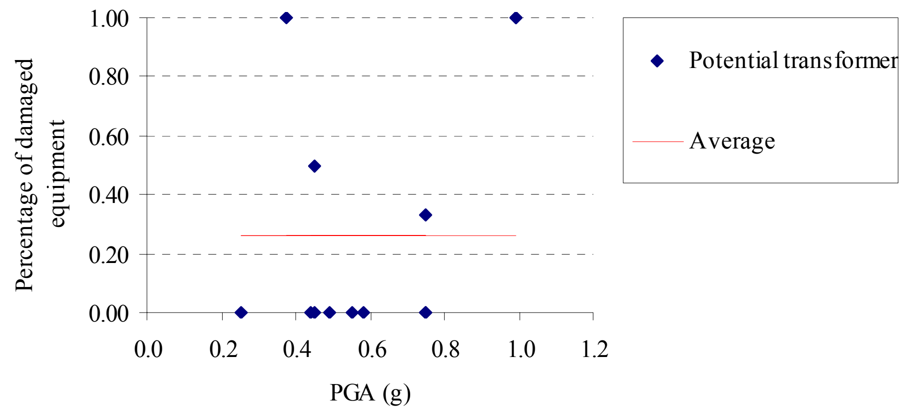

Figure 10 Percentage of damaged potential transformers in medium- and high-voltage substations

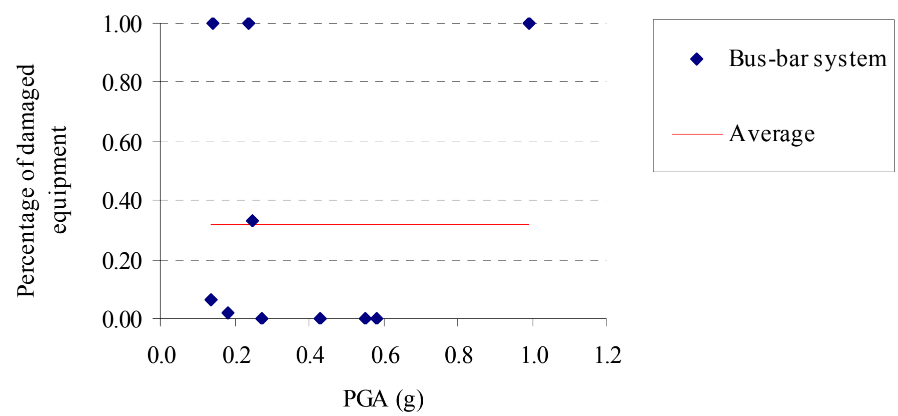

Figure 11 Percentage of damaged bus-bar systems in medium- and high-voltage substations

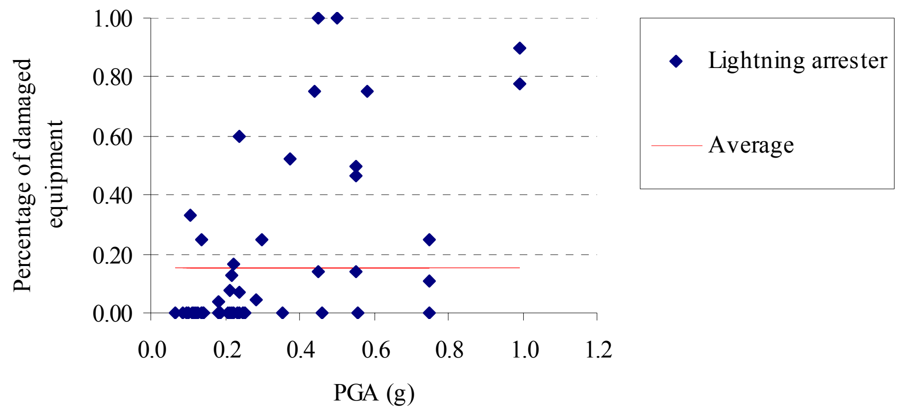

Figure 12 Percentage of damaged lightning arresters in medium- and high-voltage substations

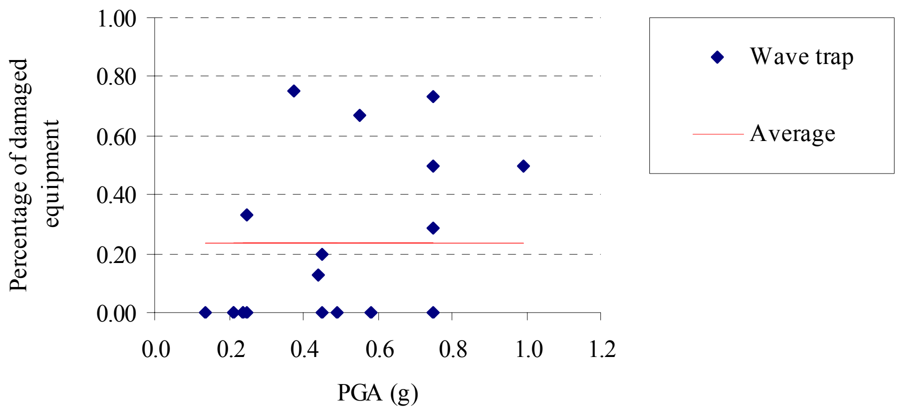

Figure 13 Percentage of damaged wave traps in medium- and high-voltage substations

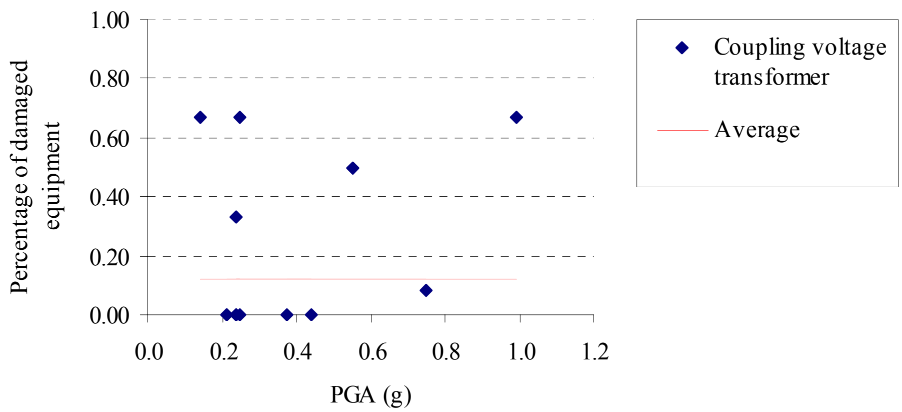

Figure 14 Percentage of damaged capacitive coupling voltage transformer in medium- and high-voltage substations

Table 1 shows total number, number of the damaged and undamaged equipments, in which disconnect switches by 429 cases, live-tank circuit breakers by 150 cases and power transformers by 90 cases, bus-bar systems by 83 cases, lightning arresters by 81 cases and current transformers by 78 cases are damaged repeatedly in the 58 studied substations in past earthquakes. Table 1 also depicts percentage of damaged substation equipments, which indicates live-tank circuit breakers by 32.3% are the most vulnerable equipment and dead-tank circuit breakers by 2.5% have the best seismic performance. Current transformers, bus-bar systems, potential transformers and power transformers are the other vulnerable equipments. An interesting point is that disconnect switches by maximum reported number of damages, has better performance in comparison with live-tank circuit breakers, current transformers, bus-bar systems, potential transformers and power transformers.

Table 1 Performance of the 58 medium- and high-voltage substation equipments in past earthquakes

No.	Equipment	Total number	Damaged number	Undamaged number	Average of percentage of damage
1	Power Transformer	351	90	261	25.6%
2	Live-tank Circuit Breaker	464	150	314	32.3%
3	Dead-tank Circuit Breaker	1133	28	1105	2.5%
4	Disconnect Switch	3376	429	2947	12.7%
5	Current Transformer	250	78	172	31.2%
6	Potential Transformer	89	23	66	25.8%
7	Bus-bar System	261	83	178	31.8%
8	Lightning Arrester	540	81	459	15.0%
9	Wave Trap	114	27	87	23.7%
10	Capacitive Coupling Voltage Transformer	142	17	125	12.0%

3.1 Damage Ratio Curve of Medium and High Voltage Substations

In this section, a damage ratio curve for the medium and high voltage substations is proposed, which is shown in Figure 15. The curve is a bilinear curve, which is divided in two parts: first part is for PGA less than 0.55g and second part belongs to PGA more than 0.55g. For PGA equal to 0.55g, damage ratio is approximately estimated 0.28 and maximum damage ratio is approximately estimated 0.4 for PGA more than 1.1g.

4. CONCLUSIONS

This paper seeks physical performance of power supply systems in past earthquakes. Damages to the power systems in 43 earthquakes, from the 1923 Kanto Earthquake until the 2006 Java Earthquake are studied. The selected earthquakes have proven widespread vulnerability of power system equipments from different points of view. Obtained results are summarized as follows:

1- Damage to porcelain units of high- and medium-voltage substation equipment has been a recurring problem. Equipment operating at low voltages performs well when good seismic installation practices of anchorage and conductor interconnection flexibility are followed. Some types of equipment, which operating at voltages of 220 kV and above, are vulnerable. Generally, we can say: the higher operating voltage, the more vulnerable equipment.

2- The highest voltage equipment, which is subjected to earthquake, is 500 kV.

3- In medium and high-voltage substations, several types of failures are frequently observed. Inadequately anchored rail-supported transformers have fallen from their elevated platforms and have been severely damaged. Leaking or broken bushings are common.

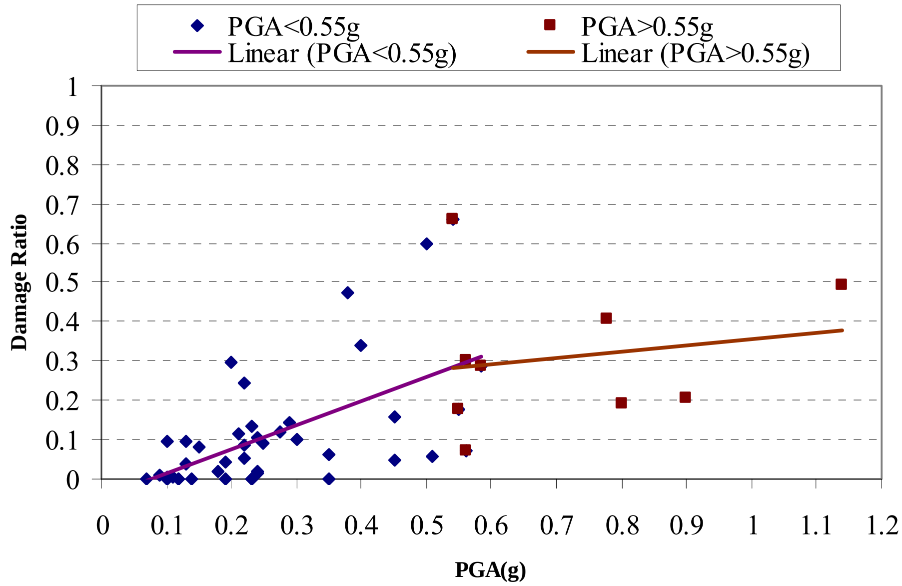

Figure 15 Damage ratio curve of the medium and high voltage substations

4- Design of some equipments appear to be inherently vulnerable, while other equipment that serves the same function and operates at the same voltage can be quite rugged; for example, some live-tank circuit breakers versus dead-tank circuit breakers.

5- Damage ratio curve of the medium and high voltage substations based on the 58 studied substations is developed, which could be useful for engineers in practical purposes.

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REFERENCES

Bastami, Morteza (2007). Seismic Reliability of Power Supply System Based on Probabilistic Approach. Ph.D thesis, Kobe University, Japan.

Japan Electric Association Guideline, (1999). Earthquake Resistant Design Guideline for Electric Facilities in Power Substation. JEAG 5003-1999, Japan, (in Japanese).

JSCE/JGS mission on the 2004 Niigata Chuetsu earthquake (2004). Reconnaissance report on the 2004 Niigata Chuetsu Earthquake (ver1.0), Chapter 9.4 Power supply system (9pages) Available at http://shake.iis.u-tokyo.ac.jp/chuetsu/9-4.pdf (in Japanese).