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Evaluation of Seismic Behavior of Circuit Breaker Based on Probabilistic Approach

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Abstract

Electrical Network as one of the main lifeline plays vital role in the economic, social and political relations of a country. Among the various components of Electrical Network, such as power plants, substations and transmission lines, high voltage substations have important consideration, and Play a vital role in network. So if for any reason disorder happens on the transmission and distribution of the network happens, it may cause irreparable damage. So this study is going through the evaluation of the seismic power substation as an important part of Electrical Network. One of the most effective methods to assess the vulnerability and seismic behavior of power substation is to use the fragility curves. In this method, the evaluation of the value of seismic vulnerability of structures proportion with the seismic parameters will be expressed. In fact, the aim of fragility curves is to create a relation between a failure criterion and a criterion of magnitude. In this study the circuit breaker as one of the most widely used equipment in power substation will be study and fragility curves will be drawn for it.

Keywords: Lifeline, power substation, fragility curves, seismic evaluation, crisis management.

Introduction

History of Electric Power: Benjamin Franklin is known for his discovery of electricity. Born in 1706, he began studying electricity in the early 1750s. His observations, including his kite experiment, verified the nature of electricity. Between 1750 and 1850 there were many great discoveries in the principles of electricity and magnetism by Volta, Coulomb, Gauss, Henry, Faraday, and others. It was found that electric current produces a magnetic field and that a moving magnetic field produces electricity in a wire. This led to many inventions such as the battery (1800), generator (1831), electric motor (1831), telegraph (1837), and telephone (1876), plus many other intriguing inventions. In 1879, Thomas Edison invented a more efficient light bulb, similar to those in use today. In 1882, he placed into operation the historic Pearl Street steam–electric plant and the first direct current (dc) distribution system in New York City, powering over 10,000 electric lightbulbs[1].

Power Substation: In order to reduce the electricity energy losses of the power transmission lines, amperage must be decreased and voltage must be increased. Similarly, in distribution and consumption of electrical power should reduce the voltage to make it possible for consumers to use electricity. Substation is named on collection equipment, electrical or electromechanical that connects the multi-input electrically to the multi-output electrically and operations such as maintain, care, conversions, monitor and control the switching will be done[1,2] (figure-1)

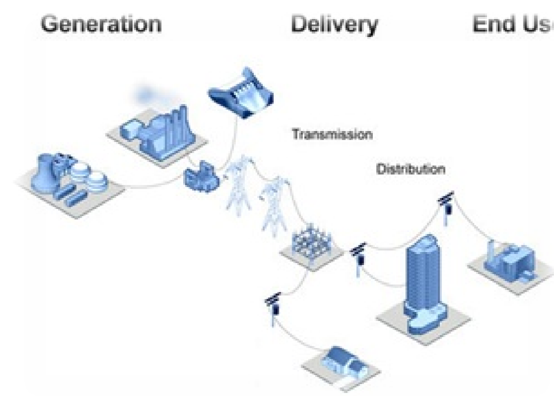


Figure-1
System overview

The main task of post is switching voltage, in many substations the combination of two modes are seen. The task of distribution post is taking over the power from transmission system and delivers it to the Distribution System. Economic and safety aspects of consumers connected directly to the transmission network is not cost efficient. So the task of substation is isolating each of the distribution networks or transmission that happens by errors occurring in the other.

Behavior of Substations in Earthquake: About the assessment of equipment seismic vulnerability, the injury studies and similar structures during past earthquakes will always be checked, as a starting point perfectly reasonable and logical is desired. Equipment such as power transformer, current transformer, and the circuit breaker, is fixed components and critical component of every single process. Previous evidence suggests that the failure rate of theses equipment have a direct connection with operating voltage, and Failure patterns each of them is nearly equal[2,3].

Investigate the effects of the earthquake occurred, is shown that the whole reason for the high vulnerability of substation equipment is as follows: The use of brittle materials in the core and critical part of equipment (including ceramic materials). Inadequate lateral strength and stiffness. Low levels of equipment damping, interactions between adjacent equipment, interactions with the internal components of equipment, excessive equipment load, Inadequate and irregular distribution of load on height, inappropriate installation and maintenance.

The fragility curves: To achieve good vision in relation Seismic behavior of substation, fragility curves will be drawn. In fact the fragility curve is a useful tool in order to estimate the seismic vulnerability of substation, which could positively result as[3]: Fragility curves are used for comparison of seismic modification techniques. Since time management, determine the process in the relief and rescue Emergency Incident, Fragility curves can be a useful tool to estimate the amount of damage to substation and to determine the requirements of a post after damage. Development of fragility curves can be used to assess the seismic vulnerability substation injury scenario to provide better guidance for operational teams in emergency cases. Also these curves can use to order the parts and equipment in the manufacturing sector. That is the appropriate parameters to verify the quality and acceptance criteria of specified equipment.

Theory of fragility curves: Fragility curves Indicates the conditional probability of reaching or passing of a damage index against the Ground motion intensity. In order to express the damage of structural or non-structural vulnerability of the various components in terms of earthquake risk probability of passing of certain in terms of a known earthquake characteristics such as PGA, PGV, PGD can be expressed. Repeat this function for different values of PGA with another single-parameter to produce a normal curve called fragility curves. Fragility curve can be defined both as a component or set of components and system. Fragility curve can use to compare different techniques for correcting seismic and seismic design of structures and improvements. In general, the vulnerability curves of equation-1 can be represented[2,5].

Figure-2
Photos of 230 kV Post

Figure-3
Damage to high voltage equipment in Caopo Power Plant in the 2008 Wenchuan, China earthquake (China Earthquake Administration, 2008)[4]

$$F_i(im) = P(D \geq d_i | IM = im) \quad (1)$$

In this formula Fi (im) is the possibility of reaching or passing damage (D), of the damage index (di) in the intensity ground motion (IM) expresses. In the basic theory of reliability, vulnerability only probabilistic cumulative distribution function (CDF) is to work, to determine the function of only two parameters, the mean and the standard deviation is required. A vulnerability curve according to equation-2 has the analytical form[6]:

$$P_f = \Phi\left[\frac{Ln(a/M)}{\beta}\right] \quad (2)$$

This formula P_f is potential vulnerability, ø is the standard normal cumulative distribution function (Gaussian), a maximum ground acceleration given (PGA), M is Average of accelerations, ß is the logarithmic standard deviation. You can replace whit maximum ground acceleration (PGA) of peak ground velocity (PGV) and spectral displacement (SD).

Log-normal distribution: If the function y as a function of the variable x: logarithm Y = Ln (x), then we say that the variable x has a normal distribution. Probability density function of a normally distributed variable is defined in equation-3:

$$f(x) = \frac{e^{-((\ln(x-\theta))/m)^2 i(2\sigma^2)}}{(x-\theta)\sigma\sqrt{2\pi}} \qquad x \geq \theta, m, \sigma > 0 \quad (3)$$

In this formula σ is the shape parameter, and Y is the location parameter, m is the magnification parameter, When m=1 andY=0 the standard logarithmic distribution is called. When Y=0 it is called two-parameter logarithmic normal distribution. Standard logarithmic distribution function is defined as a relation-4:

$$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} \; e^{-((\ln(x-\theta))/m)^2 i(2\sigma^2)} \qquad x^3\theta, m, \sigma > 0 \quad (4)$$

Since the general form of probability functions can be expressed in terms of standard distribution sentences, formulas are given for the standard form. In previous figure, for four values of the probability density function in the form of a log-normal distribution is plotted. There are several typical parameters for a normal distribution, the form of which was used in this study, is given below. The basic theory of reliability, vulnerability, only the cumulative probability function (CDF) is to work.

Cumulative distribution function: Formulation of the cumulative distribution function of the normal distribution logarithmic is equation-5.

$$f(x) = \Phi\left(\frac{1n(x)}{\sigma}\right) \qquad x \geq \theta \ , \ \sigma > 0 \quad (5)$$

In this formula ø is the cumulative distribution function of the normal distribution. In the figure below, the log-normal cumulative distribution function similar **σ** values, as in figure 4 was used, is drawn.

Logarithmic normal distributions (two parameters) have at least three fundamental roles in human and ecological risk assessments: First, many of the functions of the physical, chemical, biological and statistical are tended to generate random variables that follow a normal logarithmic distribution. First, many of the functions of the physical, chemical, biological and statistical are tended to generate random variables that follow a normal logarithmic distribution. Next when the conditions of the central limit theory is obtained Mathematical methods for multiplying a series of random variables, will create a new random variable (product), regardless the distribution of input variables. The tendency (in effect limit applies) having a logarithmic characteristic is normal. Third, the normal distributions are able to be reproduced using multiplication and division. It is most reasonable that the resulted error will consider as independent small errors. It can be used with the central limit theory. This theory states that the distribution of a large number of independent random variables follows approximately a normal distribution.

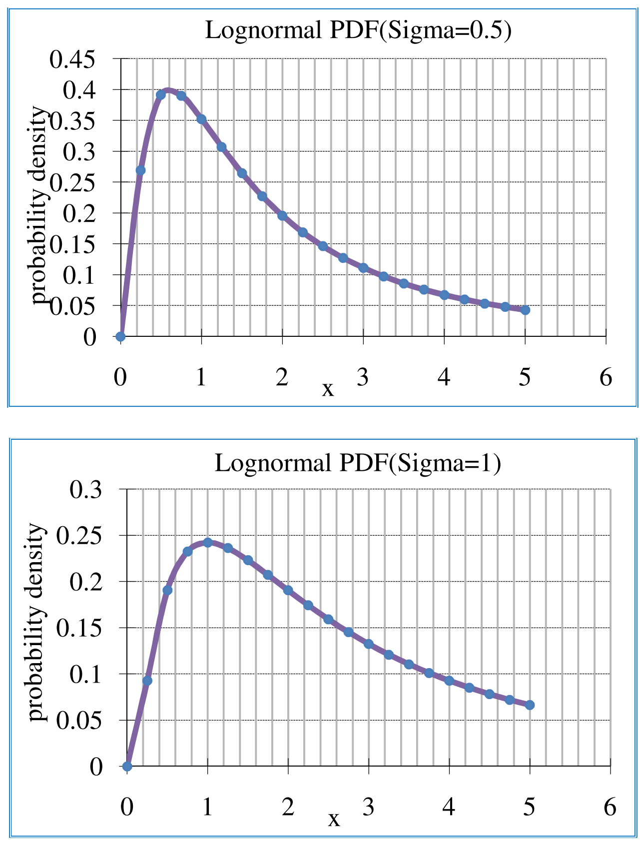
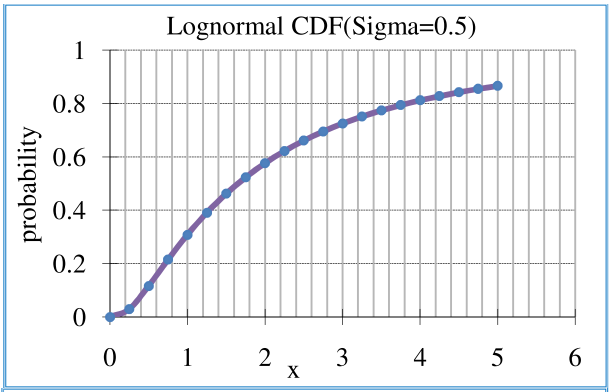


Figure-4
Probability density functions of the log-normal distribution for the four mean values of 0.5, 1



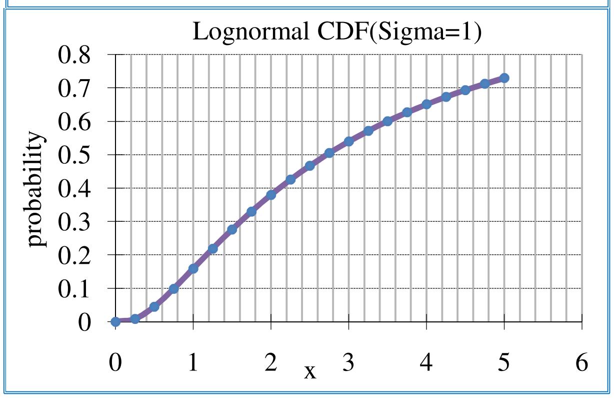


Figure-5
Log-normal cumulative distribution functions for four mean values of 0.5, 1

Modeling and Seismic Analysis: The circuit breaker can be mounted on the various types of structures, and various bases will have different effects. This section examines the seismic behavior of circuit breaker singular and without regard to base effects. Materials used in the construction of this equipment are Ceramics and composite that ceramic part is for its insulating and flanges are made of aluminum. Geometrical characteristics and material properties are listed in the following tables.The circuit breaker in this study is producing in Iran Switch Company, and structural detail that used are according to companies detail[2,7,8].

Table-1
Materials and Height of the Equipment Components

Part Name	Material	Height (mm)
Bot Porcelain	Ceramic	1320
Top Porcelain	Ceramic	2403
Flanges (Bot and Top)	Aluminum	variable

Table-2
Materials Properties[2, 7]

Material	Young Modulus $(\frac{N}{mm^2})$	Poisson's Ratio	Density $(\frac{tonne}{mm^3})$
Aluminum	72400	0.24	2.0 E -9
Porcelain	70000	0.23	2.65 E -9

In this section, the fragility curves based on the description given in the previous section are given. Fragility curves obtained in this study are based on time history analysis. The process of doing so is that: after modeling, analysis was performed by finite element method. Then using the results of FEM analysis fragility curves were drawn.

Modal Analysis: Before performing dynamic time history analysis, modal analysis method was used to compare the results with values in the literature and should be verified. The modal analysis results are given in the following table**.** This result verified by literature review in reference-2.

Table-3
Modal analysis results

Modal analysis (Frequency)			
Mode -1	Mode -2	Mode -3	Mode -4
9.05	9.11	68.5	68.6

Records used in the analysis: In the following table, the used records in the time history analysis are given. As it can be seen, in some cases there is a record of an earthquake or two. There records are two components and then the records number are 35 and generally there are 70 time history of acceleration that used after correction in the analysis.

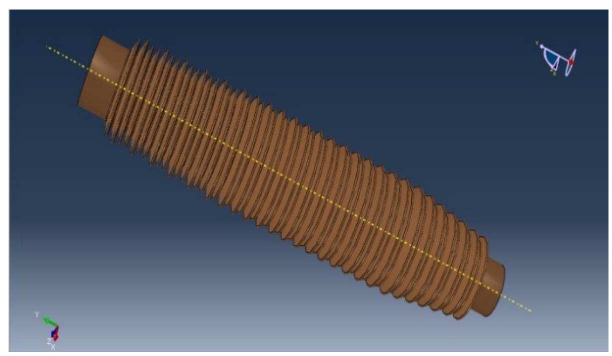


Figure-6
Geometry of Top Porcelain (Left is from Modeling and right is from Company)

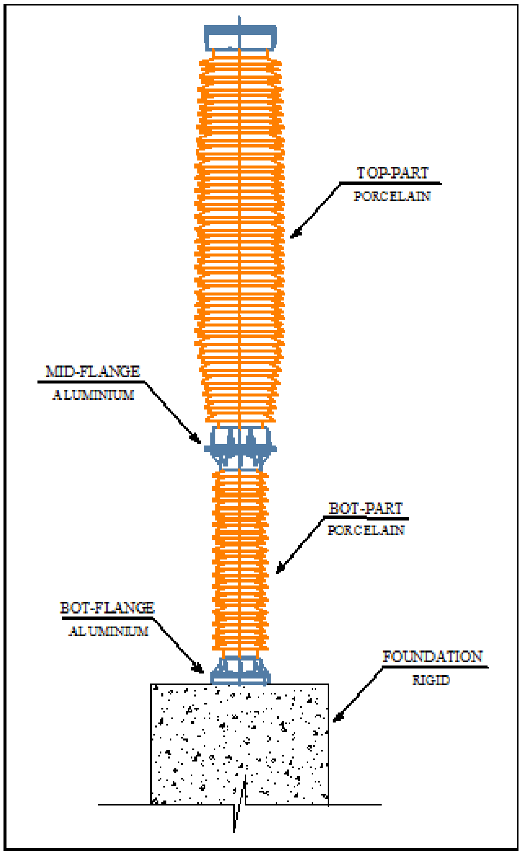


Figure-7
Geometry of Circuit Breaker Mounted on Rigid Base

Fragility Curves for Circuit Breaker (CB): Failure Modes in the first case, damage of the equipment, are described as the ceramic cracking or failure of the ceramic units due to a high stress. According to the experiences of past earthquakes, a ceramic unit can be broken into two modes as follows: tensile failure, compressive failure[9,10].

Due to axial force or bending moment stresses in ceramic or combined effect of greater tolerance values and ultimately lead to failure. Ceramic composition and structure of each manufacturer is different and therefore the resistance will vary. However, resistance of insulators and bushings are strongly influenced by the type of the end connections. End connection that is designed improperly can actually create stress concentrations in a narrow band or in a spot, reduce insulation resistance. It should also be noted that the stress concentration in a narrow band or in a spot, reduces the resistance of insulators. It should also be noted that the ceramic materials resistant to stretching are several degrees of pressure. Some studies based on several catalogs and guide the company's Japanese Electric Factory JEAG-5003 (1999) authorized the tensile and compressive stresses, respectively 40 Mpa, 24 MP Compressive stress on the contact surface between cross are a function of ceramics and anchor flange . Due to the limitations in different editions to determine the allowable stress suppose 40Mpa in this study.

Accordance to the regulations of the 1984 edition of IEEE, the maximum allowable stress for a cross made of porcelain can be between 25 to 50 % of its maximum tension. Accordance to the regulations of the 1997 and 2005 edition of IEEE, the maximum allowable stress for porcelain can be 50 % of its maximum tension .in this study the fragility curves derived from the 25% strength ceramic and other members of number 40 Mpa is used. In the second case, yielding of aluminum flanges has been considered. Allowable stress considered for of aluminum is 100Mpa[2,10].

Fragility curves for each case are given below. As can be seen in the following figures, probability of failure of bottom porcelain is most. After it, after that, bottom flange is in second place. Top porcelain and middle flange are in 3th and 4th place, respectively.

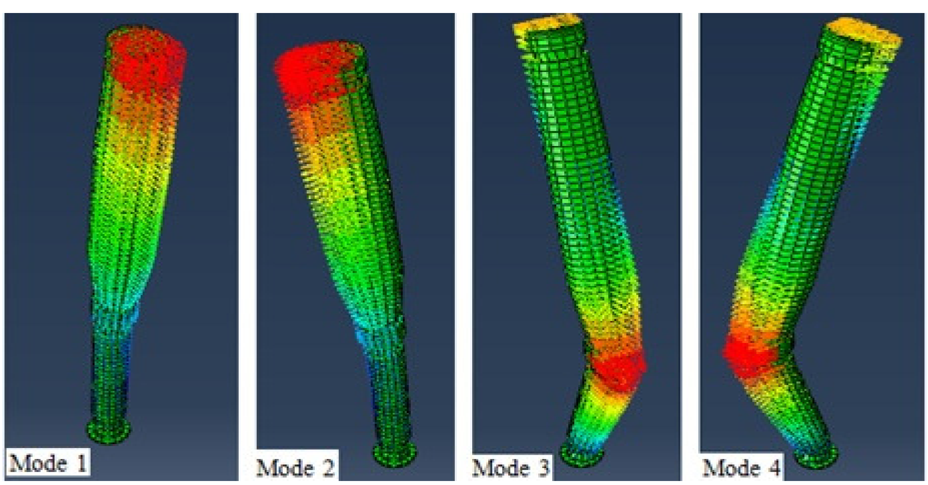


Figure-8
Mode Shapes
Table-4

List of record used in the dynamic analysis

	No Event	Year	Station	M	Distance (km)	Vs30 (m/s)
1	Bandar-e-Abbas	1975	Bandar-e-Abbas	6.1	36	**337**
			Boshrooyeh	7.4	55	**564**
2	Tabas	1978	Tabas	7.4	54	**645**
3	Tularud (Gilan)	1978	Talesh	6	15	**539**
4	Qaen(Khorasan(south))	1979	Khezri	7.1	75	**701**
			Gonabad	7.1	93	**529**
5	Golbaft	1981	Golbaf	7	13	**365**
			Qazvin	7.4	94	**456**
6	Manjil-roodbar	1990	Abhar	7.4	101	**291**
			Ab-bar	7.4	41	**291**
7	Eslamabad(Ardebil)	1997	Kariq	6	48	**589**
8	Avaj	2002	Kaboodar Ahang	6.5	62	**613**
			Razan	6.5	35	**314**
9	Kajoor,Firooz abad	2004	Hasan Keyf	6.3	42	**339**
			Moalem Kelayeh	6.3	99	**490**
10	Enchehborun	2005	Agh Gala	6.1	14	**341**
11	Zarand	2005	Zarand	6.4	16	**226**
12	ERZURUM	1983	Meteoroloji İstasyon	6.6	65	**316**
13	ADANA	1998	Tarım Ice	6.2	48	**263**
			Meteoroloji İstasyon	6.2	65	**366**
14	KOCAELI	1999	Devlet Hastanesi	7.4	81	**348**
			Meteoroloji İstasyon Merkezi	7.4	101	**282**
			Marmara Araştırma Merkezi	7.4	43	**701**
15	DUZCE	1999	Bayındırlık ve İskan	7.1	36	**294**
16	BINGOL	2003	Bayindirlik ve iskan Mudurlugu	6.3	12	**529**
			Beverly Hills	6.7	13	**356**
17	Northridge	1994	Canyon country - WLost cany	6.7	27	**309**
18	Friuli	1976	Tolmezzo	6.5	20	**425**
19	San Fernando	1971	La-Holly wood Stror FF	6.6	40	**316**
20	Imperial Valley	1979	Delta	6.5	34	**275**
21	Landers	1992	Yermo Fire Station	7.3	86	**354**
22	Loma Prieta	1989	Hollister City Hall Annex	6.9	47	**199**
23	New Zealand	2010	Heathcote Valley Primary Schoo	7.0	43	**299**
24	Chi-Chi	1999	Chi-Chi-CHY101	7.6	32	**259**
			Chi-Chi-TCU045	7.6	76	**701**

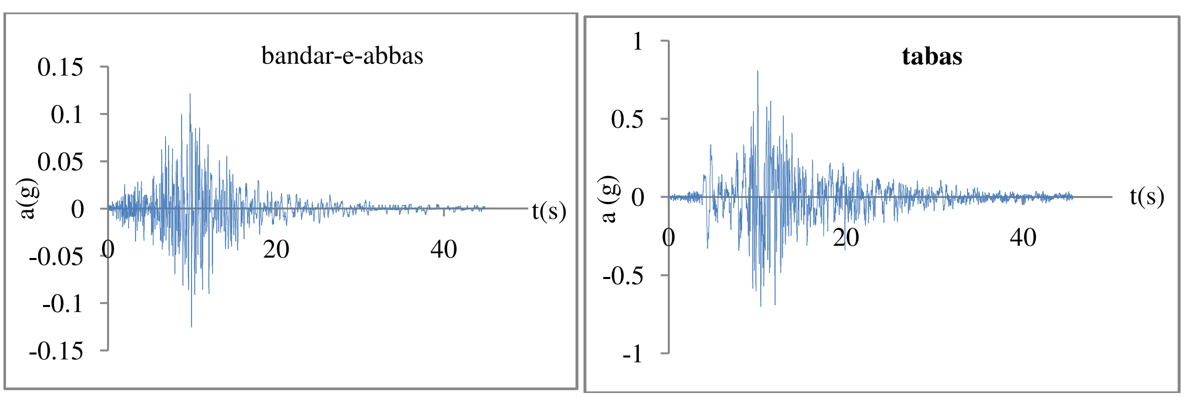


Figure-9
SomeAcceleration Time History Used in Analysis

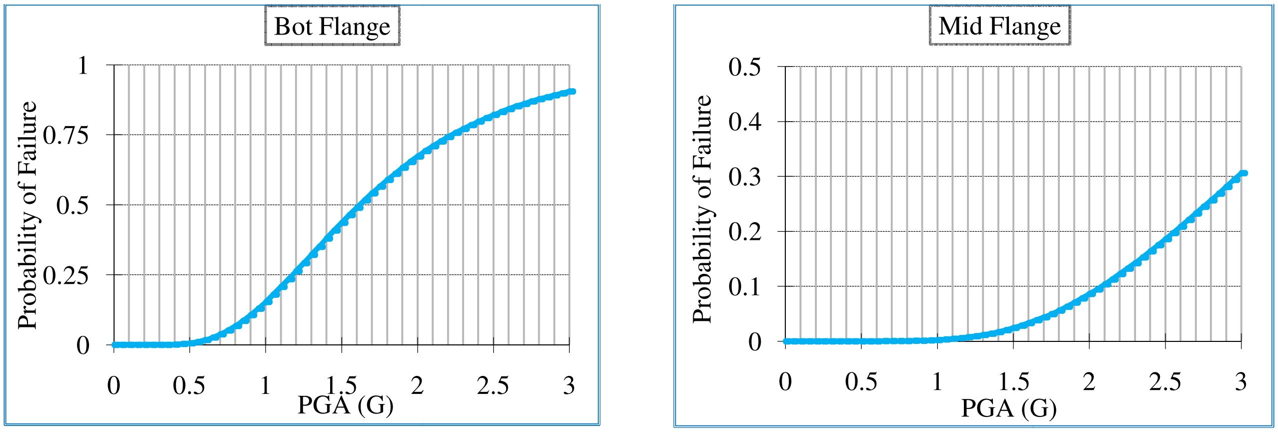


Figure-10
Fragility Curve for Bot Flange and Top Flange

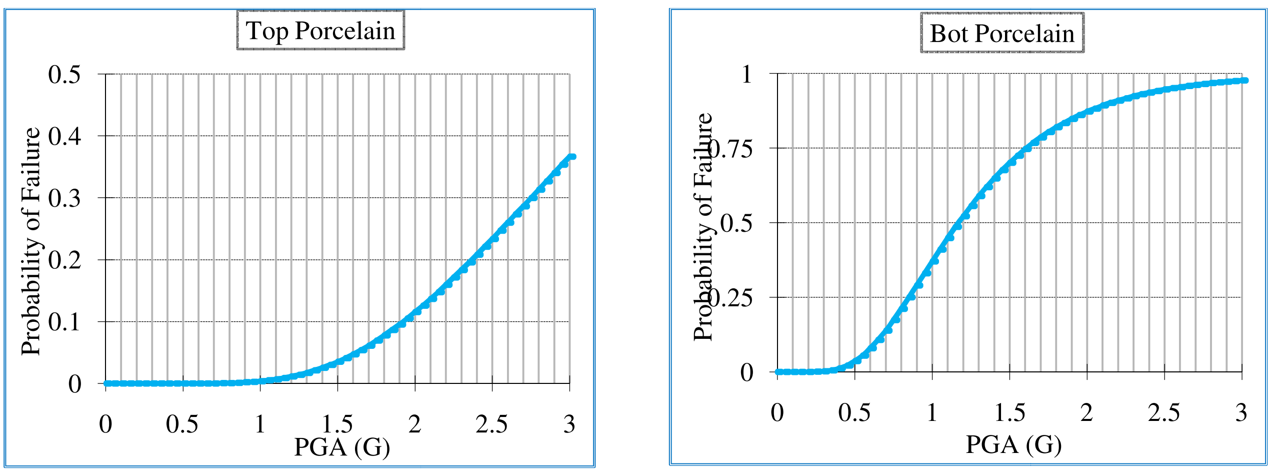


Figure-11
Fragility Curve for Top Porcelain and Bot Porcelain

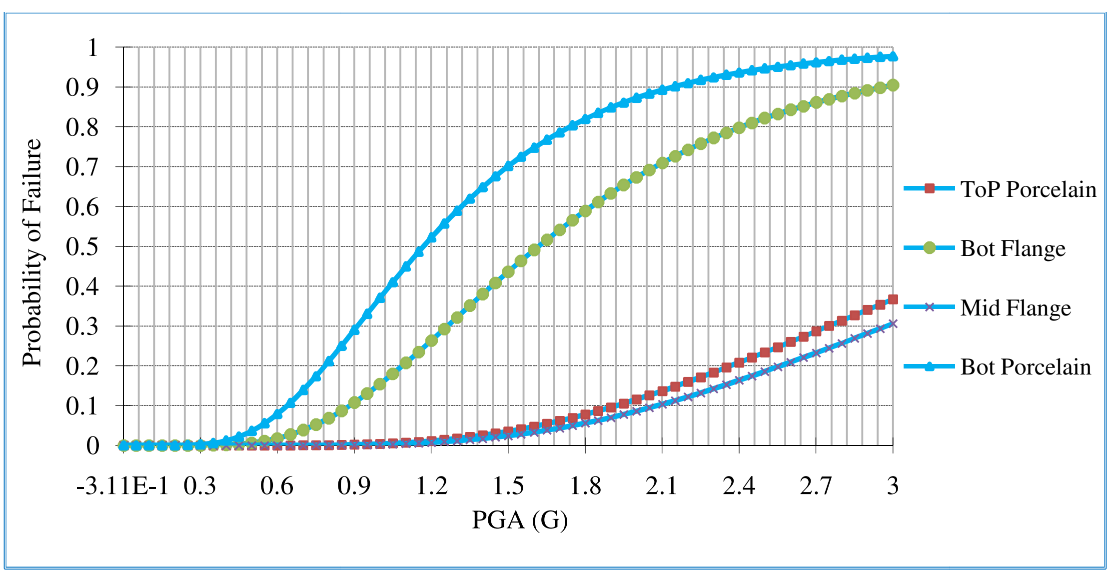


Figure-12
All Fragility Curves in One View

Conclusion

Since circuit breaker (CB) is widely used in power station, in this paper seismic behavior of it was discussed. Because of the effect of the various bases on the seismic performance of CB, The basic effect is not considered here and CB considered singular. Geometry of CB was modeled and dynamic analysis was done, after this, fragility curves were drowned. As seen figure-11, the Product has high reliability in earthquake and in PGA=1g, Probability of failure is about 0.3. Among any part of circuit breaker, bot porcelain has most failure probability and mid flange has least.

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