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The Quantitative Evaluation of CB-S9222 Power Transmission Substations during Earthquake

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ABSTRACT: The quantitative evaluation of CB-S9222, ASEA made, power transmission substation which are vital phenomena during earthquake is being discussed in this article. The procedure is extracted from IEEE-Std 97. Here all the effort is applied to observe the regulations in accordance with safety coefficients of the design. For simulation Sap 2000 software is used based on spectrum modal analysis. This spectrum is specified for the location of the power substation for two periods of 475 & 2475 years. Acceptance criteria is deduce from AISC-ASD. The conducted control on foundation evaluation consist of: the soil pressure control, overturning moment control, anchor bolt control, individual pad and pedestal control. The article is concluded by introduction of the separate evaluation conducted on foundation condition, anchors, porcelain and steel support plate.

1. INTRODUCTION

The power industry is one of the most sensitive, strategic and fundamental industries. It not only provides for residential electric energy consumption but also the energy needed for industrial activities in a vast range.

The seismic vulnerability assessment of the Power Transmission Substations is important since it contributes to the social, economical and even political activities, when in good performance, as a lifeline. Any disturbance in this performance can lead to serious damages in the future such as fire, communications cut-off, explosion and even the spread of contagious disease. Undistributed electrical power for the performance of rescue and relief activities is a must when an earthquake occurs, even after the disaster. Therefore a multilateral attention should be directed towards improved seismic security, an inevitable necessary. In this respect the identity and recognition and the functionality of such structures is a must for provision of proper design for their seismic rehabilitation. Therefore the whole power network and its facilities must be designed in a manner by which any power disturbance during rescue and relief operations will be prevented, and it would be able to tolerate damage infliction on the network.

In this article, initially the types of inflicted damages on Circuit breaker are being specified and then the function and the type Circuit breaker are introduced. The seismic evaluation of these facilities is expressed with a qualitative assessment as an outcome in two qualitative and quantitative assessments in detail.

2. EVALUATION THE TYPES OF DAMAGES INFLICTED ON CIRCUIT BREAKER DURING AN EARTHQUAKE

It is obvious that the rate of damage on these structures has to do with distance between their location and the epicenter of the earthquake, other tectonic factors and the resistance of the structure itself. The seismic investigation in the past revealed that the observed damages on Circuit breaker and Sectioneers are more compared to other facilities. It should be added that, the seismic vulnerability of different Circuit breaker depends on the voltage, the manufacture and site location which are not the same among them.

The important factors that influence the damage on circuit breaker due to earthquake:
-The strength of the structural complex and equipment and its specific spectral limitations with respect to seismic energy release tolerance
-The tectonic state and the seismic activity of the region
-Lack or non proper anchorage of the equipment
-Interacting with adjacent equipments, due to lack of proper setting or looseness in the joints
-The soil condition of the site

The past records indicate that the inflicted damage on these equipments had a direct relation with the operational voltage capacity. The damage rate on the Circuit breaker in 400 KV section is greater the 230 and 132KV section. Lack anchorage and non proper installation of the same have contributed to most of damages in Circuit breaker which lead to the extra movement of the equipment or even their failure. Lack of flexibility and looseness of connections in Circuit breakers may cause fracture in conductor's joints or the porcelain. Moreover, lack of anchorage brings about load strokes that may cause porcelain breakage.

Here, the authors refer to anchorage as the provider of the force path from the equipment to the foundation where the strength of the holding structure, the state and the specifications of the equipment close to the anchorage, strength of anchor bars and joints should be respected. On the other hand, the ductile anchorage of the equipment allows for more displacement, something that in turn leads to more displacement of the upper conductor of Circuit breaker and its interaction with the neighboring equipments.

As one of the other damages inflicted on Circuit breaker is the breakage of the bracing rods that displaces the Circuit breaker due to intense jolts of the ground.

Another important issue in the effect rate of the earthquake on the Circuit breaker is their localization. The distance between the equipment effects the weight of the string insulator and the anchor bolts that tolerate the bushings and porcelain and this is of essence in their dynamic interaction. There has been an instance where the string insulators had not enough room for flexibility and have broken from the connecting point.

Non stable soil of the location is another effective factor in Circuit breaker behavior when earthquake occurs. In case the post is located closed to and there exist the possibility of land slide and rock-fall. Non symmetric earth settlement and liquefactions in susceptible soils lead to displacements, hence damage and breakage of the joints. All in all, authors should bear in mind that the qualitative and quantitative aspects of seismicity. Tectonic conditions of the site and the characteristics of the types of seismic activities in the region can affect the quality and quantity of the inflicted damage on Circuit breaker.

The various damage modes are as follow:
-Breakage of porcelain at the lower flange and middle joints and the fall of circuit breaker
-Breakage of crevice of the porcelain at the upper go conductor joint due to the stretch in the Circuit breaker

-Breakage of aluminum clamps at the conductor joints and disconnection of Circuit breaker from other neighboring element
-Rocking movement of Circuit breaker due to interaction of soil-structure that leads to load aggravation and seismic displacement.

3. CIRCUIT BREAKER

The circuit breakers are vital and constant components in any Power Transmission Substations. These components perform the rapid cut and connect function under load. In case of any short circuit and any abnormal flow of the line, the circuit breaker cuts the circuit rapidly. Their malfunction equals a cut in power flow.

The types of circuit breakers consist of full oil, low oil, SF6, aqua switch, pneumatic and flat vacuumed gas bed. In this article the authors emphasis on the low oil type that are made for 765KV with strong high cut ability. The high voltage keys often have consecutive cut-off and their combustion clamber is usually placed in V shaped porcelain. In this type the porcelains are bolted and held next to one other through flanges. Not many records are available on the seismic functionality of this type of circuit breakers, but many of them have resisted tense shocks.

In the low oil switches oil is not used as an insulator among phases or the phase with earth, but only to extinguish the sparks and that is the reason of lower oil capacity in this type. In the new circuit breakers the oil chamber is located at the bottom of the isolator and the function of the structure against earthquake has improved drastically in such a manner that in the last earthquake almost all of this type of circuit breakers were left with no damage and continued their function.

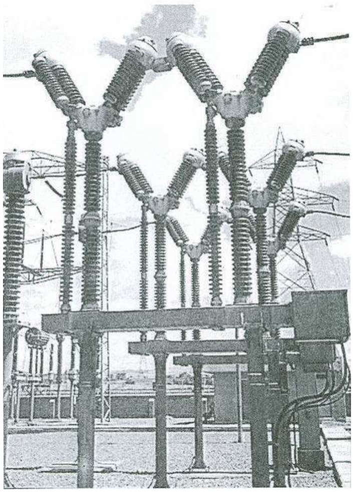

Figure1. Low oil circuit breaker with V shape; Oil chamber on top.

4. THE SEISMIC REHABILITATION METHOD, CIRCUIT BREAKER CB-S9222

In order for us to be able to properly compare the conditions of circuit breaker type CB-S9222 with ideal status and to give suggestions, qualitative and quantitative studies and evaluation were conducted.

4.1 Qualitative study and evaluation of circuit breaker

In this process two aspects are of our concern. First, the performance quality and exploitation in existing conditions is reviewed in order to illustrate the circumstance and quality of the circuit breakers (i.e. Concrete quality, proper tightness of the nuts, etc.). In addition, what kinds of damages have been inflicted on them up to now (i.e. Deformations, corrosion of the metal members, and concrete corrosion due to different factors). Second, it was also checked whether different sections have been implemented in accordance with the drawing. This measure contributed to the comparison of exiting and ideal condition. After the assessment of the circuit breaker behavior during the last seismic activities in the past the following were checked as well:

- Higher elevation of the core
- Interaction with the neighboring element
- The slender of porcelain
- The looseness of the conductor
- Lack of strength in the base
- No proper foundation
- No proper anchorage of the equipment to the bottom

In these elements the deficiencies 1 and 3 are clearly observed while any final suggestion about them needs more tests and analysis.

4.2 The quantitative evaluation of the circuit breaker

Here after simulation of the structure and the elements in SAP2000 program based on the selected rehabilitation objective and the function level according to regional conditions and different loadings the critical conditions were determined and enforced on different sections. In this process, the weld quality, member section, plate dimensions, number and diameter of the bolts etc. are controlled to see whether they fit the existing conditions. The general seismic evaluation procedures including required function level, seismic analysis method for the structure and the acceptance criteria will be discussed in due course.

4.2.1 General specification of circuit breaker CB-s9222

This type of circuit breaker is manufacture by ASEA with the following specifications:

Voltage	400 KV
Height	6 m
Weight	1323 daN
Foot height	2.5 m
Foot weight	285 daN

Figure 2 shows that the oil chamber of this element on the top of the isolator as a central core.

Figure2. A general view of a CB-S9222.

4.2.2 The acceptable criteria method and the analytic method

Authors have followed the IEEE-Std 97 procedures and have tried to observe the requirements with respect to the design safety coefficients. Here due to the complexity the structure and existing different modes is the seismic limitation, finite element method became necessary in order to compute the forth coming modes effect and accurately and the (qualification method) IEEE-Std 97 is enforced. The damping coefficient equal 2% was assumed and the modal stresses were combined with the SRSS method. The required spectrum for the analysis is the spectrum of risk analysis study for two risk levels of 475 years and 2475 years. These spectrums are the non-reduced design spectra with the damping coefficient of 2%. The significance coefficient for the assigned structure is 1.4 accordance with the Iranian code (2800, third edition).

For the functional level the acceptance criteria is as follow:

-For steel element: internal stresses due to the spectra in half in the steel members should not exceed the allowable stresses AISC-ASD code, plus 33% allowable stress increase due to extra ordinary loading.
-For the breakable elements (porcelain): the internal stresses due to the spectra in half in the porcelain should not exceed the half of final stress.
-For the connecting elements (nuts, bolts, welds): the internal stresses due to the spectra in half should not exceed the allowable stress indicated in AISC-ASD code. Increasing the allowable stresses on connecting element in extra ordinary loading condition is prohibited.
-Stresses due to load without coefficient in the sub base soil should not exceed the allowable soil stresses.
-Stresses due to load with coefficient in the sub base soil should not exceed the final concrete strength in accordance Iranian concrete code (ABA).

4.2.3 Equipment modeling

SAP 2000 version 10 program is used for this simulation. In simulating the porcelain is modeled as a shell. The weight of the porcelain and the oil is assigned totally to the shell in a manner that the distribution mass does not change in height.

According to the available drawings the base cross section of the equipment is box 200×200×10 and the material is ST-37 with the 240 MPa yield stress and ultimate stress is 370 MPa.

The thickness of porcelain is 20 mm and the porcelain is modeled as a shell element with inner diameter, 230 mm and outer diameter, 250 mm. According to the IEEE the lowest suggested strength of porcelain is 50 MPa which is observed here, a regular strength (C110) Unglazed. Other specifications of porcelain correspond of IEEE code.

In case the computed safety coefficient is close to one, no final determination is given regarding the seismic function of the element. The further the safety coefficient from one, the safer the function of the structure. The other conditions are enforced on the limiting element of the structure according to the real model.

4.2.4 Foundation evaluation

The foundation of this equipment is a pad, 1400×1400×500 mm and a pedestal, 1100×1100×1500 mm. the concrete strength is assumed to be 21 MPa.

4.2.4.1 Evaluation of soil stresses

According to geotechnical studies conducted on the soil, the allowable stress of soil is 0.185 MPa, with no cohesion, 28.5 angle of internal friction and specific gravity of $1.86 t/m^3$. In controlling the exerted stresses on the soil, the seismic intensity in the main X and Y direction consist of 45 degree. The exerted stresses on the soil at the risk level of 475 years is less than the allowable soil stresses, while at the risk level of 2475 years it is more than allowable value.

4.2.4.2 Overturning stability control

In the computing the overturning moment, the uplift effect of seismic power is on the structure is accounted as well as the resisting moment due to soil surrounding the pedestal and soil pressure (passive). Here the safety coefficient for the sustainability of the structure with respect to overturning is 1.75. The value of this coefficient at 475 years risk level is 2.32 and at 2475 years level risk is 1.78.

4.2.4.3 Anchor bolt control

Here the tension stress established in anchor bolt rods their anchor bolt length is controlled. For stress control the shear stress, tension stress (with respect to the reduced tension capacity due to the tension & shear interaction) have been evaluated and the safety coefficient of the anchor bolt rod design is obtained.

The rod length control is in accordance with the chapter eighteen of Iran concrete code. In each footing four M20 anchor bolt rod is used. The anchor bolt rods, at both risk level do not compensate for inflected stresses but the hold tight to the concrete base.

4.2.4.4 The pad control

In pad control, the final bending moment at critical point of the footing is conducted for the most critical loading condition (*1.2D+EQH+EQV*). One way shear and punch shear control are conducted according to chapter seventeen of Iran concrete code and safety coefficient design. The pad strength is fit against inflicted stresses at both the risk levels.

4.2.4.5 Pedestal control

To evaluate the pedestal, the shear stress interaction and bending are controlled by short column regulation of Iran concrete code. The pedestal strength against the influence of bending stress at both the levels of risk is sufficient.

4.2.5 Element footing evaluation

Here the following have been controlled:
- Interaction axial strength with the moment bending at the beam elements.
- Compress or tension stress at braces elements.
- Bearing stress at bolted joints.
- Footing welded joints.
- Extreme stress in porcelain.
- Evaluating the extreme displacement at the joining point of equipment to the upper conductor.

In all of the above cases the stresses have been obtained from the combination of the most critical conditions. For example , for the control of the interaction stress ad bending on the bars around the footing , the load combination of *D+EQH+EQV* that are the most critical were obtained; for the control of welded joints the load combination of *D+EQH-EQV* are used that create the highest shear stress at the corner weld.

EQH is the horizontal component of the seismic force in the direction where the most stress is created in the considered member and *EQV* is the vertical component of the seismic force.

Figure3. The 3D model of the equipment in SAP2000.

5. CONCLUSIONS

A-The foundation condition

The load bearing capacity of the soil at the second risk level (2475 year) is not sufficient.

B- Anchor bolt

The safety coefficient of the structure sustainability for both the safe levels are adequate the anchor bolt rods can not compost stress the inflicted stresses at both the levels but have sufficient cohesion to the concrete base.

C- The pad

The pad strength is adequate for the inflicted loads. The pedestal against the capacity of compressed and bending stress at the both risk levels is sufficient.

D- Porcelain

Porcelain with the assumed strength can not compensate for either of the risk levels on the structure.

E- The equipment base

The holding column strength at the both risk levels is evaluated. The footing joint do not compensate for the needs of the structure at 2475 year level.

Table1. The briefed results at 475 years

component	Moment, shear, torsion, tension, combination, etc.	Calculated value (f)	Allowable value (F)	F/f	
Pier section	Compression & Bending Ratio	0.94	1.33	1.4	OK
Pier section	Tensile Stress	0.00	1.33	----	OK
Connection Bolts (Equipment to Support)	Tensile & Shear Stress	0.28	1.33	3.6	OK
Connection Bolts (Equipment to Support)	Shear Stress	0.08	1.33	13	OK
Weld (Pier to Base Plate)	Tensile Stress	0.91	1	1.1	OK
Weld (Pier to Base Plate) plate	Critical Stress	0.91	1	1.1	OK
Porcelain(MPa)	Critical Stress	60	50	0.8	NG
Top Displacement(mm)	Max Lateral Displacement	300	-----		

Table 2. The briefed results at 2475 years

component	Moment, shear, torsion, tension, combination, etc.	Calculated value (f)	Allowable value (F)	F/f	
Pier section	Compression & Bending Ratio	1.30	1.33	1	OK
Pier section	Tensile Stress	0.00	1.33	----	OK
Connection Bolts (Equipment to Support)	Tensile & Shear Stress	0.40	1	2.5	OK
Connection Bolts (Equipment to Support)	Shear Stress	0.12	1	8.3	OK
Weld (Pier to Base Plate)	Tensile Stress	1.30	1	0.8	NG
Weld (Pier to Base Plate) plate	Critical Stress	1.31	1	0.8	NG
Porcelain(MPa)	Critical Stress	85	50	0.6	NG

Top Displacement(mm)	Max Lateral Displacement	400	-------

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