Experience and considerations for substation equipment seismic design
Agenda

- ABB experience of substation equipment seismic design
  - Plants
  - Transformers, bushings, capacitors, reactors
- Circuit Breakers
  - Experience for seismic verification
  - Application of stronger insulators, structures and seismic dampers
  - Composite insulators versus ceramic insulators
- Conclusions
Benmore station, New Zealand HVDC link
Intermountain Power project, Adelanto station
HVDC transformer, flexible bushing attachment
DC filter suspended structure to minimize seismic stresses

Insulator chains are fixing the capacitor stack.
Insulator chains are provided with dampers attached to ground foundation to minimize deflection of capacitor stack
Smoothing reactor provided with two steel bases with seismic damping units in between
First shake table test 1978 on ABB breakers

- 245 kV Oil minimum circuit-breaker type HLR
  - Ceramic insulators

- Customer in Central America
- Tested by ISMES, Bergamo, Italy
- 0.4g horizontal acceleration
- NEMA response spectra (at that time)
- Time history testing satisfying the response spectra
Last test made on ABB 550 kV SF6-gas circuit breaker

- Breaker type HPL 550B2
  - Ceramic insulators

- Customer LADWP

- Tested by University at Buffalo, USA (SEESL)

- Standard IEEE 693 2005

- Tested
  - 0,5g horizontal acceleration
  - 1g for proving 1g performance

- Time history testing satisfying the response spectra

- Movie clip shows 3-axial testing at 0,5g
Last test made on ABB 550 kV SF6-gas circuit breaker

- IEEE 693 2005
- Testing of 1g performance level
ABB 550 kV SF6-gas circuit breaker

- Breaker type HPL 550B2
  - Ceramic insulators
- Customer
  - ENDESA/TRANSELEC
- Tested in Juelich, Germany
- Standard ETG 1020
- Tested
  - 0.5g horizontal acceleration
- Time history testing satisfying the response spectra
Seismic verification

- Analysis
  - Static analysis for simple or rigid equipment
    - For an initial calculation of the breaker
  - Dynamic analysis
    - Time history analysis
      - Non-linear behaviour of for example seismic dampers can be considered
    - Actual recorded accelerogram
    - Artificial accelerogram created from the specified response spectra
      - Response spectra analysis
- Testing
  - On vibration table
**Time history analysis, complicated equipment**

Finite element structure

Seismic dampers

### Required Response Spectrum

- **Without seismic damper**
  - $\zeta = 0.5$ g: $F_1 = 2.20$ Hz, $F_2 = 8.85$ Hz
  - $\zeta = 1.0$ g: $F_1 = 2.17$ Hz, $F_2 = 8.70$ Hz
  - $\zeta = 2.0$ g: $F_1 = 2.10$ Hz, $F_2 = 8.40$ Hz
  - $\zeta = 3.0$ g: $F_1 = 2.05$ Hz, $F_2 = 8.26$ Hz
  - $\zeta = 5.0$ g: $F_1 = 2.00$ Hz, $F_2 = 8.00$ Hz
  - $\zeta = 7.0$ g: $F_1 = 1.95$ Hz, $F_2 = 7.95$ Hz
  - $\zeta = 10.0$ g: $F_1 = 1.87$ Hz, $F_2 = 7.50$ Hz
  - $\zeta = 20.0$ g: $F_1 = 1.70$ Hz, $F_2 = 6.80$ Hz

### With seismic damper

- $F_1 = 0.5$ Hz
- $F_2 = 1.0$ Hz

**Horizontal acceleration**

- With seismic damper: $7.447$ m/s²
- Without seismic damper: $6.29$ m/s²

**Requirement of 0.5g horizontal acceleration**

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Composite insulators

- HPL 550B2
  - High seismic withstand
  - Non-brittle material in insulators
  - Excellent pollution performance
Breakers with composite insulators

- Composite insulators
  - Used up to 1100 kV
  - Seismic withstand
    - 0,3g without seismic dampers
    - > 0,3g equipped with seismic dampers
- Advantages
  - Non-brittle material
  - Standard deviation of material strength much less than for ceramic insulators
  - Better predictability of mechanical strength than for ceramic insulators
  - Robust behaviour under service and seismic condition
Conclusion 1

- **High seismic withstand >0.3g**
  - Standard type breakers are preferred for economic reasons but usually need to be modified.

- **Efficient modifications**
  - **Stronger insulators**
    - Not always sufficient
  - **Seismic dampers**
    - Increased damping of critical damping
      - Minimum response to earthquake
    - Frequency modification
      - Moving out of dangerous response of the earthquake

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**Without seismic damper**
- $\zeta \%, \; F_1 [Hz], \; F_2 [Hz], \; A/g$

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**With seismic damper**
Conclusion 2

- IEEE 693 standard
  - The standard is negative to the use of seismic dampers especially with frequency modification and especially negative to disc washers

- ABB dampers are maintenance free
  - Endurance testing performed
  - Characteristics maintained during entire lifetime of the equipment
  - Service experience with dampers, >7 % damping, since 1978 and improved dampers, >20 % damping, since 1992
Conclusion 3

- IEEE 693 standard
  - 1g performance or "safety factor 2" shall be proven by sine beat testing at 0,5g sine beat wave
    - The response at **low damping** is much more than two – means a too high safety margin and a too expensive product
      - Please note that vibration table at testing might not have a complete stiff behaviour and the natural frequency cannot be kept very accurately - the resonance frequency cannot be kept
      - Please note the most equipment will show increased damping characteristic when the mechanical load is increased and the natural frequency will shift to lower values out of the region of resonance
    - 1g performance shall be proven by 2 x 0,5g time history testing – will give a reliable result of the intended test
Conclusion 4

- Comparison of ETG 1020 (Chilean) and IEEE 693 response spectra

- The IEEE 693 response spectra is a bit more severe than the Chilean response spectra

- For ETG response spectra the cut off frequency is at about 2 Hz while the IEEE 693 cut off frequency is about 1 Hz

- The February Chilean seismic event seems in some locations to have had a bit higher response in the lower frequency range between 1 and 2 Hz
Dynamic Analysis versus Vibration test

- The measured test result at a seismic test has priority and is determining the capability to withstand a seismic event.
- Local yielding of ductile material can be allowed – improved damping of critical damping.
- Local yielding of especially arranged metal member can be allowed.
- The ETG standard limit the utilized stress to 80% of the yield point and is outruling the use of local yielding – more expensive designs.
Conclusion 6

- Mechanical strength of ceramic and composite insulators
  - Ceramic insulators
    - ETG 1020 standard specify testing for determining the average strength – 2 standard deviations.
      - Testing is often made on one batch of manufacturing
      - If testing is made on several batches it is likely that the standard deviation will be larger than on one batch
      - IEC 62155 is considering type testing and sample testing of about one insulator per 100 produced. It is these values which should have the priority for determining strength values of ceramic insulators
  - Composite insulators
    - Has inherent a much lower standard deviation of the mechanical strength, the SML value
    - The mechanical behaviour under seismic condition is more predictive
Conclusion 7

- ETG 1020 standard with respect to load combination
  - For a seismic event we feel that the load combination of IEC 62155 shall be respected
  - Short circuit forces shall not be considered in combination with the seismic event
Conclusion 8

- Influence of surrounding equipment
  - Flexible connections to neighbouring equipment shall be such that they allow for the free vibration of the connected equipment
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