PARIS 2022

KONČAR INSTRUMENT TRANSFORMERS

Study Committee A3

Transmission and Distribution Equipment

Paper 10948_2022

Seismic Performance Of Instrument Tranformers

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Motivation/Aim

- Seismic events are one of the most unpredictable events affecting modern society, including power grid

Three main goals of this paper are:

- To provide a systematic comparison of relevant seismic standards available worldwide
- To provide recommendation on what is the best practice when performing seismic qualification of instrument transformers
- To advocate FEM Analyses as an indispensable and very useful tool for seismic qualification and calculations

Method/Approach

- The paper is based on actual shake table tests performed on two instrument transformers tested according to IEEE 693 (2005 an 2018 versions)
- Both transformers tested with a support structure included
- Associated FEM analyses were conducted on those units
- Results from both shake table tests and FEM analyses are compared and analyzed and recommendations given

Comparison of Relevant standards

IEEE 693

- The most well-rounded and the most demanding is the IEEE 693 (2005 and 2018 versions)
- Covers a wide range of high-voltage equipment, including instrument transformers
- Mostly used in North America; accepted in the entire world

IEC 62271-300

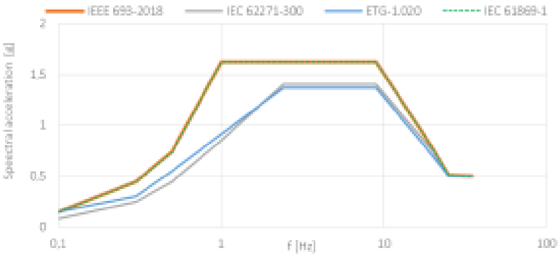
- IEC 62271-300 primarily intended for circuit breakers
- Generally less demanding requirements compared to the IEEE 693
- Mostly used in Europe

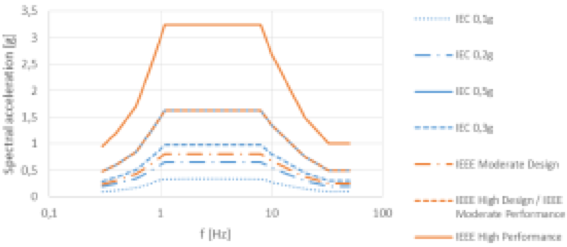
ETGI/ETGA

- ETGI and ETGA are Chilean standards
- Very conservative
- Hard to optimize the components due to the high requirements for both brittle and ductile materials
- Symultaneous use of short circuit force with seismic forces
- IEEE 693 is accepted as equivalent at High Performance Level

IEC 61869-1 (draft 38/652/CD)

- New revision of IEC 61869-1 will contain a specific annex for seismic qualification
- It will use the same RRS as the IEEE for 0,5 g
- Upper right figures show the comparison of IEC vs IEEE





Standard	Qualification level [g]	Acceptance Criterium	Safety factor
IEEE 693-2018	Design Level: 1. Low: ZPA≤0,1 2. Moderate: ZPA=0,3 3. High: ZPA=0,5	Ductile materials: ≤ yield strength/ Ω (AISC 360, ASD) Brittle materials: ≤ 50% breaking strength (SML)	1,67 2,0
	Performance Level: 1. Low: ZPA≤0,1 2. Moderate: ZPA=0,5 3. High: ZPA=1,0	Ductile materials: ≤ yield strength / Ω (AISC 360, ASD) Brittle materials: ≤ 100% breaking strength (SML)	1 1
IEC 62271-300	Low: ZPA≤0,2 Moderate: ZPA=0,3 High: ZPA=0,5	Ductile and Brittle materials: ≤ 100% Yield strength	1
IEC 61869-1 38/652/CD	Very light: ZPA=0,1 Light to medium: ZPA=0,2 Medium to strong ZPA=0,3 Strong to very strong: ZPA=0,5	Ductile materials: ≤ 100% yield strength Brittle materials: ≤ 100% breaking strength	1
ETGA (ETGI) 1-0.20	0,5	Ductile materials: ≤ 80% yield strength Brittle materials: ≤ 50% breaking strength	1,25 2

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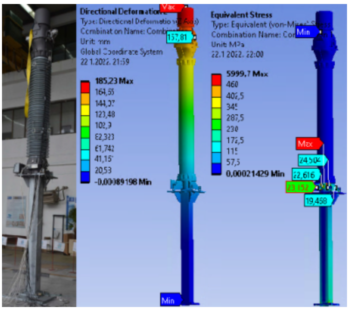
Units considered

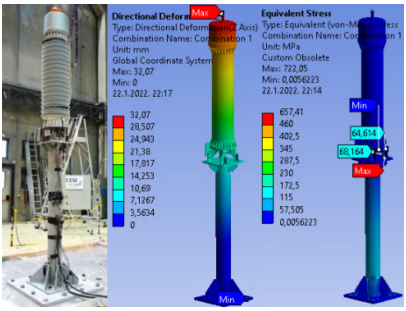
COMBINED UNIT TYPE VAU-245

- Tested according to IEEE 693-2005 version
- Transformer was tested on a bi-axial shake table test in IZIIS (Institute of Earthquake Engineering and Engineering Seismology) in Skopje, Macedonia
- RRS was multiplied with the factor of 1,4 due to the significant coupling and the real ZPA was 0,7 g



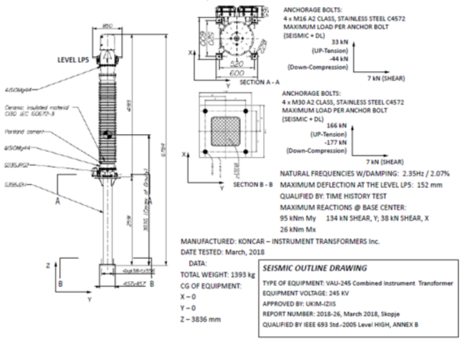
INDUCTIVE VOLTAGE TRANSFORMER TYPE VPU-145

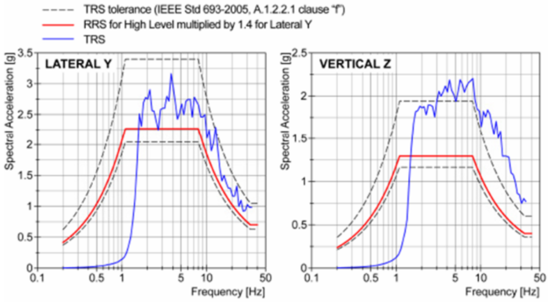
- Tested according to IEEE 693-2018 version
- Transformer was tested on a tri-axial shake table test in CESI (Seismic & Vibration Test Laboratories) in Bergamo, Italy
- ZPA was 1,0 g



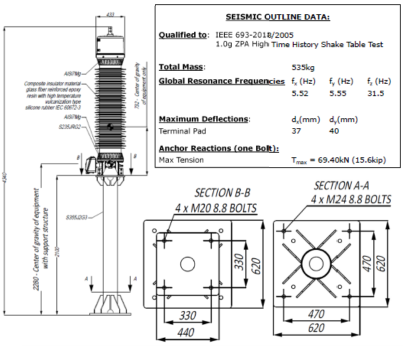
Experimental setup and test results

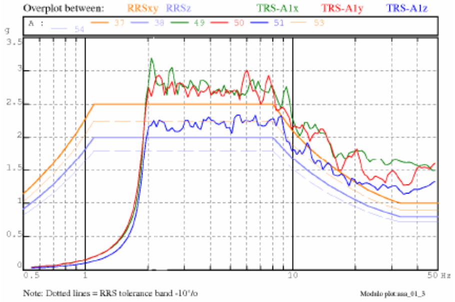
COMBINED UNIT TYPE VAU-245





INDUCTIVE VOLTAGE TRANSFORMER TYPE VPU-145





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Comparison of FEM Analysis to actual tests

- There is a good corelation between shake table test results and associated FEM analyses
- Natural frequencies calculated in FEM analyses are almost identical to shake table test frequencies
- This was a firm confirmation that the model was correctly designed
- Stresses and deflections under 15 % of difference which gives solid ground for design optimization

	VAU-245				VPU-145			
	Natural frequency [Hz]	Base assembly stress [MPa]	Insulator stress [MPa]	Directional deformation [mm]	Natural frequency [Hz]	Base assembly stress [MPa]	Insulator stress [MPa]	Directional deformation [mm]
Shake table test	2,35	21	14,3	152	5,55	74,4	10,93	37
Response Spectrum method	2,27	24	14,8	158	5,61	68,2	9,5	32
Difference [%]	3,5	13,3	3,4	3,9	1	8,7	14	14,5

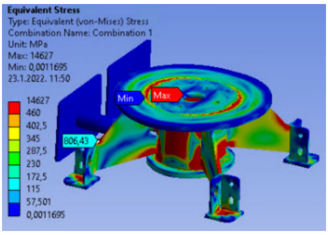
Influence of the support structure

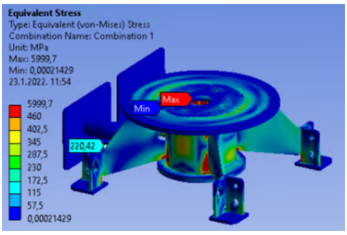
- When tested without support, test and analysis shall be carried out with the multiplication factor of 2,5
- This causes increased stresses in transformer components that are not present in actual operation
- Calculated stress for VAU-245 without a support structure are roughly more than two times higher than ultimate stress and almost four times higher in absolute change.
- VPU due to much lower weight, centre of gravity and a composite insulator has lower but visible increases in stress, especially in the base assembly.

	VAU 245		VPU 145	
	Base assembly stress [MPa]	Insulator stress [MPa]	Base assembly stress [MPa]	Insulator stress [MPa]
FEM with support structure	220	14,8	68,2	7,15
FEM without support structure	806	33,5	118,3	7,7
Increase [%]	266	126	73	7,7

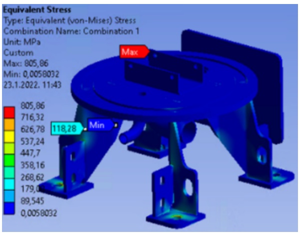
WITHOUT SUPPORT STRUCTURE | **WITH SUPPORT STRUCTURE**

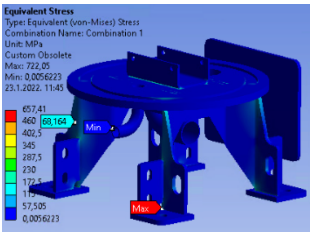
VAU-245





VPU-145





Conclusion

- IEEE 693:2018 is the most well-rounded standard for seismic qualification. Qualifications performed according to that standard should be inherently acceptable for all other standards as well
- FEM analysis can be used as a reliable tool for seismic qualification as well as for design optimization.
- Instrument transformers should always be qualified with support structures included. Otherwise they have to be dimensioned for stresses they will not encounter in actual operation

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