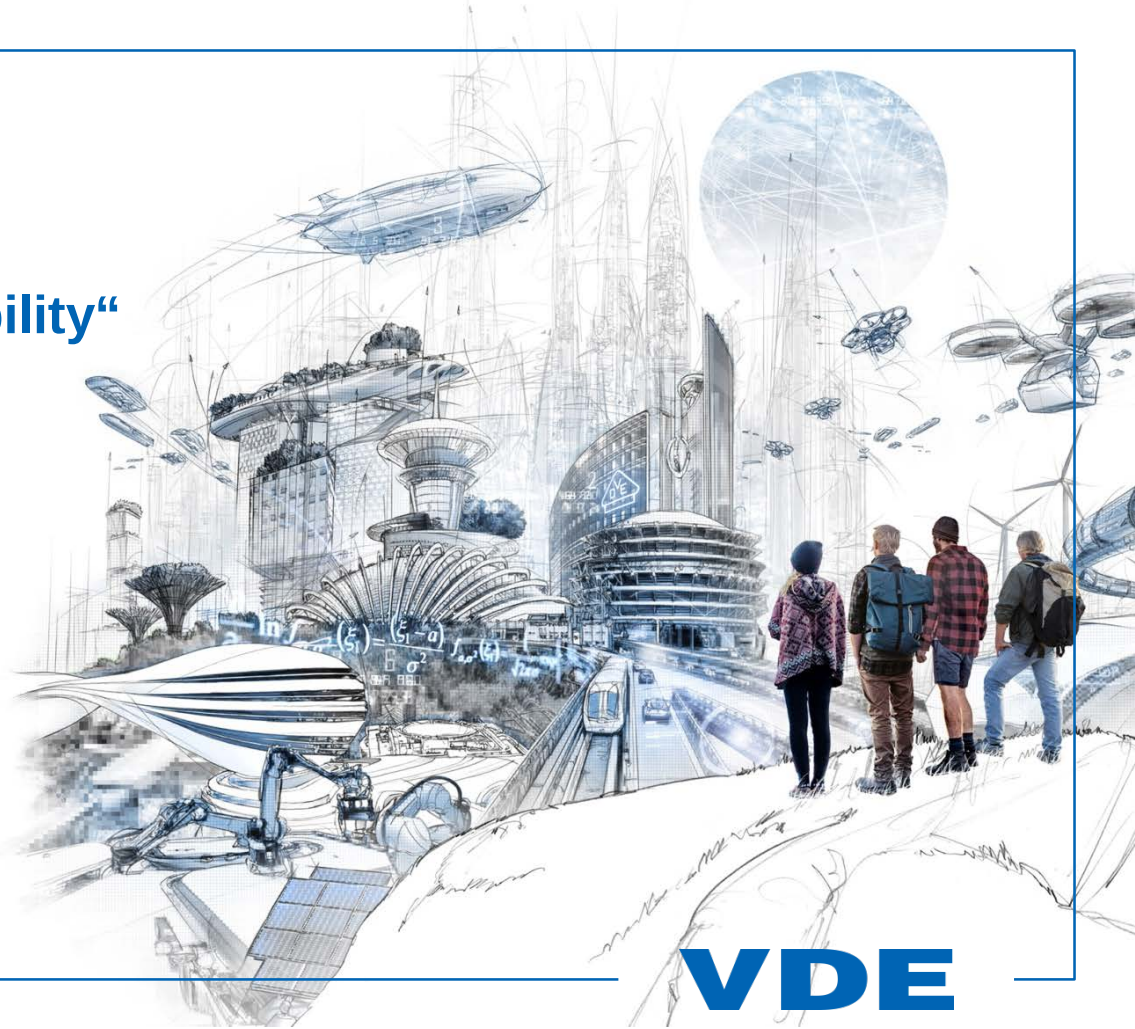
FNN-Study
„Voltage Withstand Capability“

VDE|FNN

09.03.2021

The Study have been conducted by Prof. C. Neumann und Prof. V. Hinrichsen. The study cases and examples have been provided by German TSO‘s, DSO‘s and some manufacturers. The results have been commonly discussed and agreed upon.
https://shop.vde.com/en/dielectric-strength-study-2



Introduction

- The European network codes have been transferred to national regulation VDE-AR and it request temporary operation at voltages exceeding the maximal operating voltage of equipment (Um):
  - 420 kV → 440 kV
  - 245 kV → 253 kV
  - 123 kV → 127 kV
- Applied equipment with U_m = 123/245/420 kV (OHL, AIS, GIS, CB, D, E, CT, VT, Transformer, reactors, surge arresters, cables)
- Nearer considerations of restrictions related to the following aspects are needed
  - insulation ageing
  - functionality

Probable scenarios for power frequency temporary overvoltages > Um

Nr.	Scenario	Probable voltage	Probable occurrence frequency	Probable duration
1	Energisation of long cable sections or overhead lines	up to 440 kV	20 - 100 / year	10 s – 15 min
2	Weak load	some kV above Um	100-300 / year	1-5 h
3	System split	up to 440 kV	1 / 10 years	1 h
4	Outage of generators (active and reactive power)	up to 440 kV	1 / 10 years	1 h
5	Load shedding	up to 440 kV	1 / 10 years	1 h
6	Heavily loaded networks with a high percentage of capacitive compensation	up to 440 kV	1 - 5 / years	1 h
7	Heavily loaded networks with a high percentage of cables	up to 440 kV	1/100 year	1 h
8	Reconfiguration of the network with MSCDN plants or plants that supply capacitive reactive power	up to 440 kV	20 - 100 / year	30 min
9	Load tripping in start-up network	up to 440 kV	1/100 years	30 min

Praxis examples of temporary overvoltages

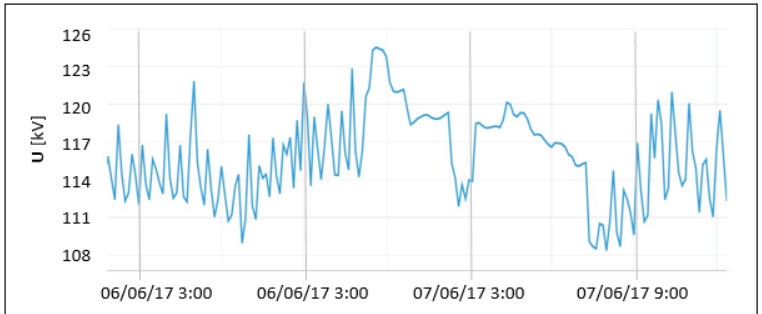
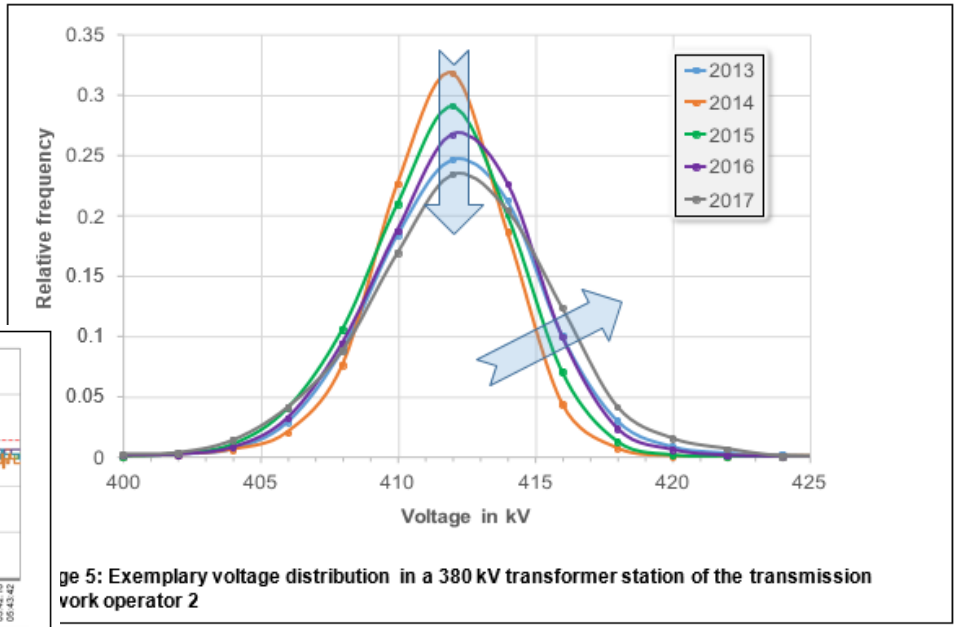


Image 8: Voltage curve in a network node in a primarily urban and rural 110 kV network with intermittent voltage >123 kV



ge 5: Exemplary voltage distribution in a 380 kV transformer station of the transmission vork operator 2

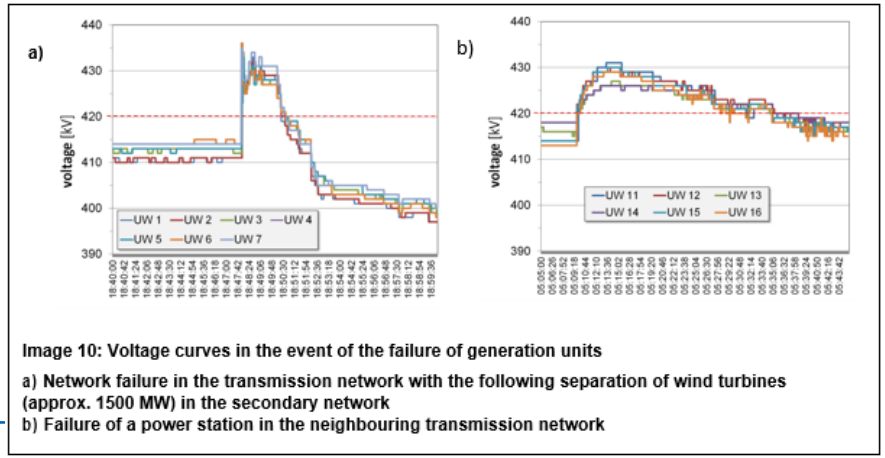


Image 10: Voltage curves in the event of the failure of generation units

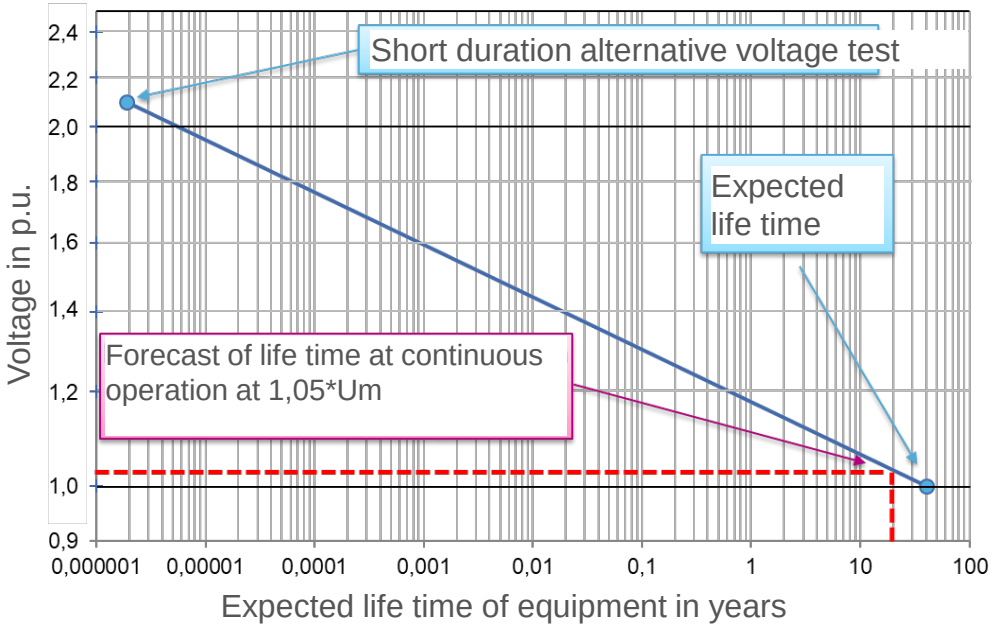
a) Network failure in the transmission network with the following separation of wind turbines (approx. 1500 MW) in the secondary network
b) Failure of a power station in the neighbouring transmission network

Considerations of insulation ageing

- Insulation ageing rule

  $E^N_d * t_d = \text{const.}$

- Continuous operation at 1,05*Um would half the life time expectation of the equipment.
- Short duration overvoltages with magnitude of 1,05*Um have no significant impact on ageing



Study results 1: Effect on ageing of equipment insulation

- The temporary operation with voltage 1,05*Um represents an operation at temporary overvoltage (according to IEC 60071). The latter one is generally allowed, nevertheless it should be restricted in duration and frequency.
- Based on physics and on standards, the **continuous operation** of equipment above Um is not allowed.
  ➔ A continuous stress with 1,05 Um would **significantly reduce** (at latest of 50%) **the life time** of equipment.
- With assumption that considered equipment (eg. 380 kV) will be loaded twice a week for roughly 30 min with a **temporary overvoltage** of 1,05 Um
  ➔ **no significant reduction** of the **insulation life time** is expected.
- The results can be transferred to 220 and 110 kV equipment as well.
- The detailed considerations are presented in the study.

Consideration of equipment functionality (e.g. CB)

With U=1,05*Um, 5% higher currents and 5% higher recovery voltages after short circuit are expected:

- Terminal fault – in the nominal short circuit current range exist typically favourable network conditions (pole factor Kpp< 1,3).
- Short line fault – occurs typically as one phase to ground short-circuit, which is smaller than three-phase short circuit current.
- T10,T30 transferred short-circuit currents – In case of isolated star points of transformers the transient recovery voltage may exceed the range given in standard

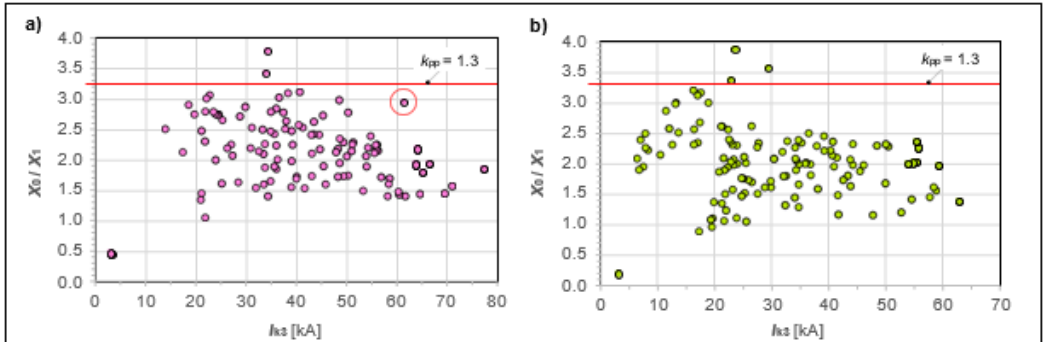


Image 18: Ratio X_0 / X_1 in dependence of the three-pole short-circuit current I_{k3} for the 380 kV and 220 kV network of a transmission network operator not further identified here

a) 380 kV network b) 220 kV network

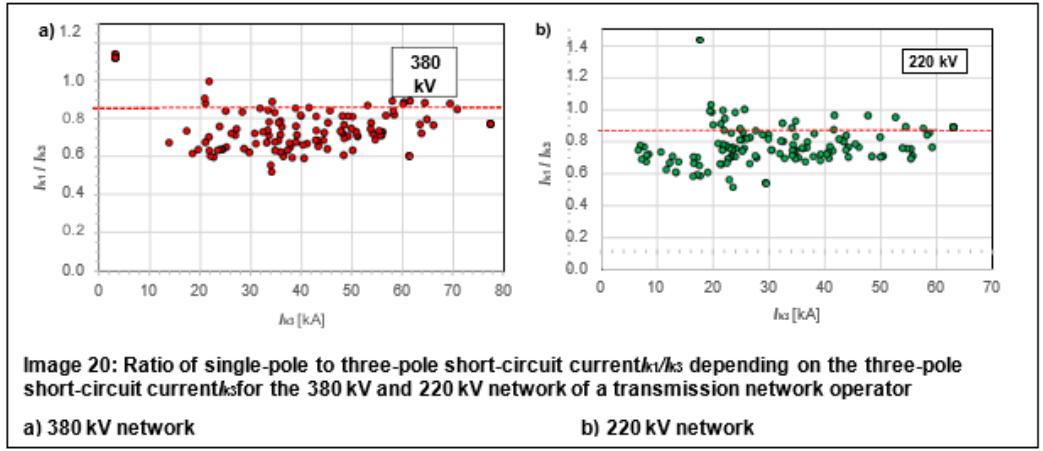


Image 20: Ratio of single-pole to three-pole short-circuit current I_{k1}/I_{k3} depending on the three-pole short-circuit current I_{k3} for the 380 kV and 220 kV network of a transmission network operator

a) 380 kV network b) 220 kV network

Potential restrictions caused by temporary ovevoltages

Equipment	Relevant parameters	Potential functionality restriction in DE	Significant ageing of insulation
Over head lines	Air clearance, dimensioning of components	No	No
Air insulated substations	Air clearance	No	No
Gas insulated substations	Voltage withstand capability	No	No
Circuit breaker	Switching of nominal short circuit currents Switching of capacitive currents Switching of small short circuit inductive currents	Yes Yes Yes	No
Disconnector	Switching of small capacitive currents	GIS Yes AIS No	No
Transduces (voltage and current)	Adequacy and Ferro-resonances	No Yes	No
Surge arrester	Thermal overloading	110 kV Yes 380 kV No	No
Transformers	Mechanical stress by energisation, oversaturation, thermal overloading, noise	Yes	No
Shunt	Mechanical stress by energisation, oversaturation, thermal overloading, noise	Yes	No
Cables	Insulation withstand	No	No

Study results 2: Effect on the equipment functionality

- Temporary overvoltages with 1,05*Um are allowed and equipment can in most of cases cope with this surge.
- The restriction of equipment functionality in most of the cases is not expected
- The operational conditions in real network are in most of cases covered by the considered standards.
- The potential restrictions of equipment functionality are named in the study and potential remedial measures are suggested.
- **The consideration of singular network conditions is necessary!**
  => Responsibility of Transmission System Operator to verify the network condition remains unchanged.