## Study Committee A2

POWER TRANSFORMERS AND REACTORS

10943_2022

# Statistical Analysis and Grouping of Measured Power Transformer Overvoltages

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## Motivation

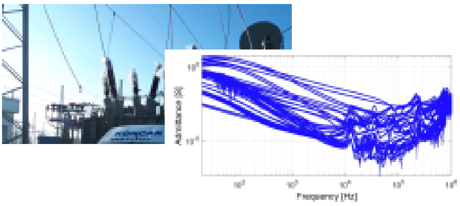
- Modern power systems with high share of renewable energy sources (RES) and implementation of power electronic devices, such as DC lines, are more prone to transient events
- In the case of a power transformer failure due to overvoltage, economic consequences can be severe
- It is necessary to establish asset management system for such important components

## Methodology

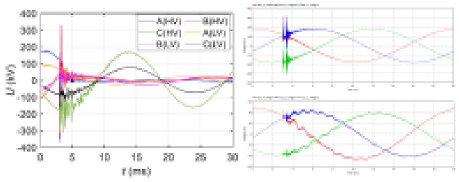
- To know the real types and severity of overvoltage events two approaches are possible:
  - To simulate possible overvoltages using EMTP simulations with detailed substation modelling
  - To continuously monitor overvoltages at the transformer terminals using transformer monitoring system equipped with devices for monitoring of transients
- Both approaches lead to gathering more knowledge on overvoltages:
  - Used for proper dimensioning of both the transformer and its protection devices
  - Lead to better economic decisions and general increase in reliability
- Based on the field experience a framework for overvoltage management based on field data and modelling is presented

## EMTP simulations of overvoltages

- To simulate fast and very fast transients in the power system, high frequency transformer models are needed
- Black box power transformer models based on frequency response measurements done on field, using standard VNA equipment




On field measurements of power transformer admittance matrix.




Measured (left) and simulated (right) overvoltages.

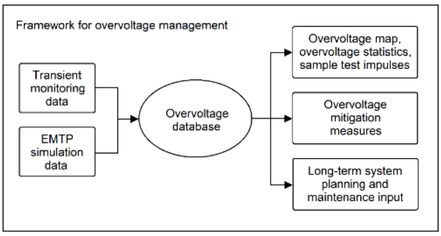
## Continuous monitoring of overvoltages

- Transient monitoring system measures voltages on a measuring tap of the transformer's bushing up to 1 Mhz
- Statistical analysis of overvoltage parameters (double exponential equivalent), measured at 220/110 kV, 150 MVA autotransformer located in Croatian coastal area during 5 months period

| Parameters | $\mu$ | $\sigma^2$ | Geometric mean $\mu^* = e^{\mu}$ | Geometric stand. dev. $\sigma^* = e^{\sigma}$ |
|---|---|---|---|---|
| Amplitude [kV] | 4.53 | 0.81 | 92.29 | 2.46 |
| Front time [μs] | 3.06 | 1.21 | 21.27 | 3.00 |
| Tail time [μs] | 5.05 | 0.17 | 156.44 | 1.52 |

- Results can be used to choose insulation level specifically for the transformer unit and as an input for transformer manufacturer in order to make a design more persistent for a specific type of overvoltages

## Framework for overvoltage management based on field data and modelling




## Conclusions

- An integral approach to assessing and handling the specifics of overvoltages in the power network from the viewpoint of the utility
- Increasing the reliability of the equipment and reducing its eventual down-time

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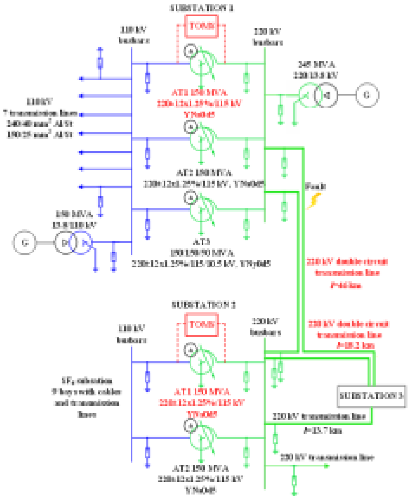
## EMTP simulations of overvoltages

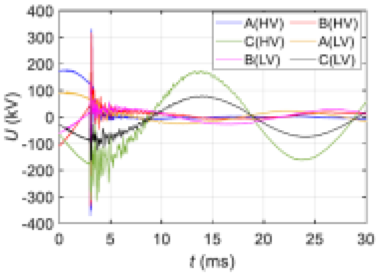
- To simulate fast and very fast transients in the power system, high frequency transformer models are needed
- Black box power transformer models:
  - Based on frequency response measurements, using standard SFRA or VNA equipment
  - Measurements can be done on field with proper grounding with transformer deenergized and disconnected from the network
- 150 MVA 220/110 kV autotransformer unit has been measured on field and EMTP model is established
- Case under consideration included lightning strike to a 220 kV overhead line tower, which led to flashover in phase B, following by the flashover in phase A



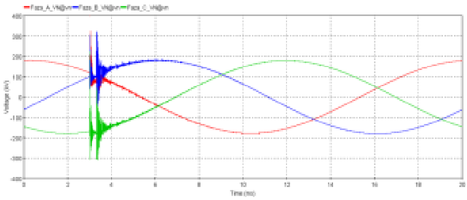

Observed part of the power network, simulated in EMTP.

- Lightning strike detected with lighting location system while SCADA detected double phase to ground short circuit

- The amplitude of the simulated overvoltage at transformer terminals is comparable to the measured ones
- EMTP model includes detailed model of the substation 1 together with detailed model of 220 kV overhead line




Measured overvoltages, by transient recorder, in the case of double phase to ground short circuit



Simulated lightning overvoltages in EMTP using power network model together with detailed black box transformer model

- Simulated overvoltages consist of lightning strike overvoltage and system response
- The amplitude of the simulated overvoltage is comparable to the measured ones while the oscillations following the initial overvoltage differ due to lack of damping in the model
- These models can provide utilities with an idea of the overvoltages that can exist at the transformer terminals
- It can be valuable when it comes to testing of the transformer and comparing the insulation stresses and safety factors to standard test impulses

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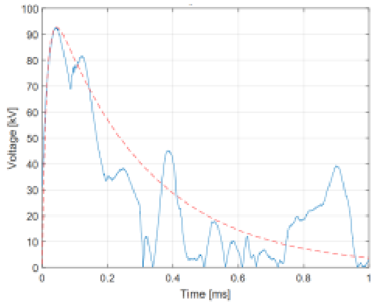
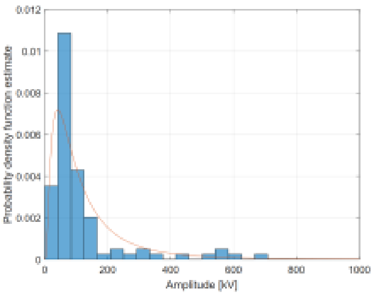
$$U(t) = kA(e^{-\alpha t} - e^{-\beta t})$$




Example of absolute values of measured (full curve) and fitted signal (dotted curve), using double exponential

- Three different double exponential waveshape parameters can be observed statistically: amplitude, front and tail time
- It is assumed that parameters are distributed according to the log-normal law




Amplitude distribution

| Parameters | μ | $\sigma^2$ | Geometric mean $\mu^* = e^{\mu}$ | Geometric stand. dev. $\sigma^* = e^{\sigma}$ |
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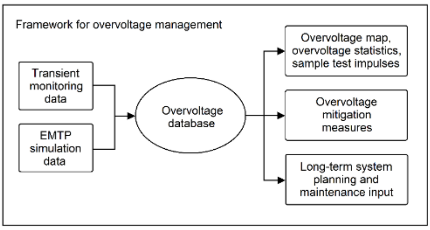
- Statistically derived overvoltage parameters can be used to check the severity of the overvoltages
- Data incorporate specifics of geographic and electric location
- Results can be used to choose insulation level specifically for the transformer unit and as an input for transformer manufacturer in order to make a design more persistent for a specific type of overvoltages

## Framework for overvoltage management based on field data and modelling

- Considers understanding of the different natures and causes of the overvoltages in the power system
- Equipment for transient monitoring can be installed at critical points in the network, together with the EMTP models of these parts of the network




- Overvoltage preview (map and statistics) gives an idea of the overvoltage severity in the network
- The most severe overvoltage waveforms can be used as sample test impulses
- Overvoltage mitigation measures consider actions to limit the overvoltages by changing network configuration, by installing additional surge arresters, by installing snubbers, filters, etc.
- Long-term planning input considers more accurate specification of needed insulation levels for the high voltage equipment or going beyond standard insulation level and requiring equipment that is capable of withstanding nonstandard waveshapes
- Input for asset management and intelligence condition monitoring