Study Committee C4

Power System Technical Performance

Paper ID 10809

Analysis of Transient Measurements in Transmission Systems Correlation with Network Protocol Data and Lightning Location System Data

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Motivation

- Current developments in the field of transient voltage measurements with respect to insulation coordination
- Correlation of transient voltage measurement data of a transmission system with its Network Protocol (NP) data and Lightning Location System (LLS) data
- On-site recorded transient measurements gathered in the years 2017 to 2019
- Significant information can be gained to get insights on the resilience of the analyzed high voltage system and the safety and reliability of the grid

Methodology

- Data handling as well as a new correlation method are developed and applied to a data set including 13800 transient recordings
- The Data set was recorded in four substations of the Austrian transmission system operator at the voltage levels of 380 kV and 220 kV (see Fig. 1)
- Effects of transients were analyzed to categorize them and to evaluate the range and allocation by voltage level
- Recent research methods regarding the measurement concept underlying the present transient measurements are explained
- Data handling and correlation of extensive data sets are shown
- Developed signal processing methodology allows a categorization with respect to maximum voltage peaks

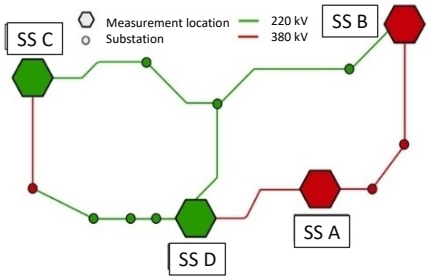

Fig. 1: Schematic of instrumented 220 kV (green) and 380 kV (red) substations (SS X) from 2017 to 2019 in the Austrian transmission grid

Experimental Setup

- Additionally installed broadband resistive-capacitive voltage dividers (RC dividers, DC to 20 MHz)
- Transient-capable measurement setup (see Fig. 2)
- Setup is operated in parallel to the already installed protection and measuring equipment

Fig. 2: Left: 400 kV RC divider installed at the overhead transmission line feeder, Right: Measurement technology with (a) measurement computer, (b) digital oscilloscope, (c) double-shielded measurement cables and (d) remote network access in the secondary equipment room of the substation

Data

- Transient Voltage Measurements
  - Approximately 13800 high-resolution records (12 bit, 100 MS/s), from the years 2017 to 2019
  - Installation of transient measurement equipment at two 380 kV substations (SS A and SS B) and two 220 kV substation (SS C and SS D)
- Network Protocol Data
  - Network protocol data records contain temporally and spatially documented information on switching operations performed within the grid and the associated underlying grid levels
  - Entries limited to switching operations of circuit breakers and disconnectors as well as cleared by protection devices
- Lightning Location System Data
  - Data of the Austrian Lightning Location System LLS ALDIS (location accuracy of approx. 100 m)
  - Cloud-to-ground flashes with negative and positive polarity as well as cloud-to-cloud flashes in a corridor of ±3 km around the respective line corridors included (see Fig. 3)

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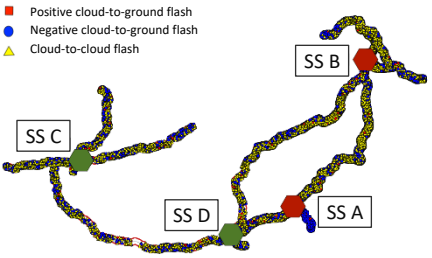

Fig. 3: ALDIS LLS detected negative (blue) and positive (red) cloud-ground flashes as well as cloud-to-cloud flashes (yellow) for investigated lines and substations

Correlation and Analysis

- The correlation method focuses on successive classification of transient measurements in terms of the causes of their origin
- Correlating the transient datasets with NP data and LLS data over time (interval of ±1 s around the time stamp of transient record)
- Data set was analyzed according to switching operations of different types of equipment (circuit breakers and disconnectors or cleared by protection devices) as well as LLS data (see Fig. 3)
- Transient measurement data was correlated with switching operations from the lower voltage levels
- Correlation of events regarding their occurrence at different substations
- Separation of the transient signal components from the 50 Hz signal enables a categorization according to the maximum value of the transient voltages
- Three categories are predefined (see Table 1) with regard to the attainment of the normative rated insulation level in the respective voltage level ($BIL_{220\,kV}$ = 1050 kV and $SIL_{380\,kV}$ = 1050 kV)

Table 1: Predefined category limits for the 220 kV and 380 kV voltage level

Voltage Level	Category 1	Category 2	Category 3
220 kV	< 127 kV	127 kV to 722 kV	> 722 kV
380 kV	< 106 kV	106 kV to 601 kV	> 601 kV

- Category 1 events can be described as low transient interference with no effect on the operating condition of the grid
- Category 2 events, considered as moderate interference, are in the range of the respective insulation level in superposition to the operating voltage (worst case occurrence of transients in the voltage maximum)
- Significant interferences of Category 3 are high enough to cause disturbances even if they occur in another point of time than at the voltage maximum

Results I

- As shown in Fig. 4, in terms of correlation of transient signals with NP data, 89 % were classified as low transient interferences (Category 1), 10 % as Category 2 (moderate interference), and five cases (0.2 %) as significant interferences (Category 3)

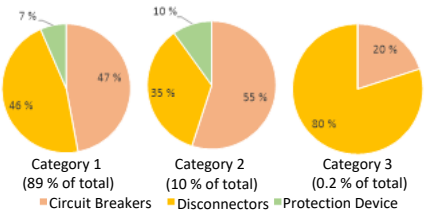

Fig. 4: Category distribution in accordance to switching operations by circuit breakers, disconnectors and cleared by protection devices

- To analyze the visibility of transient events at distant measurement locations it was investigated whether a correlated switching event can also be correlated with records of other measurement locations (see Fig. 5)

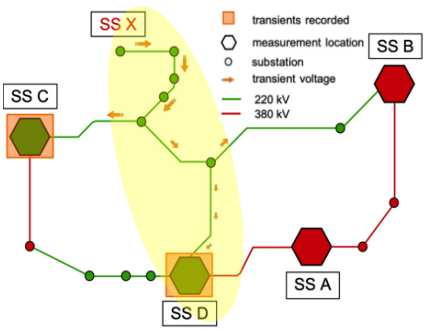

Fig. 5: Schematic network diagram of the propagation path of the transient voltages (approx. 250 to 300 km)

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Results II

- Furthermore, the data was correlated with assigned switching actions from distant substations without an additionally installed transient recording system
- Within this analysis 145 transient events were detected at distances of up to 430 km between the substation and the measurement site
- Fig. 6 show an event of multiple transient measurements and the possible propagation paths of the transient voltage signals caused by the switching of a compensation system (capacitor bank C1) in a distant substation SS X
- Transient voltage signals occurring in SS C, after the switching of C1 in SS X, are strongly attenuated by the high-voltage system and the propagation along the 250 km long overhead transmission line (Category 1)
- Same switching action was also detected in SS D. The effects of this switching action are less pronounced than in SS C (larger distance of approx. 300 km)

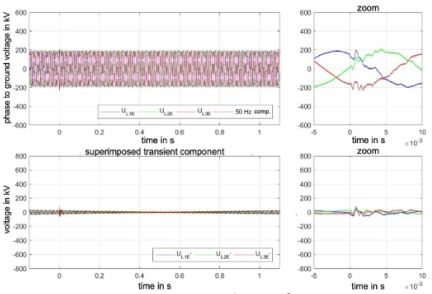

Fig. 6: NP assignment, switching of a compensation system in a distance of 250 km to the measurement location at SS C, recorded phase voltage (top) and transient component (bottom)

Conclusion

- Presented work gives an insight into research activities at Graz University of Technology of **transient recordings on-site** and its correlation and assignments to NP data and LLS data
- Data set of **approx. 13800 transient voltage measurements** recorded in the years 2017 to 2019 in cooperation with Austrian Power Grid AG
- Effects of transient voltages within the Austrian high-voltage transmission system were analyzed
- Described methods demonstrate possibilities of how such data sets can be processed
- Since **more switching operations are expected** in the coming years due to the integration of renewable energy sources, the present results and information are significant for the design of future high-voltage equipment
- For a **qualitative detection of transient voltages, broadband Resistive-Capacitive (RC) voltage dividers** as modern instrumentation in high voltage systems **have to be installed**
- Inductive voltage transformer are only suitable for such assessment to limited extent
- About **38 %** of the evaluated transient voltage measurements have been **successfully correlated** with NP data or LLS data by using the newly presented time wise correlation method
- **Majority** of the transient voltages can be assigned to **Category 1**, about **6 % to Category 2**. **Category 3 events occur only occasionally** (see Fig. 7)

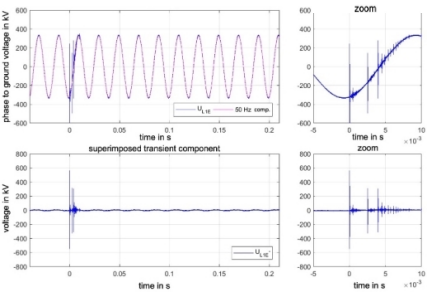

Fig. 7: NP assignment, switching of a breaker in SS A

Outlook

- Future observations of transients in the transmission system will deal with investigations of different effects of identical switching operations
- Transient voltages from the available data pool will be compared for one and the same switching action
- Importance of a high quality acquisition of transient voltages on-site and the use of its information for the best possible grid performance is shown
- These analyses contribute to the understanding of the transient voltage situation to ensure a stable grid operation

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