

PSCAD: Tracing ground path resonances in a Subtransmission network with cables. *Dr. Adel Hammad,*

SwissPowerSystems.

This article summarizes a comprehensive study carried out by the Swiss Utility NOK following a 3-phase-ground fault at a 110-kV cable terminal connected to a large distribution substation. The fault developed a particularly high overvoltage in another 110-kV substation, which entailed damage to potential transformers and cable sheath arresters. The initial analysis showed that the overvoltage had a very high component at 127 Hz.

This study was, therefore, necessary in order to clarify the source of this abnormal event and to define existing and future problems in the 110 kV network and offer solutions to prevent potential problems encountered during the several phases of the 110 kV network expansions.

The fault event

Figure 1 depicts the part of the network affected during the disturbance. The 110 kV network is fed from the 220 kV transmission via Star-Star transformers. The neutral points on the 220 kV side are solidly grounded, whereas most of the neutral points on the 110 kV side are grounded through reactors. And the 16 kV distribution network is directly fed from the 110 kV substations.

The inadvertent closing of the cable terminal grounding switch 'FT' while the breaker 'XB' at the other terminal 'B' is still closed developed a 3-phase-ground short circuit. This was cleared by the opening of the breaker 'XB' in about 400ms.

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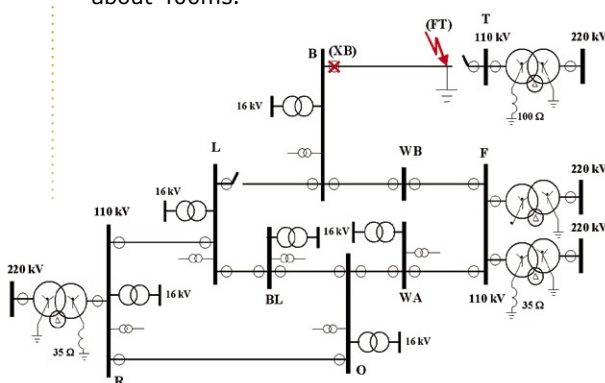


Fig. 1: Schematic of network portion affected by the disturbance.

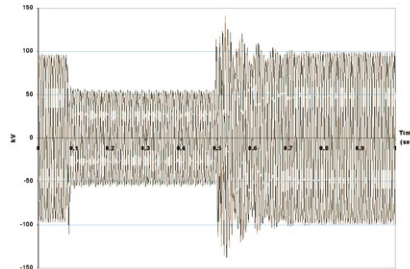


Fig. 2: Three-phase voltage measured at substation WA (1 sec. duration).

Figure 2 shows the 3-phase voltages produced by the disturbance fault recorder located at substation 'WA'. However, after less than 20 seconds, several new phase-ground faults (phases c and a) occurred successively at substation 'WB' and on cables 'WB'- 'B' and 'WB'-'F'. As a result, substation 'B' and all the 16 kV distribution networks fed from it lost all supply. Apparently, after the fault clearing the overvoltages caused damage to the voltage measurement transformers and cable sheath arresters in substation 'WB'. Figure 2 shows the brutal voltage oscillations which represents also an asymmetry between the phases. The oscillations and asymmetry are damped after approximately 250 ms.

Figure 3 shows the Amplitude vs. Frequency of the measured voltage signal. Along with the 50 Hz component and the dc offset one recognizes the very high component at 127 Hz, followed by a smaller 150 Hz component.

EMTDC Simulations

The complete 110 kV network of NOK was simulated in details using PSCAD®/ EMTDC™. The 16 kV distribution

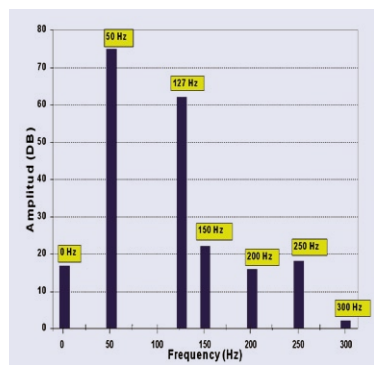


Fig. 3: Frequency composition of the measured voltage.

networks connected to the substations in the vicinity of the disturbance were represented as well. Low order filtered measurements were also necessary to reproduce the actual measured signals. Minor adjustments of the 16 kV load models were required in order to match the amplitude and damping of the measured voltage signals at substation 'WA'.

Figures 4 and 5 illustrate respectively the voltage waveform at substation 'WB' and the filtered voltage at substation 'WA' of the EMTDC simulations. As shown in figure 4, the voltage at 'WB' have very large spikes, particularly in phases c and a, at the fault clearing instant. The peak voltages at 'WB' are generally slightly higher than at 'WA'.

In order to make a robust comparison with the measured values, the simulated filtered voltage at 'WA' is split into two segments, namely at fault start and after fault clearing, and synchronized in time with the measured signal. The comparison of the 3-phases of measured and simulated filtered voltage at 'WA' for the two segments is shown in figures 6 and 7. Indeed, the coherency between the two signals proves the accuracy of the model used for simulations.

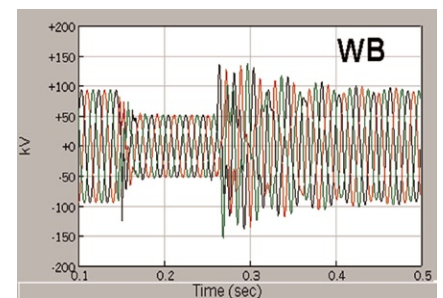


Fig. 4: Simulated network voltage at substation 'WB'.

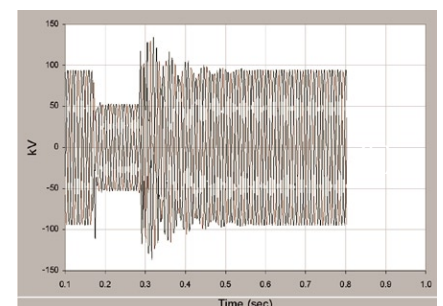


Fig. 5: Simulated filtered voltage at substation 'WA'.

(see continued on page 5)

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Note that short-circuits in the three phases do not start all simultaneously and the opening of the faulted line takes place for each individual phase successively. This means that the network during fault start and fault clearing periods is asymmetrical.

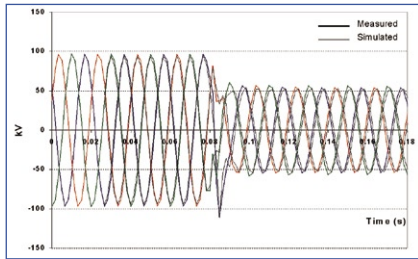


Fig. 6: Comparison between measured and simulated filtered voltage at substation 'WA' at fault start.

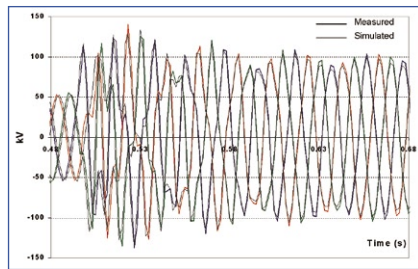


Fig. 7: Comparison between measured and simulated filtered voltage at substation 'WA' after fault clearing.

Therefore, any frequency-domain analysis should consider all sequence impedances of the network. The frequency scan [1] for the sum of network positive, negative and zero sequence impedances seen at substation 'WB' is shown in figure 8 during three stages of asymmetric operation of the network; (1) start of short circuit at 'FT' with resonance frequency of 100 Hz, (2) opening breaker 'XB' with resonance at exactly 77 Hz and (3) after fault clearing where the impedance resonance moves to 65 Hz but has an additional peak at 77 Hz. Due to the 50 Hz carrier frequency effect of the AC system, a 77 Hz resonance in the frequency domain shows as (77+50) 127 Hz in the time domain. Similarly, the 100 Hz resonance frequency shows as 150 Hz in the time domain. The damping of such resonances is approximately inversely proportional to the peak impedance. It is clear that the 77 Hz resonance is dominant, whereas the 100 Hz resonance is well damped.

This result explains the outcome of frequency composition of the measured voltage of figure 3.

In an attempt to explain why the equipment damages were confined to substation 'WB' and to cables 'WB'-'B' and 'WB'-'F', the impedance frequency scan during short circuit and opening of breaker 'XB' is established for different sub-stations as shown in figure 9. It is evident that the strongest resonance effect for this particular fault location lies at 'WB', 'B' and 'F' substations. A resonance that led to a very high overvoltages with 127 Hz at those locations.

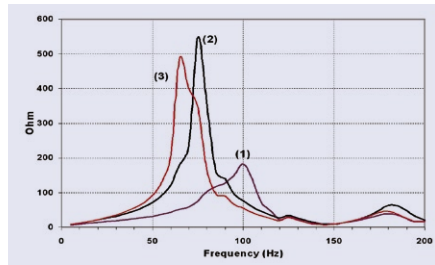


Fig. 8: Frequency scans at substation 'WB' for asymmetric network operation.

Resonance Influencing Factors

»»» Fault Type

Both 3-phase-ground and 2-phase-ground faults can excite such low frequency resonances.

»»» Circuit Cable Content

Due to the difficulty of isolating all the factors affecting the resonance and the arising overvoltages, a range of 25% to 30% of cable contents were identified as being a critical limit.

»»» Neutral Point Grounding

Since the resonance is predominantly affected by the zero-sequence impedance of the network, the relatively high values of neutral-point grounding reactors used throughout the network are the main cause of the low frequency (< 200 Hz) resonance problem.

Damping of resonance

Reducing the reactance of neutral-point grounding reactors can be a possible solution for alleviating the low frequency resonance problem [2].

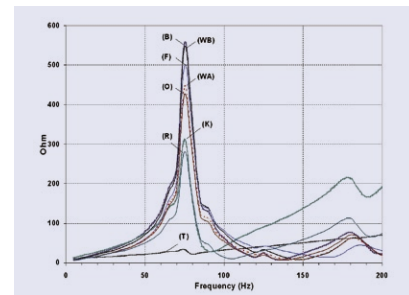


Fig. 9: Frequency scans at different substations for asymmetric network operation during short circuit and opening of breaker 'XB'.

However, the obvious disadvantage of this method is the increase in fault currents that may be beyond the existing switchgear design values.

Another method is to increase the resonance damping, without changing the frequency of oscillations. This can be realized by adding a small resistance in series with the existing neutral point reactors or by adding a large resistance in parallel to those reactors. Figure 10 shows the results of the simulation which is realized with all neutral point grounding reactors shown in figure 1 fitted with parallel resistors having approximately three times the impedance value of such reactors. Note how the overvoltage in the 3-phase voltage at 'WB' is reduced and all post-fault oscillations are practically eliminated.

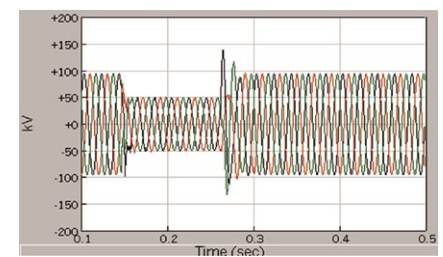


Fig. 10: Voltage at substation 'WB' with parallel neutral point resistances.

For practical implementation of a standard economic solution, all existing and future neutral point reactors in the network are replaced with new reactors having very high inherent resistance by using different material other than aluminium.

References

- [1] A. Hammad, 1990, "Eigenvalue and Frequency Domain Analysis of Second Harmonic Resonance in a Complex AC/DC Network", IEEE Power Engineering Society Special Publication, No. 90, TH0292-3 PWR, 61-66.
- [2] S. Läderach and G. Köppl, 2001, "Beeinflussungsproblem bei Mehrfachleitungen", Bulletin SEV, 7/02, 9-12.