Study Committee C4

System Technical Performance

10549_2022

Sympathetic Interaction Phenomena in an AC Offshore Grid An Investigation Analysis of a C-Type Harmonic Filter Trip Incident & Lessons Learned

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Motivation

- In April 2020, a 220 kV Temporary Overvoltage filter bank was tripped by its protection system
- The fault log analysis indicated that the overcurrent trip of the filter bank resistors coincided with an event external to the filter
- A root-cause analysis based on detailed EMT simulations was conducted to reproduce and analyze the system event

Description of the system under study

- Simplified single line diagram in Figure 1
- The AC offshore grid connected to the Dutch 380 kV Transmission Grid at the Borssele area facilitates the transmission of the power generated by the 1400 MW wind farm
- Two offshore platforms, Alpha and Beta, two export cables routed to each platform
- Two 70 MVAr harmonic filters at the 220 kV land station
- Purpose of the TOV filters is to control and limit TOVs within the insulation withstand capability of the components under possible excitation of the 2nd order harmonic resonance

Table 1. Filter bank information

Rating [MVAr]	70
Tuned frequency [Hz]	100
Main capacitor C1 [uF]	4.6
Capacitor C2 [uF]	13.81
Reactor L [mH]	733.7
Resistor R1 [Ohm]	2432

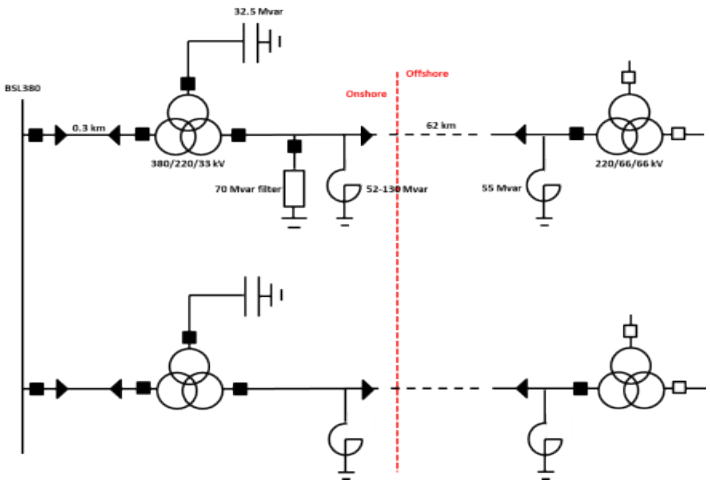

Figure 1. Simplified single line diagram of the offshore grid

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Root-cause analysis

- The overcurrent protection of the filter resistor was picked up during a system disturbance:
  - A 555 MVA step-up transformer was energized at the BSL380 substation
  - Registered voltage dip of 8% and sympathetic inrush currents in the power transformers of the offshore grid (Figure 3)
  - Sudden increase of the filter resistor currents (Figure 2)

Hypothesis & event re-production

- The sympathetic inrush currents caused harmonic distortion at the 380 kV but also at the 220 kV
- 2nd harmonic components matched the TOV filter tuning frequency (100 Hz) and properly lead the filter into conduction mode
- The event was re-produced by means of detailed EMT simulations (Figure 4)
- Similar sympathetic interaction phenomena would lead the TOV filters to trip

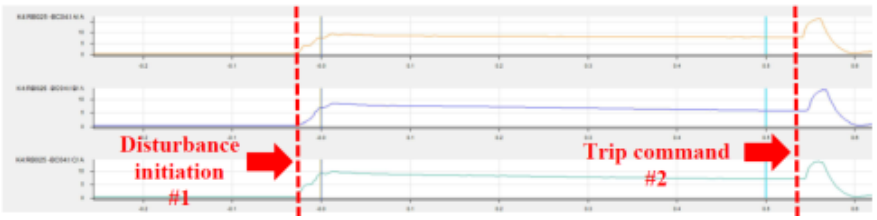

Figure 2. Fault recording (primary side of the CT) – RMS currents through the filter resistor

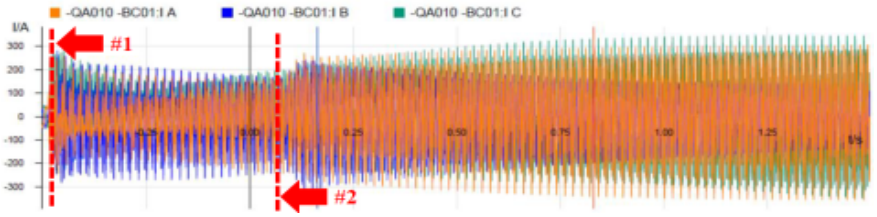

Figure 3. Fault recording (primary side of the CT) – Sympathetic inrush currents in the 220 kV feeder

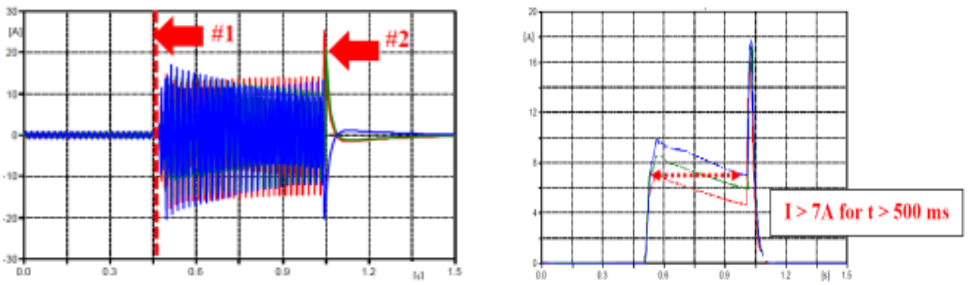

Figure 4. Filter resistor instantaneous currents (left) and simulated RMS currents (right)

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Filter design review

- Additional EMT simulations were performed to account for the expected worst case TOV conditions for which the filters were specified
- The worst case system contingency considered a 2nd harmonic resonance with the highest amplitude (Figure 5)
- The worst case system event referred to a three-phase-ground fault at the 380 kV substation and its subsequent clearance
- The worst case TOV conditions resulted in the exceedance of:
  - the energy withstand of the filter resistors
  - the energy withstand and charge transfer ratings of the filter surge arrester

Conclusions

- The root-cause analysis concluded that:
  - Based on the existing TOV filter design, any sympathetic inrush interaction phenomena within the offshore grid would lead the TOV filters to trip due to the resistors' overcurrent protection
  - The energy withstand of the filter resistors and the energy withstand and charge transfer ratings of the filter surge arrester were exceeded under the worst case TOV conditions
- Following the TOV filter design review it was decided to:
  - Replace the existing resistors with ones of higher thermal withstand
  - Replace the single surge arrester unit with an arrester bank that consists of multiple arrester units in parallel
  - Update the protection coordination of the complete filter

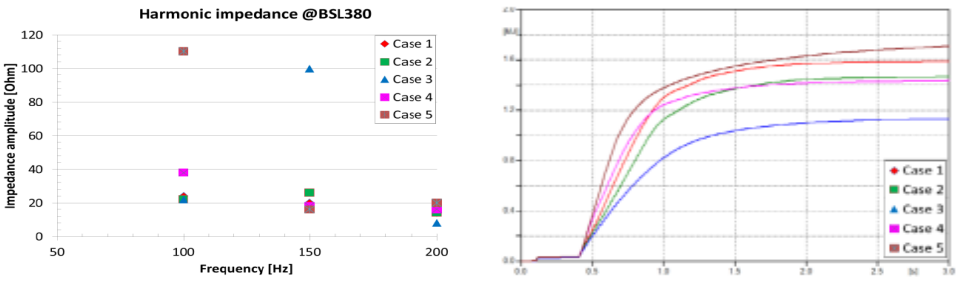

Figure 5. Harmonic impedance amplitudes (left) and resistor bank energy dissipation per case (right)