Study Committee B4

DC Systems and Power Electronics

Paper 10260_2022

Mutual Electromagnetic Interaction between VSC-HVDC Underground Cable Systems and HVAC Systems in Germany

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Motivation

- The potential for electrical, magnetic and Ohmic coupling between HVDC and HVAC transmission systems via their electric and magnetic fields is an issue of concern to the owners of HVDC transmission systems, AC transmission lines and communications lines
- The paper explores factors that could have a significant influence on the inductive coupling effects between the DC cable system and the parallel AC systems and communication cable and quantifies the degree of impact of each of the factors on the inductive coupling between facilities.

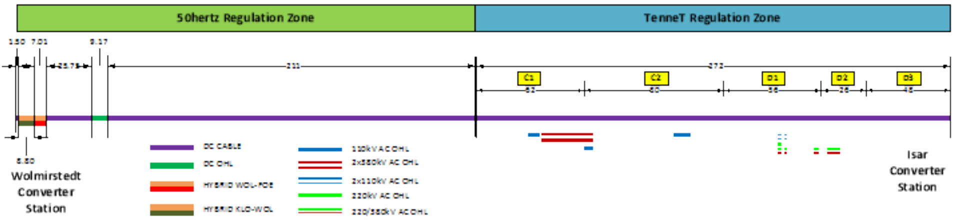

Figure 1 - SuedOstLink DC Transmission Line Overview Showing the AC lines Adjacent to DC cables in TenneT Regulation Zone and adjacent to OHL Sections in the 50hertz Regulation Zone

Approach

Sensitivity Analysis - Factors that are expected to have an impact on the inductive coupling between the AC and DC systems during steady state and during short-time transient conditions were identified as a first step in the study.

— *separation distance between the HVDC cables and AC facilities*

— *coupled length, location of coupled sections along the line*

— *resistance between the DC cable sheath grounding points and remote earth*

— *AC system fault types and fault locations*

— *AC system short circuit level*

— *X/R ratio of AC system impedance*

— *AC and DC line/cable crossings*

— *AC system grounding arrangements*

— *HB or FB VSC converter technology*

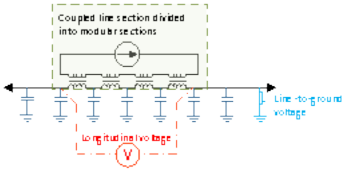

Figure 2 – Conceptual Illustration of Longitudinal and Line-to-Ground Voltages

Effect of Separation Distance Between AC and DC Lines/Cables under Steady State Conditions

Maximum induced voltage under steady state conditions is inversely proportional to the effective actual separation distance (Deff) between AC conductors and DC cables as defined in Figure 3.

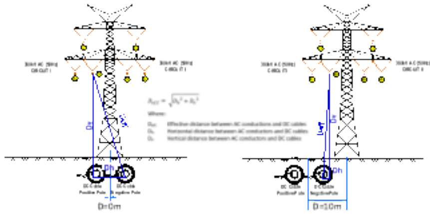

Figure 3 –Concept of Effective and Horizontal Separation Distance Phase B of AC line and Negative HVDC Pole Cable

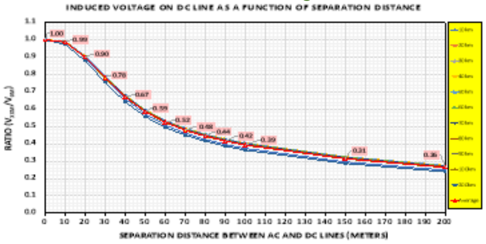

Figure 4 - Coupled Voltage versus Horizontal Separation Distance between 380kV AC and DC Lines

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Variation of coupled voltage with location of coupled line sections under Steady State Conditions

- Location of the coupled line section along the HVDC line was not expected to make a noticeable difference in the amount of longitudinal AC voltage coupled to the DC line as the coupling is purely electromagnetic and the mutual impedance between conductors of the same geometrical orientation would be the same for a given length of coupled section anywhere along the line.
- However, the line-to-ground voltage on the DC cables may vary with location of the coupled location even with the same longitudinal voltage coupled into the DC line. This is due to differences in the apparent impedance of the DC circuit on each side of the coupled section due to the shunt capacitive component of the impedance as well as the differences in terminating impedance of the converters at the ends of the line

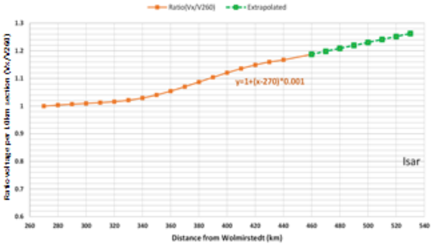

Figure 5 - Variation of Induced Voltage versus Coupling Location

Variation of Coupled Transient Voltage with AC fault type and fault location

- Coupling from AC lines to the DC cables, during transient faults, was investigated for ten fault types applied every 10km along the AC lines within the TenneT Regulation Zone.
- The magnitude of induced voltage is function of residual (unbalance) current flowing on the AC lines within the coupled section. Different fault types result in different levels of unbalance current in the AC line conductors. As the voltage coupled to the DC line is proportional to the magnitude of the unbalance current, higher coupled voltages will result from fault types with higher unbalance currents. Single line-to-ground faults have the highest unbalance currents and cause the highest induced voltage values on the DC line.

Effect of AC and DC Line Crossings

- The induced voltage is a function of the crossing angle, the length of the crossing section and the total coupled length of the AC line and the effect of them as summarized below.

— *If the coupled line length is relatively long compared to the crossing section length and if the length of crossing section is short (<20m), the crossing angle does not have much impact on the induced voltage.*

— *Coupling gradually increases with the increase of the crossing section length as it increases the separation distance between non-crossing section of the lines which reduces the coupling between the non-crossing part of the AC line and DC cables.*

— *When there is no risk of inter-circuit contact, line crossings are of little concern when considering coupled voltages and currents from the AC to the DC side or from the DC to AC side.*

— *Repeated crossings of the AC and DC lines would in general not be effective as a form of "transposition". Although this could theoretically reduce pole mode coupling from the AC to the DC cables, the coupling mode is primarily zero sequence and arises from the unbalance current of the AC circuit which would remain in the same direction regardless of which side of the DC cables the AC line is located.*

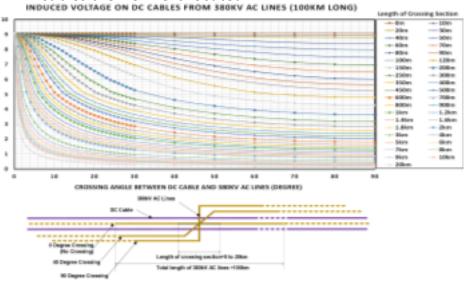

Figure 6 - Maximum Power Frequency Induced Voltage on DC Cables from 100km 380kV AC Lines as a function of Crossing Angle and Length of Crossing

Effect of Grounding Arrangement of 110 kV AC Systems

In Germany, 110kV AC systems are either solidly grounded or grounded using a resonant neutral earthing with a Petersen coil. The grounding method was expected to affect decay time of the DC current coupled to the AC circuits.

- With FB converter controls the DC current is not required to decay naturally due to system resistance, but is instead rapidly reduced by converter control.
- With HB converter controls the induced currents in the AC circuits are also reduced rapidly due to tripping of the AC breakers. Some trapped DC current in the AC circuits after the converters are tripped which decays to low values within 1 second and is not expected to be an issue for the AC equipment or AC protections.

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Effect of VSC Converter Technology and Controls and Protections

- The coupled voltage on the DC line reduces towards the sending end VSC converter and increases towards the receiving end converter due to different input impedances of the converters when viewed from the DC side.
- The sending-end converter, which is controlling DC voltage, presents lower DC side input impedance while the receiving-end converter, which is controlling current (or power), presents higher DC side input impedance when viewed from the DC side. Thus, the sending end converter absorbs 50Hz current from the DC line and reduces the DC line 50Hz voltage. The receiving converter which presents the higher input impedance absorbs almost no 50Hz current from the DC line, and as a result is exposed to higher coupled AC voltage.
- FB converters more aggressively suppress the 50 Hz voltage at the sending end compared with HB or Open circuit resulting in a higher voltage rise at the receiving end terminal with FB

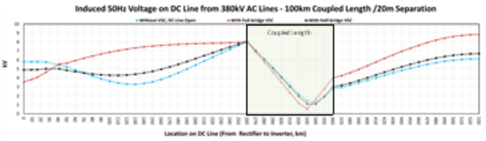

Figure 7 - Effect on Coupled Voltage of Converter Representation at DC Line Termination

Summary and Conclusions

- **AC to DC Coupling**

— *Coupling between AC and DC systems during faults and short-time events results in lower magnitude of coupled voltage than the transients normally encountered in the affected AC or DC systems and thus these are not governing on the design.*

— *For steady-state coupled fundamental frequency (50Hz) voltage, the acceptable level of AC voltage coupled to the DC system is related to the ability of components of the DC system to withstand the coupled voltage and/or currents on a continuous basis. The DC side equipment that is most affected by coupled AC voltage includes the DC cables, DC cable field joints and the DC capacitors of the converters and must be designed to be able to tolerate reasonable amount of steady state power frequency ripple.*

— *To permit rapid estimation of the induced voltage on the DC line due to a particular AC line/ DC cable configuration/separation without detailed study, relationships were derived from the study results as shown in Figure 8.*

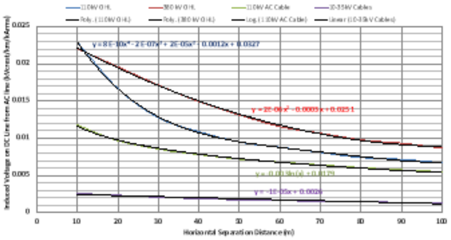

Figure 8 - Relationship between Coupled Voltage and Horizontal Separation Distance

- **DC to AC Coupling**

— *The level of coupling is influenced by the magnitude of the change and rate of change of the DC current during the fault and fault clearing. The behavior of the DC fault current and current reduction is dependent on the type of VSC converter (FB or HB) and differences in fault clearing.*

— *The DC currents coupled into the AC system do not persist long enough to affect thermal ratings of AC equipment, Analysis carried out in this study indicates DC currents of the magnitudes and durations are unlikely to cause protection maloperation since the coupled current from DC line faults are no more severe than DC offset current due to AC system faults that the CT's would normally have to withstand.*

- **Coupling From DC Cables to Communication Cables**

— The induced voltage on communications cables is proportional to the coupled length when the DC line fault is outside the coupled section. The highest coupled voltage occurs when the fault is outside the coupled length. If the DC cable fault occurs within the coupled section, the induced voltage on the communications cable would be smaller as the total induced voltage is the sum of induced voltage produced by currents on both sides of the fault location which have opposite directions and thus at least partially cancel each other.

— Coupling from the DC cable to underground metallic communications conductors during faults can result in high sheath to ground voltages and high common mode voltages on the communication circuit pairs within the cables. Mitigation of such voltage is possible and can be achieved by:

I. Grounding the sheath at both ends and, if necessary, at intermediate points along the cable.

II. Protecting the line to ground and conductor to conductor insulation of the communication circuit pairs using MOVs.