Available online at www.sciencedirect.com

ScienceDirect

IFAC-PapersOnLine 48-30 (2015) 102–107

Comparison between separated and not separated positive and negative sequence control in a high voltage direct current transmission system during unbalanced grid faults

Tobias Neumann, István Erlich

Department Electrical Power Systems, University Duisburg-Essen, Duisburg, Germany;
e-mail: tobias.neumann@uni-due.de, istvan.erlich@uni-due.de

Abstract: Especially during unbalanced grid faults the behavior of voltage source converter based generation or transmission units is highly dependent on the implemented control of the converter. For the control strategy of the converter the two general alternatives are on the one hand a separated control of positive and negative sequence quantities and on the other hand a not separated control in which voltages and currents are not decomposed in the symmetrical components.

Furthermore the quickness of the converter control allows the injection of reactive current during grid faults in order to stabilize the voltage locally. The possibilities and limitations of this so called dynamic voltage control depend highly on the implemented control strategy as well.

In this publication the advantages and disadvantages of the two control strategies with separated and not separated positive and negative sequence are explained and demonstrated during an unbalanced grid fault. For this an AC-DC hybrid transmission test system in which the converter control of the high voltage direct current transmission system is equipped with both control strategies forms the basis for this comparison.

Keywords: Control, Converter, Negative Sequence, Unbalanced Fault, High Voltage Direct Current Transmission

1. INTRODUCTION

In power systems the short circuit contribution of directly grid connected machines, e.g. synchronous generators, is determined by its natural response. In contrast the short circuit behavior of voltage source converter based generation or transmission units is mainly determined by the dynamic response of the corresponding converter control. In this converter control there are certain degrees of freedom especially during unbalanced short circuits. During unbalanced short circuits a negative and in case of grounding a zero sequence component occur beside the positive sequence component. The zero sequence component is mainly determined by the earthing of the transformer and has usually no influence on the converter and thus its control. In the converter control positive and negative sequence components can be controlled separately from each other (Feltes, 2011 and Engelhardt, 2011). Main focus of this paper is to investigate and compare the separated and the not separated positive and negative sequence control with each other.

Therefore an AC-DC hybrid transmission test system is used to investigate the differences in control complexity and performance. Here AC-DC hybrid transmission system means that a DC-circuit is added to an AC-circuit on one hybrid tower (Fig. 1) (Lundkvist, 2009; Halamay, 2005; Staudt, 2014)). The AC-DC hybrid transmission system has advantages with respect to the control of the active power flow, the reactive power management at the sending and receiving end converter (SEC respectively REC) on account of decoupled control of active and reactive power in the high voltage direct current (HVDC) voltage source converter, reduced voltage drop and lower losses when used for long distant power transfer and a controllable response of the HVDC converters during grid faults. Disadvantages are the high investment costs and space requirements of the HVDC stations, the limited overload capability and the small short circuit current contribution of the converters.

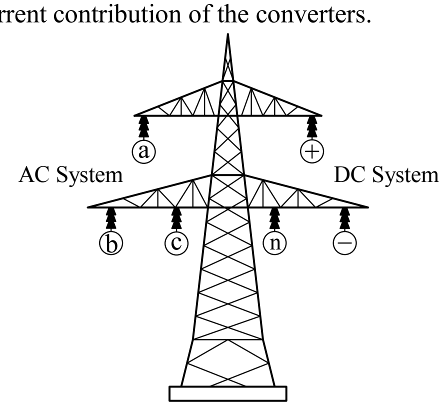

Fig. 1. Hybrid tower

2. TEST SYSTEM

For analyzing the dynamic behavior of the AC-DC hybrid transmission system the test system of Fig. 2 is used. Hereby two AC grids (Grid 1 and Grid 2) are modeled using their

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2015.12.361

Thévenin equivalent circuits. Both have the nominal voltage of 400 kV with a fault level of 8 GVA. Magnitudes and phase angles of both AC grids have been adjusted according to the initial power flow results in the AC transmission circuit.

The two AC grids are connected through a 200 km AC overhead transmission line and a 200 km bipolar DC overhead transmission line operating in parallel to one another. The nominal voltage for the bipolar DC circuit is 760 kV. At the ends of the DC transmission lines the HVDC stations are connected to the AC system. Here two voltage source converters constitute one station where one converter is controlling the positive against neutral power flow while the second converter is regulating the power flow between the neutral and negative pole. This complex configuration allows various operational modes (symmetrical bipolar mode, unsymmetrical bipolar mode and different monopolar modes). For this study only the symmetrical bipolar operation mode is considered. Each converter has a nominal active power of 1 GW resulting in an overall nominal power of 2 GW per station. The converters are connected to the AC grid via transformers in order to guarantee an appropriate modulation level between the AC and DC voltage.

Modern HVDC systems are equipped with modular multi-level converters; but in this study standard two-level systems with DC capacitor are used in order to reduce the level of complexity. Each converter is equipped with an independent, local control system for a separate control of active and reactive power. The current overloading capability of each converter is selected as 1.1 p.u. The hybrid transmission system is operating at a unity power factor at both ends, so that the HVDC stations compensate the reactive power demand of the AC transmission lines.

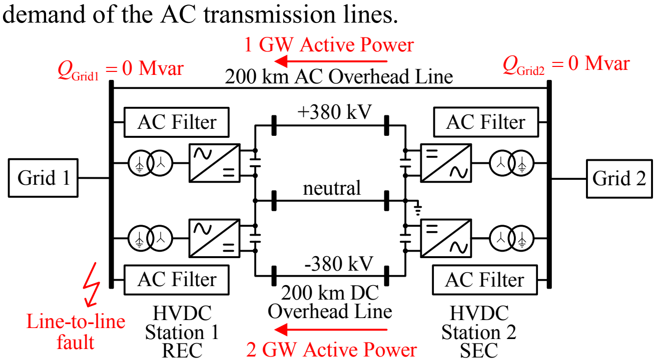

Fig. 2. AC-DC hybrid transmission test system

The power flow direction is from grid 2 to grid 1 and the DC circuit is transmitting 2/3 of the entire active power of 3 GW. For investigating the dynamic response of this test system a line-to-line grid fault is investigated at the busbar of grid 1. The overhead transmission system was assumed to be based on 4 x 265/35 Al/St conductors.

The mutual coupling between the DC and AC overhead lines is not in the focus of this article and is assumed to be not critical for the technical operation (Kizilcay, 2014). There is a German pilot project of an AC-DC hybrid transmission system in the development phase (Staudt, 2014), thus a real implementation of such a technical system seems to be feasible.

3. CONTROL

In this section the two different control strategies with separated and not separated positive and negative sequence are explained individually and in detail based on block diagrams. The decomposition of the positive and negative sequence component can be done by various decomposition algorithms. In this publication the decomposition method according to Lê based on a phase shift element is used (Lê, 1989). Furthermore in this publication the consumer oriented reference system is used in which generated active and capacitive reactive power are negative.

3.1 Separated control of positive and negative sequence

Fig. 3 and Fig. 4 show the voltage oriented space vector control of the active (d-axis) and reactive (q-axis) current for the separated positive and negative sequence components. In Fig. 3 the positive sequence (Index 1) control with feed forward and cross-coupling terms are depicted while the identical design of the negative sequence (Index 2) control, only with negative sequence quantities, is shown in Fig. 4. As reference angle for the negative sequence control in steady-state the positive sequence phase angle is used, while under unbalanced fault conditions the alignment switches to the negative sequence phase angle, guaranteeing the correct orientation (Wijnhoven, 2014).

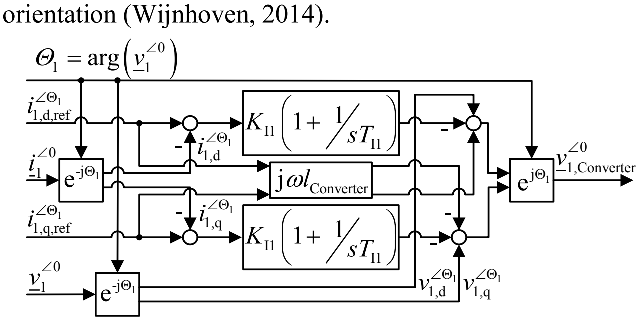

Fig. 3. Inner positive sequence current control

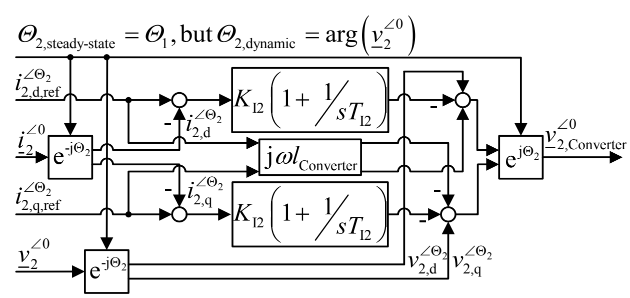

Fig. 4. Inner negative sequence current control

The reference space vector for the voltage of the converter consists of positive and conjugate complex negative sequence space vector ($\underline{v}_{Converter}^{\angle 0} = \underline{v}_{1,Converter}^{\angle 0} + \underline{v}_{2,Converter}^{*\angle 0}$).

While the inner current control loops are for both stations identical, for the outer control loop a distinction has to be made between active power control (SEC) and dc voltage control mode (REC). Thus the active current reference in the d-axis of the positive sequence is different. Fig. 5 shows the active power controller for the SEC with the capability to reduce the reference active power in case of a DC overvoltage due to a power imbalance between AC and DC side of the converter. This limitation controller eliminates the need for a DC chopper.