Abstract

Voltage source converters (VSCs) have been widely used due to their flexibility to control voltages and power independently and bi-directionally. Typically, the control system of VSCs mainly consists of two parts: outer voltage and power controllers and inner current controllers. The vector control current based dq decoupling technique enables to control the active power, reactive power, DC voltage and AC voltage. However, the d- and q-axis of grid voltages and currents comprise AC and DC components under unbalanced grid conditions. The AC components of the d- and q-axis currents make the grid currents unbalanced. In this paper, a novel current control is presented and investigated under unbalanced grid condition for a Back-to-Back Modular Multilevel Converter (B2B-MMC) based HVDC system and validated using the Real Time Digital Simulator (RTDS). Further, the active power oscillation under fault is eliminated by controlling the AC component of grid currents in the dq frame. The RTDS results demonstrate the feasibility of the proposed controllers under unbalanced grid voltage conditions.

Mathematical Model of the MMC

- Under Normal Conditions

\[
\begin{align*}
\psi_{d} &= \psi_{d0} + \psi_{d1} \\frac{d\theta}{dt} + R_{d} i_{d} \\
\psi_{q} &= \psi_{q0} + \psi_{q1} \\frac{d\theta}{dt} + R_{q} i_{q}
\end{align*}
\]

- Instantaneous active and reactive power controls

\[
P = \frac{3}{2}(v_{d}i_{q} - v_{q}i_{d})
\]

\[
Q = \frac{3}{2}(v_{d}i_{q} + v_{q}i_{d})
\]

Similarly,

\[
P_{dc} = \frac{1}{2}(v_{d}i_{dc} - v_{q}i_{dc})
\]

\[
Q_{dc} = \frac{1}{2}(v_{d}i_{dc} + v_{q}i_{dc})
\]

- Under Unbalanced Grid Conditions

\[
v_{d} = v_{d0} + v_{d1} \\frac{d\theta}{dt} + L_{d} \frac{di_{d}}{dt} + R_{d} i_{d}
\]

\[
v_{q} = v_{q0} + v_{q1} \\frac{d\theta}{dt} + L_{q} \frac{di_{q}}{dt} + R_{q} i_{q}
\]

we can say

\[
i_{d} = i_{d0} + i_{d1} \\frac{d\theta}{dt} + L_{d} \frac{di_{d}}{dt} + R_{d} i_{d}
\]

\[
i_{q} = i_{q0} + i_{q1} \\frac{d\theta}{dt} + L_{q} \frac{di_{q}}{dt} + R_{q} i_{q}
\]

Therefore,

\[
i_{d} = \alpha_{d} i_{d} + \beta \\frac{d\theta}{dt} + L_{d} \frac{di_{d}}{dt} + R_{d} i_{d}
\]

\[
i_{q} = \alpha_{q} i_{q} + \beta \\frac{d\theta}{dt} + L_{q} \frac{di_{q}}{dt} + R_{q} i_{q}
\]

Control System

- Inner Current Controller (ICC)

\[
i_{d} \rightarrow \text{Notch Filter} (120 Hz) \rightarrow i_{d0} \rightarrow \text{PI} \rightarrow i_{d}
\]

\[
i_{q} \rightarrow \text{Notch Filter} (120 Hz) \rightarrow i_{q0} \rightarrow \text{PI} \rightarrow i_{q}
\]

Case Study

- Case#1: Current Control

- Case#2: Active Power Control

Case Study

Active and reactive power DC component controls

Active AC component control

Reactive power AC component control

Fig. 3. ICC under balanced and unbalanced grid conditions

Fig. 4. Back-to-Back MMC system based HVDC

Fig. 5. RTDS results of the MMC-1 under unbalanced grid conditions