Modeling and Control Method for MMC B2B System under Balanced and Unbalanced Grid Voltages

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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 current control 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.

Configuration of the MMC

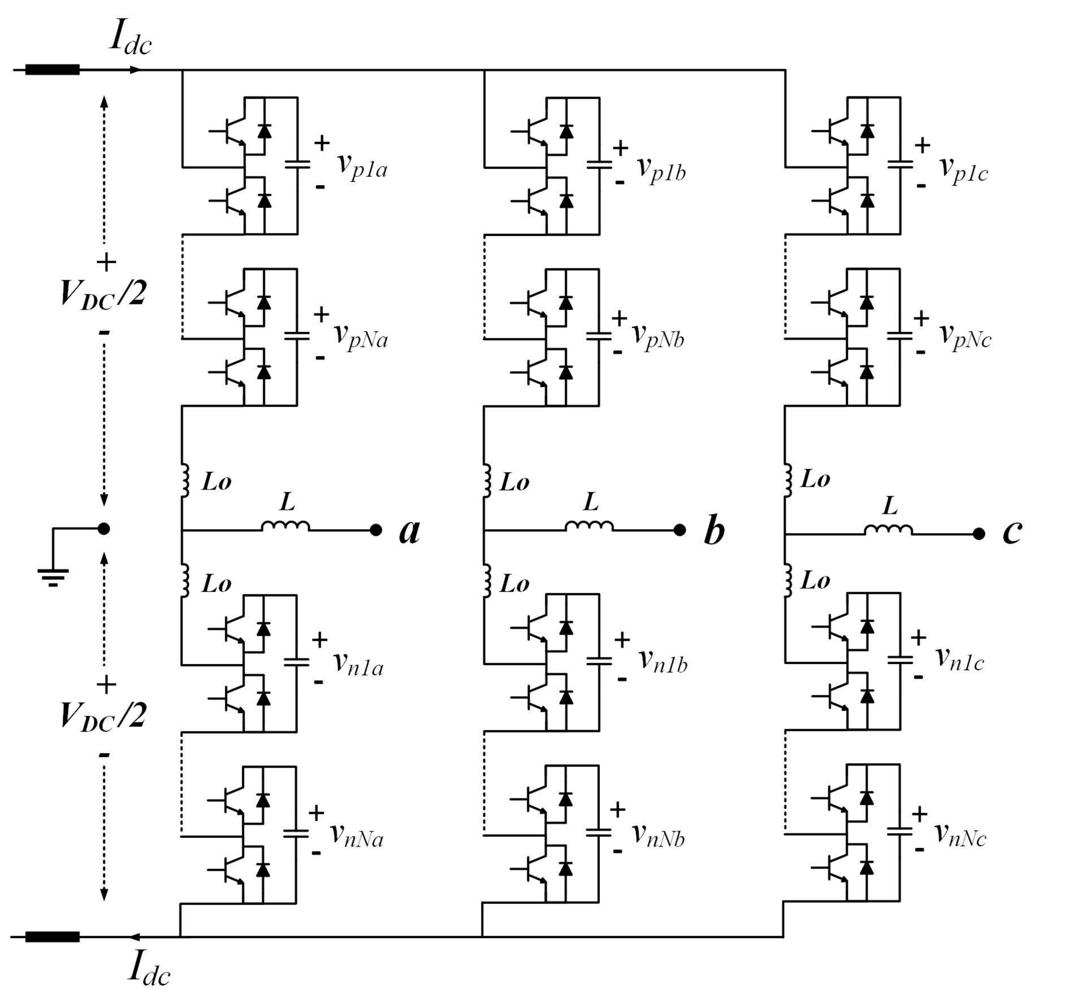


Fig. 1. Three-phase Modular Multilevel Converter (MMC) configuration

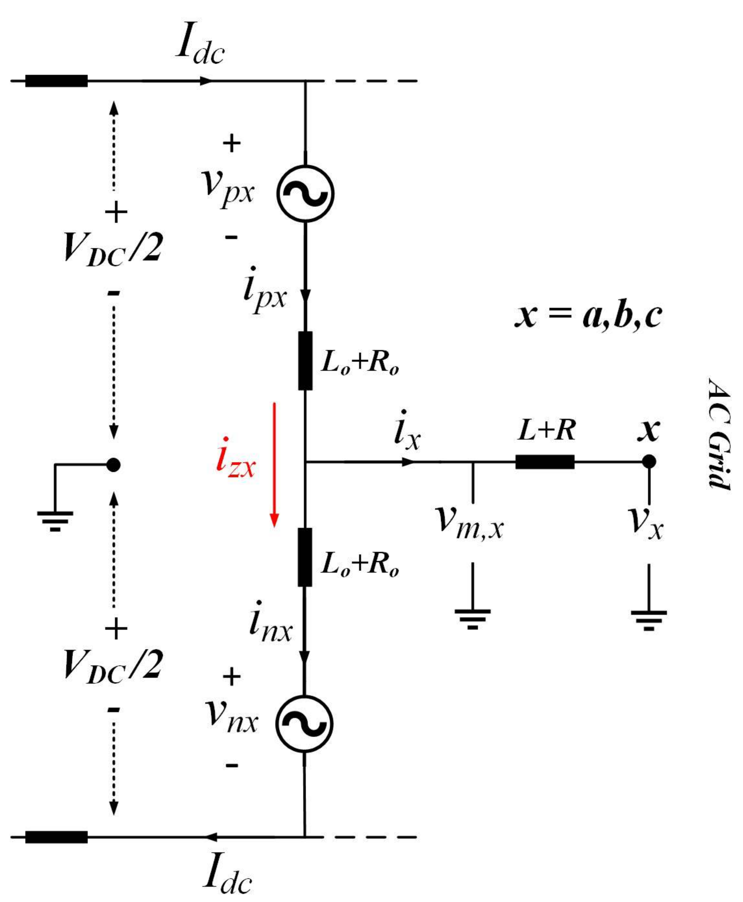
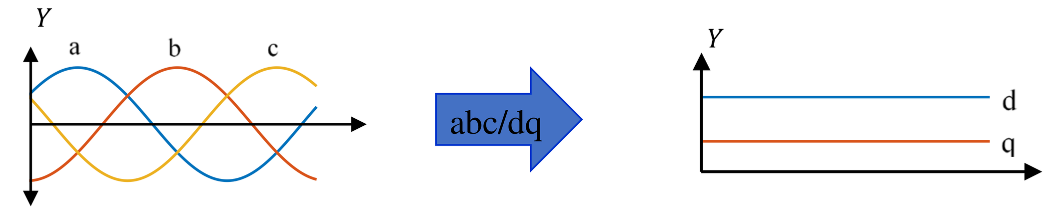


Fig. 2. Single-phase equivalent circuit of the MMC

Mathematical Model of the MMC

- **Under Normal Conditions**

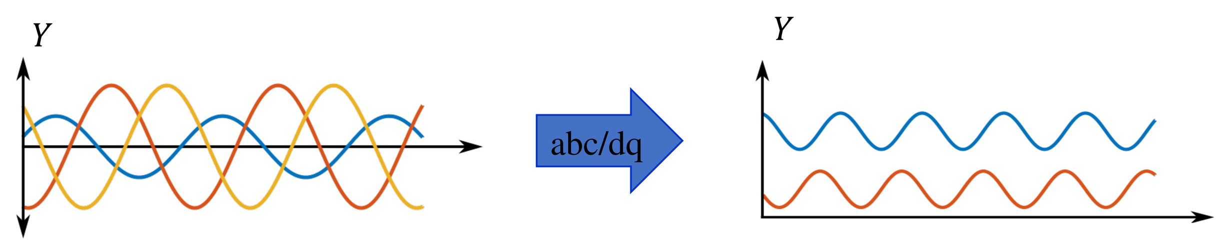


$$[Y_{dq}]_{2\times1} = [T]_{2\times3}\,[Y_{abc}]_{3\times1}$$

$$T = \frac{2}{3}\begin{pmatrix} \sin(\theta_a) & \sin(\theta_b) & \sin(\theta_c) \\ \cos(\theta_a) & \cos(\theta_b) & \cos(\theta_c) \end{pmatrix}$$

$$v_{m,x} = v_x + L_e\frac{di_x}{dt} + R_e\, i_x \quad \xrightarrow{abc/dq} \quad \begin{cases} v_{m,d} = v_d - \omega L_e\, i_q + L_e\frac{di_d}{dt} + R_e\, i_d \\ v_{m,q} = v_q + \omega L_e\, i_d + L_e\frac{di_q}{dt} + R_e\, i_q \end{cases}$$

- **Under Unbalanced Grid Conditions**



we can say → $\begin{cases} v_k = v_{k,dc} + v_{k,ac} \\ i_k = i_{k,dc} + i_{k,ac} \end{cases}$ where $k = d, q$

Therefore,

$$\begin{cases} v_{m,d} = v_d - \omega L_e\, i_q + L_e\frac{di_d}{dt} + R_e\, i_d \;\; (\text{DC},\ \text{AC}) \\ v_{m,q} = v_q + \omega L_e\, i_d + L_e\frac{di_q}{dt} + R_e\, i_q \;\; (\text{DC},\ \text{AC}) \end{cases}$$

Control System

- **Inner Current Controller (ICC)**

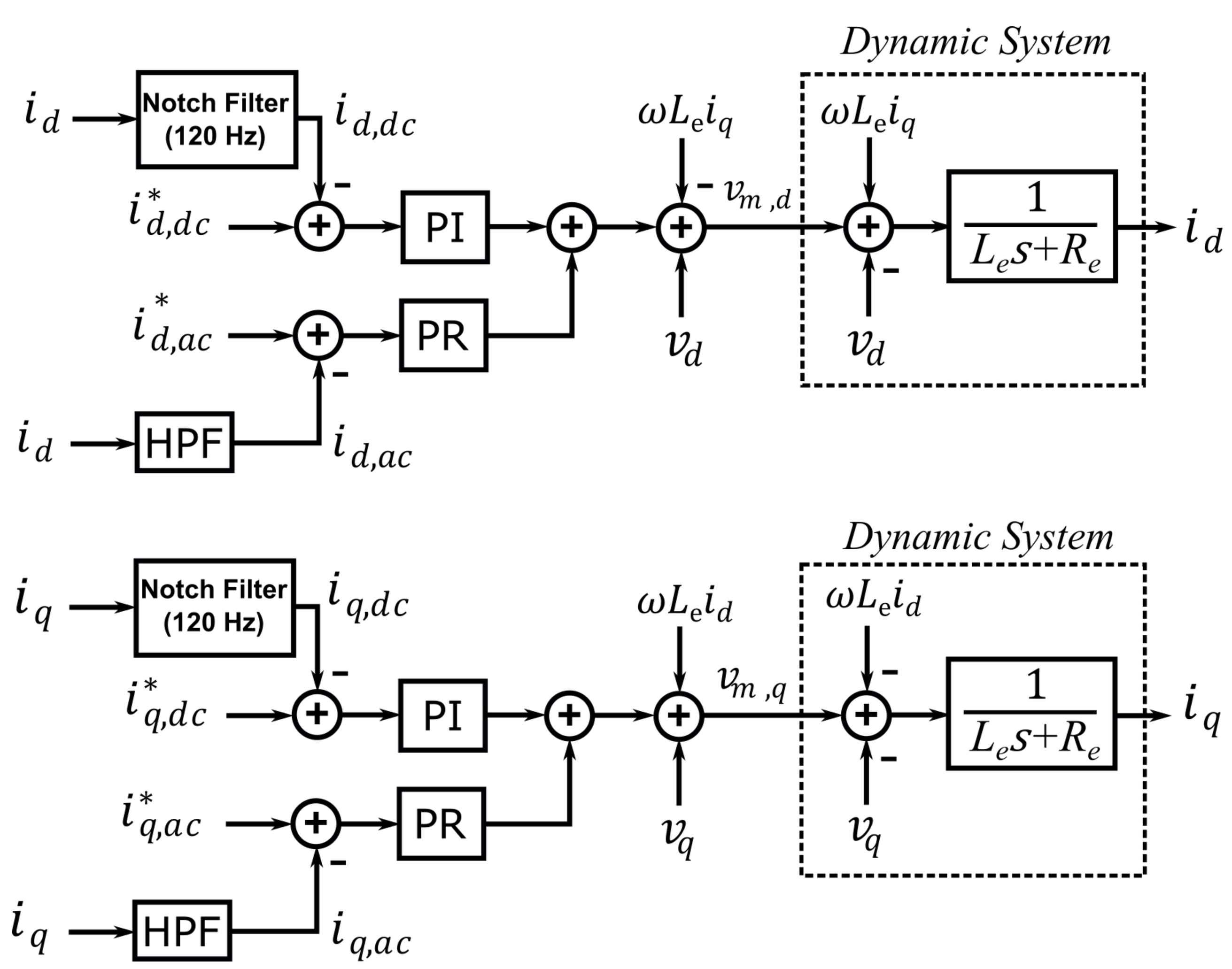


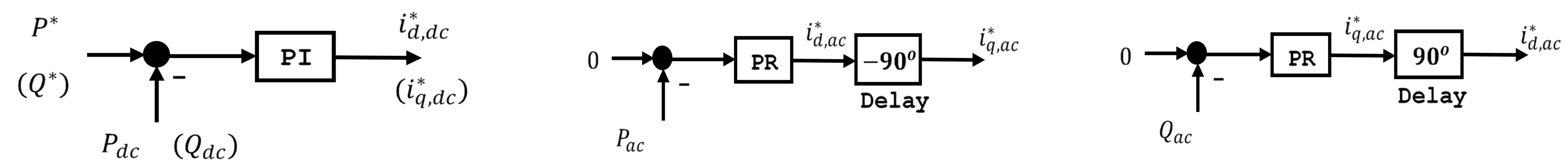
Fig. 3. ICC under balanced and unbalanced grid conditions

- **Instantaneous active and reactive power controls**

Similarly,

$$\begin{cases} P = \frac{3}{2}(v_d i_d + v_q i_q) \;\; (\text{DC},\ \text{AC}) \\ Q = \frac{3}{2}(v_q i_d - v_d i_q) \;\; (\text{DC},\ \text{AC}) \end{cases}$$

$$\begin{bmatrix} P_{dc} \\ Q_{dc} \\ P_{ac} \\ Q_{ac} \end{bmatrix} = \frac{3}{2}\begin{bmatrix} v_{d,dc} & 0 & v_{d,ac} & v_{q,ac} \\ 0 & -v_{d,dc} & v_{q,ac} & -v_{d,ac} \\ v_{d,ac} & v_{q,ac} & v_{d,dc} & 0 \\ v_{q,ac} & -v_{d,ac} & 0 & -v_{d,dc} \end{bmatrix}\begin{bmatrix} i_{d,dc} \\ i_{q,dc} \\ i_{d,ac} \\ i_{q,ac} \end{bmatrix}$$



Active and reactive power DC component controls — Active power AC component control — Reactive power AC component control

Case Study

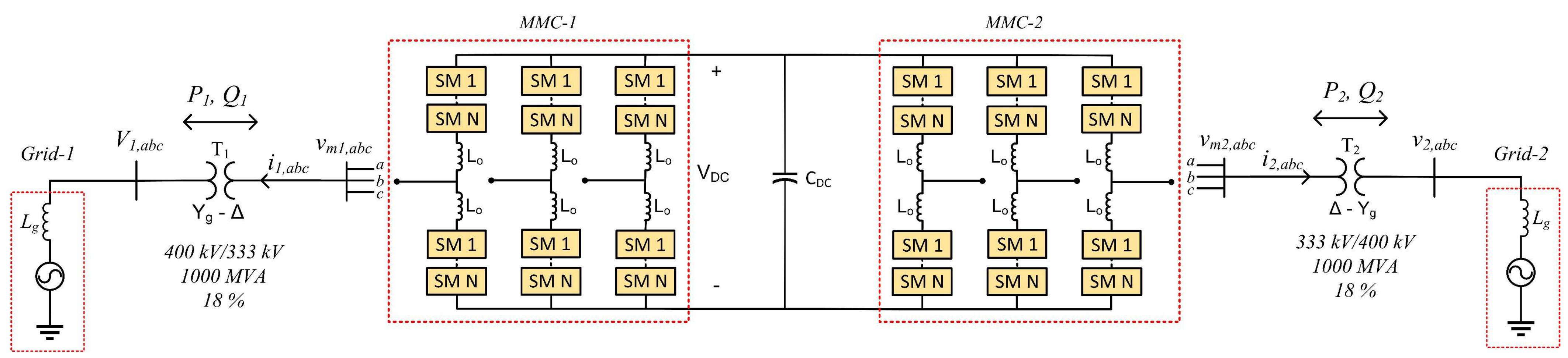


Fig. 4. Back-to-Back MMC system based HVDC

- **Case#1: Current Control**
- **Case#2: Active Power Control**

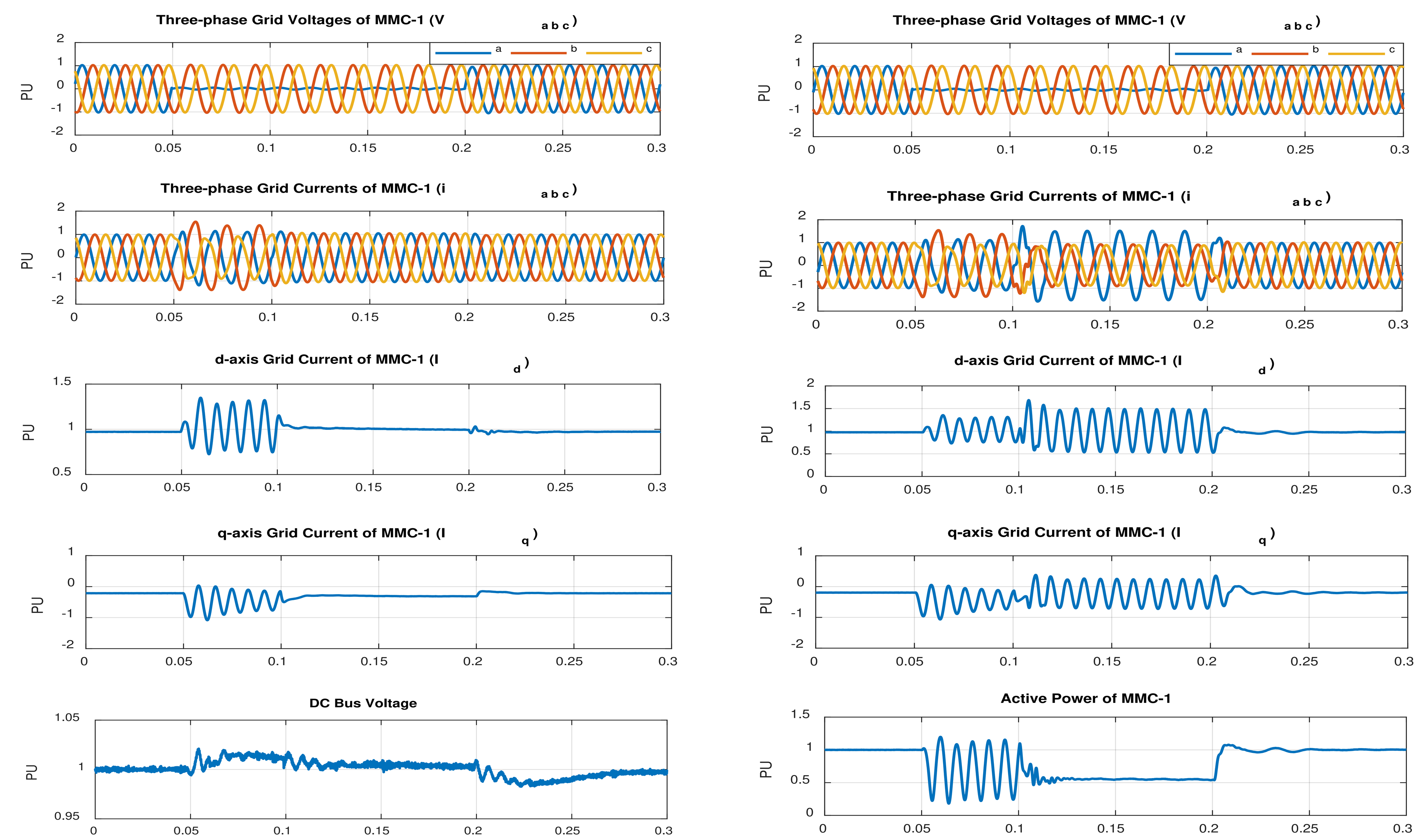


Fig. 5. RTDS results of the MMC-1 under unbalanced grid conditions