IMPERIAL
Department of Electrical
and Electronic Engineering

Control of a Voltage Source Converter HVDC link using grid-forming controls on both ends of the link

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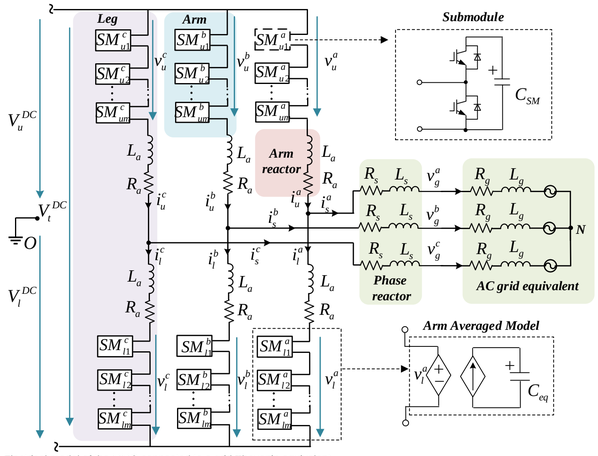
Introduction

Future power systems will be weaker due to fewer synchronous machines. Ensuring stability requires a shift from GFL to GFM control. This project studies a point-to-point HVDC link under different control strategies for cross-country transmission and renewable integration.

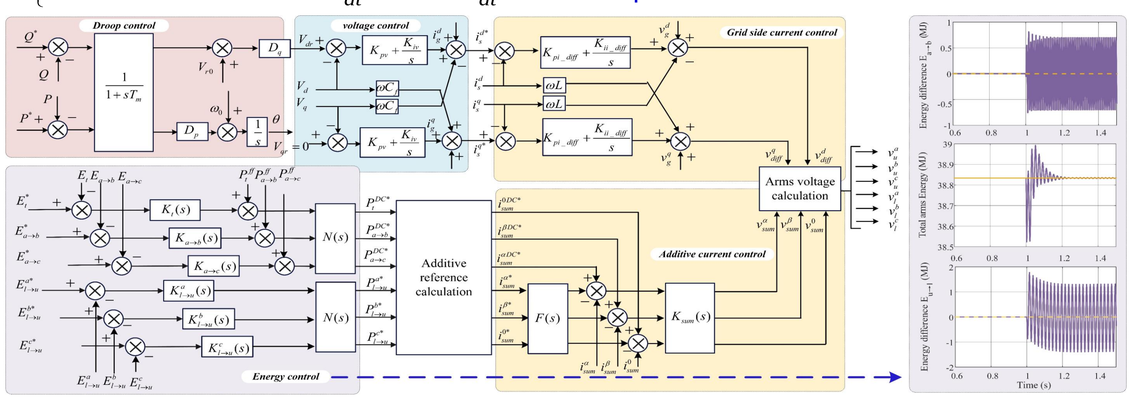


Electrical model of the MMC connected to a grid Thevenin equivalent.

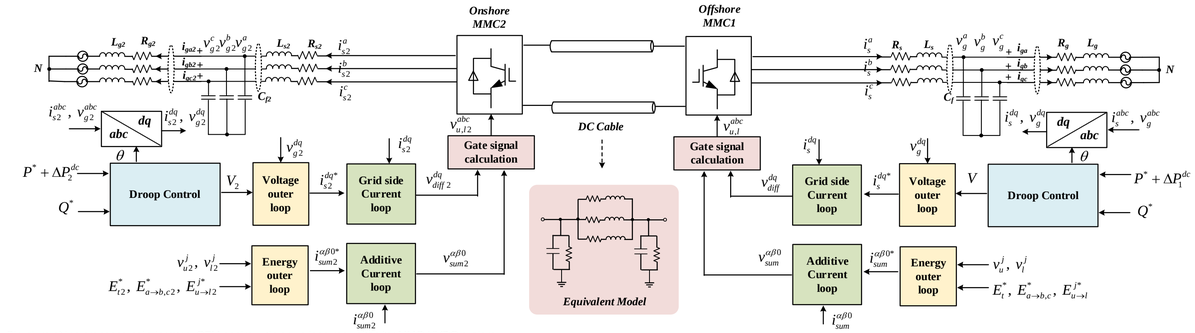
Methods

- KVL loop equations

$$\begin{cases} V_u^{DC} - v_u^j - v_g^j - v_n = R_a i_u^j + L_a \dfrac{di_u^j}{dt} + R_s i_s^j + L_s \dfrac{di_s^j}{dt} \\ -V_l^{DC} - v_l^j - v_g^j - v_n = -R_a i_l^j - L_a \dfrac{di_l^j}{dt} + R_s i_s^j + L_s \dfrac{di_s^j}{dt} \end{cases}$$



MMC overall control system.



Structure of the proposed both-terminal GFM control with dc voltage regulation for MMC-HVDC system.

- Definition of sum and diff variables

$$v_{diff}^j \triangleq \frac{1}{2}(-v_u^j + v_l^j),\ v_{sum}^j \triangleq v_u^j + v_l^j,\ i_{sum}^j \triangleq \frac{1}{2}(i_u^j + i_l^j)$$

- Loop equations for sum and diff variables

$$\begin{cases} v_{diff}^{abc} - v_g^{abc} + (V_{OFF}^{DC} - v_n)\begin{bmatrix}1 & 1 & 1\end{bmatrix}^T = R i_s^{abc} + L \dfrac{di_s^{abc}}{dt} \\ v_{sum}^{abc} - V_t^{DC}\begin{bmatrix}1 & 1 & 1\end{bmatrix}^T = -2R_a i_{sum}^{abc} + 2L_a \dfrac{di_{sum}^{abc}}{dt} \end{cases}$$

Conventional : Both-terminal GFL

- Onshore terminal: DC voltage control
- Offshore terminal: PQ control

Hybrid GFL+GFM

- GFL terminal: regulates DC voltage
- GFM terminal: establishes AC voltage/frequency and transfers PQ

Proposed focus: Both-terminal GFM

- Both terminals operate in droop control
- Share the same reference (PQ)
- Share Vdc regulation by adjusting ΔP

$$P_j^{*tot} = P^* + \Delta P_1^{dc},\ \Delta P_j^{dc} = \gamma_j Kdc(V_{dc}^* - V_{dc}),\ \text{j=1,2}$$

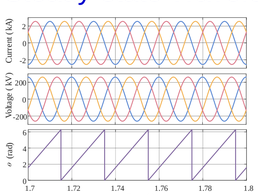
Results

Simulation Setup

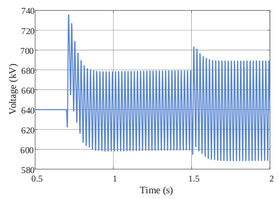
- 0.7s: P* steps from 0 to 80% rated power
- 1.5s: P* steps to 100% (1GW)
- GFM(SCR=2) GFL(SCR>>3)

Parameter	Value	Parameter	Value
P_{rated}	1 GW	R_a+jL_a	0.005+j0.1 pu
U_{rated}	320 kV	V_{SM}	640 kV
V_{dc}	±320 kV	C_{SM}	31.603 μF
R_s+jL_s	0.01+j0.2 pu		

Steady-state Waveforms

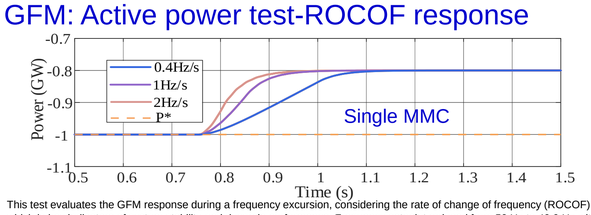


CSM waveform

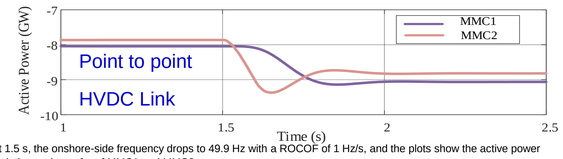


Left (top to bottom): MMC1 three-phase AC current, three-phase AC voltage, and PLL output angle under rated operating condition. Right: Submodule capacitor voltage, with fluctuations within 10% of the rated value.

GFM: Active power test-ROCOF response

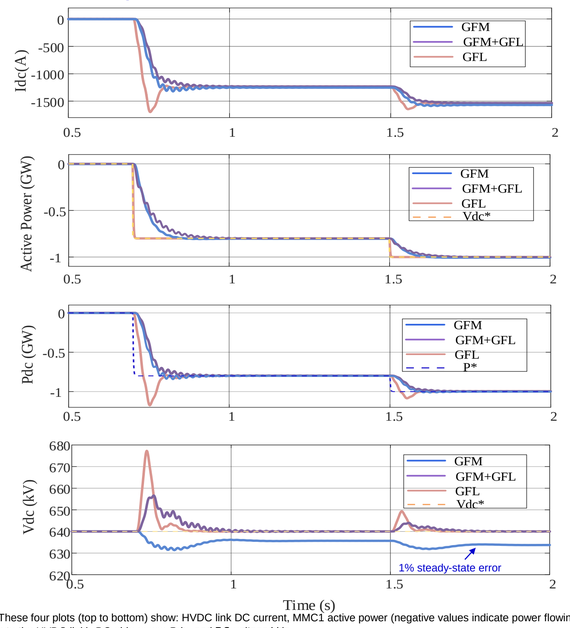


This test evaluates the GFM response during a frequency excursion, considering the rate of change of frequency (ROCOF), which is key indicators of system stability and dynamic performance. Frequency setpoint reduced from 50 Hz to 49.9 Hz with ROCOF of 0.4, 1, and 2 Hz/s. Active power response follows the droop gain setting.



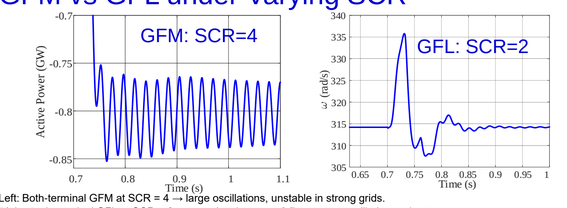
At 1.5 s, the onshore-side frequency drops to 49.9 Hz with a ROCOF of 1 Hz/s, and the plots show the active power variation and transfer of MMC1 and MMC2.

Case comparison



These four plots (top to bottom) show: HVDC link DC current, MMC1 active power (negative values indicate power flowing into the HVDC link), DC-side power Pdc, and DC voltage Vdc.

GFM vs GFL under Varying SCR



Left: Both-terminal GFM at SCR = 4 → large oscillations, unstable in strong grids.
Right: Both-terminal GFL at SCR = 2 → setpoint change at 0.7 s causes oscillation and error.

Conclusion

- A point-to-point HVDC link can operate stably with both-terminal GFM
- Smaller DC overshoot, but wider transients and steady-state error
- More stable than GFL/GFL+GFM in weak grids