Developing VSC-HVDC Oscillation Damping Control Constraints in Unit Commitment

Mingjian Tuo, Jiazi Zhang, Leonardo Rese, Xiaofei Wang

National Renewable Energy Laboratory

Motivation

- High-voltage direct current (HVDC) systems within the AC grids will play a pivotal role.
- The voltage-source-converter (VSC) HVDC technology is self-commutated which allows for independent control of both active and reactive power.
- As the rapid growth of VSC-HVDC projects around the world, there is a need to capture the characteristics of VSC-HVDC damping control in the system planning stage.

Objective

- Model the VSC-HVDC damping control as equivalent transmission capability constraints (TCC) and incorporate in unit commitment (UC). Derive the constraint from the modified power system swing equation model.
- Develop three system damping control scenarios including moderate, fully, and poorly damped cases.
- Investigate this problem in Reliability Test System Grid Modernization Lab Consortium (RTS-GMLC) system and assess the impact of the constraints on inertia, power flow, and renewable curtailment.

System Swing Dynamics

Reduced system swing equation model is used to study the behavior of the inter-area oscillation,

$$\frac{M}{\omega_s} \cdot \frac{\partial^2 \delta_m}{\partial t^2} = P_m - P_e \quad [p.u.]$$

The approximated damping ratio for the equivalent machine is derived as,

$$\zeta = \frac{1}{2} D \sqrt{\frac{\omega_s}{2H \cdot P_{max} \cdot \cos\delta_0}}$$

The damping ratio $\zeta_{threshold}$ is set to ensure stability of the equivalent model,

$$\frac{1}{2} D \sqrt{\frac{\omega_s}{2H_{sys} \cdot P_{max} \cdot \cos\delta_0}} \geq \zeta_{threshold}$$

The maximal transmitted power constraints on parallel interregional AC transmission lines are then constrained as

$$P_{max} \leq \alpha, \qquad \alpha = \frac{15{K_d}^2 \omega_s}{H_{sys} \cos\delta_0}$$

α is the VSC-HVDC damping control constraint limit, denoted as **VSC damping limit**.

VSC-HVDC Damping Control Constrained Unit Commitment

- **Final unit commitment (UC) formulation**

Objective: minimize total generator startup and shutdown cost, fuel and -dual-fuel cost, and penalty of unserved energy

Subject to

- Power Balance
- Generation Limit
- Ramping Limit
- Power Flow Limit
- Generator unit commitment status with startup and shutdown transitions
- Transmission Capability of Interregional lines

Three scenarios with different damping control modes and VSC damping limits are simulated:

Scenario	POD Control	VSC Damping Limit α
Moderate Damped	FACTS and PSS	0.7
Fully Damped	Combination of VSC-HVDC, FACTS, and PSS	1
Poorly Damped	Malfunctions of VSC-HVDC, FACTS, and PSS	0.1

Numerical Results and Conclusion

- **Simulation parameters:**
  - Simulation tool: PLEXOS 9.0
  - Test system: updated IEEE 73-bus with 3 regions, 95 AC lines, and 1 VSC line.

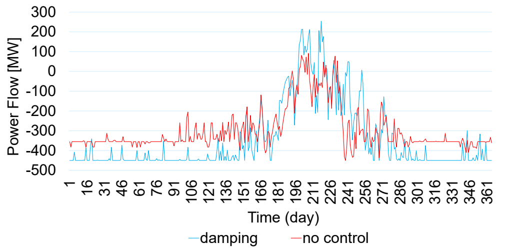

Figure 4. Power flows on line 325-121 of moderate and fully damped cases.

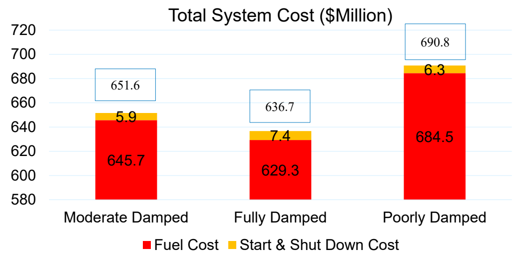

Figure 5. Comparison of annual system costs.

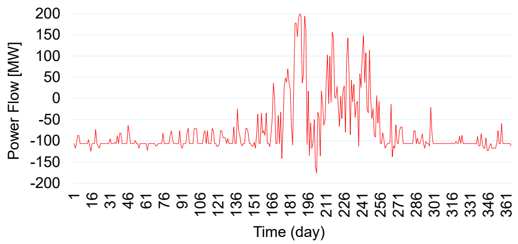

Figure 5. Power flow on AC transmission line 325-121 in poorly damped case.

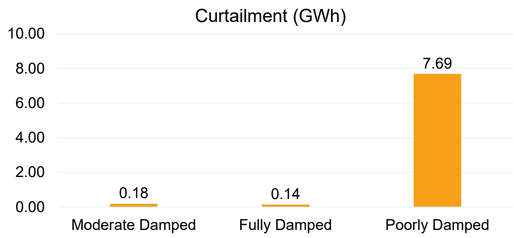

Figure 6. Comparison of annual wind and PV curtailment among scenarios.

- Implementation of HVDC POD increases the K_d of the system, and subsequently improves the transmission capability of interregional line.
- The transmission capability is significantly degraded due to oscillatory constraints with low damping coefficient setting
- The fully damped case with proper VSC-HVDC power oscillation damping control will lead to a more economic generator dispatch solution
- The annual system cost and curtailment of the fully damped case will decrease.
- The poorly damped case will dramatically increase the system cost and curtailment.

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Electricity (OE), Office of Energy Efficiency and Renewable Energy (EERE) Wind Energy Technologies Office, and Solar Energy Technology Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

IEEE PES General Meeting 2023
Conference Location - Orlando, FL
July 16-20, 2023
NREL/PO-6A40-86845