Pacific Northwest
NATIONAL LABORATORY

WEEC MVS Meeting

September 11, 2025

Introduction of HVDC Model Specification VHVDC_A1

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Pacific Northwest National Laboratory

U.S. DEPARTMENT OF ENERGY BATTELLE

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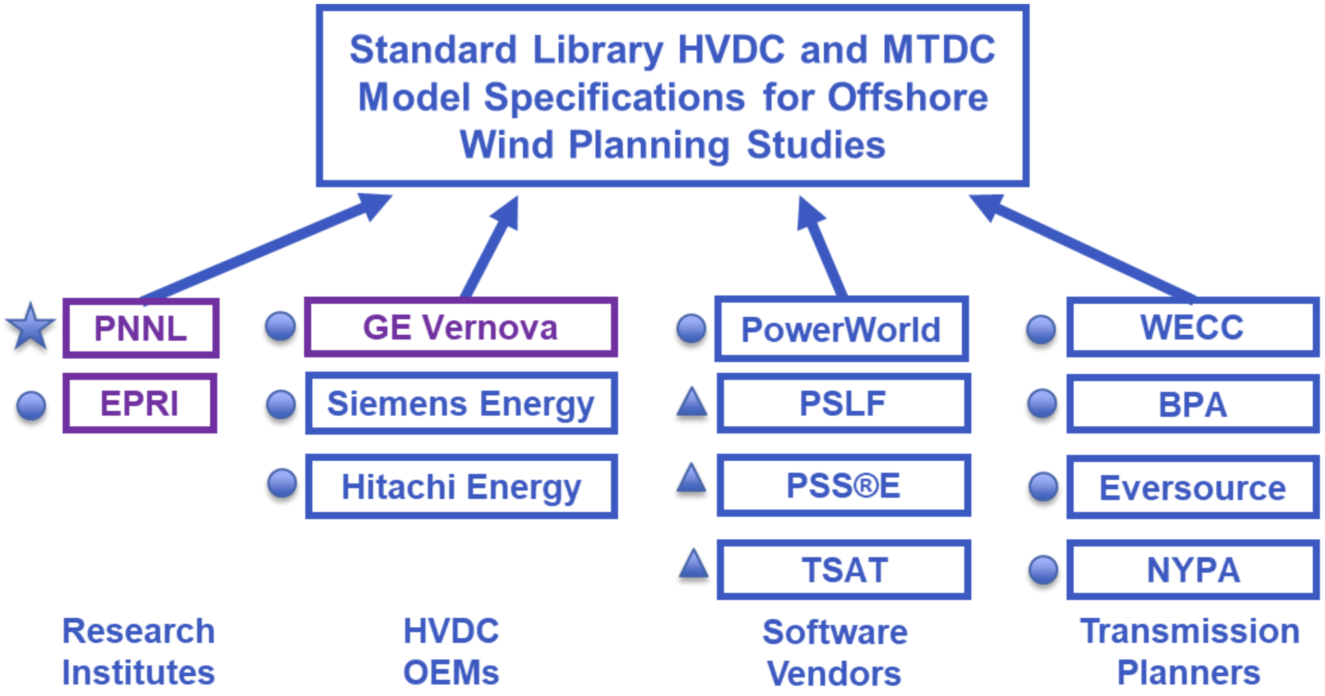
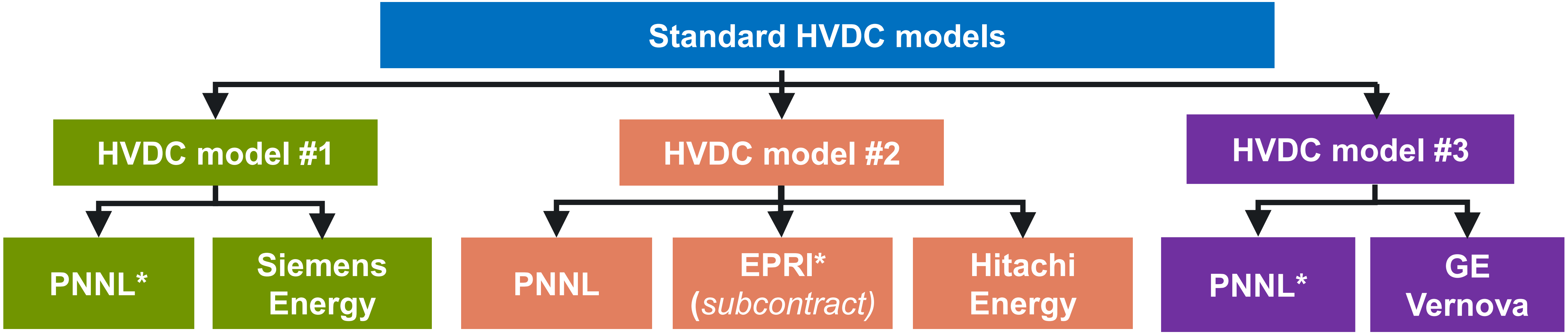
Standard Library HVDC and MTDC Models for Transmission Systems Planning Studies

- **Sponsors**: DOE wind office (WETO) and grid deployment office (GDO)
- **Objectives**:
  - Collaborate with HVDC manufacturers, software vendors, transmission planners, and research institutes to develop HVDC and MTDC models
  - Seek model approval by WECC Modeling and Validation Subcommittee
  - Support model integrations into commercial simulation tools



HVDC Model Development

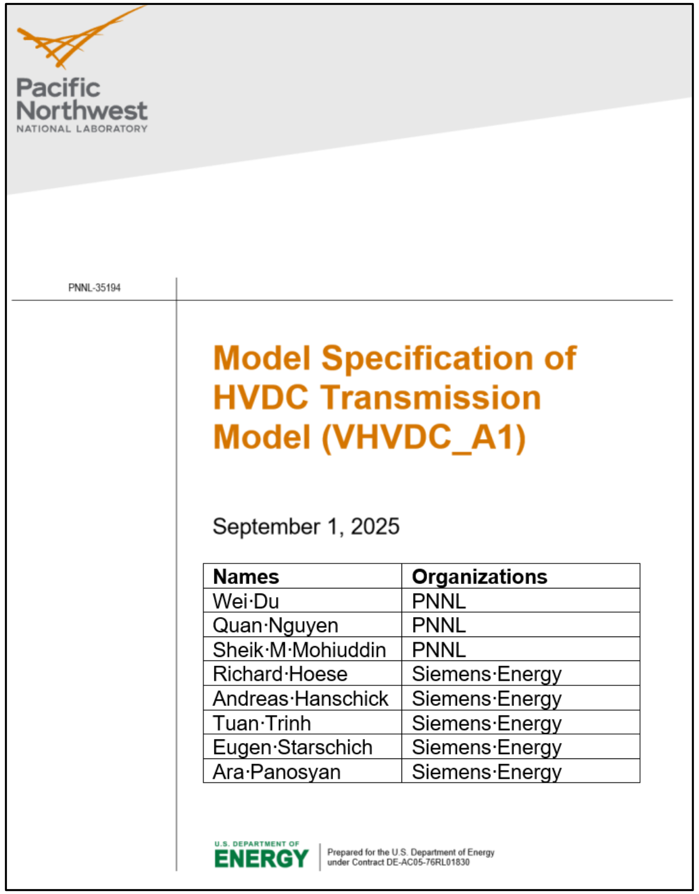
- **Approach**: Develop separate HVDC models the can better represent HVDC technologies used by Siemens Energy, Hitachi Energy, and GE Vernova



Expected Timeline

HVDC Model #1 (VHVDC_A1)

- **Collaboration with Siemens Energy**
  - Siemens Energy provided a UDM and detailed control blocks for an HVDC model
    - Interconnection applications
    - Wind park applications
  - PNNL started developing an HVDC Model Specification
  - PNNL plan on developing HVDC model #1 (VHVDC_A1):



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Model Specification of HVDC Transmission Model (VHVDC_A1)

September 1, 2025

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HVDC Model #1 (VHVDC_A1) *(cont'd)*

- **Model structure**
  - HVDC power flow model and setup in commercial tools
  - Interfaces of HVDC converters at AC and DC side
  - Control of Side-1 and Side-2 converters
    - Interconnection applications (both converters in grid-following mode)
    - Wind park applications (one converter in grid-forming mode and the other in grid-following mode)

AC-DC Power Flow Model

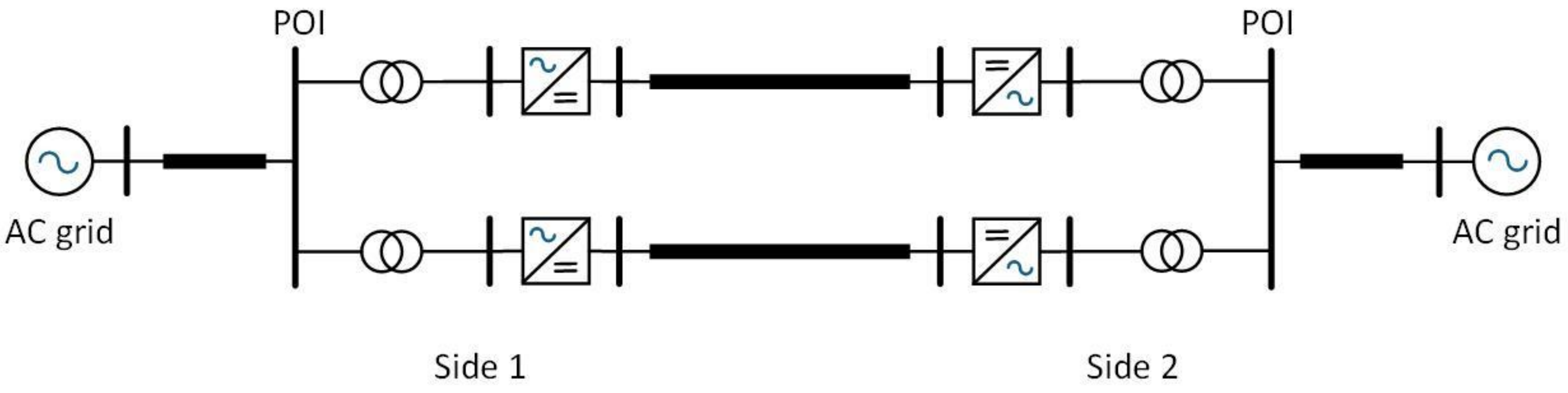


Figure: Power flow model of a 2-terminal bipole HVDC system.

- The power flow solution for initialization is obtained from the AC-DC power flow in commercial tools.
- Each HVDC converter connects to the AC grid via a two-winding transformer, with bipole poles modeled as separate links.
- The AC-DC power flow solution relies on the control modes of Side-1 and Side-2 converters. The following two options are allowed:
  - **Option 1** (for interconnection applications): Side-1 converter controls DC voltage, and Side-2 converter controls AC active power with positive power set point.
  - **Option 2** (for wind park applications): Side-1 converter controls AC active power with negative power set point, and Side-2 converter controls DC voltage.

Converter Interface with AC and DC Grids

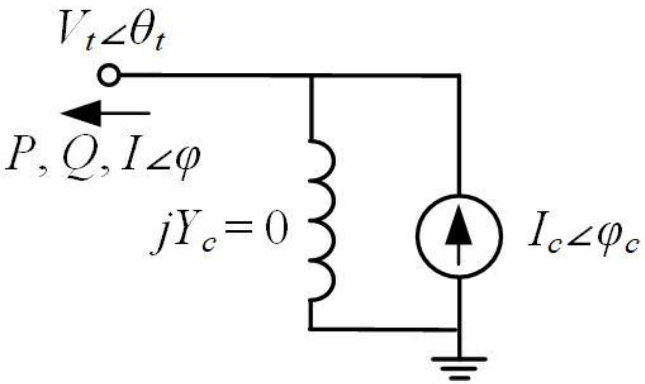


Figure: Equivalent interface of a GFL converter with the AC grid.

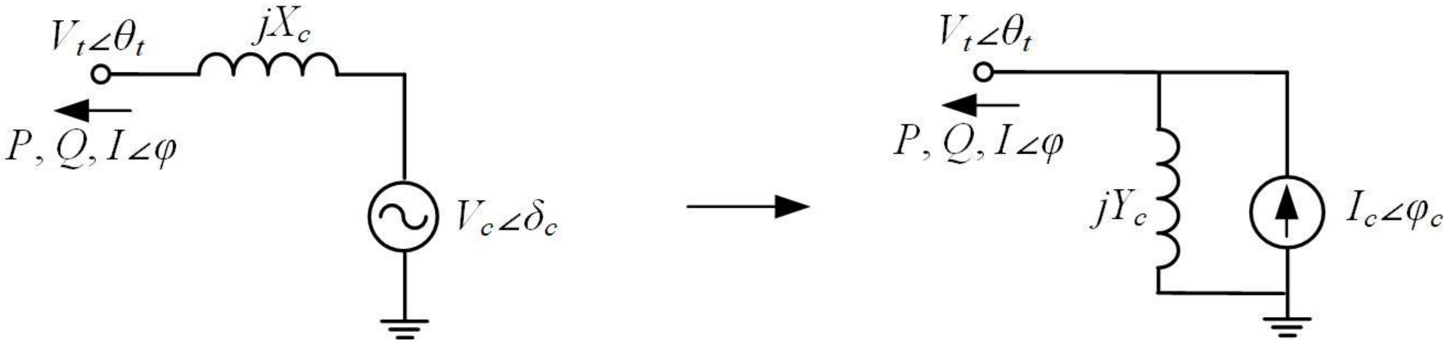


Figure: Thevenin-equivalent representation and converted Norton-equivalent interface of a GFM converter with the AC grid

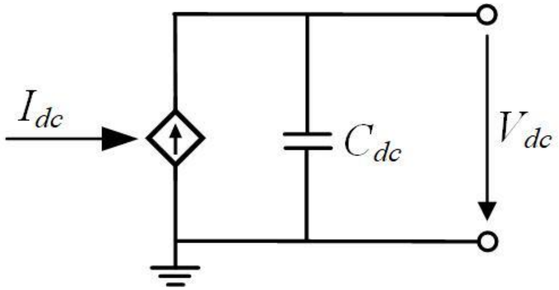


Figure: Equivalent interface of a GFL converter with the DC grid.

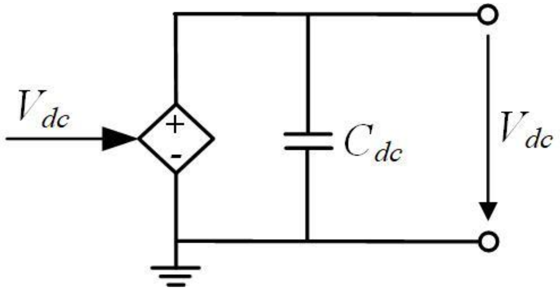


Figure: Equivalent interface of a GFM converter with the DC grid.

DC Current

$$I_{dc} = \frac{P_{dc}}{V_{dc}} = -\frac{P_{ac} + P_{loss}}{V_{dc}}.$$

DC Line Model

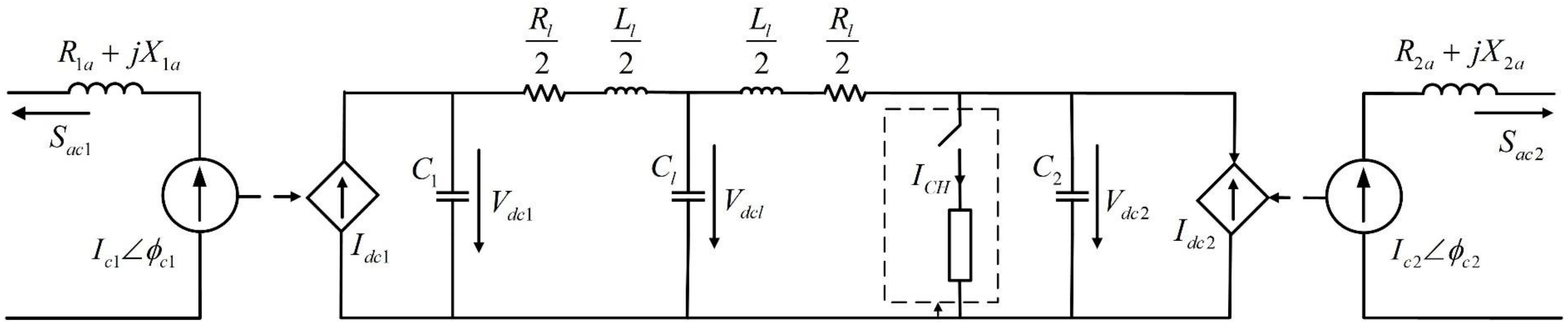


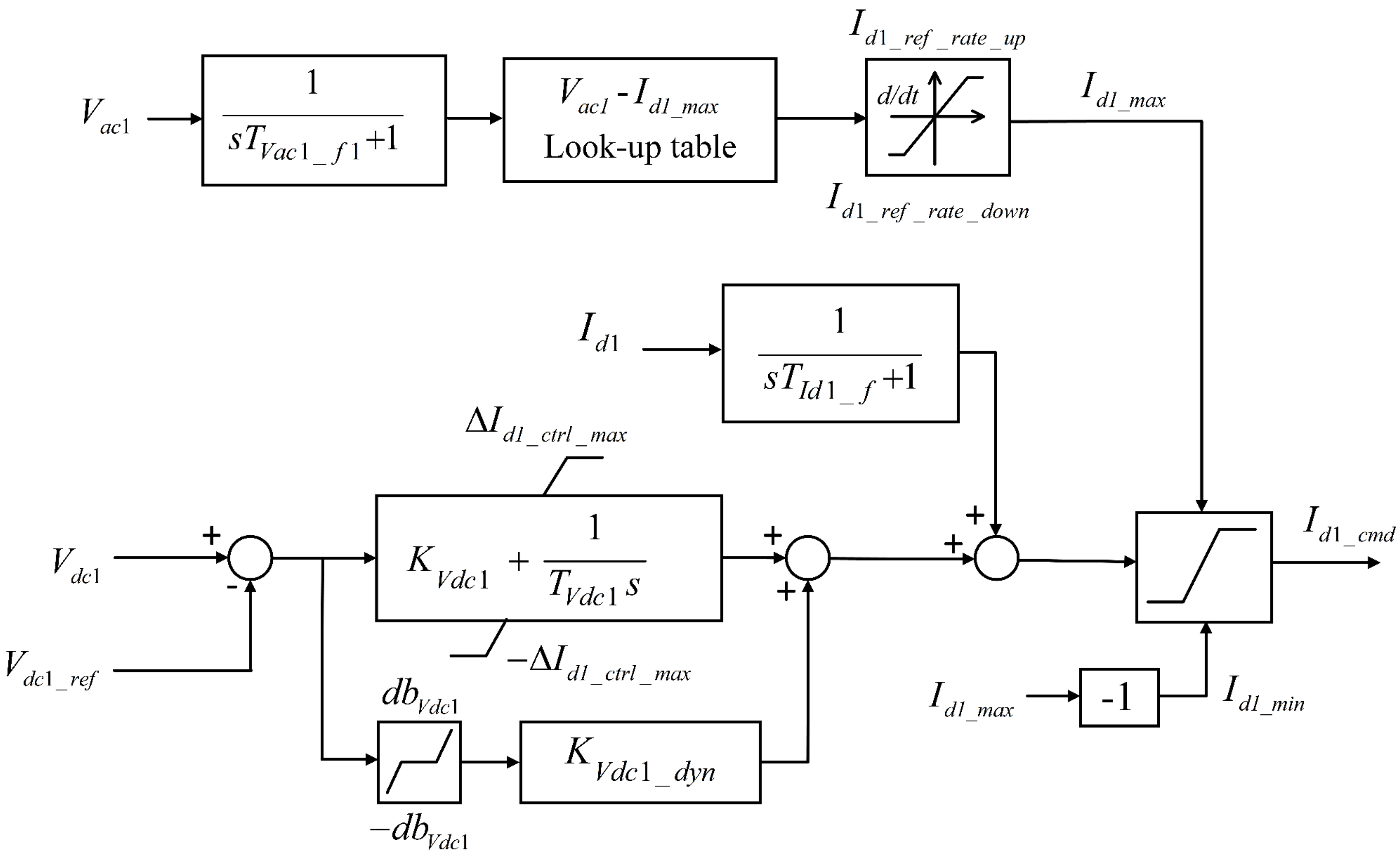
Figure: DC line model in an HVDC system.

- The DC transmission lines and cables are modelled as a standard DC line
- The equivalent capacitances C_1 and C_2 at Sides 1 and 2:

$$C_1 = C_2 = \frac{6 \times C_{SM}}{N_{SM}},$$

where C_{SM} is the capacitance of each submodule, while N_{SM} is the number of submodules per converter

Side-1 Main Converter Model



Active current references for the Side-1 Converter are generated based on the DC bus voltage controller.

Figure: Side-1 converter in interconnection applications (active current command generation).

Side-1 Main Converter Model *(cont'd)*

Reactive current references for the Side-1 Converter are generated based on the AC voltage and reactive power controller.

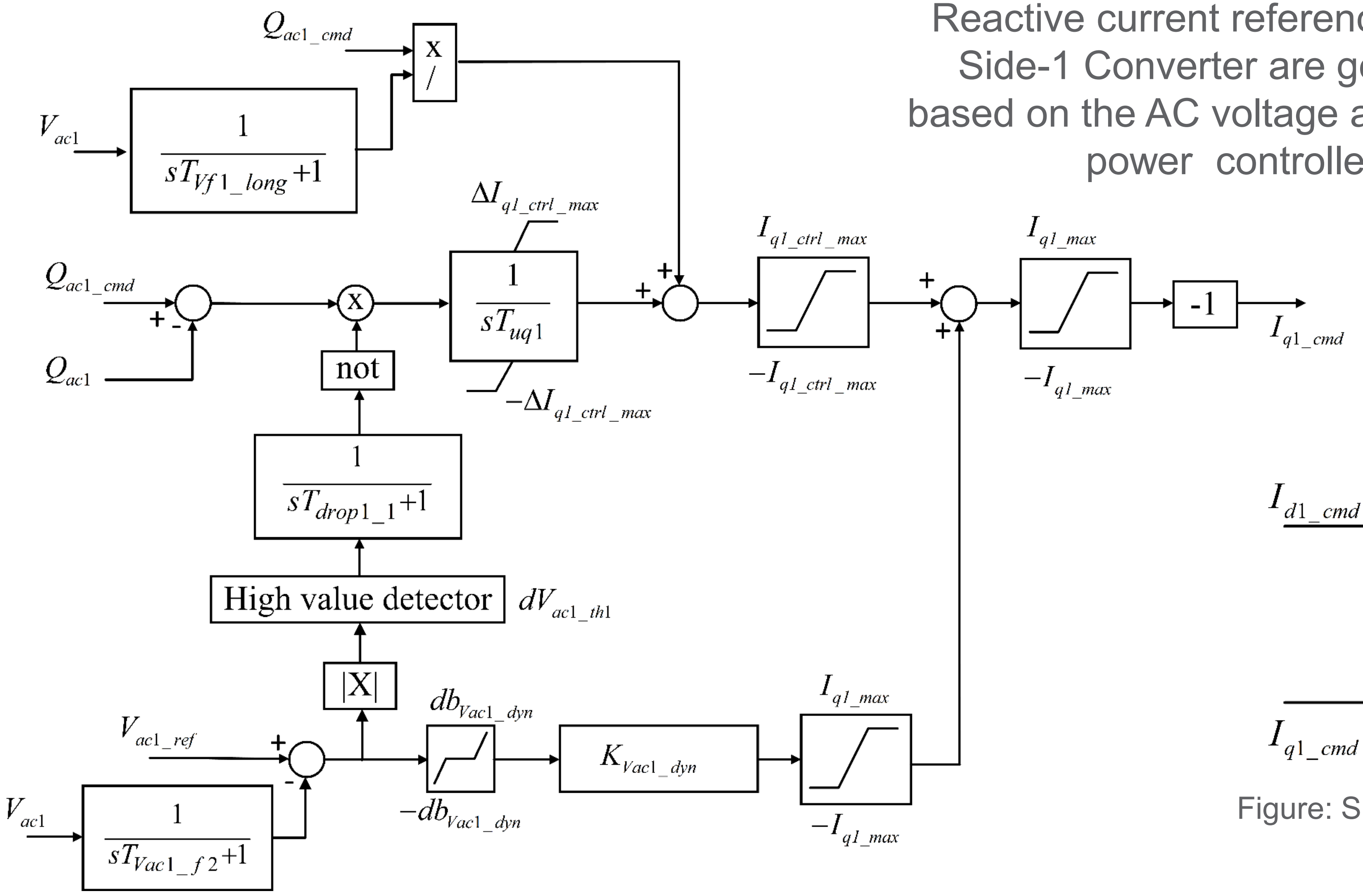


Figure: Side-1 converter in interconnection applications (reactive current command generation).

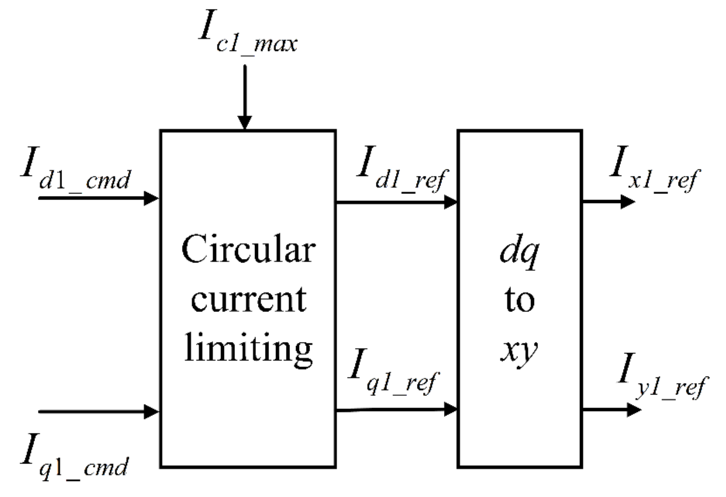


Figure: Side-1 controller current limiting control.

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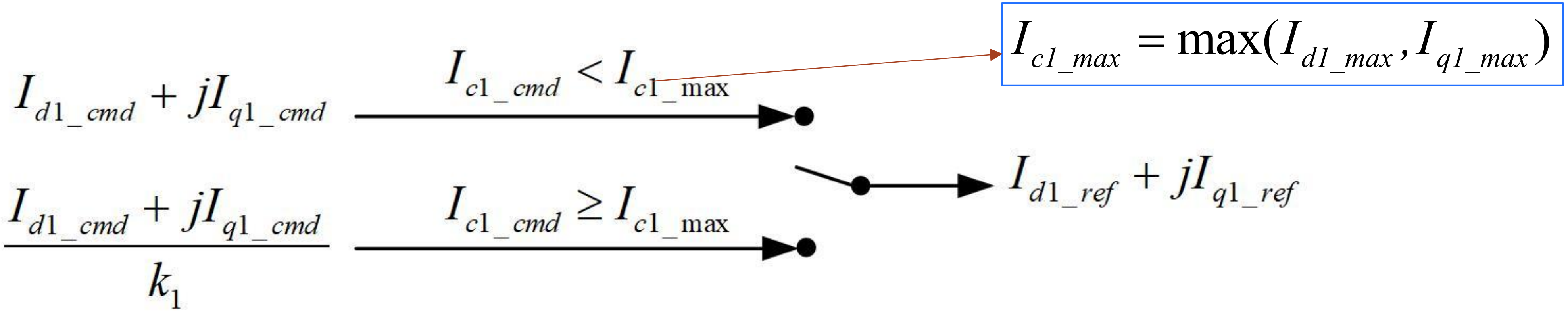
Side-1 Main Converter Model *(cont'd)*

Side 1- Circular Current Limiting Control

The circular limiting strategy is defined as follows:



Where:

$$I_{c1\_cmd} \angle \theta_{c1\_cmd} = I_{d1\_cmd} + jI_{q1\_cmd}$$

$$k_1 = \frac{I_{c1\_cmd}}{I_{c1\_max}}$$

The active- and reactive-current references I_{d1_ref} and I_{q1_ref} from the main control are used to synthesize the phasor reference current $I_{x1\_ref} + jI_{y1\_ref}$ to interface with the AC grid.

Side-1 Reactive Power Control (Outer Loop)

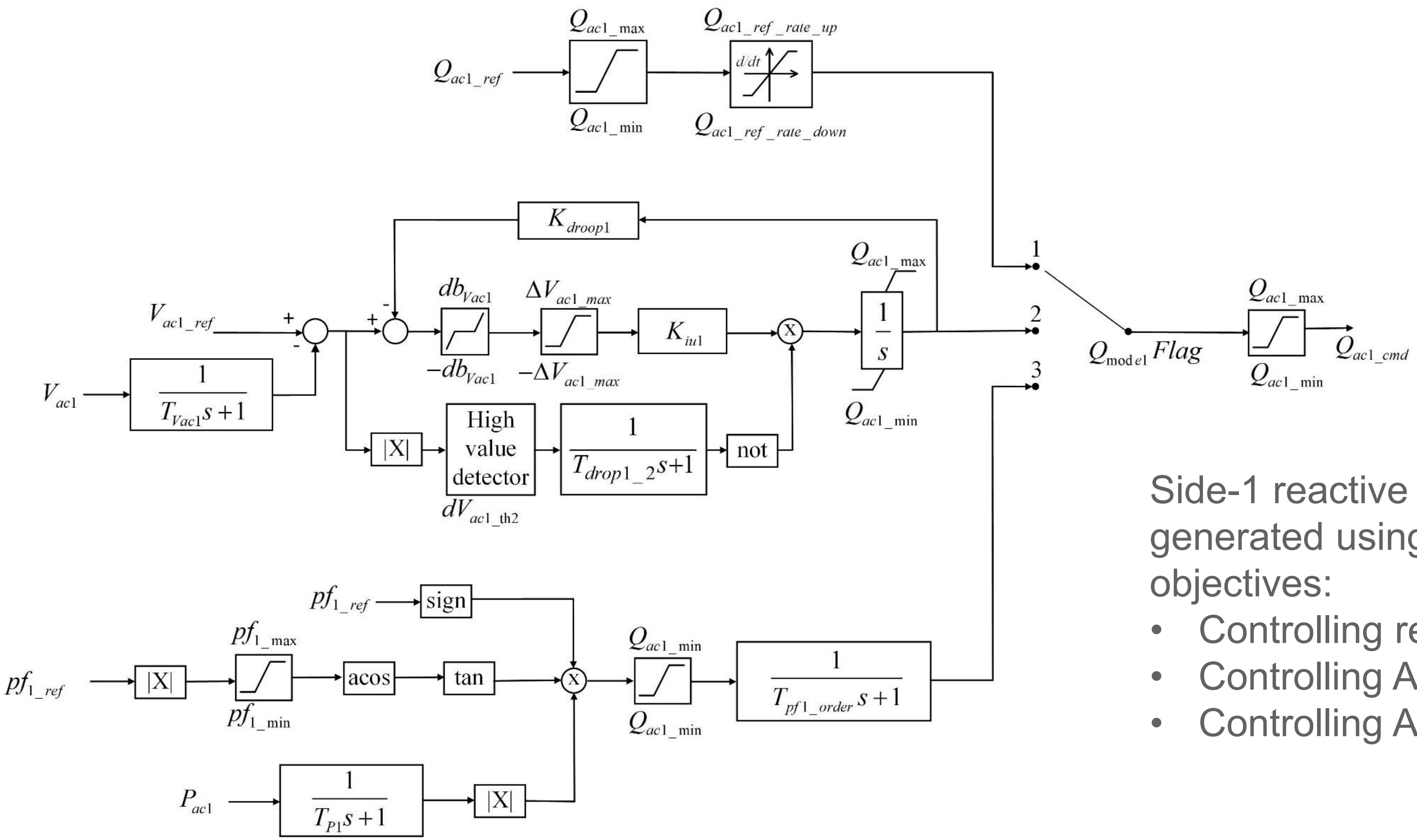


Figure: Side-1 reactive power command generation control in interconnection applications.

Side-1 reactive power command can be generated using one of the following objectives:

- Controlling reactive power
- Controlling AC voltage
- Controlling AC power factor

Side-1 Converter Model in Wind Park Applications

In wind park applications, Side-1 converter operates in GFM mode.

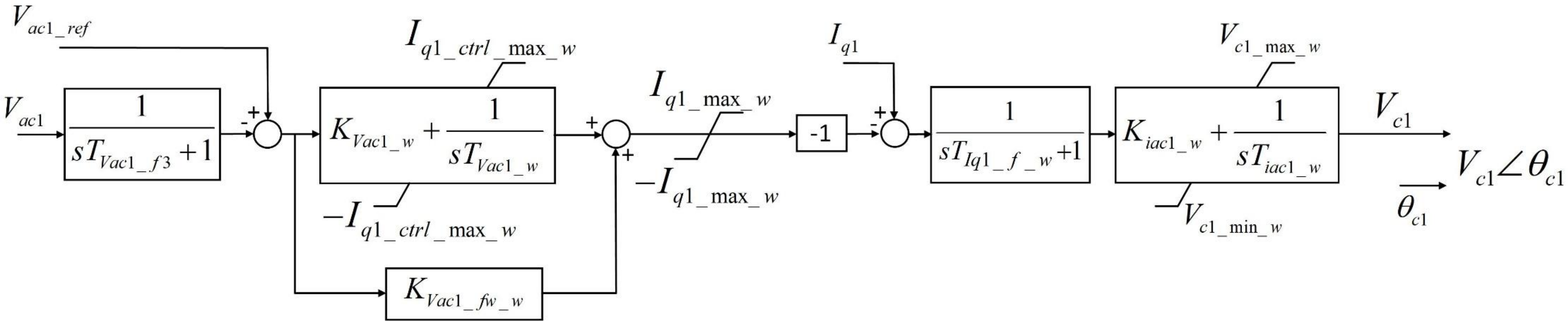


Figure: Main Converter controller of Side-1 in wind park applications.

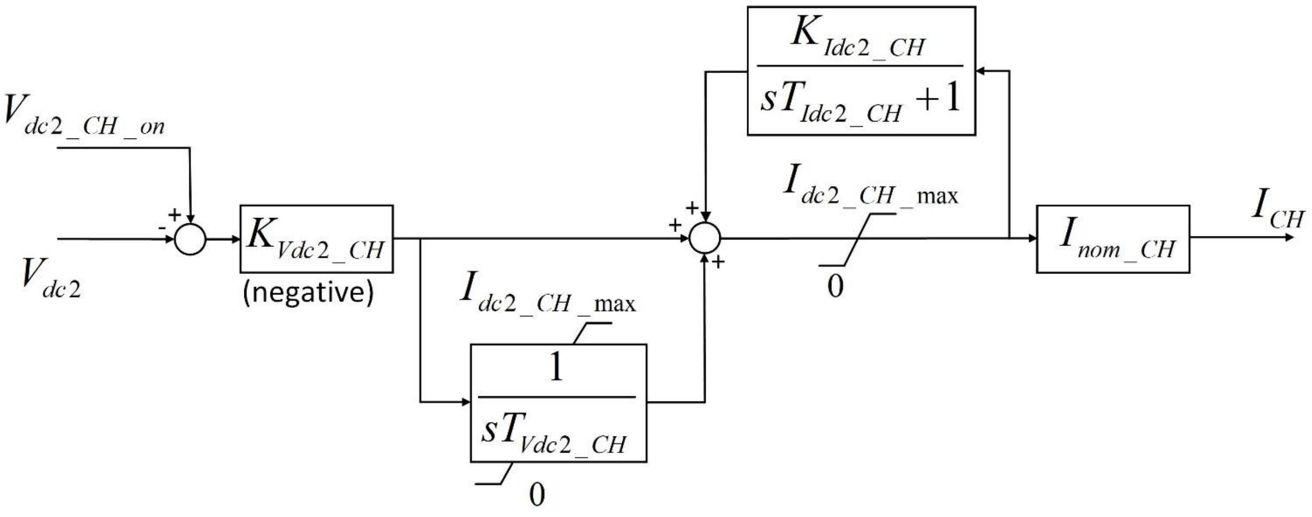


Figure: Chopper Controller.

In wind park applications, a chopper controller is used to protect the HVDC system form a fault at the AC side of Side-2 converter.

Side-2 Main Converter Model

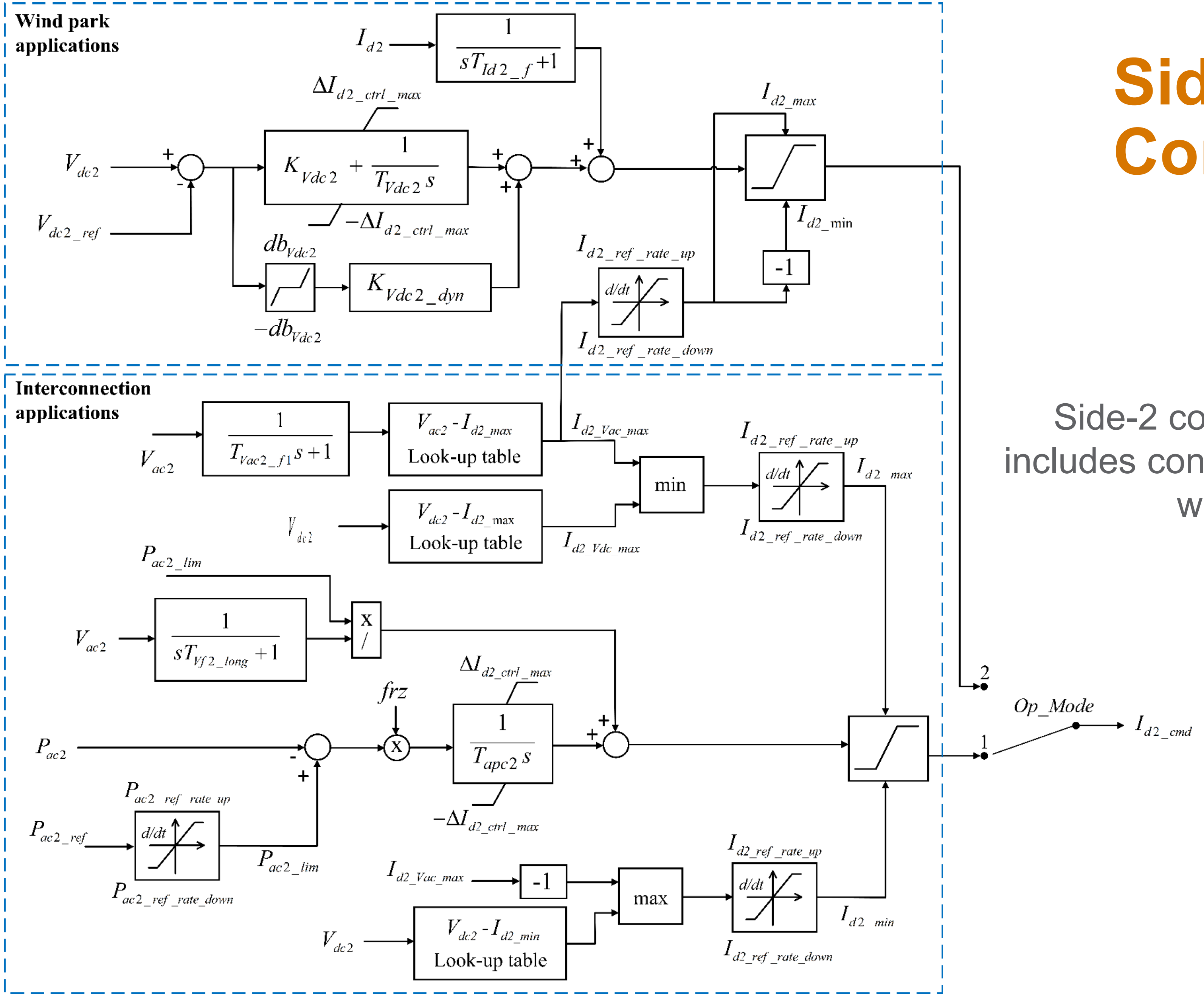


Figure: Side-2 converter active current command generation controller.

Side-2 converter active current control includes control for both interconnection and wind park applications.

Side-2 Main Converter Model

Reactive current references for the Side-2 Converter are generated based on the AC voltage and reactive power controller.

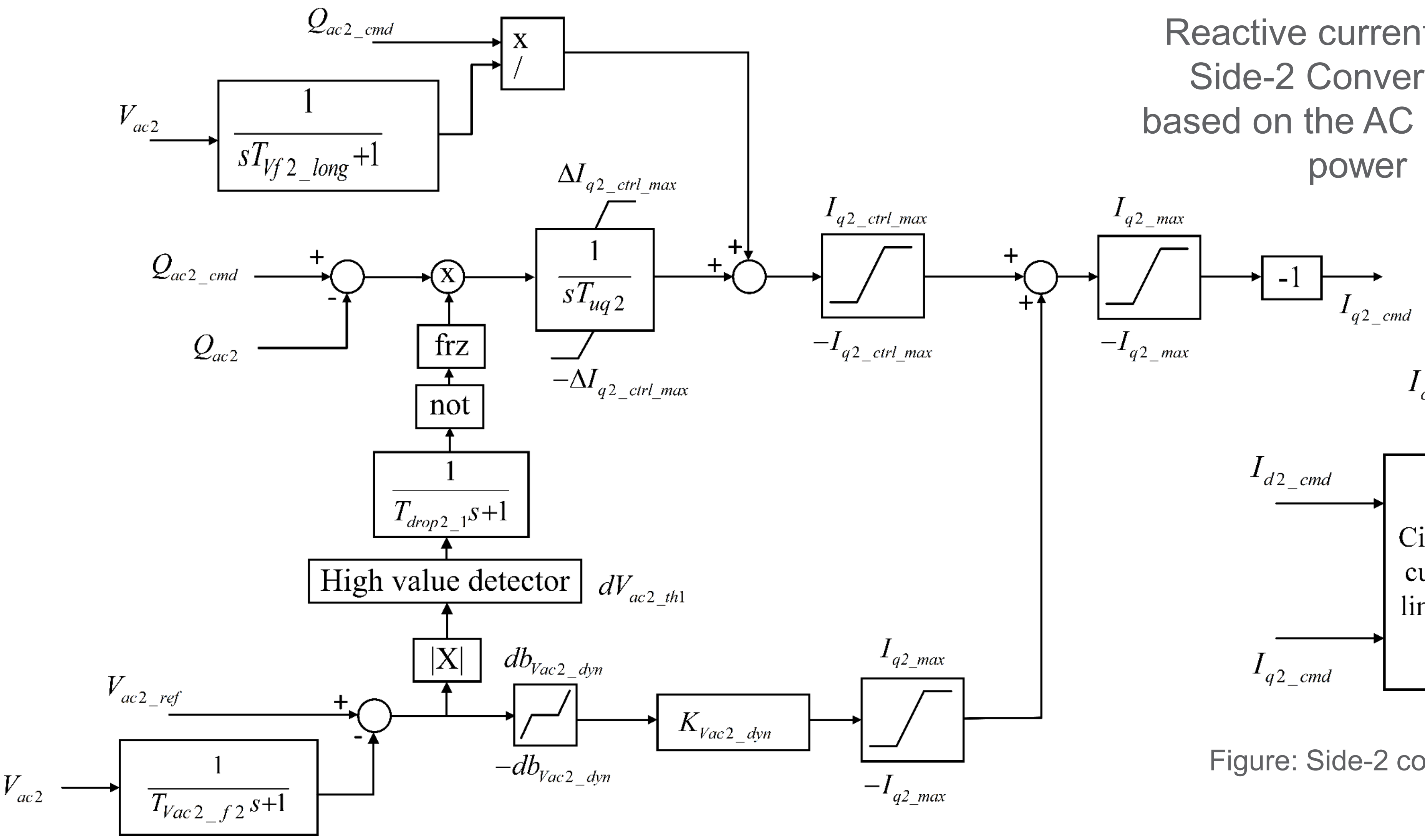


Figure: Side-2 converter reactive current command generation controller.

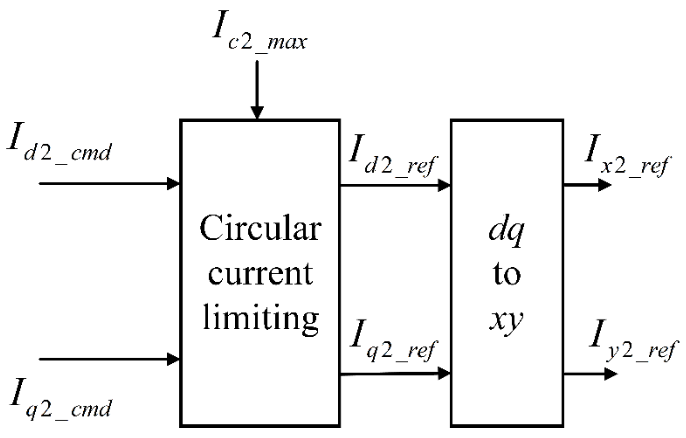


Figure: Side-2 controller current limiting control.

Side-2 Reactive Power Control (Outer Loop)

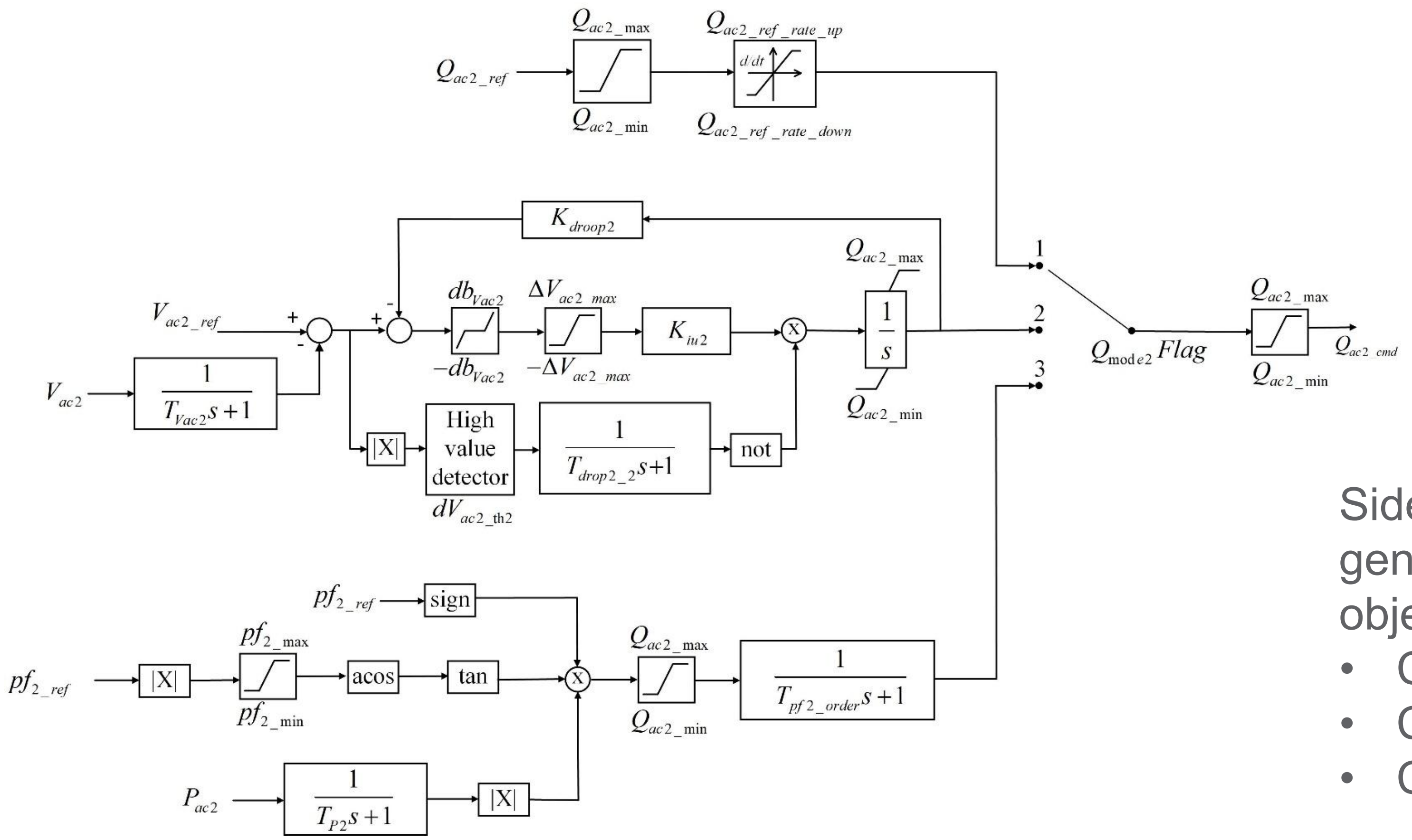


Figure: Side-1 reactive power command generation control in interconnection applications.

Side-2 reactive power command can be generated using one of the following objectives:

- Controlling reactive power
- Controlling AC voltage
- Controlling AC power factor