Pacific Northwest NATIONAL LABORATORY

Meeting with WECC MVS

January 2026

HVDC Model Specification VHVDC_A1

Presenter: Wei Du and Quan Nguyen

Pacific Northwest National Laboratory

U.S. DEPARTMENT OF ENERGY BATTELLE

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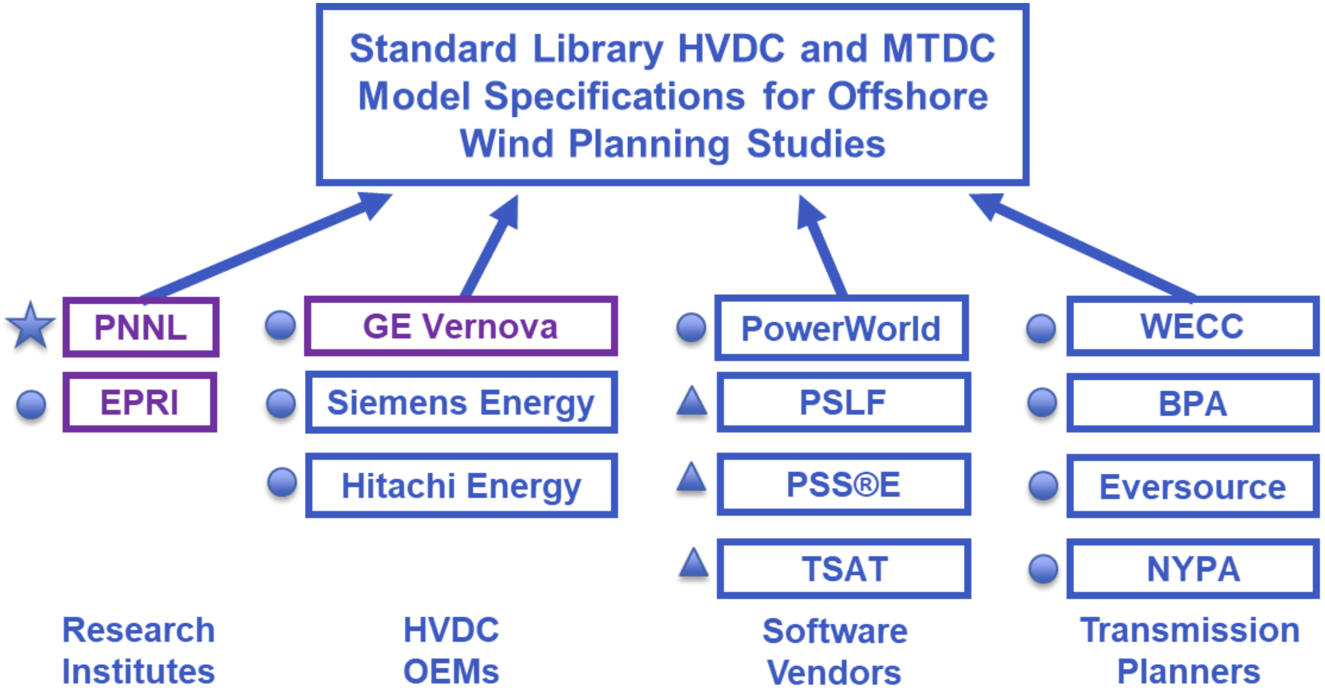
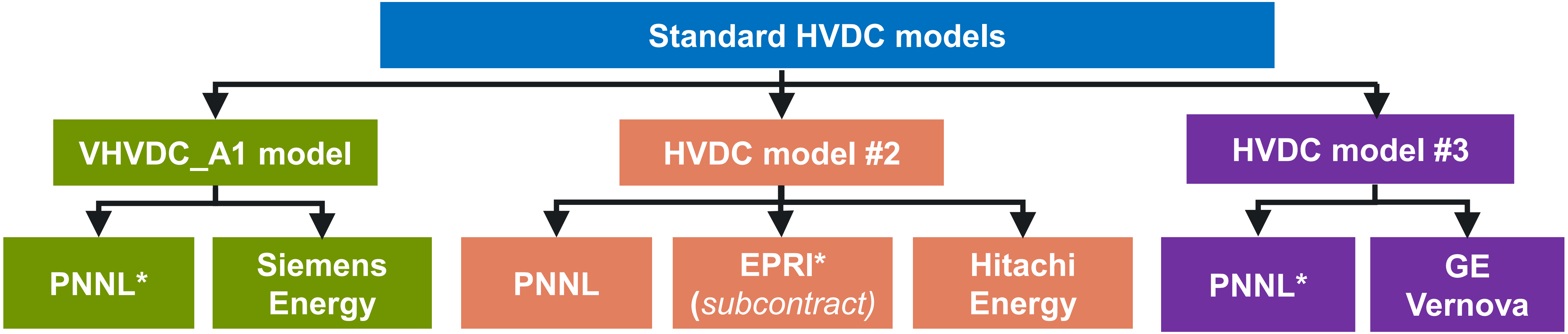
Standard Library HVDC and MTDC Models for Transmission Systems Planning Studies

- **Sponsors**: DOE Wind Energy Technologies Office (WETO) and Grid Deployment Office (GDO)
- **Objectives**:
    - Collaborate with WECC MVS, HVDC manufacturers, software vendors, transmission planners, and research institutes to develop standard library HVDC and MTDC models



HVDC Model Development

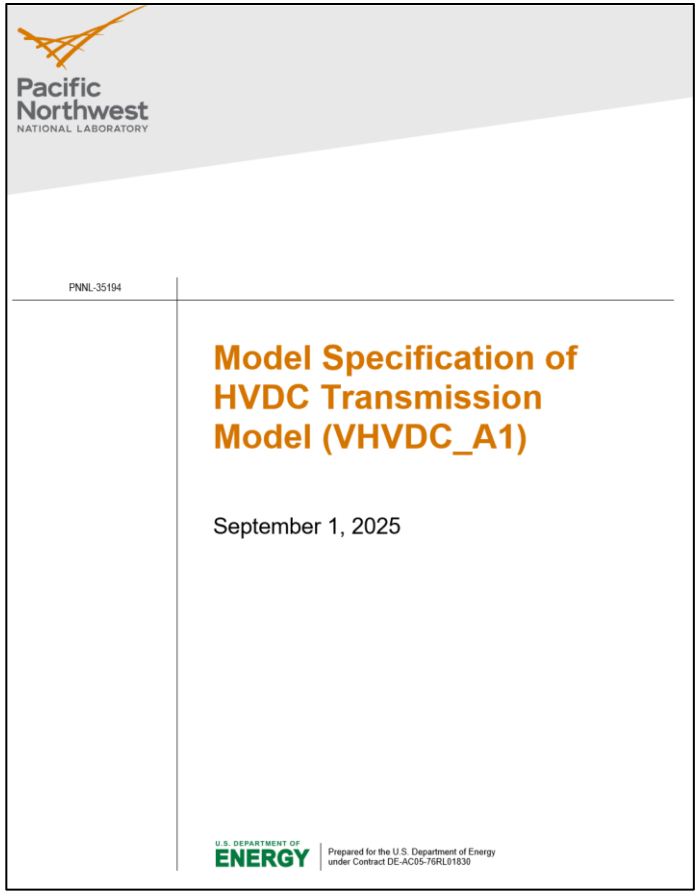
- **Approach**: Develop separate HVDC models the can better represent HVDC technologies used by Siemens Energy, Hitachi Energy, and GE Vernova



VHVDC_A1 Model Specification

Contributors

Names	Organizations
Wei Du	Pacific Northwest National Laboratory
Quan Nguyen	Pacific Northwest National Laboratory
Sheik M Mohiuddin	Pacific Northwest National Laboratory
Marcelo Elizondo	Pacific Northwest National Laboratory
Richard Hoese	Siemens Energy
Andreas Hanschick	Siemens Energy
Tuan Trinh	Siemens Energy
Eugen Starschich	Siemens Energy
Ara Panosyan	Siemens Energy
Pouyan Pourbeik	Power and Energy, Analysis, Consulting and Education (PEACE®) PLLC
James Weber	PowerWorld
Saurav Mohapatra	PowerWorld
Jayapalan Senthil	Siemens
Mengxi Chen	GE Vernova
Juan Sanchez-Gasca	GE Vernova (retired)
Jeff Bloemink	PowerTech Labs
Fred Howell	PowerTech Labs
Parag Mitra	Electric Power Research Institute
Song Wang	Portland General Electric
Doug Tucker	Western Electricity Coordinating Council
Songzhe Zhu	GridBright, a Qualus Company


Pacific Northwest NATIONAL LABORATORY

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Model Specification of HVDC Transmission Model (VHVDC_A1)

September 1, 2025

U.S. DEPARTMENT OF ENERGY

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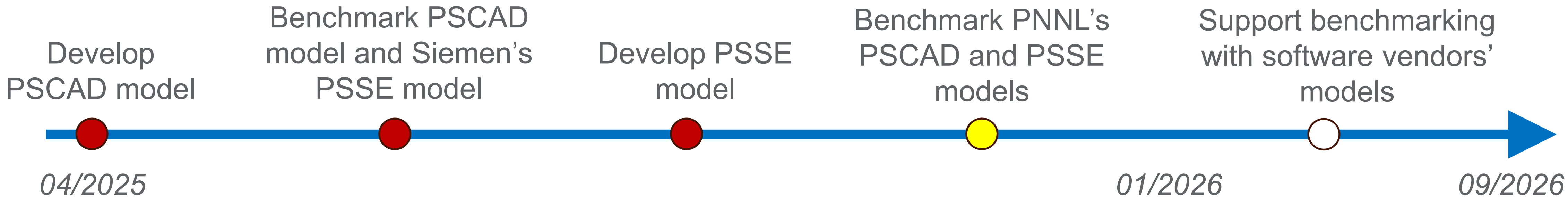
Engagement with MVS on VHVDC_A1 Model Specification

- The DOE HVDC/MTDC modeling project was introduced at MVS in Jan. 2025
- The initial version of VHVDC_A1 model spec was presented at MVS on Sept. 11th, 2025
- Multiple small group meetings was held with domain experts and software vendors to improve the spec during 2025
- The updated VHVDC_A1 was sent by the MVS chair to all MVS members on Nov. 11th, 2025

VHVDC_A1 Model Specification Development

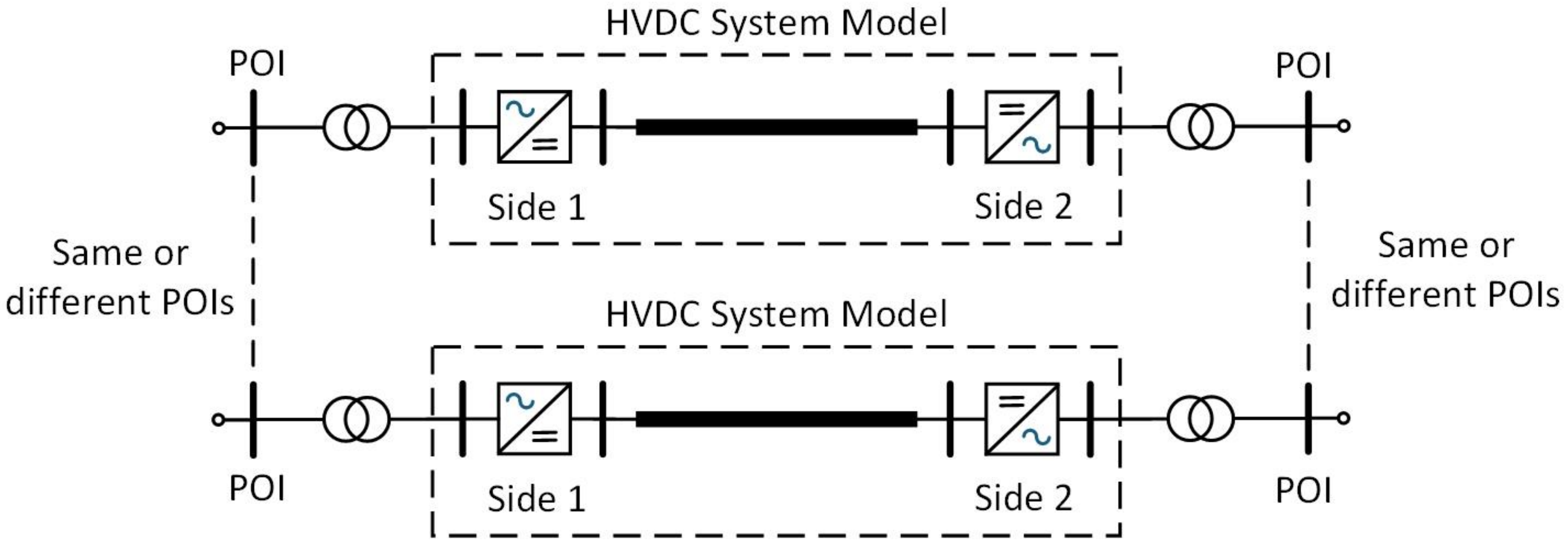
- **Siemens Energy** provided a UDM and detailed control blocks for an HVDC model
  - Interconnection applications
  - Islanded wind farm applications
- **PNNL** develops the VHVDC_A1 model specification based on Siemens Energy's inputs
  - Incorporated comments from WECC MVS members and software vendors

PNNL plan on developing VHVDC_A1 model



VHVDC_A1 Model Specification

- **Model applications**
  - Interconnection and islanded wind farm applications
  - Support general planning studies, except DC-side faults and contingencies within an islanded wind farm.
- **HVDC configuration representation**
  - Inherently represent a point-to-point monopole HVDC link
  - A bipole HVDC system can be emulated by combining two monopole links



VHVDC_A1 Model Specification

- **Model specification 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)
    - Islanded wind farm applications (one converter in grid-forming mode and the other in grid-following mode)

AC-DC Power Flow Model

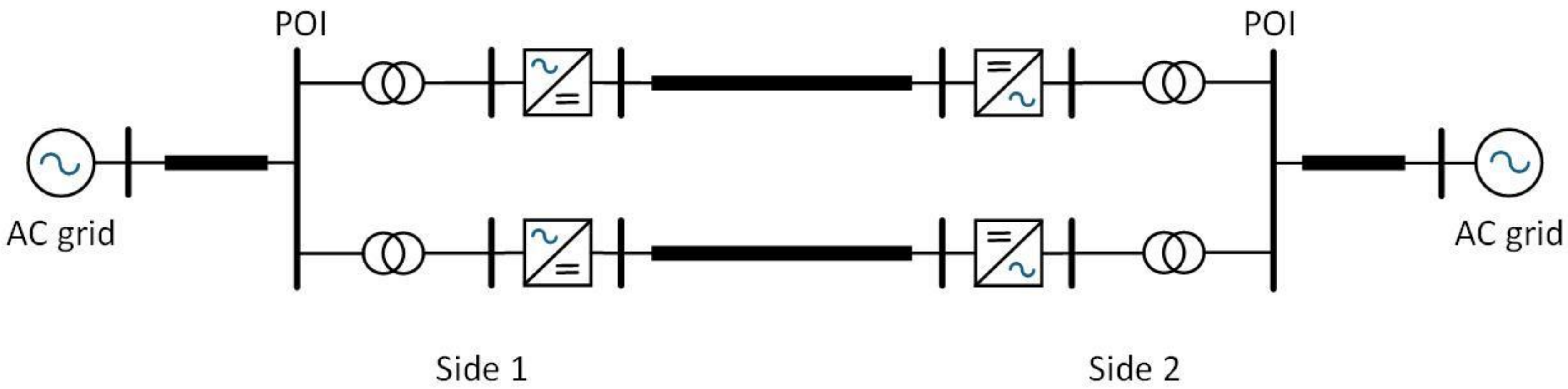


Figure: Power flow model of a 2-terminal bipole HVDC system.

- 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 the two poles modeled as separate links.
- The AC-DC power flow solution relies on the control modes of Side-1 and Side-2 converters of each HVDC link. 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 a positive or negative power set point.
  - **Option 2** (for islanded wind farm 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

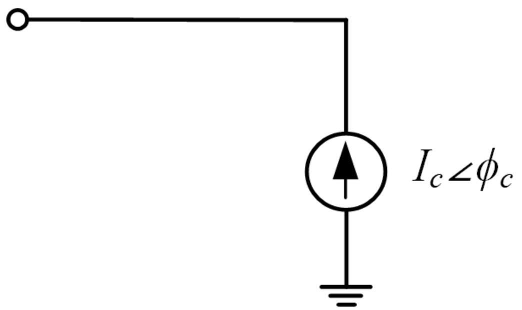


Figure: Equivalent interface of a GFL converter with the AC grid.

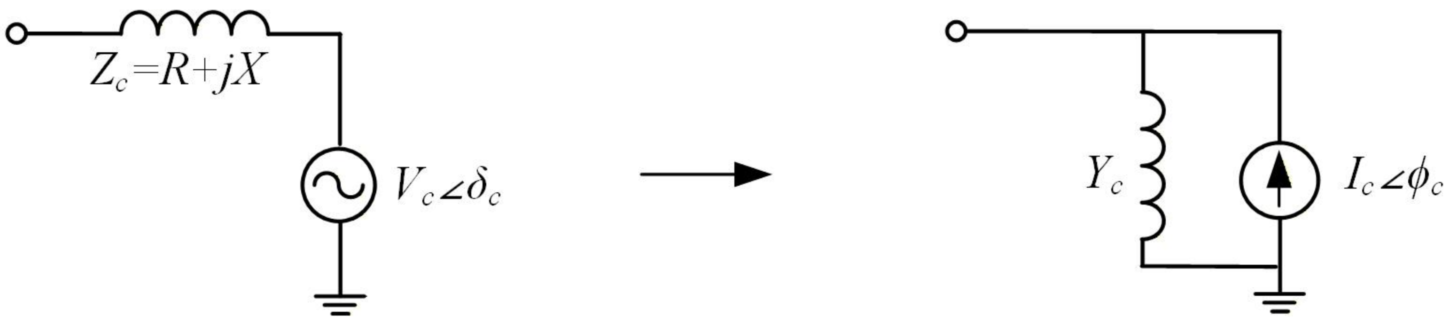


Figure: Thevenin-equivalent representation and converted Norton-equivalent interface of a GFM converter with the AC grid

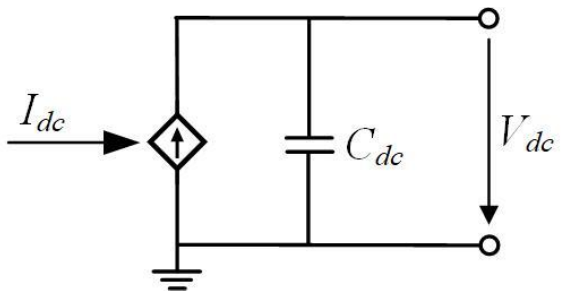


Figure: Equivalent interface of a GFL converter with the DC grid.

DC injection current

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

DC Line Model

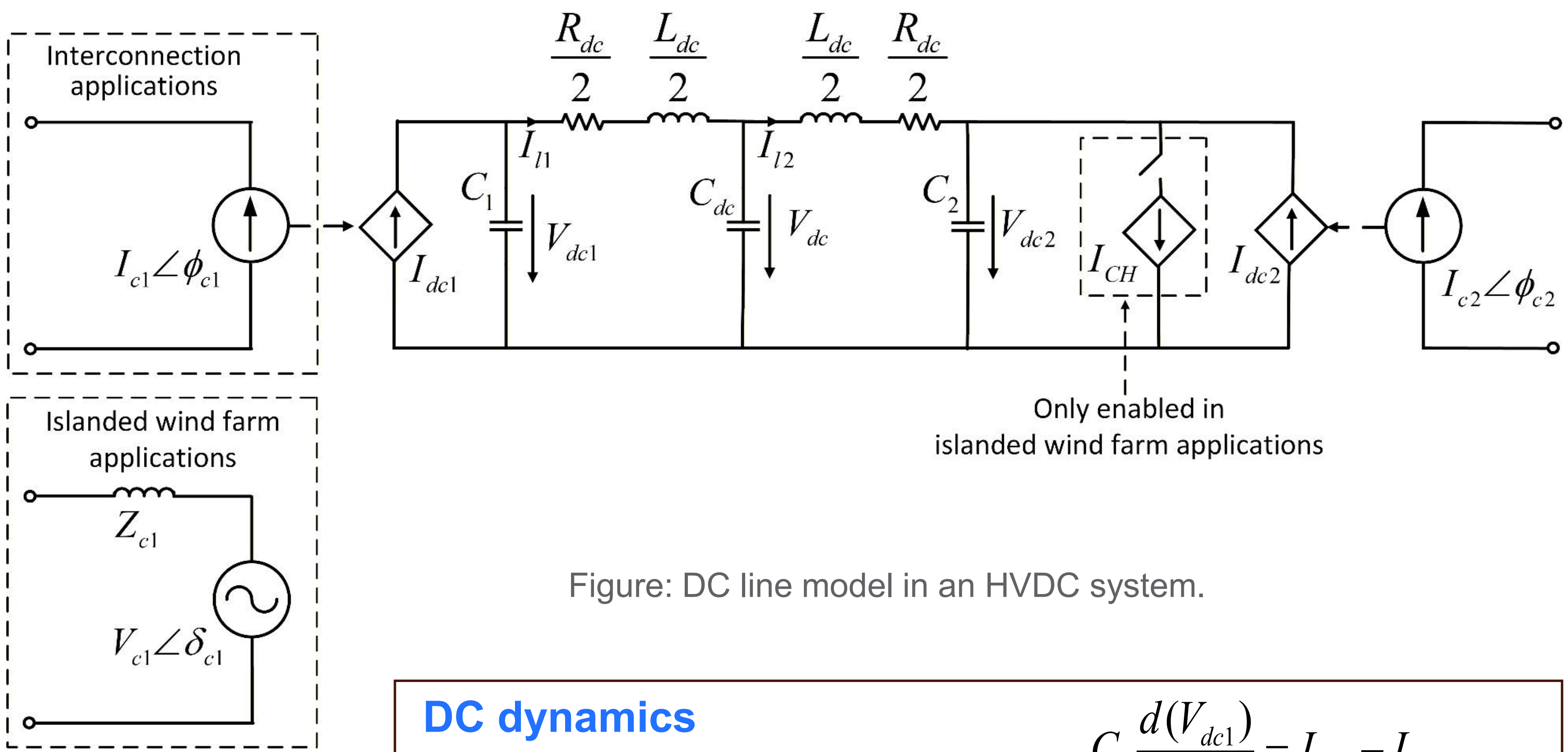


Figure: DC line model in an HVDC system.

DC dynamics

$$\frac{L_{dc}}{2}\frac{d(I_{l1})}{dt} = V_{dc1} - V_{dc} - I_{l1}\frac{R_{dc}}{2}$$

$$\frac{L_{dc}}{2}\frac{d(I_{l2})}{dt} = V_{dc} - V_{dc2} - I_{l2}\frac{R_{dc}}{2}$$

$$C_1\frac{d(V_{dc1})}{dt} = I_{dc1} - I_{l1}$$

$$C_{dc}\frac{d(V_{dc})}{dt} = I_{l1} - I_{l2}$$

$$C_2\frac{d(V_{dc2})}{dt} = I_{l2} - I_{CH} + I_{dc2}$$

Measurements and Phase-Locked Loop in Converter Control

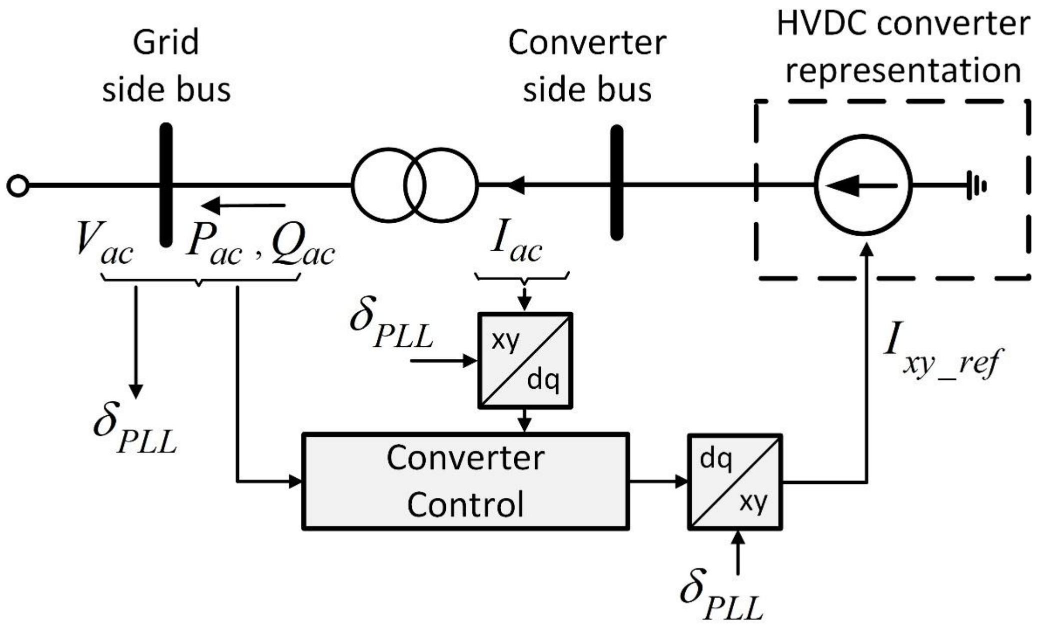


Figure: Measurements and PLL in grid-following mode.

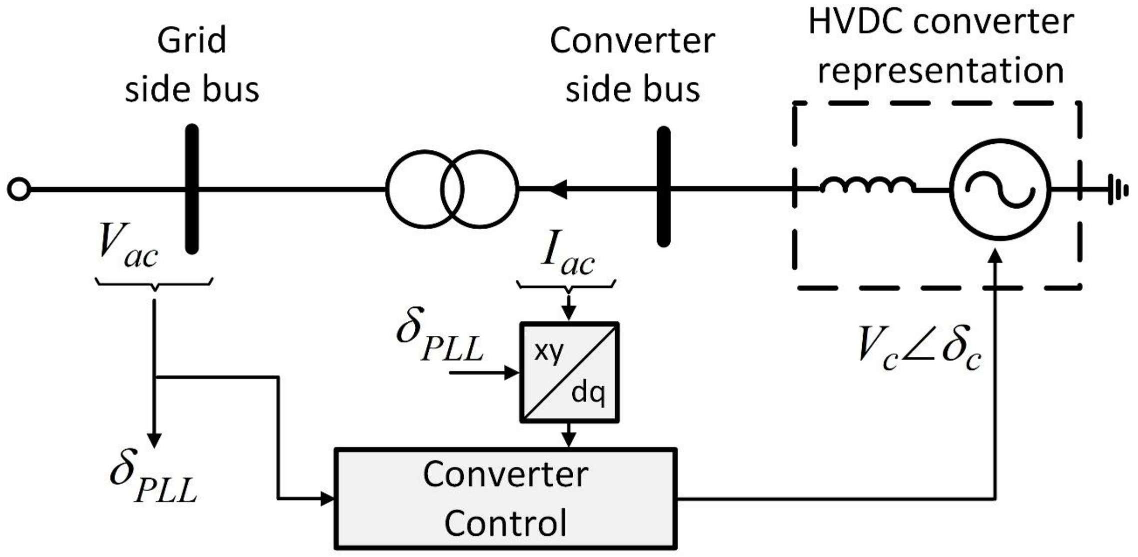


Figure: Measurements and PLL in V-F mode (Side-1 Converter in islanded wind farm applications).

$$\delta_{PLL} = \frac{1}{1 + T_{PLL,sync}s} \tan^{-1}\left(\frac{V_y}{V_x}\right)$$

(No PLL angle freezing even at low voltage condition!)

Side-1 Main Converter Model in Interconnection Applications

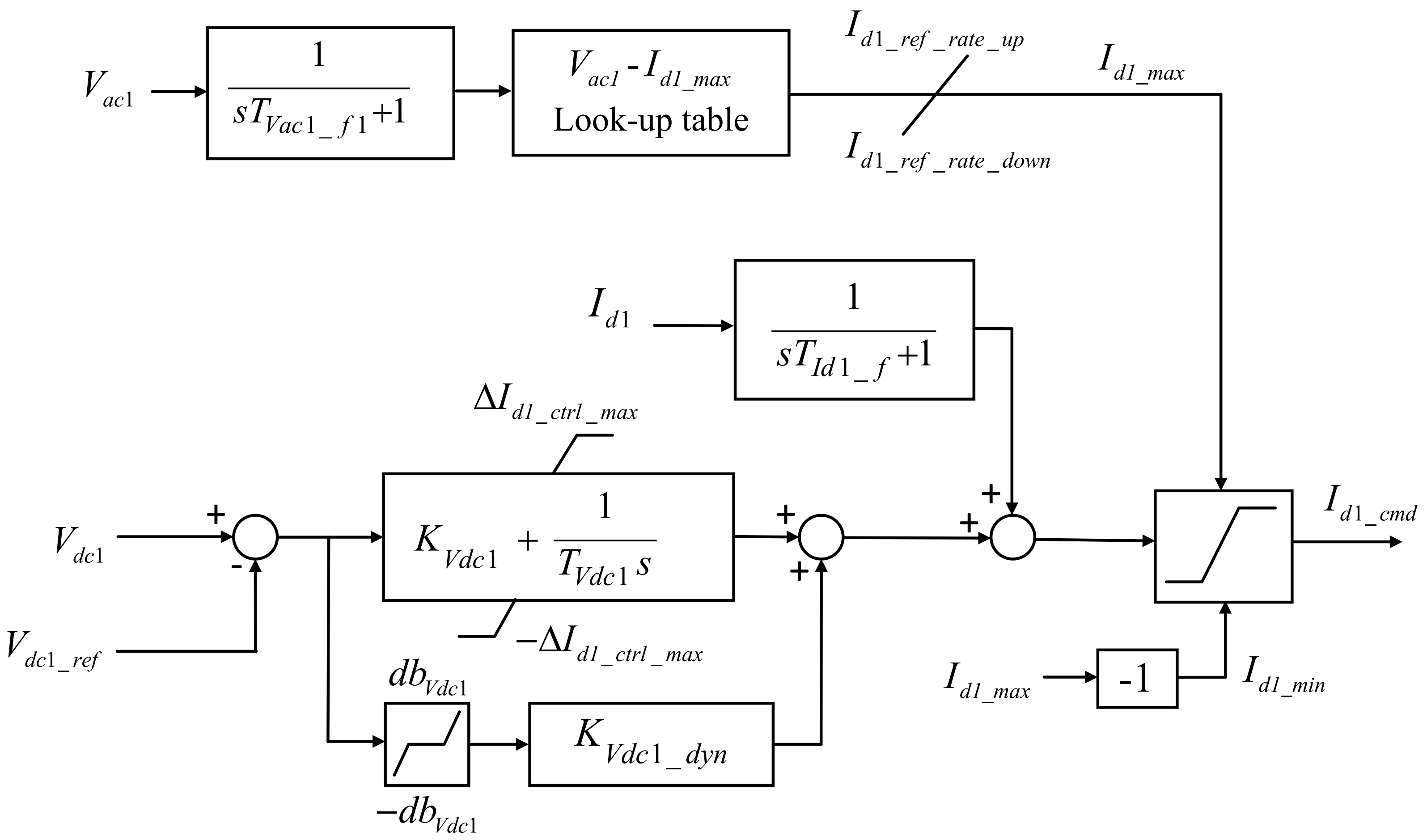


Figure: Side-1 converter in interconnection applications (active current command generation).

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

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

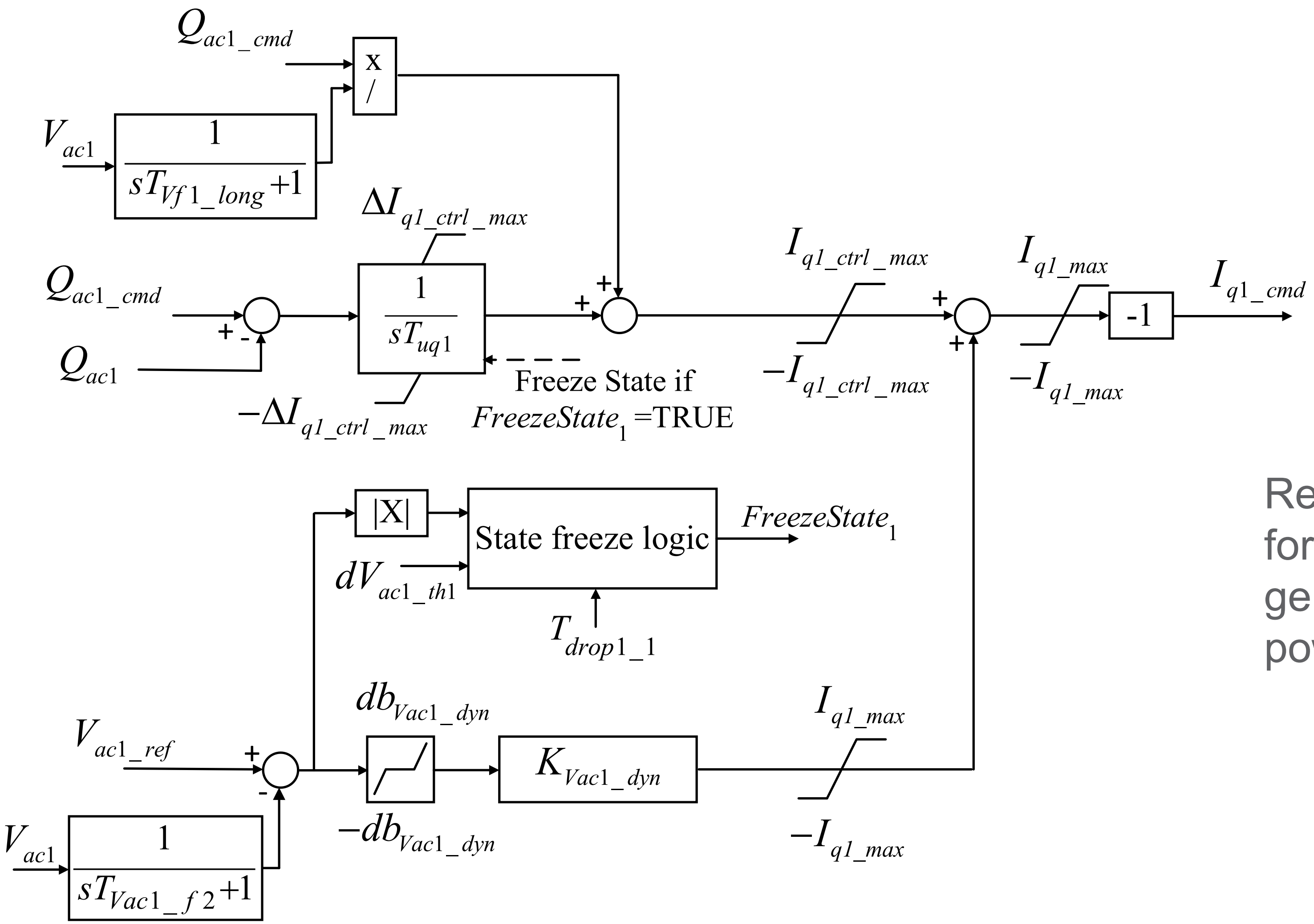


Figure: Side-1 converter in interconnection applications (reactive current command generation).

Reactive current reference for the Side-1 Converter is generated based on reactive power controller

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

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.

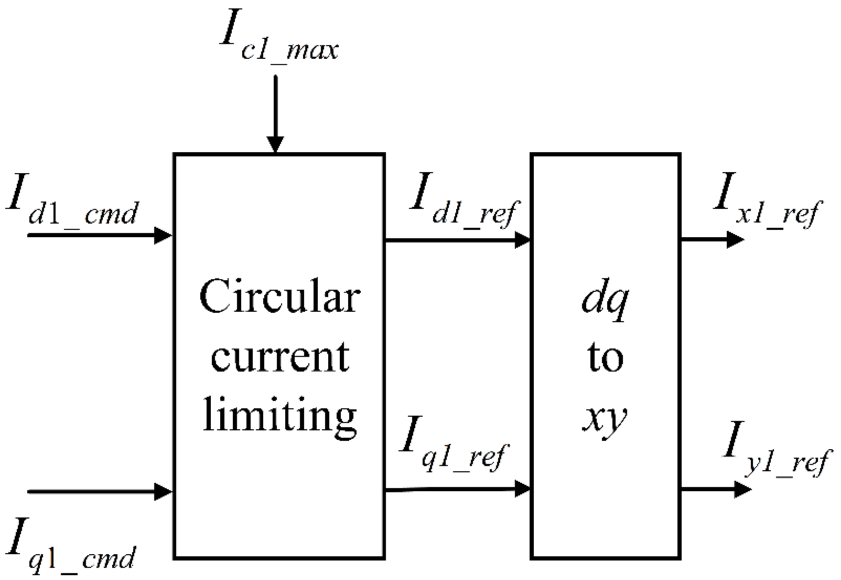
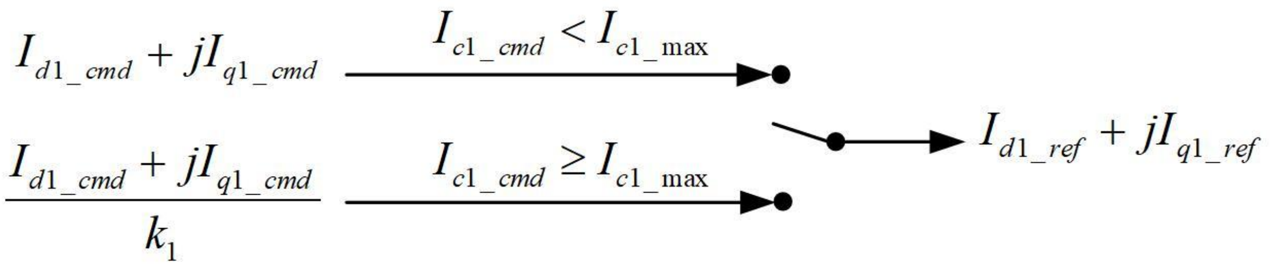


Figure: Side-1 controller current limiting control.

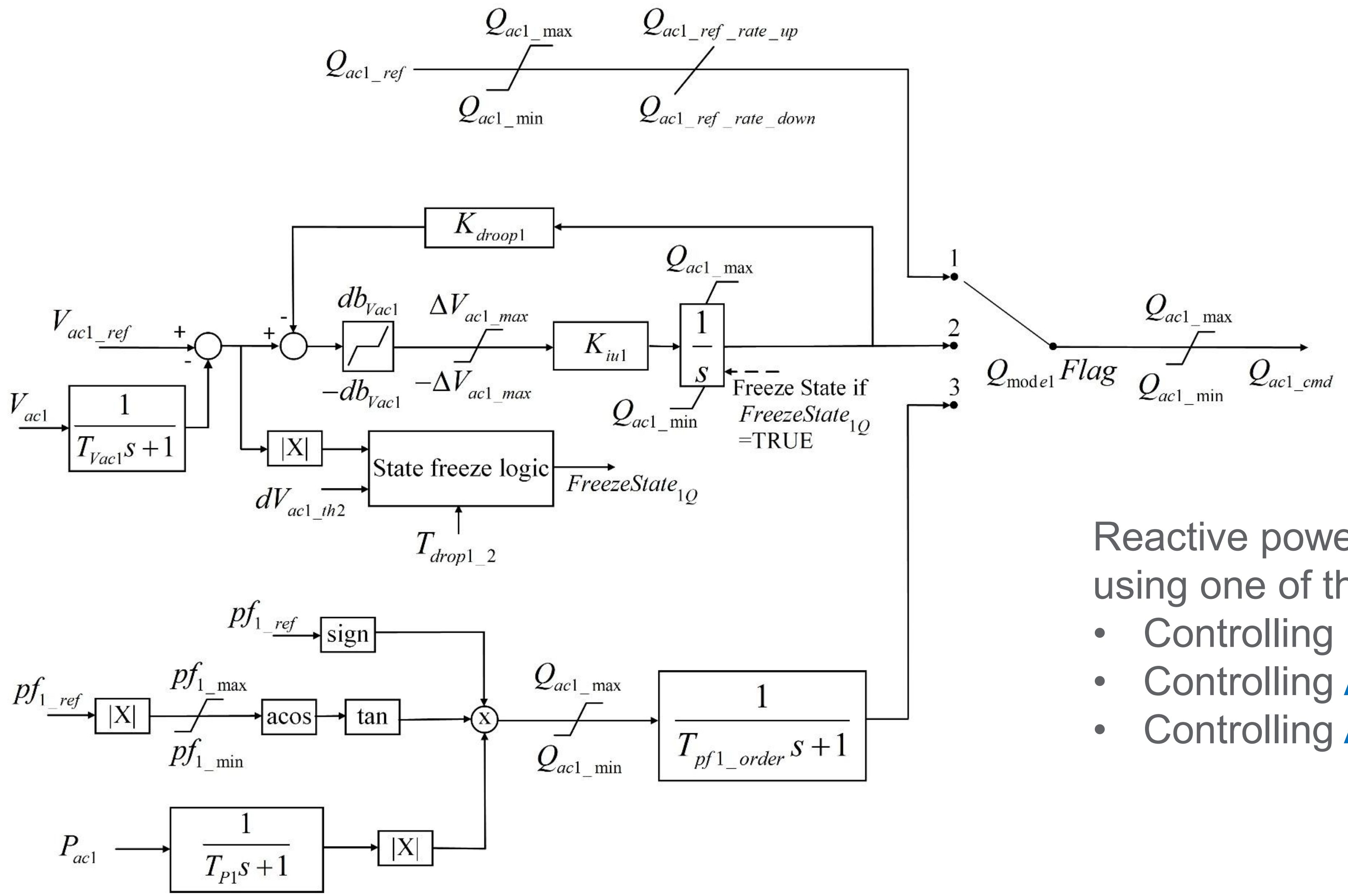
Circular Current Limiting Control



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

$$k_1 = \frac{I_{c1\_cmd}}{I_{c1\_\max}}$$

Side-1 Reactive Power Control (Outer Loop) in Interconnection Applications



Reactive power command can be generated using one of the following objectives:

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

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

Side-1 Converter Model in Islanded Wind Farm Applications

Side-1 converter operates in **V-F mode**

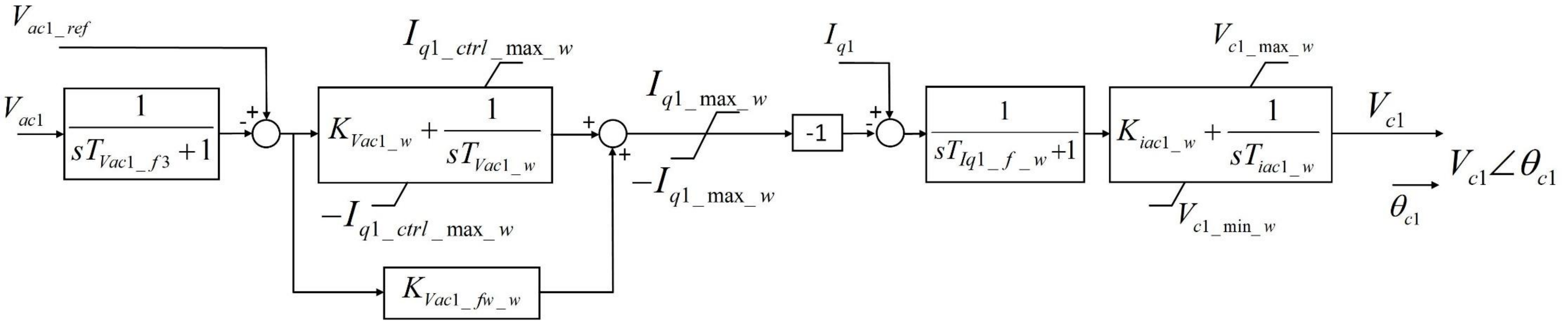


Figure: Main Converter controller of Side-1 in wind park applications.

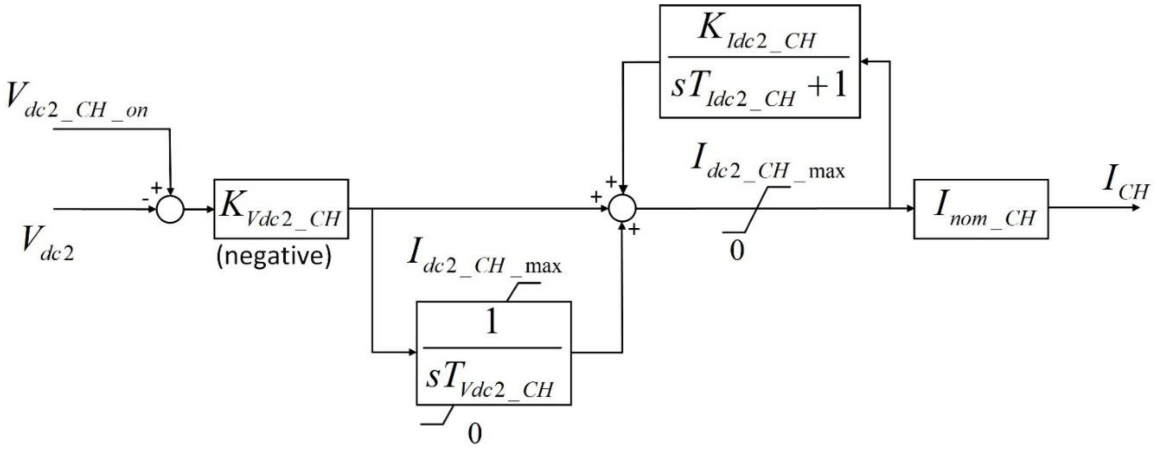


Figure: Chopper Controller.

A **DC chopper** prevents DC voltages following a fault at the AC side of Side-2 converter.

$$I_{dc2\_eff} = I_{dc2} - I_{CH}$$

$$\int_{T_0}^{t} (V_{dc2} I_{CH}) dt > E_{CH\_max} \quad \rightarrow \text{trip the chopper}$$

Side-2 Main Converter Model

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

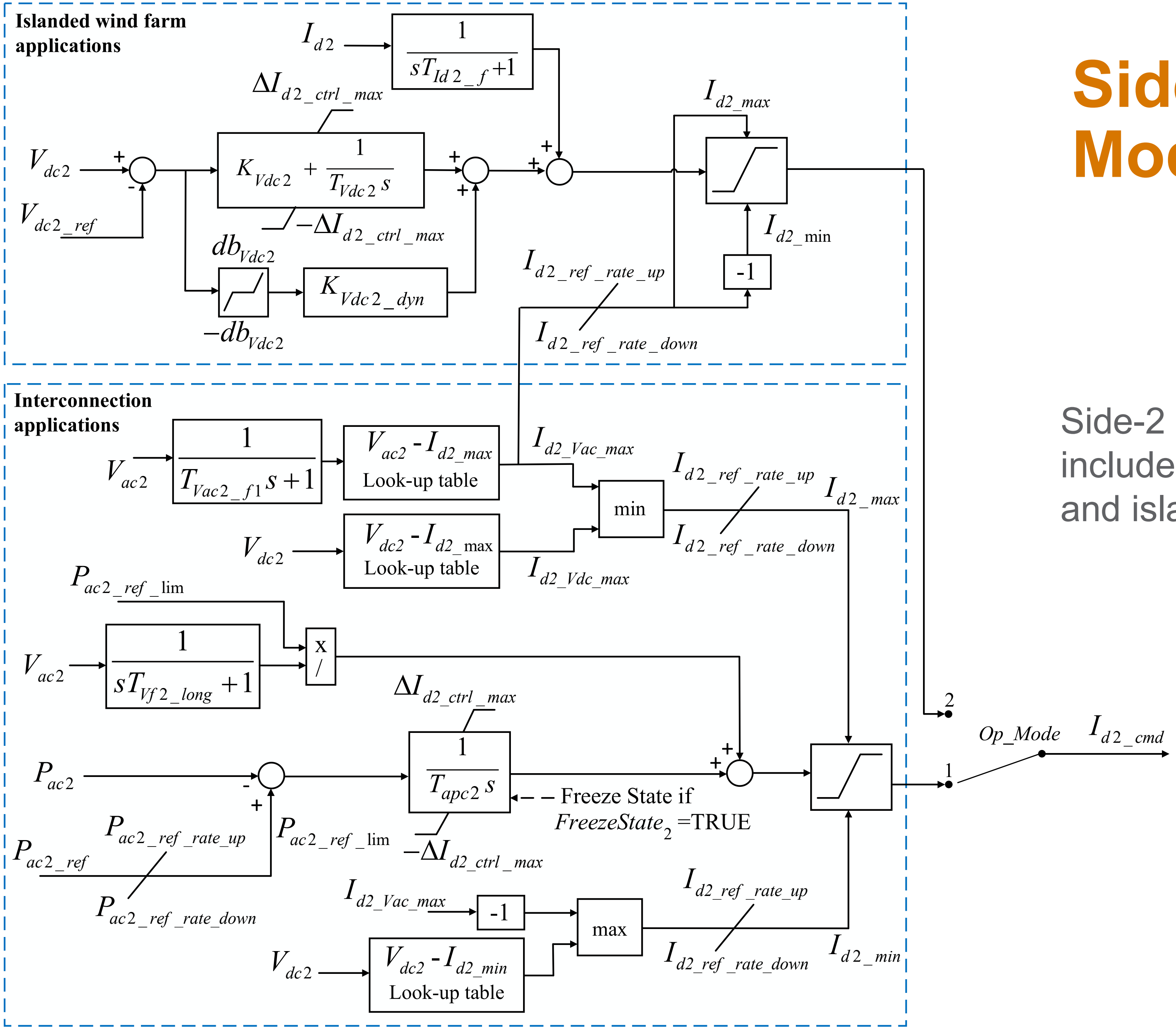


Figure: Side-2 converter active current command generation controller.

Side-2 Main Converter Model *(cont'd)*

Reactive current reference for the Side-2 Converter is generated based reactive power controller (identical to Side 1)

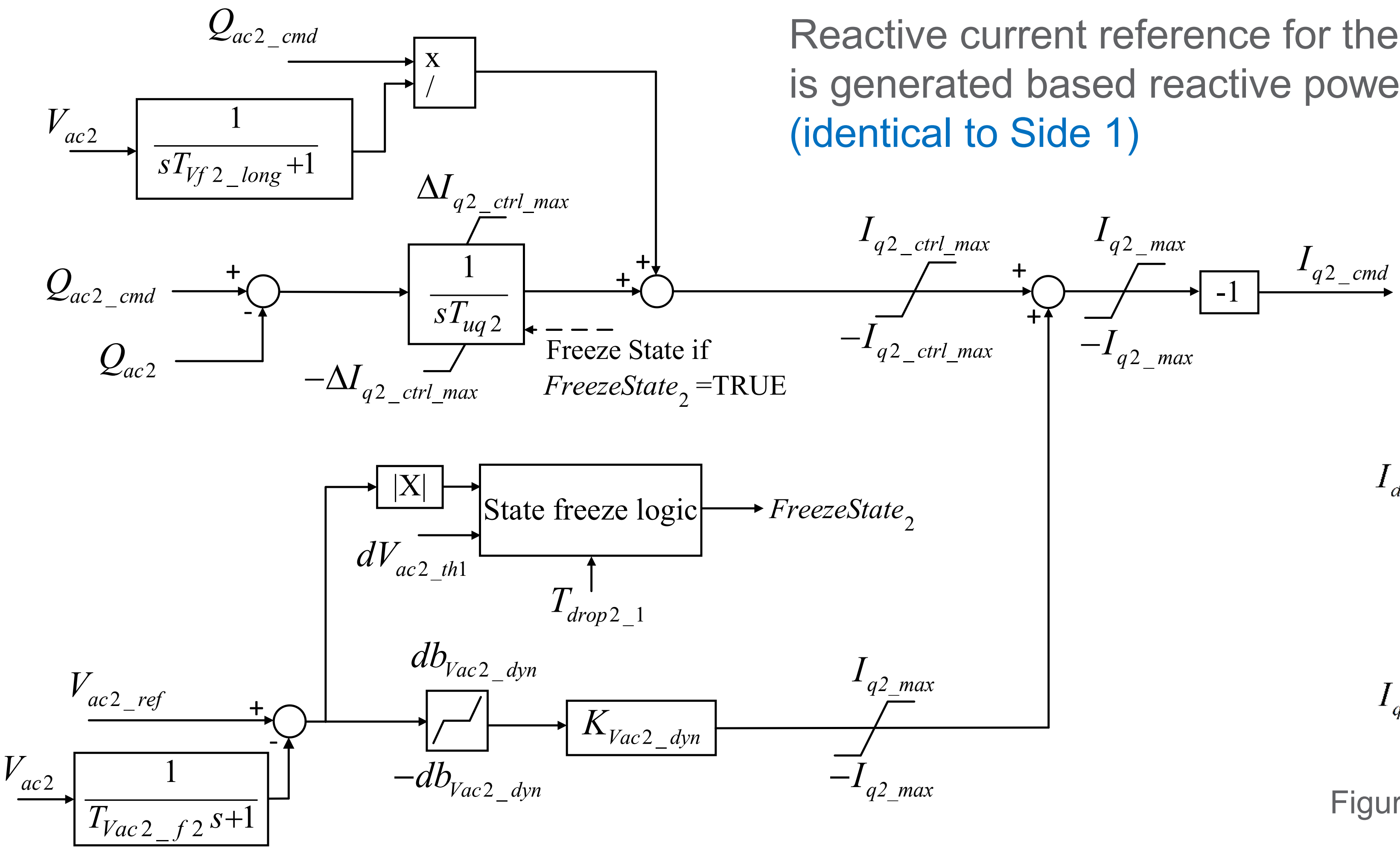


Figure: Side-2 converter reactive current command generation controller.

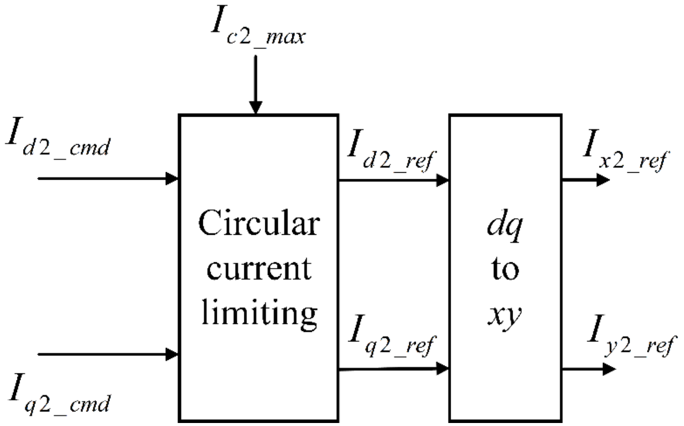


Figure: Side-2 controller current limiting control.

Side-2 Reactive Power Control (Outer Loop)

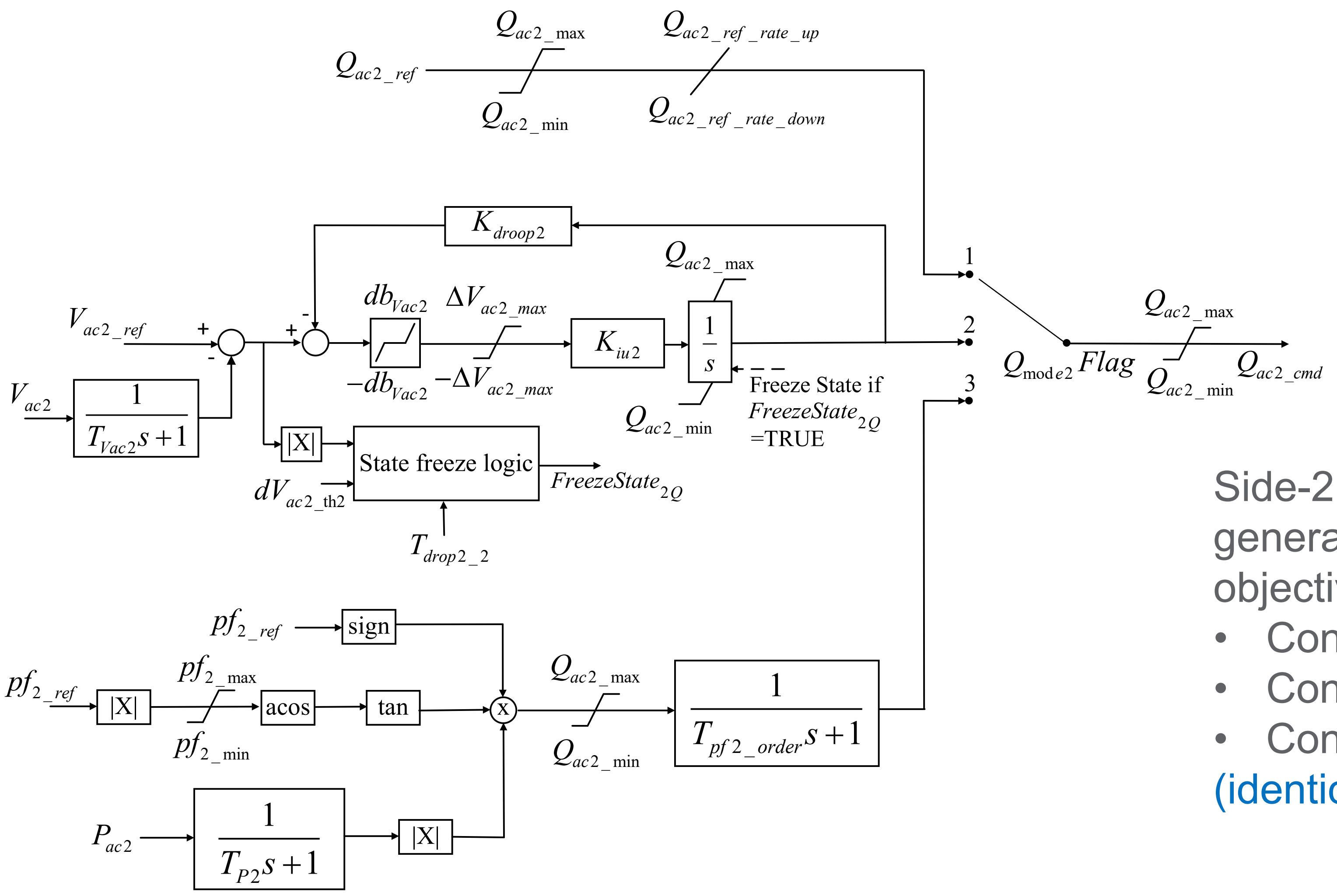


Figure: Side-1 reactive power command generation control in interconnection applications.

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

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

(identical to Side 1)