RTDS SIMULATION OF GRID FORMING INVERTER BASED RESOURCES

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RTDS TECHNOLOGIES INC.

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Introduction

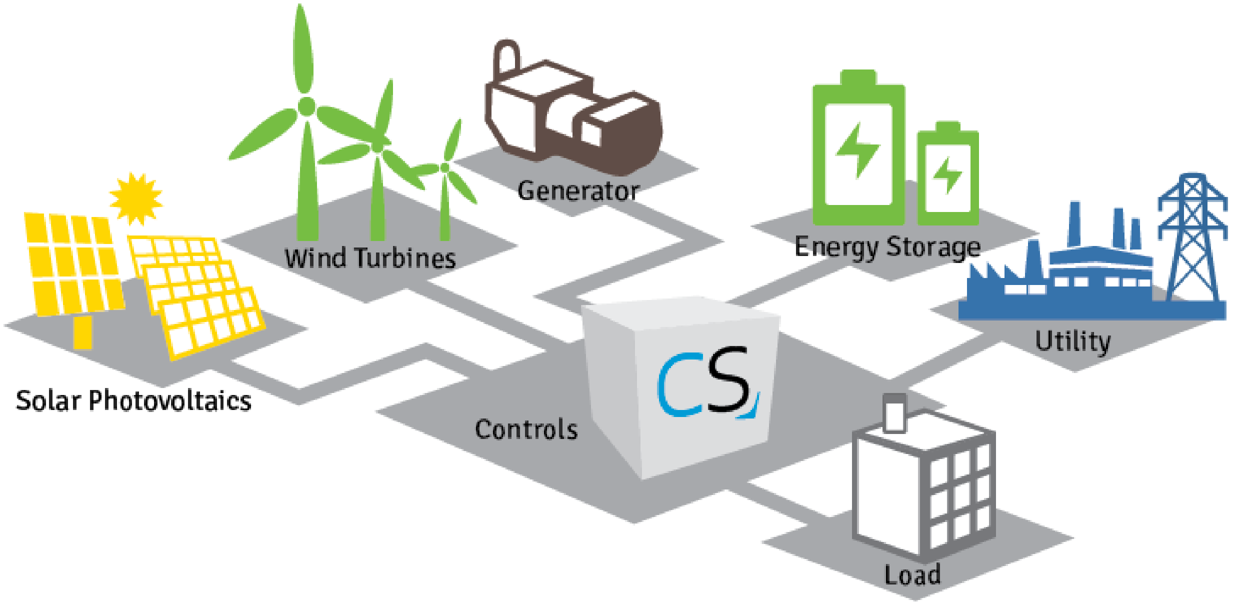


Figure 1-1 Overview of Modern Power System

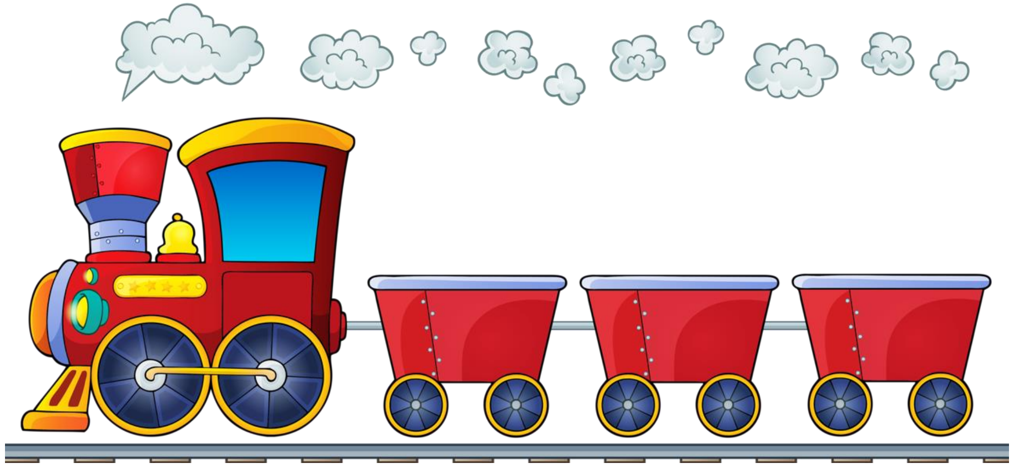
Power Electronics Applications:

- Solar/Wind energy integration
- Battery energy storage system (BSEE)
- HVDC and FACTS
- Electric vehicles and so on…

Ongoing Power Systems:

- Declining in shares of synchronous generators
- Increasing demand for renewable energy
- More integration of inverter-based resources (IBRs)
- Most IBRs are grid-following (GFL) IBRs
- System strength becoming weaker

Introduction



Old Train:

- Only the locomotive provides horse power
- The carriages does not provide any horse power
- There is a weight limit to carry
- If the locomotive loses power, the train loses synchronization and stops

High Speed Train:

- All carriages are capable to provide horse power
- Theoretically, there is no weight limit to carry as long as the number of carriages can increase
- One or a few of the carriages lose power, the train can still run at a synchronous speed

Grid Following vs. Grid Forming

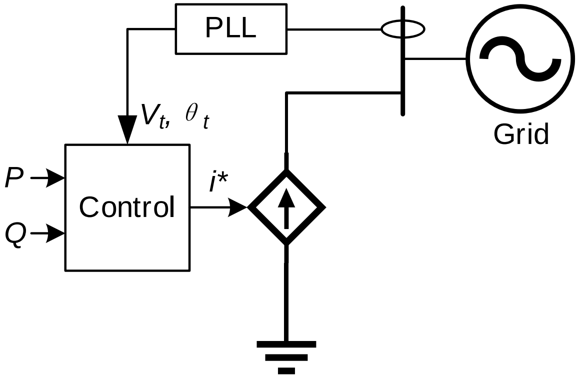


Figure 1-2 GFL IBR

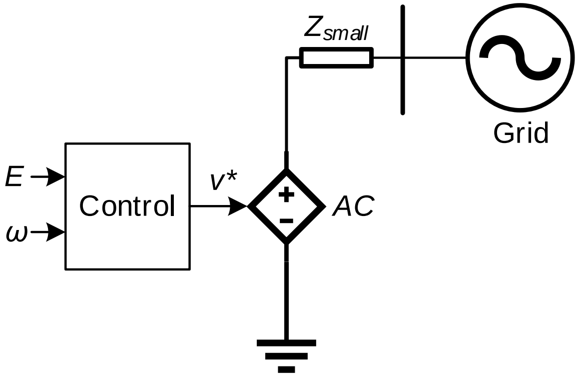
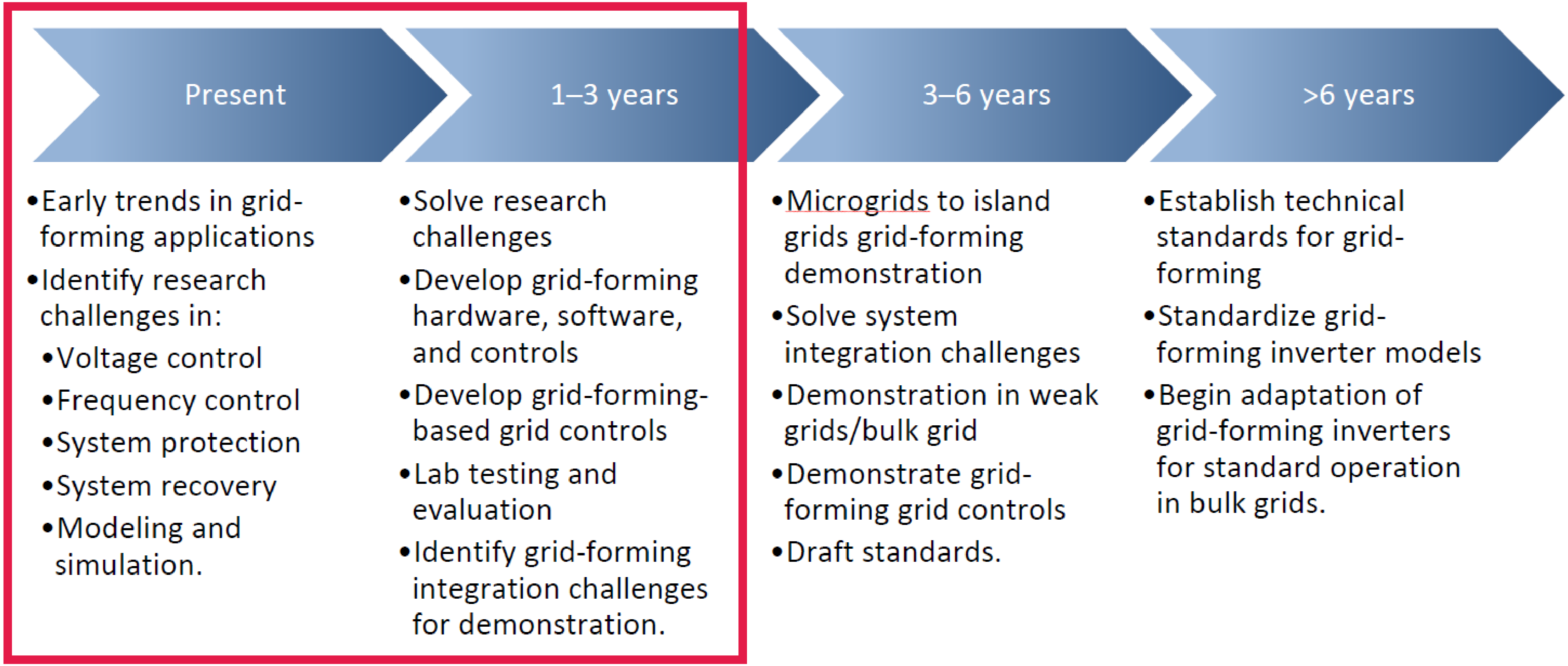


Figure 1-3 GFM IBR

Items	Grid-following IBRs	Grid-forming IBRs
Reliance	Relies on the voltage and frequency at the interconnection point	To take responsibility to maintain the grid voltage and frequency
Dynamic behavior	Control the active and reactive current component to the grid	Control the voltage magnitude and phase/frequency output
PLL	PLL or similar control is required	PLL may be used but not required
Black start	Usually not possible	Has black start capability
System SCR	May operated under low SCR but there is a threshold	No minimum SCR requirement and may operate under 100% power electronics
Standards	Well-developed standards and widely used commercially	Not well-standardized, very limited operational experience at system perspectives

Motivations



Present

- Early trends in grid-forming applications
- Identify research challenges in:
  - Voltage control
  - Frequency control
  - System protection
  - System recovery
  - Modeling and simulation.

1–3 years

- Solve research challenges
- Develop grid-forming hardware, software, and controls
- Develop grid-forming-based grid controls
- Lab testing and evaluation
- Identify grid-forming integration challenges for demonstration.

3–6 years

- Microgrids to island grids grid-forming demonstration
- Solve system integration challenges
- Demonstration in weak grids/bulk grid
- Demonstrate grid-forming grid controls
- Draft standards.

>6 years

- Establish technical standards for grid-forming
- Standardize grid-forming inverter models
- Begin adaptation of grid-forming inverters for standard operation in bulk grids.

Figure 1-4 Development Trend and Timeline for GFM IBRs [2]

TYPICAL GRID FORMING CONTROLS

Typical GFM Controls

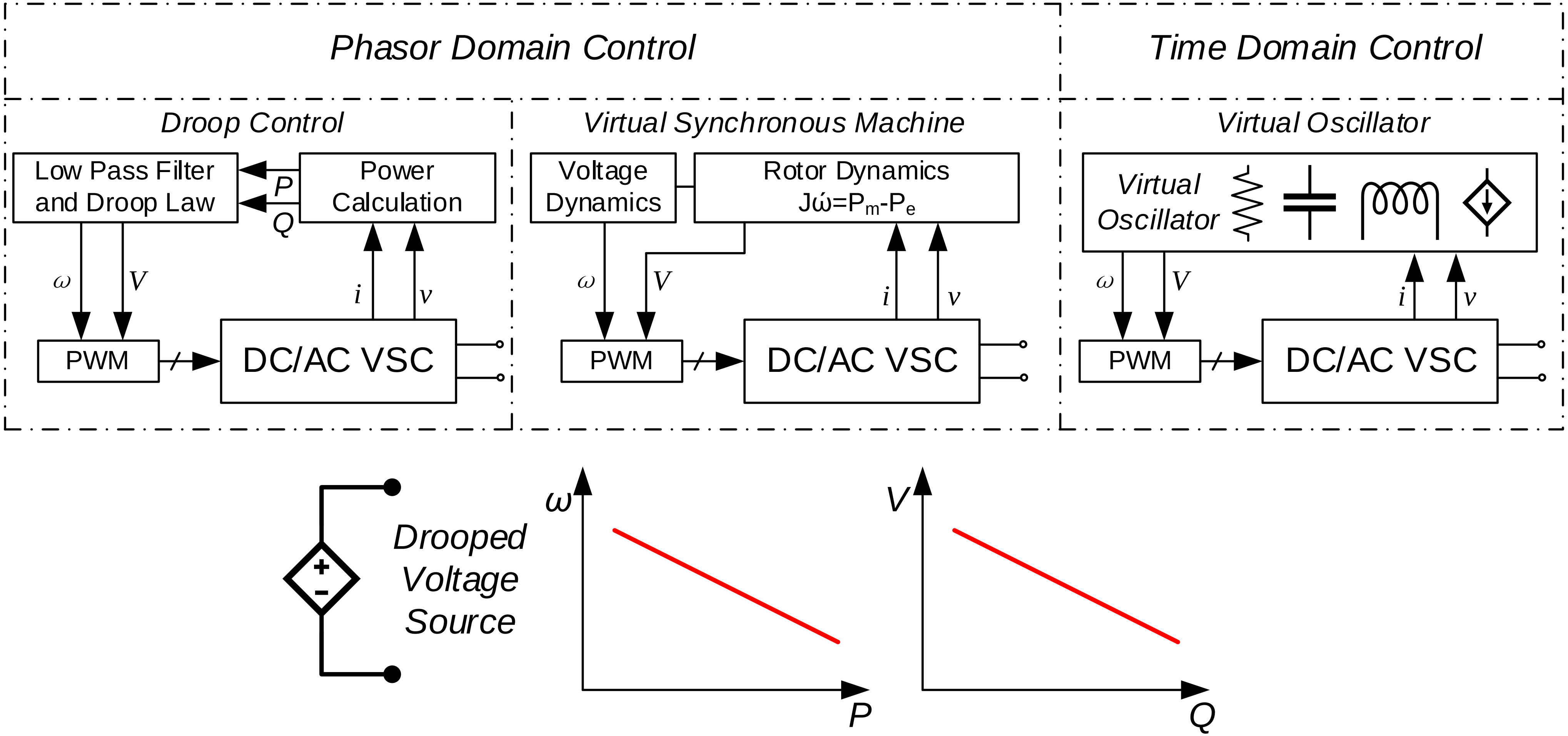


Figure 2-1 Commonly used Control Methods for GFM IBRs

Typical GFM Controls

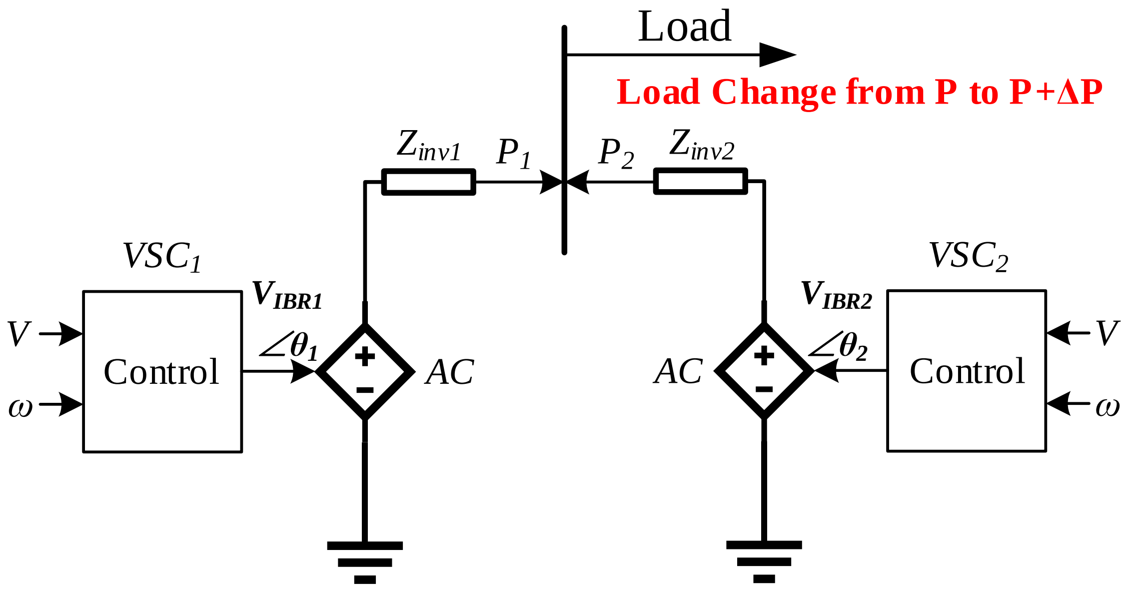


Figure 2-2 Example of two GFM IBRs

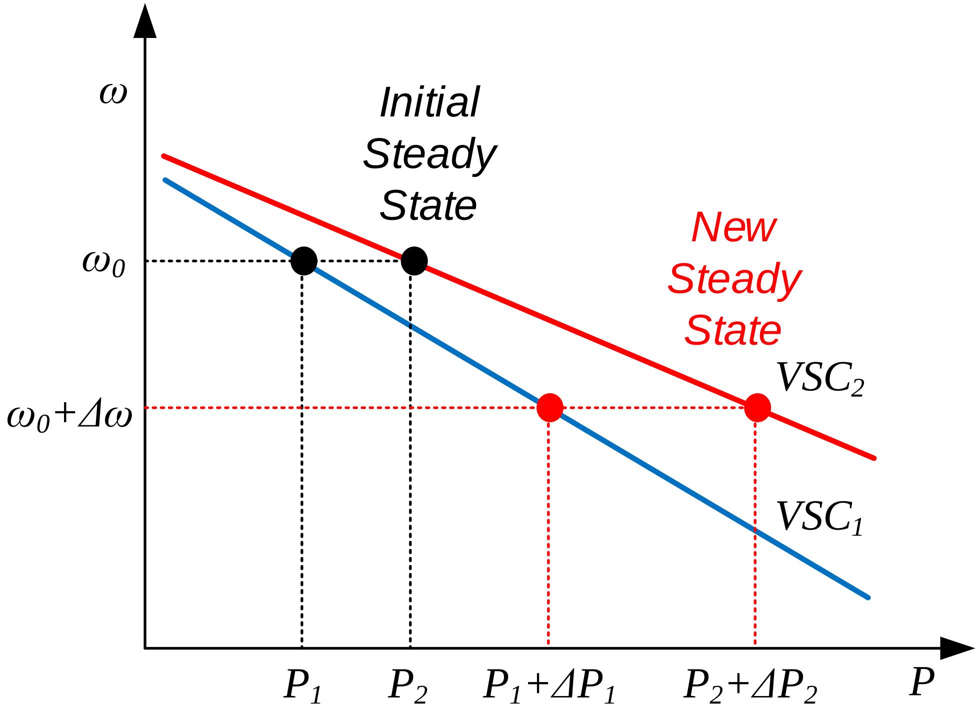


Figure 2-3 Interaction between two GFM IBRs

Typical GFM Controls

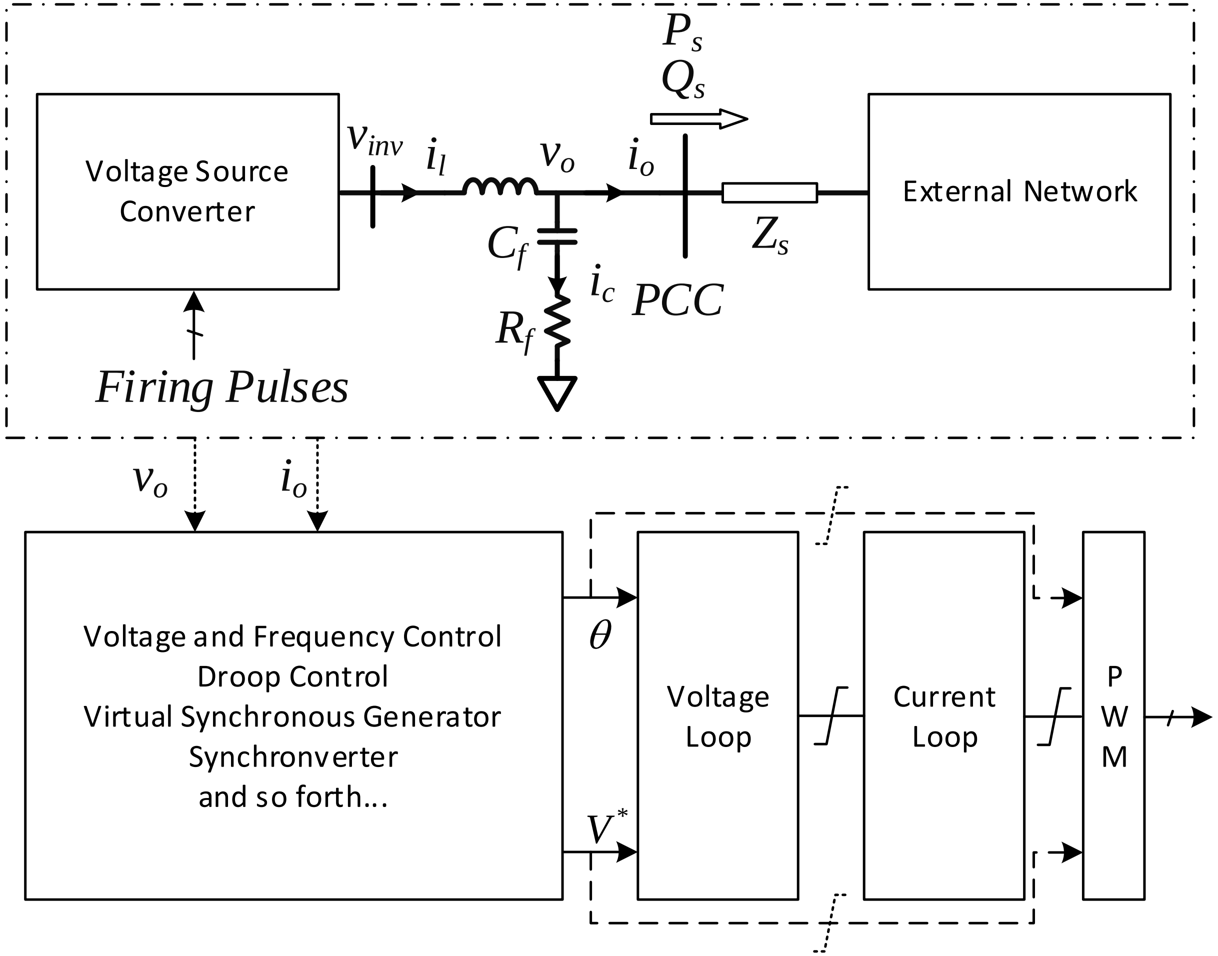
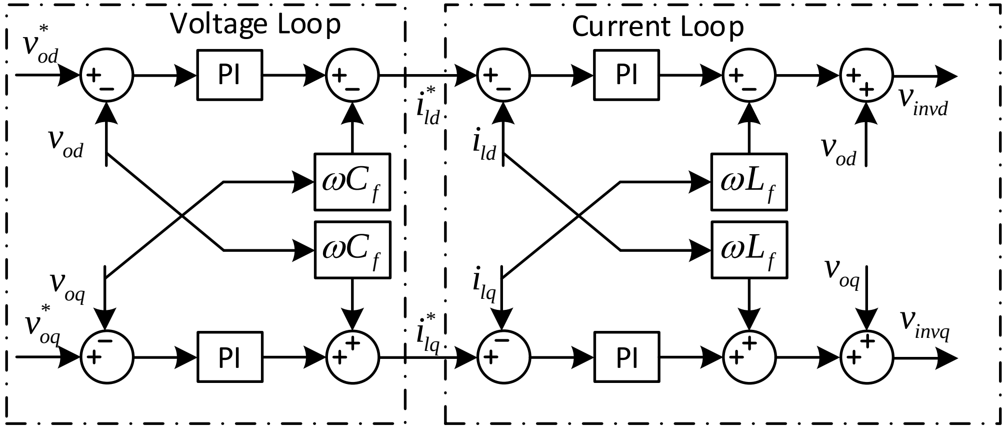


Figure 2-4 GFM Control General Structure



Note

- The output θ and V^* of the outer loop may be directly used for PWM and produce firing pulses to control the VSC
- The voltage and current loop has current limiting capability, and can provide fast control of the voltage at the PCC

Typical GFM Controls

GFM Control	Inertia Support	Operation Features	Applicable Scenarios
VF Control	No	Provides constant voltage and frequency at PCC, and there is no droop characteristics	Passive network only
Droop Control	Yes	Provides similar droop characteristics of synchronous generators (SGs)	Both active and passive networks
VSG	Yes	In addition to the features of droop control, it mimics the inertia and damping characteristics of SGs	
Synchronverter	Yes	In addition to the features of VSG, it mimics excitation characteristics of SGs	

VSG EXAMPLE

Virtual Synchronous Generator

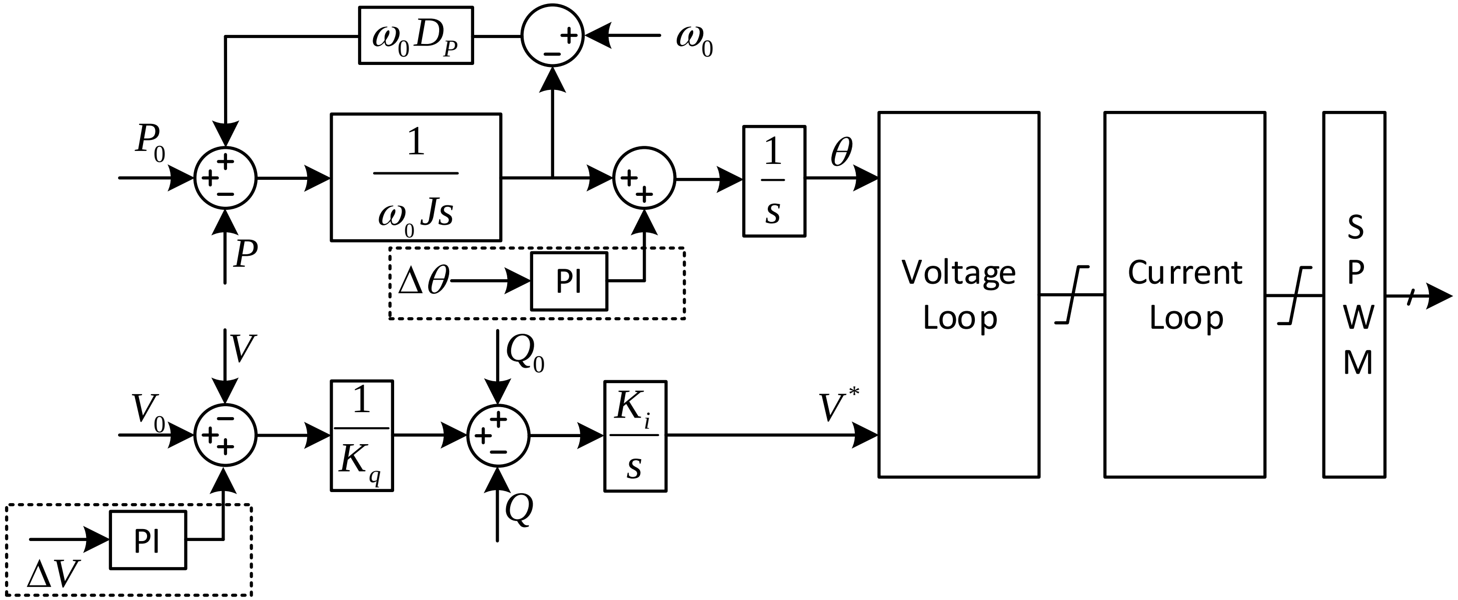


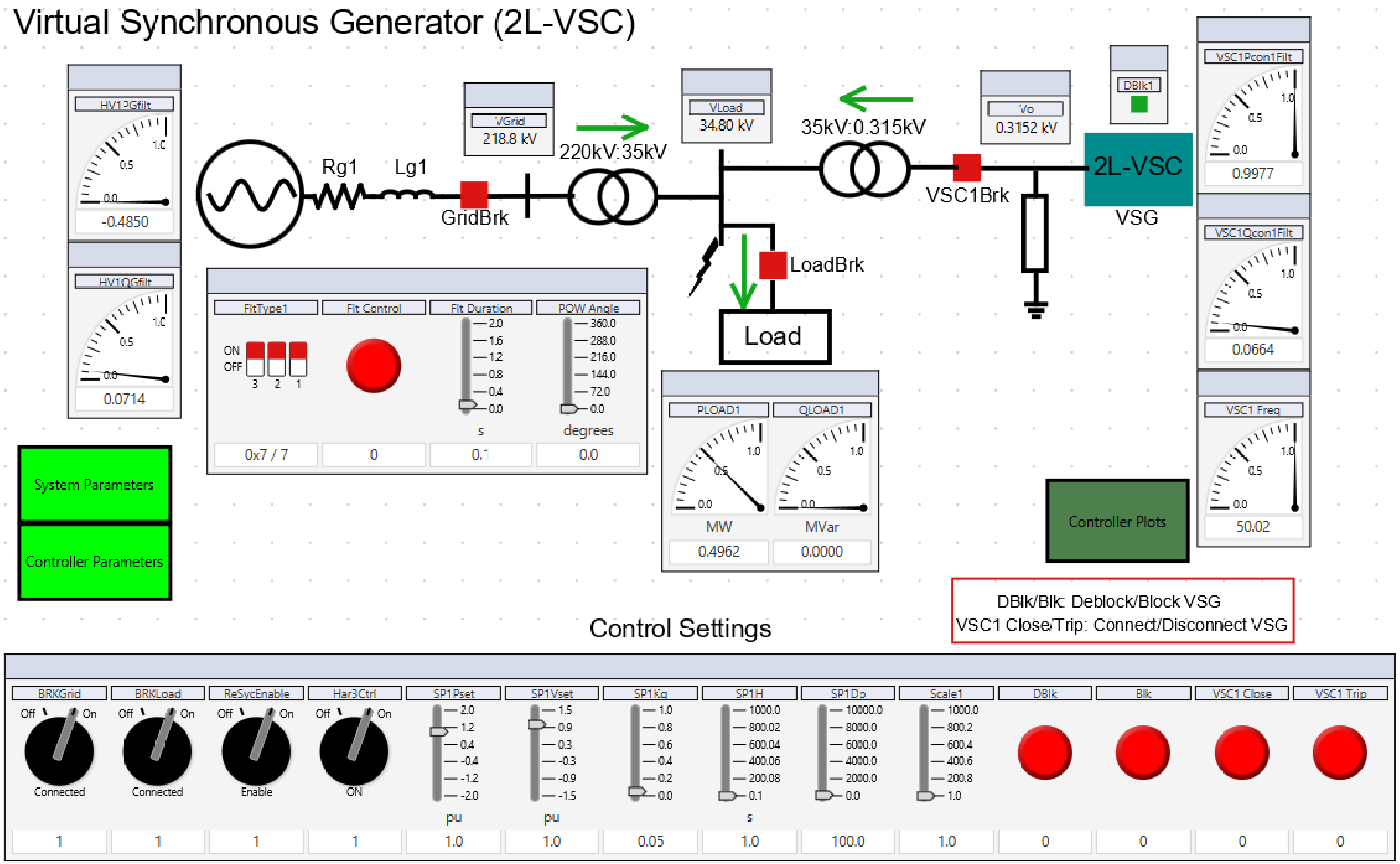
Figure 3-1 Virtual Synchronous Generator (VSG)

VSG: can simulate the moment of inertia (*J*) and the damping characteristics (D_p) of the rotor.

$$J\frac{d\omega}{dt} = T_m - T_e - D_p\left(\omega - \omega_0\right) \approx \frac{P_m - P_e}{\omega_0} - D_p\left(\omega - \omega_0\right) \qquad \omega - \omega_0 = -\frac{\Delta P}{\omega_0 D_p}$$

$$V^* = \int\left[\left(V_0 - V\right)\times\frac{1}{K_q} + Q_0 - Q\right]\times K_i dt \qquad V_0 - V = \left(Q_0 - Q\right)K_q$$

Runtime Settings



Meter	Value
HV1PGfilt	-0.4850
HV1QGfilt	0.0714
VGrid	218.8 kV
VLoad	34.80 kV
Vo	0.3152 kV
VSC1Pcon1Filt	0.9977
VSC1Qcon1Filt	0.0664
VSC1 Freq	50.02
PLOAD1	0.4962 MW
QLOAD1	0.0000 MVar

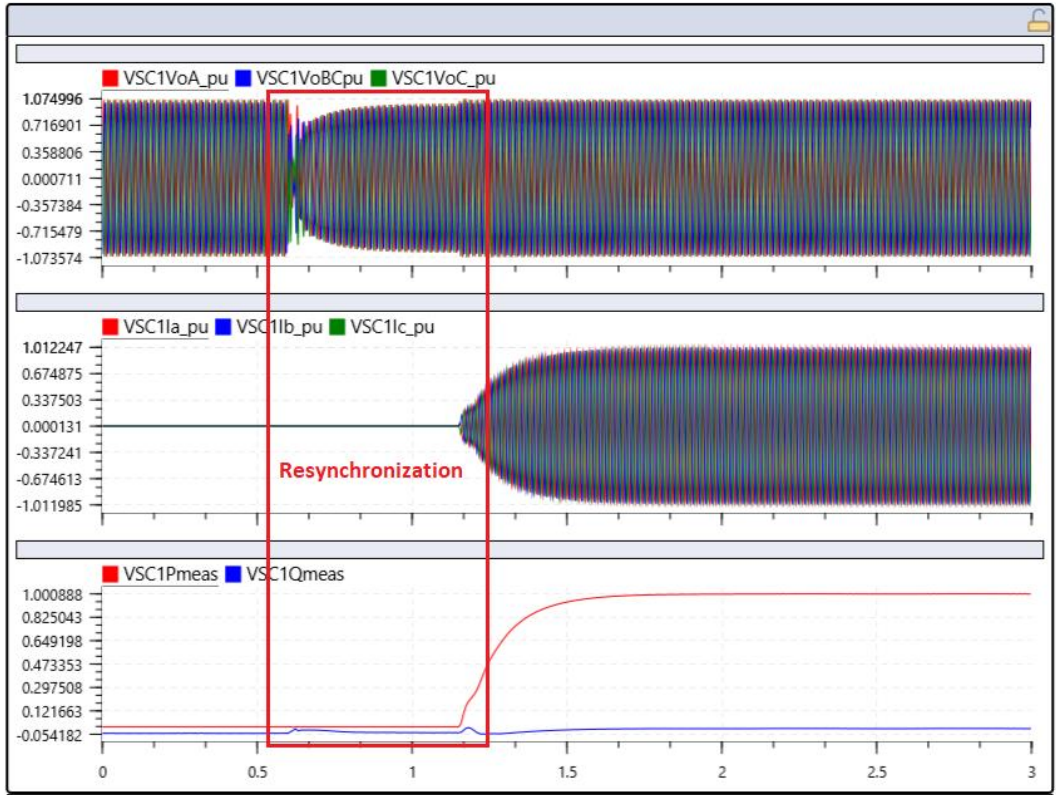
FltType1	Flt Control	Flt Duration	POW Angle
0x7 / 7	0	0.1 s	0.0 degrees

DBlk/Blk: Deblock/Block VSG
VSC1 Close/Trip: Connect/Disconnect VSG

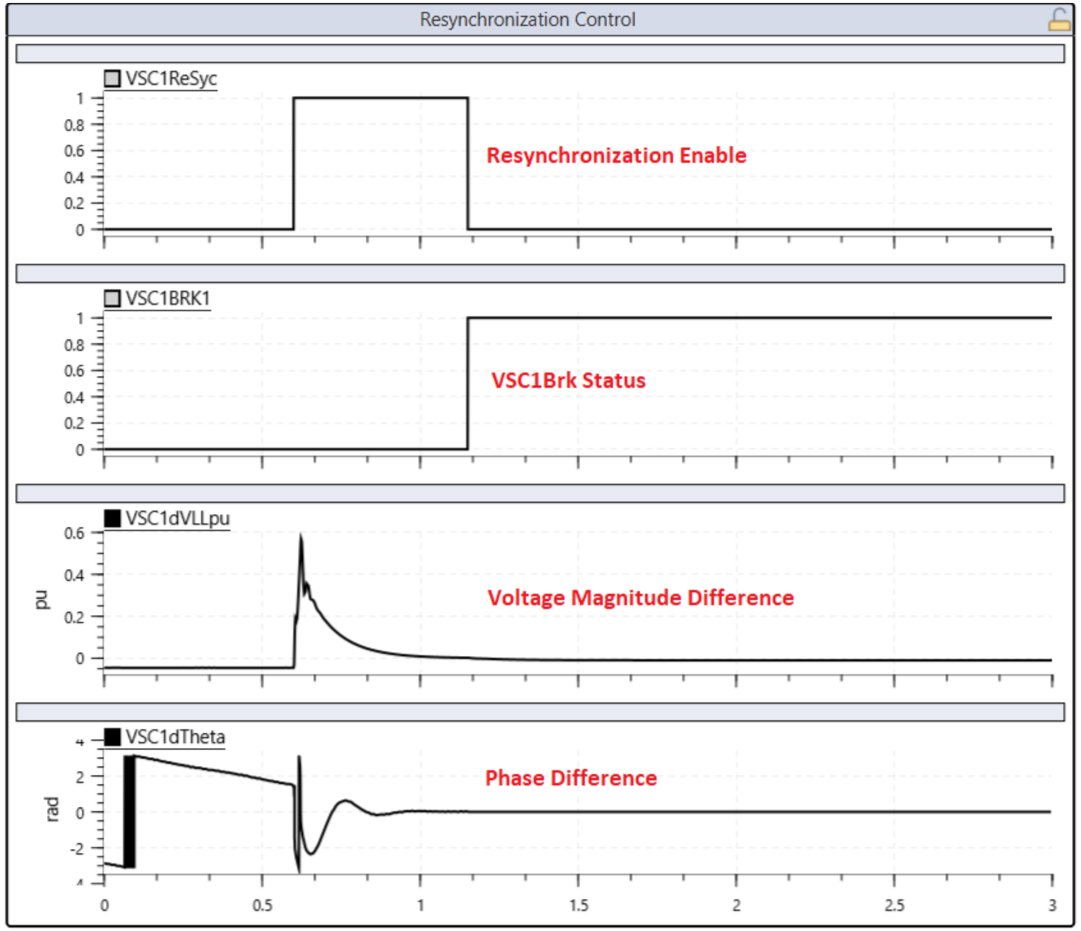
Control Settings

BRKGrid	BRKLoad	ReSycEnable	Har3Ctrl	SP1Pset	SP1Vset	SP1Kq	SP1H	SP1Dp	Scale1	DBlk	Blk	VSC1 Close	VSC1 Trip
Connected	Connected	Enable	ON	pu	pu		s						
1	1	1	1	1.0	1.0	0.05	1.0	100.0	1.0	0	0	0	0

Grid Connected Operation



Resynchronization



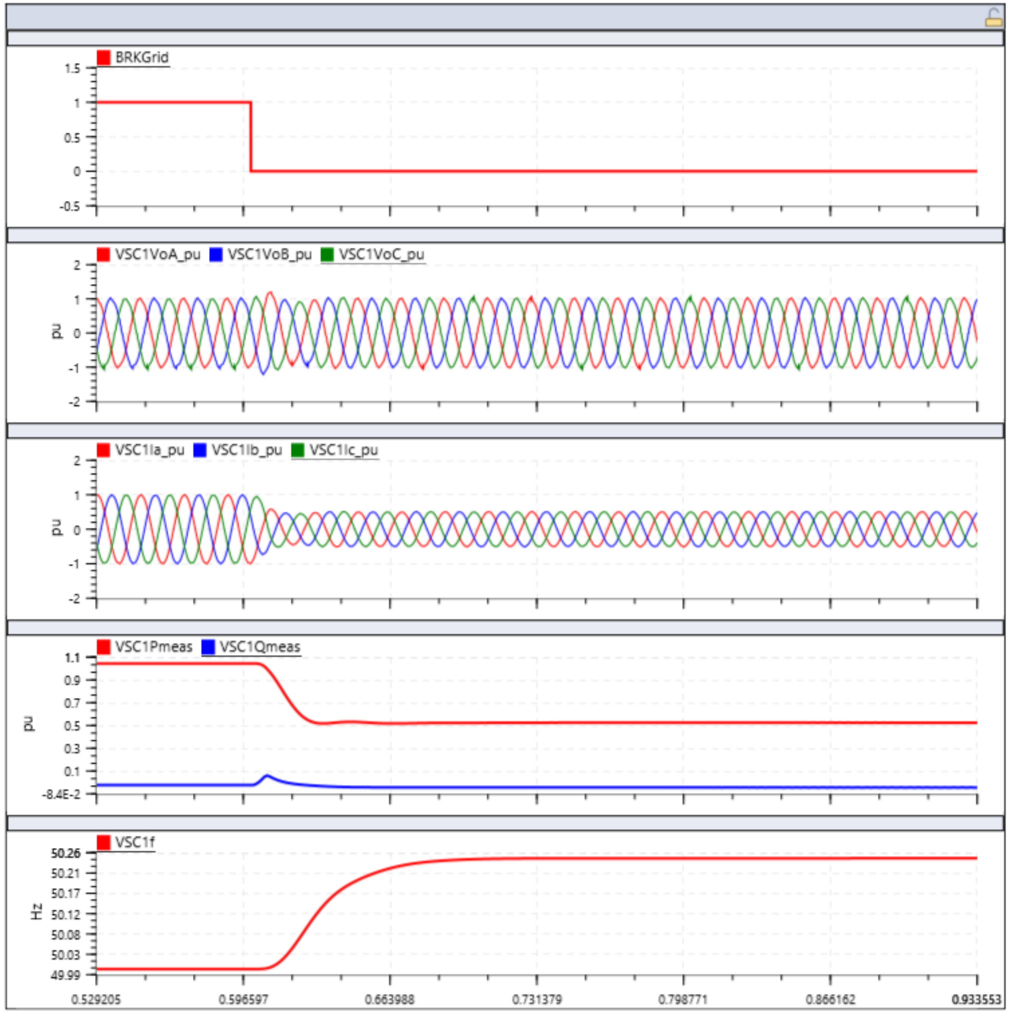
Resynchronization Enable

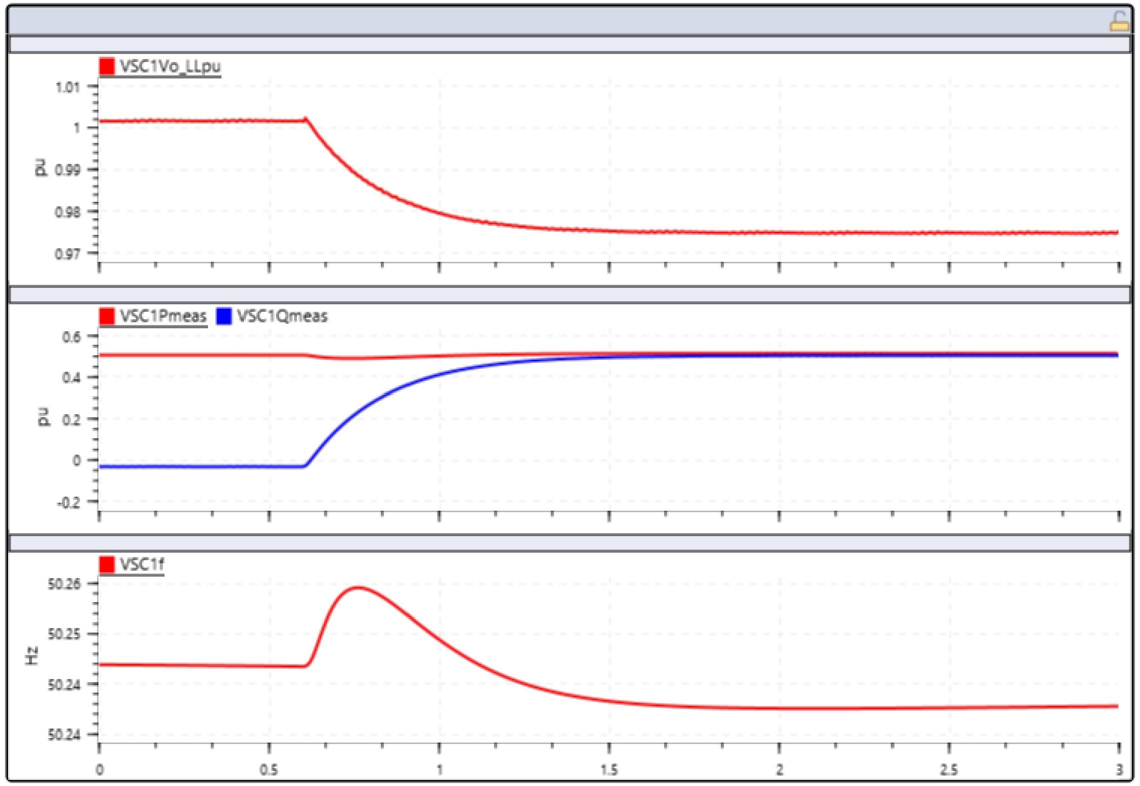
VSC1Brk Status

Voltage Magnitude Difference

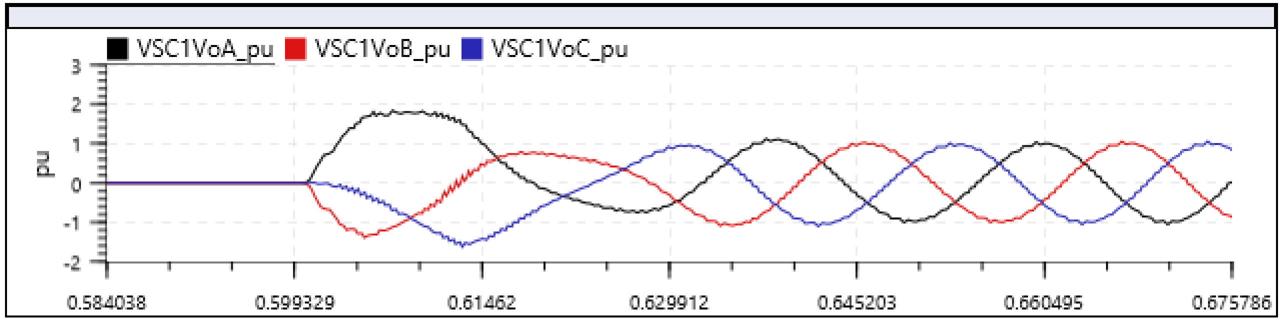
Phase Difference

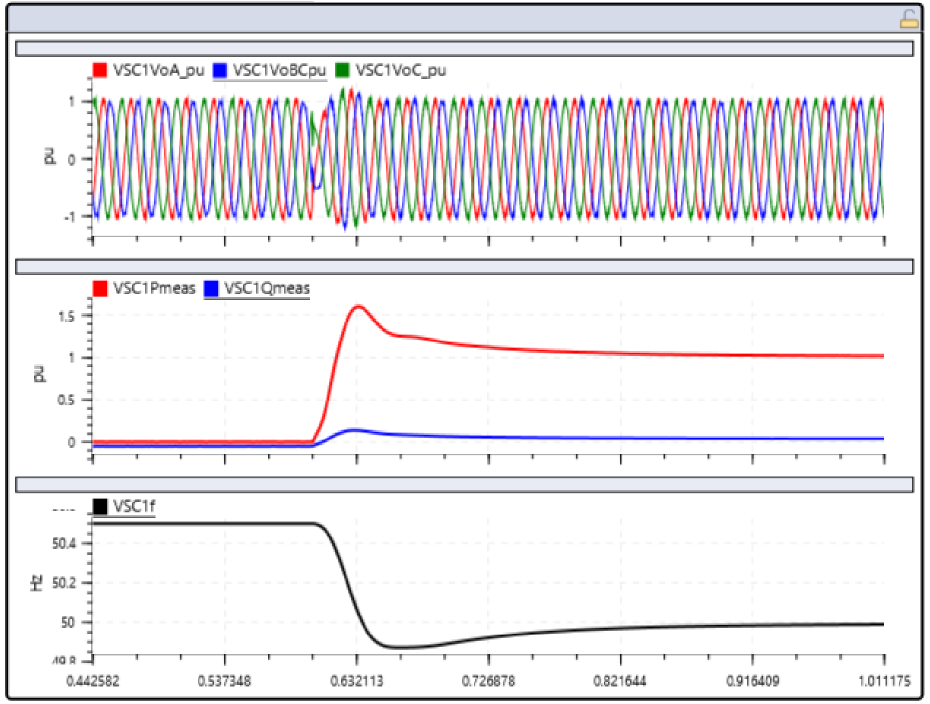
Droop Characteristics in Islanded Mode

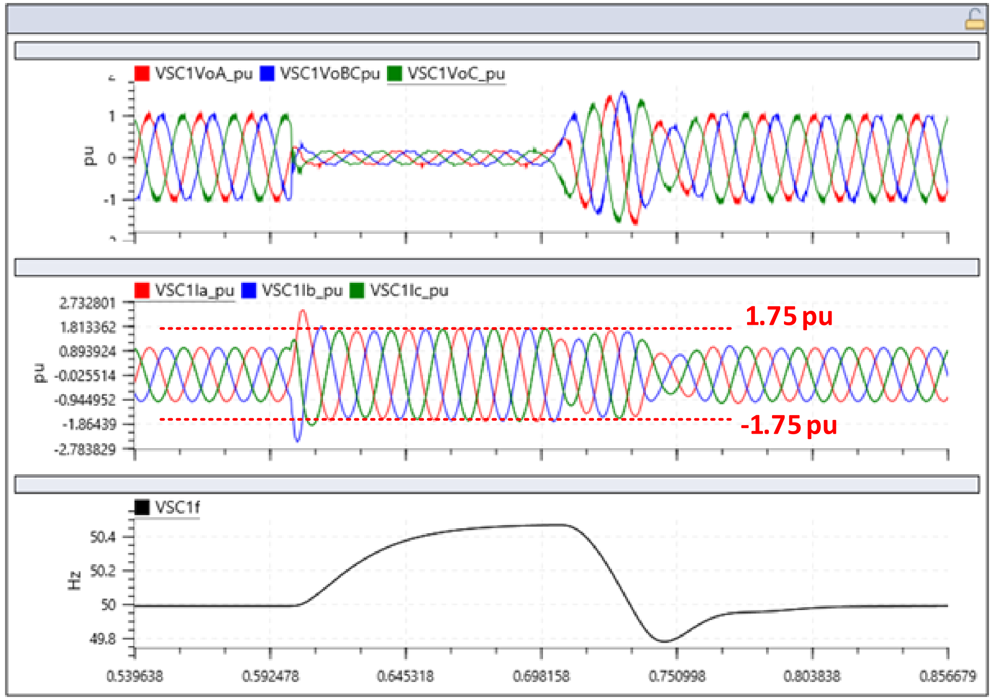




VSG Black Start and Fault Occurrence



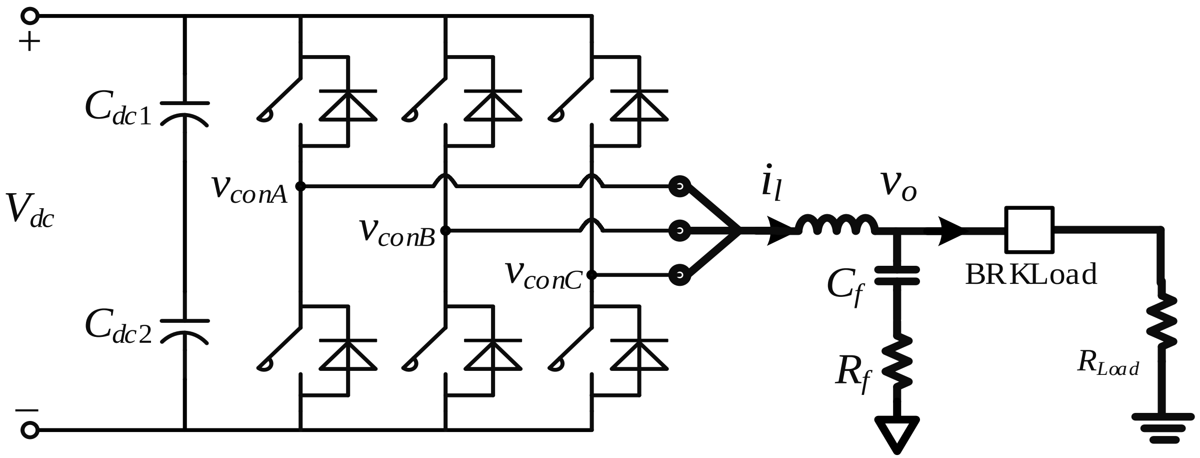


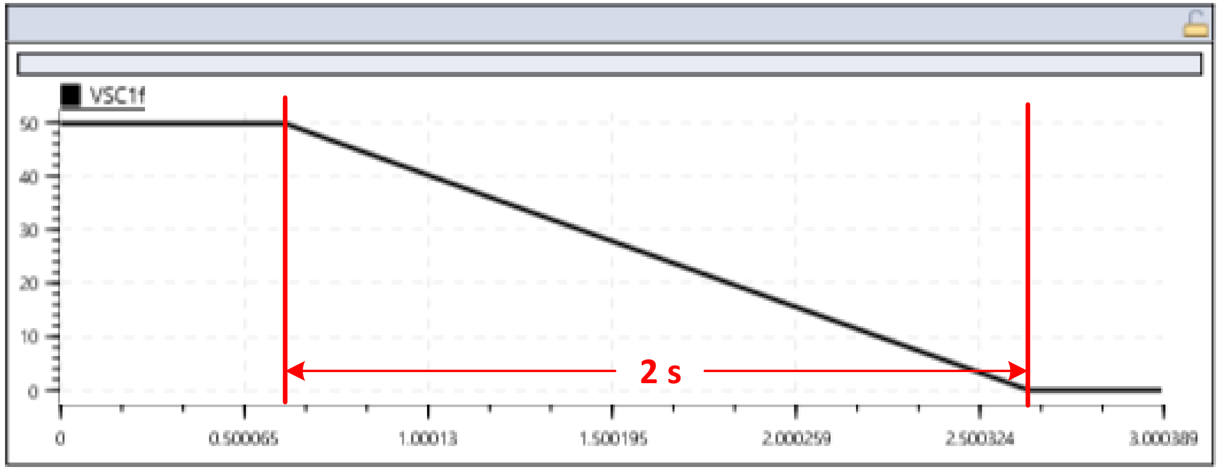


1.75 pu

-1.75 pu

Inertia Constant Validation





$$J\frac{d\omega}{dt} = T_m - T_e - D_p(\omega - \omega_0) \approx \frac{P_m - P_e}{\omega_0} - D_p(\omega - \omega_0)$$

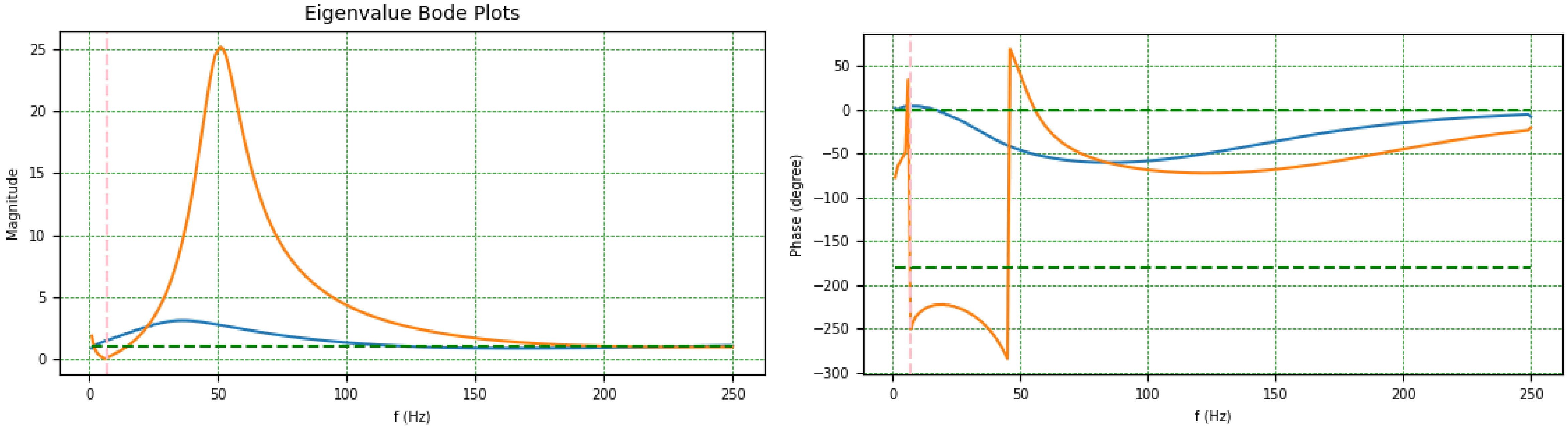
$$2H\frac{d\omega}{dt} = \Delta P - D_P\Delta\omega$$

$$H = \frac{\Delta P}{2 \times d\omega/dt}$$

$$R_{Load} = \frac{V_o^2}{P_{Rated}} = \frac{0.315kV^2}{1MW} = 0.099225\Omega$$

Stability Analysis – Frequency Scanning

SCR=3.6 and operating under rated power



RTDS EXAMPLES – VF, DROOP, VSG, AND SYNCHRONVERTER

VF and Droop Control

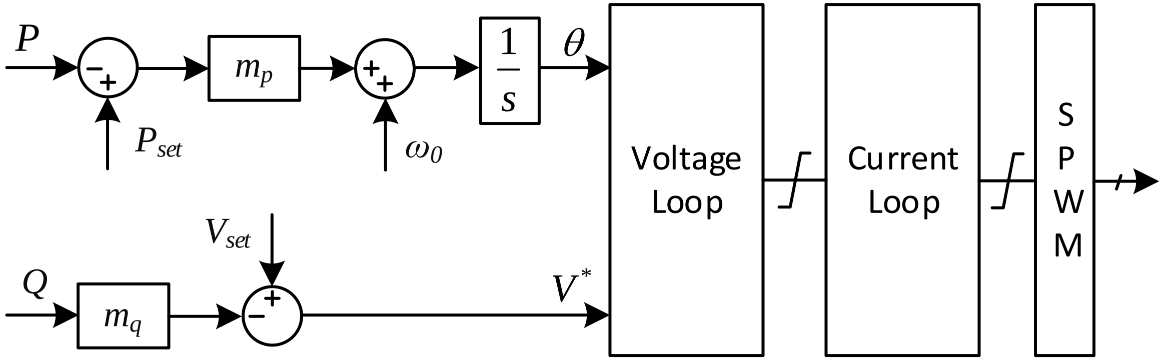
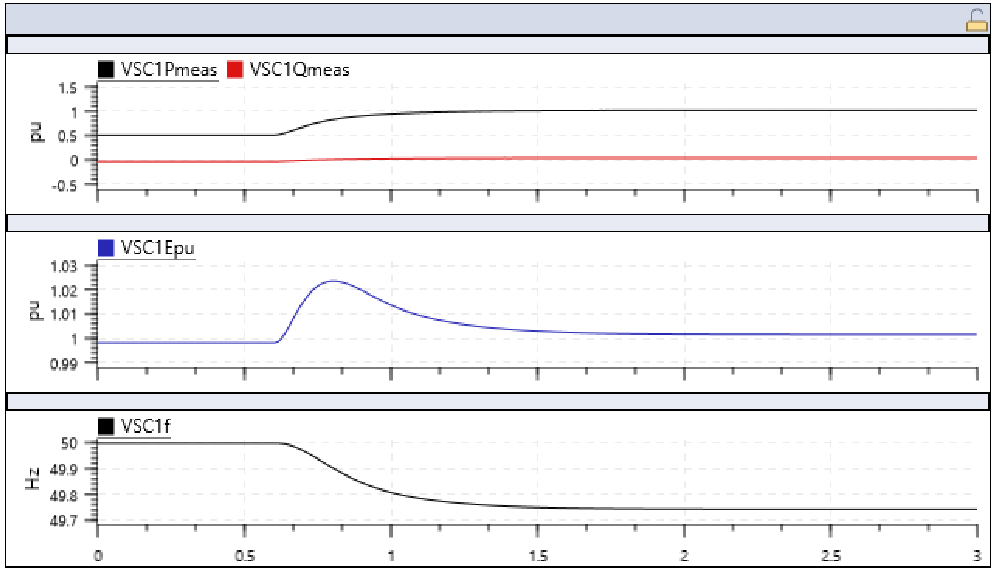
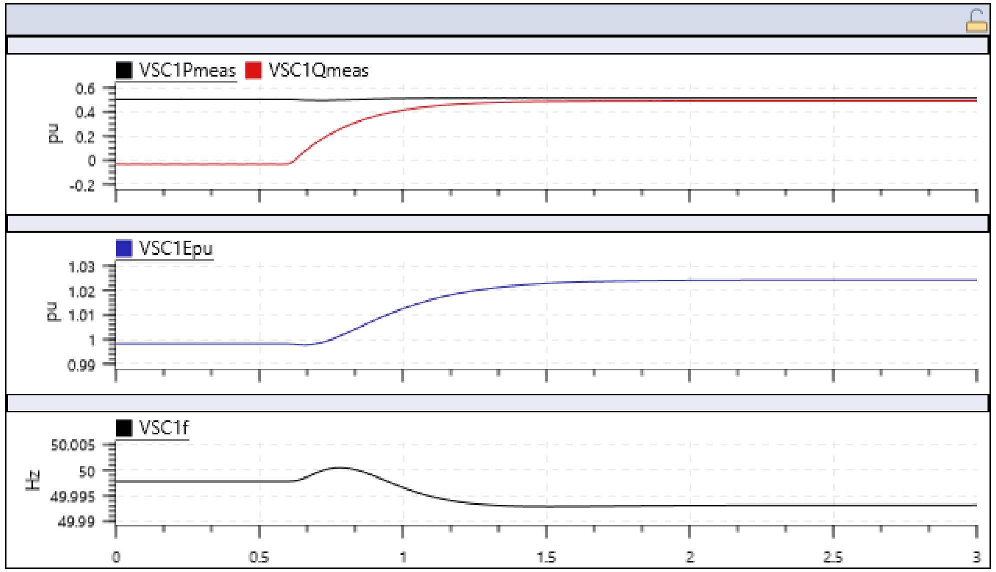


Figure 4-1 Droop Control

Note

- *P and Q* are measured active and reactive power
- m_p *and* m_q are droop coefficients of *P-f and Q-V*.
- P_{set} *and* V_{set} are targeted real power and voltage magnitude; ω_0 is the rated frequency.
- θ *and* V^* represents the magnitude, phase, and frequency of the output voltage.





Synchronverter

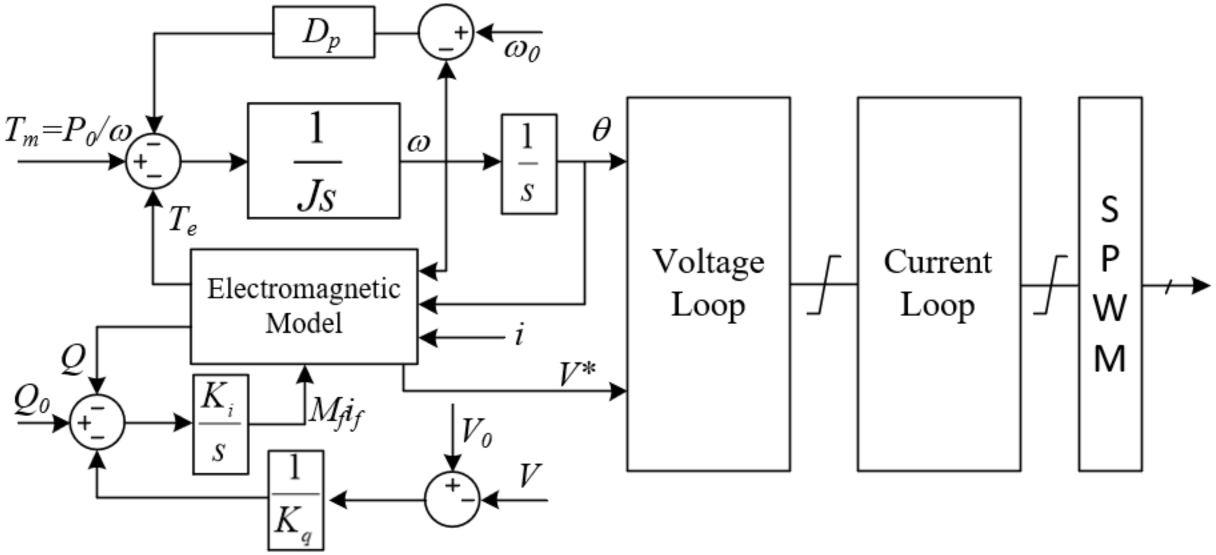
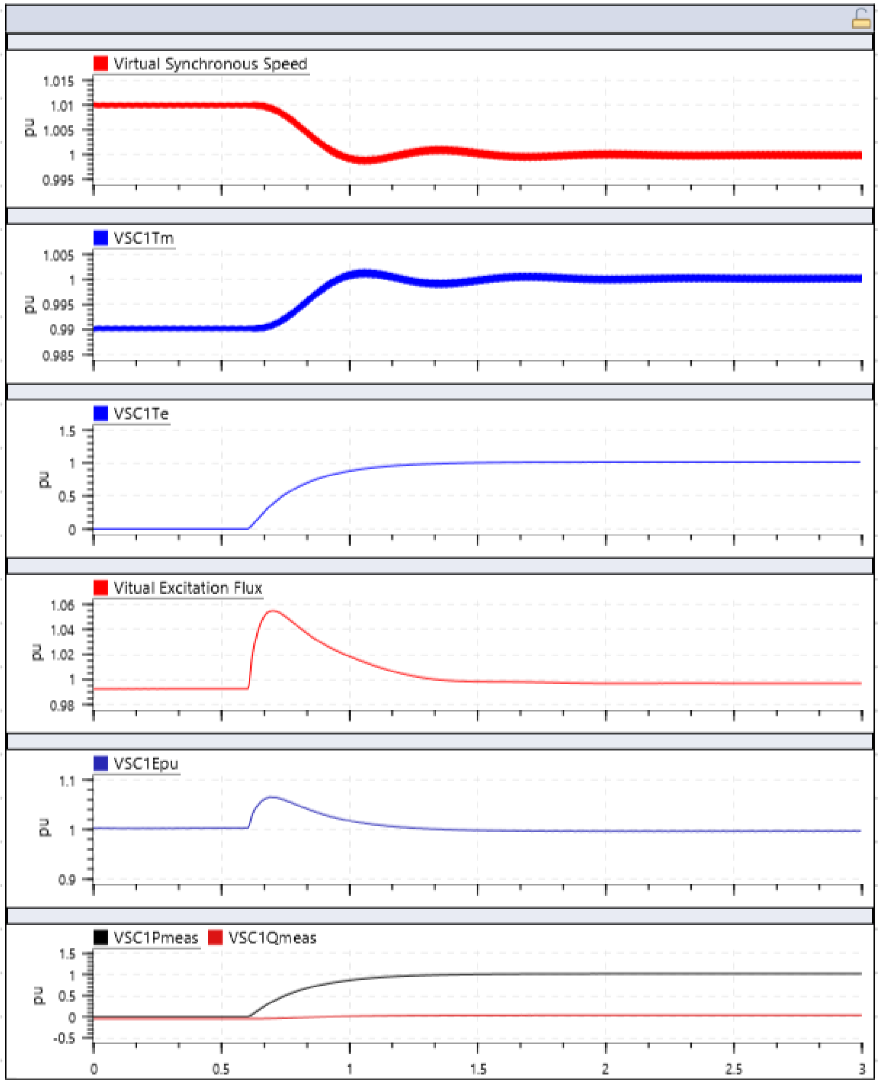


Figure 4-2 Synchronverter

Synchronverter: more characteristics of SGs are considered, including electromagnetic torque, induced electromotive force, mutual inductance between rotor and stator, and rotor excitation current



Universal GFM VSC

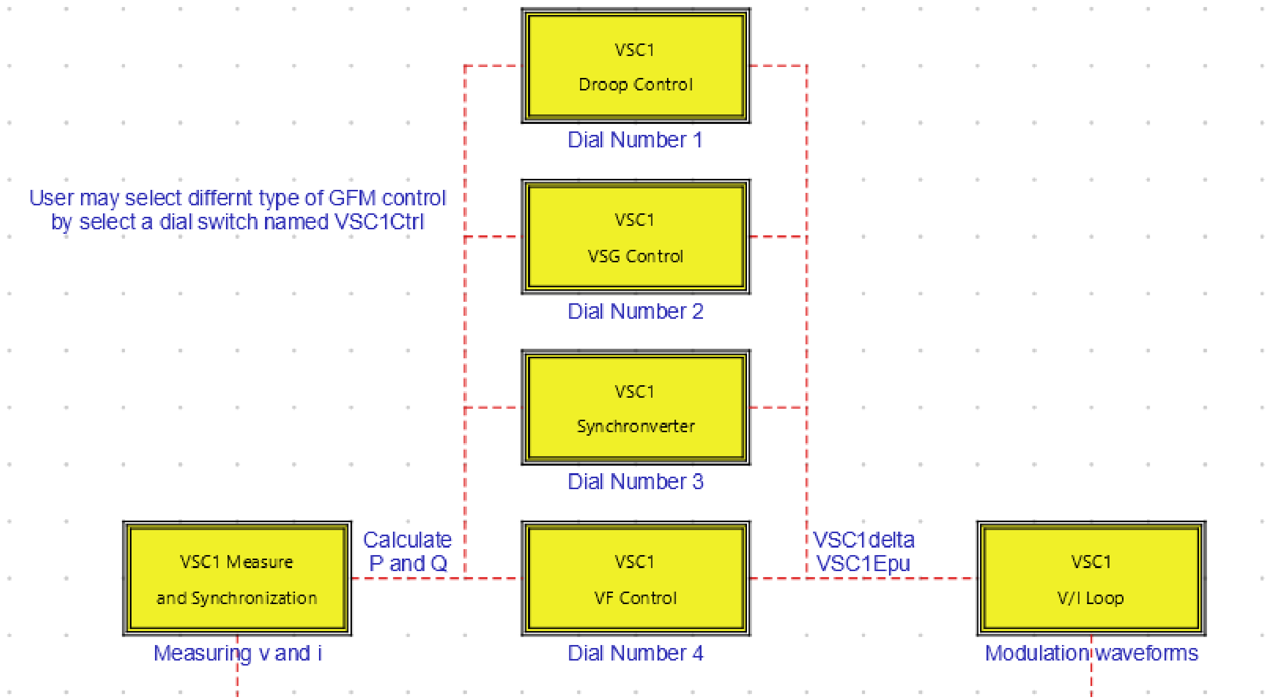


Figure 4-3 Universal GFM Example

- The Universal GFM VSC Example includes four commonly used GFM Controls, Droop, VSG, Synchronverter, and VF.
- User can switch control mode by a dial switch while running the simulation case.
- Per-unitized control parameters and users can easily integrate the VSC to systems with different conditions

RTDS GFM MODEL APPLICATIONS

Bess and Renewables

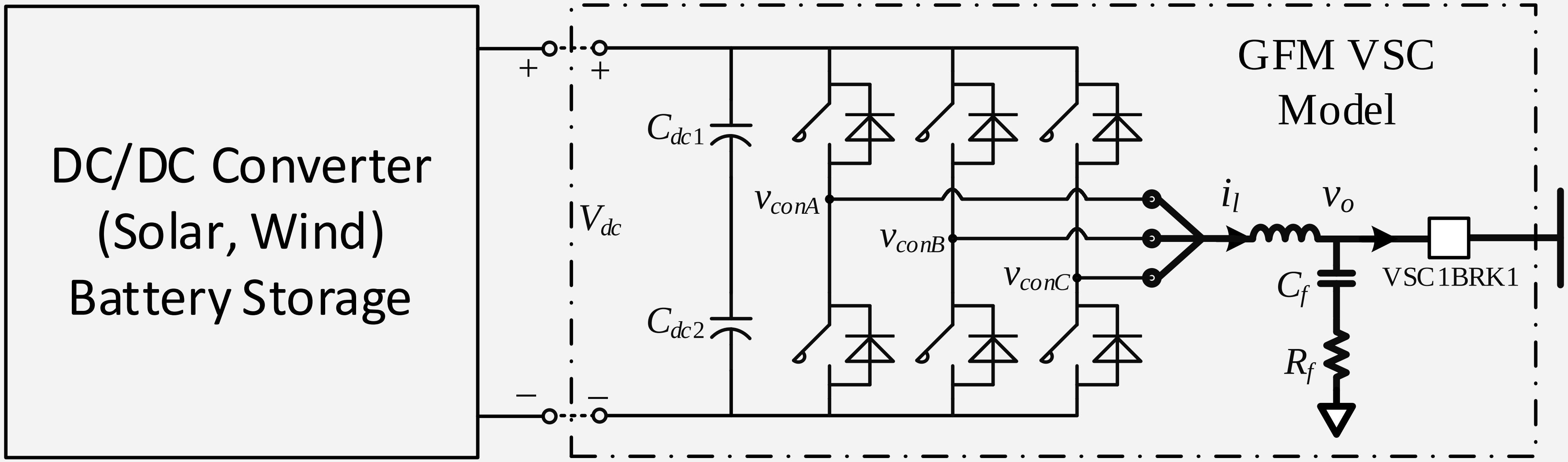


Figure 5-1 GFM VSC Applications in BESS and Renewables

Microgrid Applications

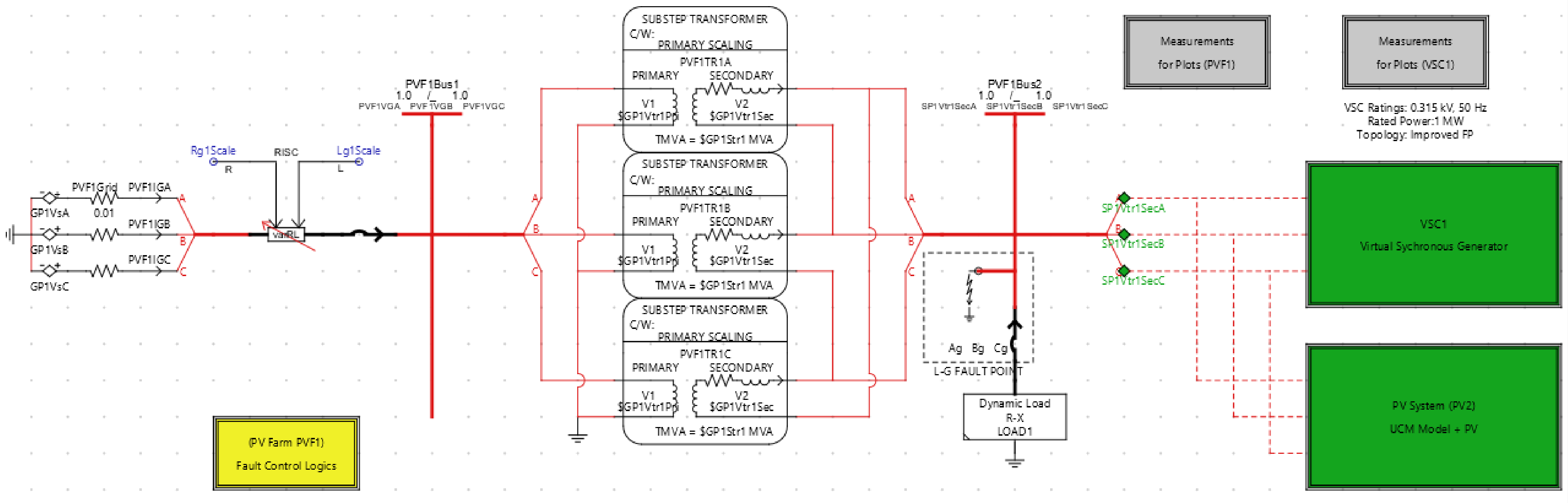


Figure 5-2 GFM VSC with a GFL Solar Farm

HVDC Applications

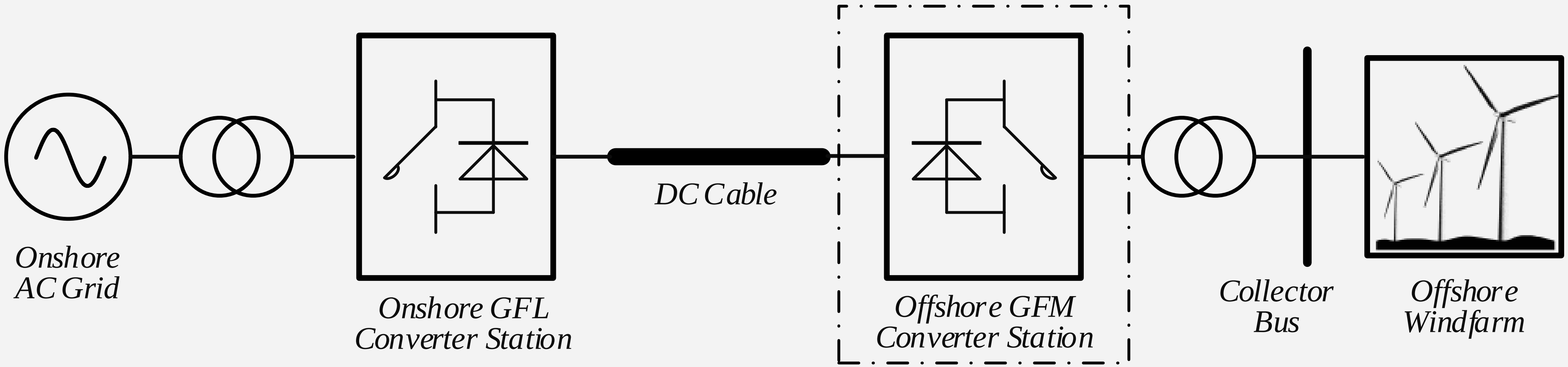


Figure 5-3 GFM VSC Application in Offshore Windfarm HVDC

HVDC Applications

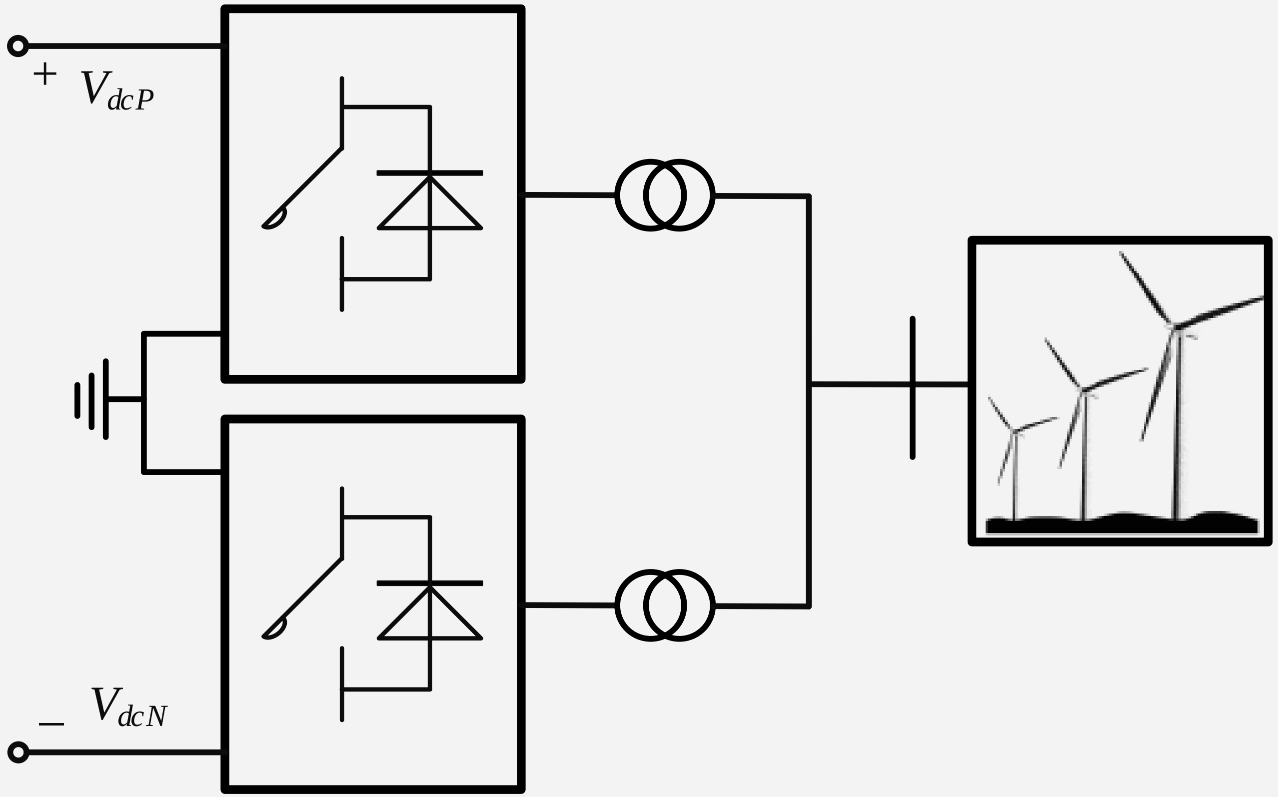


Figure 5-4 Bipolar HVDC VSC for Windfarm

THANK YOU!
QUESTIONS?

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