Simulation and Modelling of Grid Power Converters

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Friday, March 25, 2022

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Control structures

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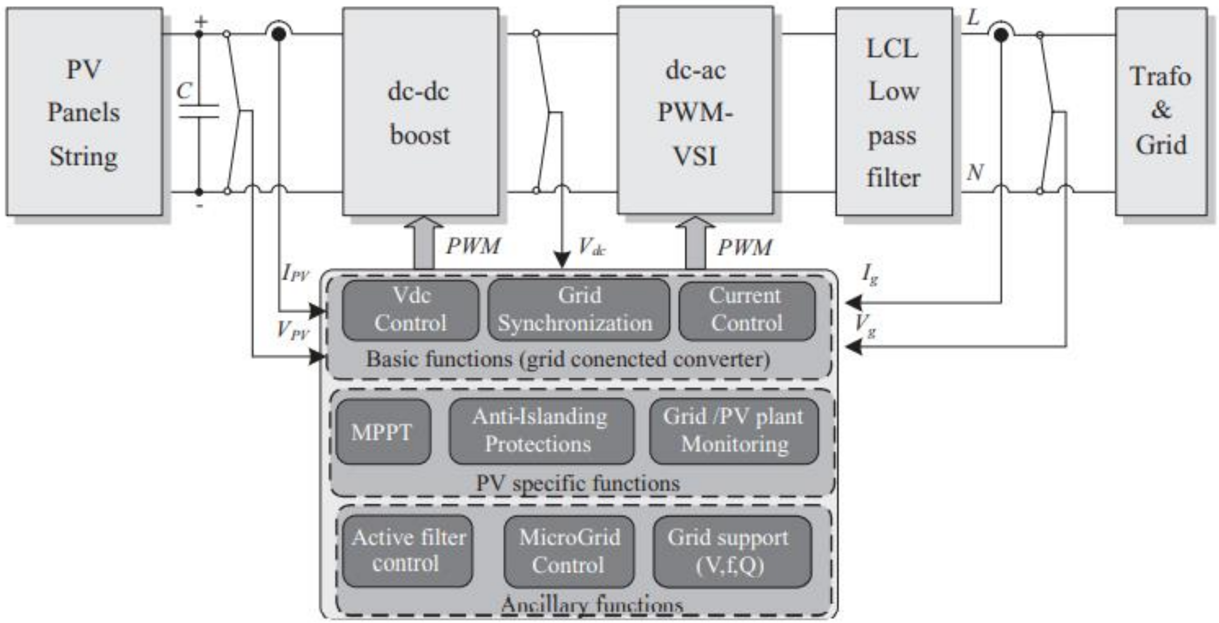
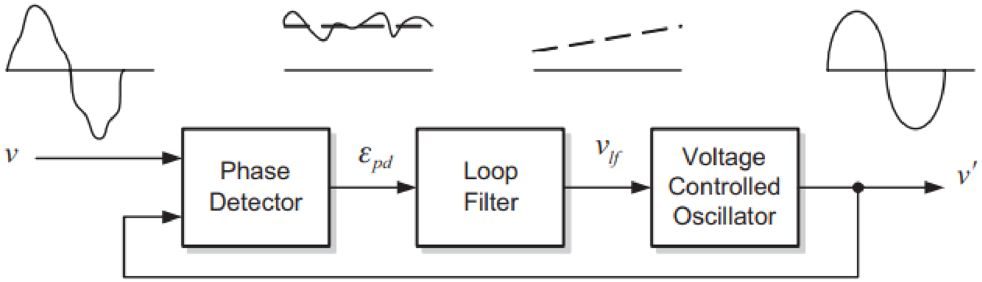
  - Grid/PV plant monitoring
    - Residual current detection
    - Isolation monitoring
- Ancillary functions
  - Grid support
  - Active Filter control
  - MicroGrid control

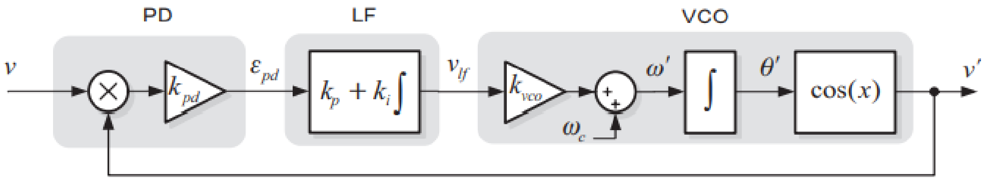


1. Recap

Grid Synchronization

- Fourier Analysis
- Phase Phase-Locked Loop
  - PD phase detector
  - LF loop filter
  - VCO voltage-controlled oscillator





1. Recap

Grid Synchronization

- Phase Phase-Locked Loop
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  - LF loop filter
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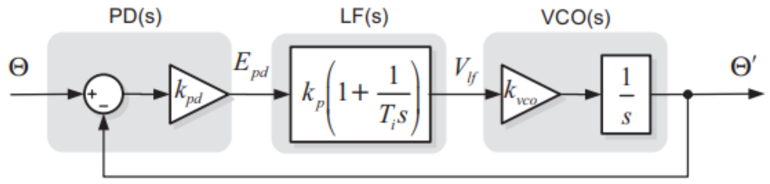


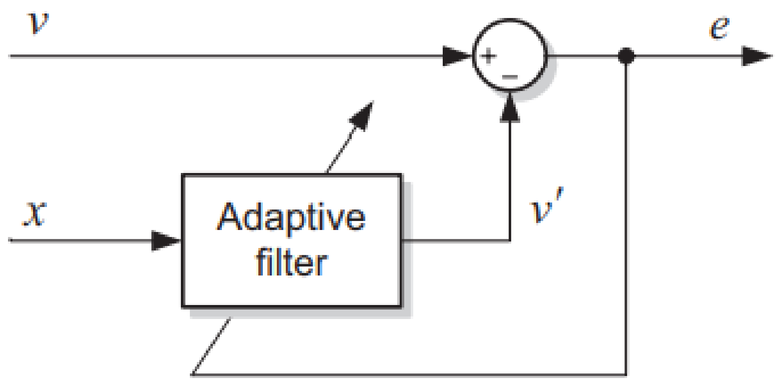
- Phase detector: $E_{pd}(s) = \frac{V}{2}\left(\Theta(s) - \Theta'(s)\right)$
- Loop filter: $V_{lf}(s) = k_p\left(1 + \frac{1}{T_i s}\right)\varepsilon_{pd}(s)$
- Controlled oscillator: $\Theta'(s) = \frac{1}{s}V_{lf}(s)$

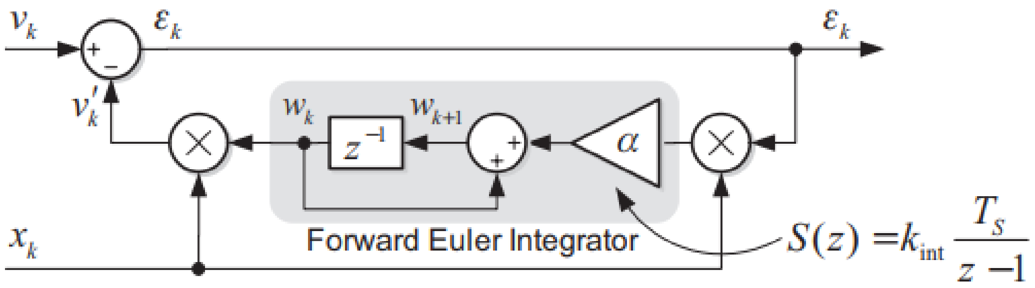
Closed-loop phase transfer function:

$$H_\theta(s) = \frac{\Theta'(s)}{\Theta(s)} = \frac{LF(s)}{s + LF(s)} = \frac{K_p s + \frac{K_p}{T_i}}{s^2 + K_p s + \frac{K_p}{T_i}}$$

Grid Synchronization – PLLs based on adaptive filtering

- Adaptive filter
  - Adaptive filter adjusts its own parameters according to optimization algorithm without prior knowledge of the signal
  - *v* input signal
  - *x* reference signal correlated to noise content
  - *e* output signal without noise

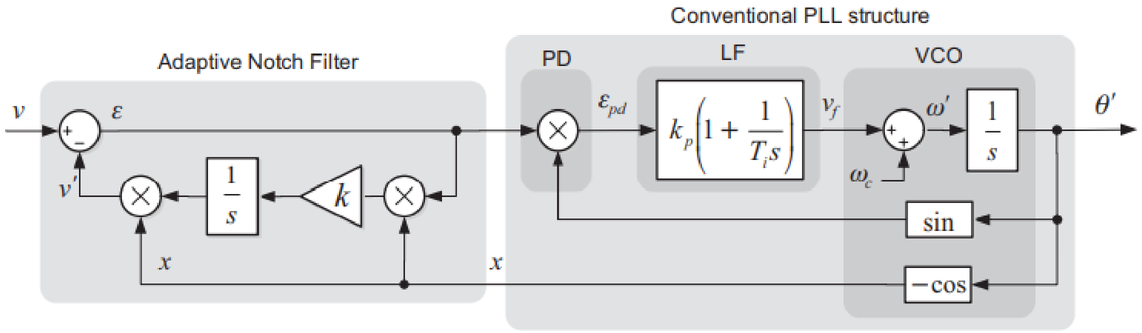


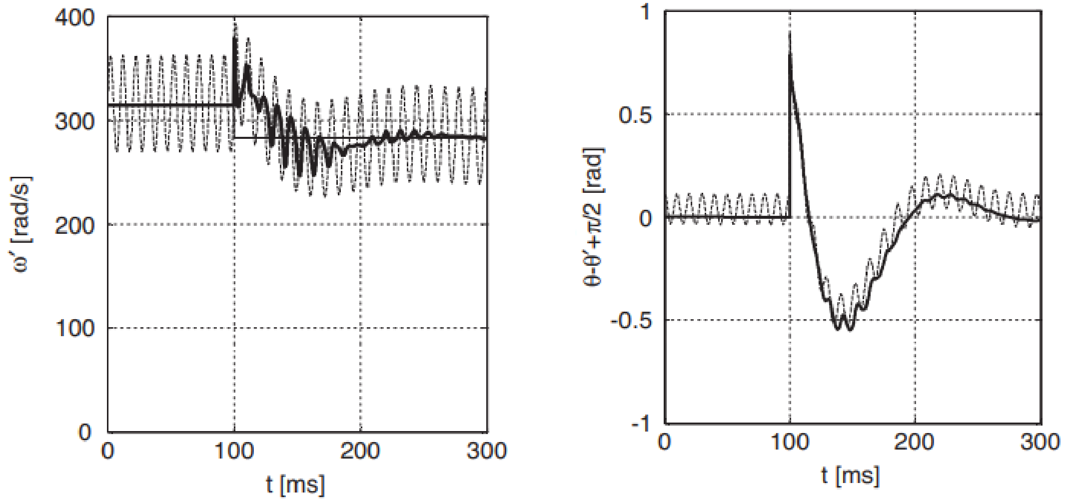


1. Recap

Grid Synchronization - PLLs based on adaptive filtering

- Enhanced PLL (EPLL)
  - Enhanced performance of PD
  - Adaptive Notch Filter
  - EPLL solid and conventional PLL dashed lines

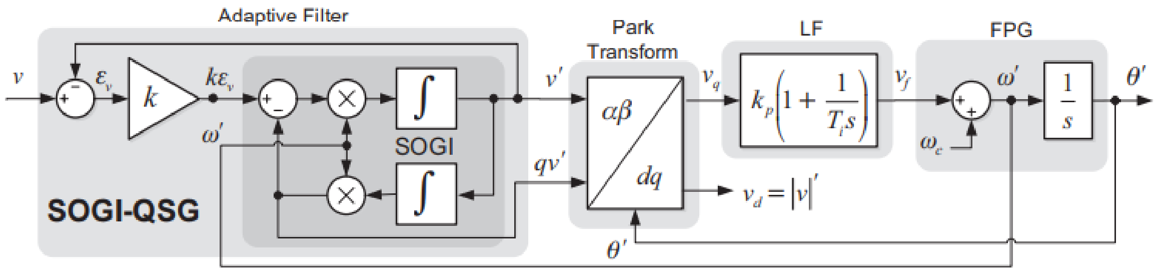


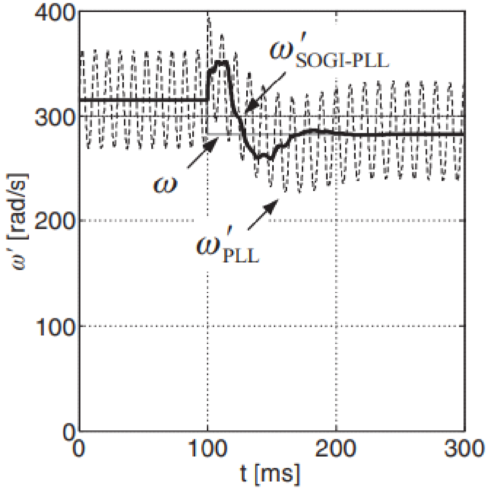


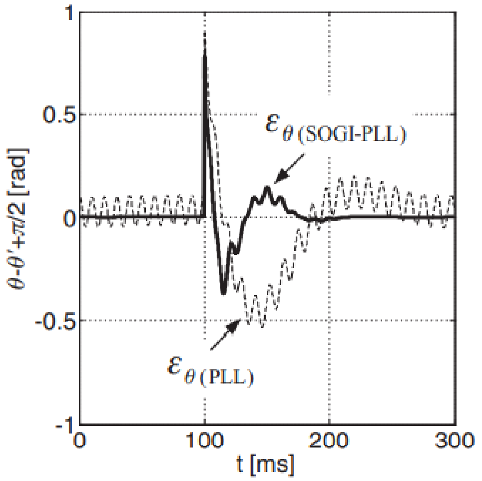
1. Recap

Grid Synchronization - PLLs based on adaptive filtering

- SOGI-based PLL
  - SOGI functions as QSG (in-quadrature signal generator)
  - SOGI is a notch filter
  - PLL locks the phase angle to the input frequency
  - the SOGI-PLL detects the input phase-angle faster than the conventional PLL and with no steady-state oscillations



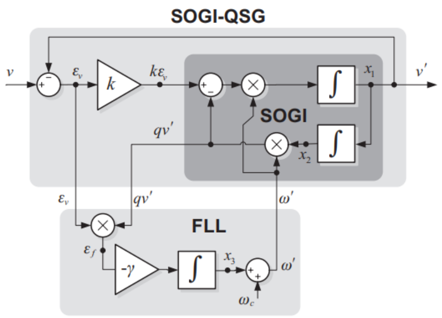




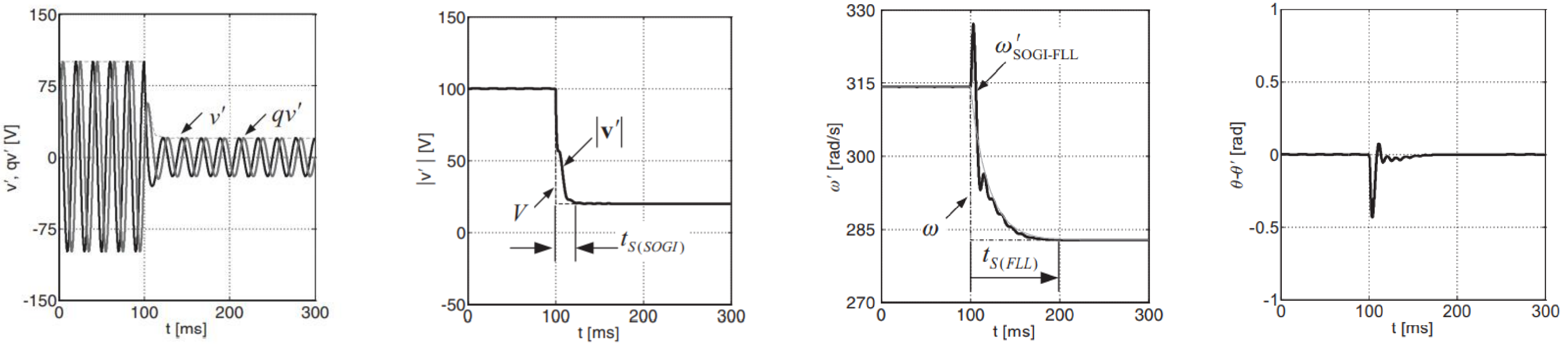
1. Recap

Grid Synchronization - PLLs based on adaptive filtering

- SOGI-FLL
  - SOGI functions as QSG (in-quadrature signal generator)
  - Frequency Lock Loop
  - Magnitude and phase can be calculated from v and v' vectors



$$|\boldsymbol{v}'| = \sqrt{(v')^2 + (qv')^2}; \quad \angle\boldsymbol{v}' = \arctan\frac{qv'}{v'}$$



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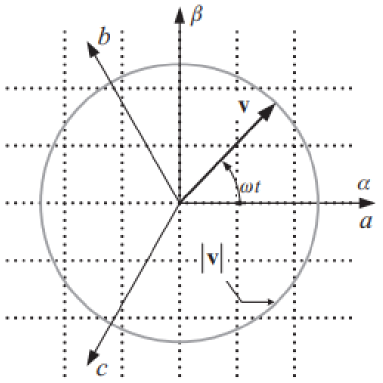
Grid Synchronization – Three-Phase Power Converters

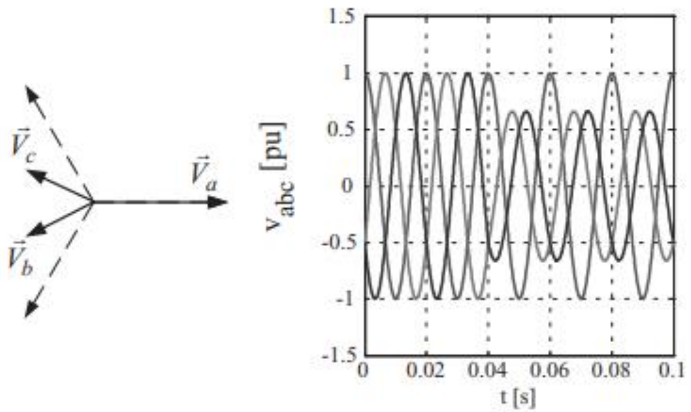
- 3-Phase PV inverter must synchronize and remain synchronized under
  - Balanced voltage conditions
  - Unbalanced voltage conditions
  - during voltage disturbances



$$\mathbf{v}_{abc} = \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = V \begin{bmatrix} \cos(\omega t + \phi) \\ \cos(\omega t - \frac{2\pi}{3} + \phi) \\ \cos(\omega t + \frac{2\pi}{3} + \phi) \end{bmatrix}$$

$$|\mathbf{v}| = \sqrt{v_a^2 + v_b^2 + v_c^2} = \sqrt{\frac{3}{2}} V$$

Balanced grid voltage

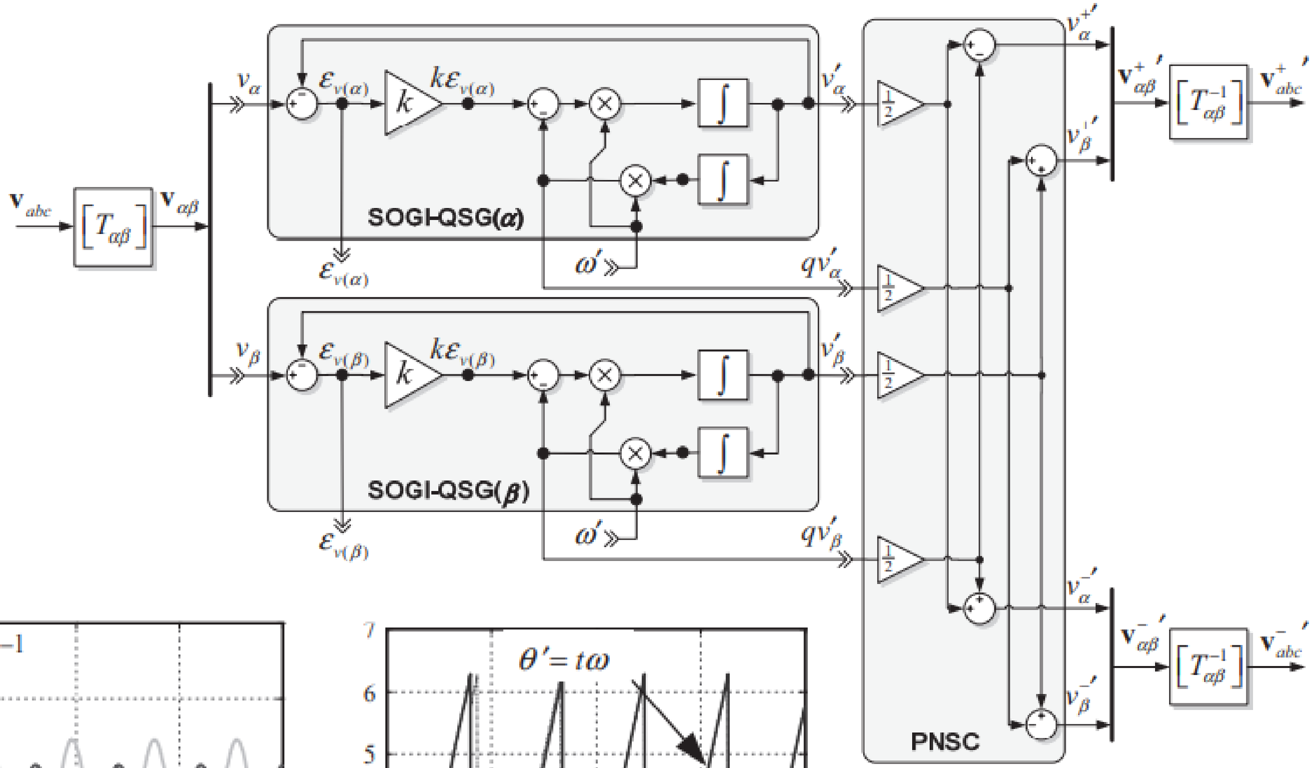


Type C Phase-to-phase fault

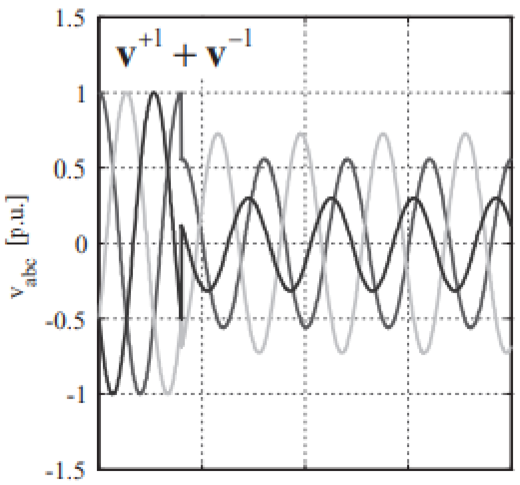
Grid Synchronization - Three-Phase Power Converters

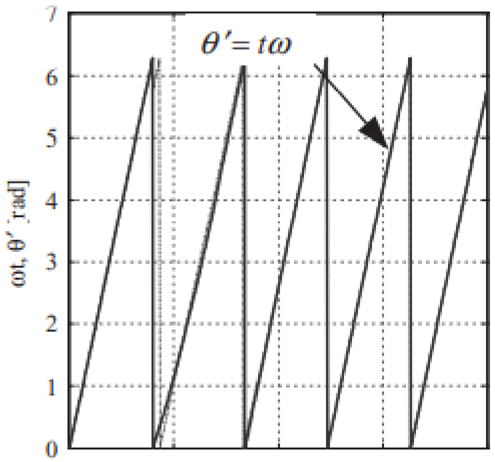
- Double SOGI -PLL
  - No oscillations of magnitude and phase during unbalance
  - Positive and Negative sequence magnitude and phase calculated from sequence vectors

$$|\boldsymbol{v}'| = \sqrt{(v'_\alpha)^2 + (v'_\beta)^2}; \quad \theta' = \tan^{-1}\frac{v'_\beta}{v'_\alpha}$$



Positive Negative Sequence Calculation

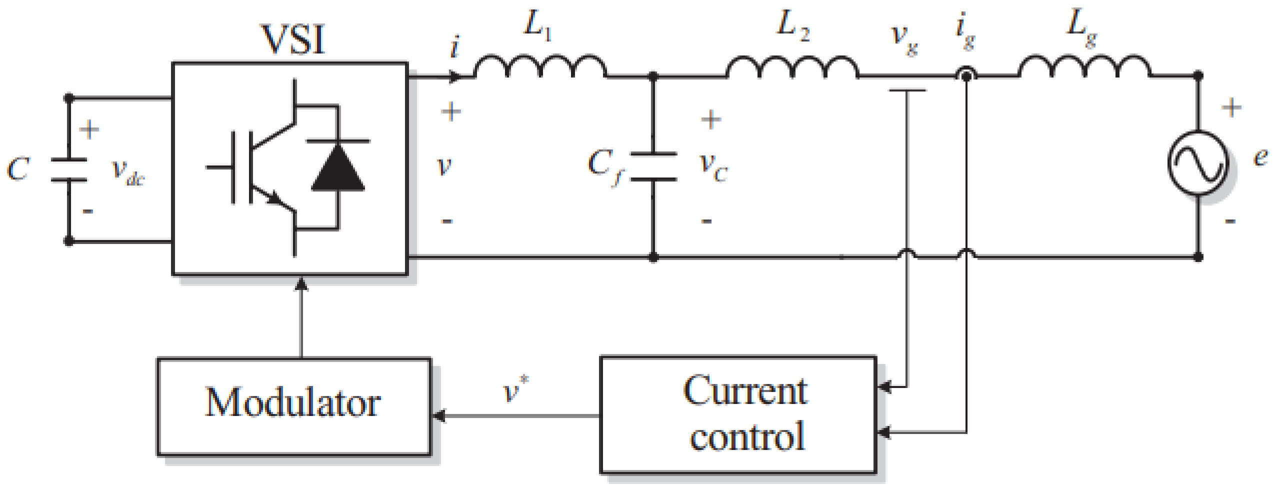




1. Recap

Grid Power Converter Control

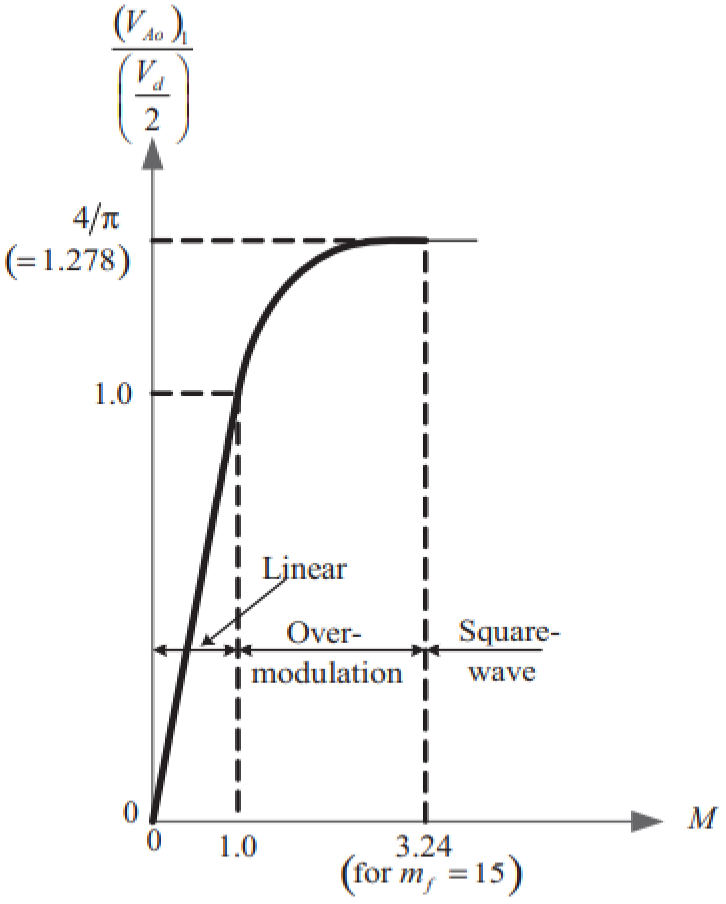
- Typical Grid Power Converter Control block diagram
  - Modulator
  - Current control
  - DC bus voltage control



Grid Power Converter Control – Modulation Techniques

- Classification of Pulse Width Modulation techniques
  - Carrier-based – pulse widths are determined by comparing a modulating waveform and a triangle carrier
    - Modulation index M – the ration between amplitudes of modulating and carrier waves
    - Carrier index m – the ration between frequencies of the modulation and carrier waves
  - Space Vector Modulation (SVM) applicable to Three-Phase systems only

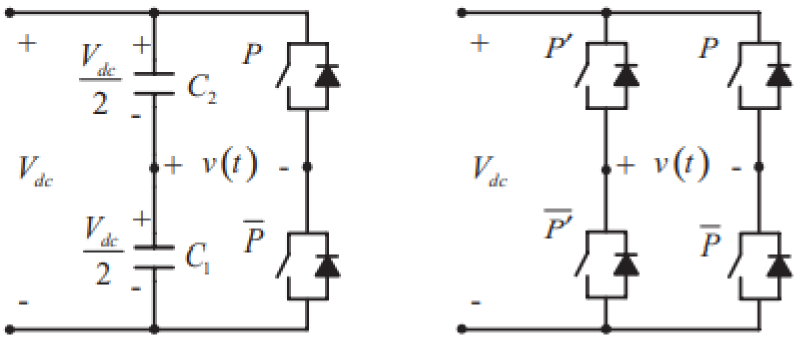
  - Objectives:
    - to obtain a lower harmonics distortion
    - reduce common mode currents
    - extend utilization of the DC bus (Three-Phase systems only)



1. Recap

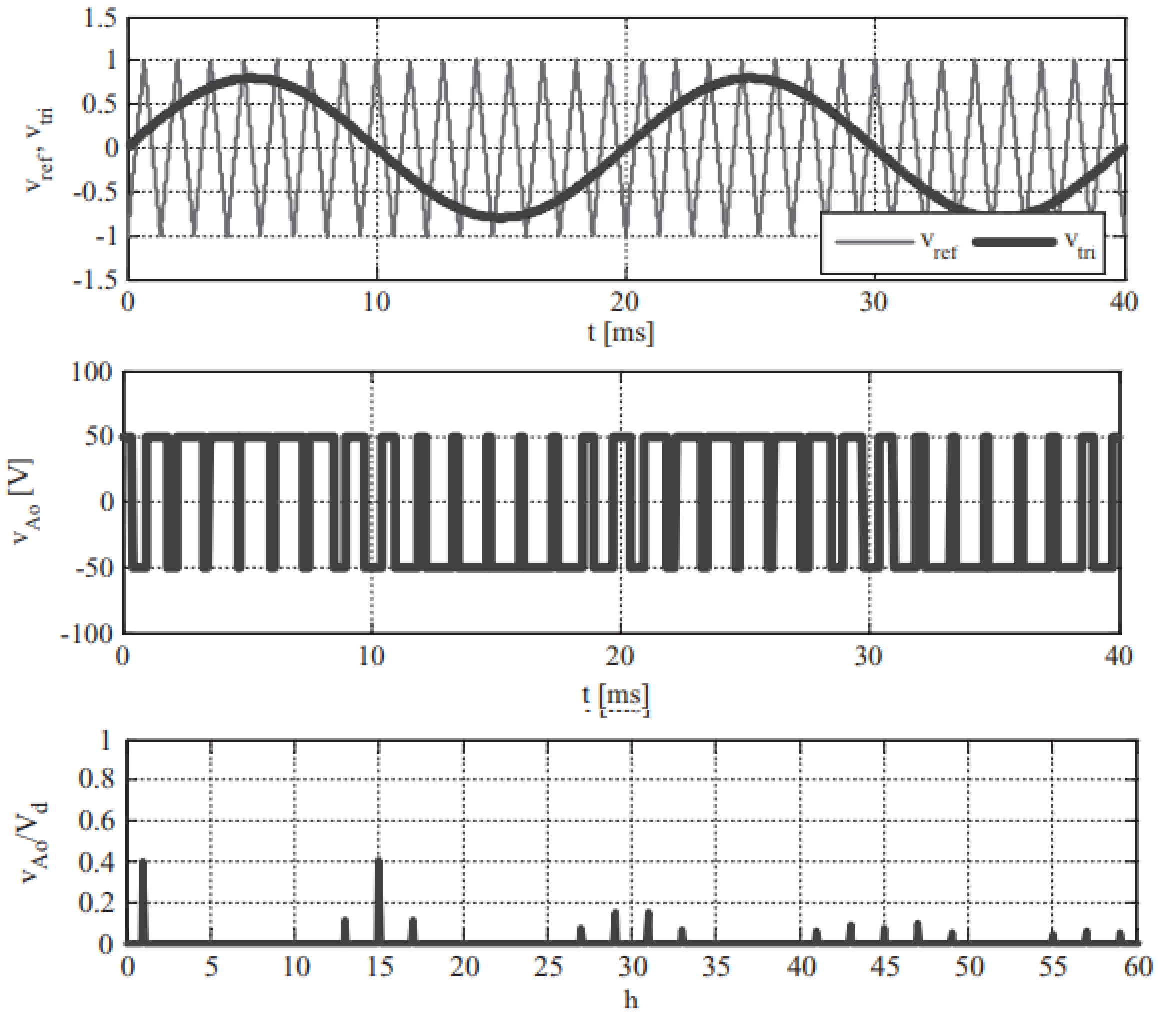
Grid Power Converter Control – Modulation Techniques

- Single Phase Carrier-based PWM modulation
  - Bipolar modulation



$$v(t) = \frac{4V_{dc}}{\pi}\sum_{\substack{m=0\\m>0}}^{\infty}\sum_{\substack{n=1\\n=-\infty}}^{\infty}\frac{1}{q}J_n\left(q\frac{\pi}{2}M\right)\sin\left([m+n]\frac{\pi}{2}\right)\cos\left(m\omega_c t + n\omega_0 t\right)$$

Jn – Bessel function of order n and q=m+n(ω_0/ω_c)

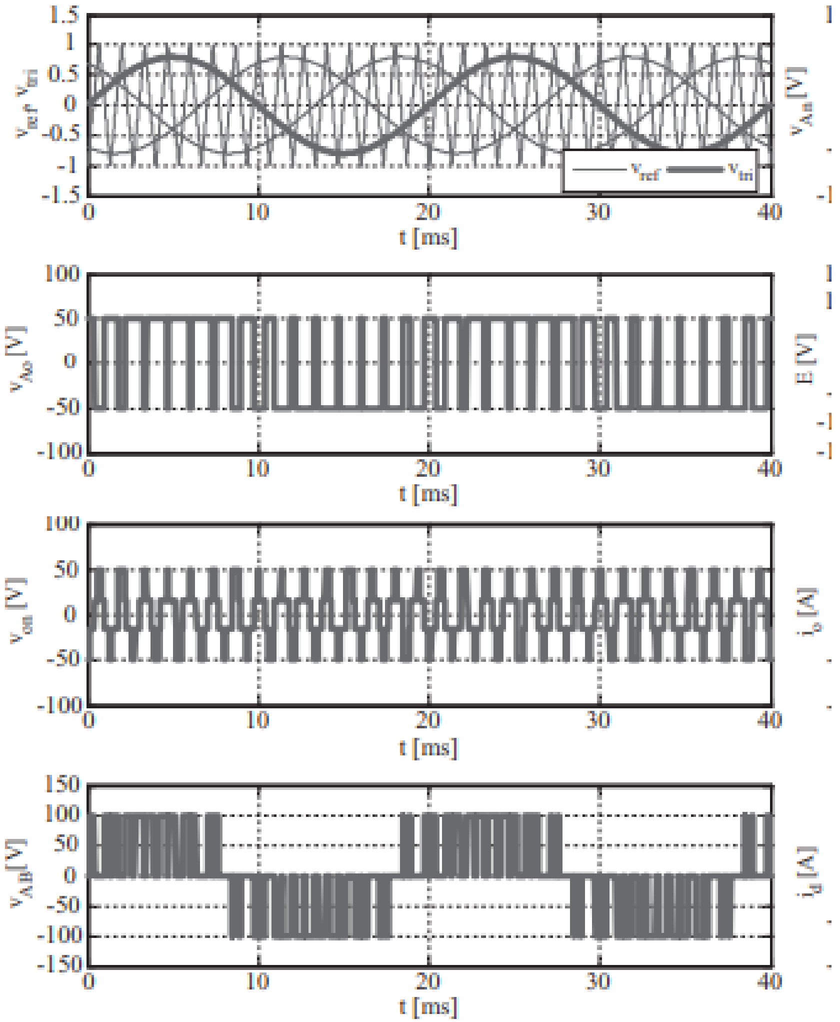


Single phase bipolar modulation

1. Recap

Grid Power Converter Control – Modulation Techniques

- Three Phase Carrier-based PWM modulation
  - Bipolar modulation
  - Increased linear modulation range by adding zero sequence signal into the modulating signal
  - No influence on the grid as Neutral is not connected
    - Sinusoidal with the third harmonic 17% (THIPWM)
    - Sinusoidal with triplen harmonics (subopt) – equivalent to SVPWM with symmetrical placement of the zero vectors in the sampling time
    - Discontinues PWM1, DPWM2 and DPWM10

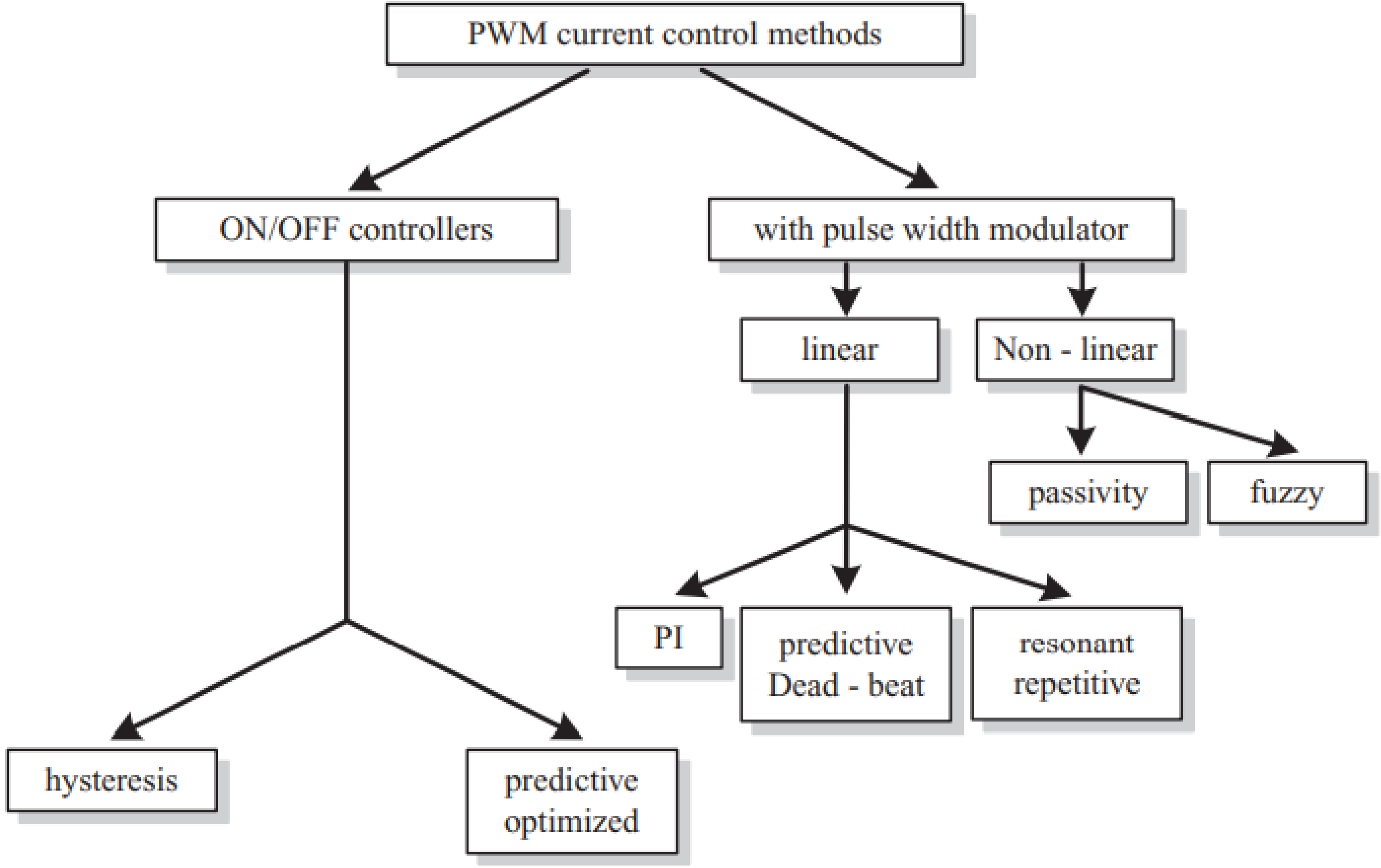


Three phase sinusoidal modulation

1. Recap

Grid Power Converter Control

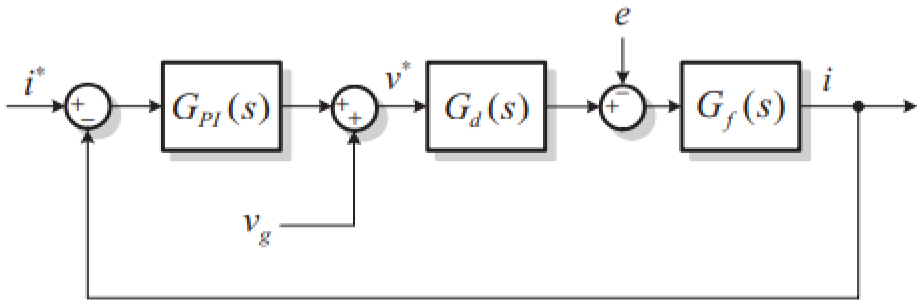
- Classification of current control methods
  - PMW based PI and Resonant most prevailing



1. Recap

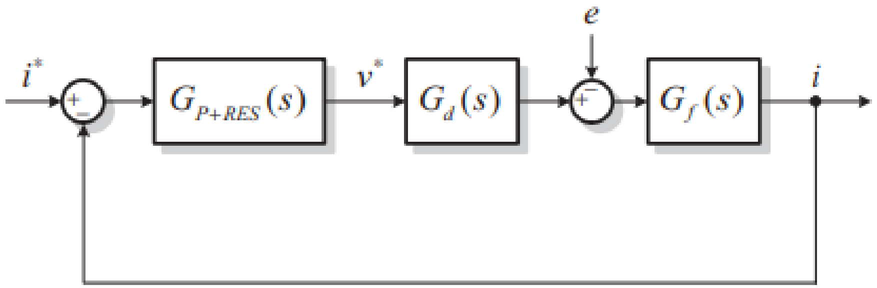
Grid Power Converter Control

- Current controller of a PI controller



$$G_f(s) = \frac{i(s)}{v(s)} = \frac{1}{R + Ls}$$

- Current controller of a P+resonant (PR) controller

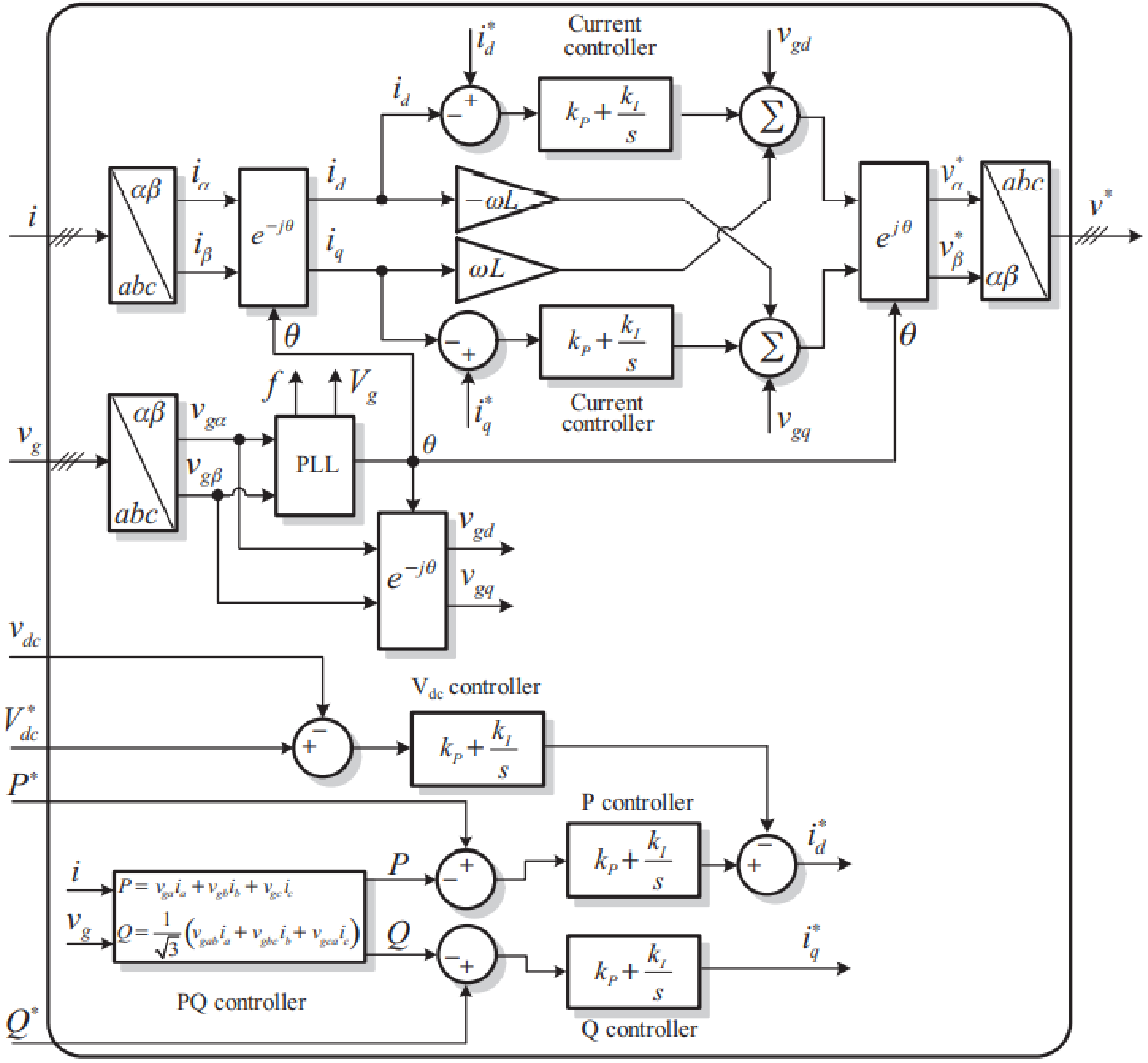


$$G_{AC}(s) = \frac{Y(s)}{E(s)} = \frac{2k_I\left(\omega_c s + \omega_c^2\right)}{s^2 + 2\omega_c s + (\omega_c^2 + \omega^2)} \approx \frac{2k_I \omega_c s}{s^2 + 2\omega_c s + \omega^2}$$

1. Recap

Grid Power Converter Control

- Three-Phase Synchronous PI dq current control



2. Setup and SW Tools

Simulation and Modelling tools

- Off-line
  - PLECS by Plexim
  - PSIM
  - Simulink/SimPowerSystems
  - Typhoon Virtual HIL
- Hardware-in-the-loop - HIL
  - RTDS
  - Opal-RT
  - RT BOX by Plexim
  - Typhoon HIL

2. Setup and SW Tools

AIT HIL CONTROLLER

2. Setup and SW Tools

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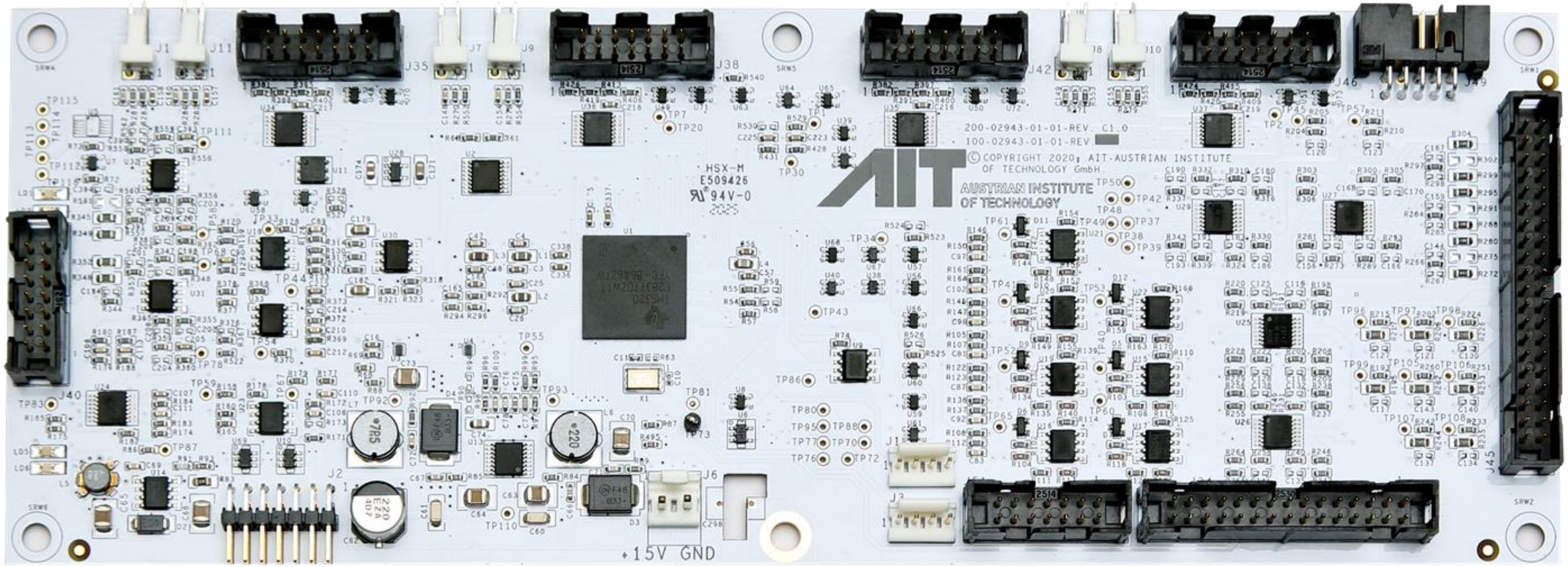
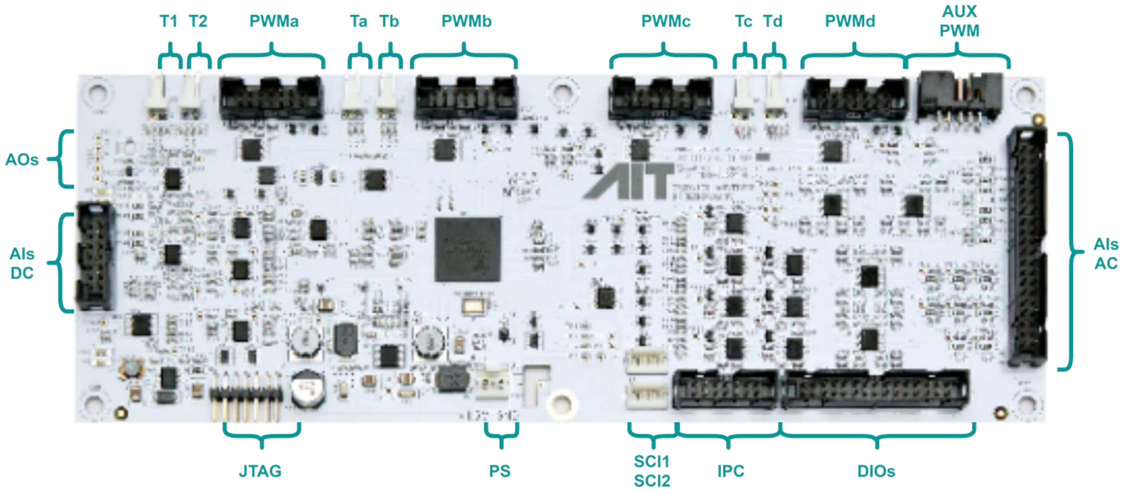
Vindobona GPIC Kit



2. Setup and SW Tools

Item	Description	Notes / Ranges
PWMa, PWMb, PWMc, PWMn, AUX PWM	Logic level PWMs & HW signals & temperature measurement	20 PWMs / 0..3.3V 1 DO HW ENA / 0..3.3V 4 DI HW FAULT / 0..5.0V Ta…Td/0..10mA / 0..3.0V
AIs DC	Analog Inputs DC side	3 VDC AIs /0..5.0V 1 VDC AI /0..5.0V or IDC AI 1 IDC AI / -45..45mA* 1 DI & 1 DO / 0..3.3V +3.3V
AIs AC	Analog Inputs AC side	9 VAC AIs / -5..+5V 8 IAC AIs / -60..60mA* 2 GP AIs / 0..+3.0V +1.5V Ref, +3.0V Ref +3.3V
AOs	Analog Outputs (optional)	4 AOs / 0..3.0V
DIOs	Digital Inputs and Outputs	25 DIOs / 0..3.3V
Ta, Tb, Tc, Td, T1, T2	Temperature measurements	Ta…Td / 0..10mA/0..3.0V T1,T2 / 0..3.0V
SCI1, SCI2	Serial Interfaces	GUI/CLI/Diagnostic Tool
IPC	Inter-processor communication port	Not used
PS	Power Supply	4.5..15V / 1A
JTAG	DSP JTAG	Not used

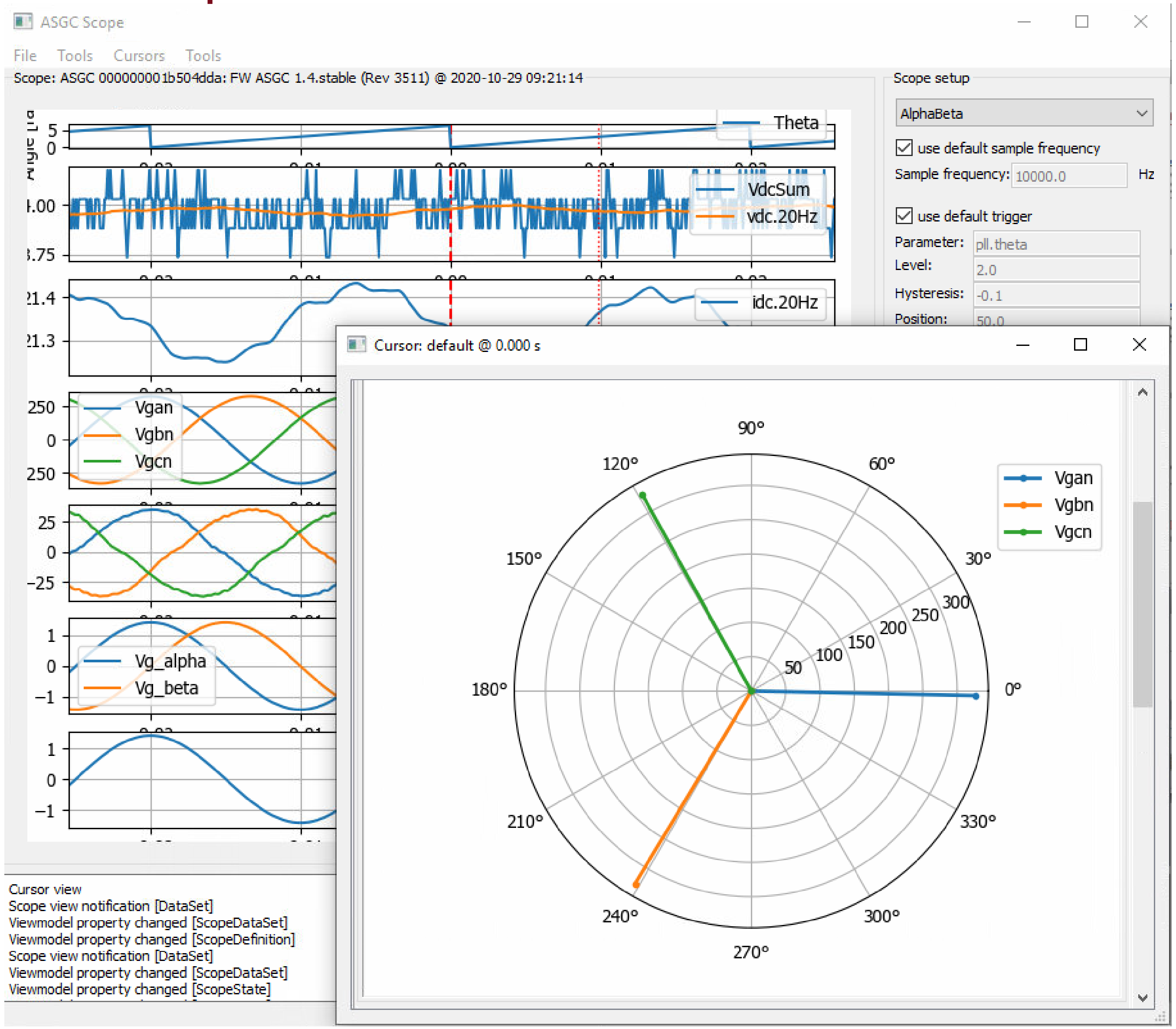
* by default, scalable to accept wider current transducer signals or bipolar voltage signals 0..3.0V referenced to +1.5V Ref



Pre-conditioning modules available for the AC and DC voltage and current ranges from 0…3.3kV and 2…+2kVA respectively

Gate drive hats: digital logic and voltage levels, current driven and fiber optic gates signals

2. Setup and SW Tools



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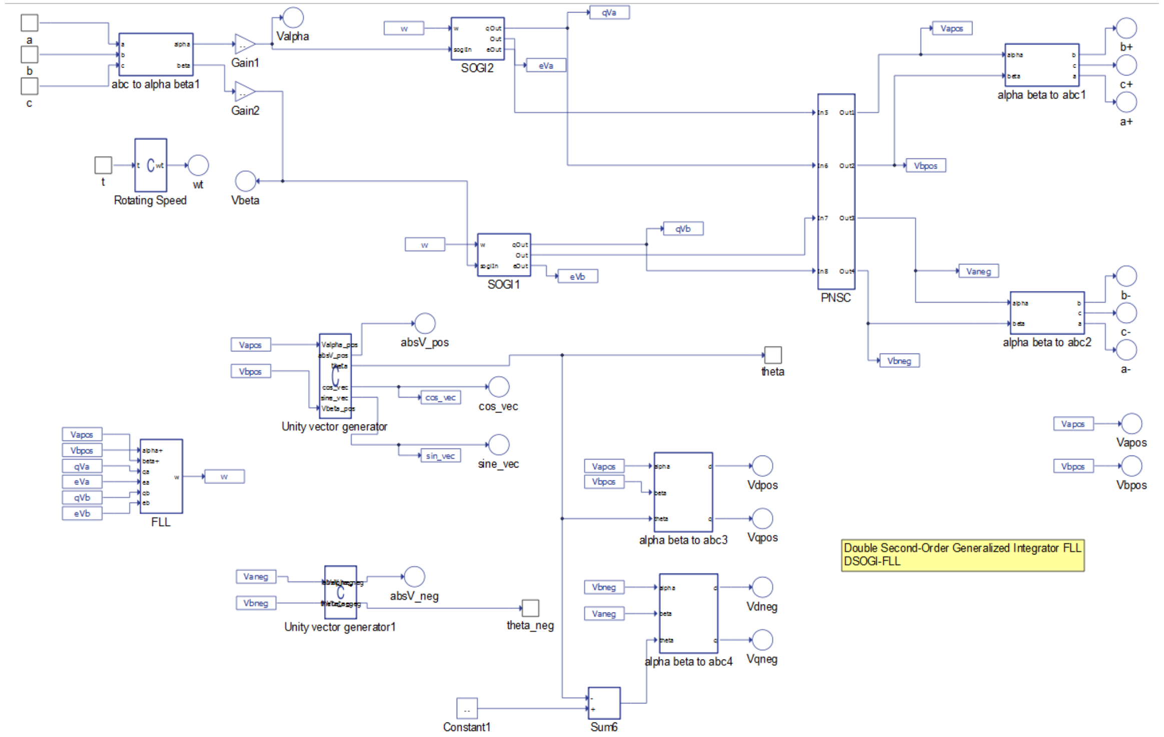
DIAGNOSTICS

- **AIT Data Logger** – log the target application and power converter data into the CSV file
- **AIT Scope/Phasor/Locus tool** – a powerful diagnostic tool, able to capture the internal controller waveforms, state space vectors, statuses, and display them as scope snapshots, phasors and locus diagrams

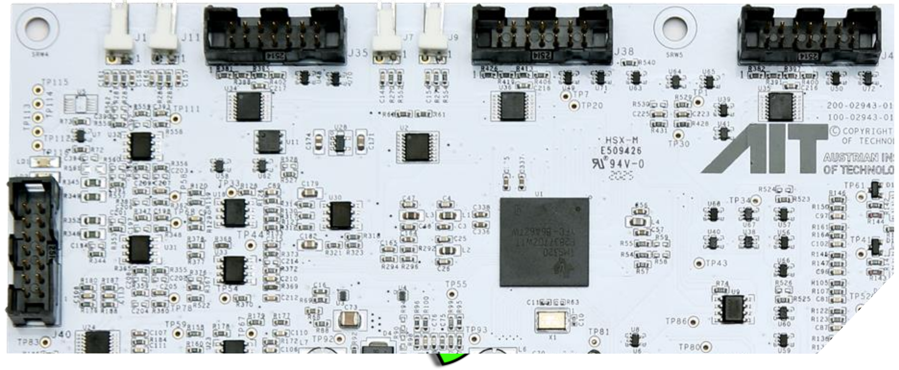
2. Setup and SW Tools

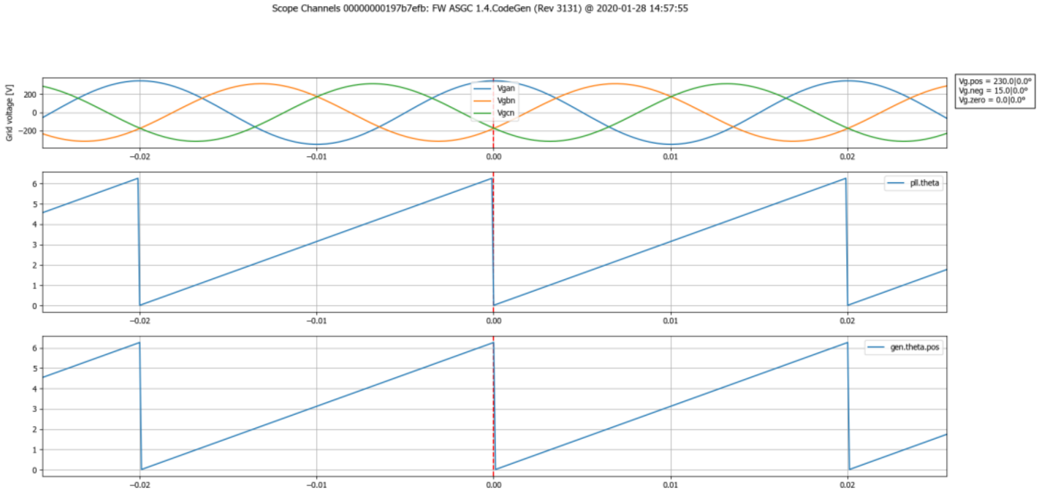
Model based Rapid Control Prototyping and Development

DSOGI-FLL Model - Typhoon HIL Schematic



AIT SGC Control





AIT SGC Scope

2. Setup and SW Tools

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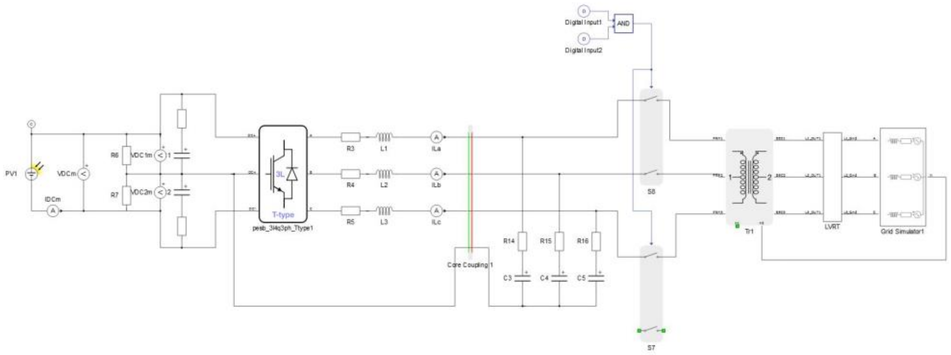
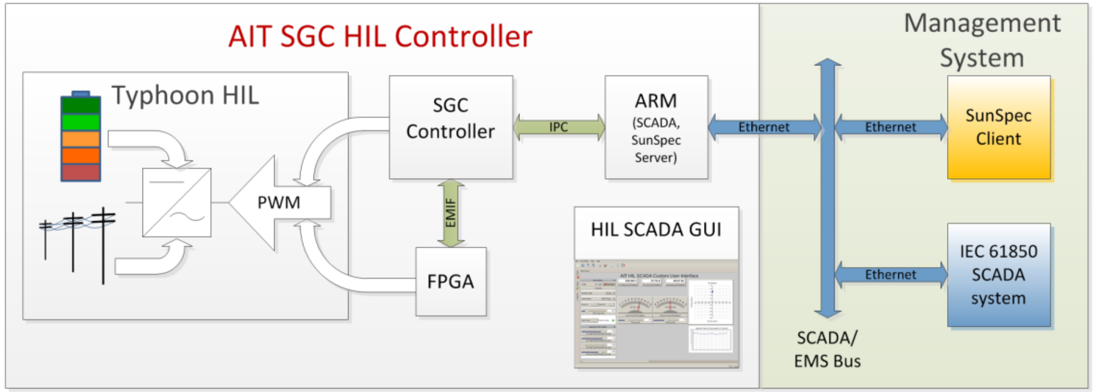
AIT SGC C-HIL Setup

- Typhoon HIL & AIT SGC HIL Controller

- AIT SGC HIL Schematic Model



- AIT SGC HIL Controller Block Diagram



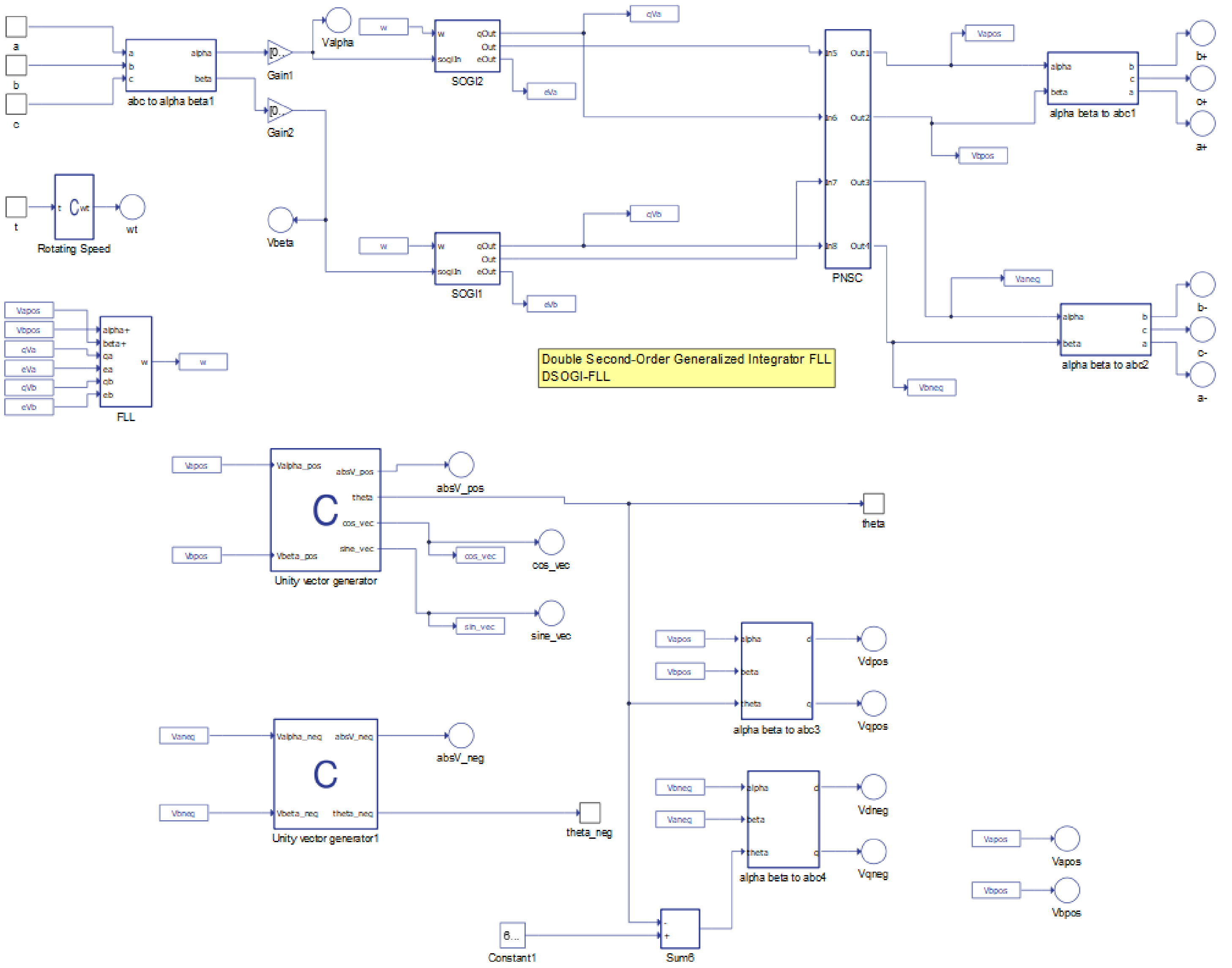
3. Reference Simulation Models

Simulation and Modelling tools

- Grid Sync - DSOGI FLL
- Reference Rapid Control Prototyping
- Reference Power Converter Application

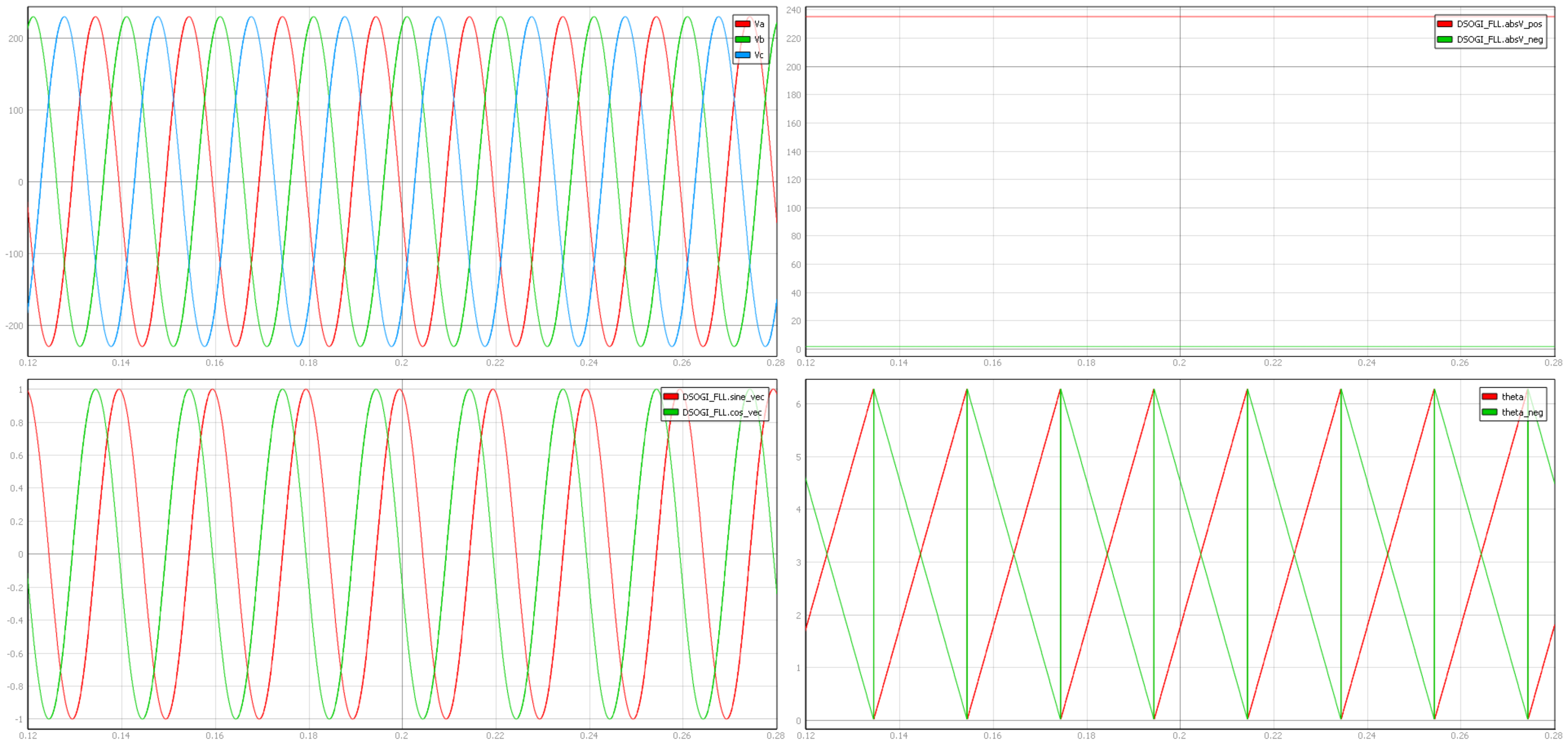
3. Reference Simulation Models

- Grid Sync - DSOGI FLL



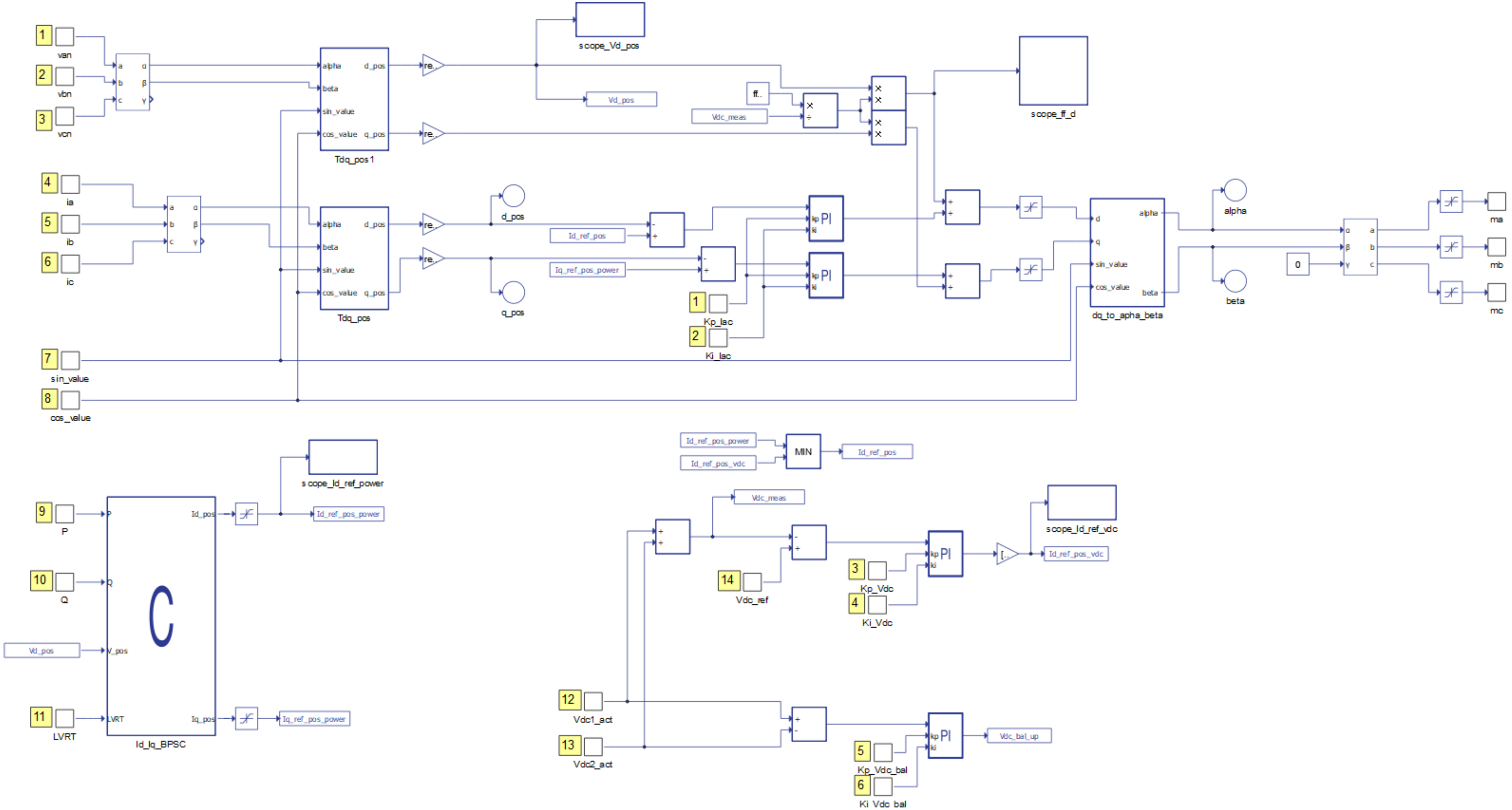
3. Reference Simulation Models

- Grid Sync - DSOGI FLL



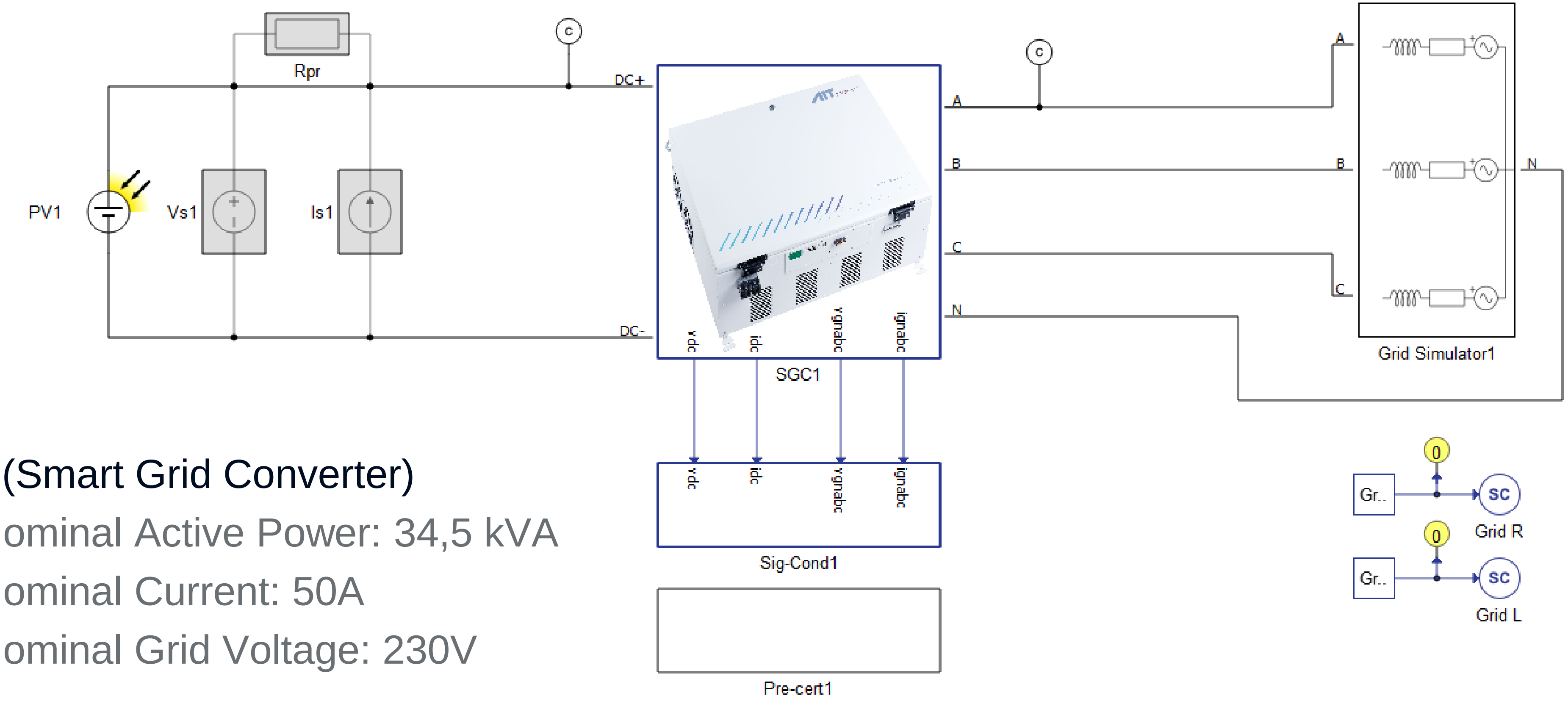
3. Reference Simulation Models

- Reference Rapid Control Prototyping



3. Reference Simulation Models

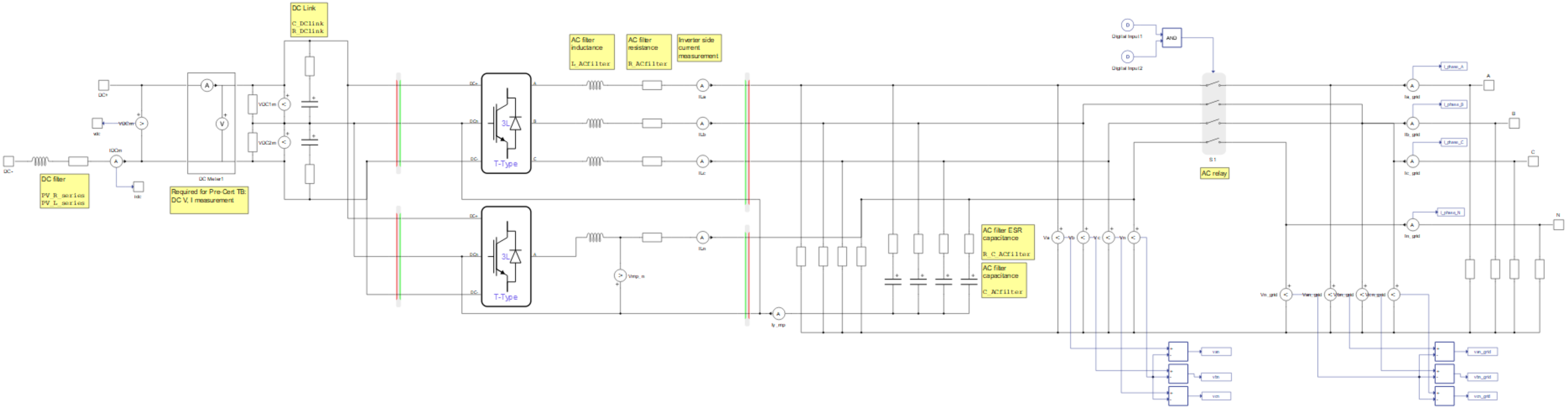
- Reference Power Converter Application



- SGC (Smart Grid Converter)
  - Nominal Active Power: 34,5 kVA
  - Nominal Current: 50A
  - Nominal Grid Voltage: 230V

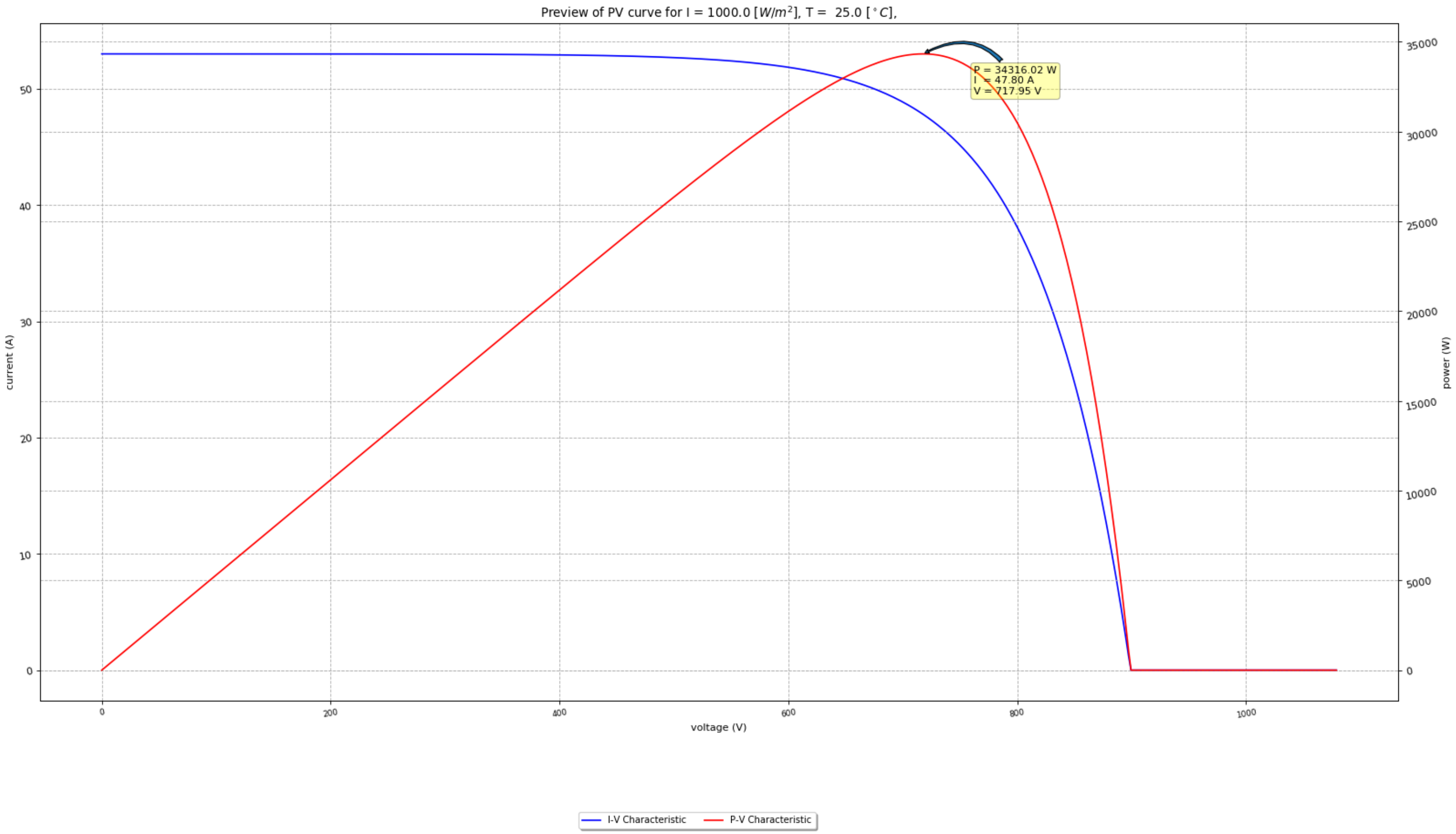
3. Reference Simulation Models

- Power Stage of the Converter



3. Reference Simulation Models

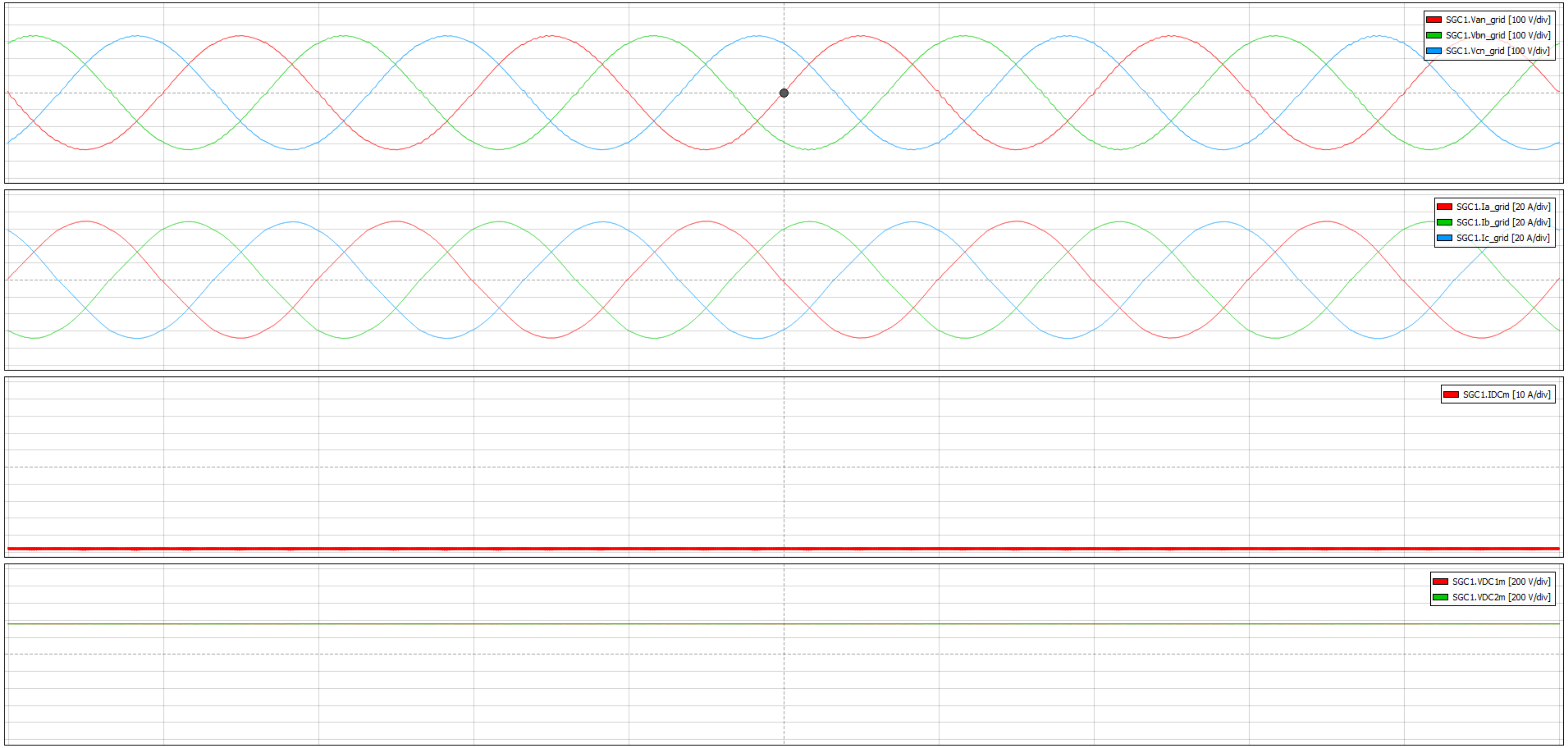
- PV Curve



- PV curve defines how the PV panel generates the power on the DC side of the converter
- Maximum Power Point (MPP) is set to the nominal power of the converter
- Once the converter is powered on, MPPT algorithm tracks the MPP

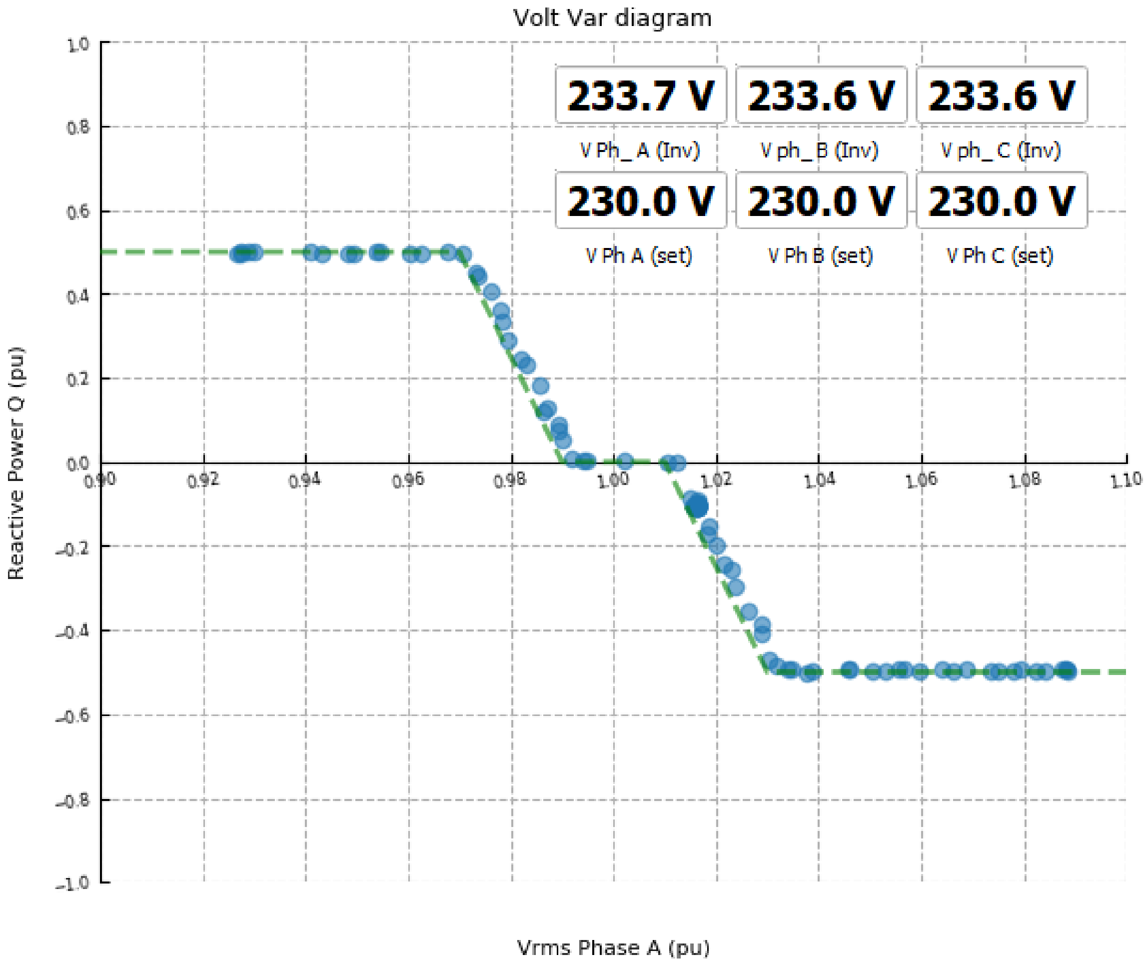
3. Reference Simulation Models

- AC and DC Voltage and Current Signals



3. Reference Simulation Models

- Volt-Var Example

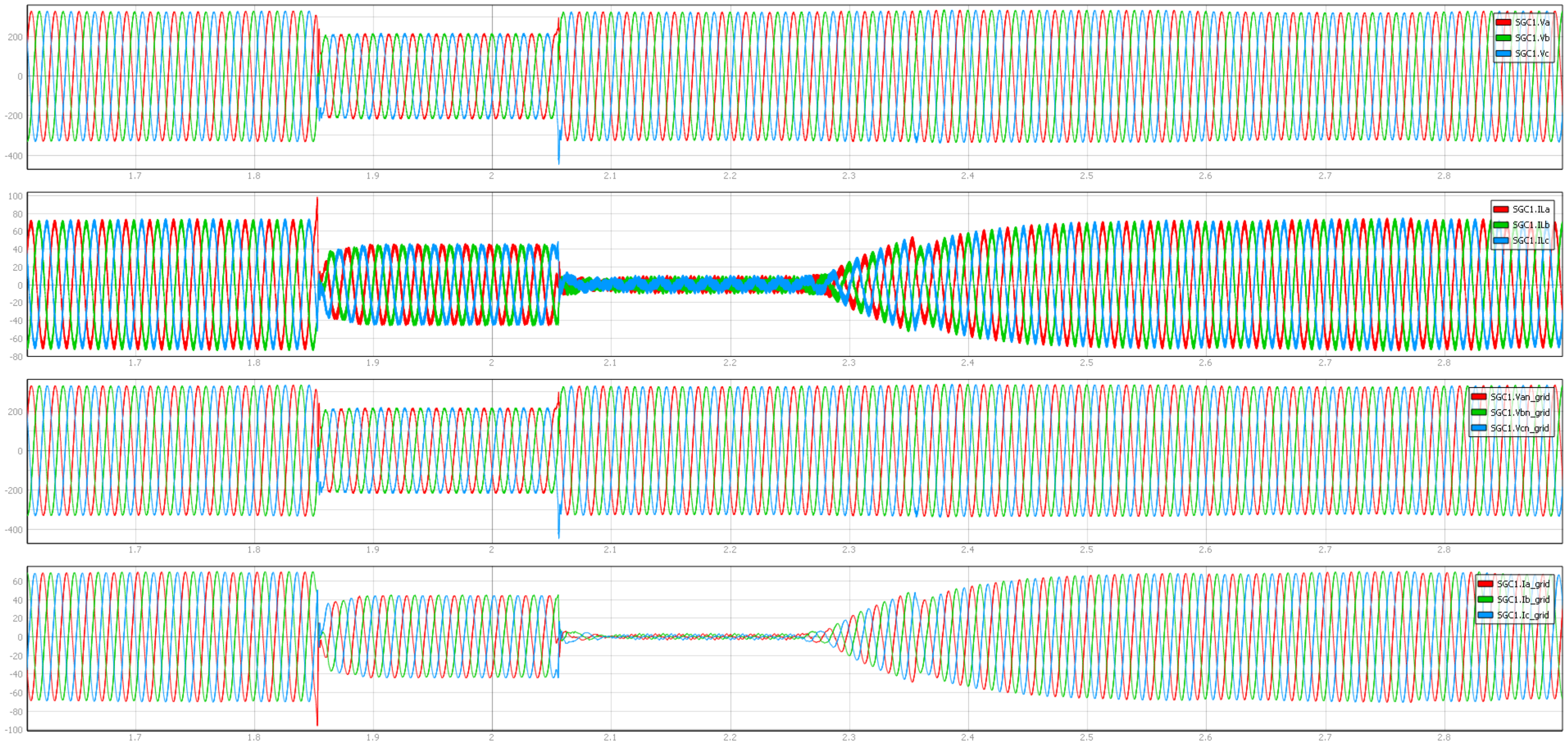


- Grid Functions:
  - Volt-Var
  - Volt-Watt
  - Frequency-Watt

- Volt-Var Example
  - Reference curve:
    [0.97, 0.5], [0.99, 0.0], [1.01, 0.0], [1.03, -0.5]
  - AC voltage between 0.99pu and 1.01pu: no reactive power contribution
  - AC voltage increases above 1.01pu: negative reactive power contribution
  - AC voltage decreases below 0.99pu: positive reactive power contribution

3. Reference Simulation Models

- LVRT Example



- Voltage dip
- Converter stops active power generation and contributes only reactive current until voltage is restored
- After the dip, converter restores active power to the value before the dip

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your ingenious partner

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