SEPOC 2025
17th SEMINAR ON POWER ELECTRONICS AND CONTROL
November 09 -12th, 2025 | Format Hybrid
University of Vale do Itajaí
Balneário Camboriú, SC, Brazil

INDUSTRIAL CHALLENGE

Typhoon HIL

SEPOC 2025 - INDUSTRIAL CHALLENGE WITH TYPHOON HIL

G2 POWER

CPT-based Multifunctional Grid-Tied Inverter with Type II Controller

Team G2 Power

Tiago Davi Curi Busarello, José de Arimatéia O. Filho, Alex Ferreira Silva, Paulo Fernando Silva, Helmo Kelis Morales Paredes

UNIVALI PPGCA PPGEE CT-UFSM IEEE
IEEE IAS/IES/PES/PELS Joint Chapter South Brazil Section - R9
Universidade Federal de Santa Maria IEEE Student Branch

Introduction and motivation

- Distributed Energy Resources (DERs) are becoming increasingly common in modern electric power systems.
- 1547 - IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with associated Electric Power Systems Interfaces

IEEE 1547 - 2003
- **Shall NOT** activelly regulate voltage
- **Shall** trip on abdnormal voltage/frequency

IEEE 1547 - 2014
- **May** actively regulate voltage
- **May** ride through abnormal voltage/frequency
- **May** provide frequency response (droop)

IEEE 1547 - 2018
- **Shall** be capable of actively regulating voltage
- **Shall** ride through abnormal voltage/frequency
- **Shall** be capable of frequency response
- **May** provide inertial response

IEEE 1547 STANDARD FAMILY	STATUS
IEEE 1547-2018: Standard for Interconnection	Published
IEEE 1547a-2020: Amendment regarding abnormal voltage trip settings of Cat_III DER	Published
IEEE P1547: Revision of 1547-2018	Started in 2023
IEEE 1547.1-2020: Standard for Test and verification requirements	Published
IEEE P1547.1a: Amendment to incorporate gaps identified by UL1741SB and industry	Started in 2024
IEEE 1547.2-2023: Guide for application of IEEE 1547-2018	Published
IEEE 1547.3-2023: Guide for Cybersecurity	Published
IEEE 1547.4-2011: Guide for Islanded Systems (Microgrids)	Inactivated
IEEE P1547.4: Revision of 1547.4-2011	Started in 2024
IEEE 1547.7-2013: Guide for Conducting DER Impact Studies	Inactivated
IEEE P1547.7: Revision of 1547.7-2013	Started in 2024
IEEE 1547.9-2022: Guide for Energy Storage System Interconnection	Published
IEEE P1547.10: Recommended Practice for DER Gateway	Started in 2023

Introduction and motivation

EPRI

TECHNICAL BRIEF

Status of IEEE P1547 Ongoing Revision

2025 Update

INTRODUCTION

IEEE Standard 1547 defines the minimum plant performance requirements for connecting distributed energy resources (DERs) to distribution systems. The 2018 revision marked a major update to the original 2003 standard and its 2014 amendment, mandating various grid-support functions, abnormal grid voltage and frequency ride-through capabilities, and interoperability requirements. A subsequent amendment in 2020 further refined the standard by enabling greater flexibility in abnormal voltage ride-through behavior. Many United States public utility commissions

All changes discussed are preliminary and subject to further modification during the revision and balloting process.

SELECTED CHANGES PROPOSED IN THE JULY 2025 DRAFT

This section summarizes selected new terminologies, requirements, and clarifications proposed in the IEEE P1547 revision. Described content reflects the state of Draft 0.6a (July 2025) and may evolve through the revision and balloting process. EPRI intends to provide future updates via webinars and technical briefs as the 1547 revision process

Introduction and motivation

- Multifunctional inverter (ancillary services) appears as an attractive solution to the new updates of connecting DERs to the electric power system

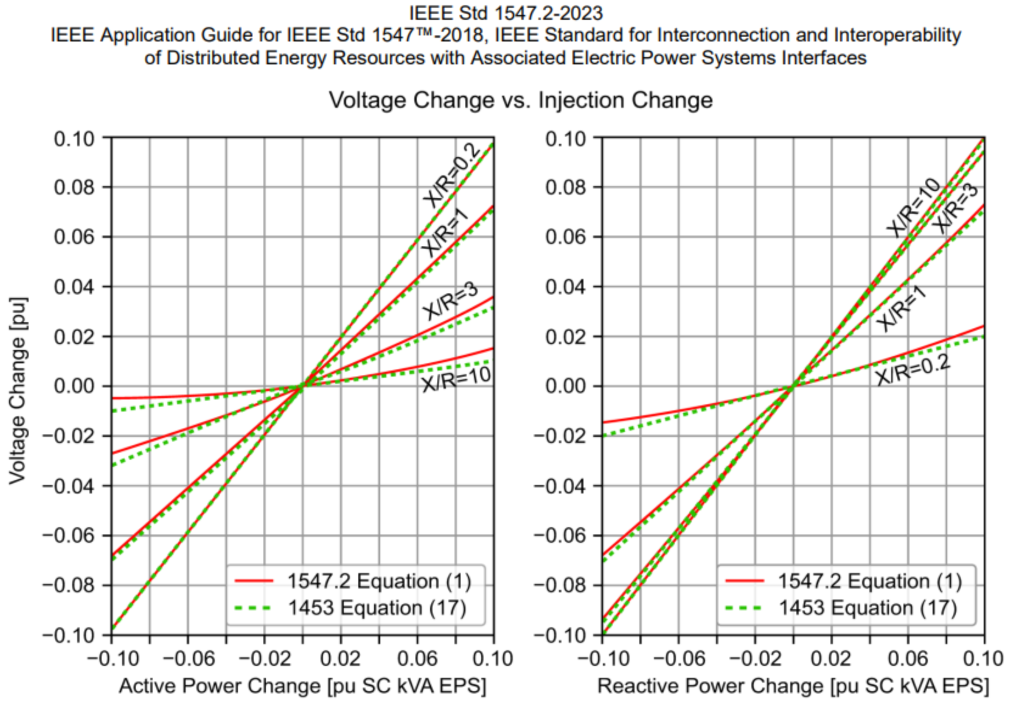


Fig. 1: Effects of active and reactive power on voltage change at diferente X/R ratios.

Proposed System and Control

- **The point is: multifunciotnal converters (MFGTI) will are a reality in power systems. And it will be much more**

- Develop a multifunctional inverter to address the IEEE1547-2023
- Even though the IEEE1547 does not talk about current Harmonic compensation, the proposed inverter is already ready for such a compensation.
- Use of the Conservative Power Theory to compute power quantities of loads.
- 7 modes of operation.
- Use just one current controller for all modes of operation, differently from switchable controller strategies in inverters with ancillary services.

Proposed System and Control

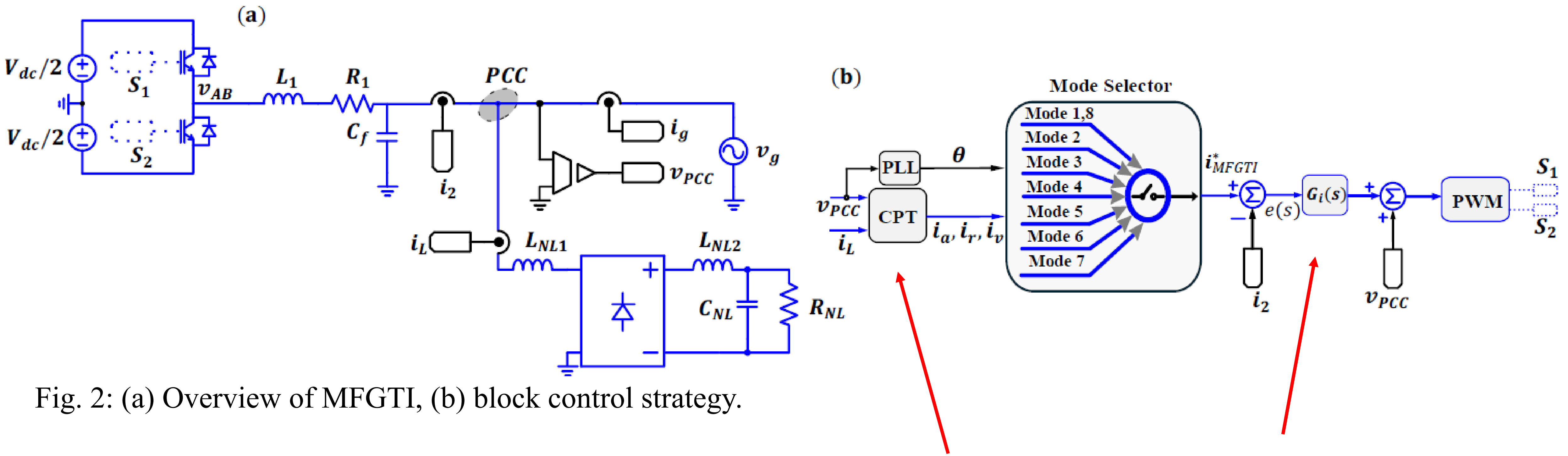


Fig. 2: (a) Overview of MFGTI, (b) block control strategy.

Proposed System and Control

- **Design current controller**

$$OLTF_u(s) = PWM(s) \cdot \frac{V_{dc}}{L_f s + R_f} \cdot K_i$$

$$\varphi_{sl} = \measuredangle OLTF_u(f_c)\ [°]$$

$$G_{Sl_{dB}} = |OLTF_u(f_c)|\ [dB]$$

- **Type-II current controller ($\boldsymbol{G_i(z)}$)**

✓ pole at the origin and single zero–pole pairs
✓ enhances robustness against load variations
✓ external disturbances
✓ efficient and relatively simple solution
✓ alternative controller in MFGTI

- **Transfer function: Type-II current controller ($\boldsymbol{G_i(z)}$)**

$$G_i(z) = \frac{b_0 + b_1 z^{-1} + b_2 z^{-2} + b_3 z^{-3}}{a_0 + a_1 z^{-1} + a_2 z^{-2} + a_3 z^{-3}}$$

Coefficients

$$b_0 = \frac{T_s D_1 + D_2 T_s^2 + T_s^3}{\beta}$$

$$b_1 = -\frac{2T_s D_1 + D_2 T_s^2}{\beta}, b_2 = -\frac{T_s D_1}{\beta}$$

$$a_1 = -\frac{3D_3 + 2D_4 T_s + D_5 T_s^2}{\beta_{dl}}$$

$$a_2 = \frac{3D_3 + D_4 T_s}{\beta}, a_3 = -\frac{D_3}{\beta}$$

where:

$$D_1 = R_2 C_1 C_3 (R_1 + R_3)$$

$$D_2 = R_2 C_1 + R_1 C_3 + R_3 C_3$$

$$D_3 = R_1 R_2 R_3 C_1 C_2 C_3$$

$$D_4 = R_1 R_2 C_1 (C_1 + C_2) + R_1 R_2 C_1 C_2$$

$$D_5 = R_1 (C_1 + C_2)$$

$$\beta = D_3 + D_4 T_s + D_5 T_s^2$$

Modes of Operation

- Mode 1: Injecting Active Power
- Mode 2: Full Shunt Power Filter
- Mode 3: Reactive Power Compensation (Statcom)
- Mode 4: Harmonic compenstation
- Mode 5 Active and Reactive power Injection
- Mode 6: Active power consumption and reative power injection
- Mode 7: stand-by

More modes could be added (combination of them)

Model – Power Structure (TyphoonSim® 2025.2)

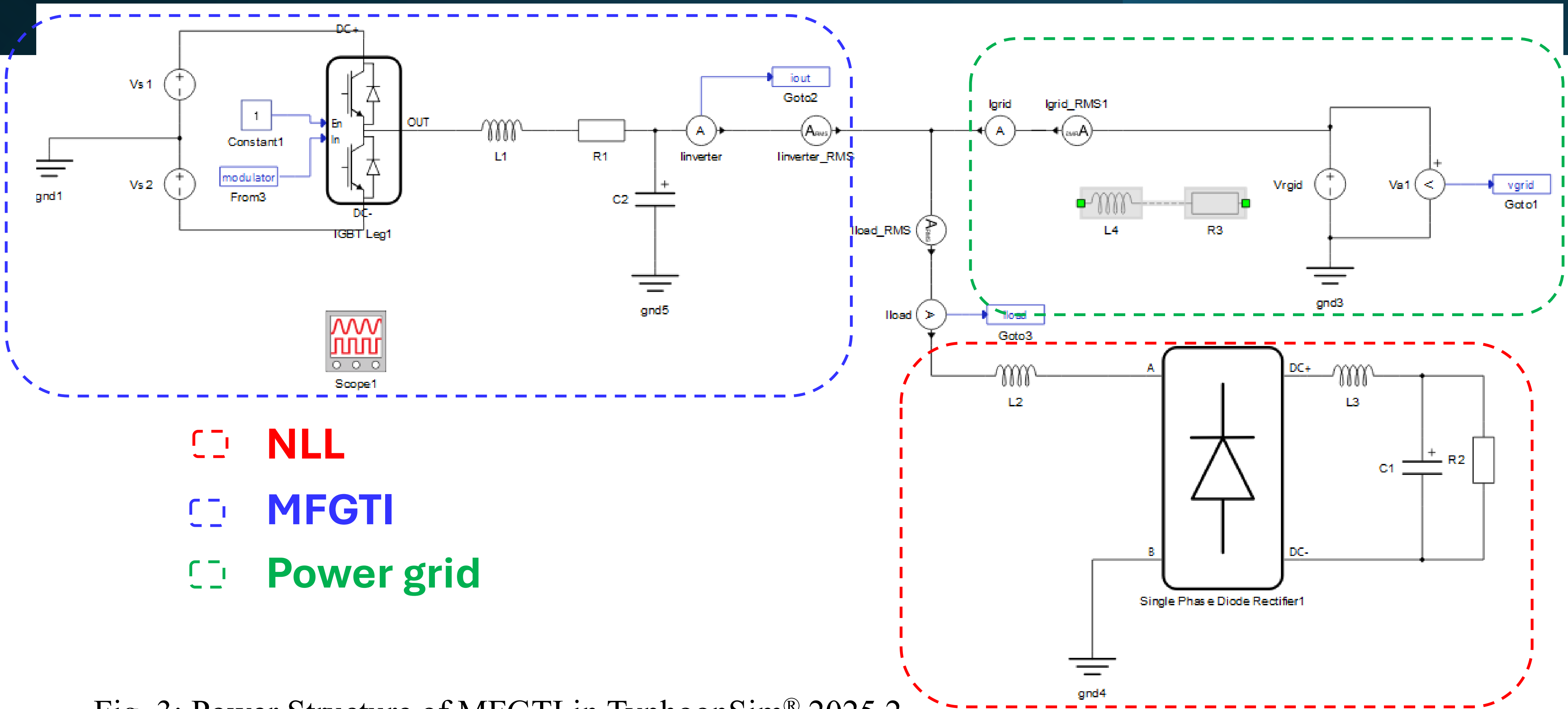


Fig. 3: Power Structure of MFGTI in TyphoonSim® 2025.2.

Model – Reference Generators (TyphoonSim® 2025.2)

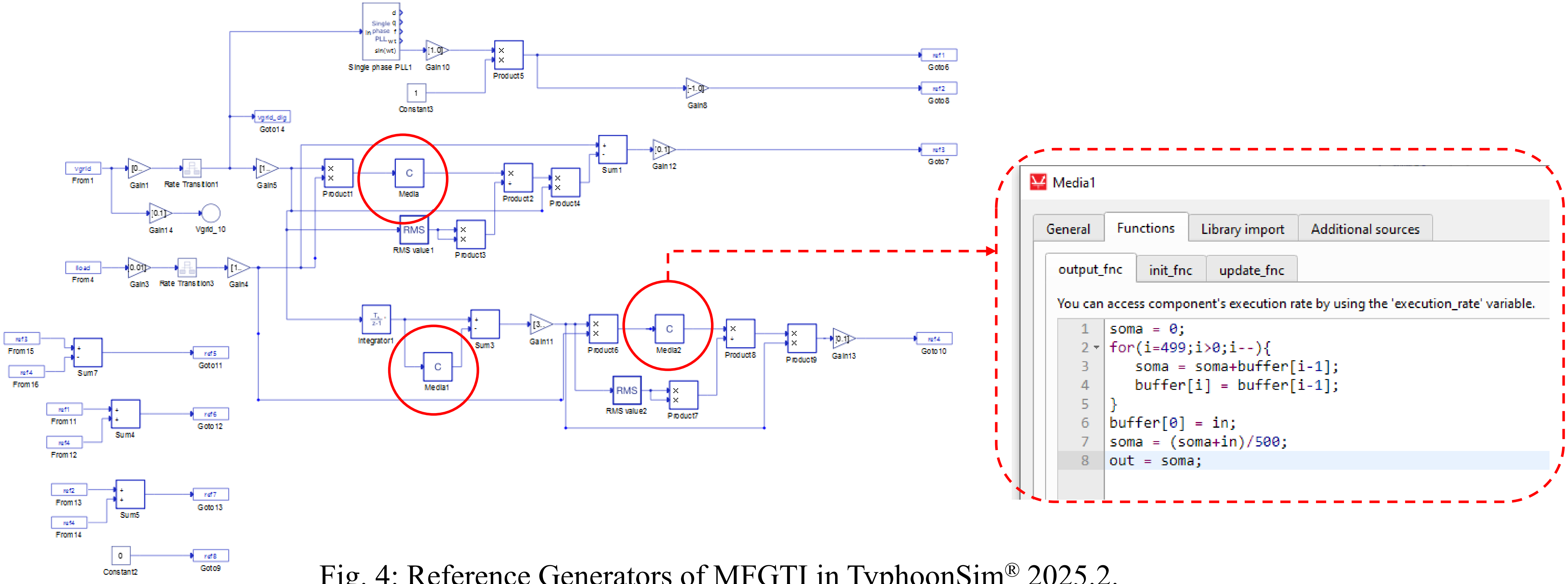


Fig. 4: Reference Generators of MFGTI in TyphoonSim® 2025.2.

Model – Model Selector and Current Controller (TyphoonSim® 2025.2)

Mode Selector

Current Controller:

(a)

(b)

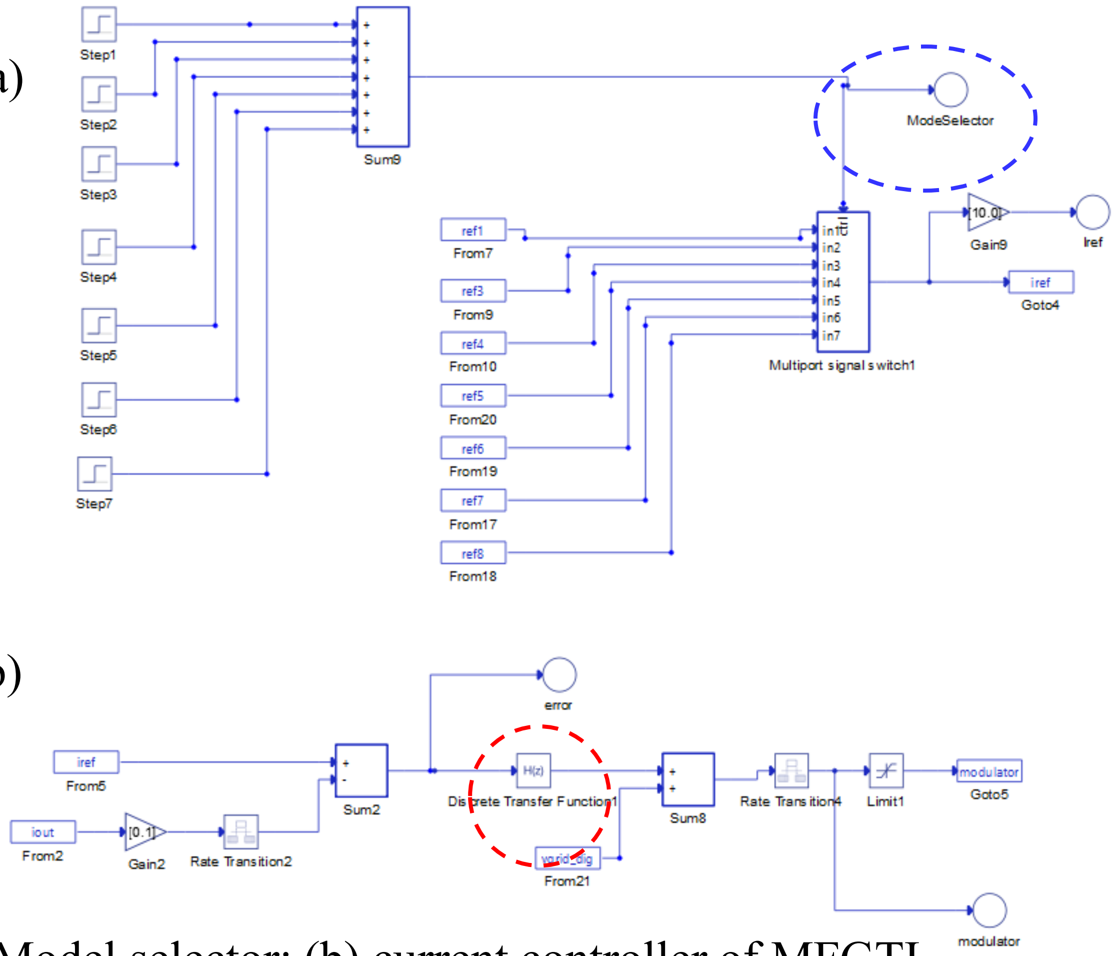
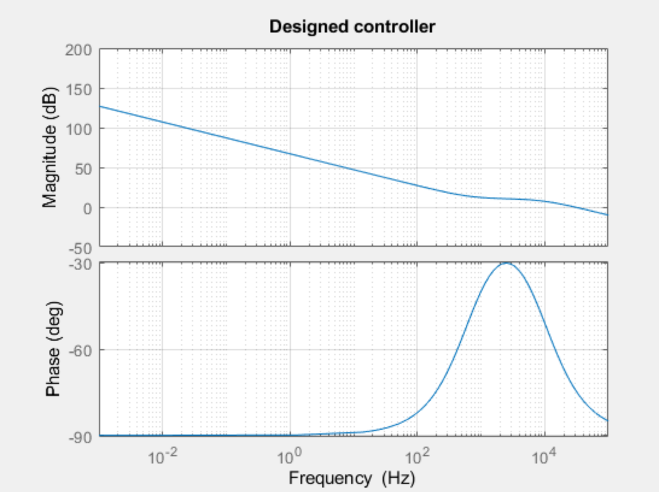


Fig. 5: (a) Model selector; (b) current controller of MFGTI.

Model – Scripts in Matlab® and Python

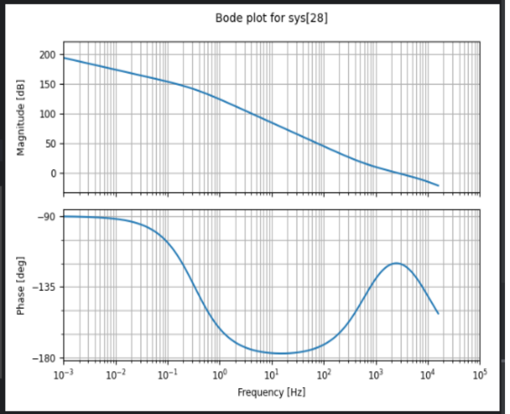
(i) Script in Matlab

```
opts = bodeoptions('cstprefs');
opts.FreqUnits = 'Hz';

figure
bode(FTMAu,opts)
title('Uncontrolled Open Loop Transfer Function');
xlim([0.001 1e5]);
grid

%Design of the type 2 current controller
inst = evalfr(FTMAu, 2*pi*fc*j);
fase_fc = rad2deg(phase(inst));

ganho_fc = mag2db(abs(inst));
ganho_real = 10^(abs(ganho_fc/20));

alpha = MFd - fase_fc - 90;

K2 = tand(alpha/2 +

Prod = 1/(2*pi*fc*ga
C2 = 100e-9;
R1 = Prod/C2;
C1 = C2*((K2^2)-1);
R2 = K2/(2*pi*fc*C1)

Ctipo2 = (1+s*R2*C1)
```



(ii) Script in Python

```
C1 = C2 * ((K2 ** 2) - 1)
R2 = K2 / (2 * np.pi * fc * C1)

Ctipo2 = (1 + s * R2 * C1) / (s * R1 * (C1 + C2 + s * R2 * C1 * C2))

# ====== Bode do controlador ======
ctrl.bode(Ctipo2, dB=True, Hz=True, omega_limits=(0.001, 1e5))
plt.grid(True, which="both")
plt.show()

# ====== Malha aberta com controle ======
FTMAc = FTMAu * Ctipo2
ctrl.bode(FTMAc, dB=True, Hz=True, omega_limits=(0.001, 1e5))
plt.grid(True, which="both")
plt.show()

inst2 = ctrl.evalfr(FTMAc, 2j * np.pi * fc)
MF_obtida = np.degrees(np.angle(inst2)) + 180
ganho_obtido = 20 * np.log10(abs(inst2))
ganho_real_obtido = 10 ** (abs(ganho_obtido) / 20)

# ====== Discretização do controlador tipo II ======
beta = 4 * R1 * R2 * C1 * C2 + 2 * ts * R1 * (C1 + C2)

b0 = (ts ** 2 + 2 * ts * C1 * R2) / beta
b1 = (2 * ts ** 2) / beta
b2 = (ts ** 2 - 2 * ts * C1 * R2) / beta

a0 = 1
a1 = (-8 * R1 * R2 * C1 * C2) / beta
a2 = (4 * R1 * R2 * C1 * C2 - 2 * ts * R1 * (C1 + C2)) / beta
```



Trade-off between filter size and power quality

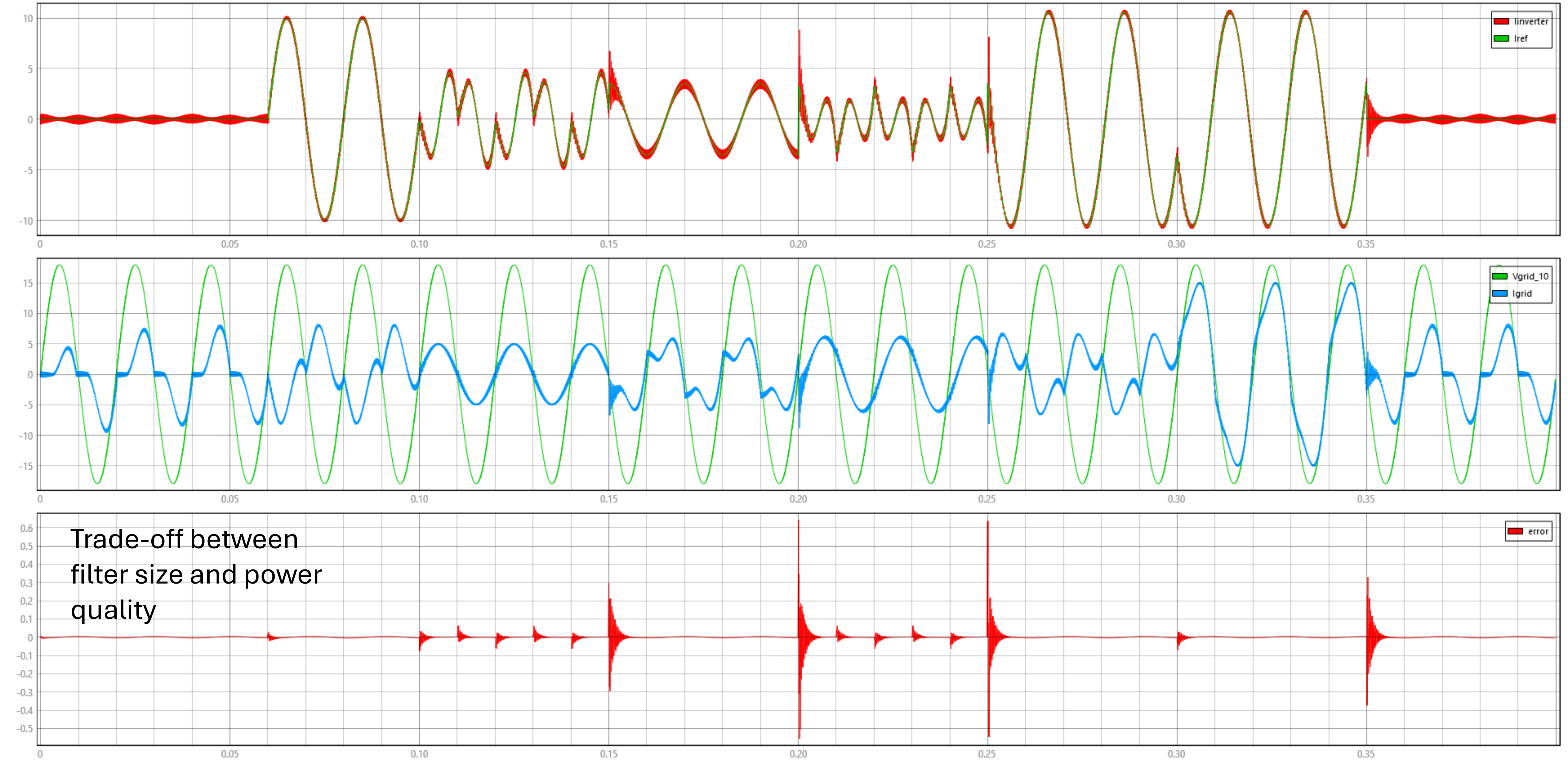


Fig. 6: (a) current reference and MFGTI current; (b) grid current, grid voltage/10; (c) error.

Extension of our model

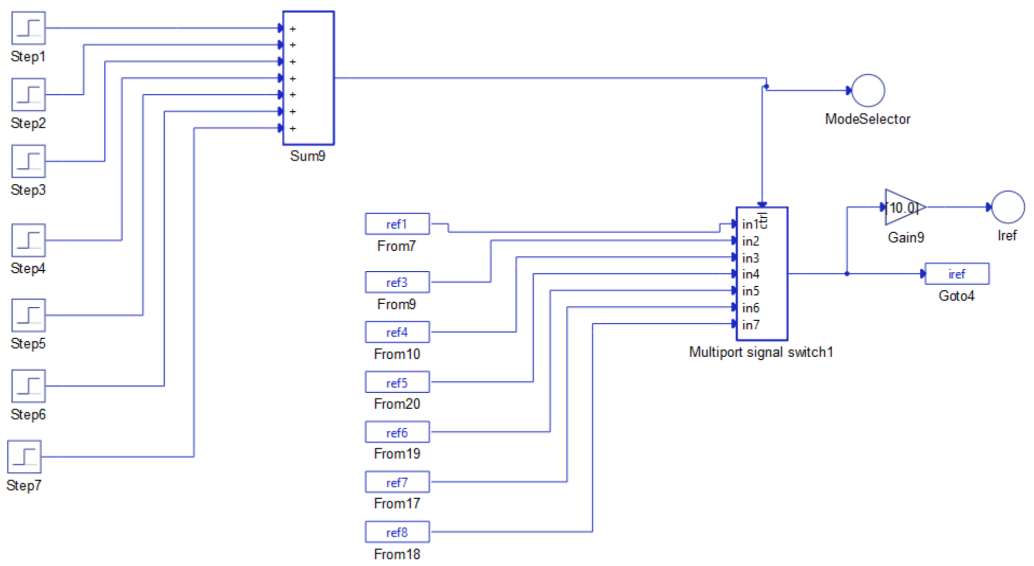
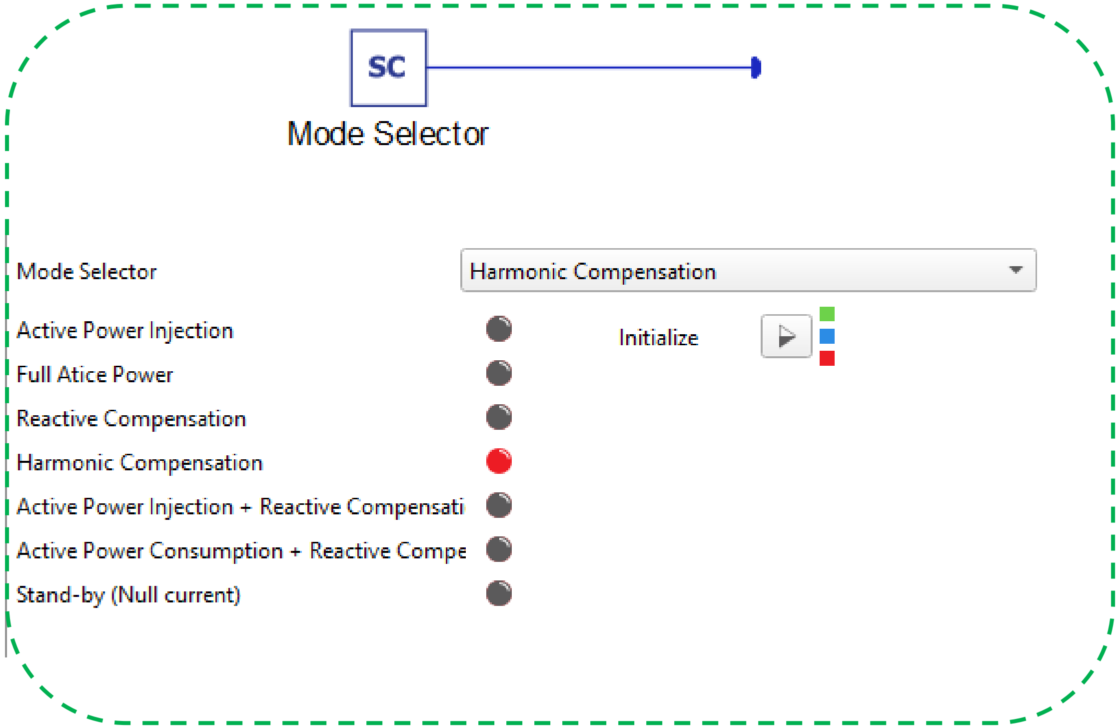


Fig. 7: Extension of the proposed model.



Extension of our model

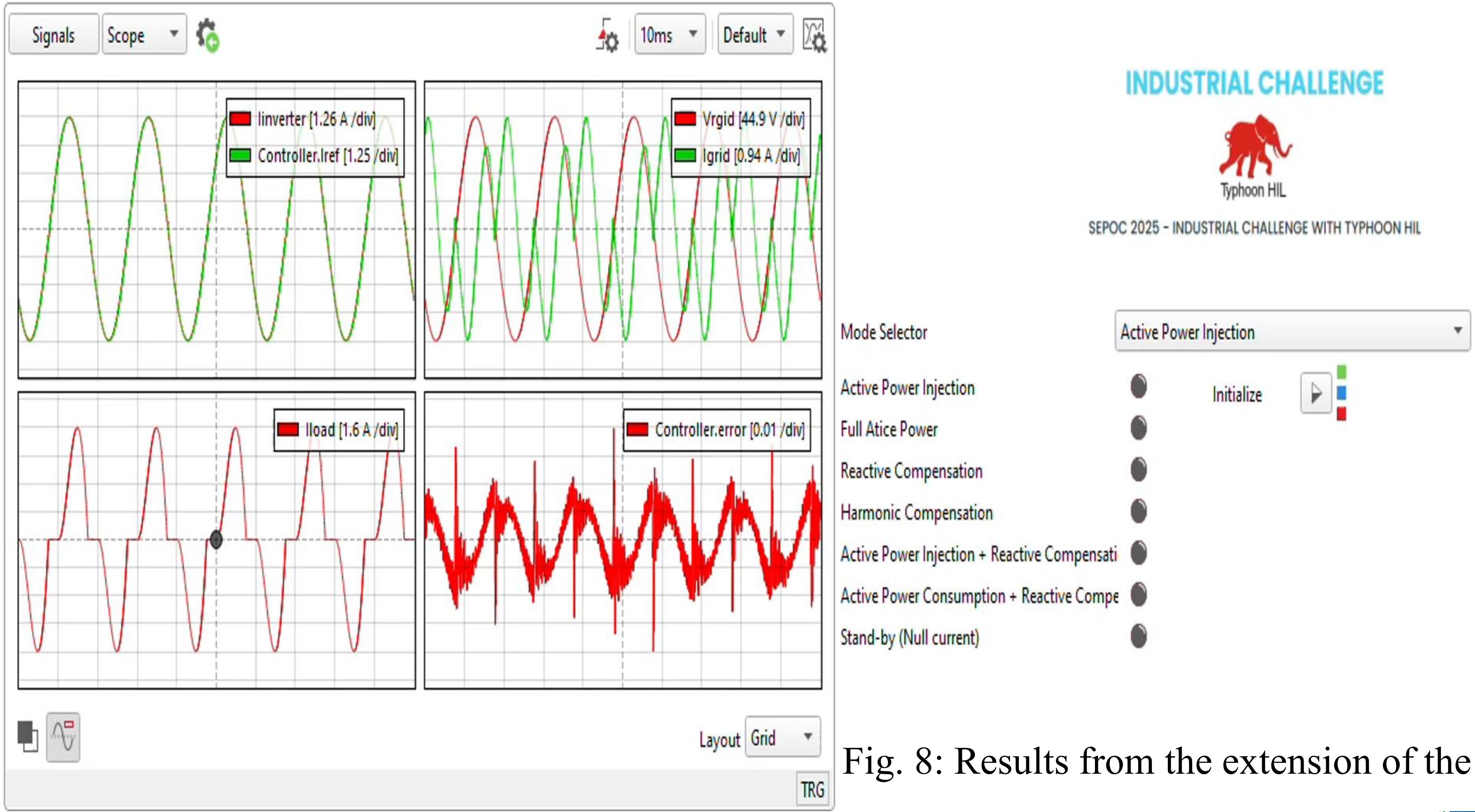


Fig. 8: Results from the extension of the proposed model.

Extension of our model

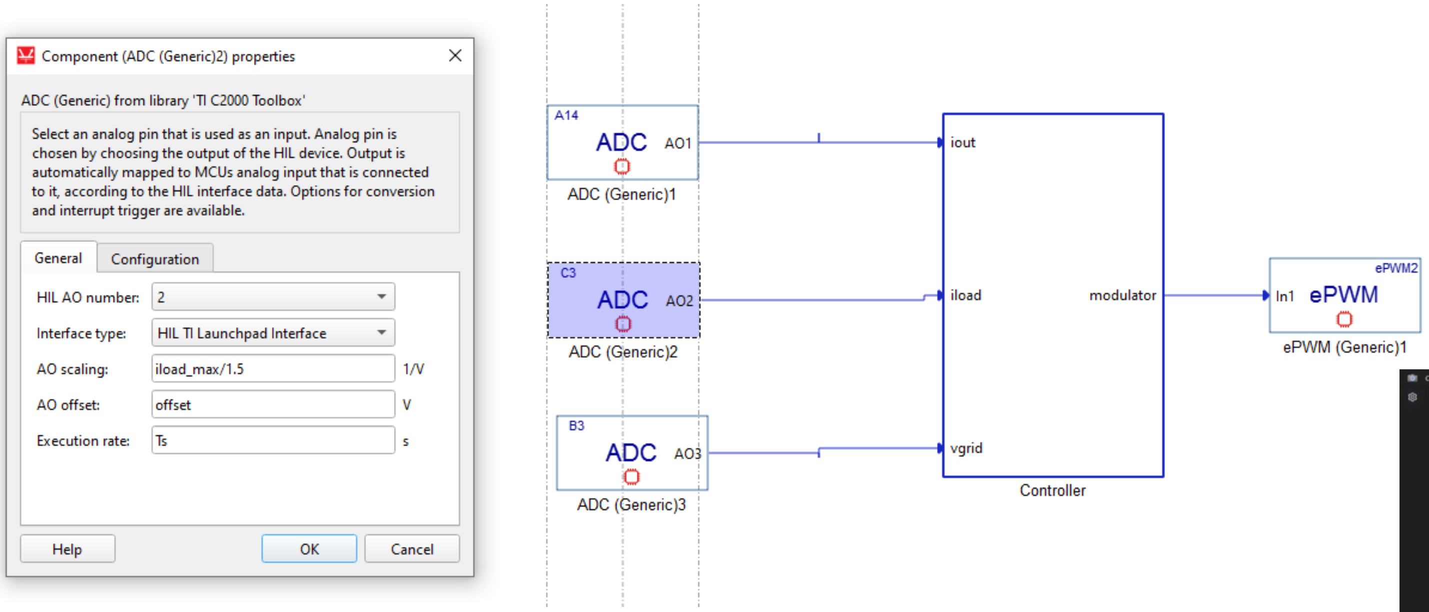
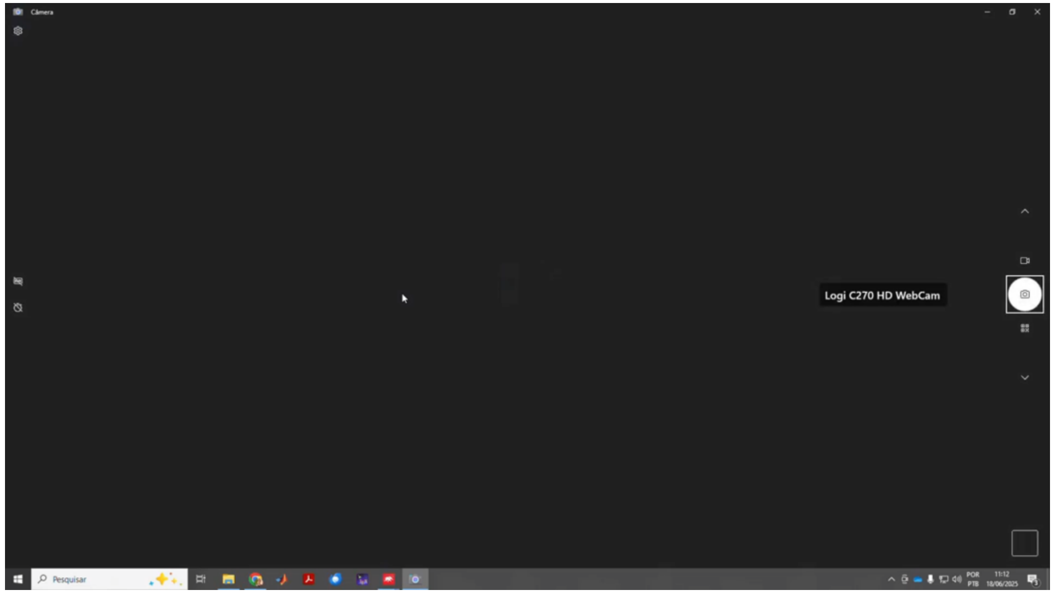


Fig. 8: Overview of the experimental MFGTI set-up.



Complete demonstration:
https://youtu.be/aGTE193b3e0

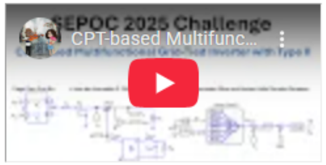
Freely available files

https://busarello.prof.ufsc.br/challenge.html

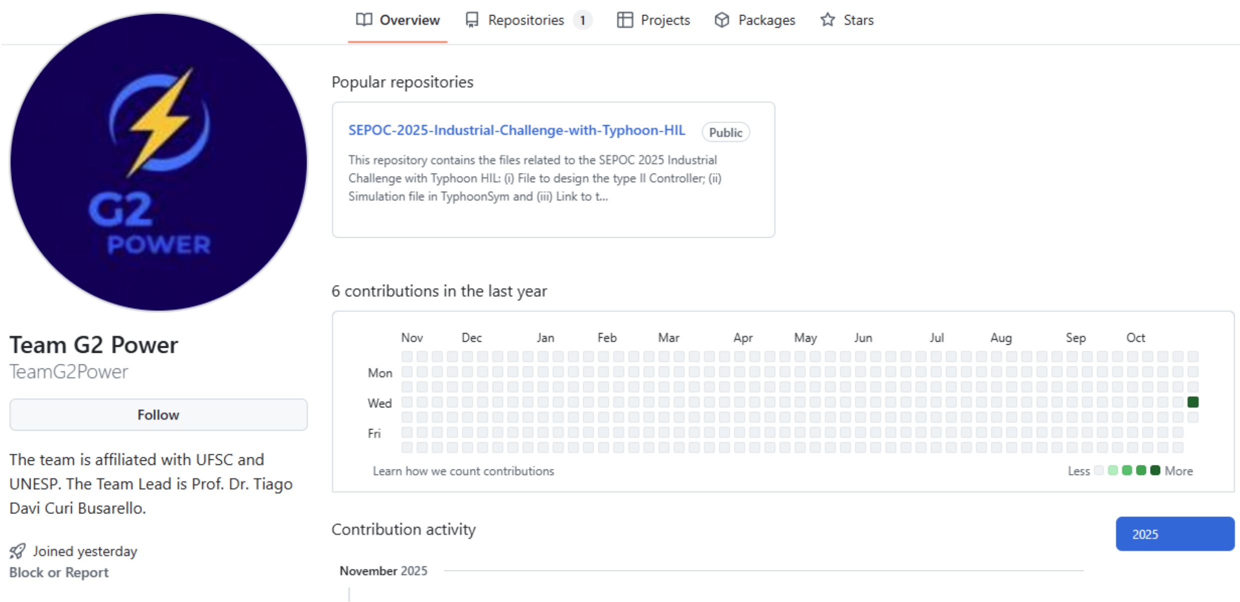
SEPOC 2025 - INDUSTRIAL CHALLENGE WITH TYPHOON HIL

Team G2 Power

All files of our proposal to the Industrial Challenge with Typhoon HIL

Team	G2 Power
Authors	Tiago Davi Curi Busarello (UFSC), José de Arimatéia O. Filho (UNESP/ICTS), Alex Ferreira Silva (UNESP/ICTS), Paulo Fernando Silva (UNESP/ICTS), Helmo Kelis Morales Paredes (UNESP/ICTS)
Year	2025
Presentation	PowerPoint (.pptx)
White Paper	PDF
Model in TyphoonSim 2025.2	File (.tse)
Model For Automatic Code Generation for TI Launchpad F28379D	File (.tse)
Video	
Script in Matlab	File (.m)
Script in Python	File (.py)
Full Paper presented at SEPOC 2025 (Coming soon)	PDF

https://github.com/TeamG2Power



Conclusions

- The proposed multifunctional inverter is an attractive solution for DER to address the new requirements of IEEE1547.
- Using only one controller for all modes of operation proved to be a good choice instead of using switchable controller when performing ancillary services.
- The CPT could compute accurately the power quantities for the operation modes.
- The proposed inverter is ready to inject the required active and reactive power for contributing to regulate voltage and frequency of the point of common coupling.

Thank you!!

INDUSTRIAL CHALLENGE

Typhoon HIL

SEPOC 2025 - INDUSTRIAL CHALLENGE WITH TYPHOON HIL

G2 POWER

Questions?

tiago.busarello@ufsc.br