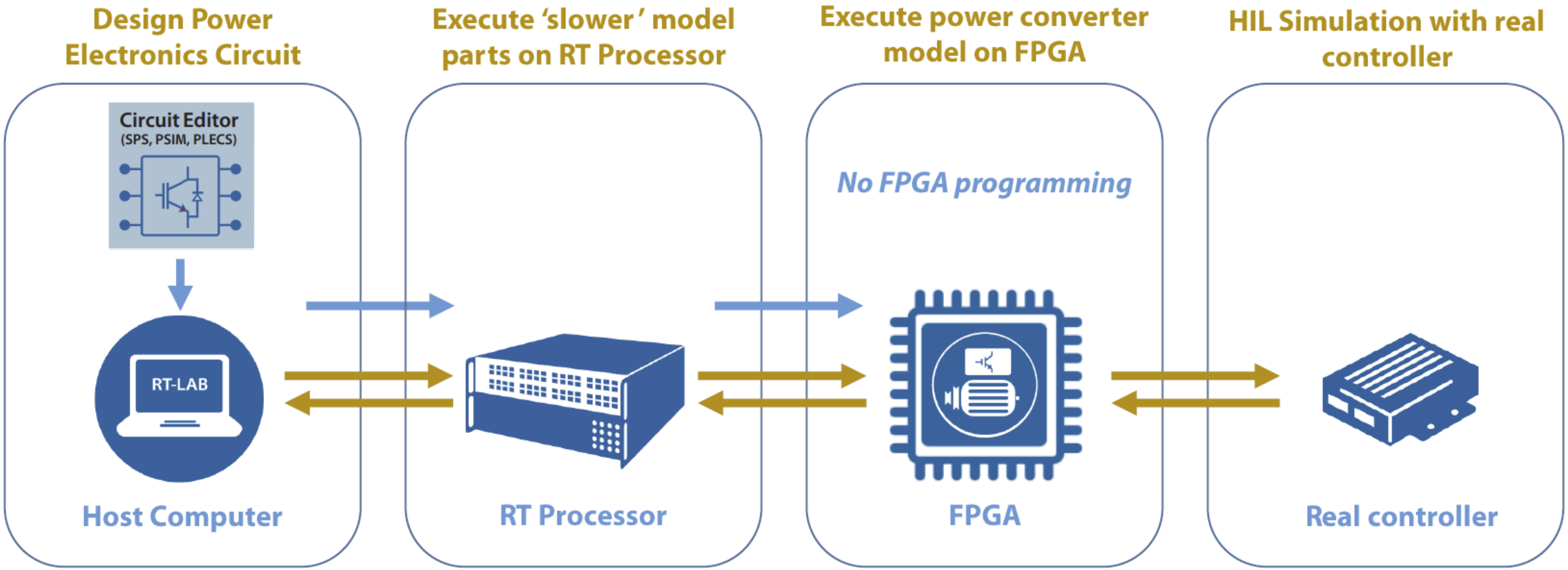
# Advancing EVSE Through Controller Hardware-in-the-Loop Validation

Sertac Bayhan, Ph.D.

# AGENDA

# INTRODUCTION – GENERAL STRUCTURE






***FPGA model:***

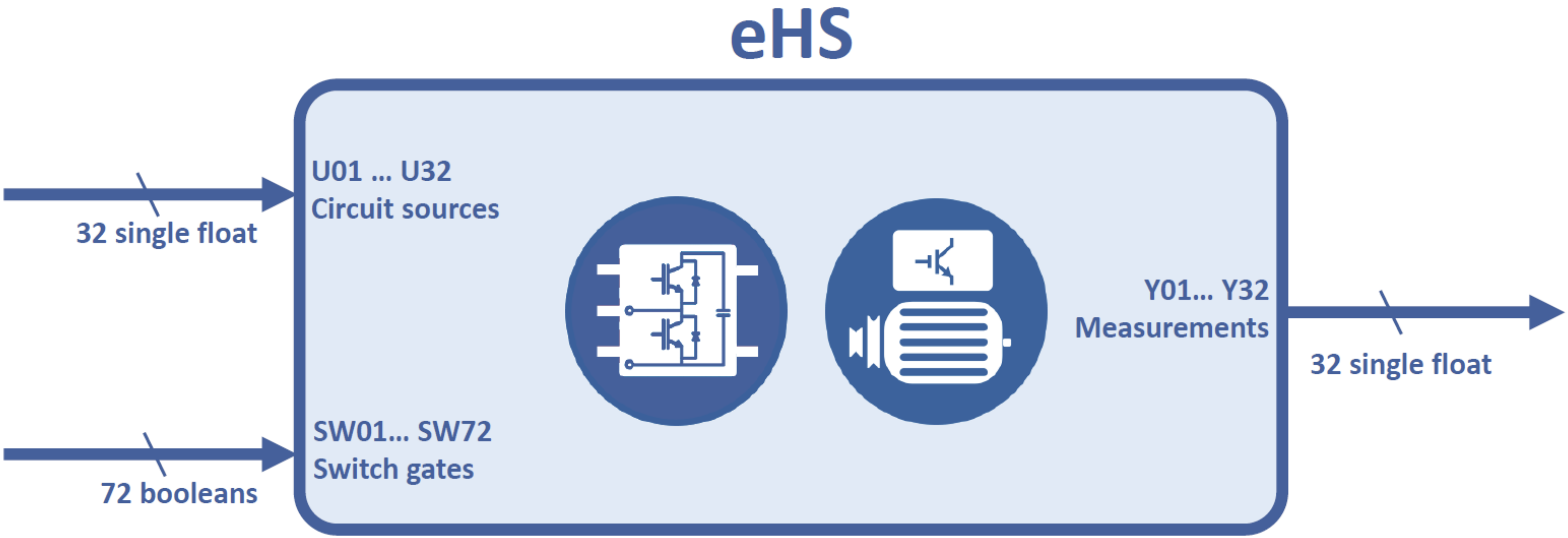
- Fast electrical circuit (user model)
- Runs in the FPGA (typical Ts<1 μS)
- Is connected with the CPU model
- Is connected with hardware I/Os

Source: OPAL-RT

RT23 YOUR IDEAS OUR ENERGY

# STRUCTURE – INTERNAL STRUCTURE

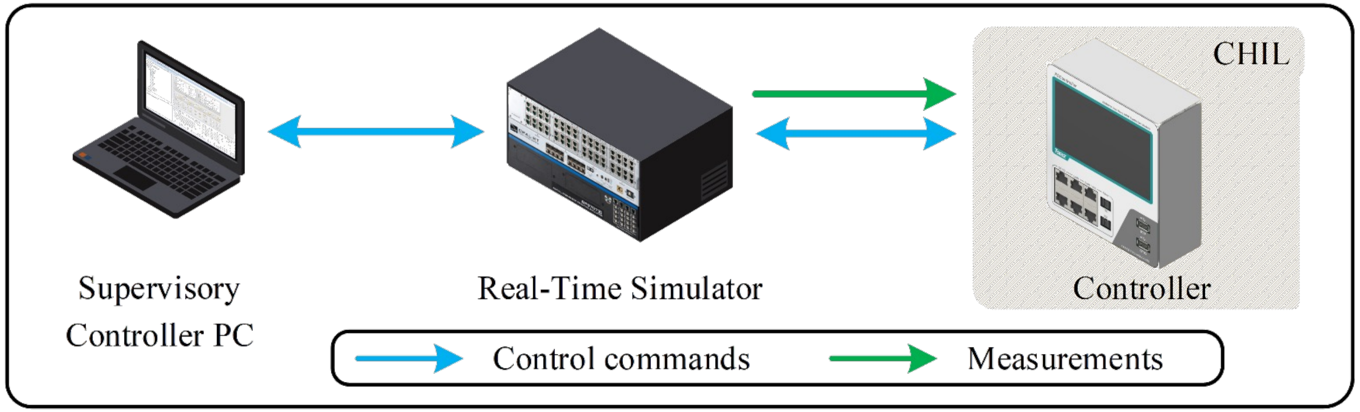


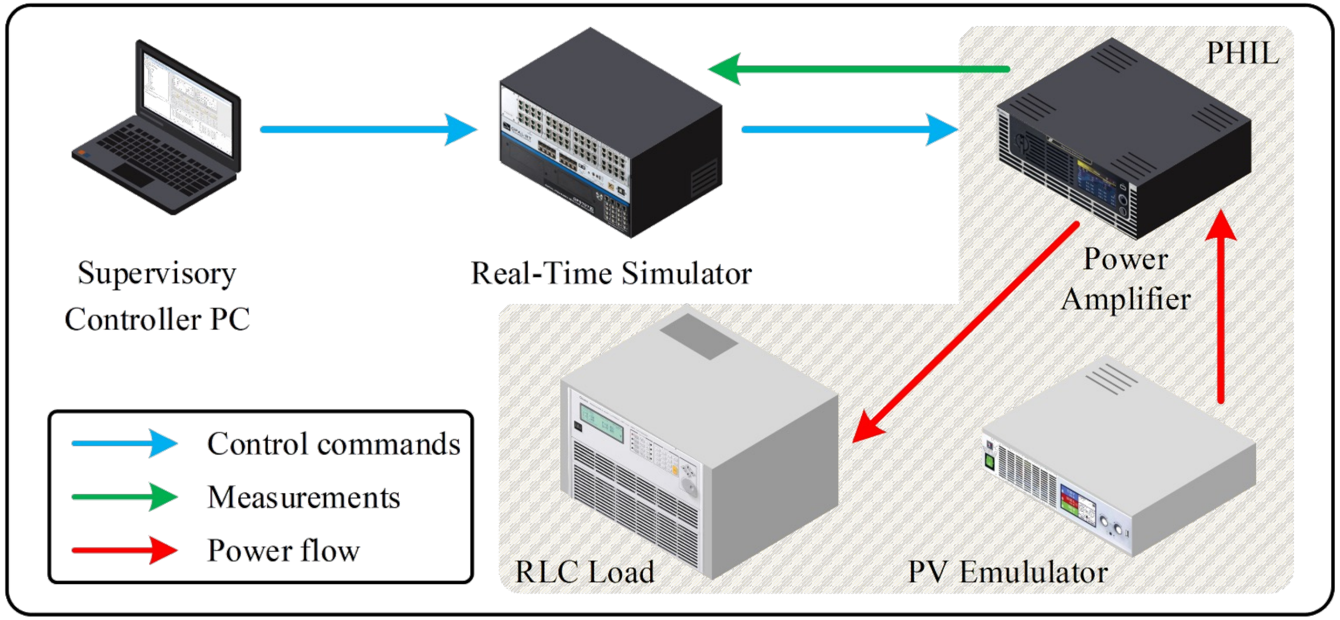


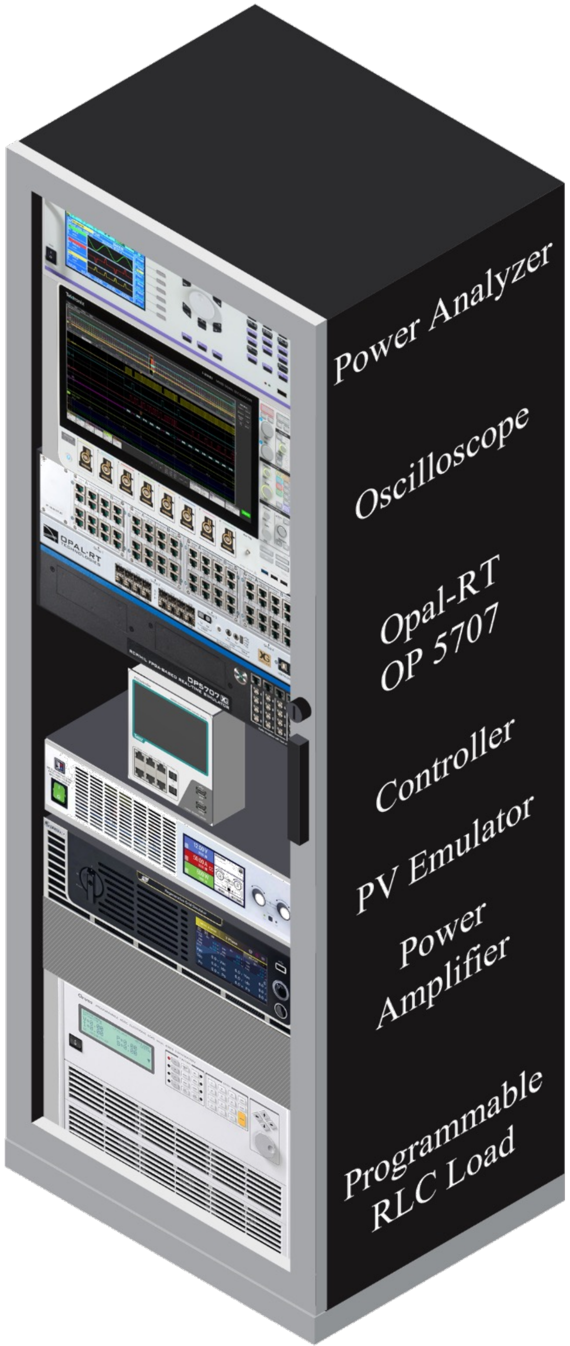

Source: OPAL-RT

# CHIL and PHIL Setup at QEERI





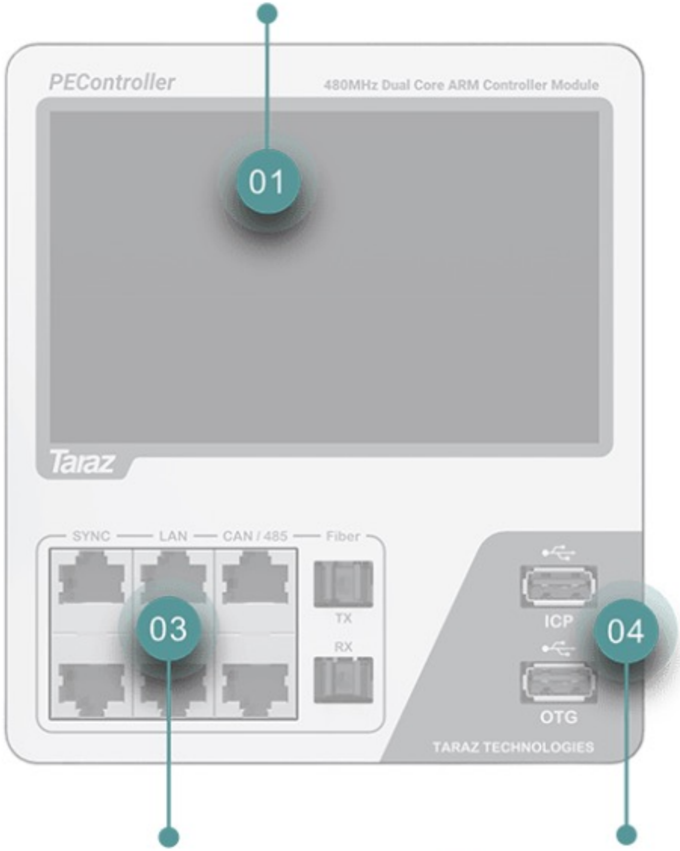



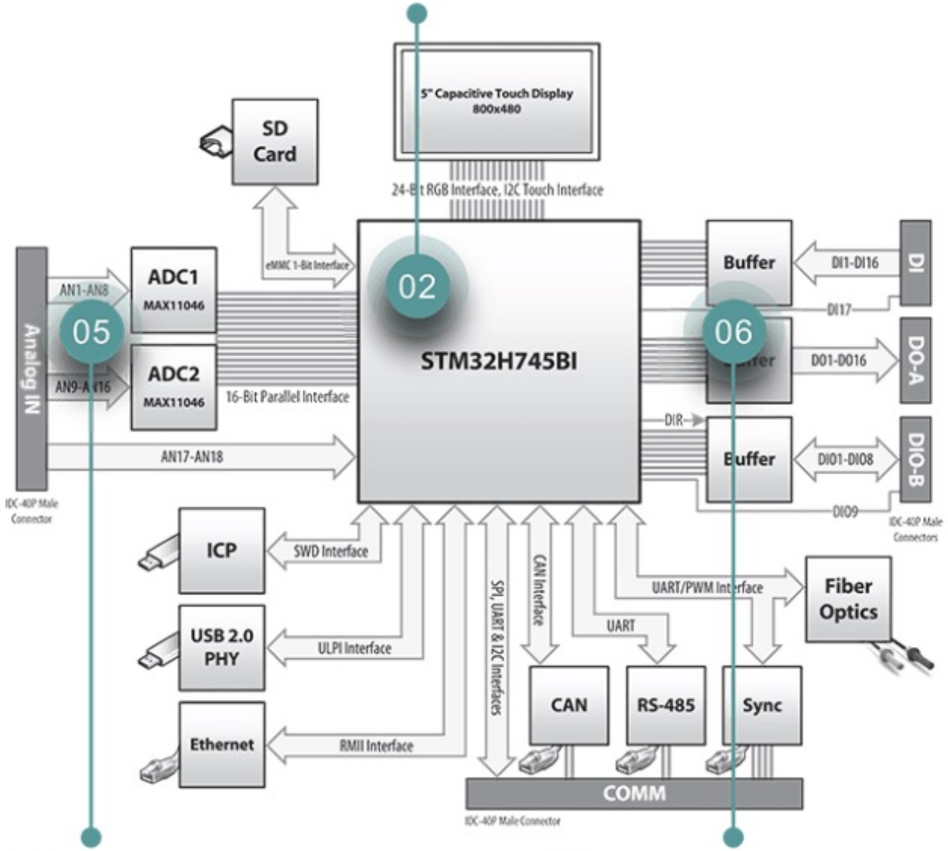
# Controller Specs

01. 5" Touch Dispay for GUI & Control

02. High-Performance Dual-Core 480MHz (M7) /240MHz (M4) Microcontroller

FRONT PANEL




ARCHITECTURE

03. Sync, LAN, CAN, RS-485 & Fiber Optics for Industrial Communication & Distributed Control System

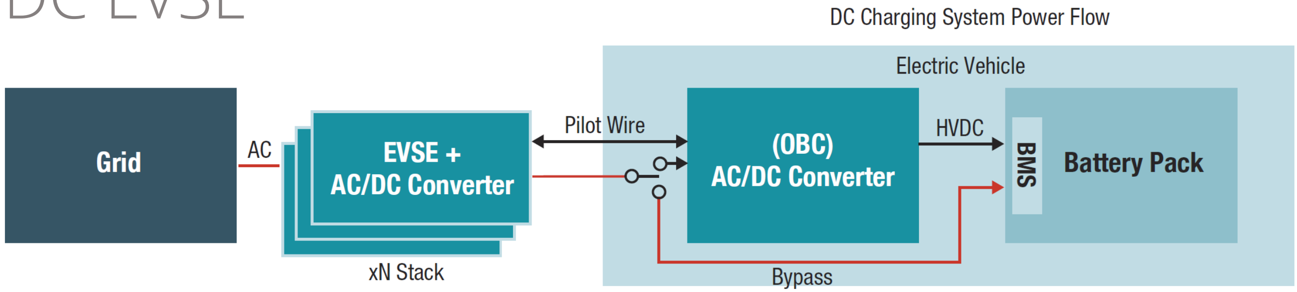
04. Programming USB & High-Speed USB for Data Acquisition

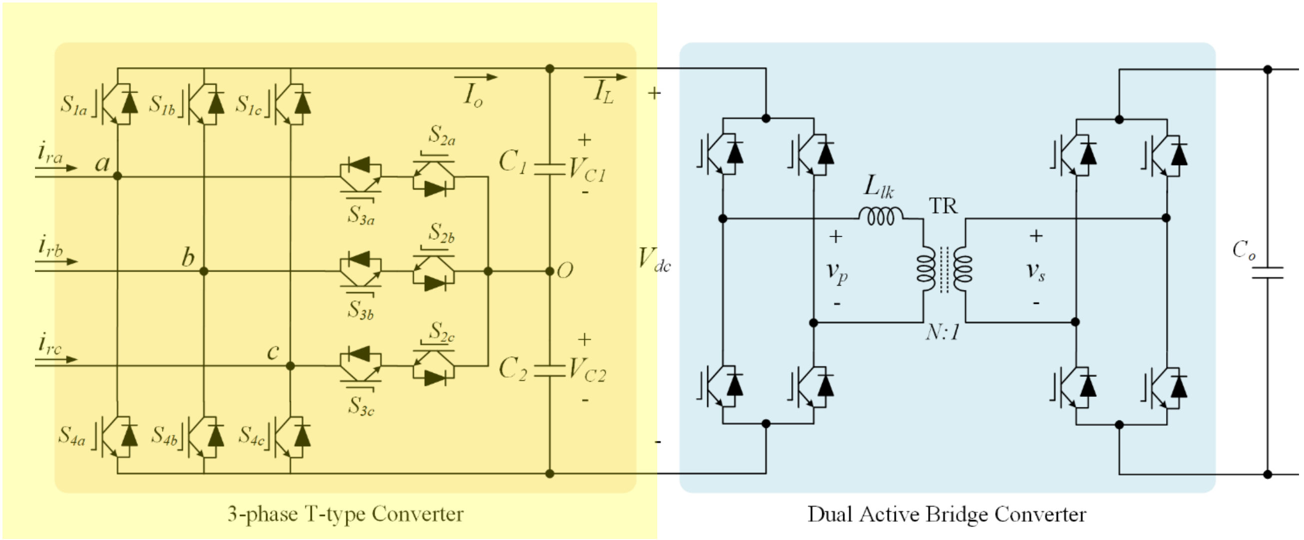
05. High Accuracy 16CH @ 16-Bit, Simultaneous Sampling ADCs for High-Performance Control

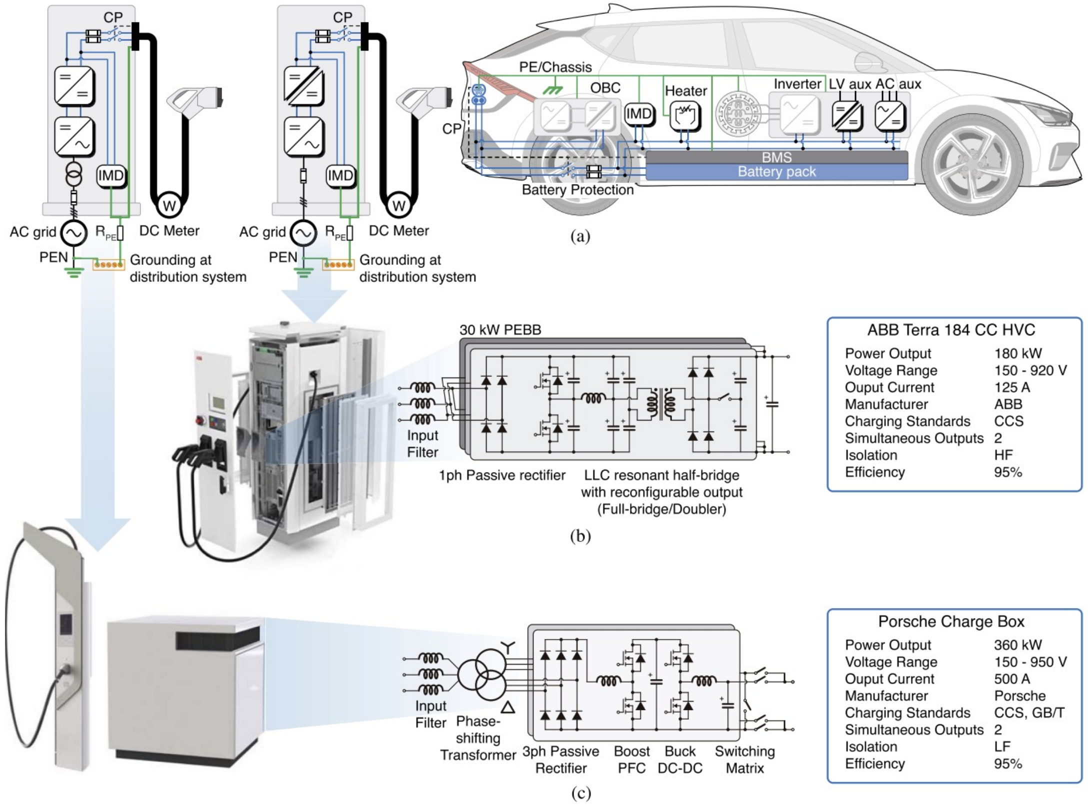
06. Upto 68 I/Os Including 24 PWMs, 18 Analog Inputs, Quadrature Encoder, SPI, UART & I2C Interfaces

# Considered System

## DC EVSE



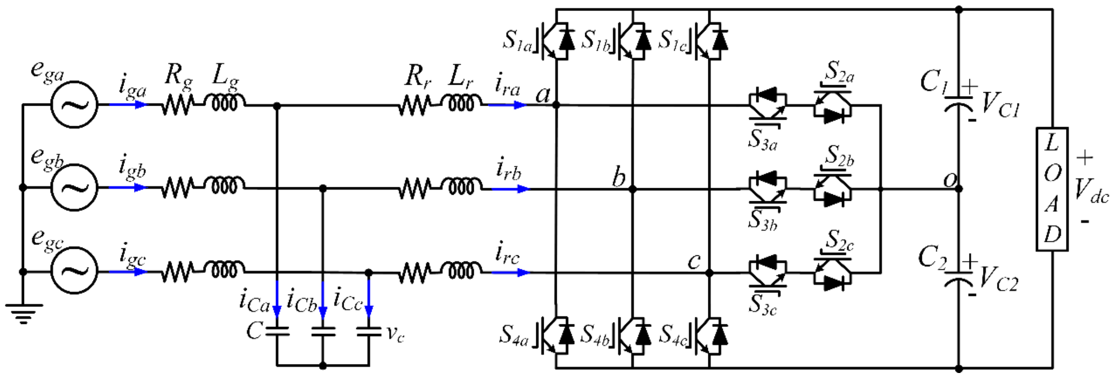



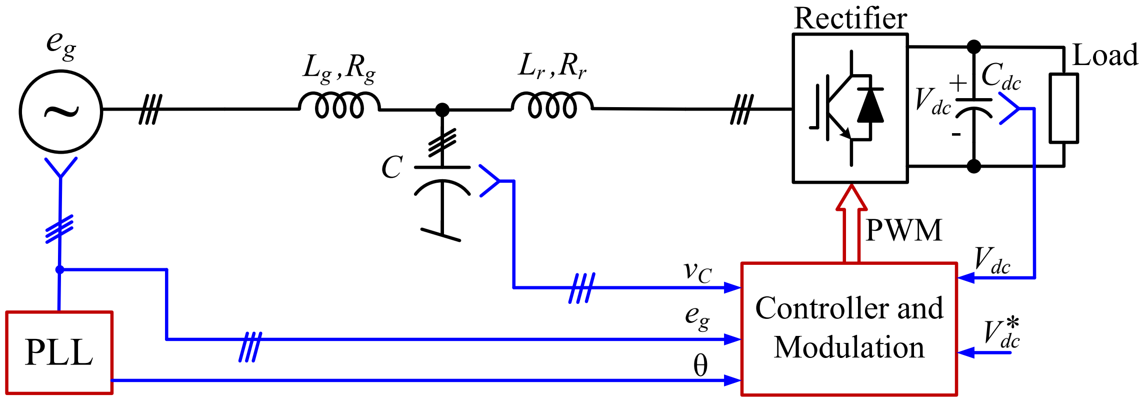




S. Rivera *et al.*, "Charging Infrastructure and Grid Integration for Electromobility," in *Proceedings of the IEEE*, vol. 111, no. 4, pp. 371-396, April 2023, doi: 10.1109/JPROC.2022.3216362.

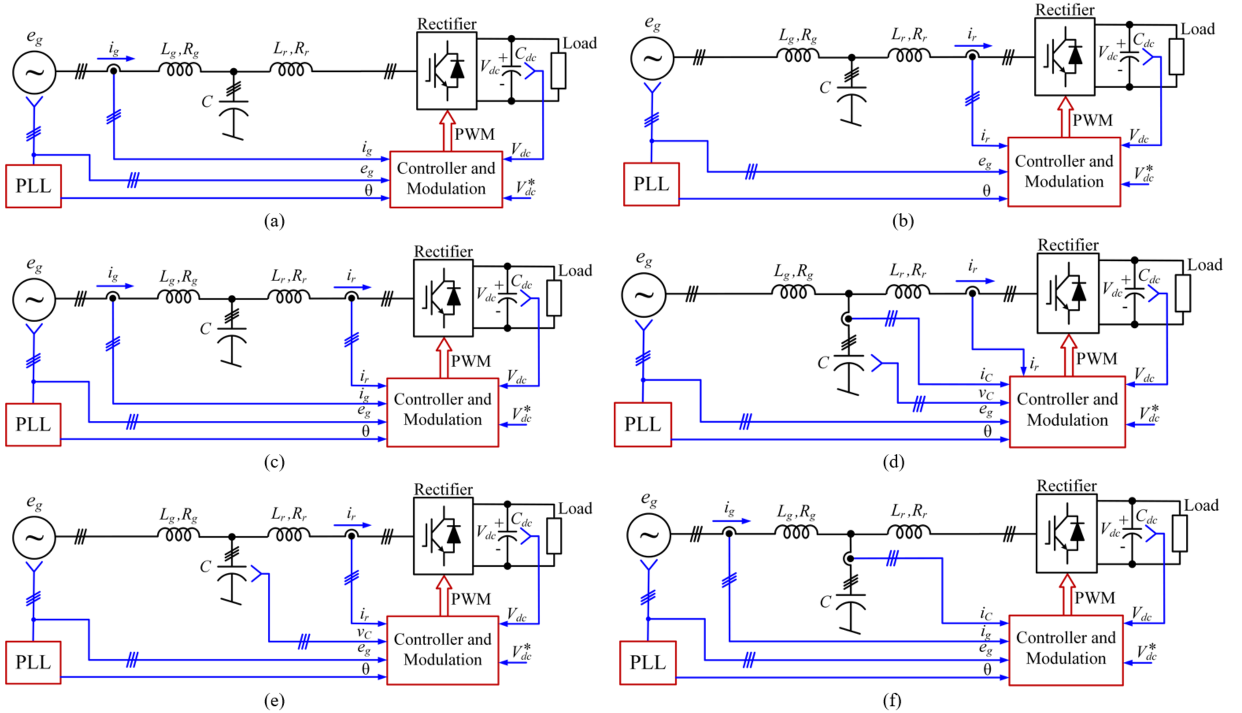
# Control Technique





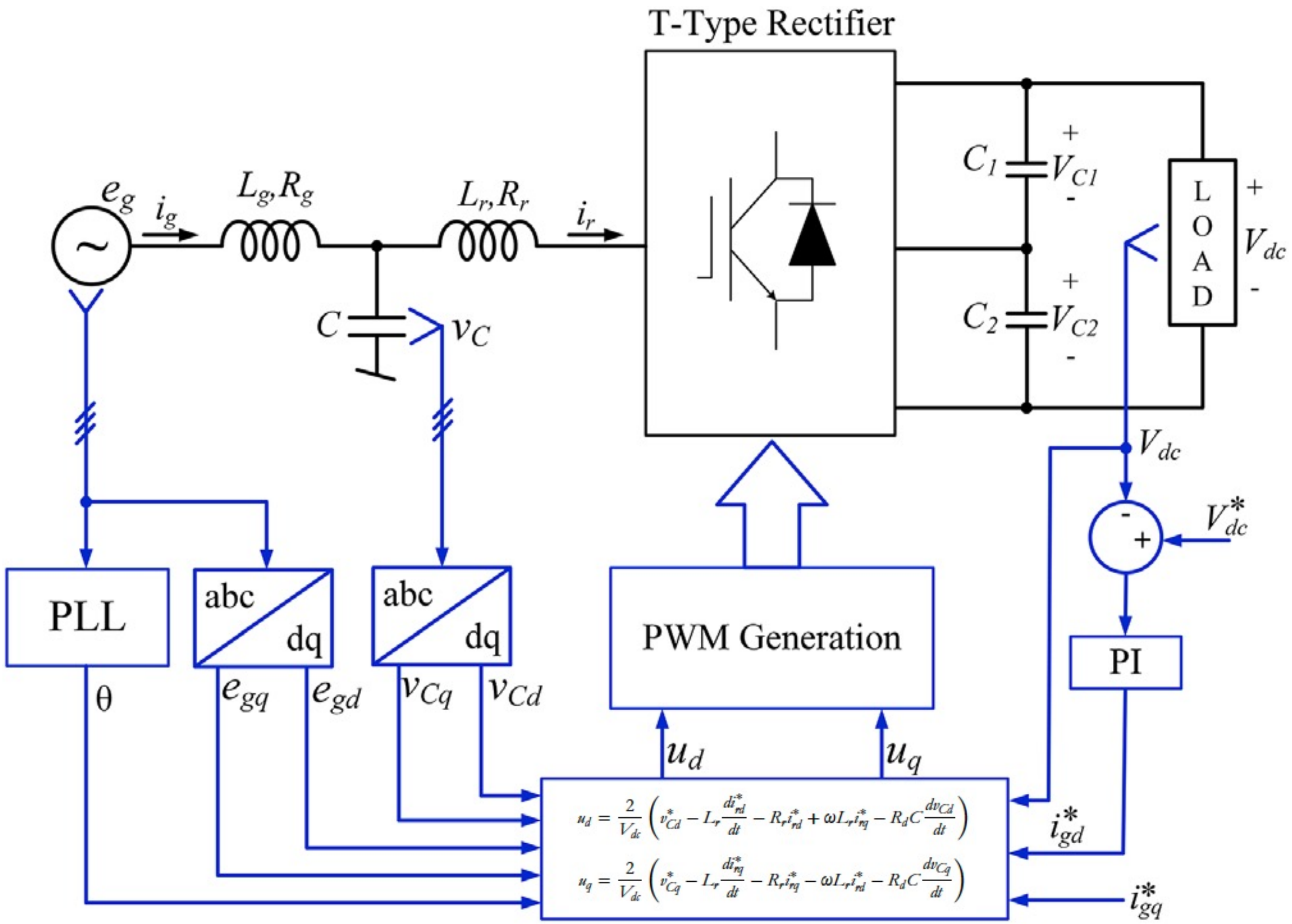




Block diagram of the proposed current sensorless control technique




Block diagrams of existing control methods for three-phase active front-end rectifier with LCL filter. (a) grid current feedback, (b) rectifier current feedback, (c) grid current and rectifier current feedbacks, (d) rectifier current, capacitor current and capacitor voltage feedbacks, (e) rectifier current and capacitor voltage feedbacks and (f) grid current and capacitor current feedback

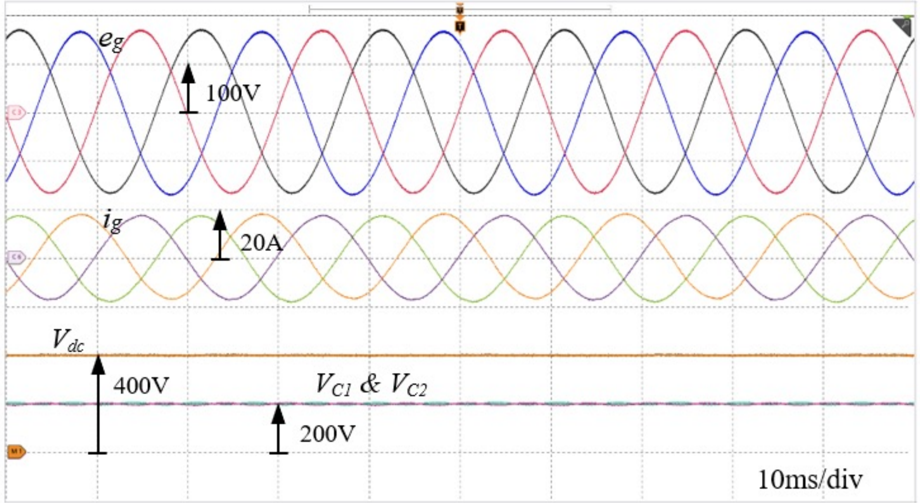
# Control Technique



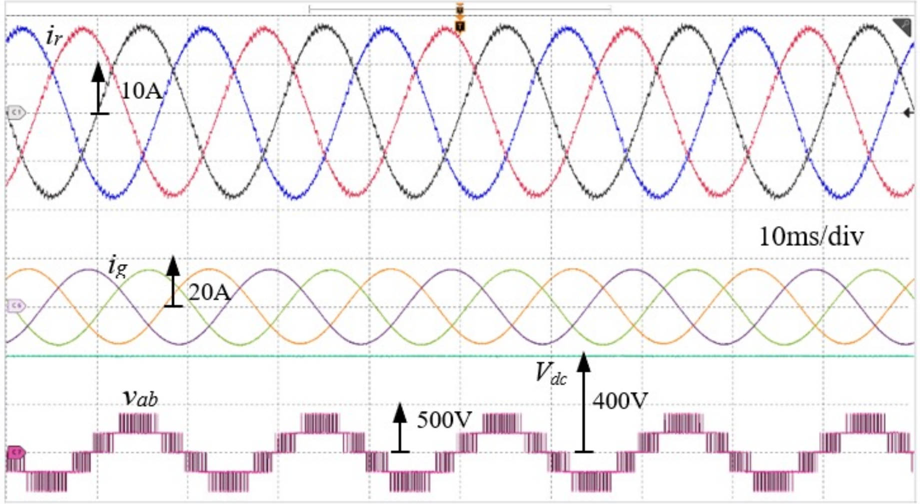

SYSTEM AND CONTROL PARAMETERS

| Description and Symbol | Value |
|---|---|
| Grid voltage amplitude, $E_m$ | $120\sqrt{2}$ V |
| DC-link voltage reference, $V_{dc}^*$ | 400V |
| Grid-side inductance, $L_g$ | 2.5mH |
| Rectifier-side inductance, $L_r$ | 5mH |
| Inductor resistances, $R_g$ and $R_r$ | 0.4Ω, 0.5Ω |
| Filter capacitor, $C$ | 22μF |
| DC capacitors, $C_1 = C_2$ | 470μF |
| Load | 40 Ω - 80 Ω |
| Virtual damping resistor, $R_d$ | 8Ω |
| PI gains, $K_p$ and $K_i$ | 0.04, 10 |
| Sampling period: $T_s$ | 40μs |

# Test Results

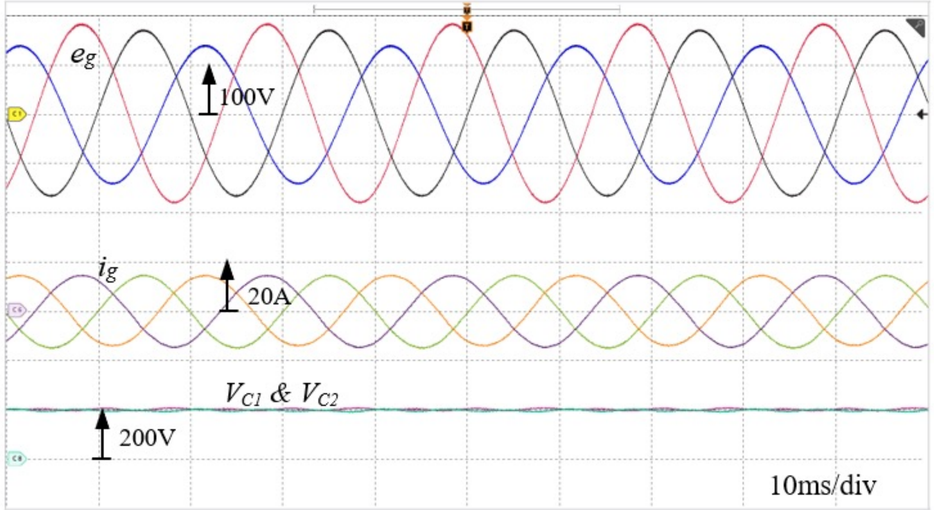



(a)

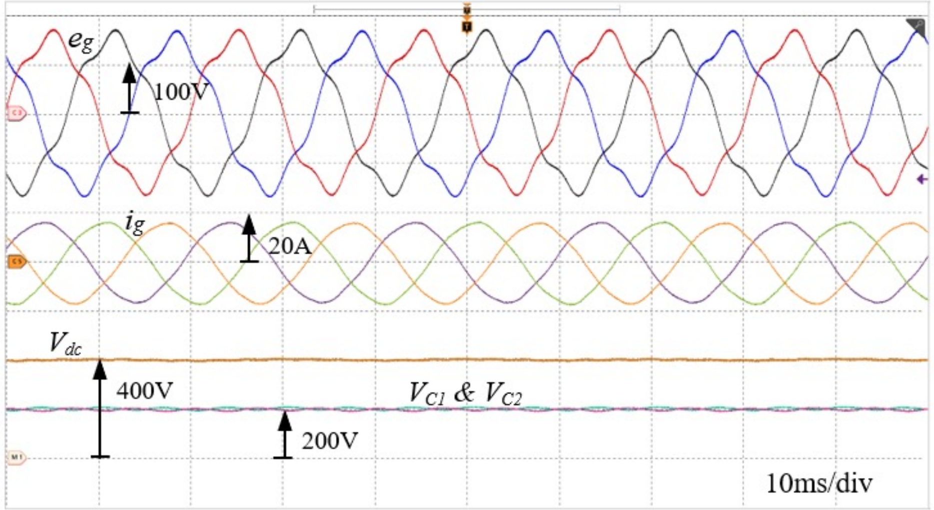



(b)

Steady-state responses of dc- and ac-side variables under balanced grid.

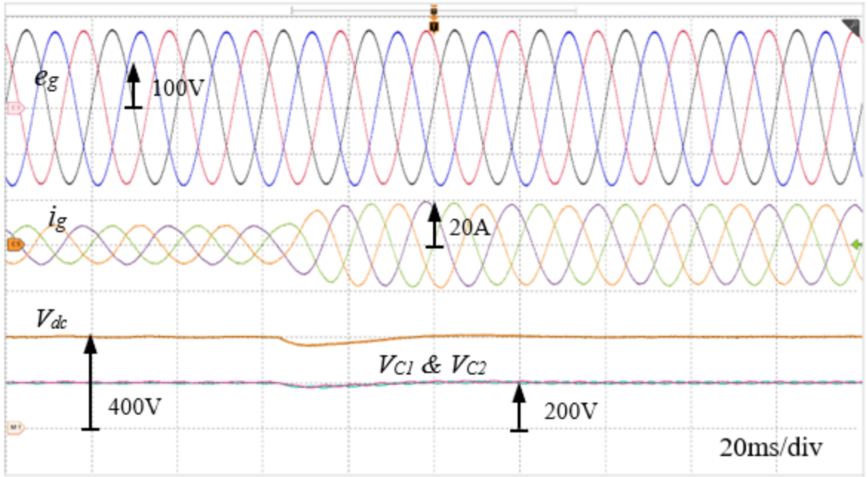



Steady-state responses of dc- and ac-side variables under unbalanced grid.

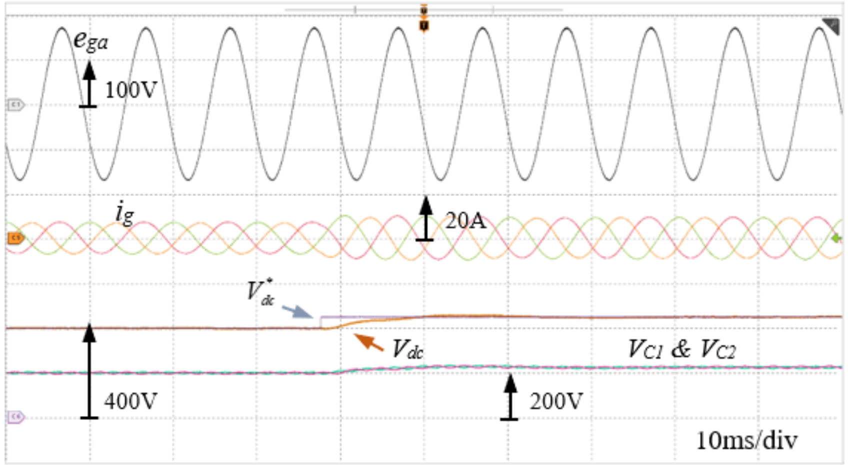



Steady-state responses of dc-and ac-side variables under distorted grid.

# Test Results

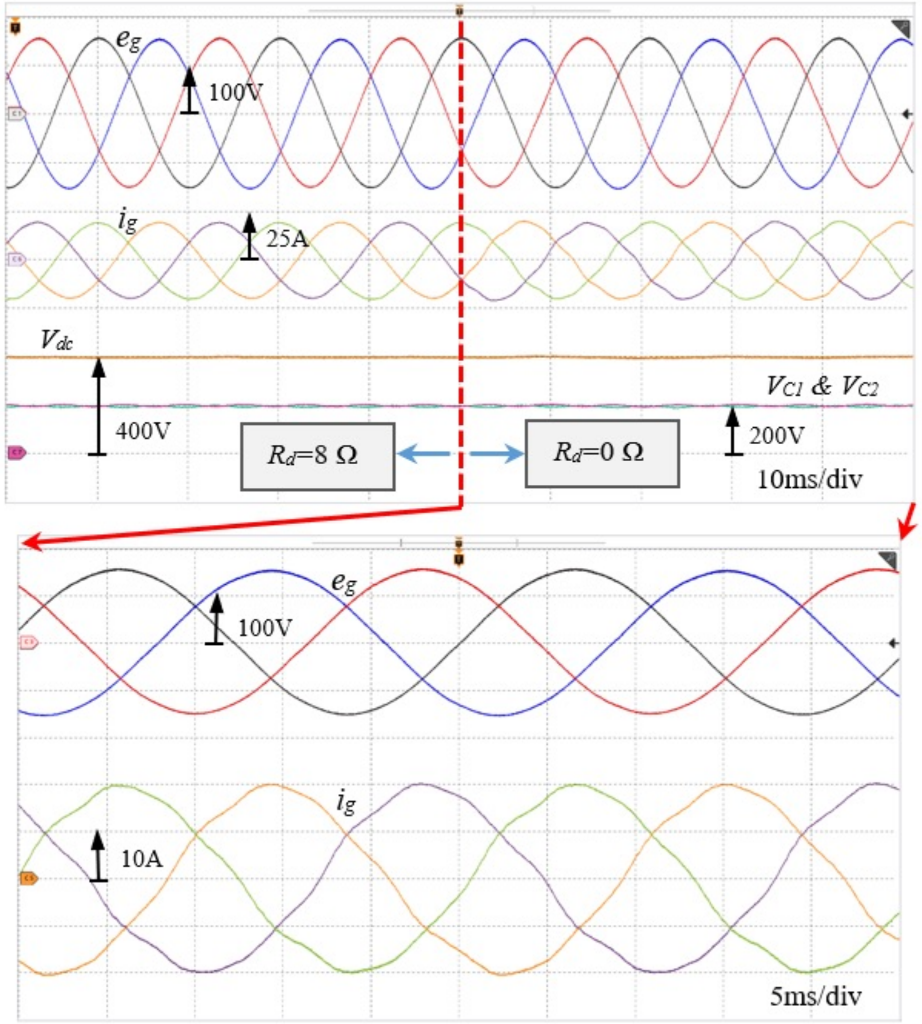



(a)




(b)

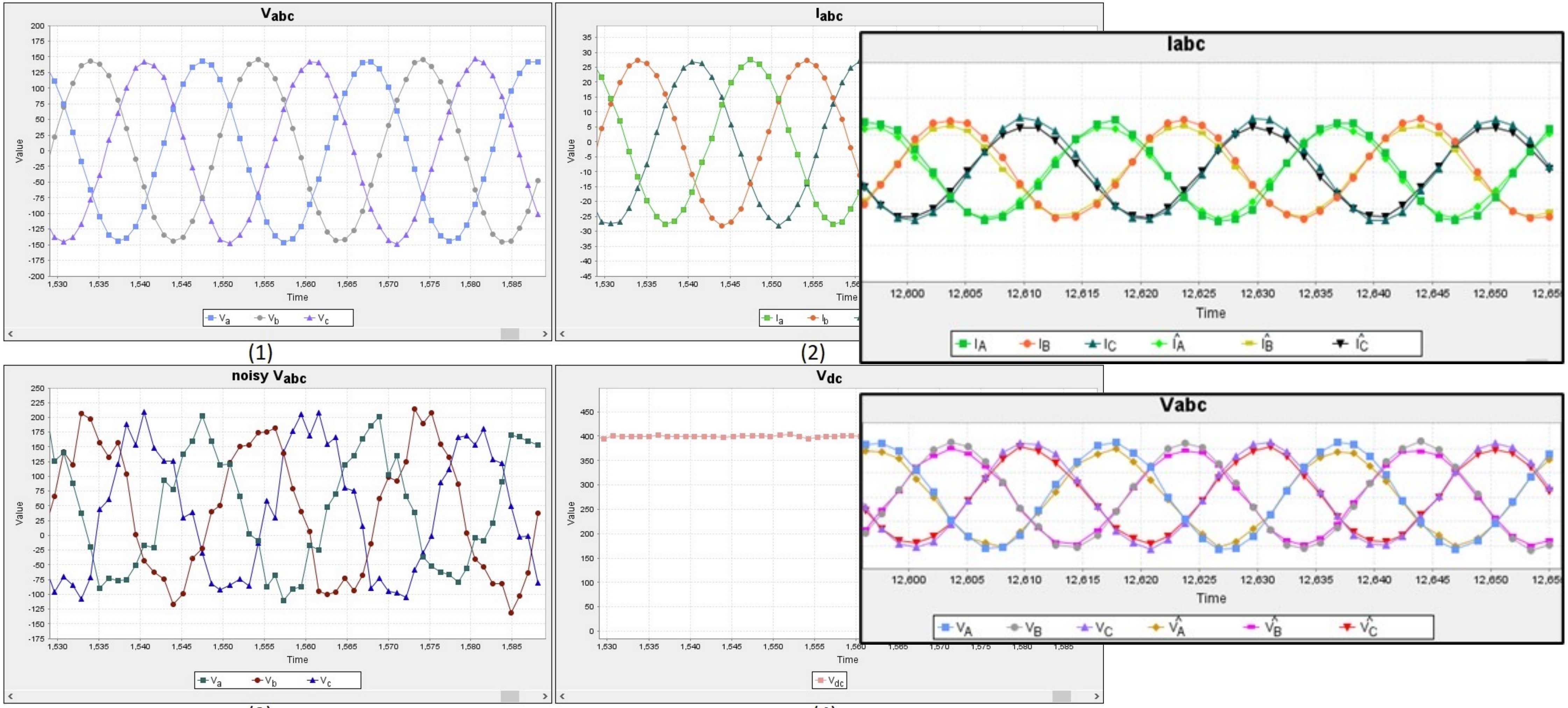
Dynamic responses of dc-and ac-side variables for a step change in load resistance from 80 Ω to 40 Ω and $V_{dc}^{*}$ from 400V to 450V.




Responses of dc-and ac-side variables for a step change in $R_d$ from 8 Ω to 0 Ω.

# Test Results

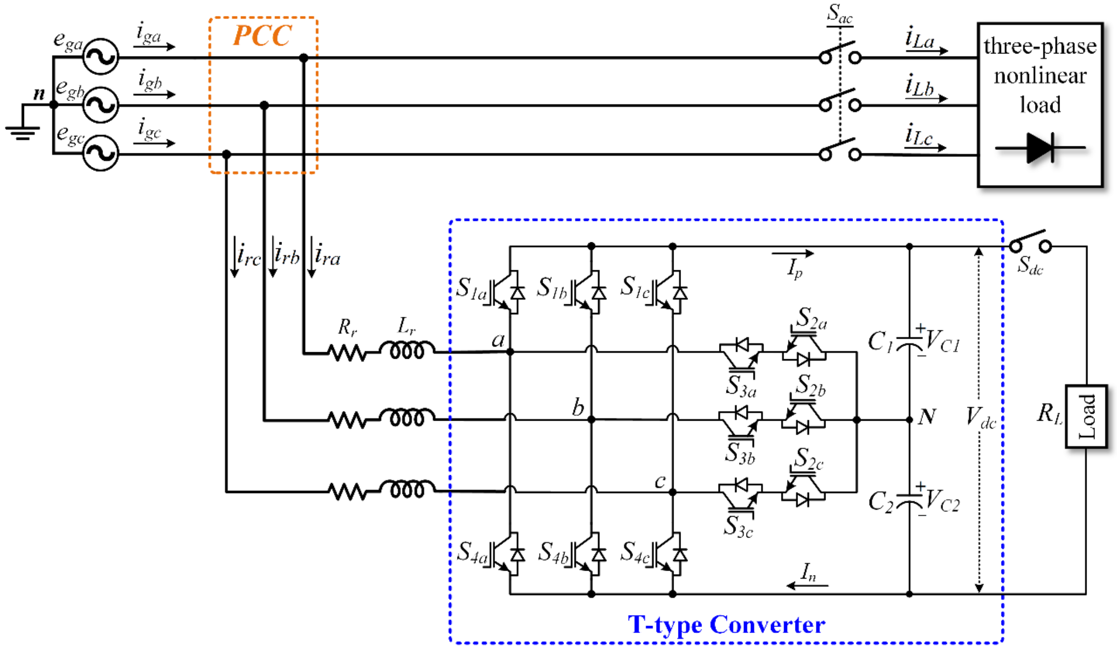


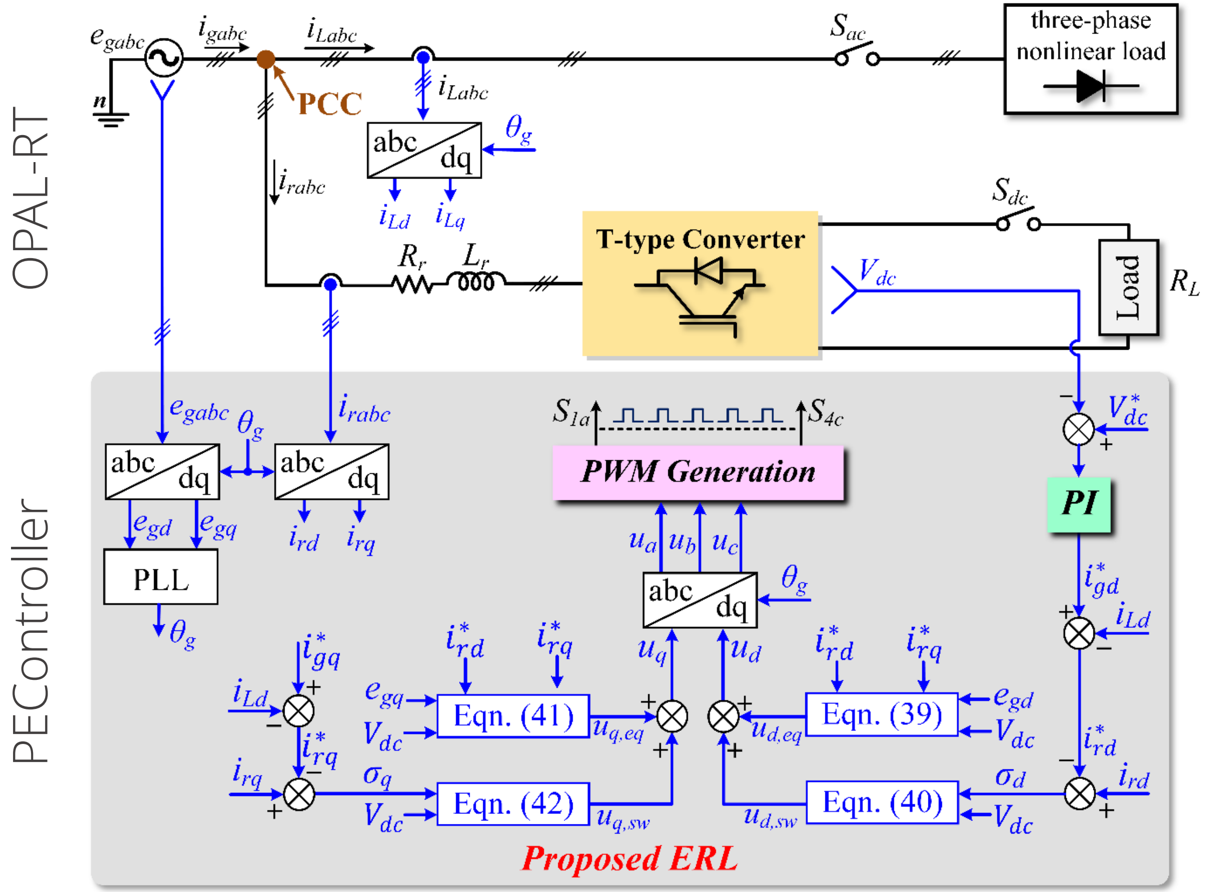



(1) (2)

(3) (4)

# Control Technique




$$u_{q,eq} = \frac{2}{V_{dc}}\left(e_{gq} - L_r \frac{di^*_{rq}}{dt} - R_r i^*_{rq} - \omega L_r i^*_{rd}\right)$$

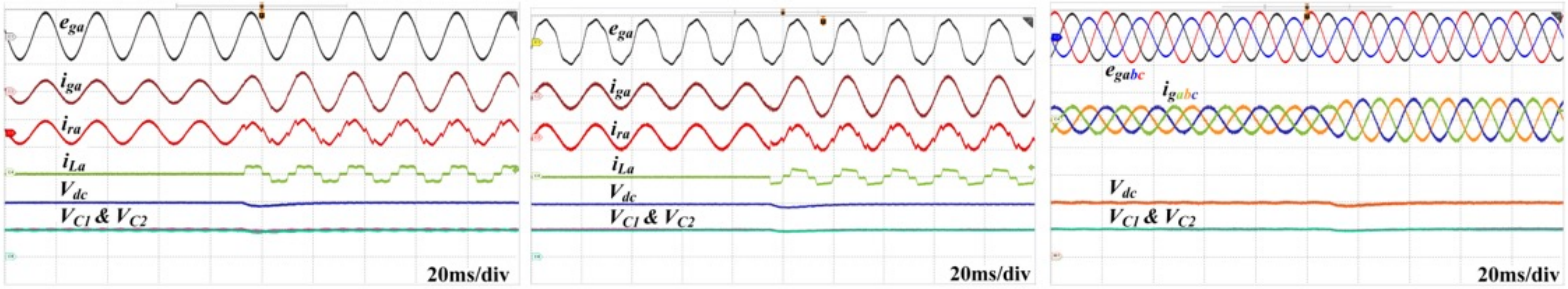
$$u_{d,eq} = \frac{2}{V_{dc}}\left(e_{gd} - L_r \frac{di^*_{rd}}{dt} - R_r i^*_{rd} + \omega L_r i^*_{rq}\right)$$

$$u_{d,sw} = \frac{2L_r k_1}{V_{dc}}\left(k_2 e^{k_3 \sigma_d} - 1\right)$$

$$u_{q,sw} = \frac{2L_r k_1}{V_{dc}}\left(k_2 e^{k_3 \sigma_q} - 1\right)$$

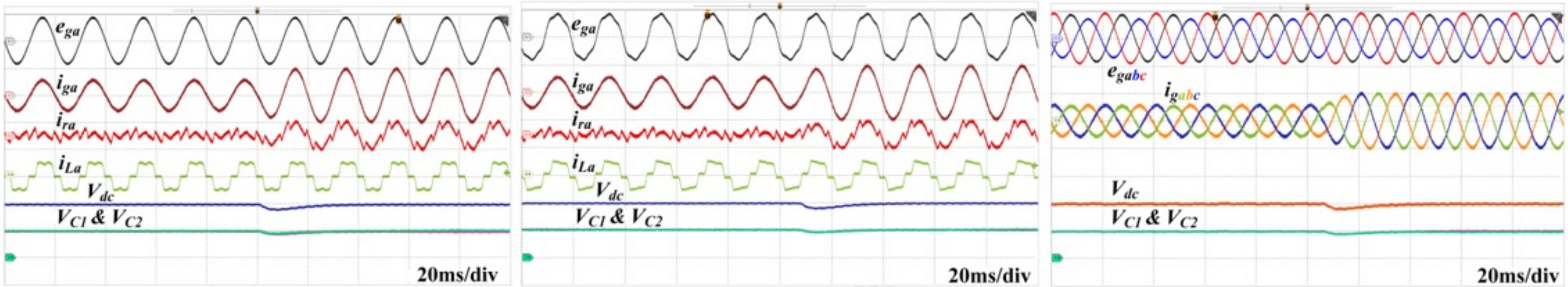
H. Komurcugil, S. Bayhan, N. Guler and H. Abu-Rub, "A New Exponential Reaching Law Approach to the Sliding Mode Control: A Multilevel Multifunction Converter Application," in IEEE Transactions on Industrial Electronics, vol. 70, no. 8, pp. 7557-7568, Aug. 2023, doi: 10.1109/TIE.2022.3229369.

# Test Results




(a) (b) (c)

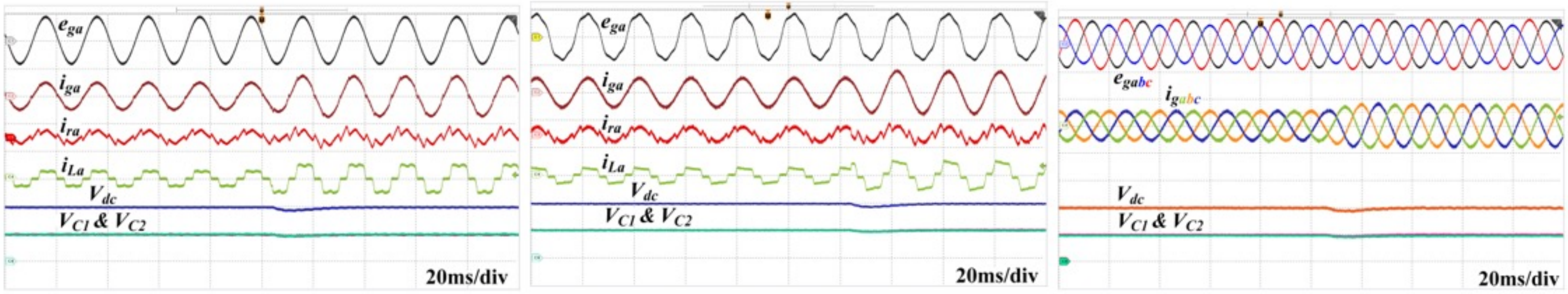
Waveforms for scenario 1. (a) Non-distorted and balanced grid, (b) Distorted and balanced grid, (c) Non-distorted and unbalanced grid. $e_{ga}$, $e_{gabc}$ (200 V/ div), $i_{ga}$, $i_{gabc}$, $i_{ra}$, $i_{La}$ (20A / div), and $V_{dc}$, $V_{C1}$, $V_{C2}$ (250V / div) .




(a) (b) (c)

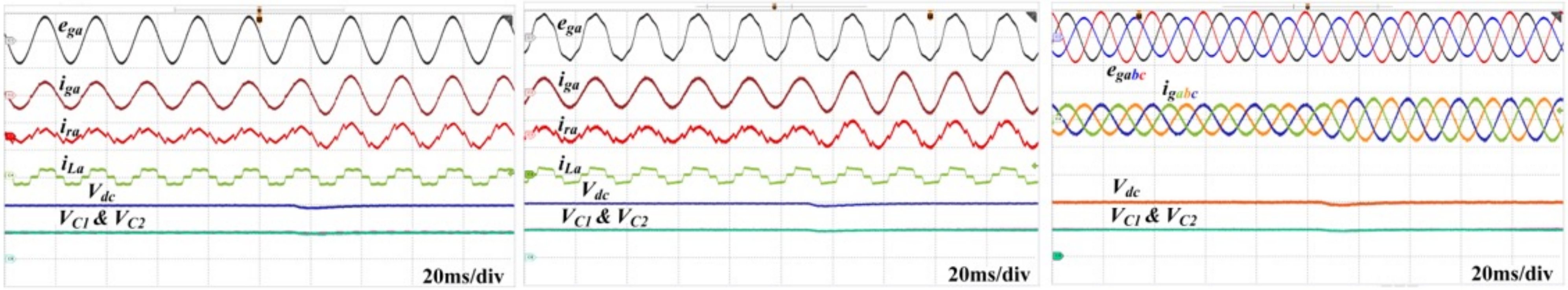
Waveforms for scenario 2. (a) Non-distorted and balanced grid, (b) Distorted and balanced grid, (c) Non-distorted and unbalanced grid. $e_{ga}$, $e_{gabc}$ (200 V/ div), $i_{ga}$, $i_{gabc}$, $i_{ra}$, $i_{La}$ (20A / div), and $V_{dc}$, $V_{C1}$, $V_{C2}$ (250V / div) .

# Test Results




(a) (b) (c)

Waveforms for scenario 3. (a) Non-distorted and balanced grid, (b) Distorted and balanced grid, (c) Non-distorted and unbalanced grid. $e_{ga}$ , $e_{gabc}$ $(200\,\mathrm{V/div})$ , $i_{ga}$ , $i_{gabc}$ , $i_{ra}$ , $i_{La}$ $(20\mathrm{A/div})$ , and $V_{dc}, V_{C1}, V_{C2}$ $(250\mathrm{V/div})$ .




(a) (b) (c)

Waveforms for scenario 4. (a) Non-distorted and balanced grid, (b) Distorted and balanced grid, (c) Non-distorted and unbalanced grid. $e_{ga}$ , $e_{gabc}$ $(200\,\mathrm{V/div})$ , $i_{ga}$ , $i_{gabc}$ , $i_{ra}$ , $i_{La}$ $(20\mathrm{A/div})$ , and $V_{dc}, V_{C1}, V_{C2}$ $(250\mathrm{V/div})$ .

# Conclusion



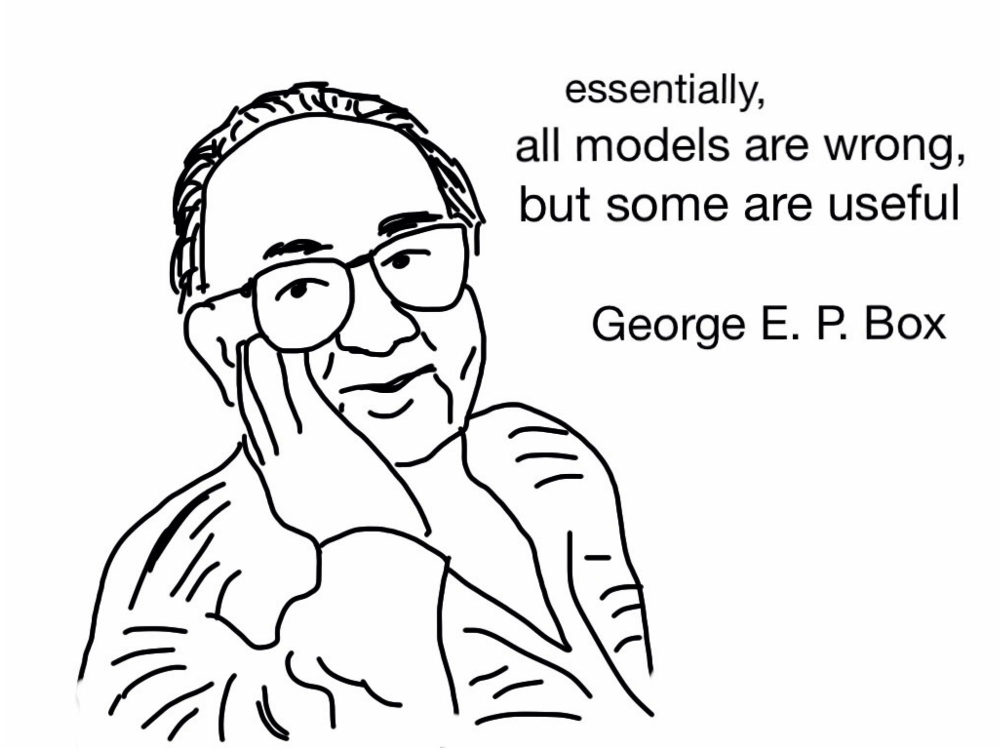
- C-HIL validation is a transformative approach that holds immense promise in advancing the development of power electronic converters for EVSE.

- C-HIL validation accelerates development processes by facilitating rapid prototyping and optimization of control algorithms, resulting in more efficient and reliable converter designs.

- It contributes to the creation of robust and resilient converter designs by evaluating controller responses to fault conditions, ensuring adaptability to unforeseen challenges.

- The validation method supports bidirectional power flow control, paving the way for advanced functionalities like vehicle-to-grid (V2G) services and efficient energy management.

- By bridging the gap between theoretical models and physical prototypes through hardware integration, C-HIL validation enhances the accuracy of converter testing and validation.


essentially,
all models are wrong,
but some are useful
George E. P. Box

# Q&A