Grid-Interfacing Converter Systems with Enhanced Voltage Quality

Contents

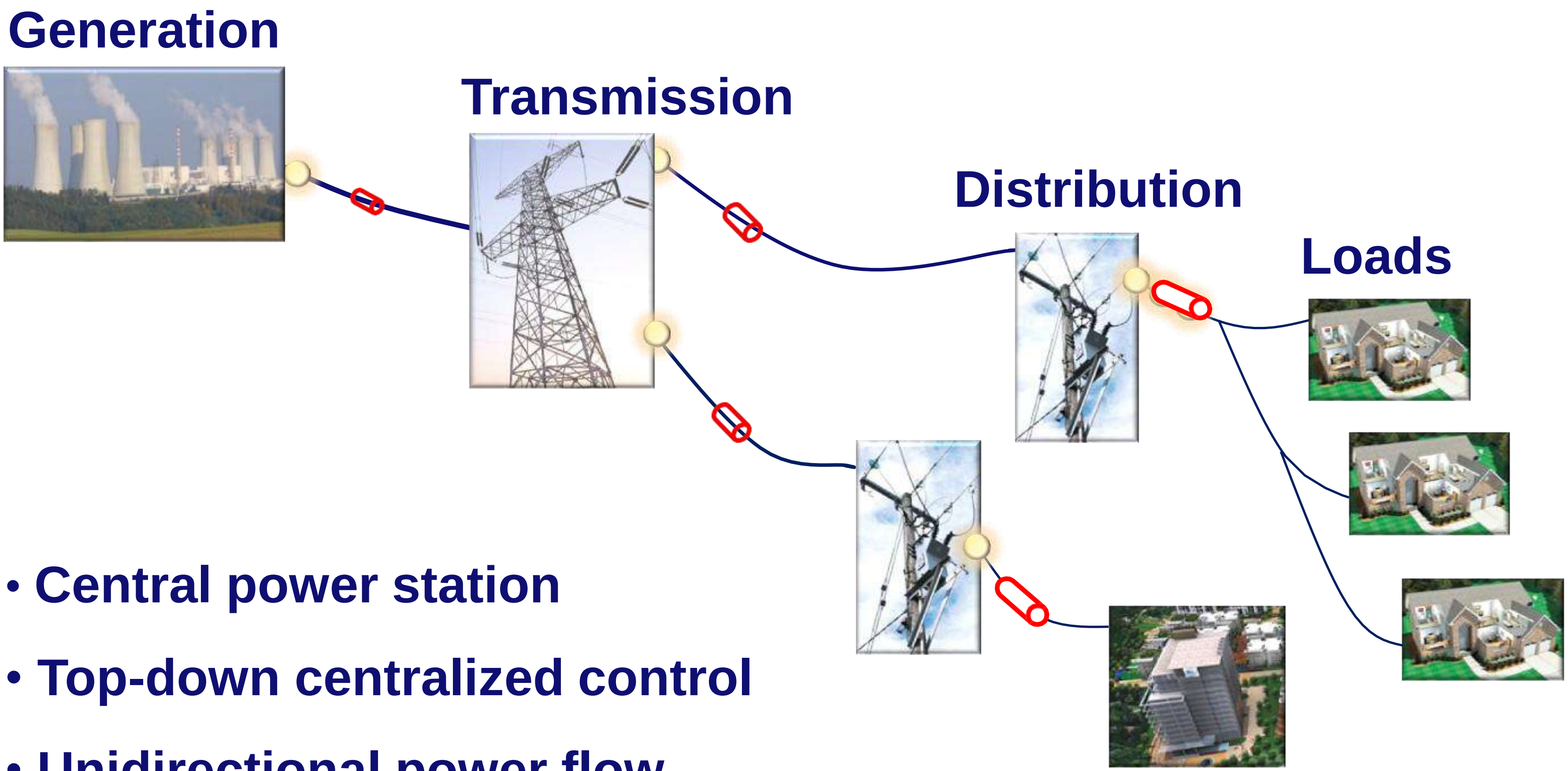
- **Introduction**
- **Grid-interfacing systems**
- **Structure and functionalities**
- **Control design and implementation**
- **Conclusions**

Transition to the future grid

- Growing electricity consumption
- Demanding high-quality electricity

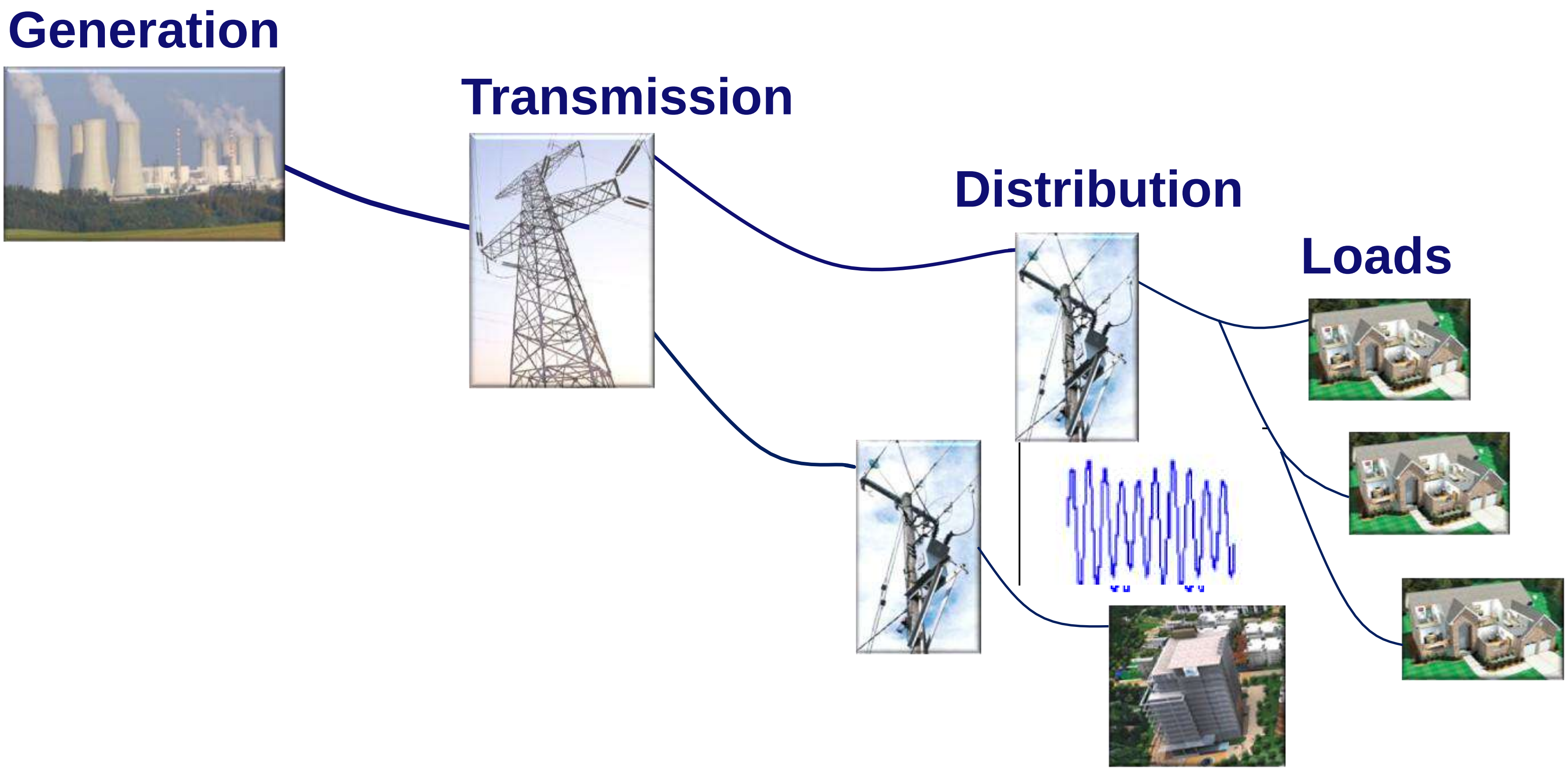
- Improving energy efficiency
- Applying sustainable energy

Conventional electricity grid



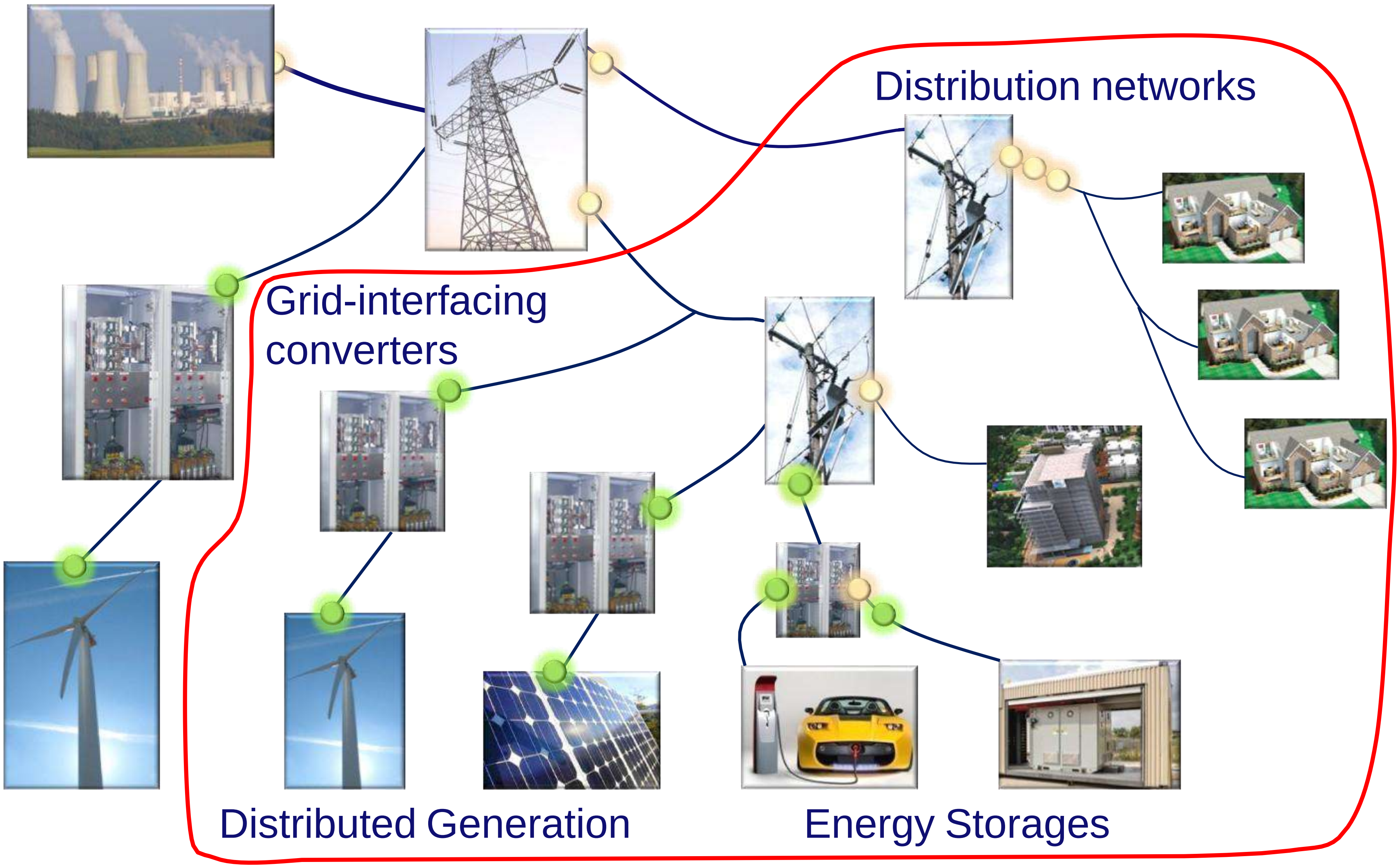
- Central power station
- Top-down centralized control
- Unidirectional power flow

Voltage quality problems

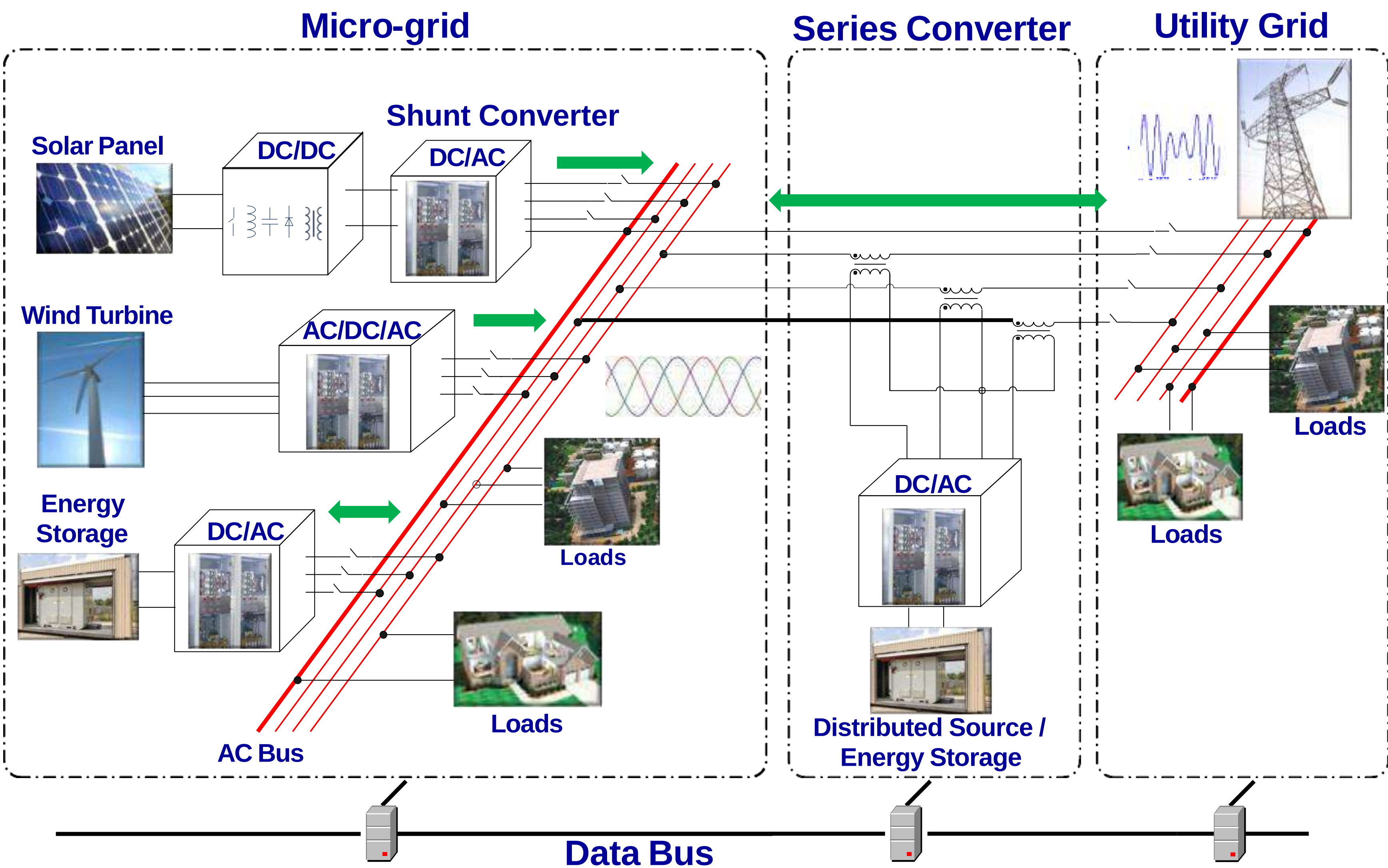


• Harmonics • Unbalance • Fluctuations • Dips

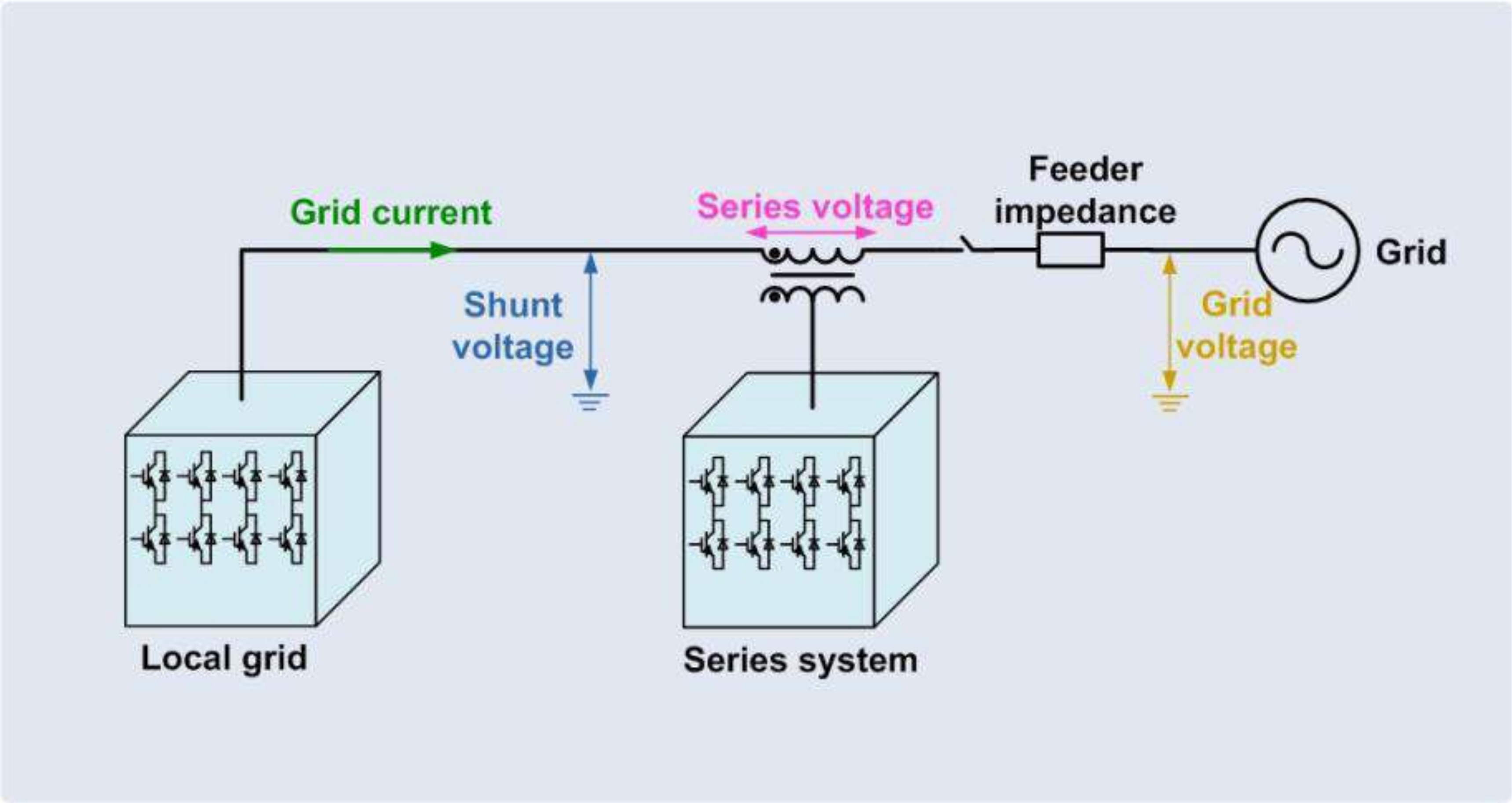
Distributed generation in the grid



Path to the future grid

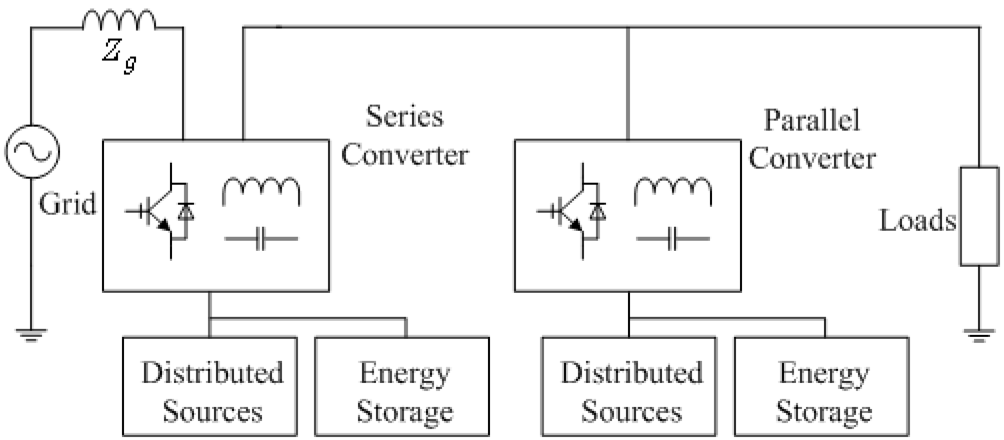


Path to the future grid



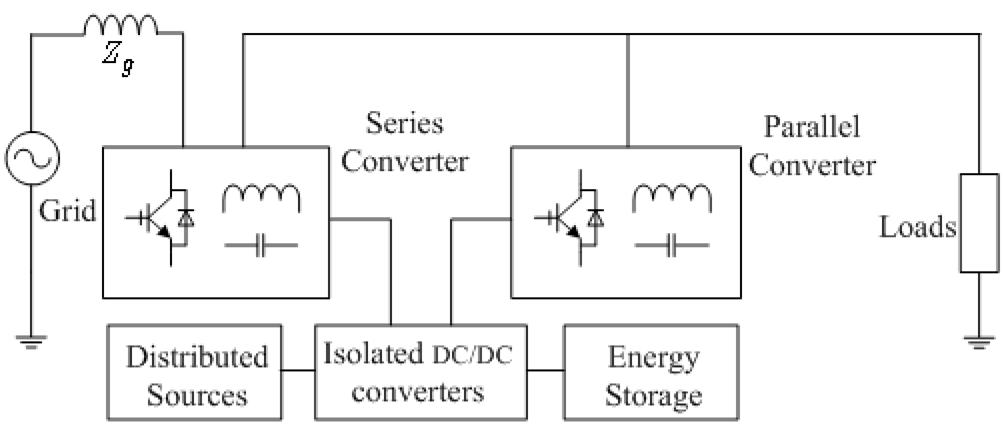
Series-parallel grid-interfacing systems

- **Independent distributed sources powered dc bus**



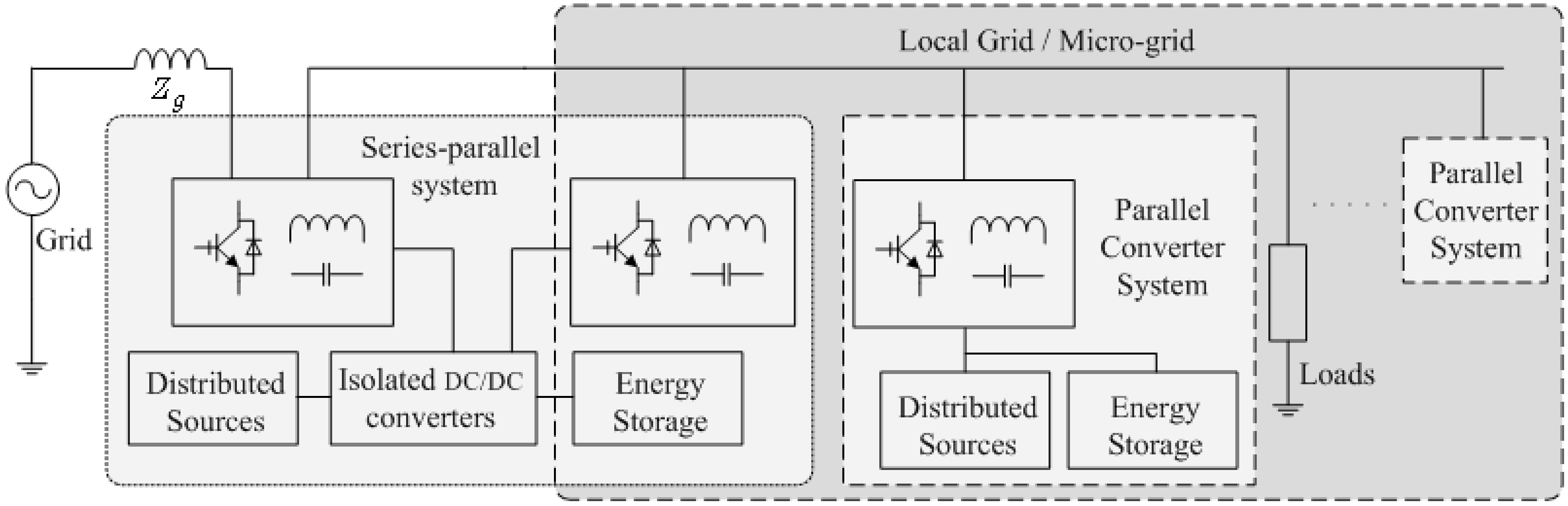
Series-parallel grid-interfacing systems

- **Common distributed sources powered dc bus with isolation techniques**



Series-parallel grid-interfacing systems

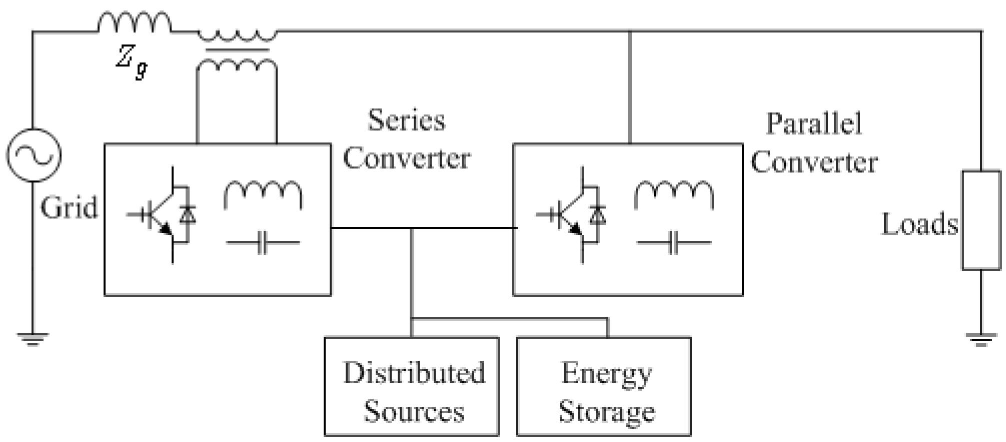
- **An example of coupling the utility grid and a local grid/micro-grid**



Series-parallel grid-interfacing systems

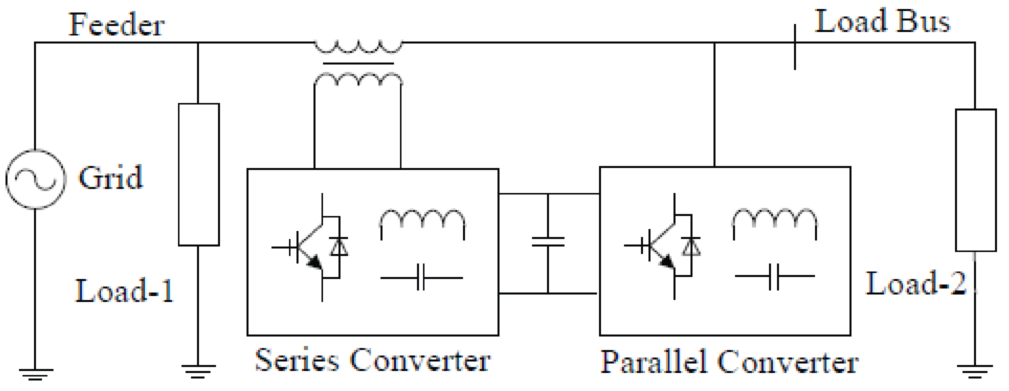
- **Adapted series-parallel structure**

  Common distributed sources powered dc bus



Reconfiguring system functionalities

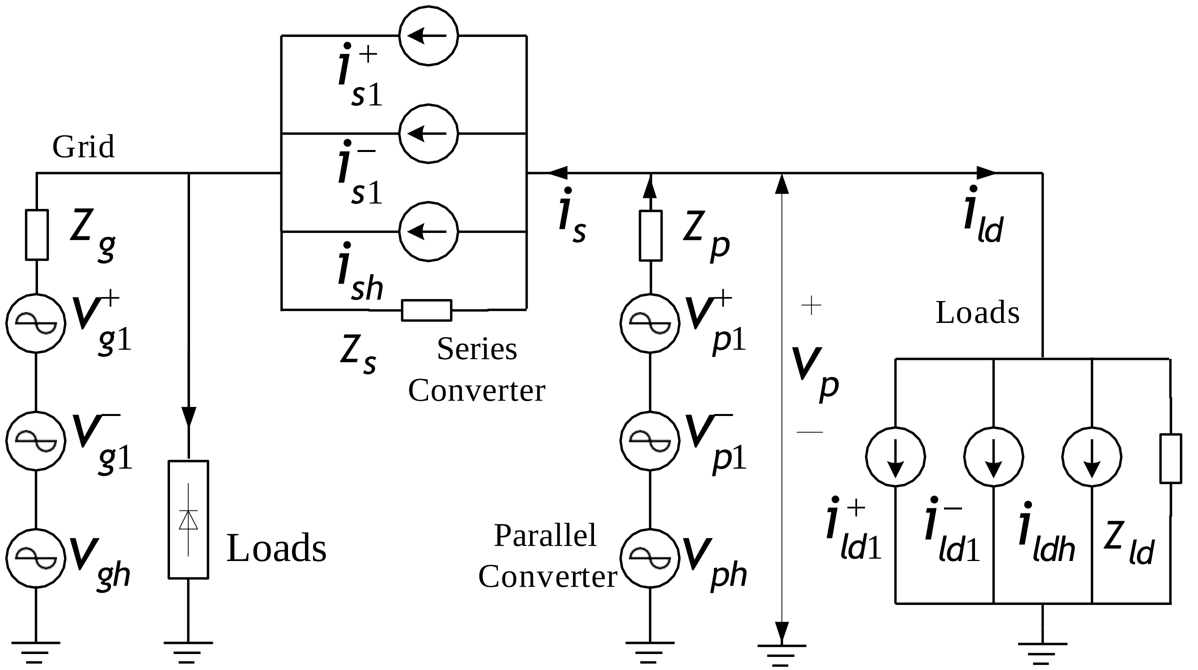
- **Conventional power quality enhancement**
  - Unified PQ conditioners (UPQC)



  - UPQC + energy storage (batteries, super-capacitors, distributed sources, etc.)

Reconfiguring system functionalities

- **Circuit presentation of the proposed grid-interfacing system**



Subscripts:

+, - : positive and negative sequence;

1: fundamental components

h: harmonics

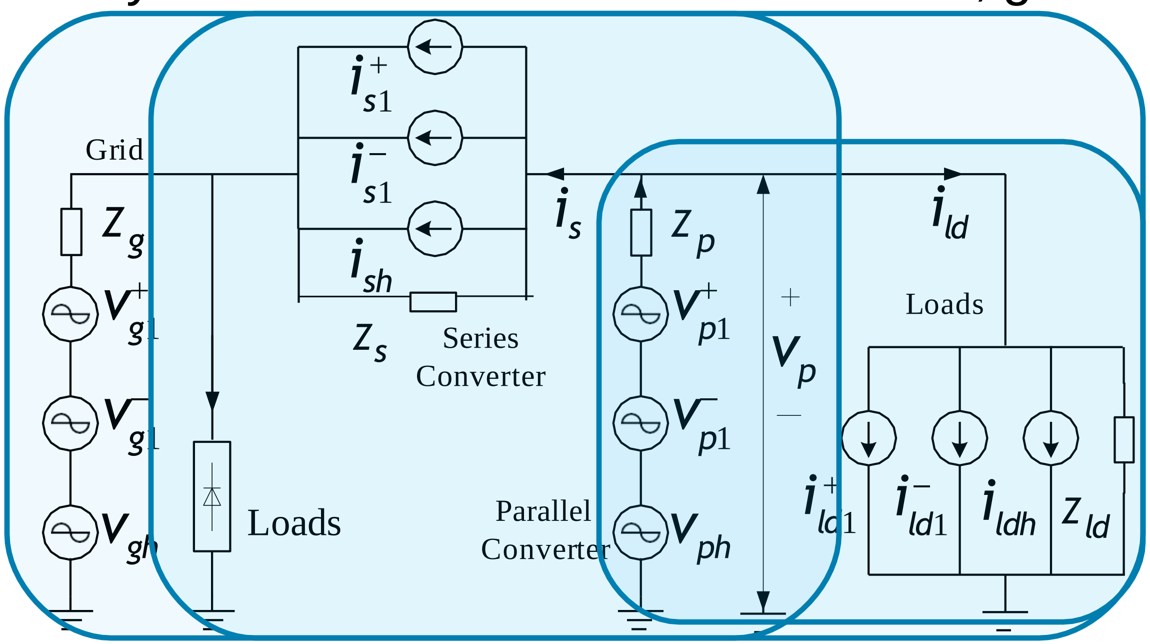
Reconfiguring system functionalities

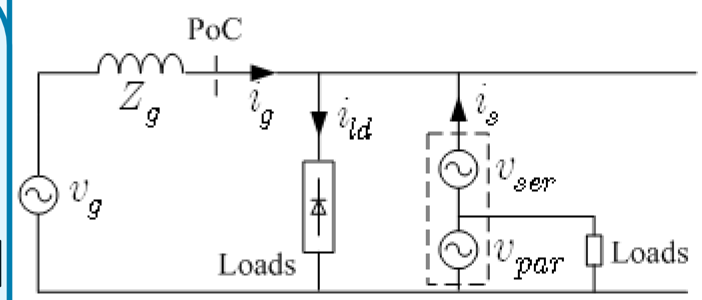
- **Multi-level control objectives**

- Level 1: Maintaining good voltage quality for local loads
  Dispatching power within the local grid (micro-grids)

- Level 2: Active power filtering function

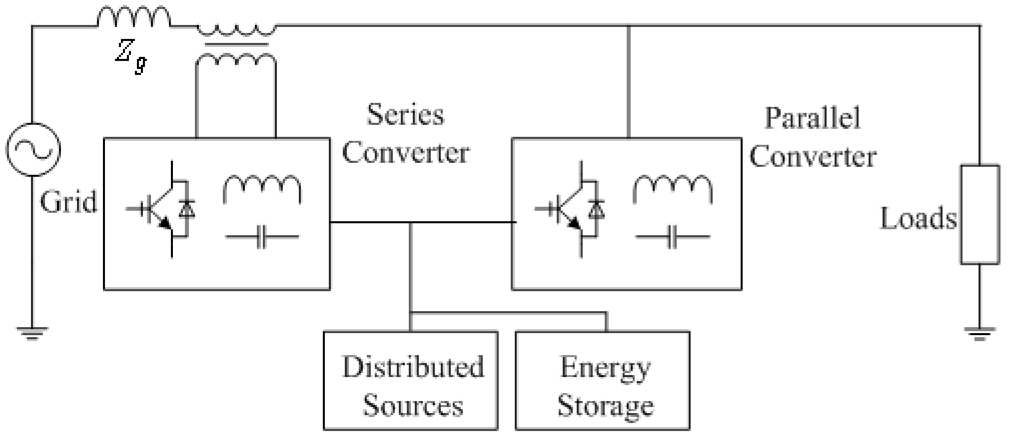
- System Level: Grid interactive control, grid support, power transfer



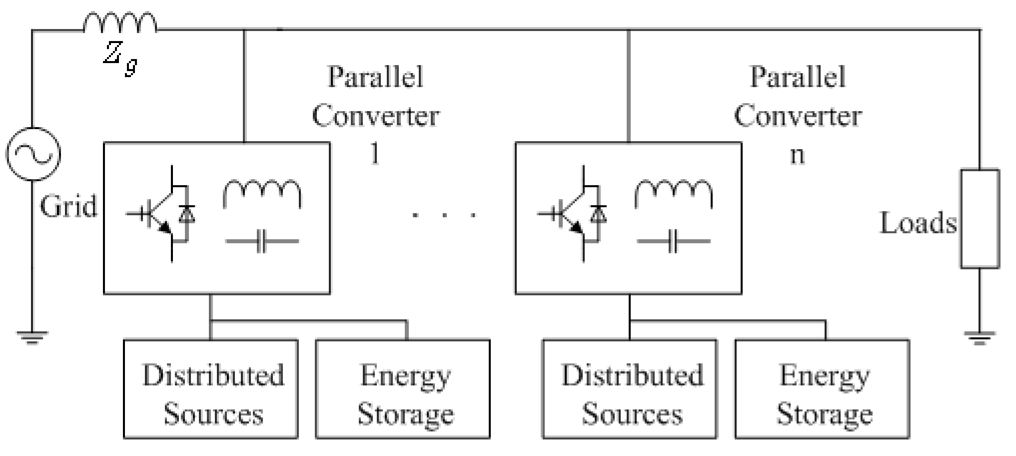


Comparison with shunt systems

(a) Series-parallel system

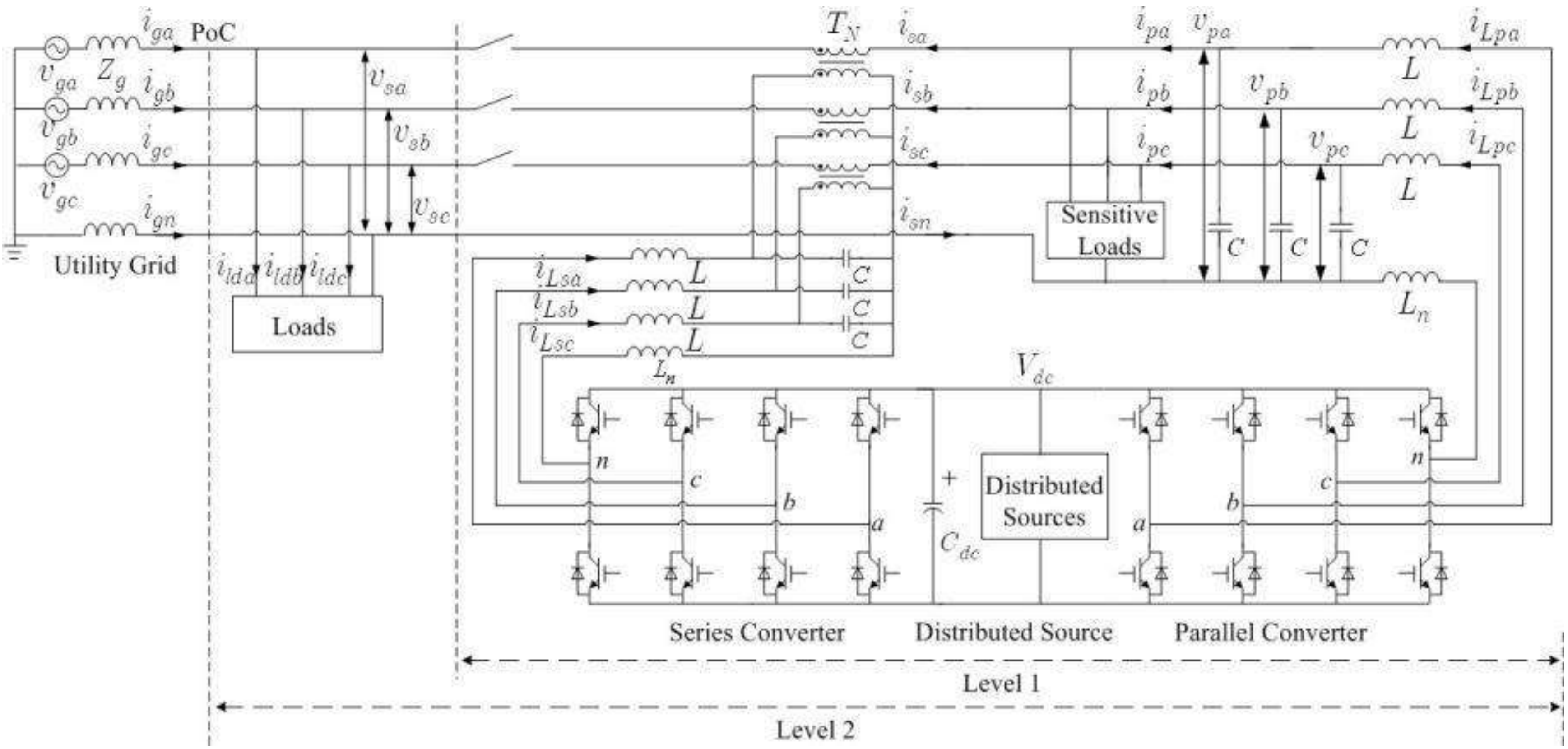


(b) Shunt-connected system



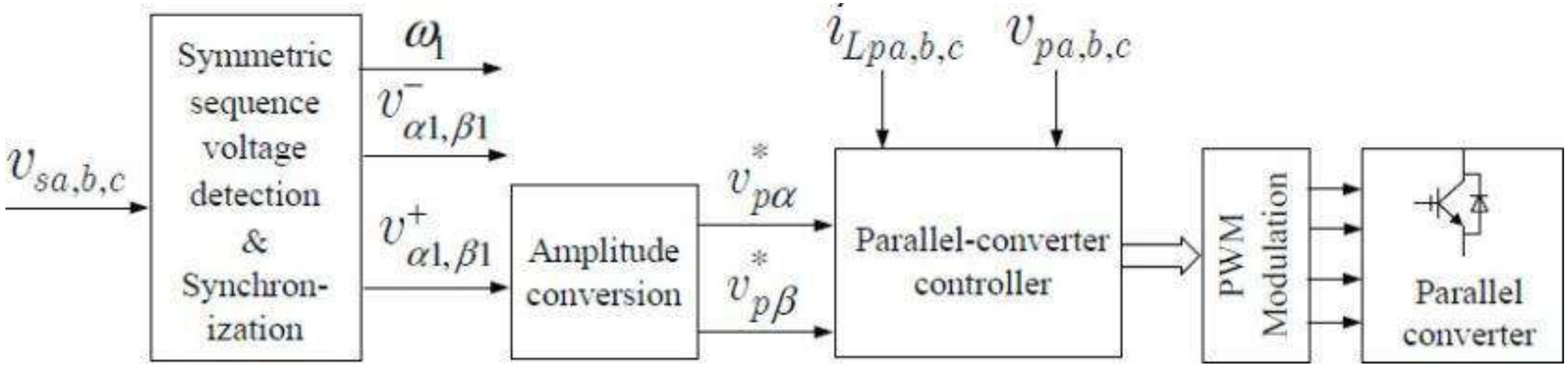
Control design and implementation

- **Employed configuration of the laboratory system**

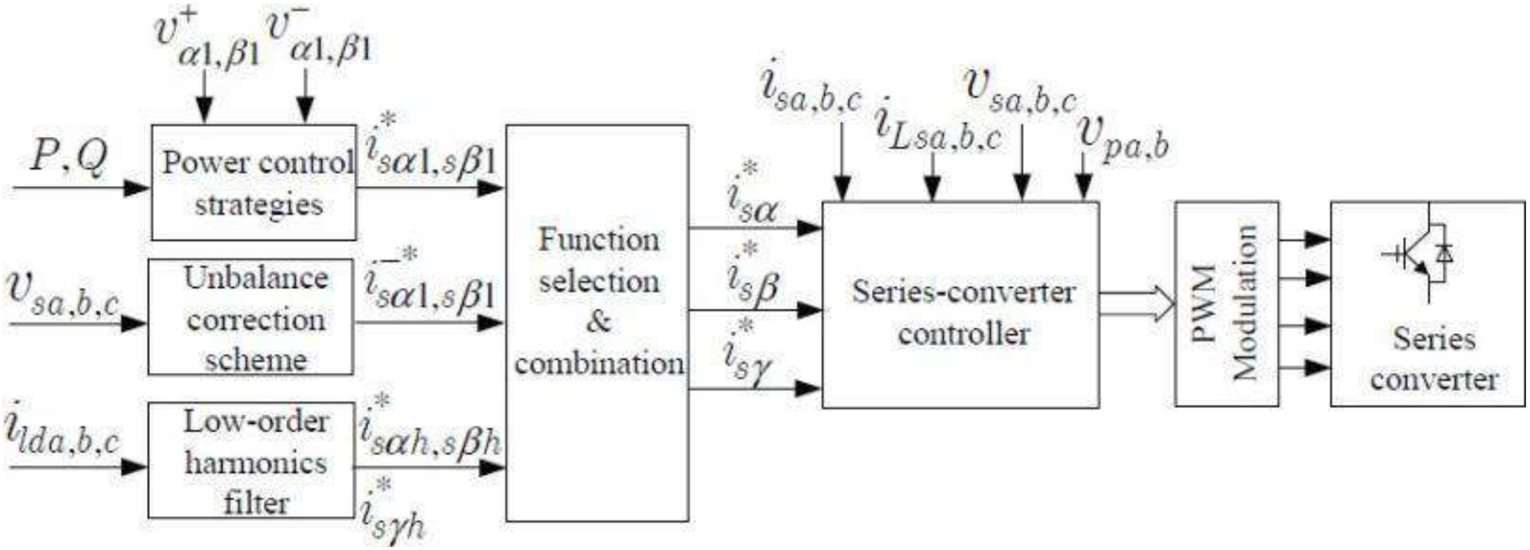


Control design and implementation

- **Overall control structure**
  - Parallel converter

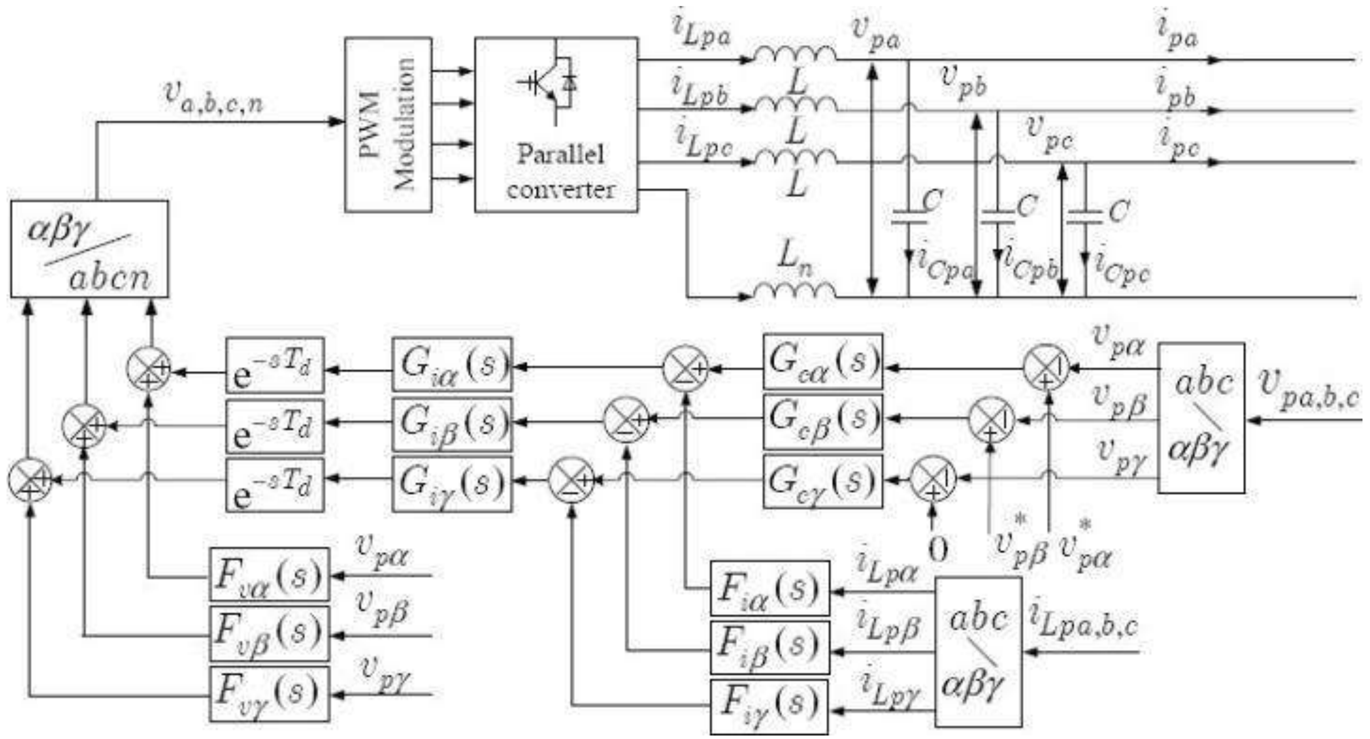


  - Series converter



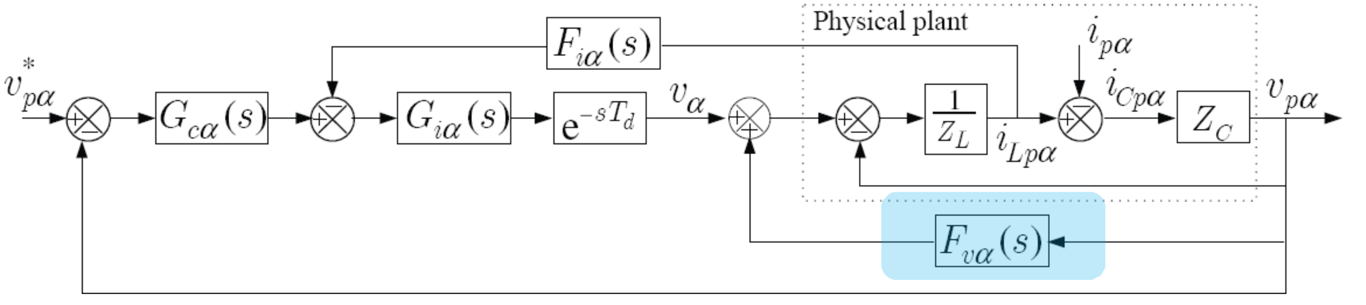
Control design – parallel converter

- **Control diagram of the parallel converter**



Control design – parallel converter

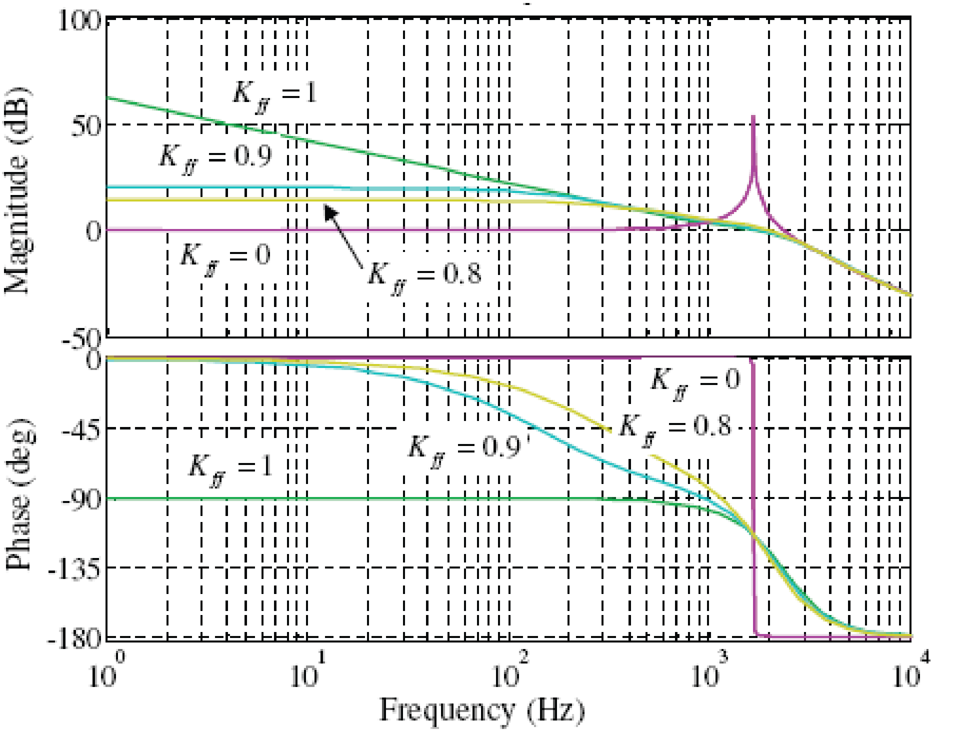
- **Instability improvement under no-load conditions**



Feedforward loop

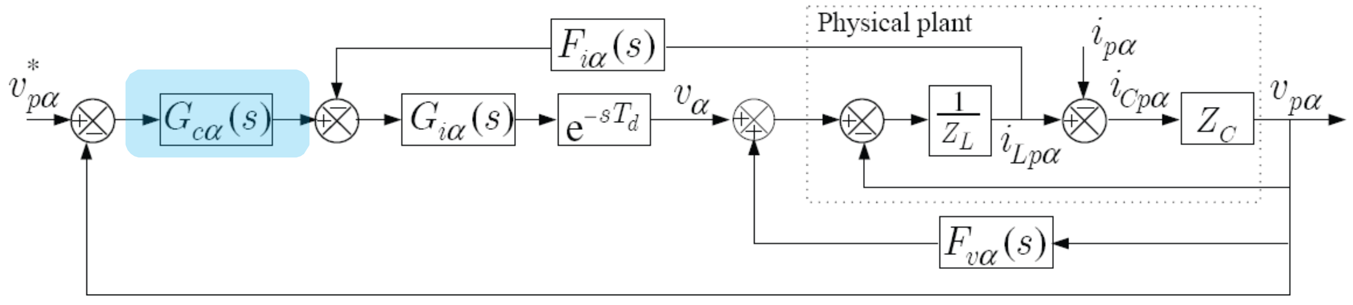
$$F_{v\alpha}(s) = K_{ff} e^{-sT_d} \approx K_{ff} \frac{1 - sT_d/2}{1 + sT_d/2}$$

Bode plots of the plant transfer function



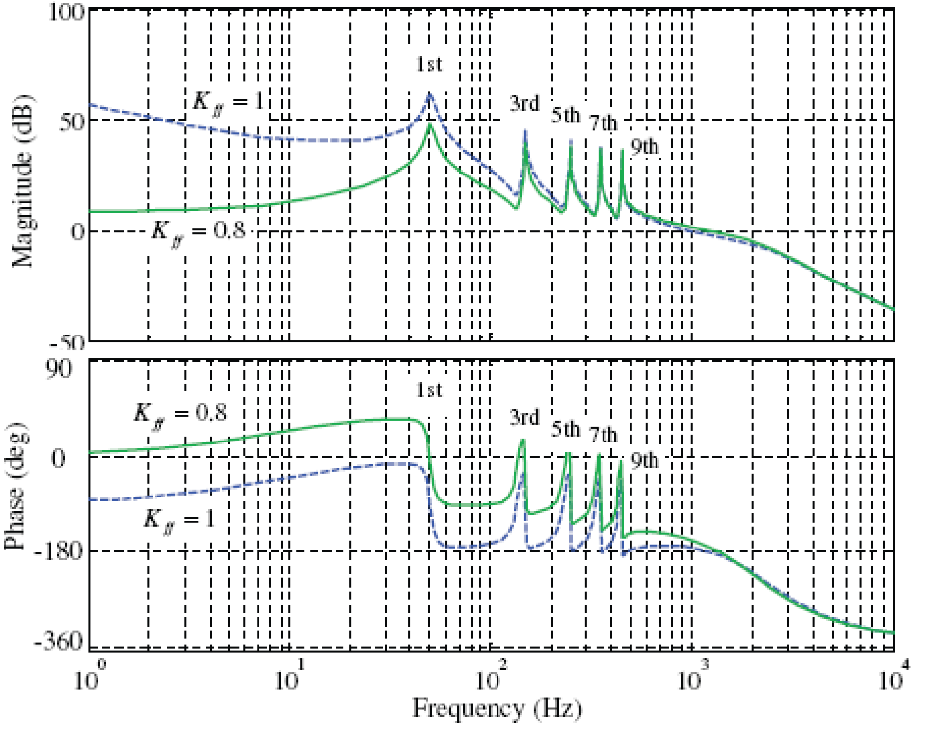
Control design – parallel converter

- **Selective harmonic regulation**



Multiple PR controllers

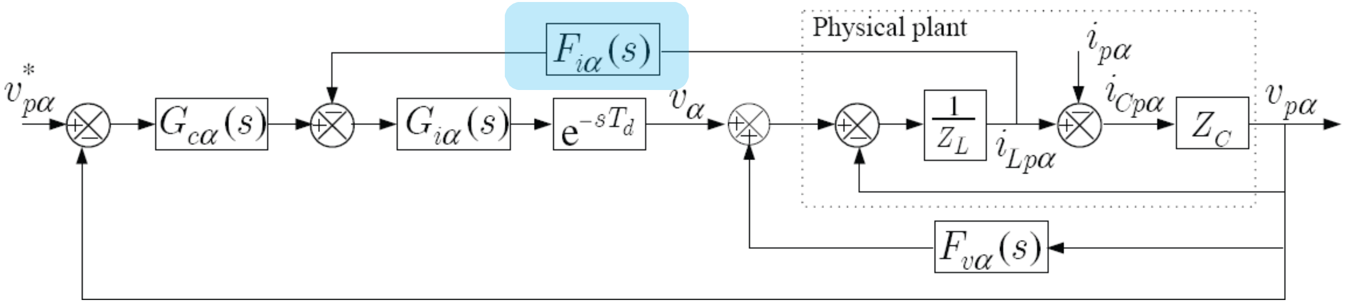
$$G_{c\alpha}(s) = K_P + \sum_{n=1,3,5,7}^{9} \frac{2\omega_{bn} K_{In} s}{s^2 + 2\omega_{bn} s + (n\omega_c)^2}$$



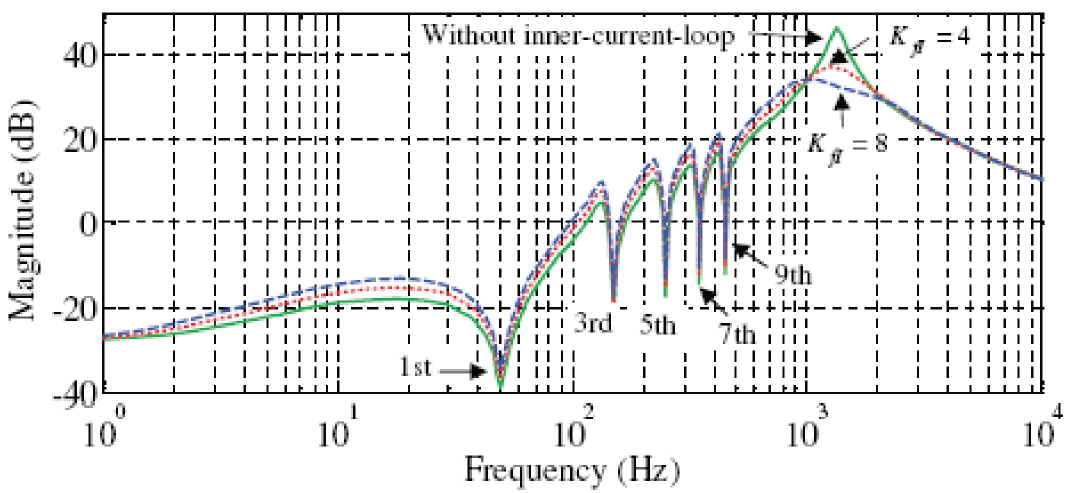
Bode plots of the open-loop transfer function with multiple PR controllers

Control design – parallel converter

- **Disturbance sensitivity improvement**



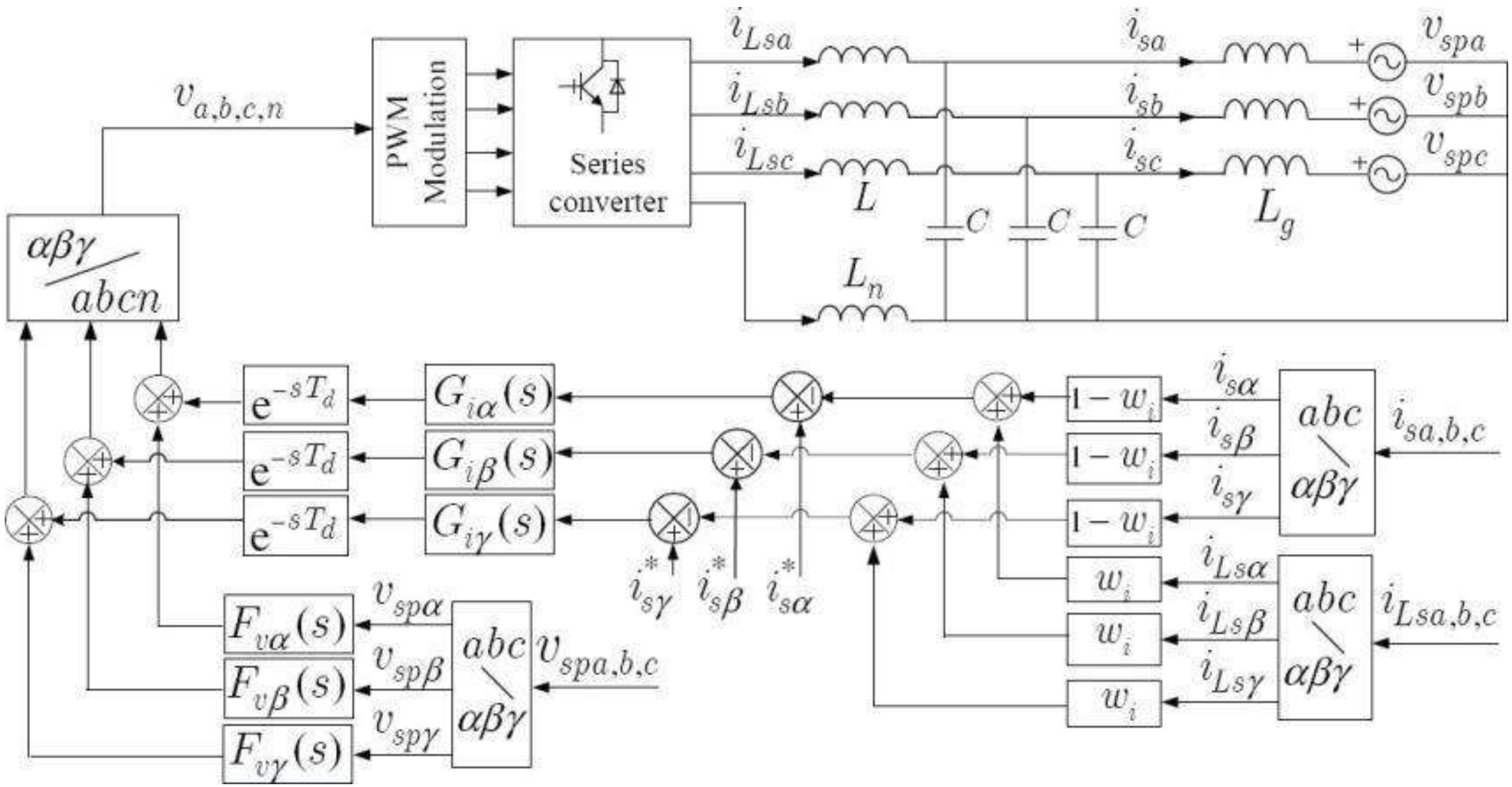
Inner current feedback loop $$F_{i\alpha}(s) = K_{fI}\frac{s}{s+2\pi f_{hp}}$$



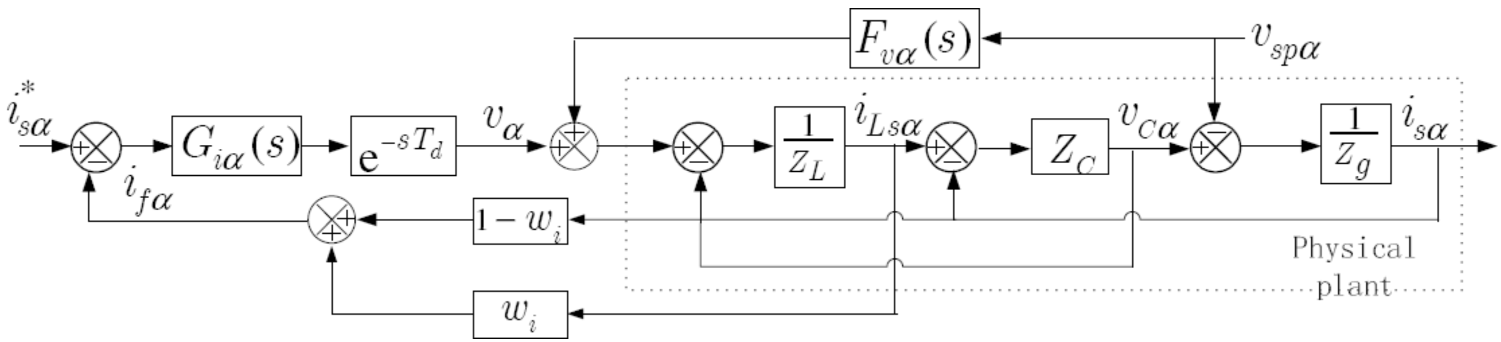
System sensitivity to current disturbances

Control design – series converter

- **Control diagram of the series converter**



Control design – series converter



Inverter output voltage to feedback current

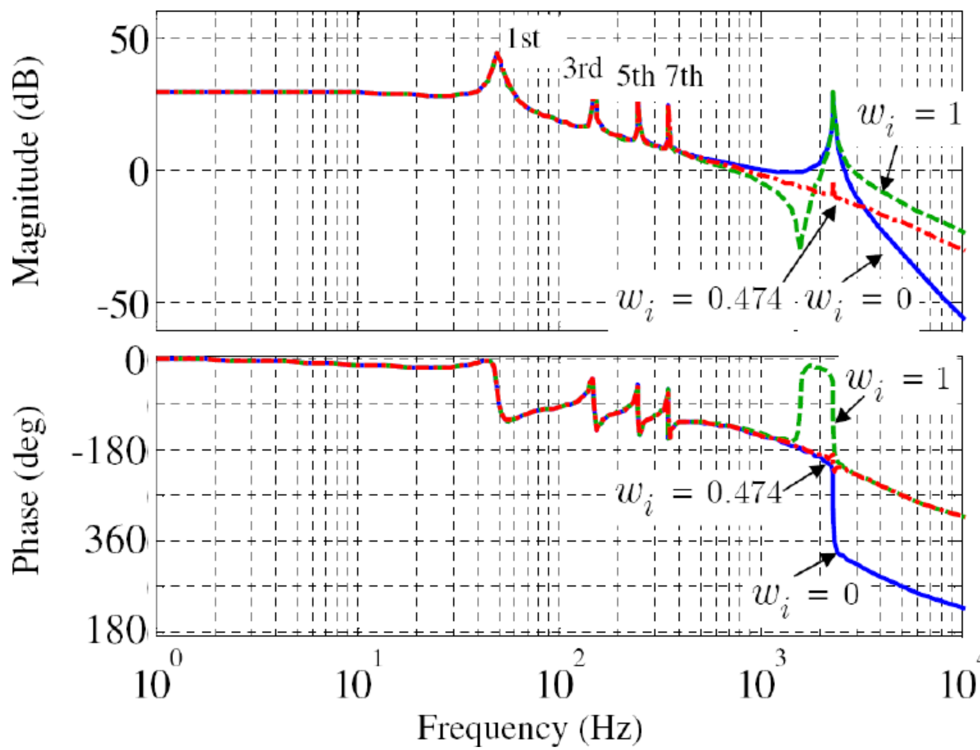
$$G_{v2i_f}(s) = w_i \frac{L_g C s^2 + 1}{L L_g C s^3 + (L + L_g)s} + (1 - w_i)\frac{1}{L L_g C s^3 + (L + L_g)s}$$

when

$$L_{sum} = L + L_g,\ w_i = L/L_{sum}$$

$$G_{v2i_f}(s) = \frac{1}{sL_{sum}}$$

Bode plots of open-loop transfer function



Laboratory system

Conclusions and recommendations

•All common grid disturbances at the distribution level can be mitigated by the proposed approach

•The voltage quality can be improved at both user and grid side, combing with distributed power generation

• Grid interaction control integrating grid-impedance adaptability

• Scaled up grid-interfacing systems for smart-grid research