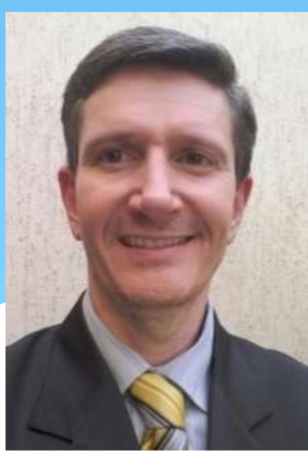
Advances and Challenges on Cooperative Control of Distributed Energy Gateways for Smarter Power Grids



Fernando Pinhabel Marafão

Associate Professor at UNESP

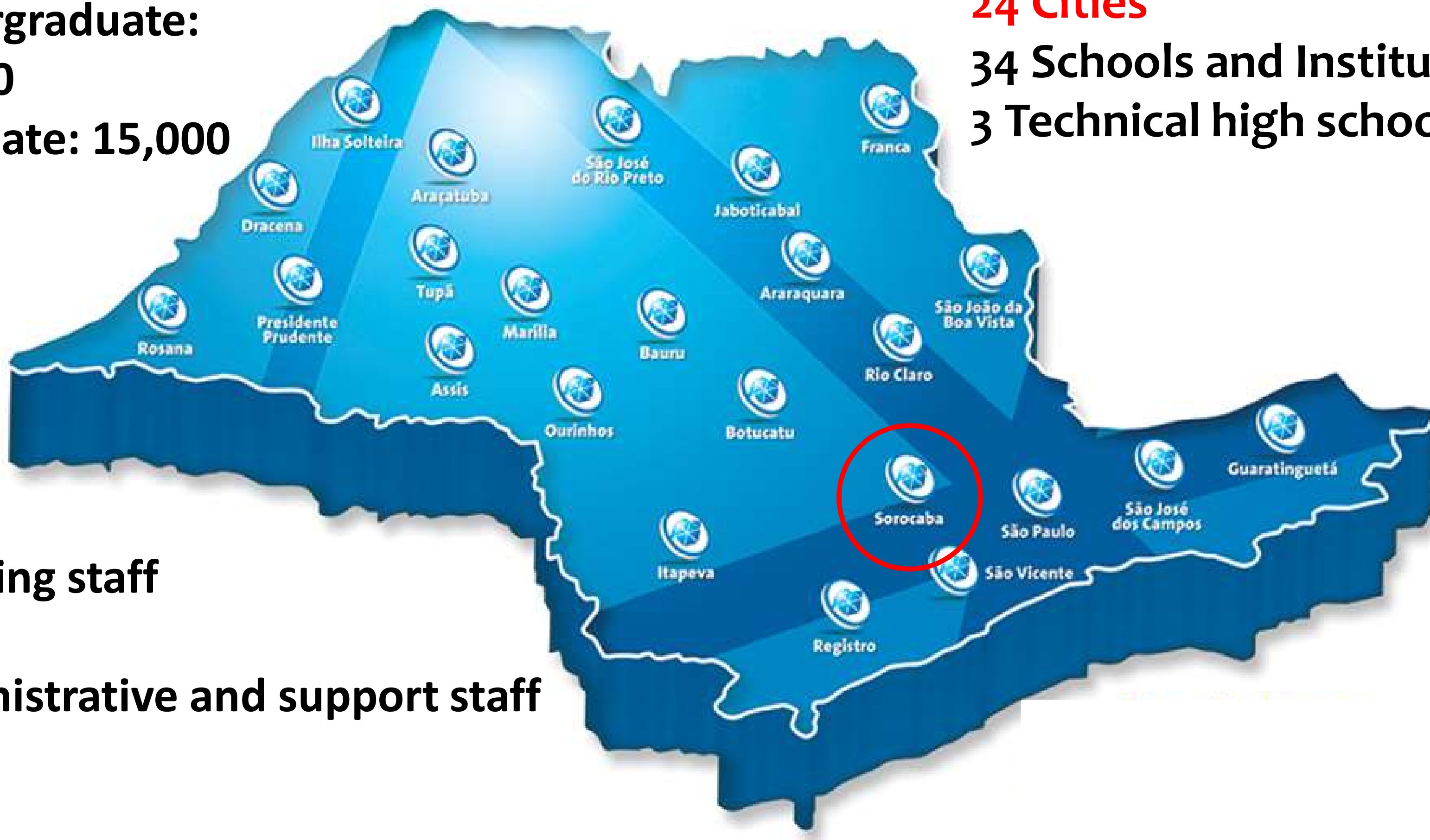
FAPESP WEEK BELGIUM

Brussels, October 2018.

UNESP - São Paulo State University

Students: 52,000
Undergraduate: 37,000
Graduate: 15,000

24 Cities
34 Schools and Institutes
3 Technical high schools



Teaching staff 3,600
Administrative and support staff 7,000

UNESP: founded in 1976

Sorocaba Campus: 2003

GASI – Group of Automation and Integrated Systems

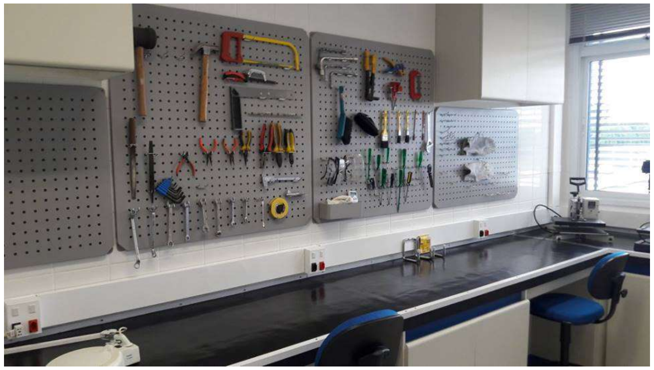
- **Main research areas are:**

- **Power Electronics (topologies, control, power quality, etc.)**
- **Renewable Energy Systems**
- **Energy Management**
- **Industrial Automation**
- **Instrumentation**
- **Embedded Systems**
- **Robotics**
- **Intelligent Systems**
- **Geoprocessing**
- **Image processing**

- **Smart Grids: microgrids, cognitive smart meters, smart buildings, iot, etc.**

GASI – Group of Automation and Integrated Systems (Research Lab)

unesp



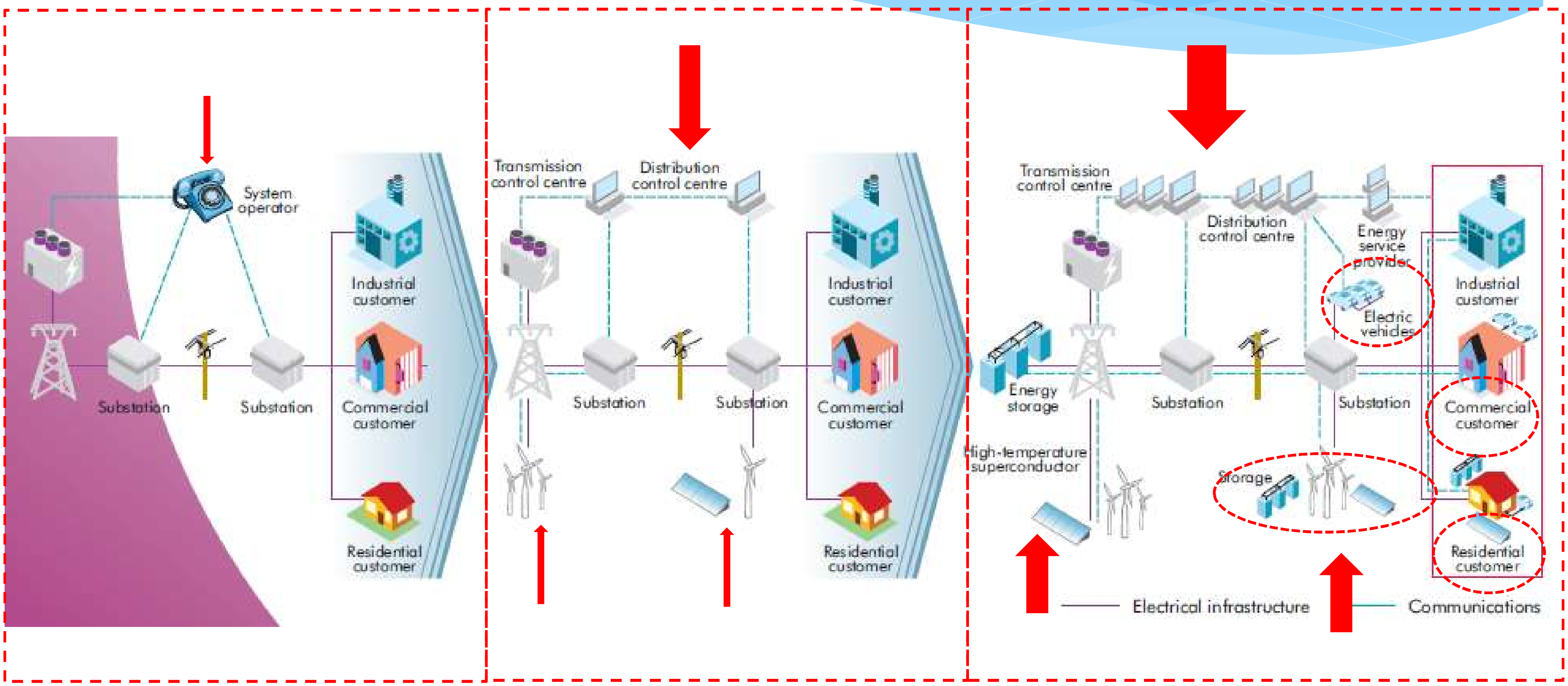
FAPESP
SÃO PAULO RESEARCH FOUNDATION

Back to the topic...

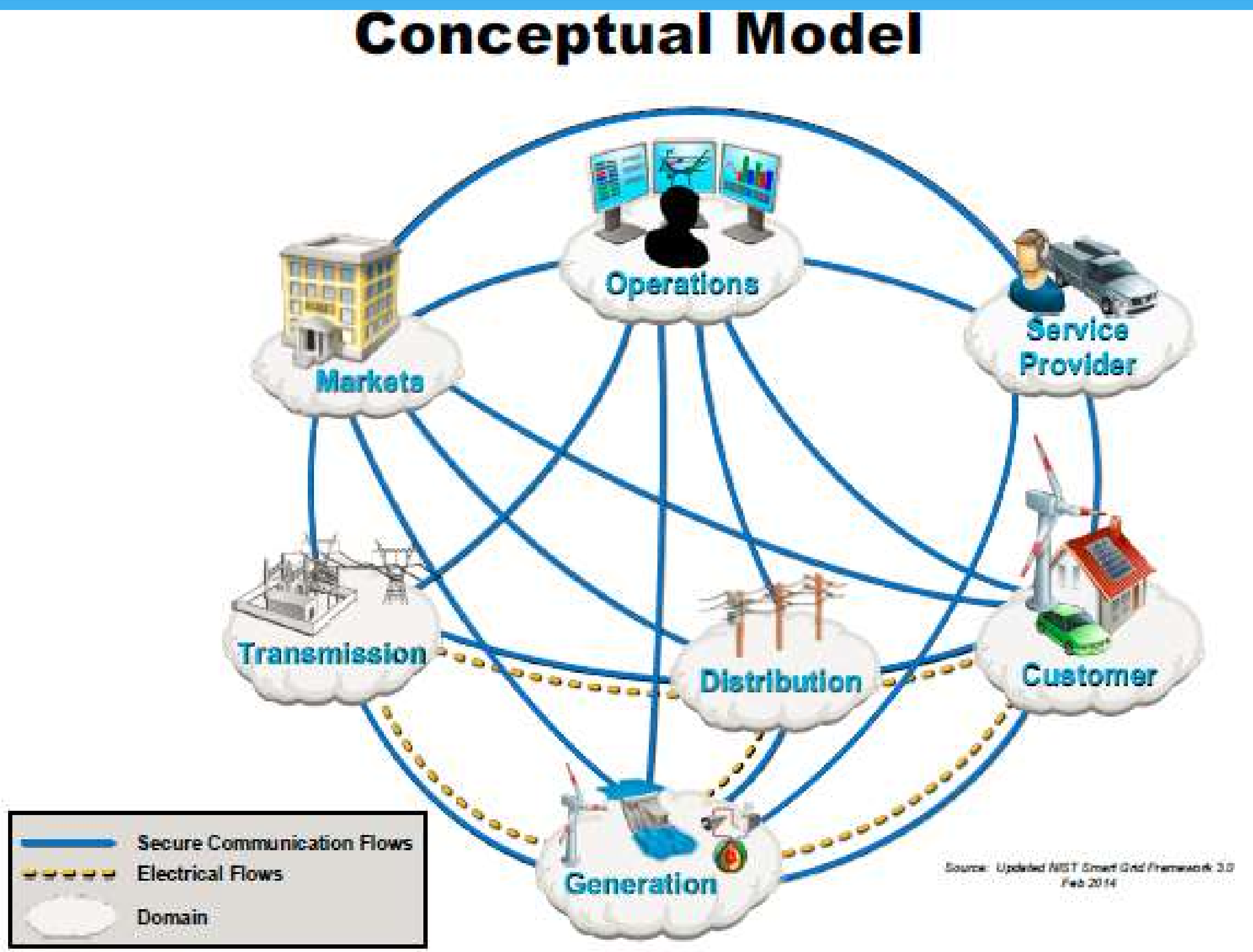
Advances and Challenges on Cooperative Control of Distributed Energy Gateways for Smarter Power Grids

unesp

Smart Grid (IEA roadmap)

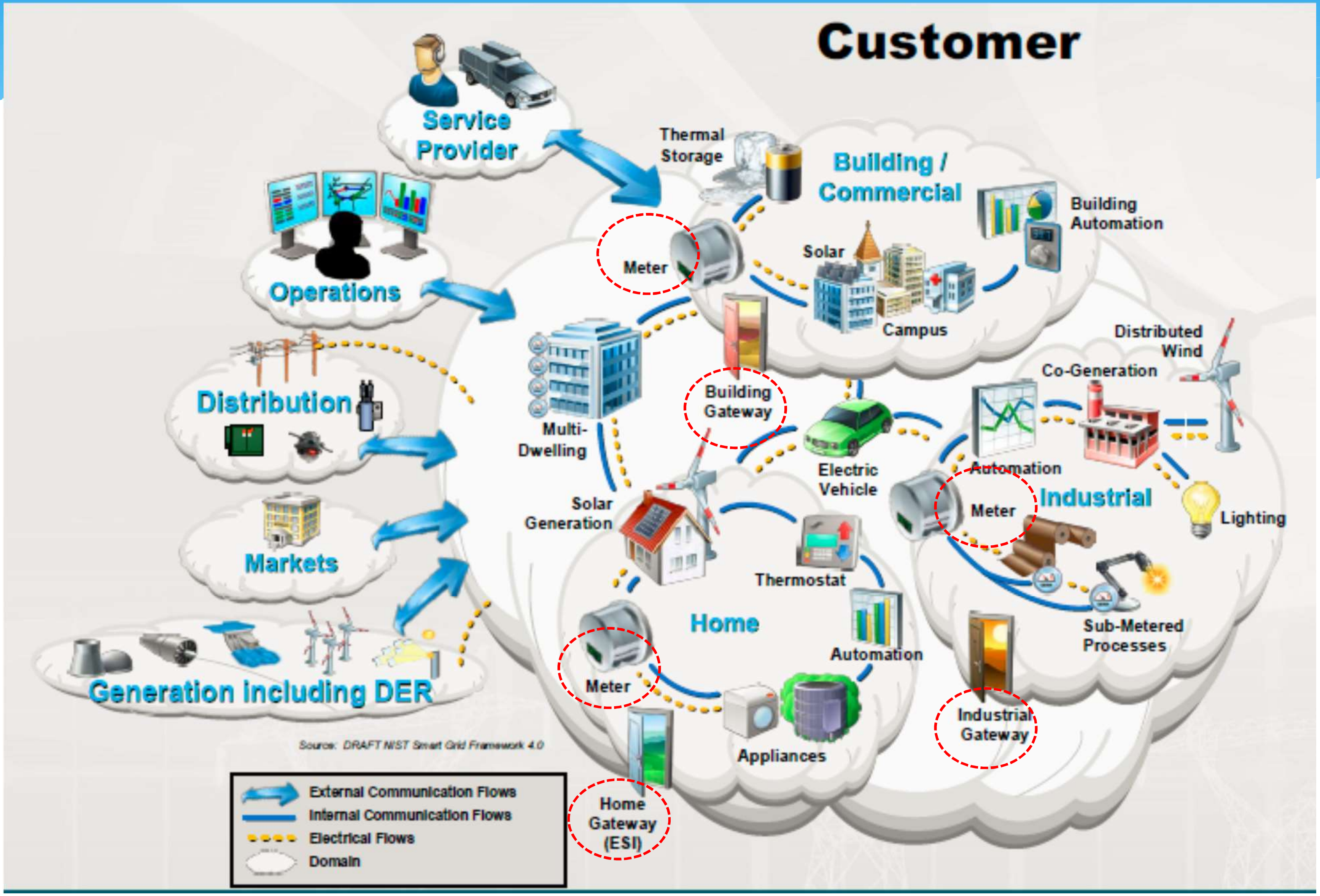


NIST Framework 2014



https://www.nist.gov/sites/default/files/documents/2018/06/06/webinar_slides.pdf

NIST Framework 2014



unesp

Main motivations for the development of Smarter Power Grids from the TECHNICAL point of view

- **Additional and new consumption models (electrical vehicles, smart homes, and smart buildings);**

- **Intermittent energy availability from renewable energy sources (solar, wind);**

- **The need for improving the efficiency of transmission and distribution systems;**

- **The increasing of prosumers (consumers/producers) and their interaction to the grid.**

Some Smart Grid Challenges

- **Development of new intelligent (cognitive) power metering, supervision and control systems;**

- **Development of network control devices and methodologies;**

- **Development of cooperative control methodologies for distributed energy gateways;**

Thinking about modern distribution grids – on smarter cities

Low voltage distributed generation…

Thinking about modern distribution grids – on smarter cities

Low voltage micro grids…

Is the Grid Prepared for Massive Power Electronics ?

- **Certainly not the LV distribution networks and utilities.**

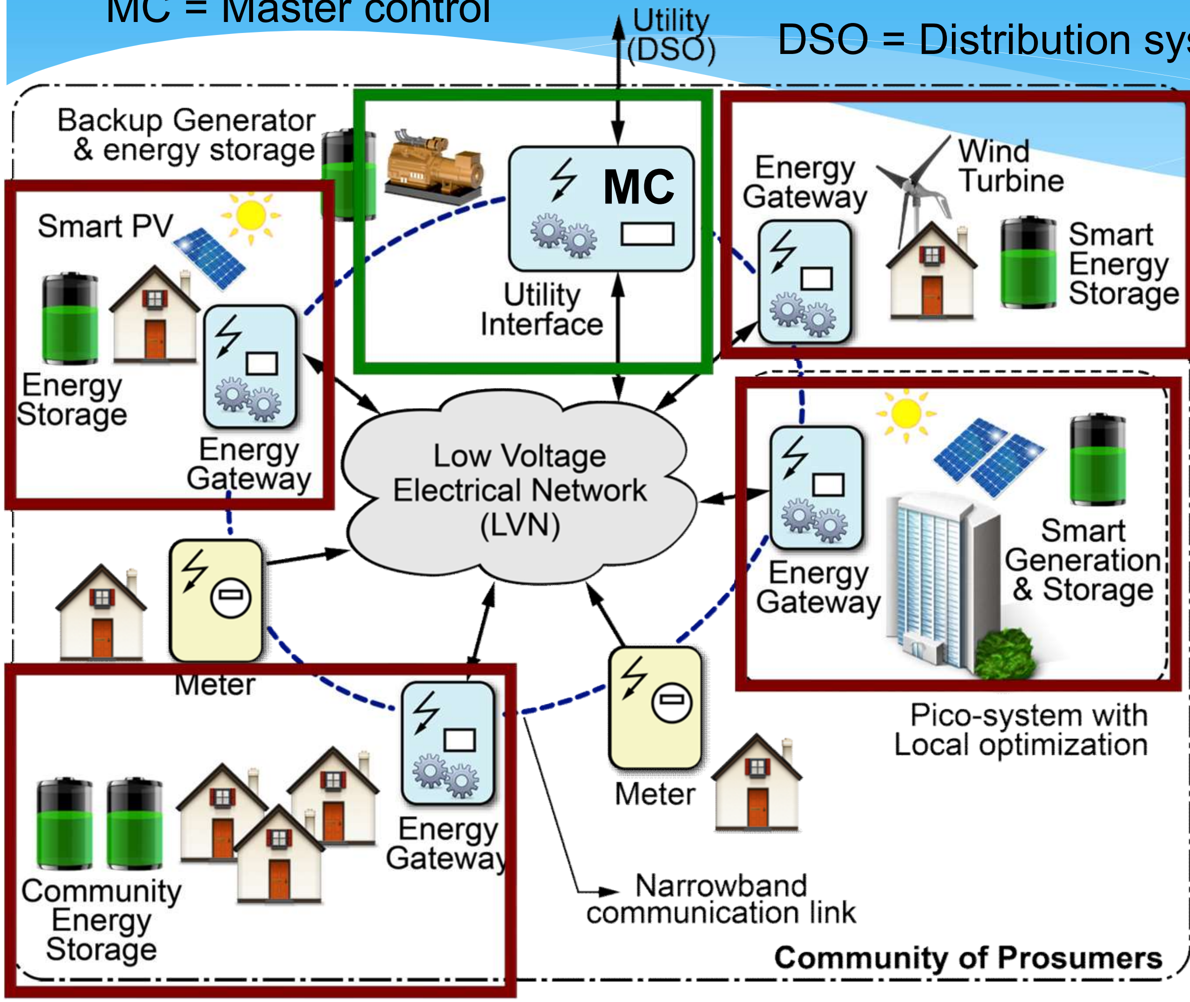
…there is much to do in terms of electronic metering, grid automation, protections, control, storage and the business itself.

And that is why PV systems are pushing to the Smart Grid Scenario worldwide, including in Brazil.

Low Voltage Intelligent Micro Grids

MC = Master control

DSO = Distribution system operator



Energy Gateways (EG)

- Connected DGs;
- Current controlled sources;
- Local control under supervision;
- Bidirectional communication.

Utility Interface (UI)

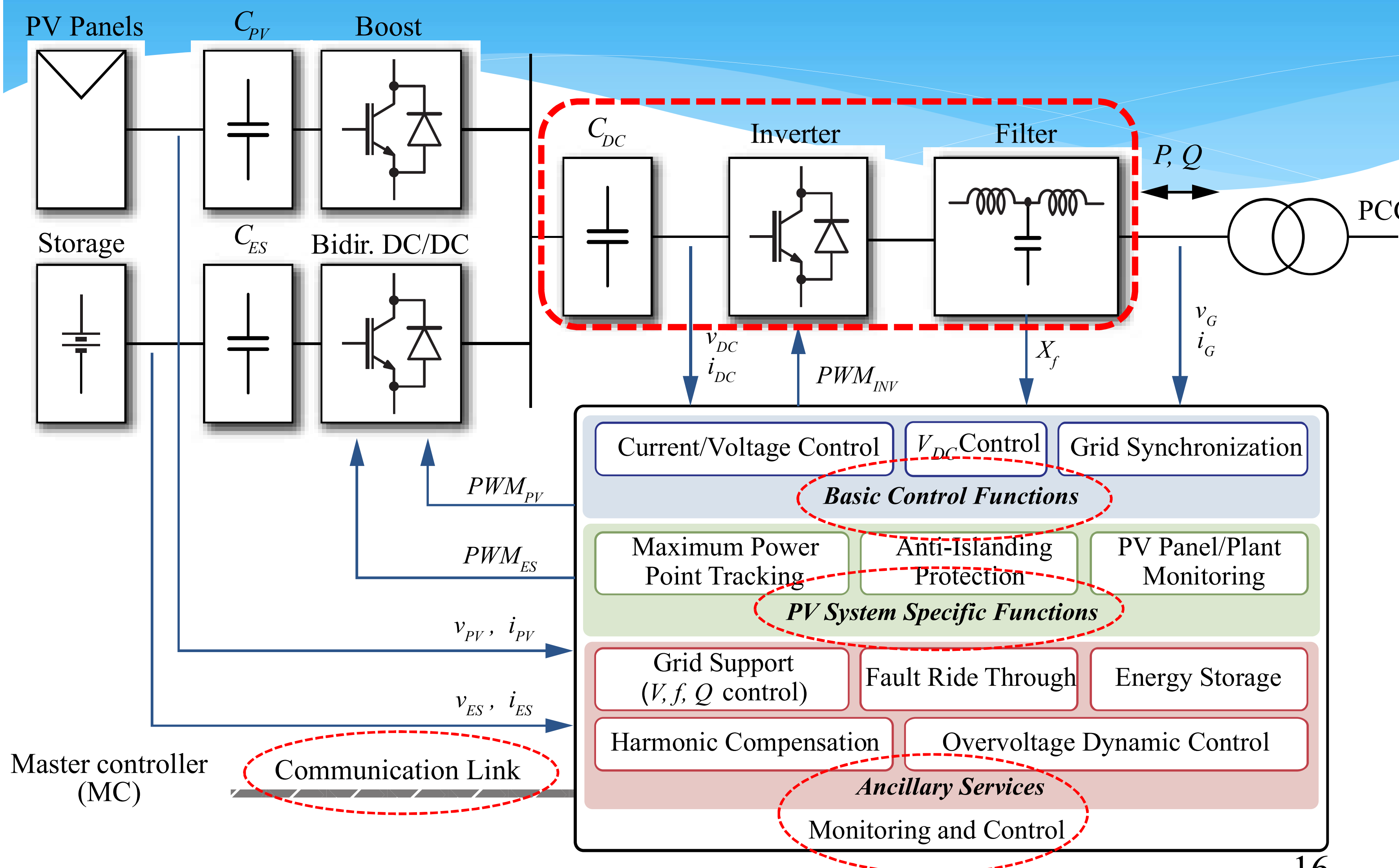
- Interface between MG and Utility;
- Voltage controlled source;
- Central controler;
- Bidirectional communication.

Low Voltage Intelligent Micro Grids

Hierarchical and cooperative control of distributed energy gateways (multifuncional gateways);

Automatic operation based on smart metering, bidirectional communication and proper power electronics control.

Intelligent Energy Gateways



Recent Goals and Contributions

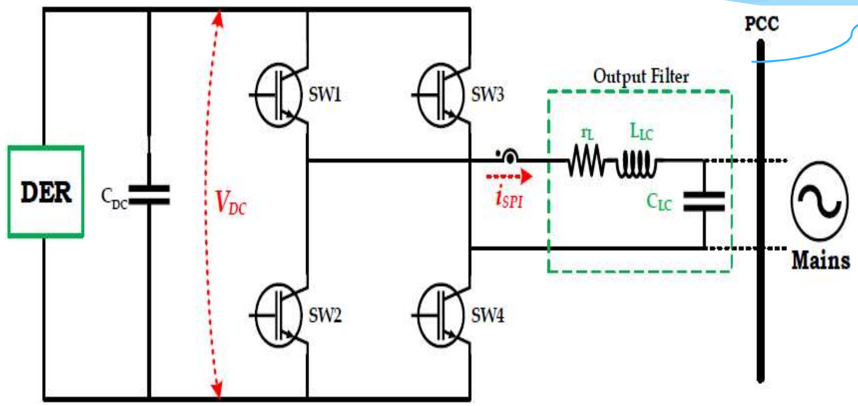
- **Present a hierarchical control methodology**

- **Current-Based Control (CBC), based on a master/slave architecture, which is able to provide current/power sharing in low-voltage microgrids;**

  - **Proportional power sharing considering different power capabilities;**
  - **Balanced thermal stress over the microgrid;**
  - **Selective disturbances compensation;**

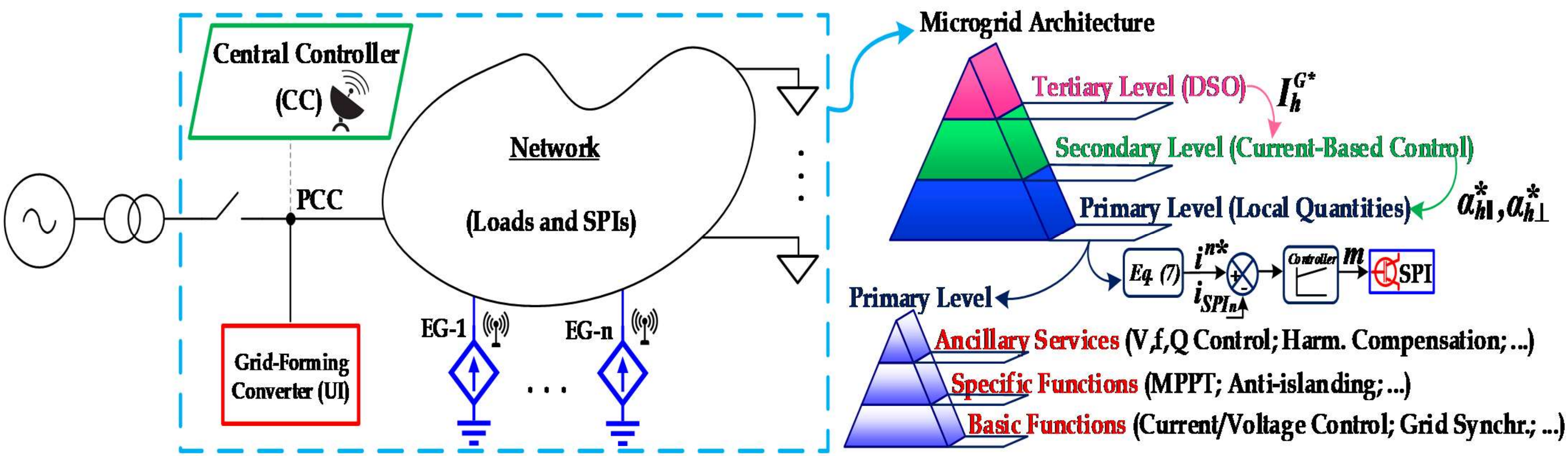
Master/Slave Hierarchical Control

- **Primary Level -** Single-Phase Switching Power Interfaces (SPI) / Energy Gateways (EG) = **INVERTERS**



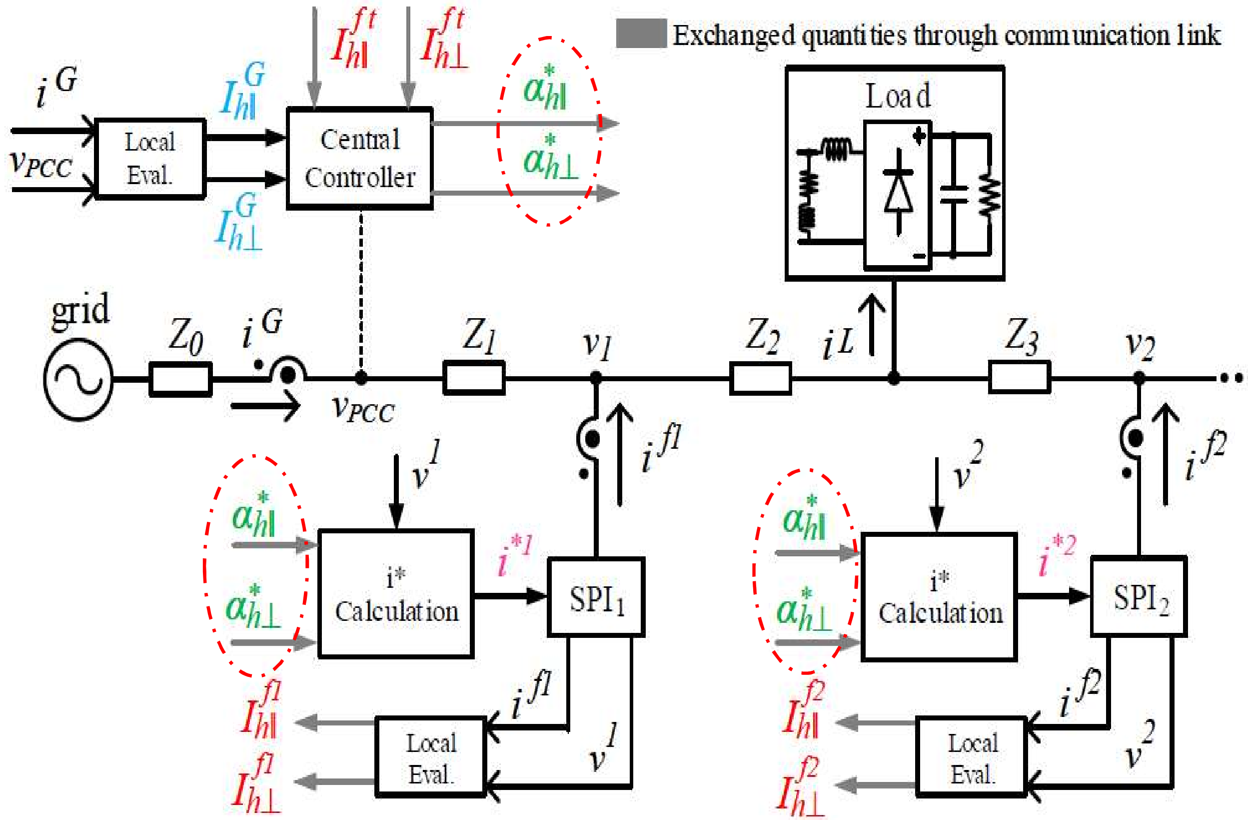
LCL – Experimental work

- **Hierarchical Methodology - Central (Master) Controller**



Hierarchical Control – SECONDARY LEVEL

- **The Current-Based Control (CBC)**
  - **Three main operational stages:**
    1. **Local Evaluation of Electrical Quantities**
    2. **Data Collection and Transmission**
    3. **Processing and Delegation of Setpoints**



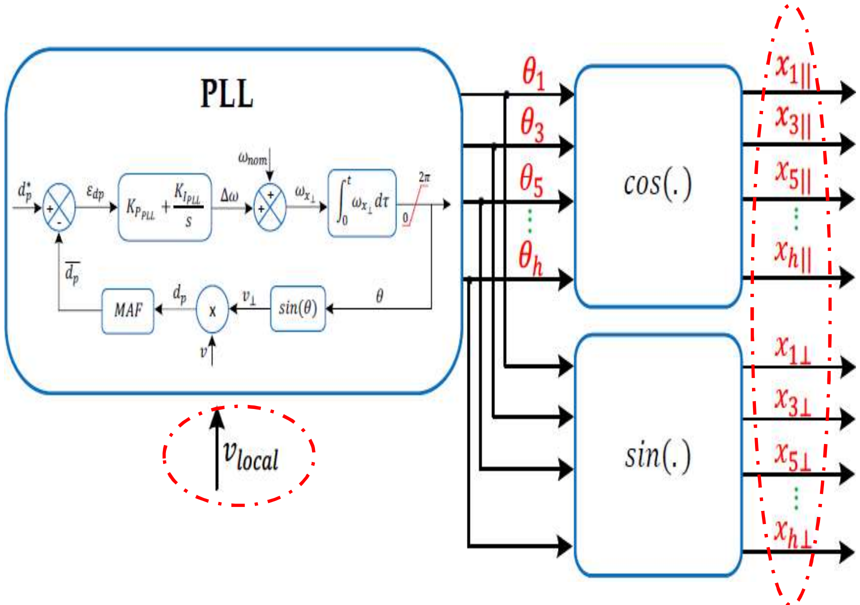
Hierarchical Topology of Controllers – The CBC

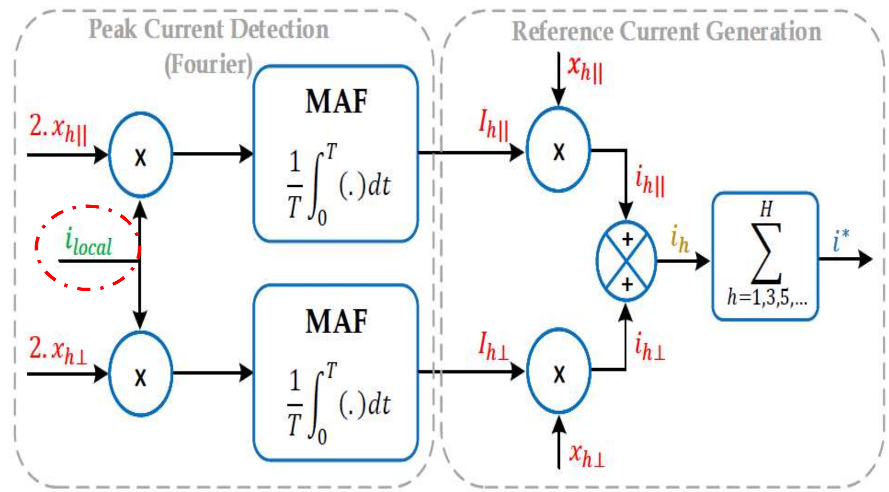
1. **Local Evaluation of Electrical Quantities (at the PCC and each EG)**

- **Quantities:** v_{local} , i_{local}

$$I_{h_{||}} = \frac{2}{T}\int_0^T i_{local}\cdot\cos\left(\frac{h\cdot 2\pi t}{T}\right)\cdot dt = \frac{2}{T}\int_0^T i_{local}\cdot x_{h_{||}}\cdot dt$$

$$I_{h_{\perp}} = \frac{2}{T}\int_0^T i_{local}\cdot\sin\left(\frac{h\cdot 2\pi t}{T}\right)\cdot dt = \frac{2}{T}\int_0^T i_{local}\cdot x_{h_{\perp}}\cdot dt$$





- **Time Domain Reconstruction**

$$\begin{cases} i_{h_{||}} = I_{h_{||}}\cdot x_{h_{||}} \\ i_{h_{\perp}} = I_{h_{\perp}}\cdot x_{h_{\perp}} \end{cases}$$

- **Reference Control Currents**

$$i^* = \sum_{h=1,3,5,\ldots}^{H} i_h$$

Hierarchical Topology of Controllers – The CBC

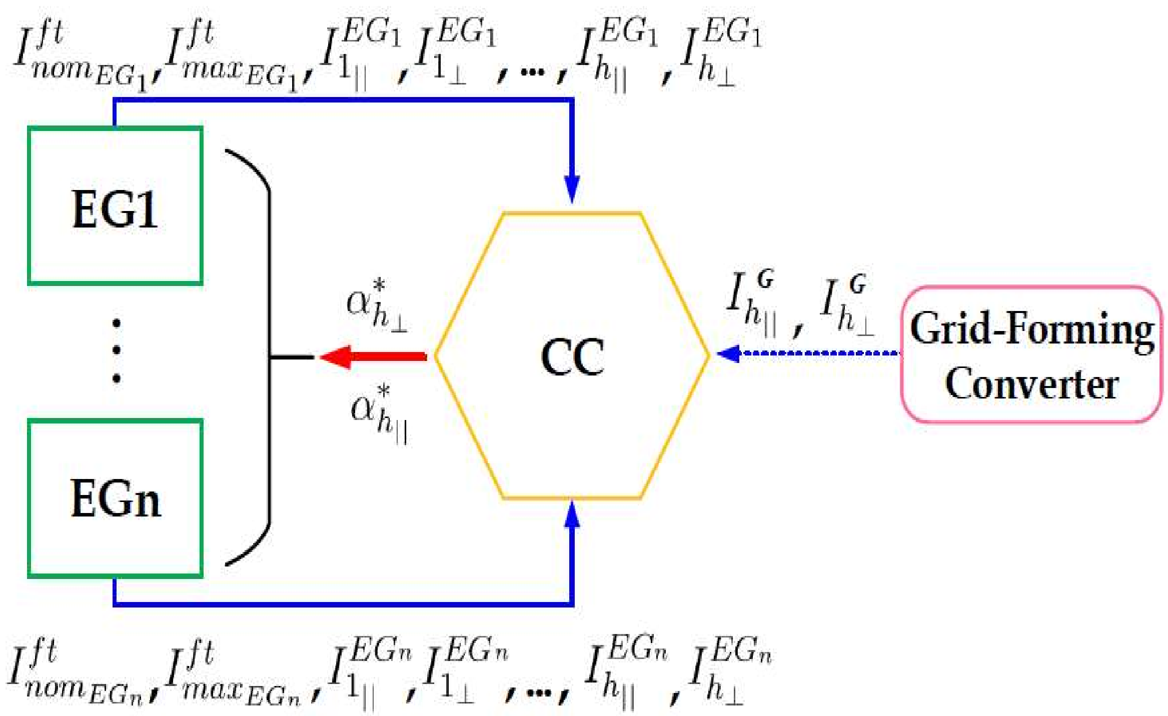
2. **Data Collection and Transmission (CC → EGs // EGs → CC)**

EGs

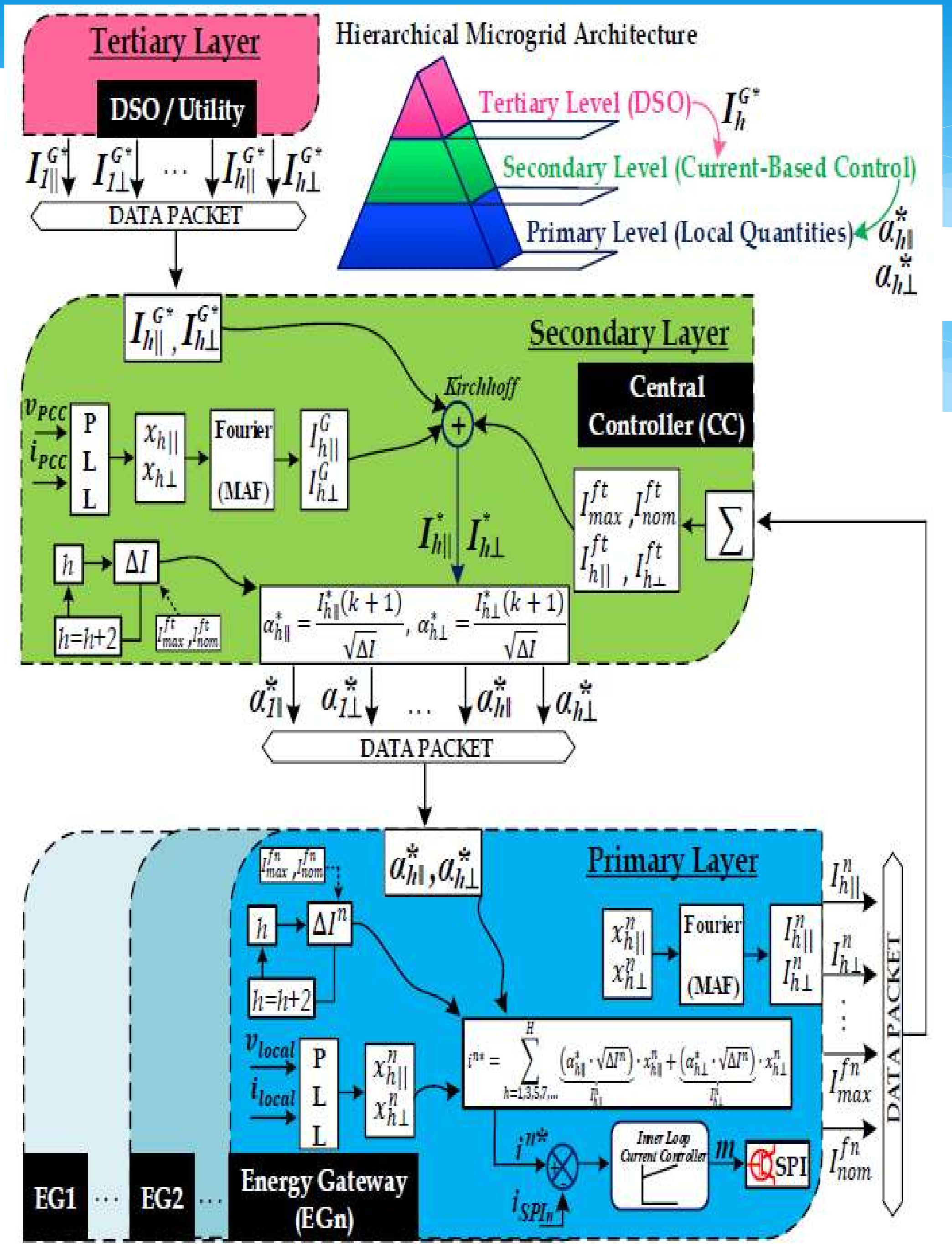
- Nominal Currents (I_{nom}^{ft})
- Maximum Currents (I_{max}^{ft})
- Local Peak Currents ($I_{h_{||}}$, $I_{h_{\perp}}$)

CC

- Control Packets ($\alpha_{h_{||}}$, $\alpha_{h_{\perp}}$)



Low rate communication links can fulfill such task!!!


Tertiary Layer
DSO / Utility
DATA PACKET
Hierarchical Microgrid Architecture
Tertiary Level (DSO)
Secondary Level (Current-Based Control)
Primary Level (Local Quantities)
Secondary Layer
Central Controller (CC)
Kirchhoff
P L L
Fourier (MAF)
h=h+2
DATA PACKET
Primary Layer
Fourier (MAF)
Inner Loop Current Controller
SPI
DATA PACKET
EG1
EG2
Energy Gateway (EGn)

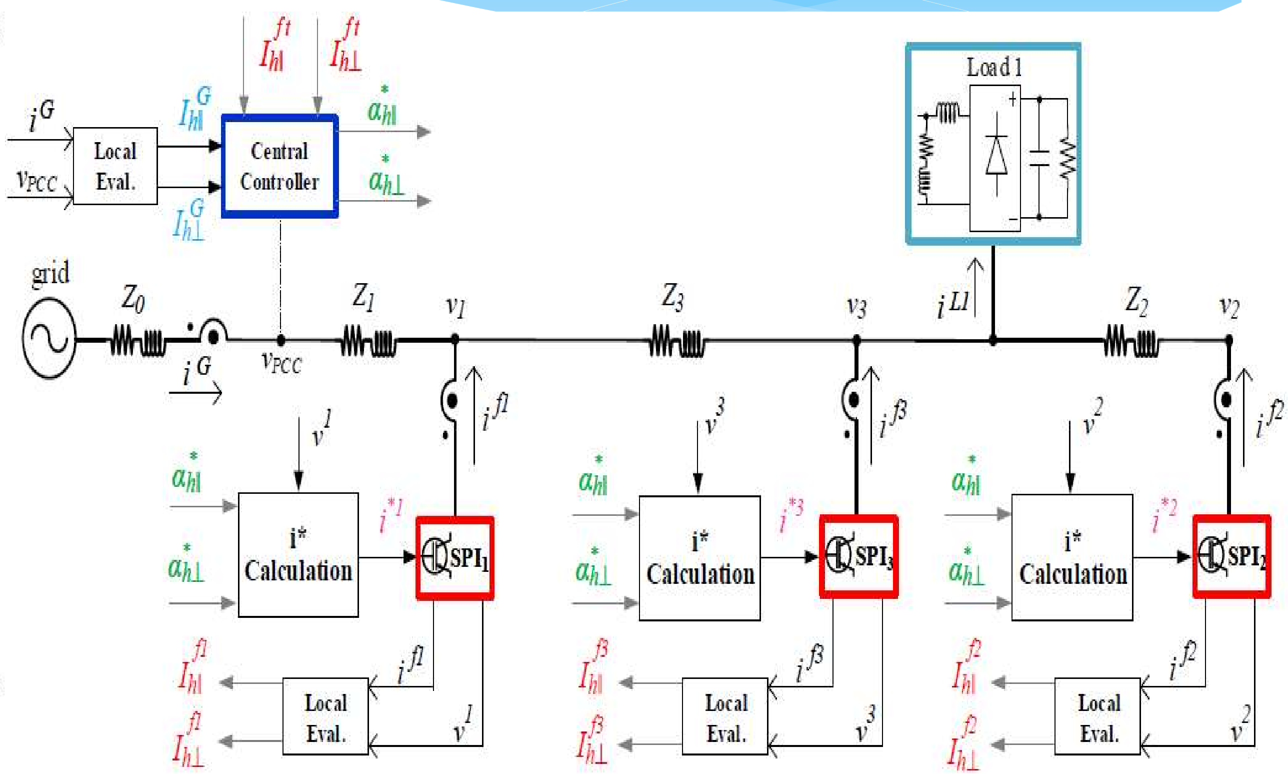
Computational Simulation

1. Distributed Selective Harmonic Compensation

Feature	Specification
SPI1 Nominal Peak Current (I_{SPI1}^{peak})	$33.30A$
SPI2 Nominal Peak Current (I_{SPI2}^{peak})	$23.31A$
SPI3 Nominal Peak Current (I_{SPI3}^{peak})	$9.99A$
SPI1 LC Filter Inductor (L_{SPI1}^{LC})	$1.47mH$
SPI2 LC Filter Inductor (L_{SPI2}^{LC})	$2.10mH$
SPI3 LC Filter Inductor (L_{SPI3}^{LC})	$4.90mH$
Switching frequency (f_{sw})	$12kHz$
Sampling frequency (f_s)	$24kHz$
Grid nominal voltage (V_g)	$127V$
Grid frequency (f_g)	$60Hz$
Line Impedances† (Z_n)	$0.1 + j0.02\ \Omega$
CC-EGs Transmission Time* (t_{data})	$16.66ms$

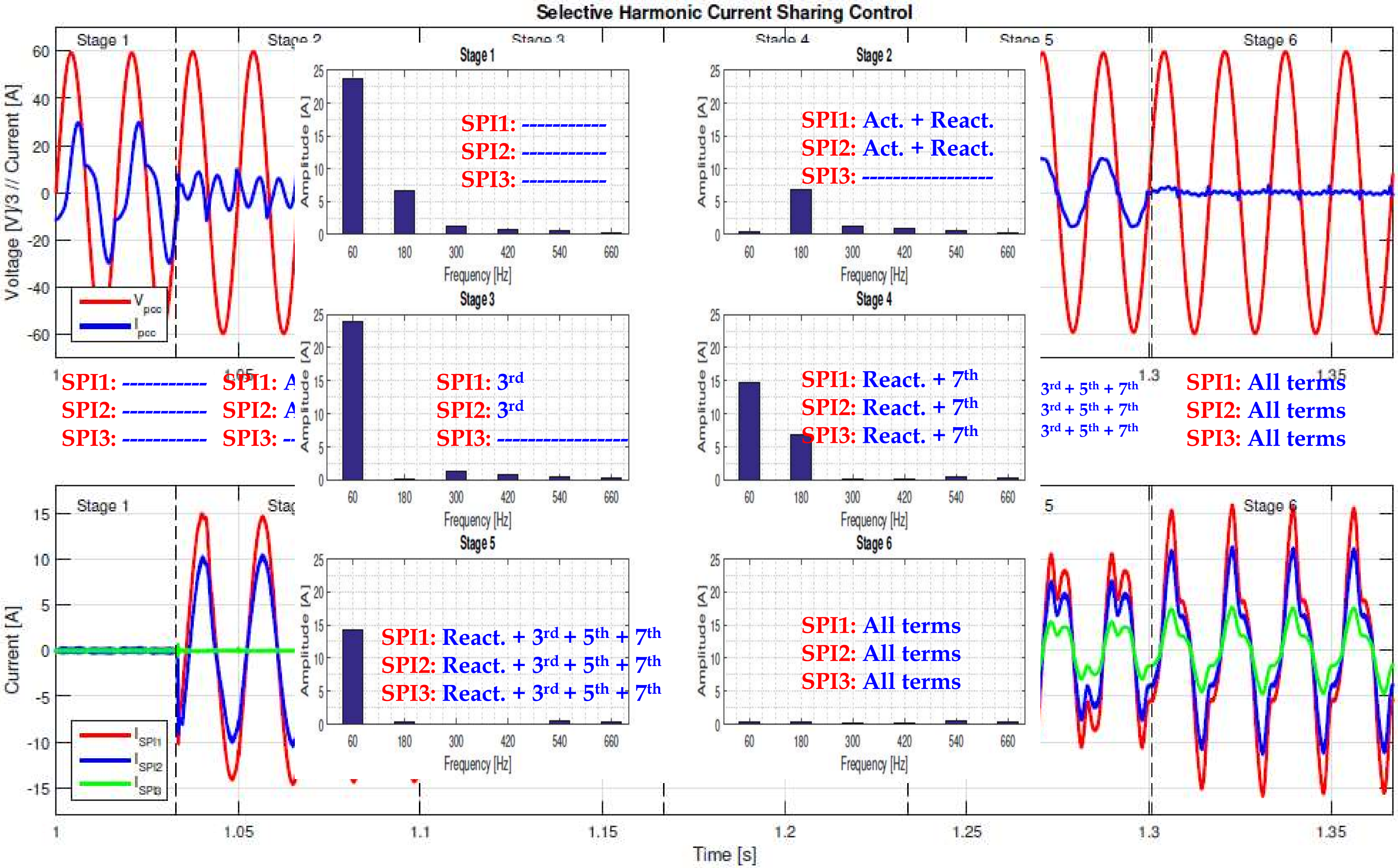
†Case 4: $Z_0 = Z_3 = 0.1 + j0.02\ \Omega$ // $Z_1 = 2 \cdot Z_0$ // $Z_2 = 3 \cdot Z_0$

*Case 4: $t_{data} = 50ms$



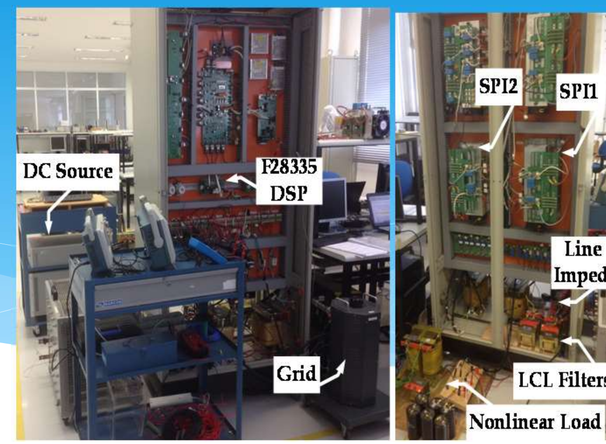
23

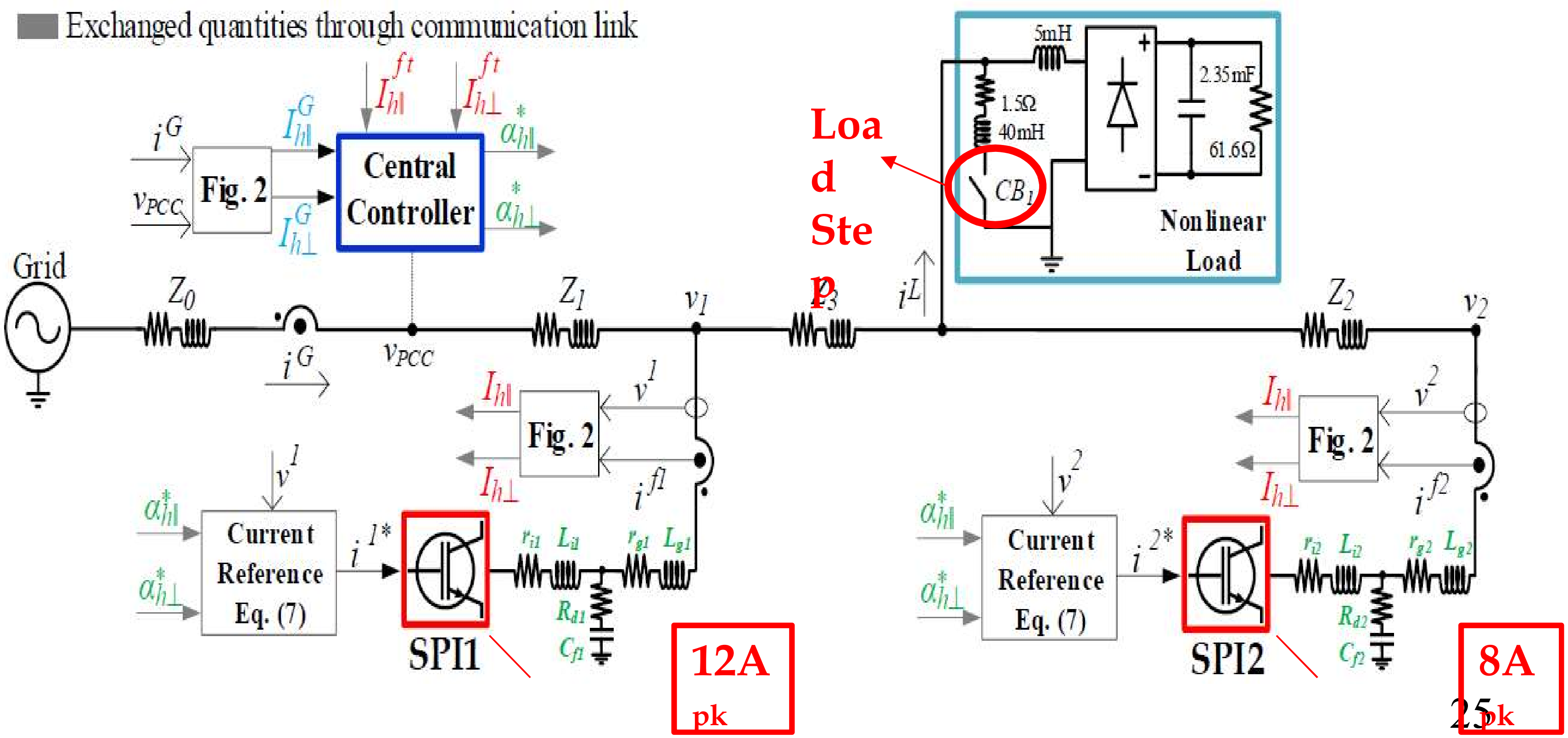
Distributed Harmonic Compensation – Selective Compensation



Experimental Evaluation

1. **Selective Current Sharing**
   a) **Active + Reactive + 3rd + 5th Harm.**



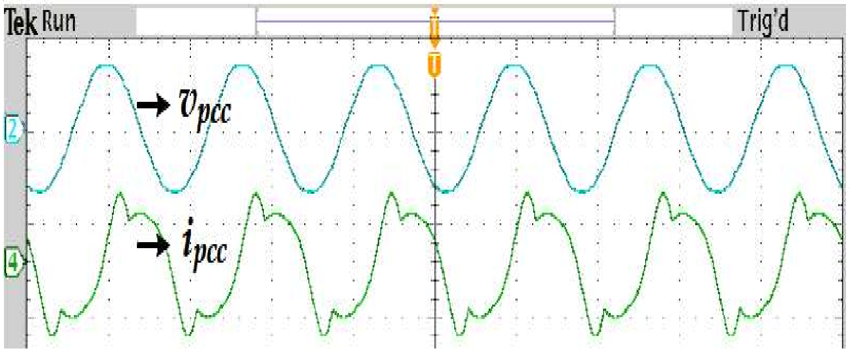


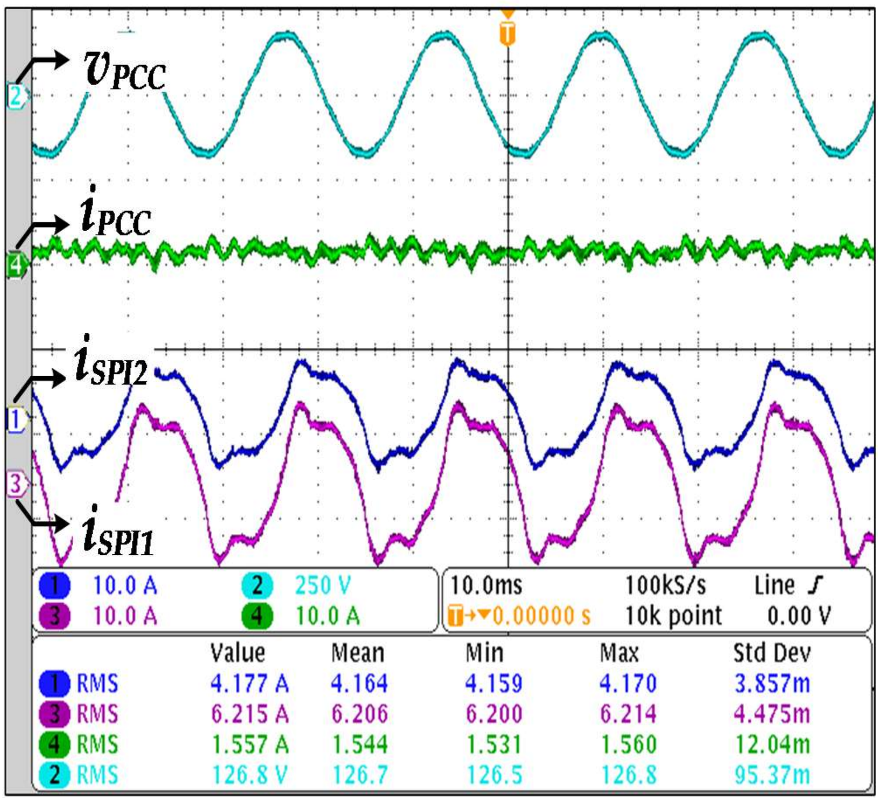
Load Step

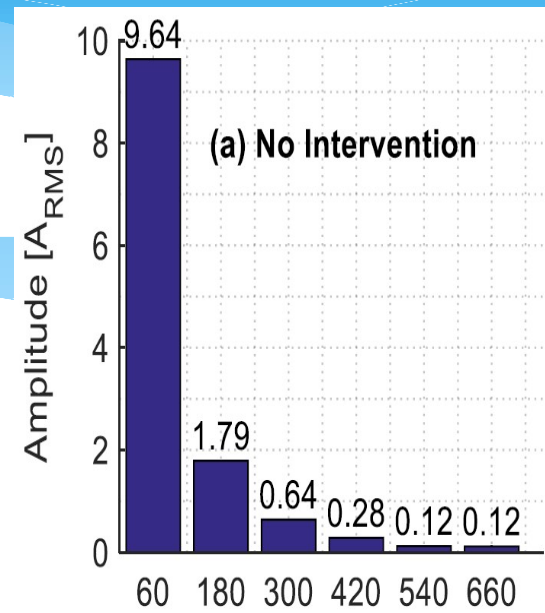
12A pk

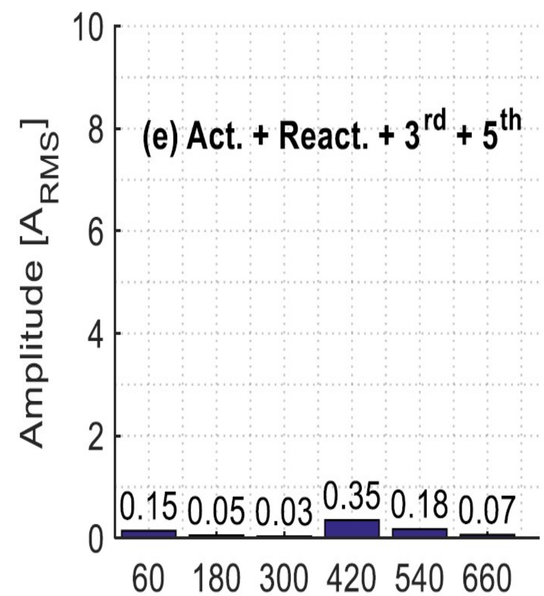
8A pk

Distributed Harmonic Compensation





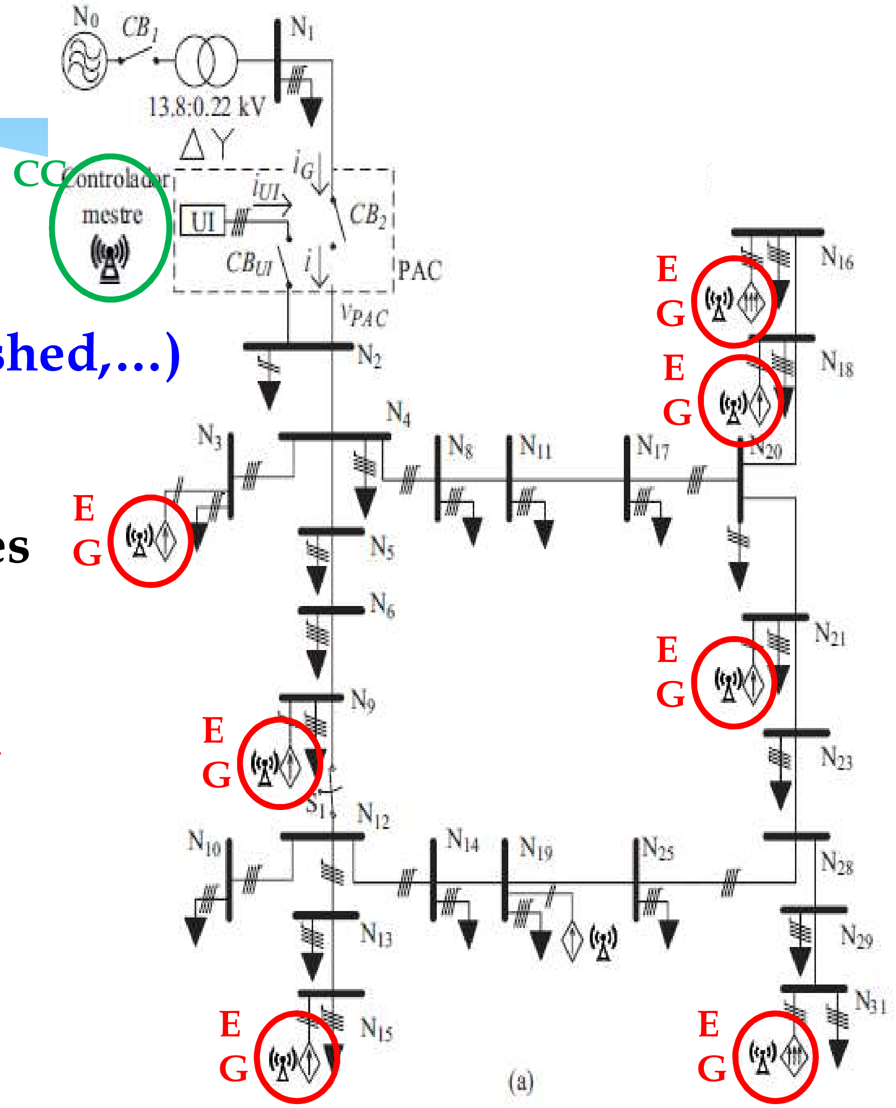




I_{PCC}

Expected Challenge: Multiobjective Distributed Control

- **Global and Local Goals**
  - Power sharing
    - Different topologies (ring, meshed,…)
  - Consider power flow at other nodes
    - Respond to codes + standards
  - MORE Intelligence / Optimization
    - Computer Science



Thanks for your attention!

Fernando Pinhabel Marafão

fernando.marafao@unesp.br

unesp