

# Decentralized and Distributed control strategies for renewable based Microgrids

*Microgrid Research Programme  
Dept. of Energy Technology  
Aalborg University*

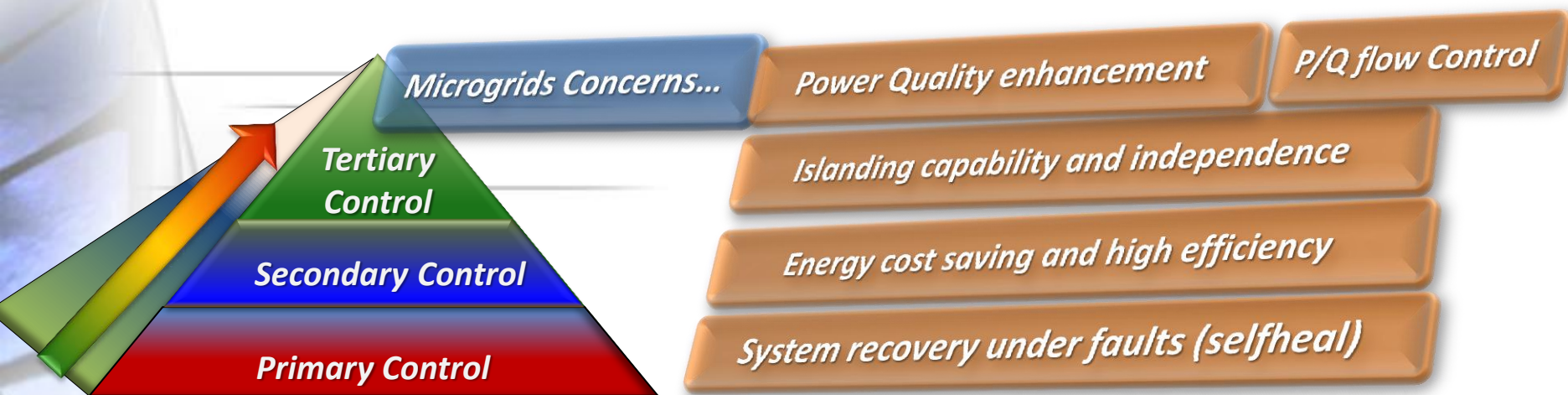
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**[www.microgrids.et.aau.dk](http://www.microgrids.et.aau.dk)**



# Microgrid Research Activities

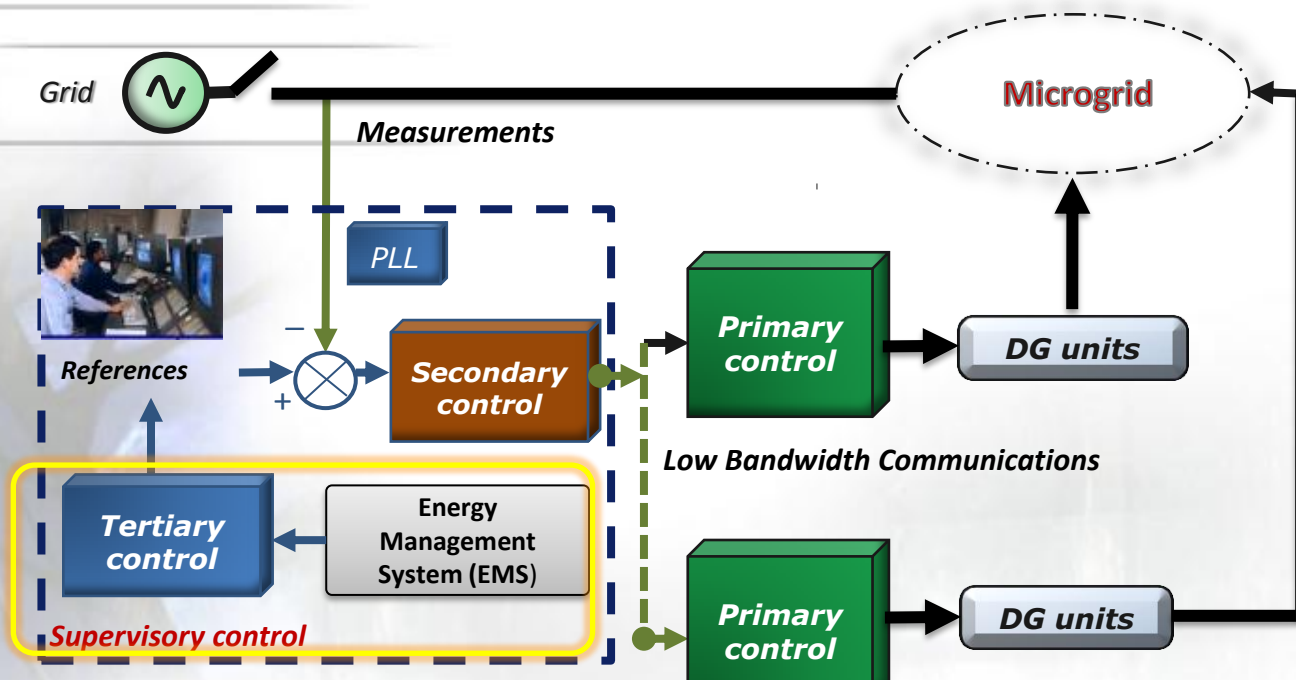
## ***Hierarchical Control for MicroGrids***





# Tertiary Control and EMS system

- **Primary Control: Modeling + Inner loops + droop Control (P/Q Sharing).**
- **Secondary Control:  $f/V$  Restoration (Island), Synchronization**
- **Tertiary Control: Tertiary Level Dispatching, Energy Management and Optimization.**





# Microgrid Research Activities

- Coordinated **Primary Control** (e. g. for Power Quality Enhancement and Load Sharing)
- Centralized and Distributed **Secondary Control** (e. g. for Power Quality and Voltage/Freq. Restoration)
- **Tertiary Control and Energy Management Systems** (e. g. for Optimization and Power Quality)
- Application of **Multi-Agent Systems** based on Consensus Algorithm
- **EV charging stations** (Analogy with Microgrid Technology)



# Coordinated Control of AC islanded Microgrids

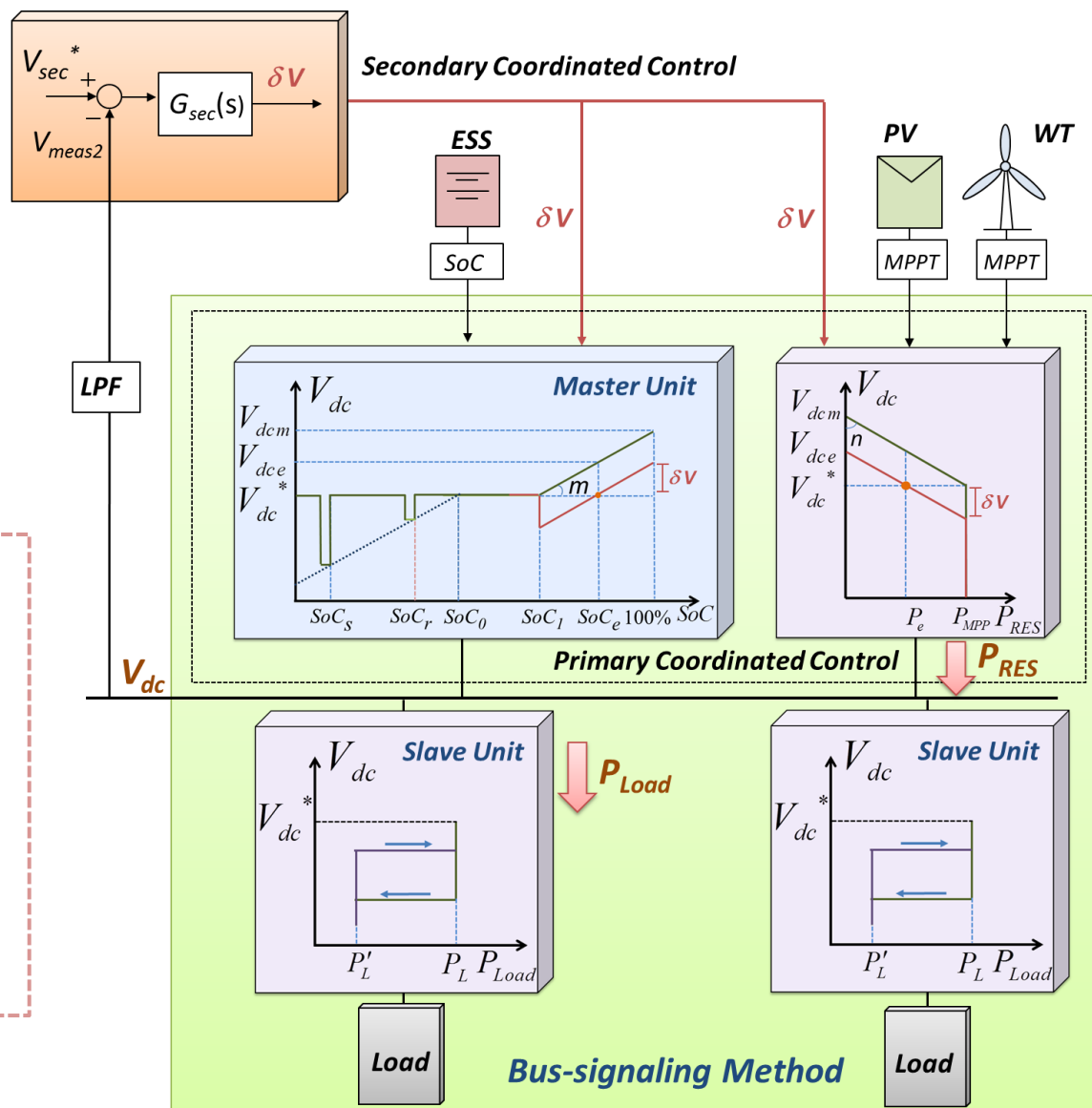
AC Low voltage MicroGrid  
coordinated control:

AC Microgrids:

Bus frequency signaling

DC Microgrids:

Bus voltage signaling





# Coordinated Control of AC islanded Microgrids

**Coordinated control when high SoC occurs**

**Inner loop:**

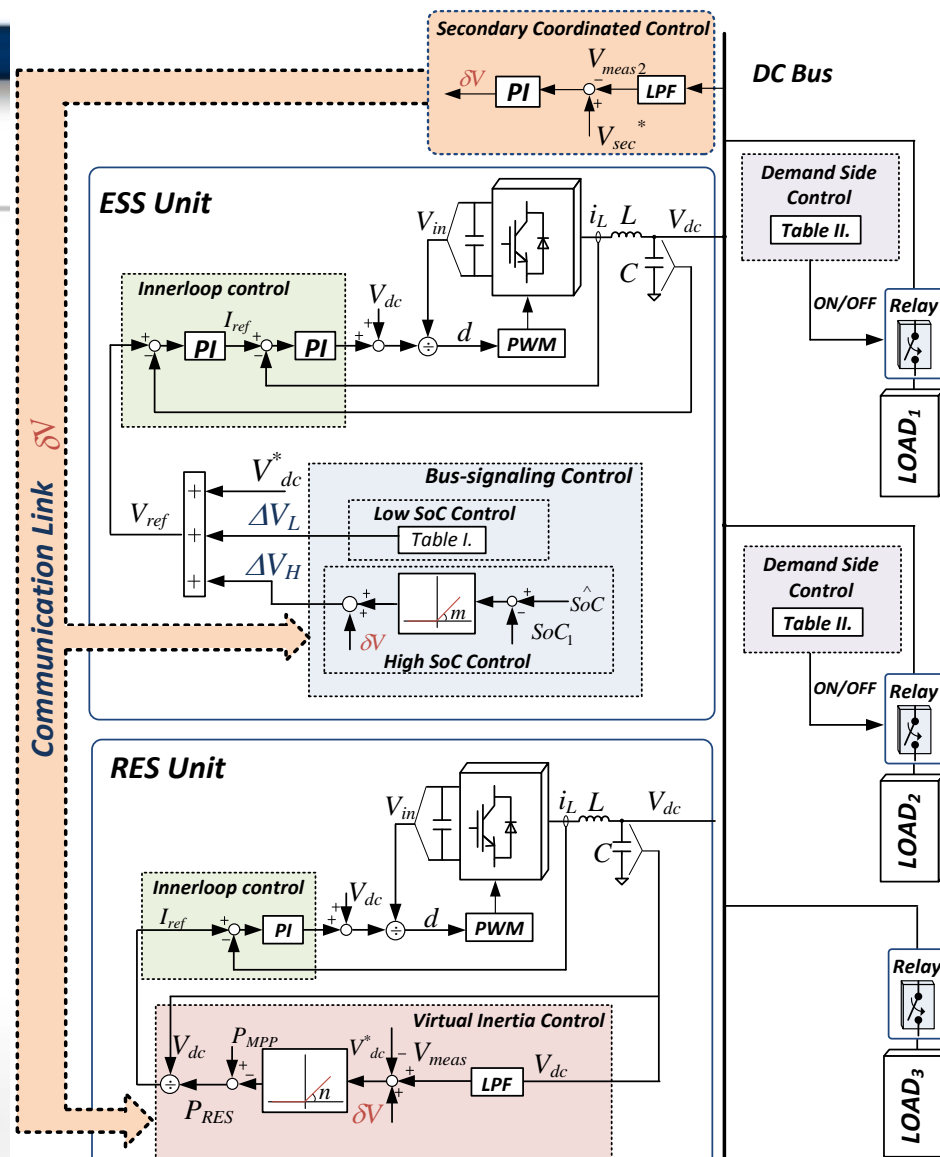
**ESS: Voltage Controlled Mode**

**RES: Current Controlled Mode**

**Primary loop:**

**ESS: Bus signaling control**

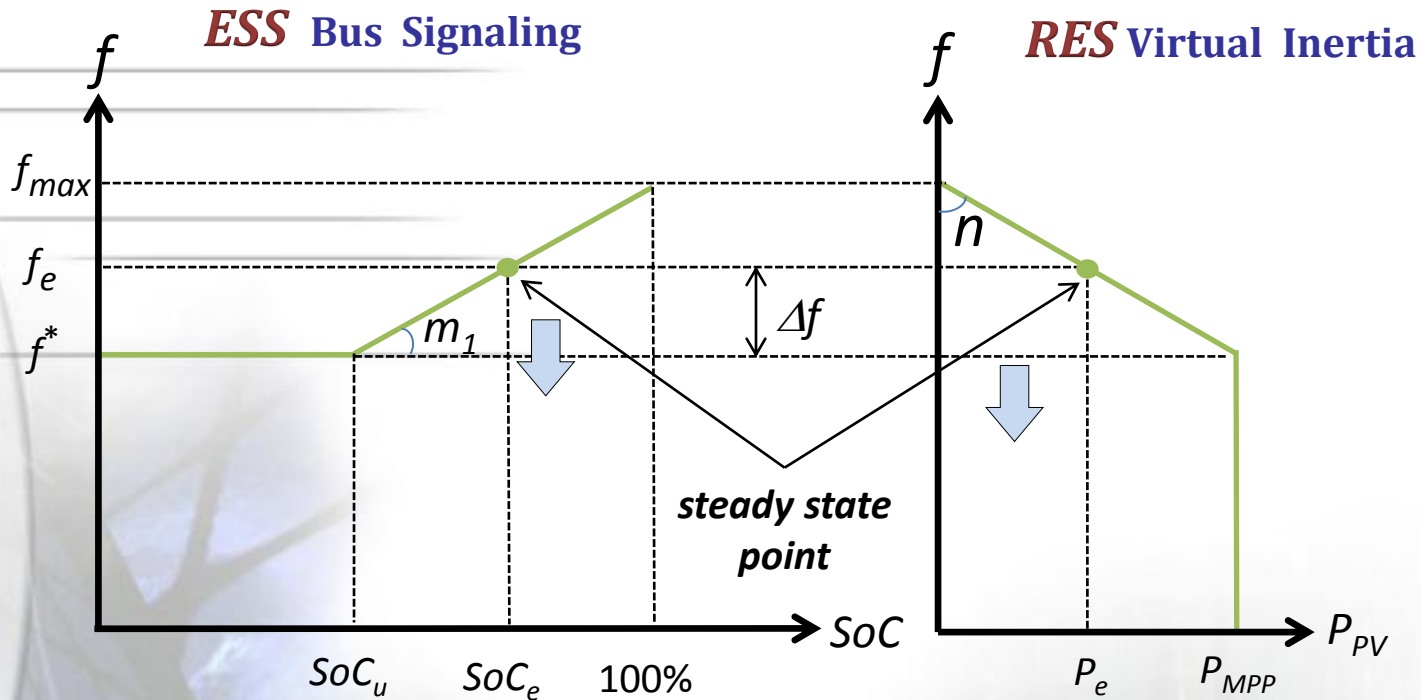
**RES: Virtual inertia control**





# Primary Coordinated Control

## Primary Control-*Bus signaling Concept*



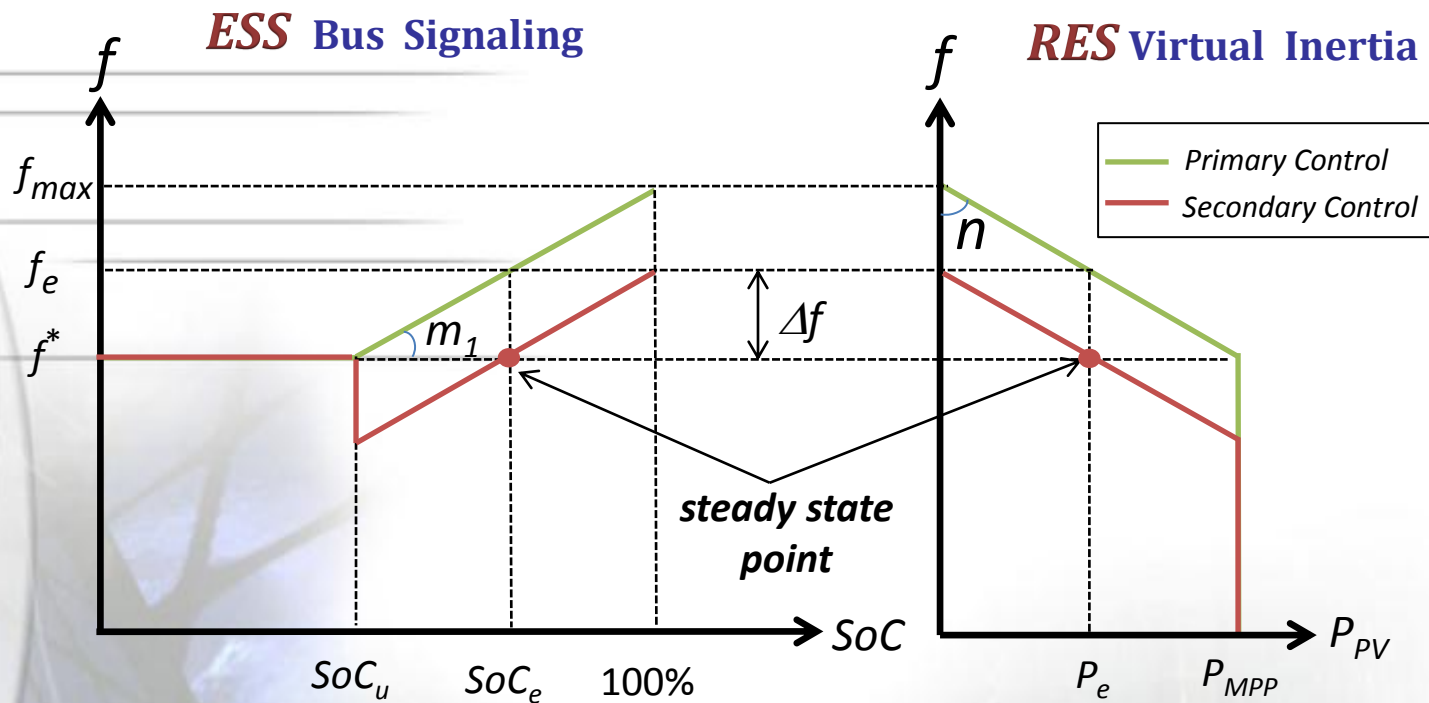
$$\begin{cases} f = f^* & SoC \leq SoC_u \\ f = f^* + m \cdot (SoC - SoC_u) & SoC_u < SoC < 100\% \end{cases}$$

$$\begin{cases} P_{RES} = P^* & f \leq f^* \\ P_{RES} = P^* - n \cdot (f - f^*) & f > f^* \end{cases}$$



# Coordinated Secondary Control

## Secondary Control-Frequency Restoration

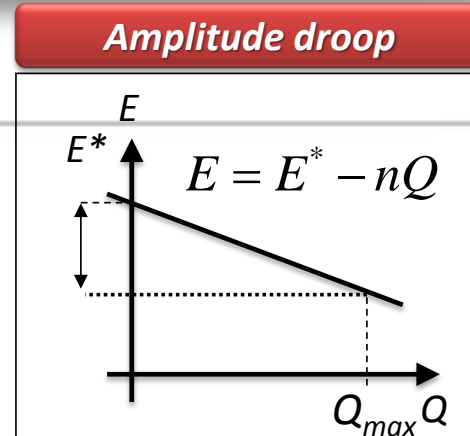
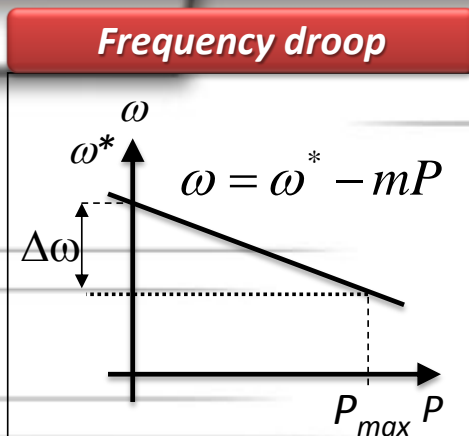


$$f = f^* + \delta f + m \cdot (SoC - SoC_u) \quad SoC_u < SoC < 100\%$$

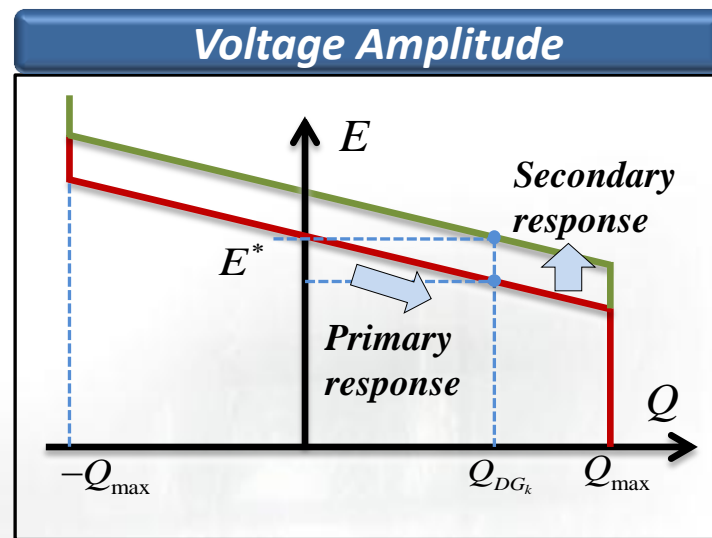
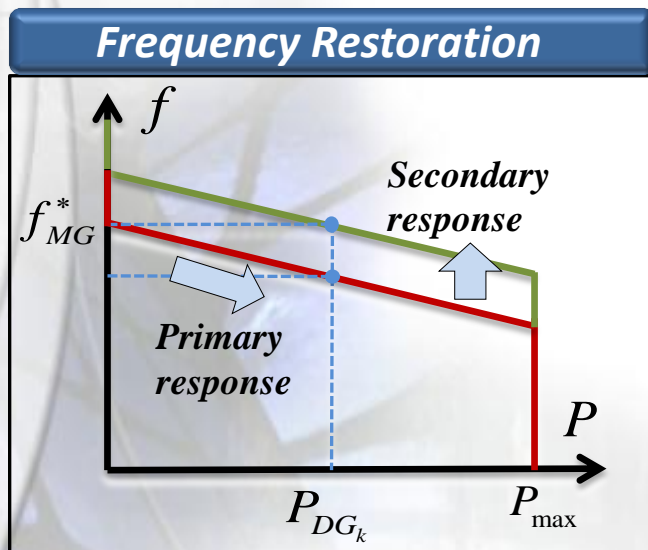
$$P_{RES} = P^* - n \cdot (f - f^* - \delta f) \quad f > f^* + \delta f$$



# Centralized and Decentralized Secondary Control for Microgrids

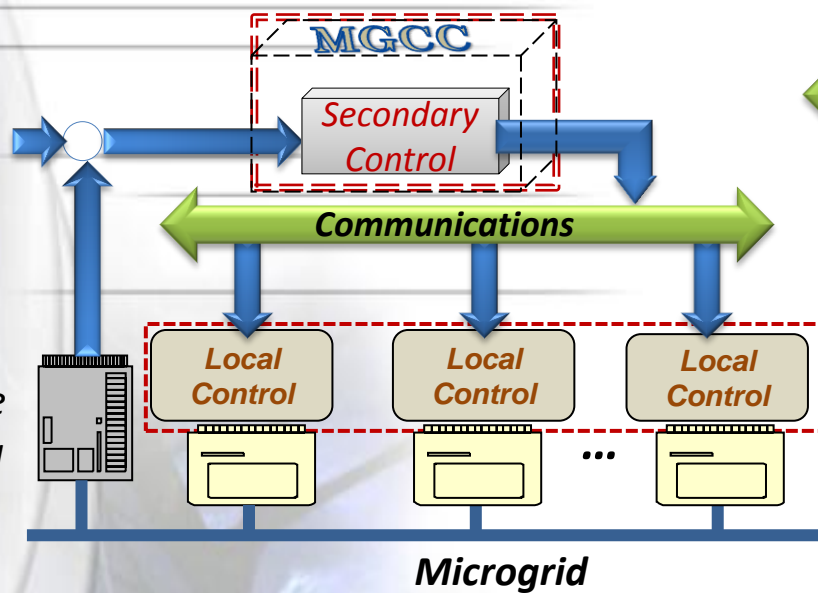


Connection/disconnection load or generation  $\rightarrow$  Frequency and voltage deviation

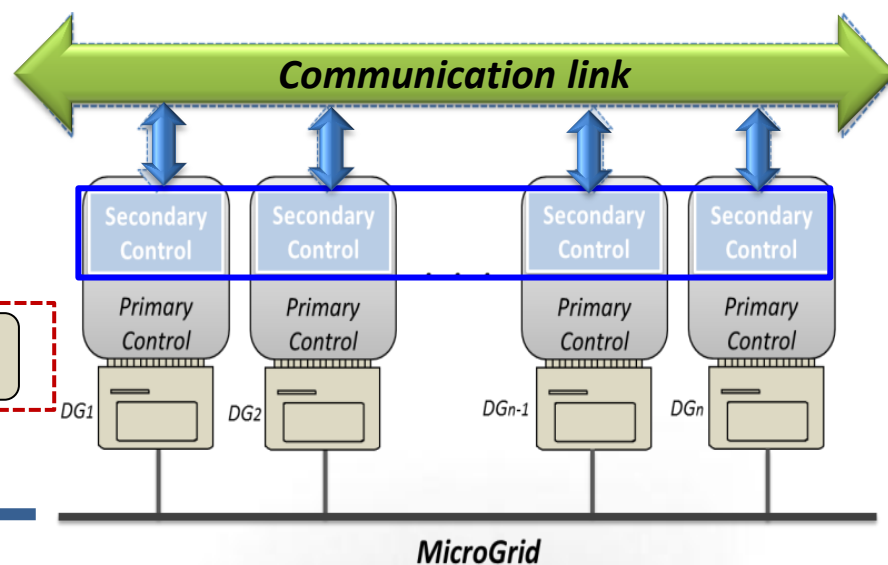




## Centralized Secondary control



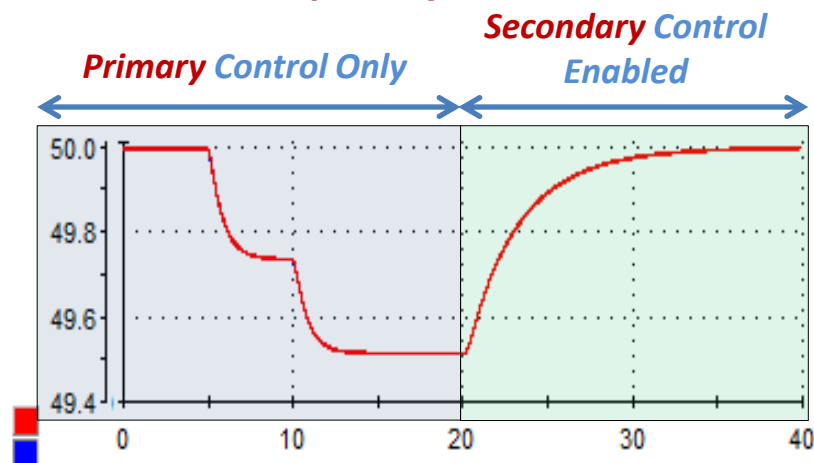
## Distributed Secondary control



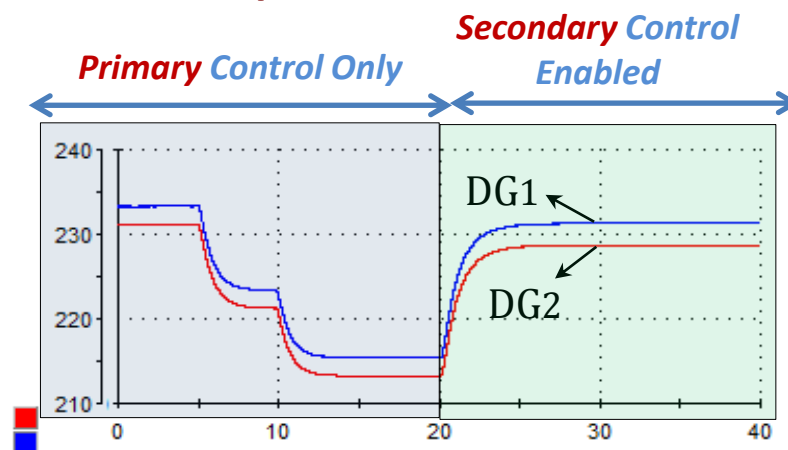


# Results

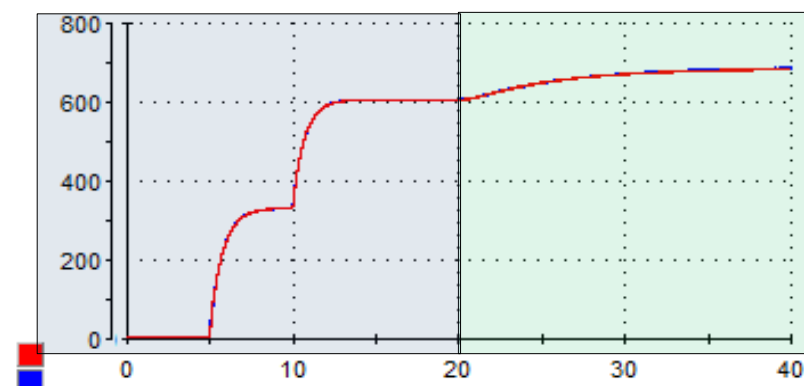
## Frequency Restoration



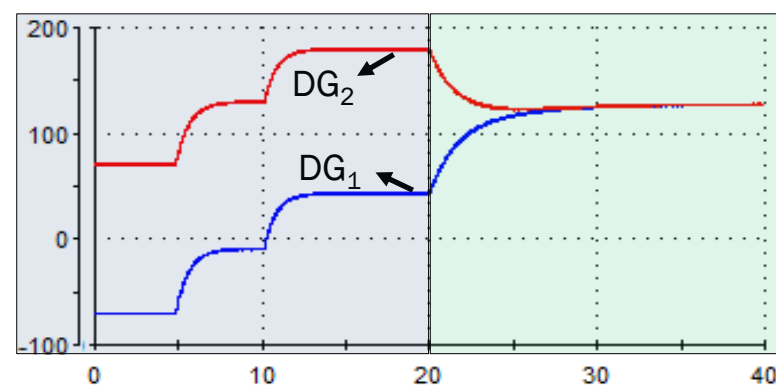
## Amplitude Restoration



## Active Power Sharing



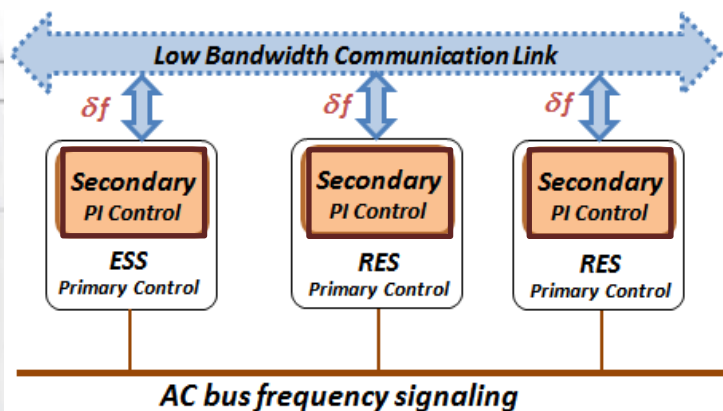
## Reactive Power Sharing





# Centralized and Distributed configuration

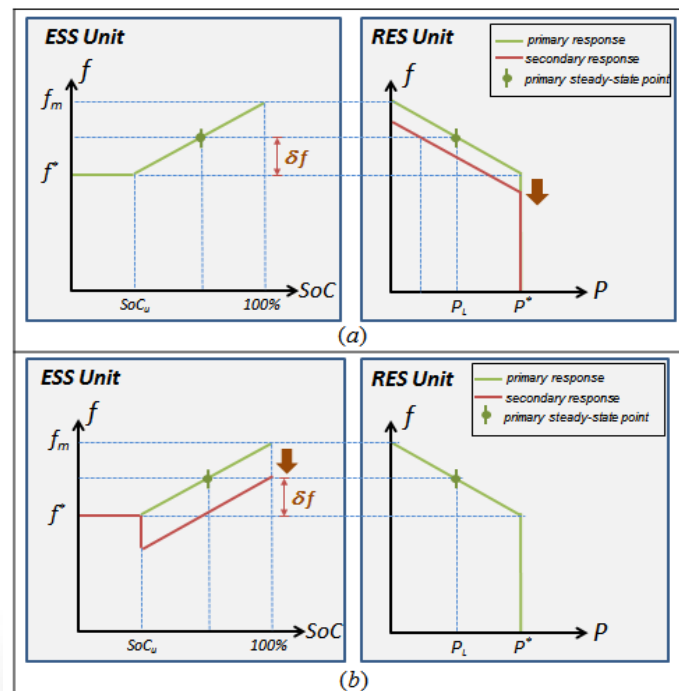
## Decentralized Secondary Control



### Decentralized Control:

- Communication burden when distributed elements increase
- Needs **synchronization** of restoration term in all elements

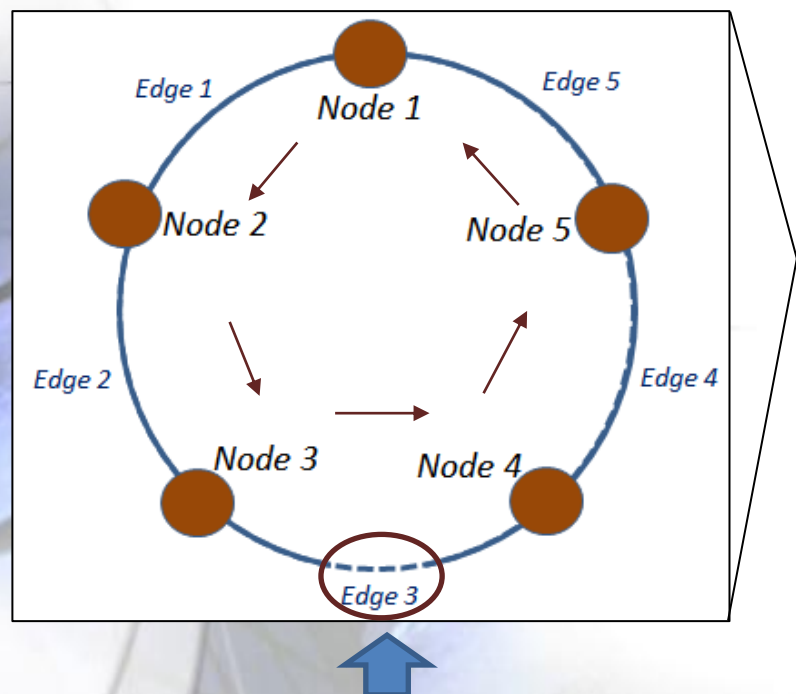
### Out of synchronization :





# Consensus Algorithm Method

## Secondary Control with *Consensus Algorithm*



The system can work properly even one edge lost communication

### Consensus Algorithm:

- Each node flood information to neighbors nearby
- All elements can reach agreement if all nodes have at least **one** connection with network

A  $Sys=(N,E)$  can be presented as multiple nodes  $N=\{1..,n\}$  and a set of edge  $E$ . For node  $i$ , its set of neighbors is defined as  $N_i=\{j|\{i,j\}\in E\}$ .

The data stored is denoted as  $x_i(k)$  with  $k$  being the iteration step.

Consensus algorithm can be described as

$$x_i(k+1) = x_i(k) + \sum_{j \in N_i} \alpha_{ij} (x_j(k) - x_i(k))$$



# Consensus Algorithm Method

Constant iteration coefficient for fast iteration steps:

$$\alpha^* = \frac{2}{\lambda_1(L) + \lambda_{N-1}(L)}$$

$\lambda_1(L)$ : largest eigenvalue of  $L$

$\lambda_{N-1}(L)$ : second least eigenvalue of  $L$

$$A = \begin{bmatrix} 1 & -1 & 0 & 1 & -1 & 0 \\ 0 & 1 & -1 & 0 & 0 & 0 \\ -1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 & -1 \end{bmatrix} \quad L = \begin{bmatrix} 4 & -1 & -1 & -1 & -1 \\ -1 & -2 & -1 & 0 & 0 \\ -1 & -1 & 2 & 0 & 0 \\ -1 & 0 & 0 & 2 & -1 \\ -1 & 0 & 0 & -1 & 2 \end{bmatrix}$$

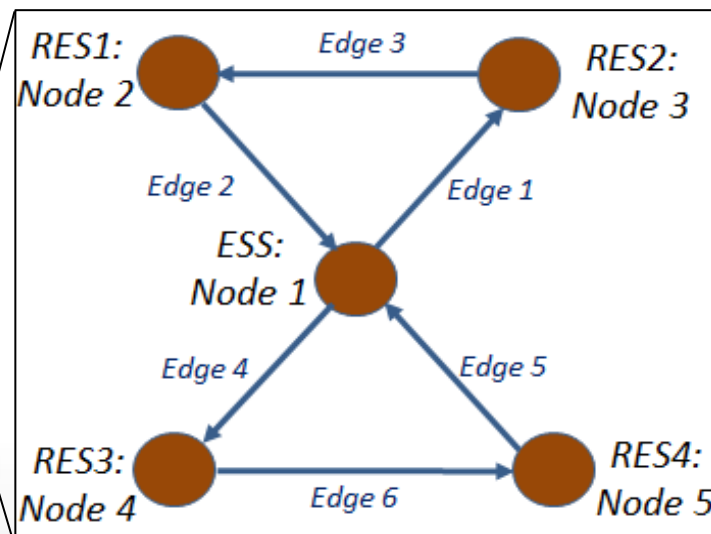
$$\lambda_1 = 5 \text{ and } \lambda_{N-1} = 1$$

$$\alpha^* = \frac{1}{3}$$

**Microgrid configuration:**

- Four RES units

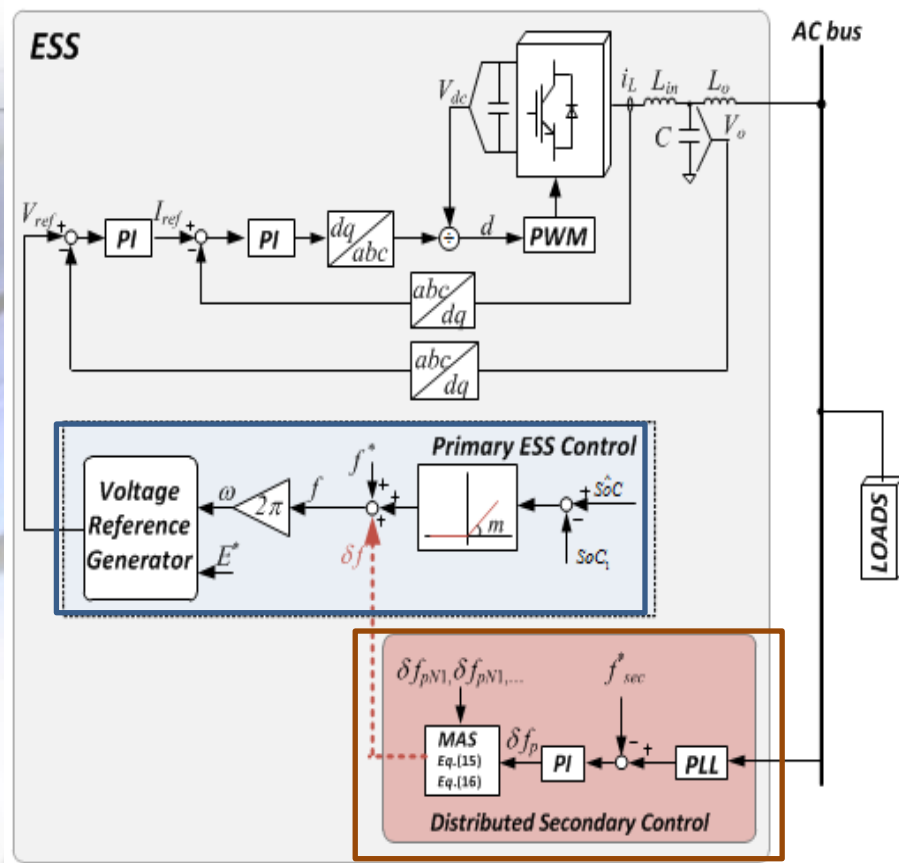
- One ESS unit



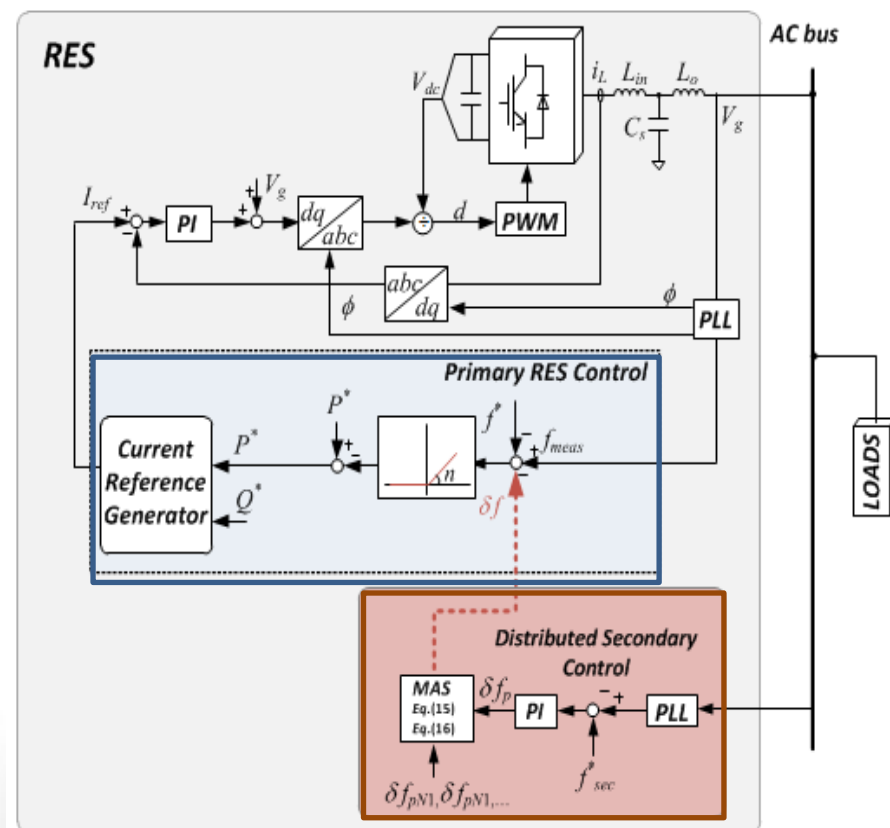


# Control Implementation with *ESS* and *RES*

## *ESS* Bus Signaling



## *RES* Virtual Inertia





# Controller Implementation

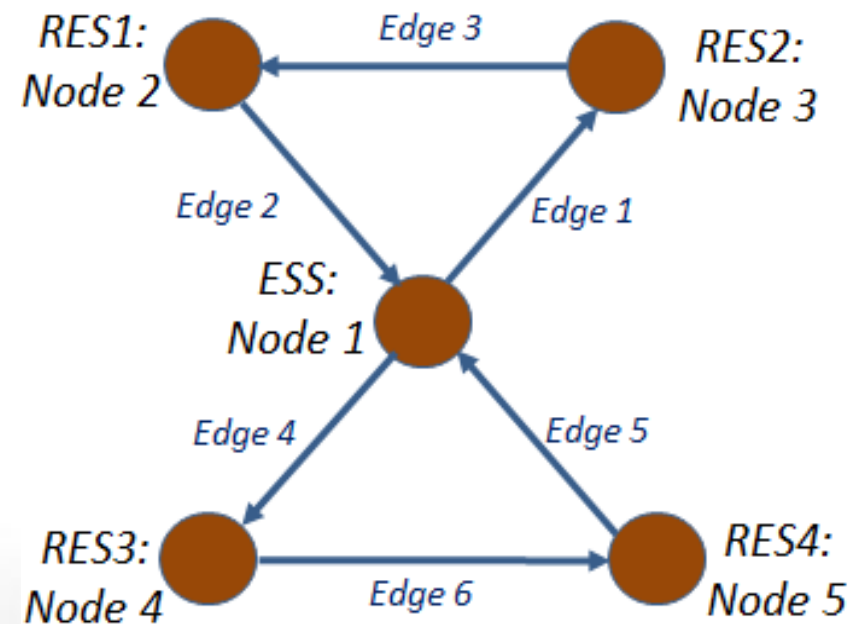
## Control Implementation with *ESS* and *RES*

### Coordinated Control Parameters

TABLE I. Coordinated control parameters

Item	Symbol	Value
Maximum frequency threshold	$f_1$	51Hz
SoC upper limit	$SoC_1$	95%
Secondary frequency reference	$f_{sec}$	50Hz
Secondary control proportional term	$k_{psec}$	0.005
Secondary control Integral term	$k_{isec}$	$0.5 \text{ s}^{-1}$
ESS voltage controller	$k_{pV}, k_{iV}$	0.1, $100\text{s}^{-1}$
ESS current controller	$k_{pI}, k_{iI}$	15, $50\text{s}^{-1}$
RES current controller	$k_{pVR}, k_{iVR}$	20, $50\text{s}^{-1}$

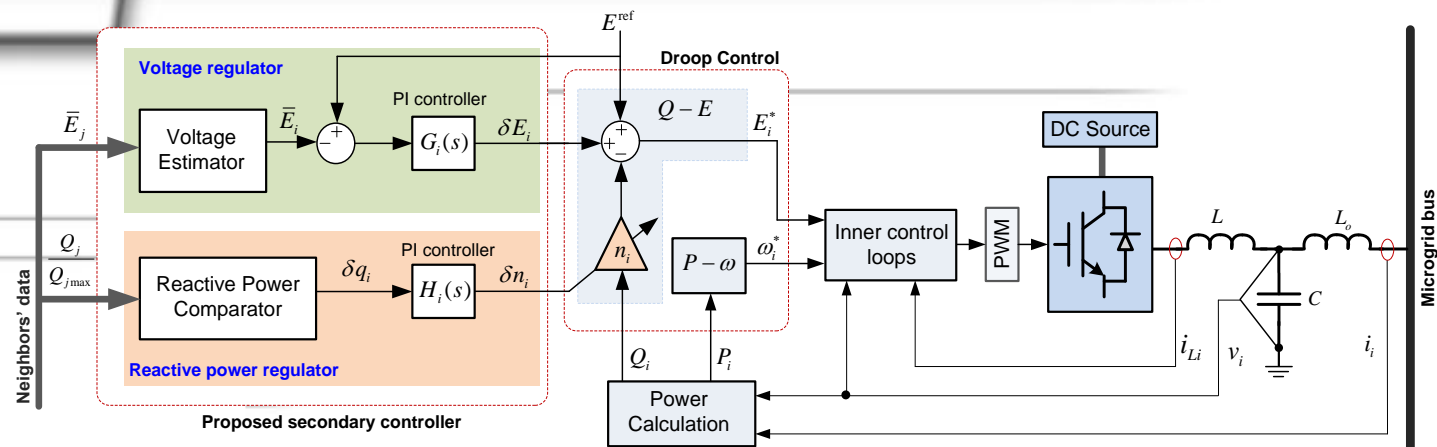
### Secondary Control Configuration



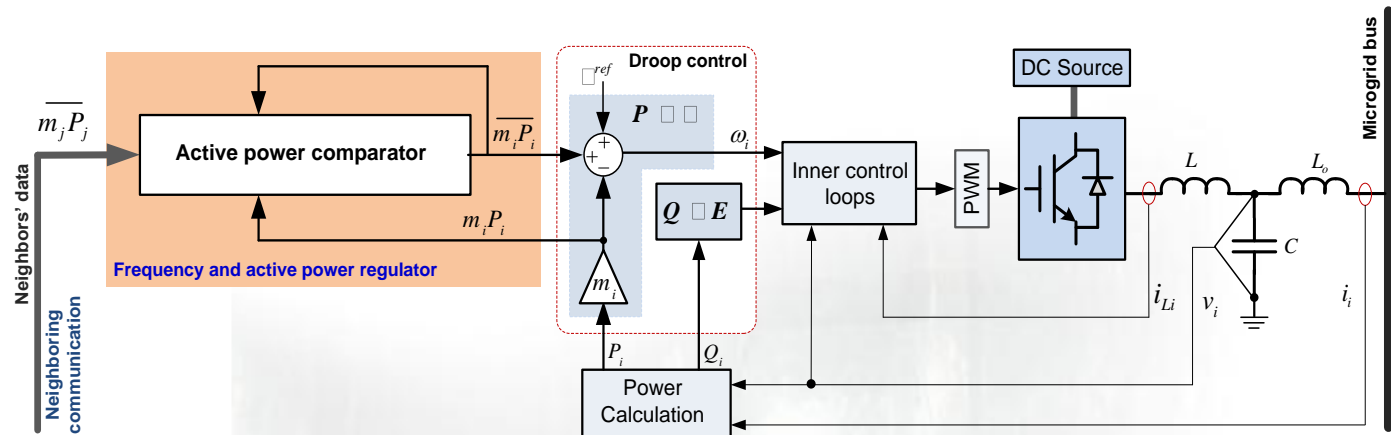


# Consensus-based distributed control for ac Microgrids

- Regulates bus voltages
- Shares reactive power proportionally
- Line impedance has no effect on controller
- Different PI parameters.

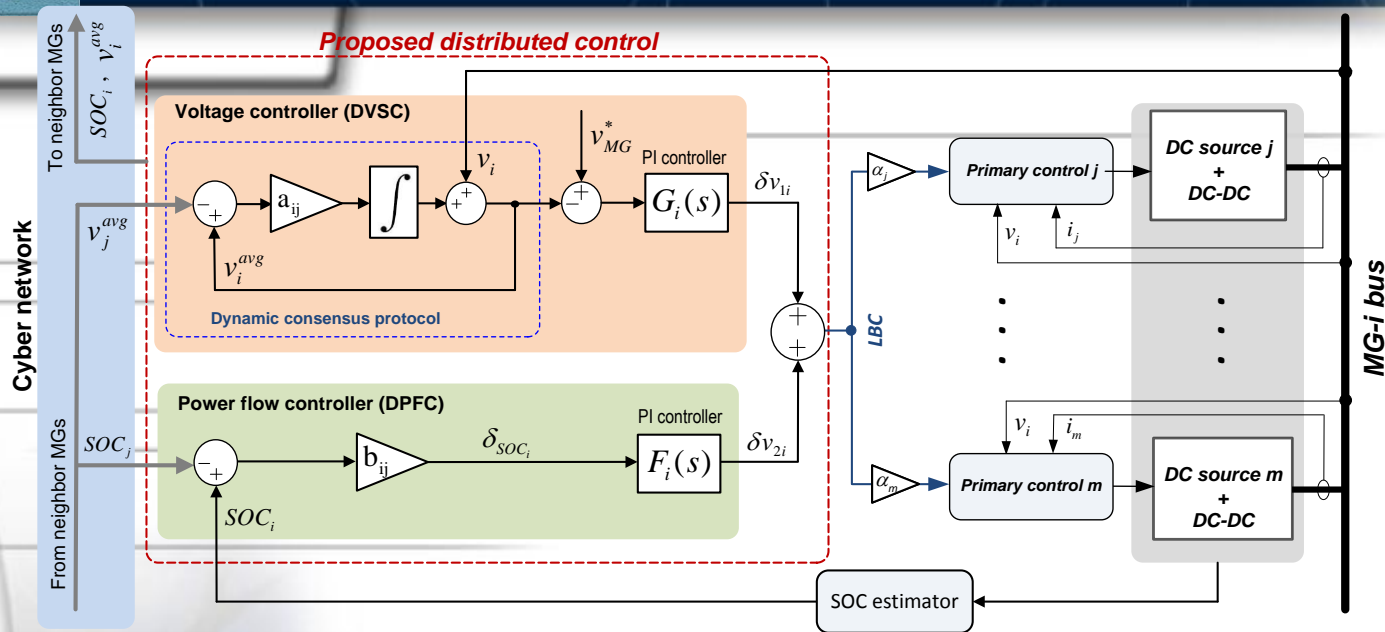


- Regulates the frequency
- Shares active power proportionally
- No frequency measurement is required.
- Different PI parameters.





# Consensus-based distributed control for dc Microgrid clusters



## Voltage regulator

- Centralized for each dc MG
- Distributed over the MG cluster
- Regulates the voltage inside each MG to the nominal value when they are not connected.
- Maintains the bus voltages within an acceptable range when they are connected.

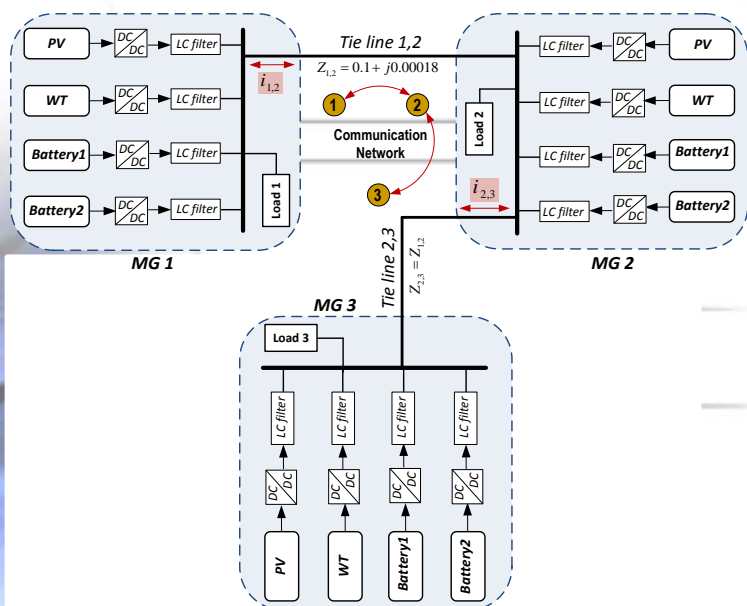
## Power flow regulator

- Using the distributed voltage regulator power flow control is achieved.
- Regulates the power flow between dc MGs when they are connected.
- Power flow is regulated according to SOC of batteries inside the MGs.



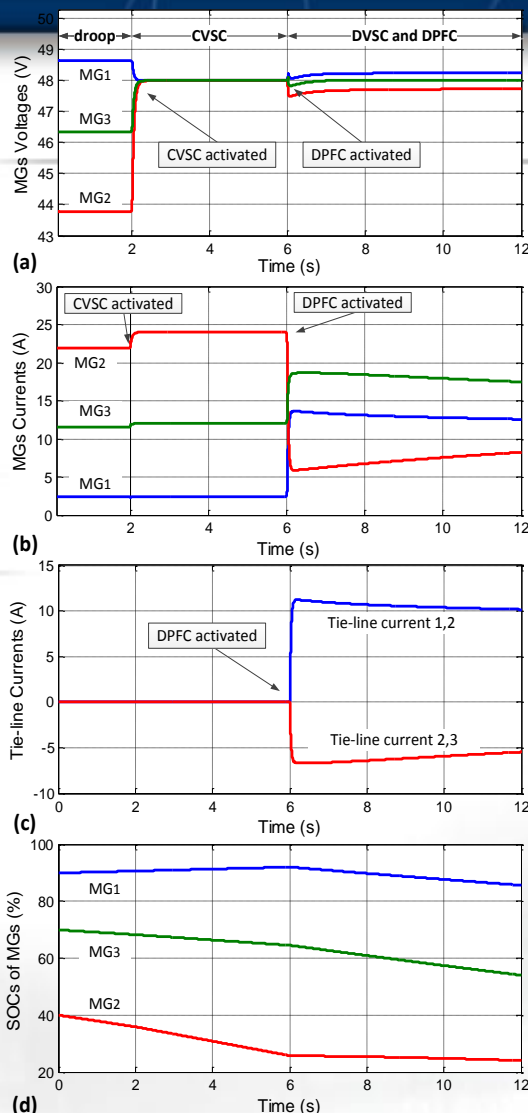
## Case study:

### Three interconnected dc MGs

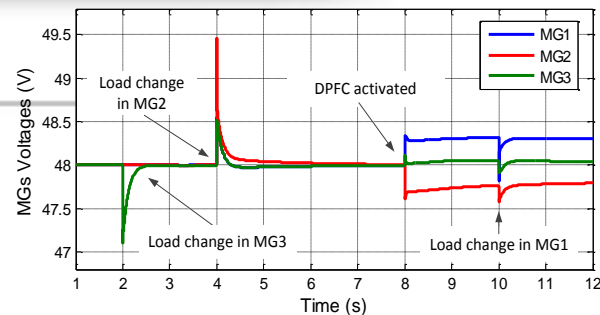


- Each dc MG consists of four units.
- Rated voltage of the system is 48 V.
- A communication network facilitates cooperation of the MGs.
- PV and WT work in MPPT and two batteries work in droop controlled mode

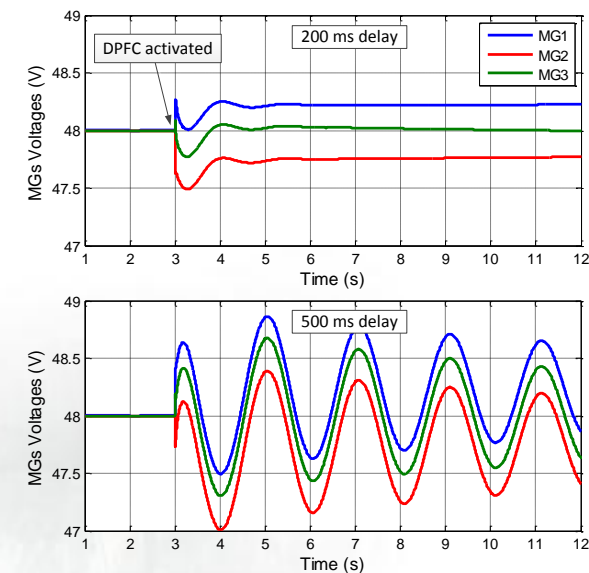
## Results



### Load change effect



### Communication delay impact





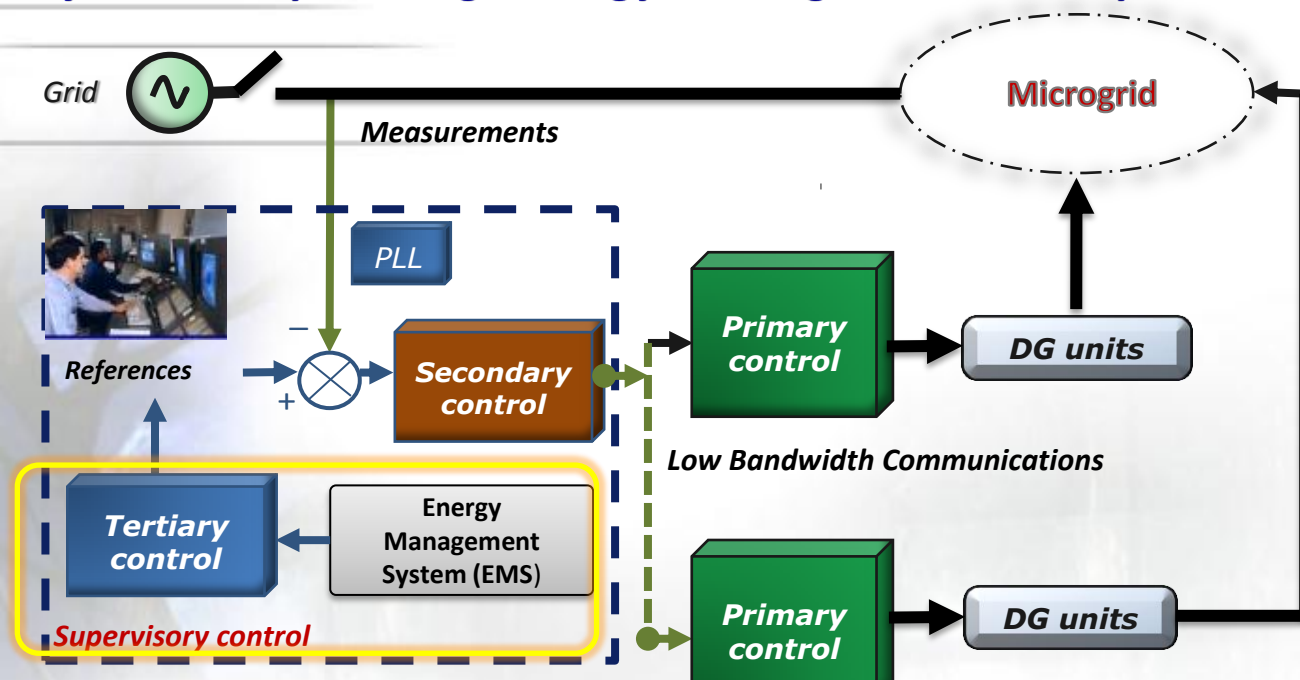
# Tertiary Control and EMS system

➤ **Primary Control:** Modeling + Inner loops + droop Control (P/Q Sharing).

➤ **Secondary Control:**  $f/V$  Restoration (Island), Synchronization

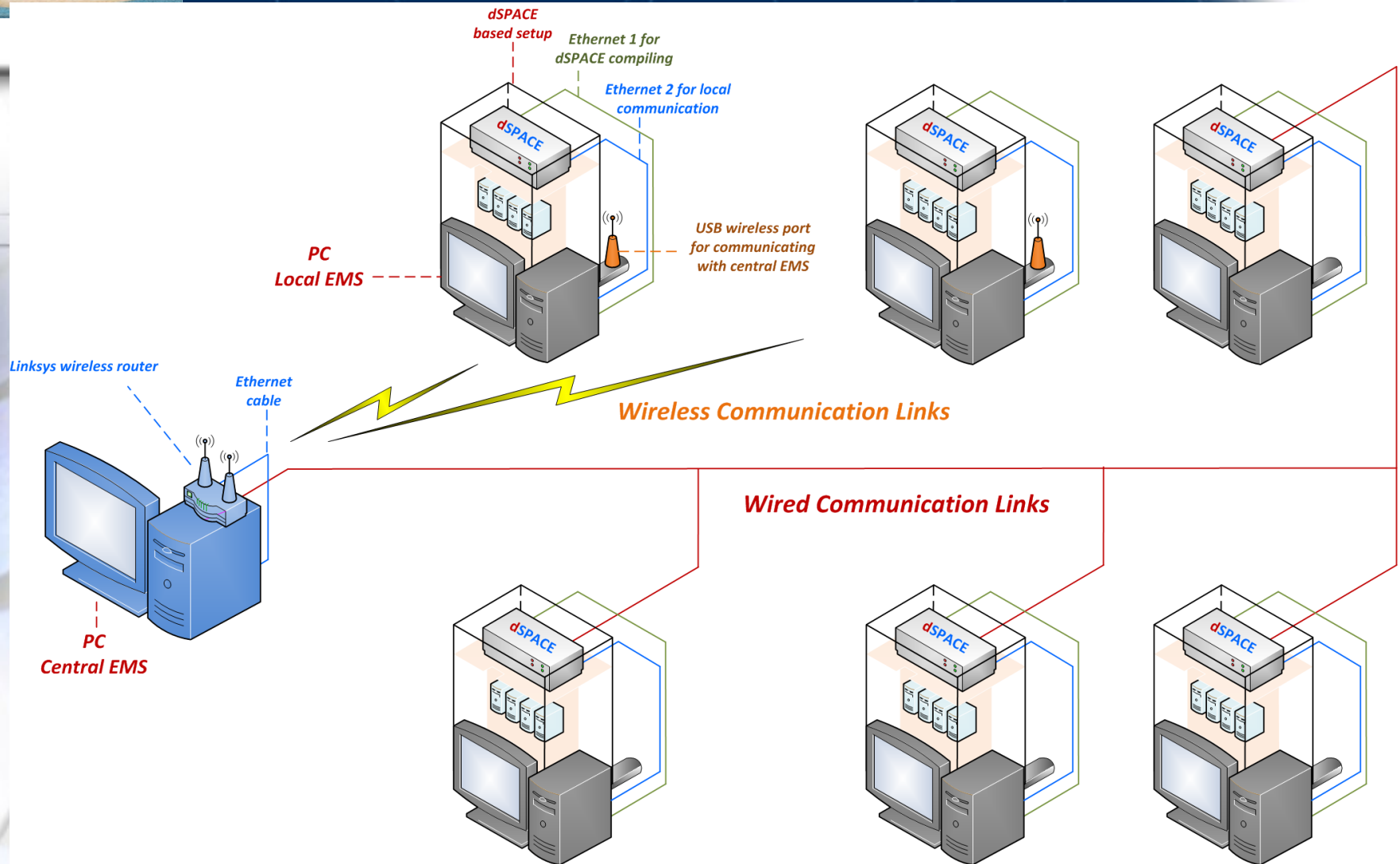
➤ **Tertiary Control:**

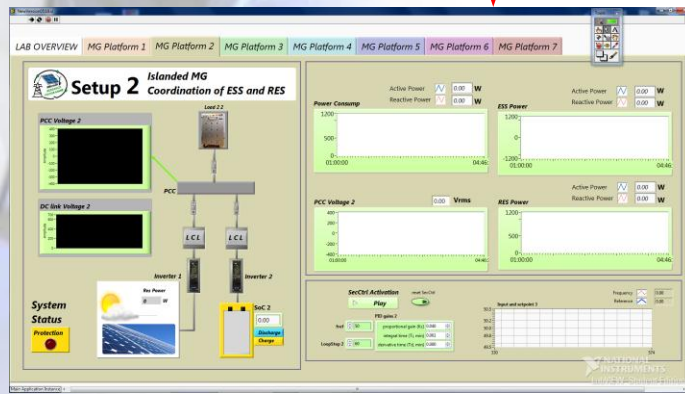
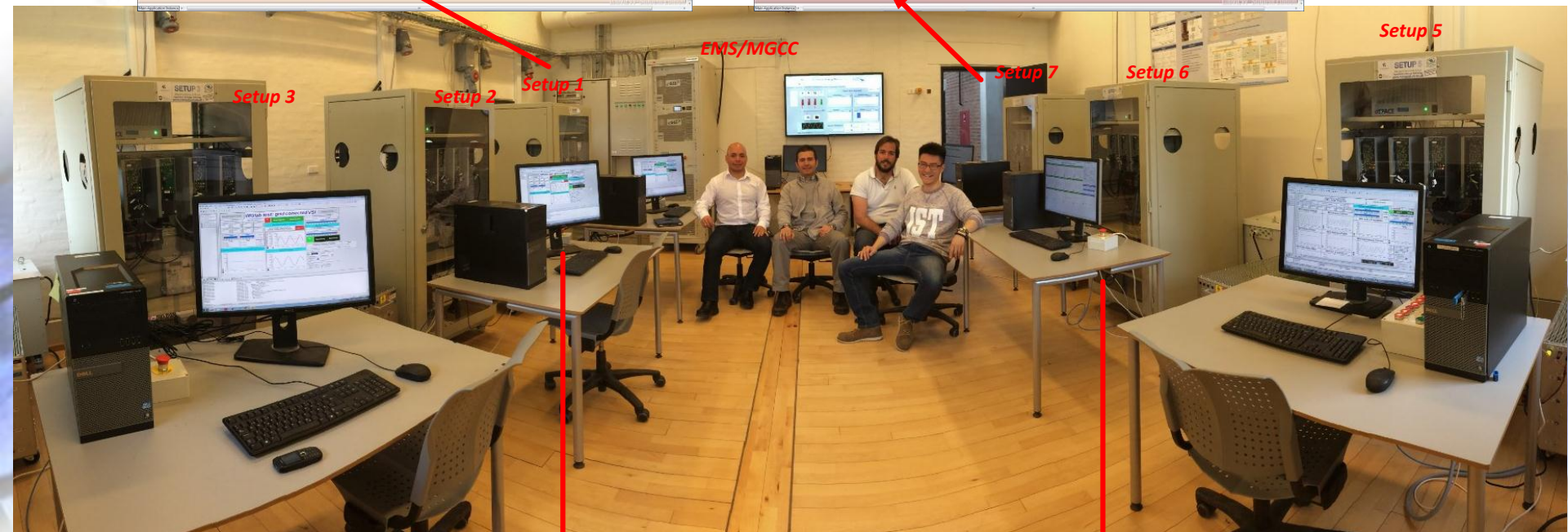
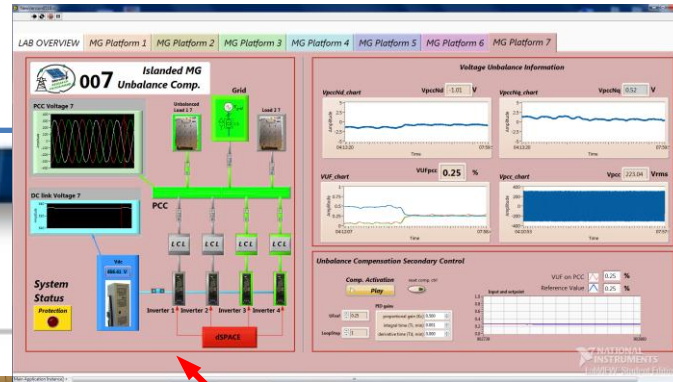
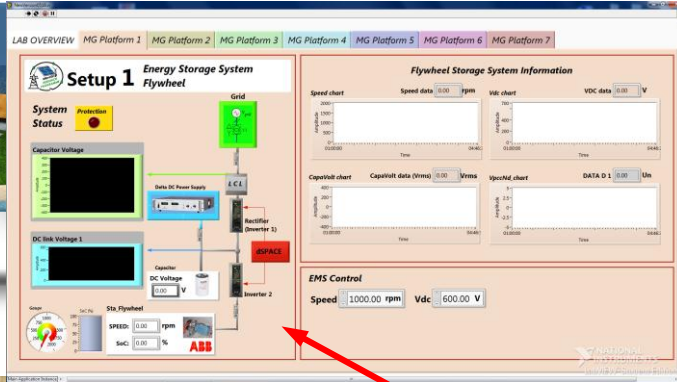
❖ **Tertiary Level Dispatching, Energy Management and Optimization.**





# EMS implementation



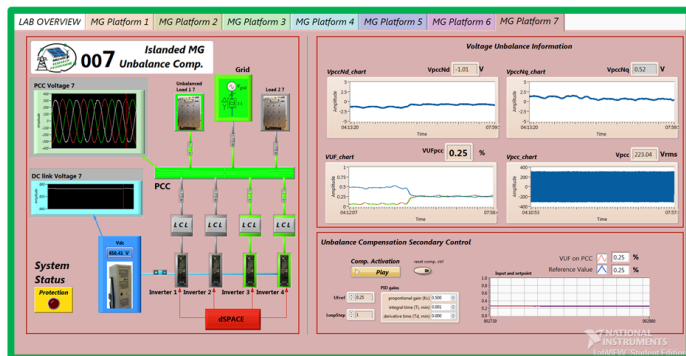




# EMS implementation

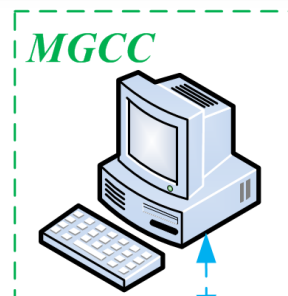
## MGCC

- PC with LabVIEW programmed control and supervision functions



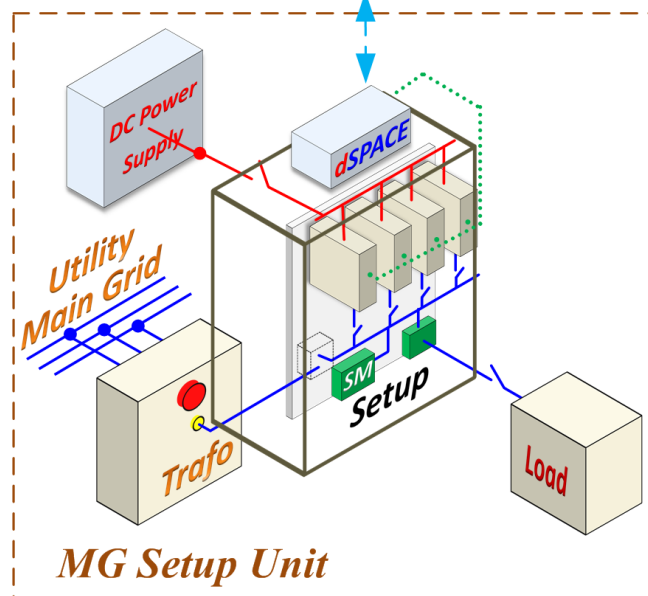
## DGC

-dSPACE with Simulink based DGC control applications



— DC lines  
— AC lines  
↔ Comm lines

UDP/IP Ethernet Comm.

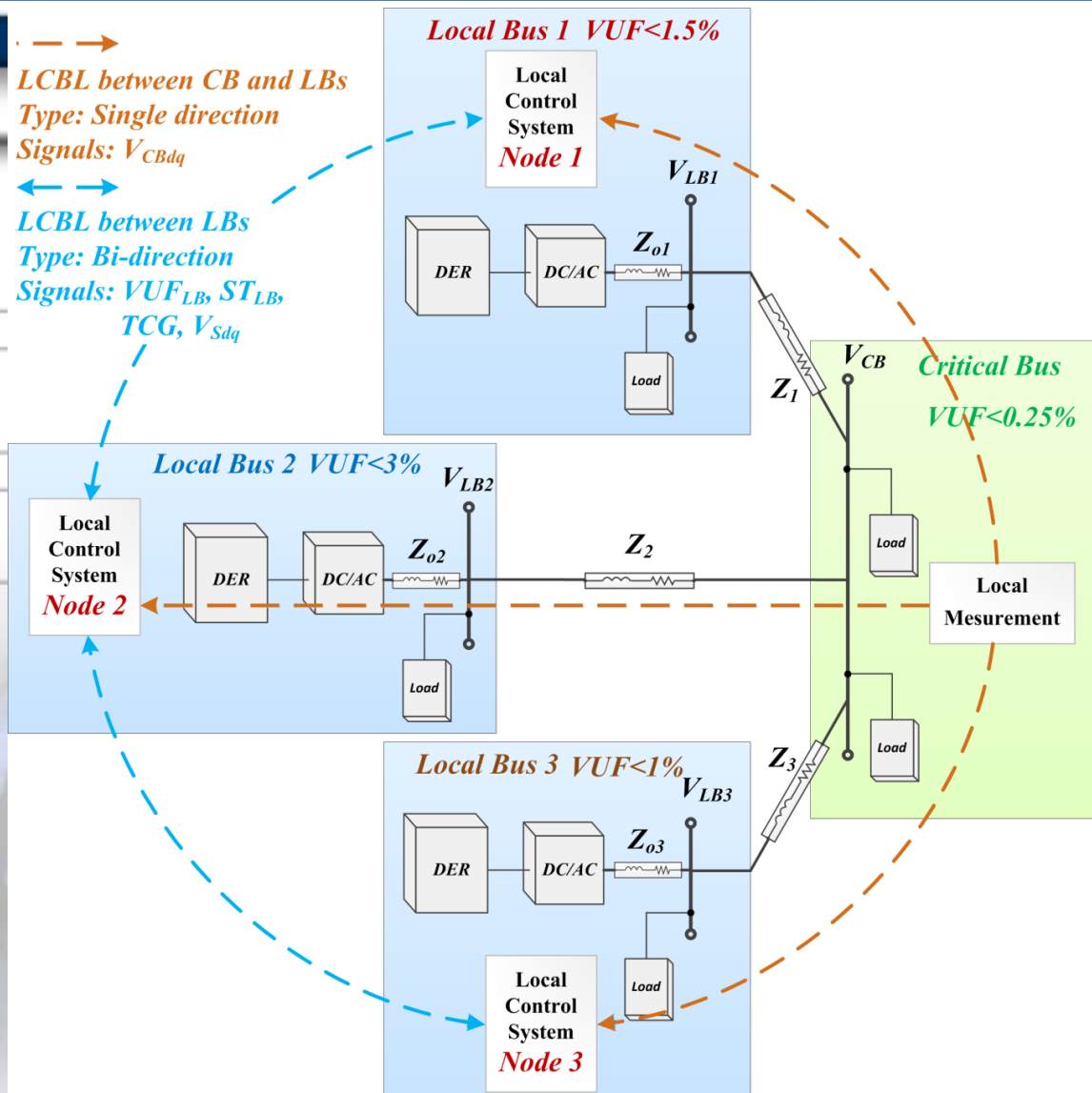


Other Setup

Other Setup

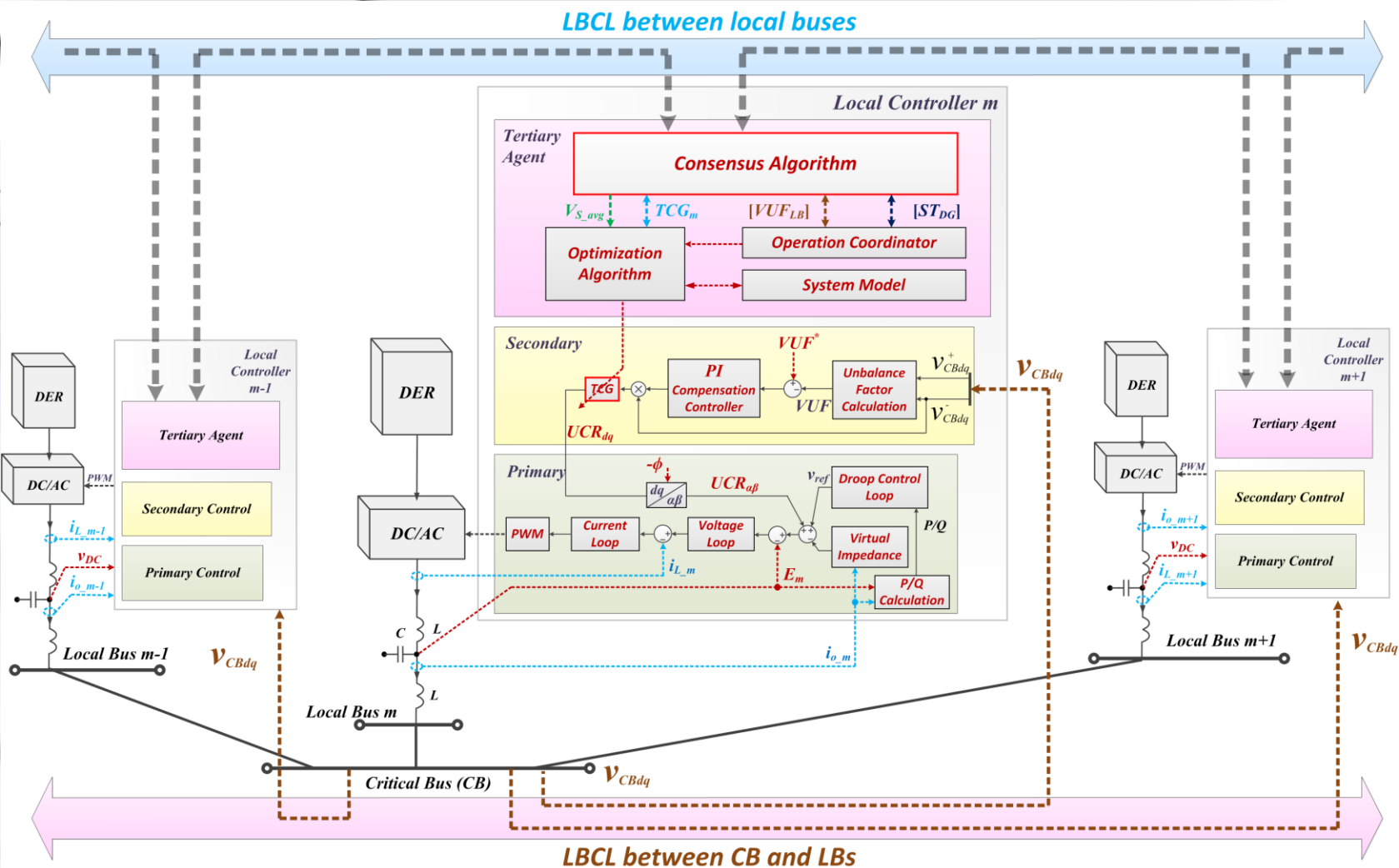


# Unbalance compensation



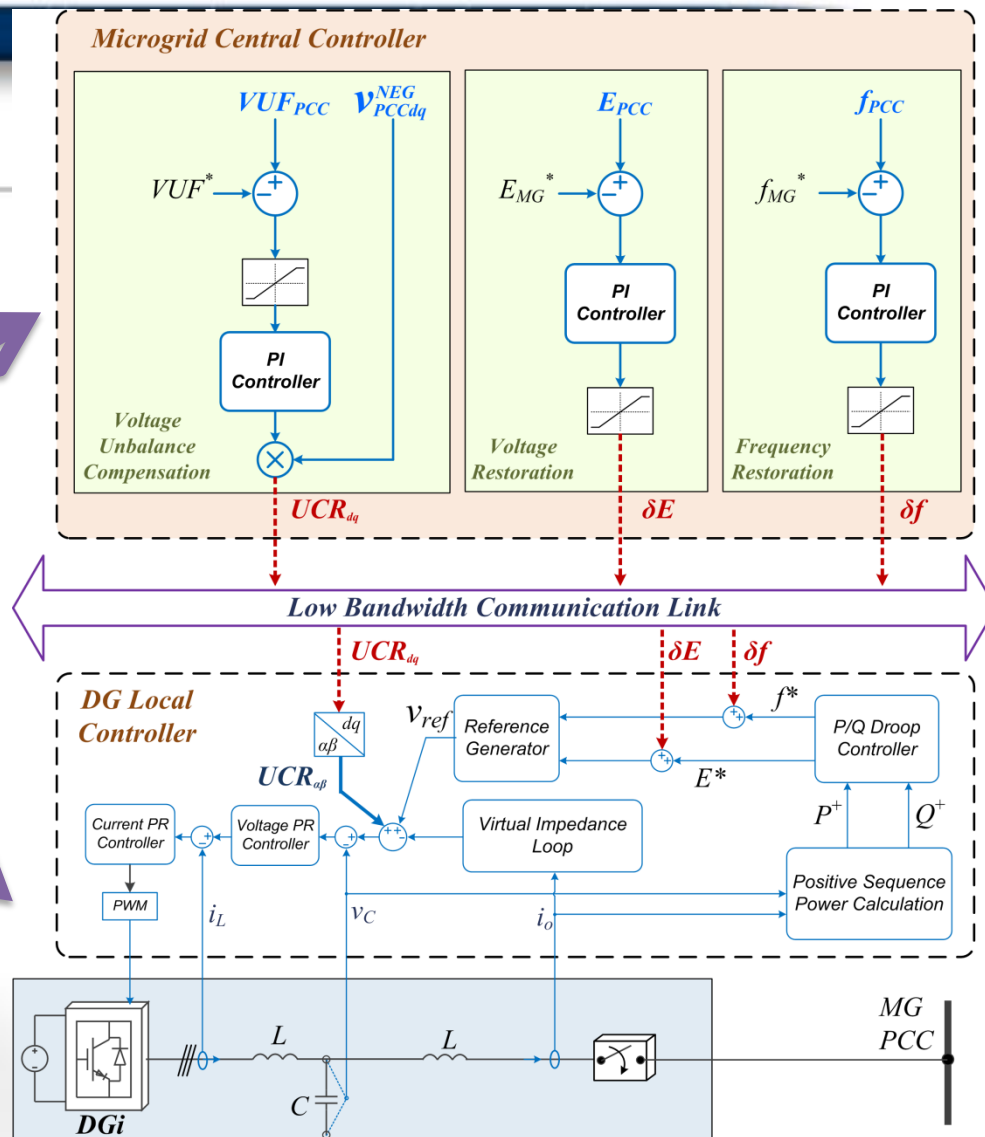
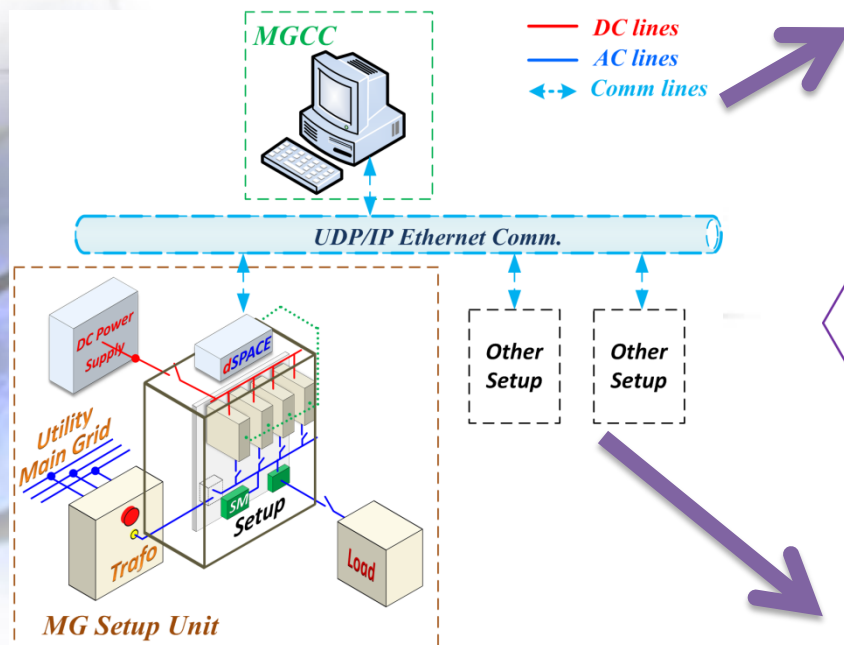


# Unbalance compensation



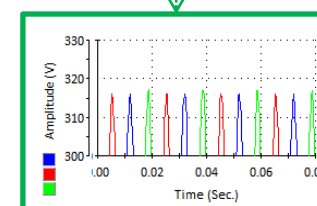
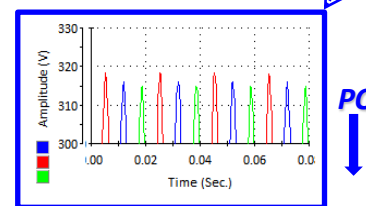
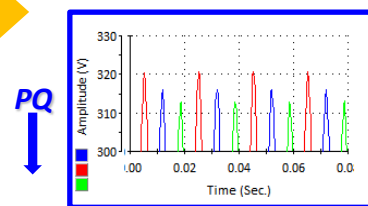
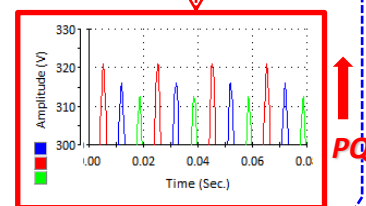
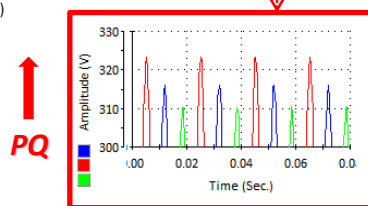
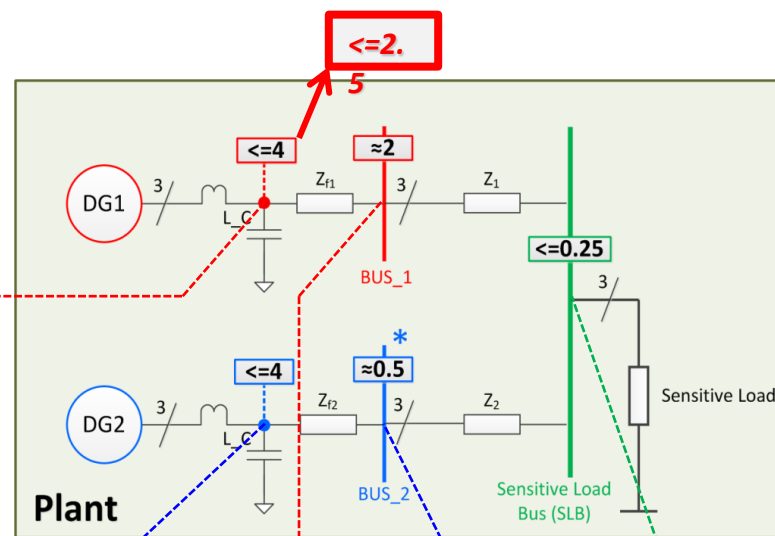
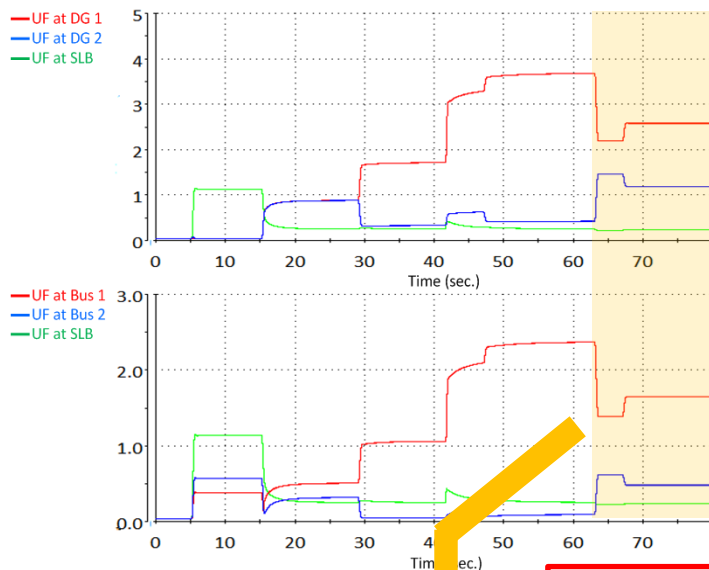


# UNBALANCE COMPENSATION OPTIMIZATION





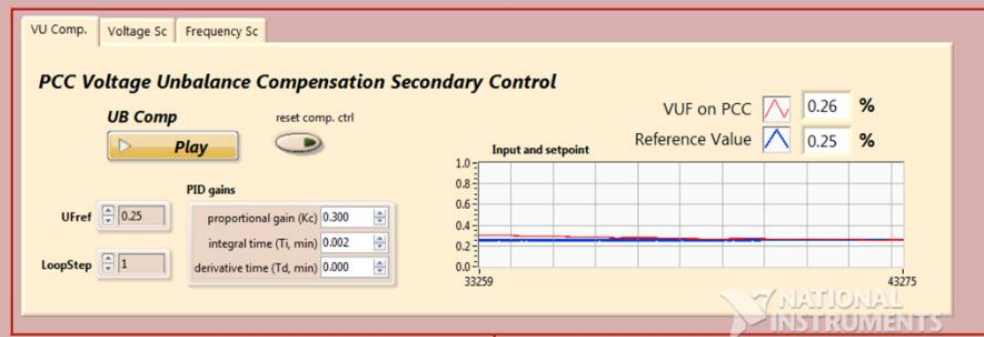
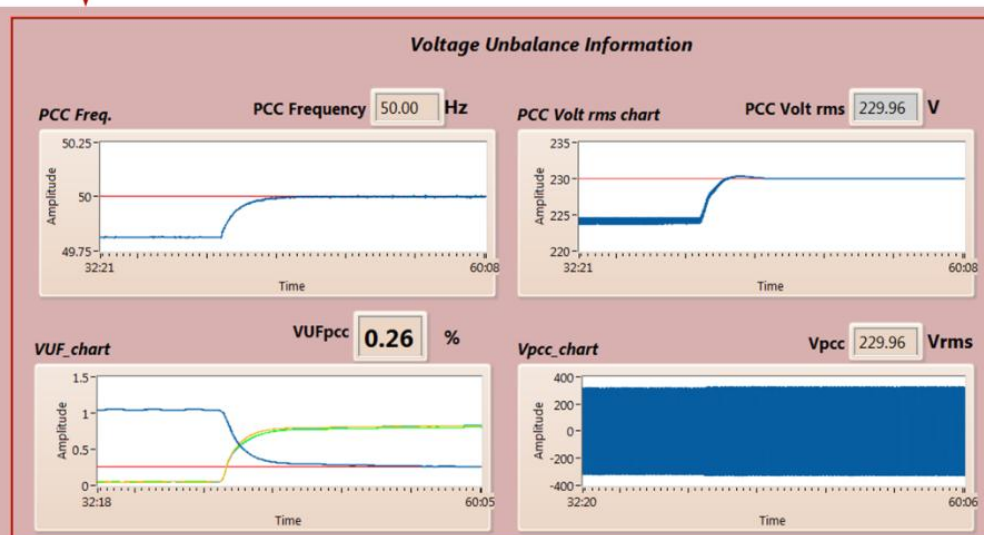
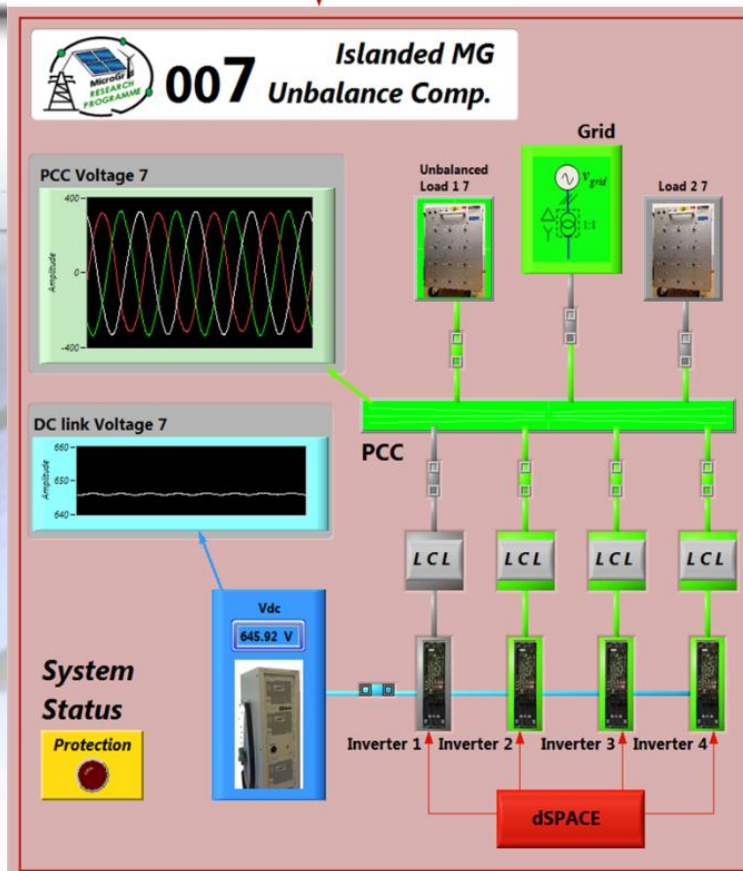
# UNBALANCE COMPENSATION OPTIMIZATION





# Unbalance Compensation in LabVIEW

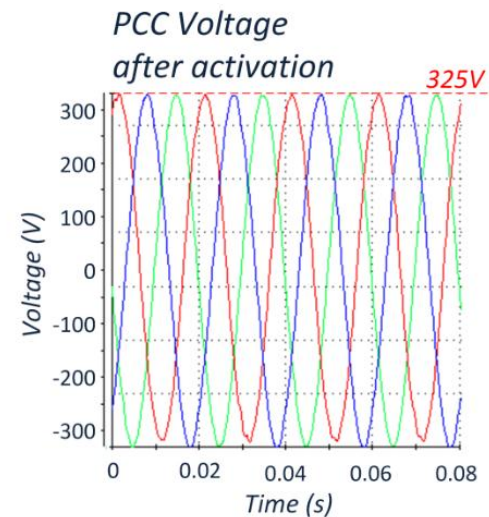
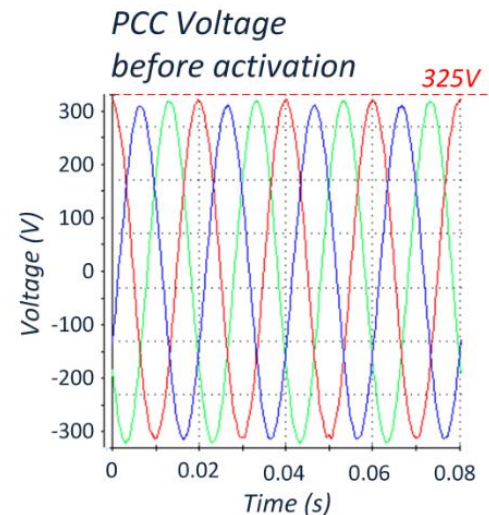
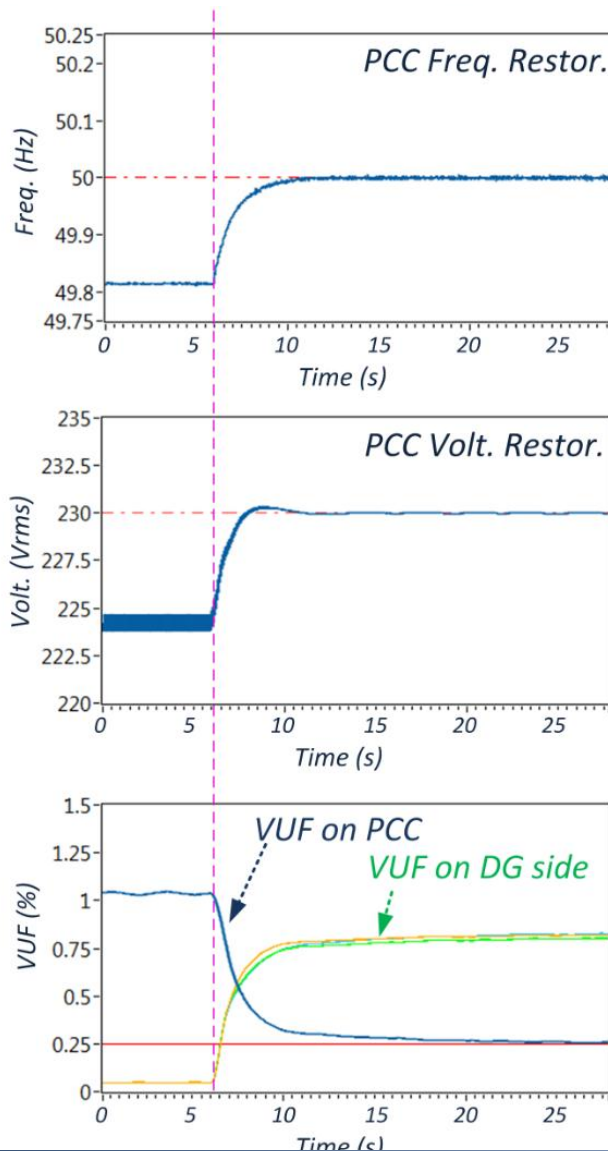
## System Supervision



## Secondary Compensation

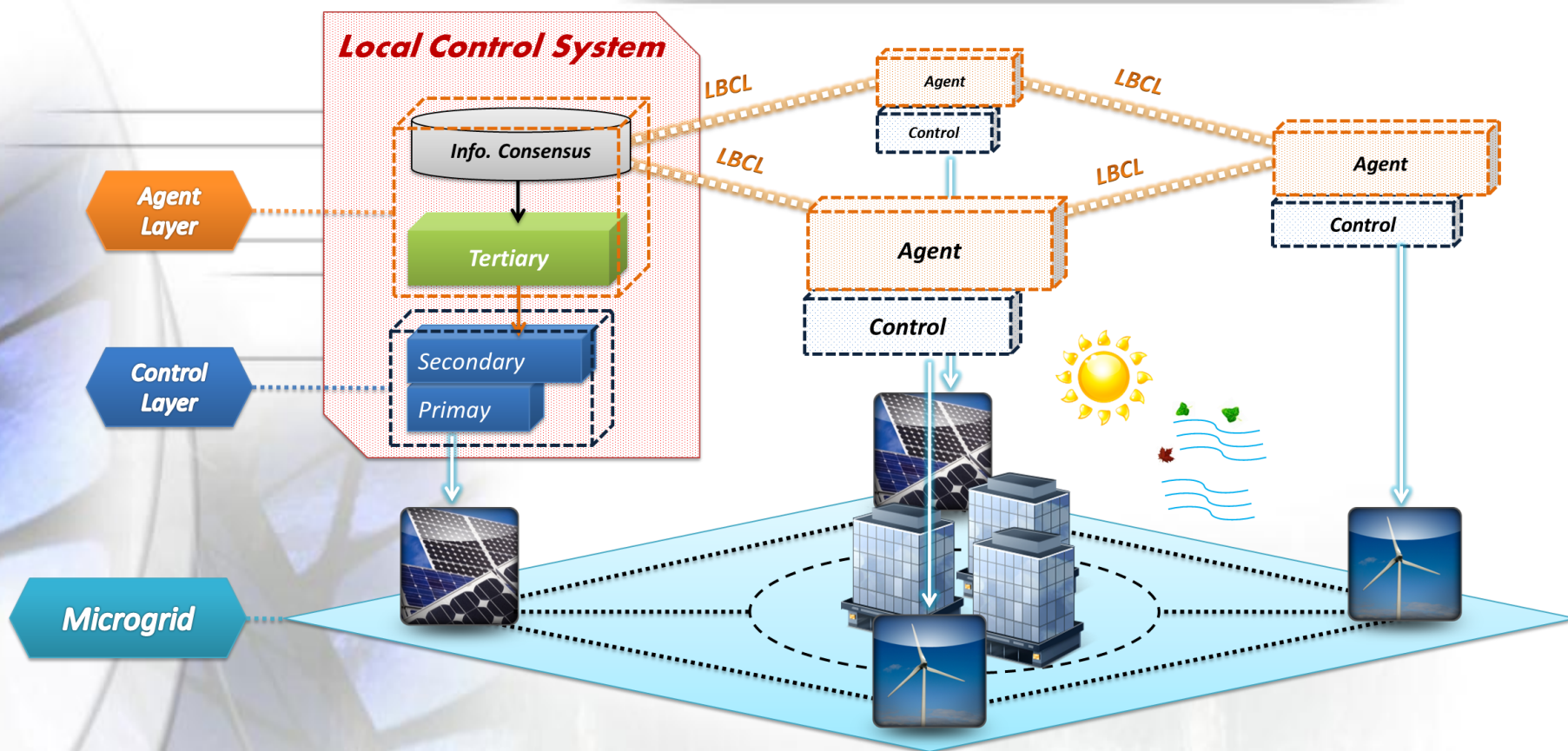


# Experimental Results



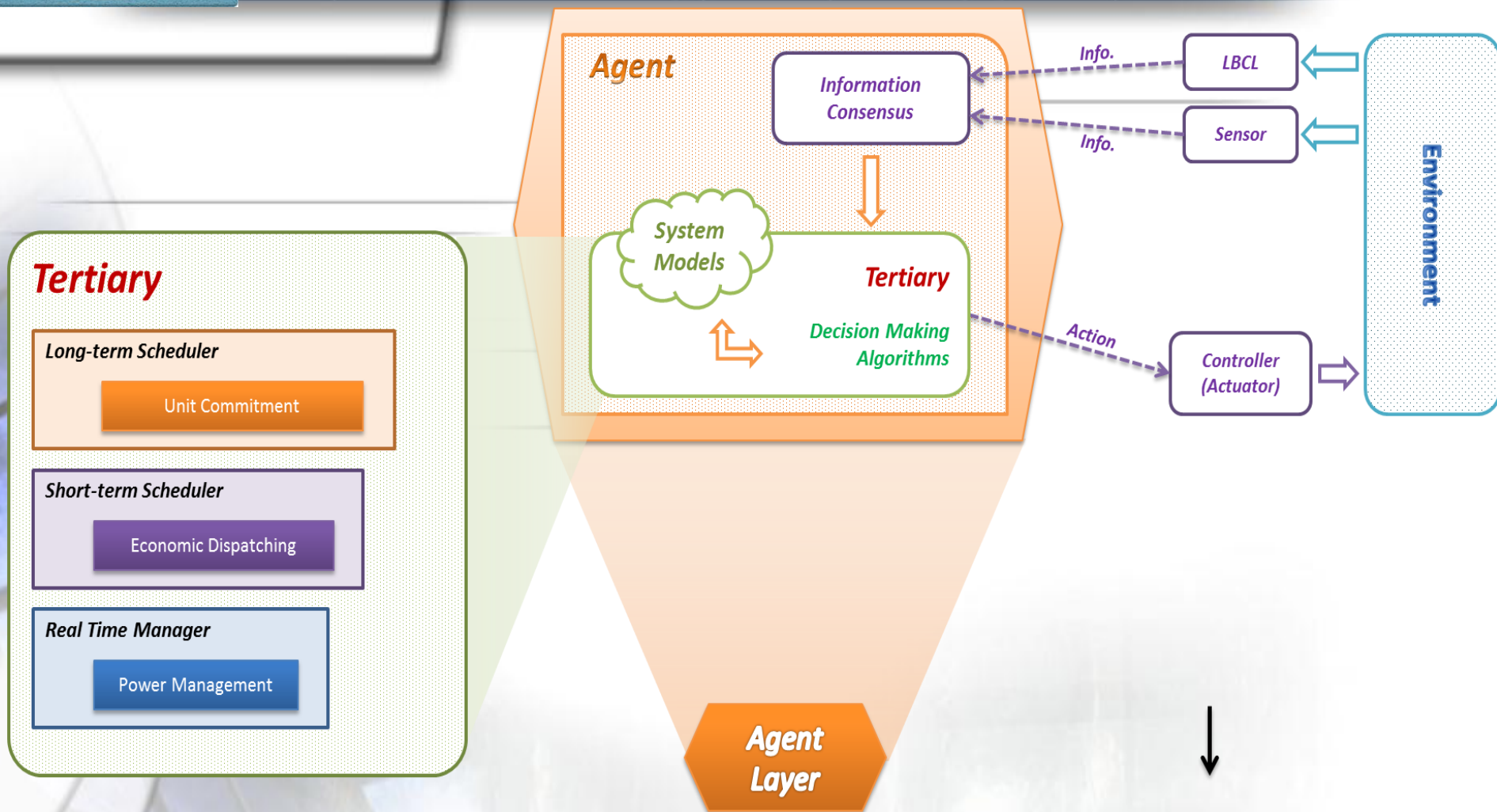


# Distributed Hierarchical Control



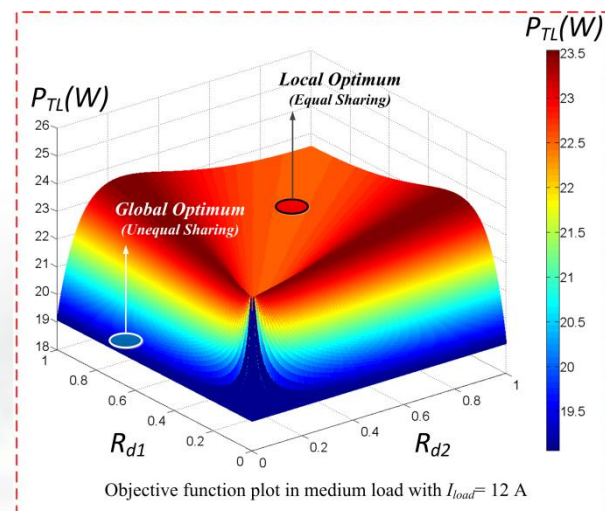
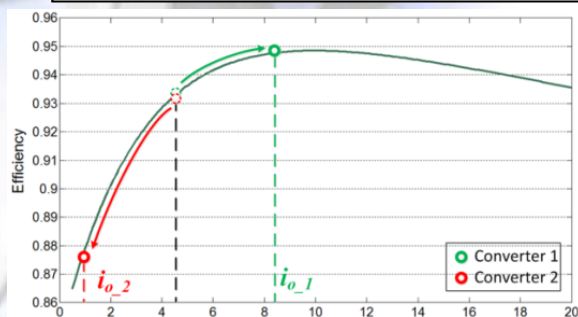
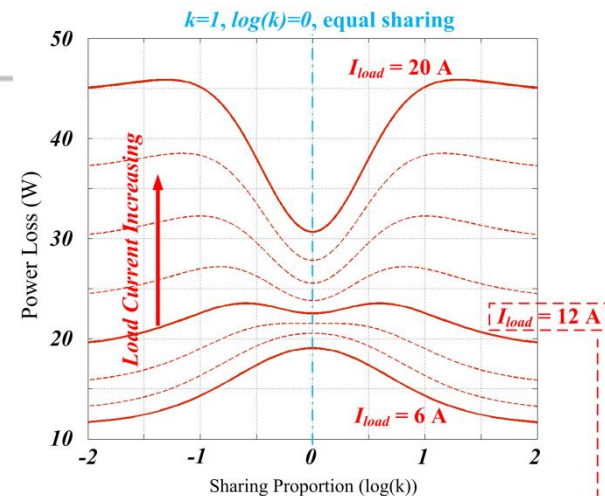
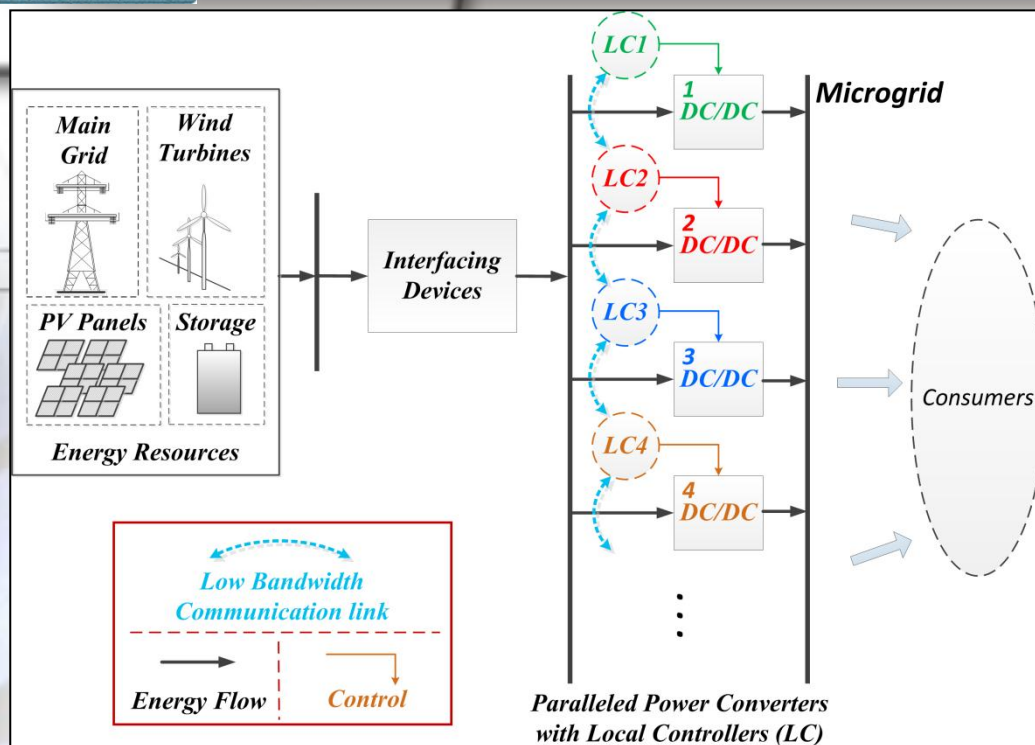


# Distributed Hierarchical Control



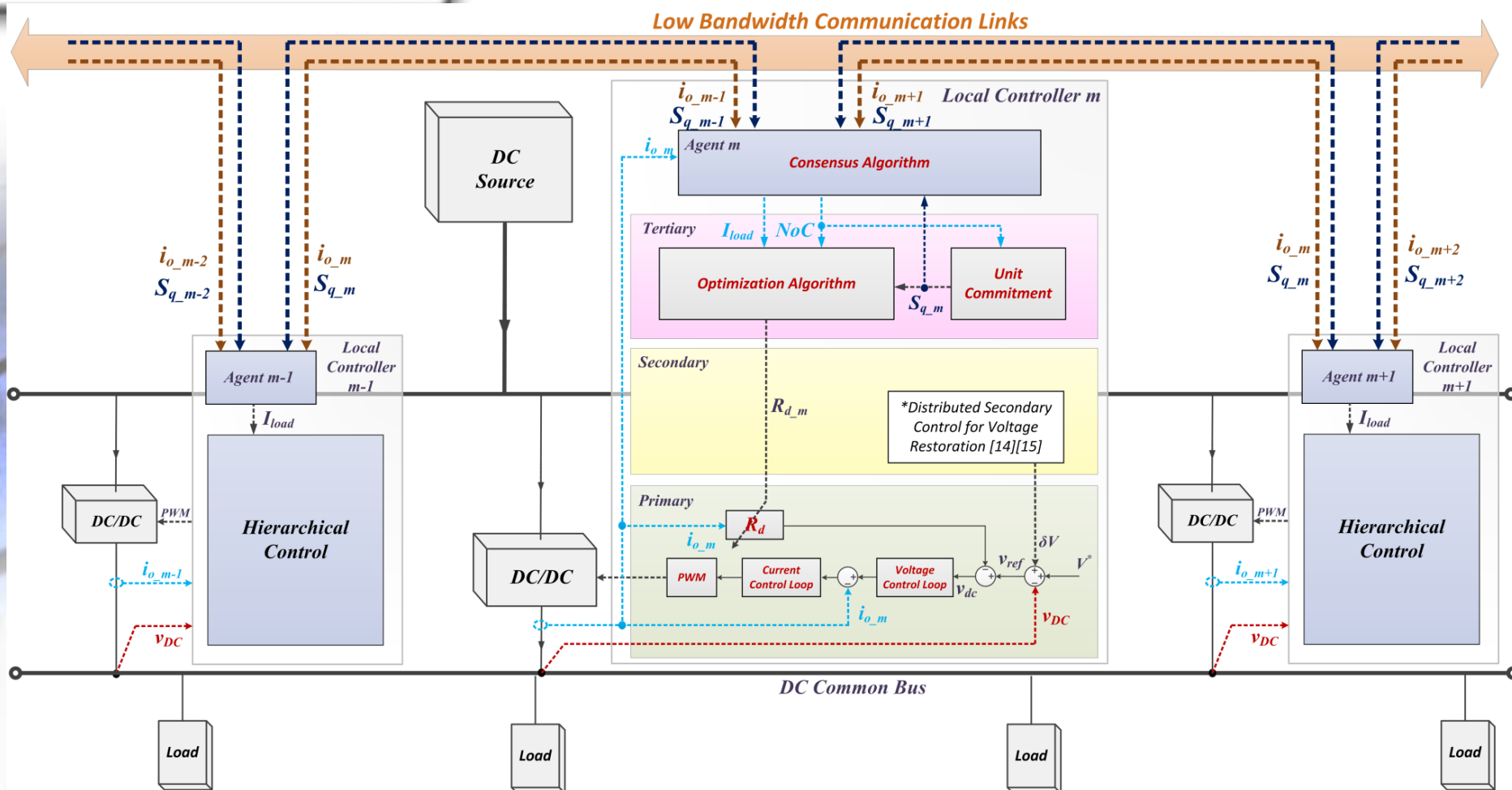


# DCA based distributed optimization for paralleled DC-DC Converters



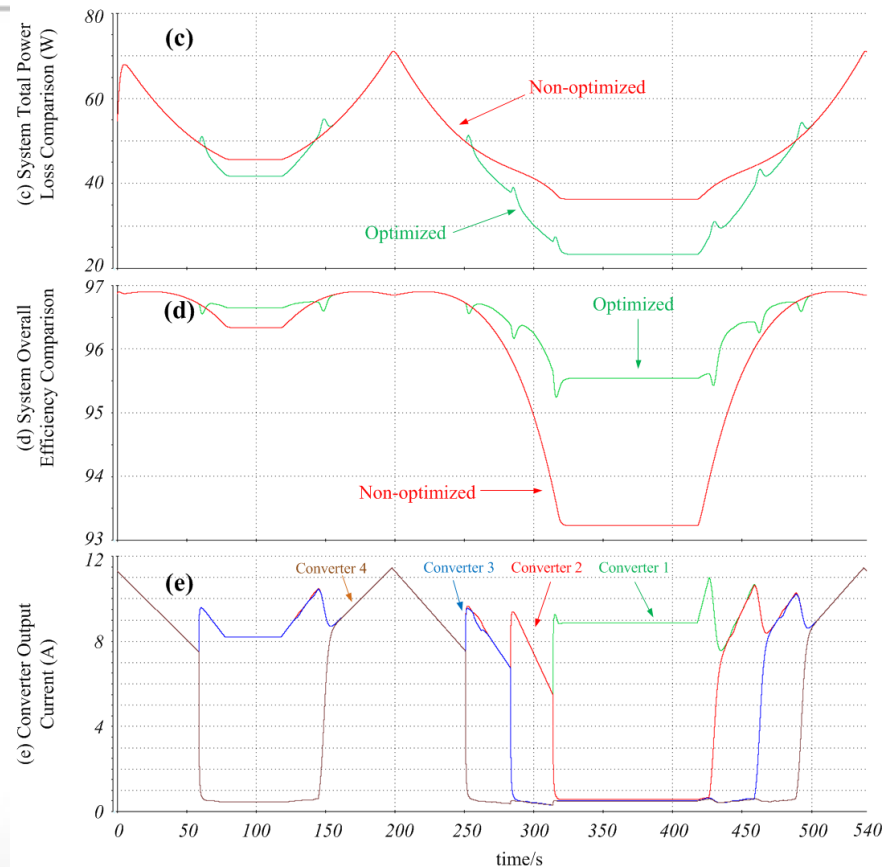
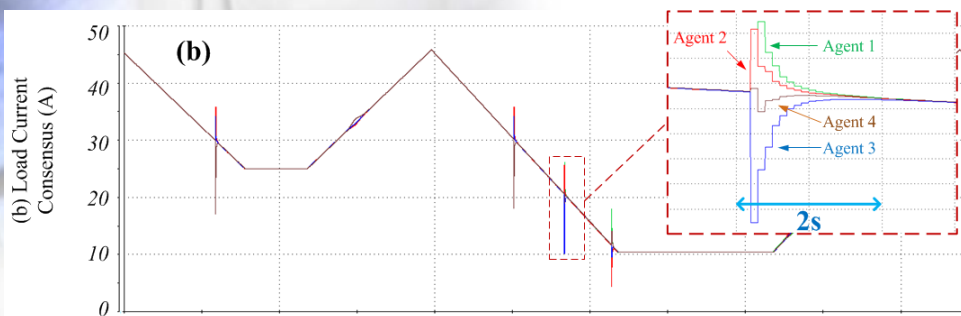
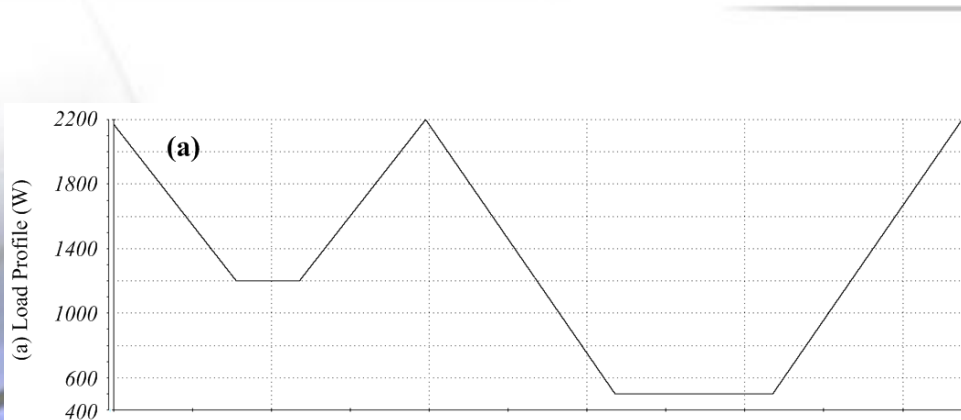


# DCA based distributed optimization for paralleled DC-DC Converters





# DCA based distributed optimization for paralleled DC-DC Converters



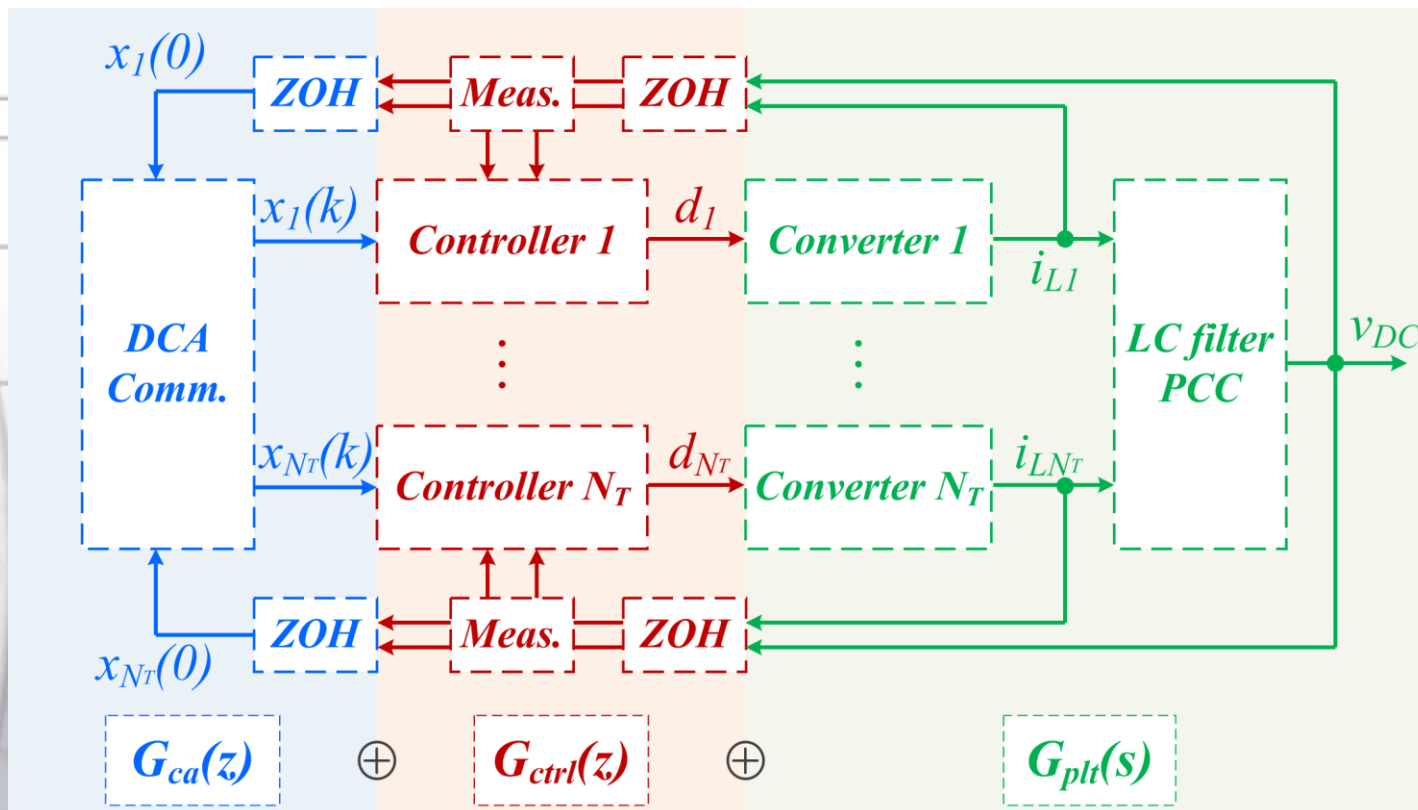


# DCA based DC MG Modeling

*Comm.*  
 $T_{ca} = 0.1s$

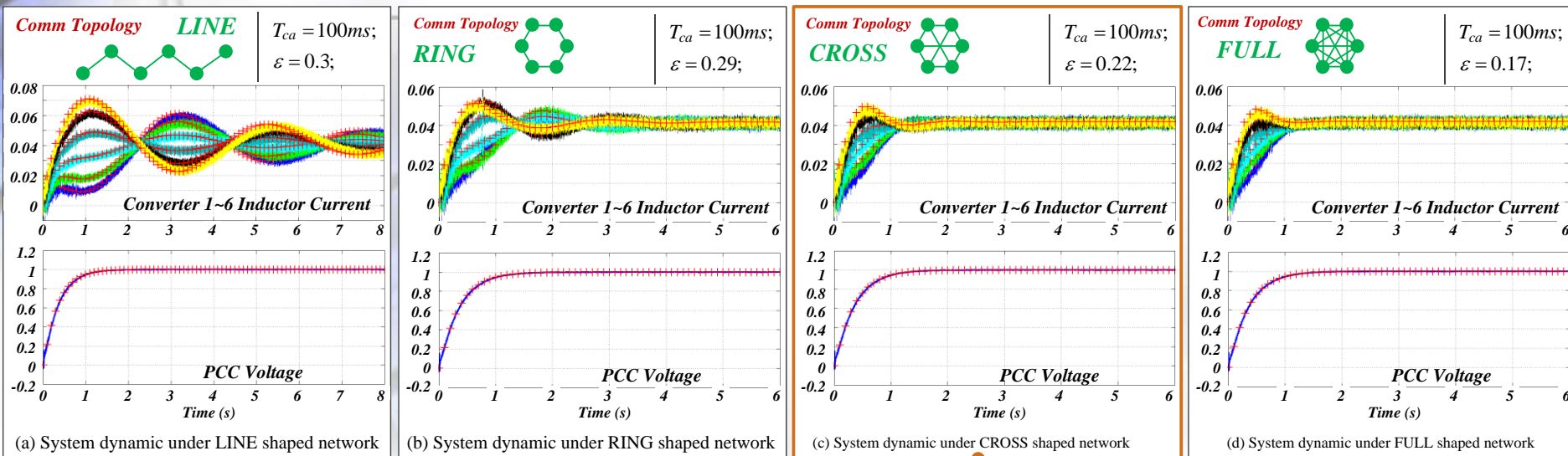
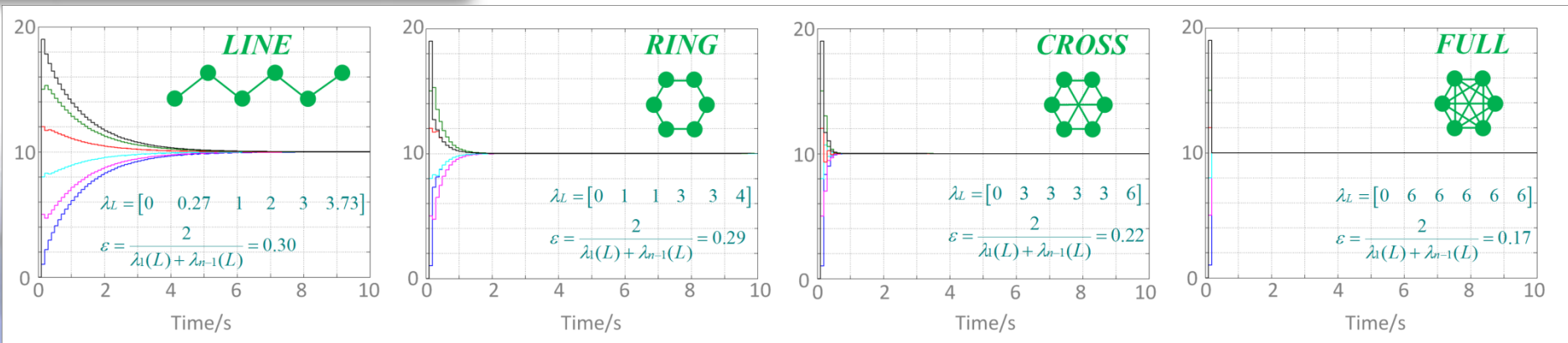
*Digital Control*  
 $T_d = 1e-4s$

*Continuous-Time*



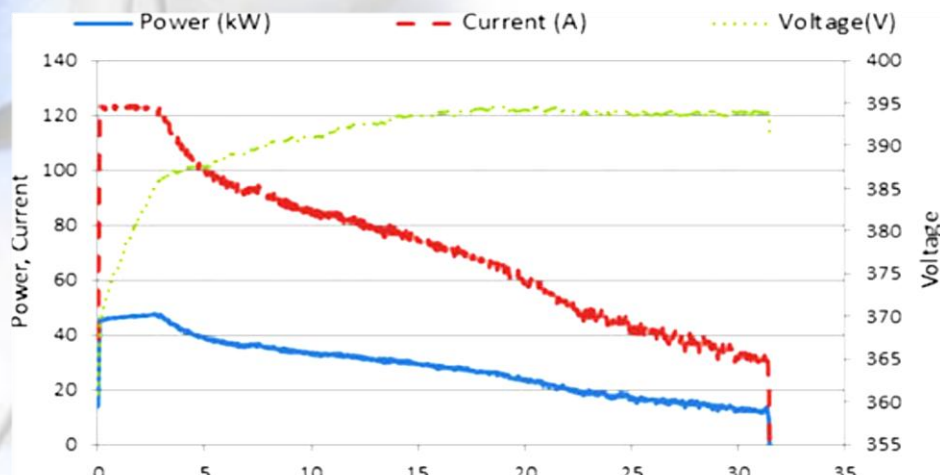
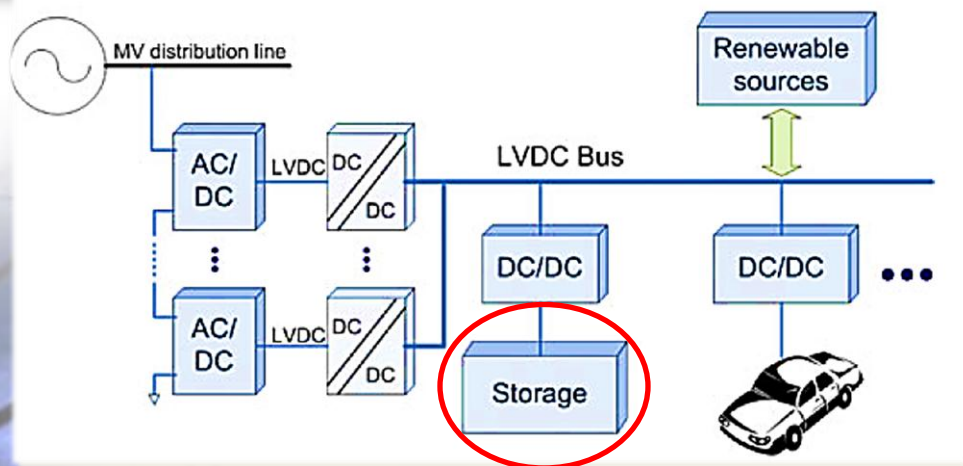


# DCA based DC MG Modeling





# EV charging stations

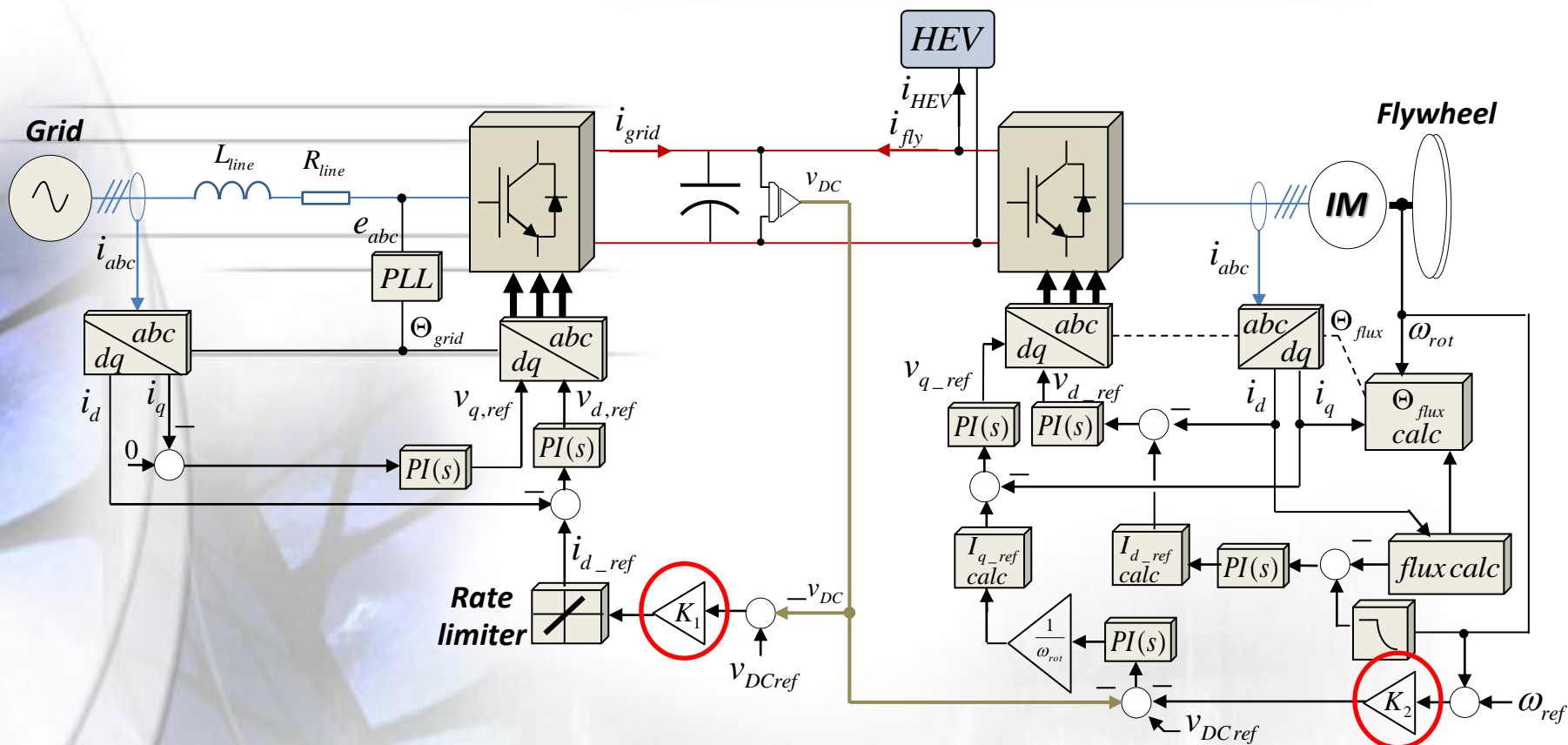


## Fast DC charging

- Most attractive from the vehicle owner
- point of view (around 30 minutes to recharge completely depleted batteries)
- Appropriate for public charging stations
- Distribution grid may experience problems
- Nissan Leaf fast recharge profile
- (Commercially available CHAdeMO compatible charger manufactured by ABB):

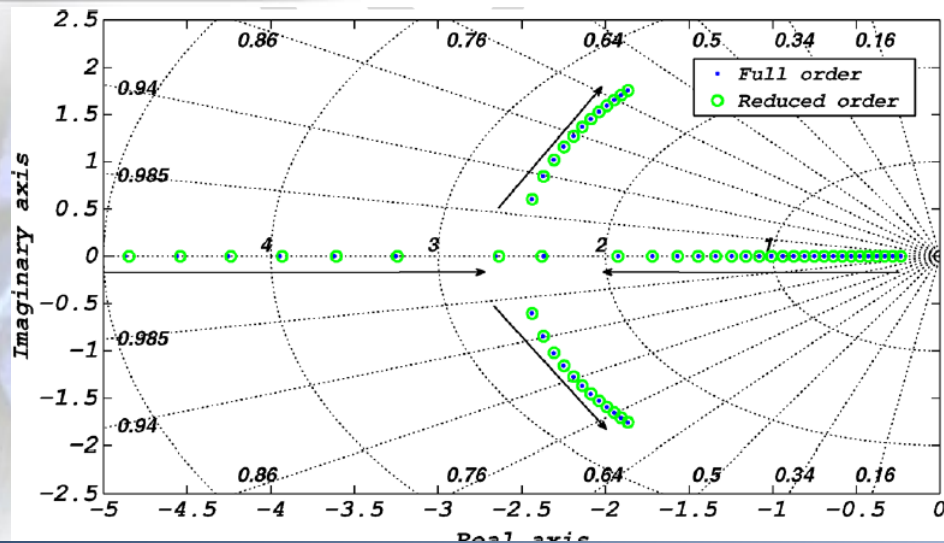
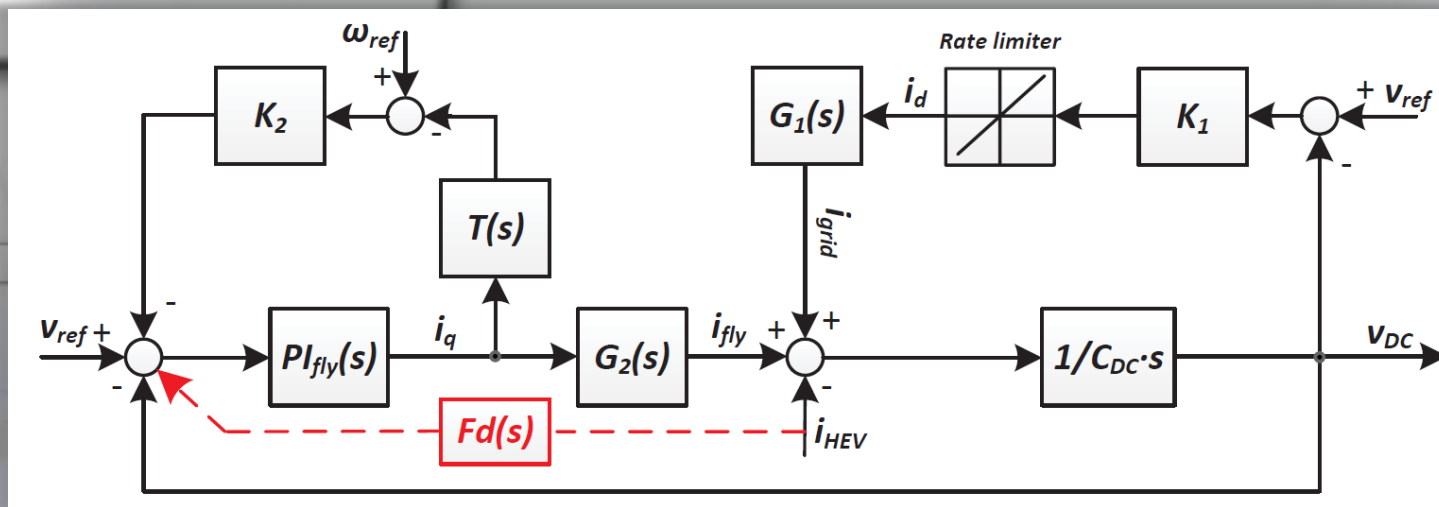


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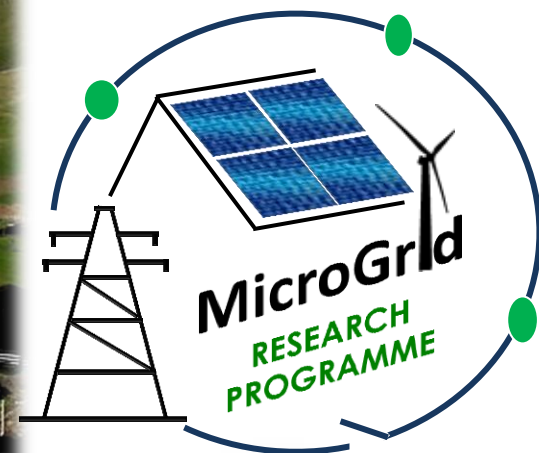
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***Thank you for your attention!***