

臺灣 2011年8月24~25日

# APEC 2011

## Advanced Control Architectures for Intelligent Microgrids

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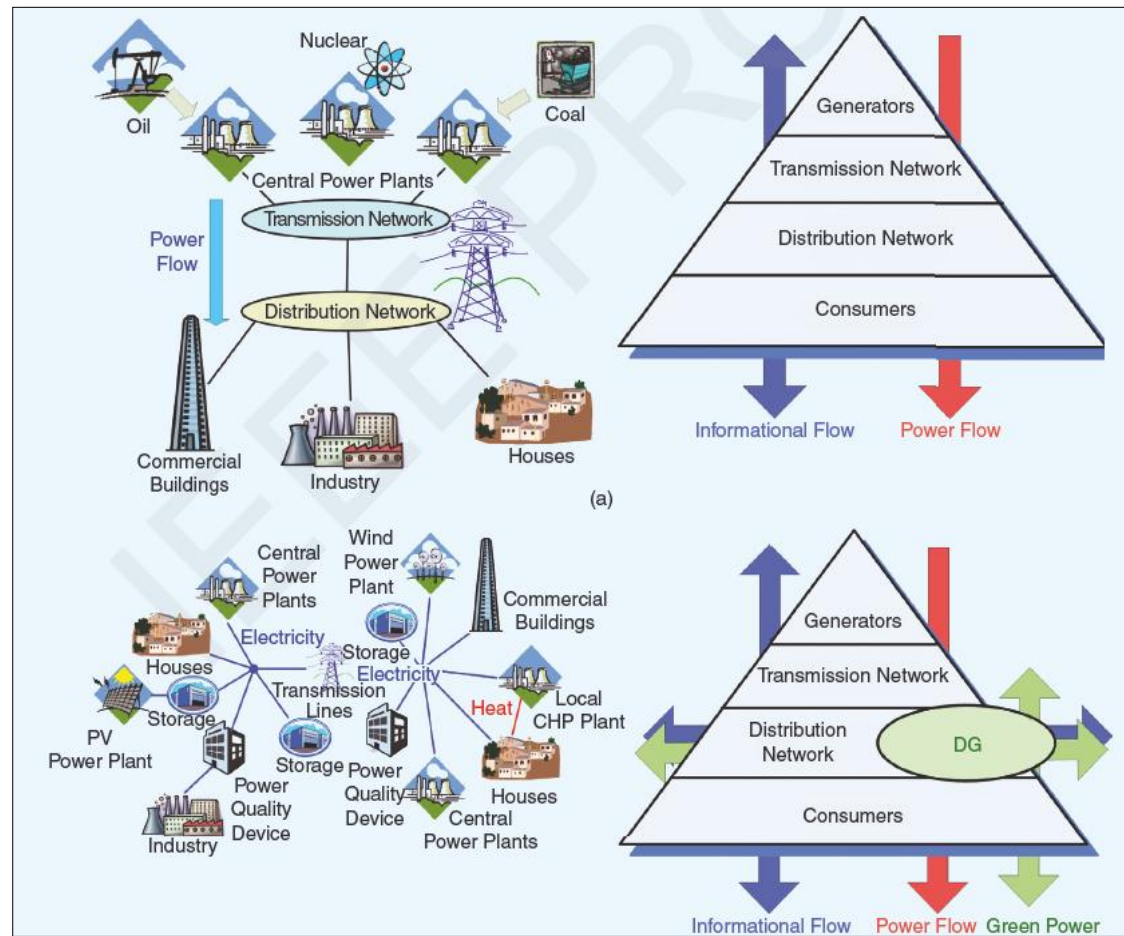
# Outline

- 1 Microgrids systems
  - 2 Control of VSIs for microgrids
  - 3 Droop control and virtual impedance concept
  - 4 Hierarchical control of microgrids
  - 5 Power quality in microgrids
  - 6 DC microgrids
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# Centralized vs Distributed Power Systems

## General advantages of the DPS:

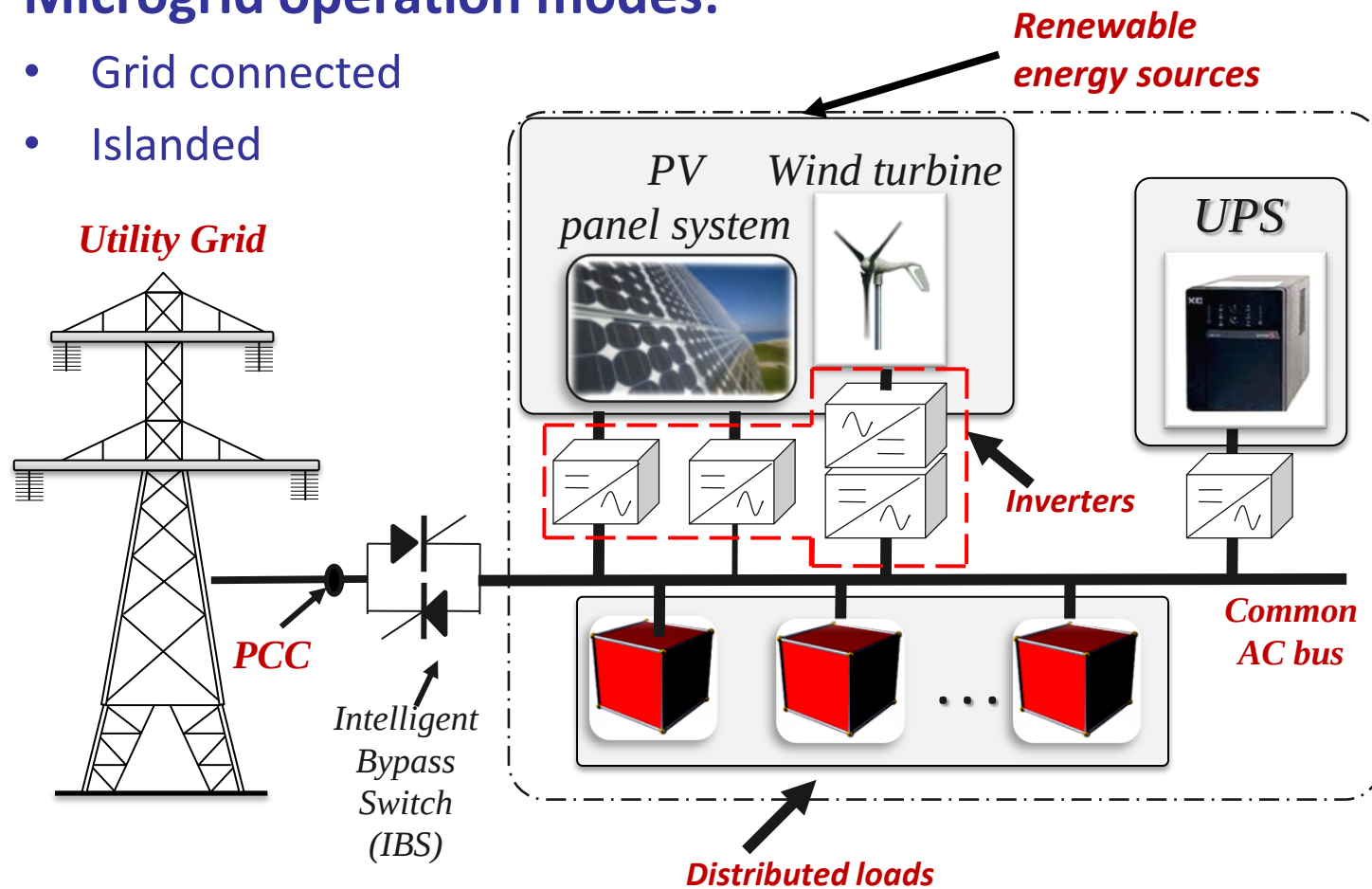
- Redundancy
- Modularity
- Fault tolerance
- Efficiency
- Reliability
- Easy maintenance
- Smaller size
- Lower design cost



# Microgrid operation

## Microgrid operation modes:

- Grid connected
- Islanded



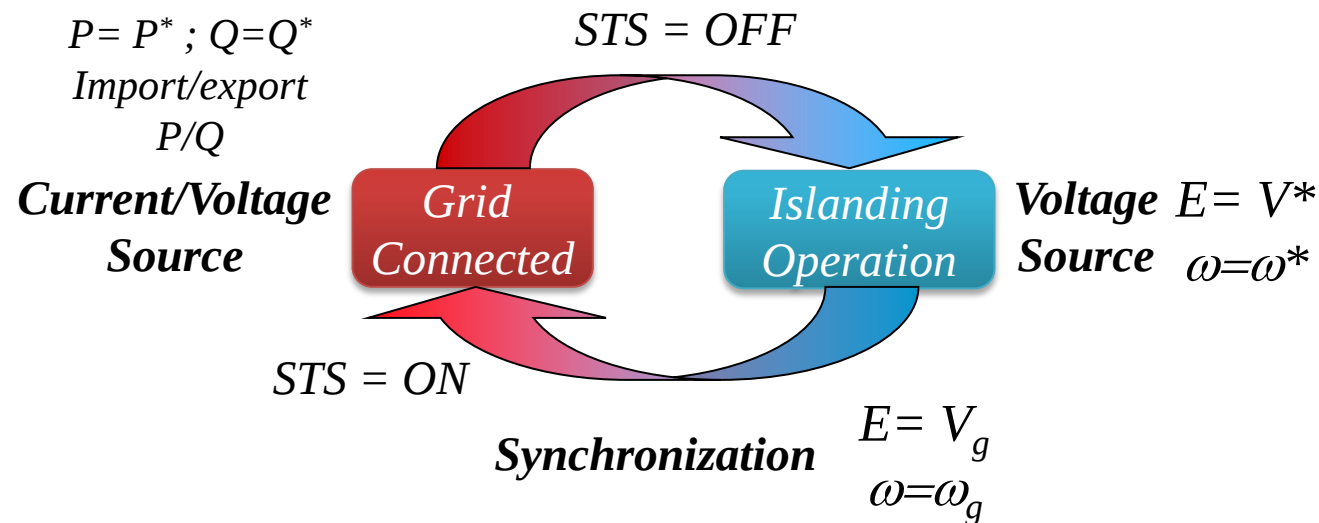
## Typical structure of a flexible microgrid

## Microgrid operation modes

- Operation modes and transfers of the flexible microgrid and STS grid status supervisory
- Virtual inertias are often implemented through control loops known as droop method.
- Intelligent microgrids are required to integrate DG, DS, and dispersed loads into the future smart grid.
- Microgrids should be able to operate autonomously but also interact with the main grid.
- CSI units are normally used for PV or WT systems that require maximum power point tracker algorithms.
- VSI units are used for storage energy systems to support the voltage and frequency of the microgrid in island mode.

## Islanded / Grid-connected operation

- Operation modes and transfers of the flexible microgrid and Static Transfer Switch (STS)

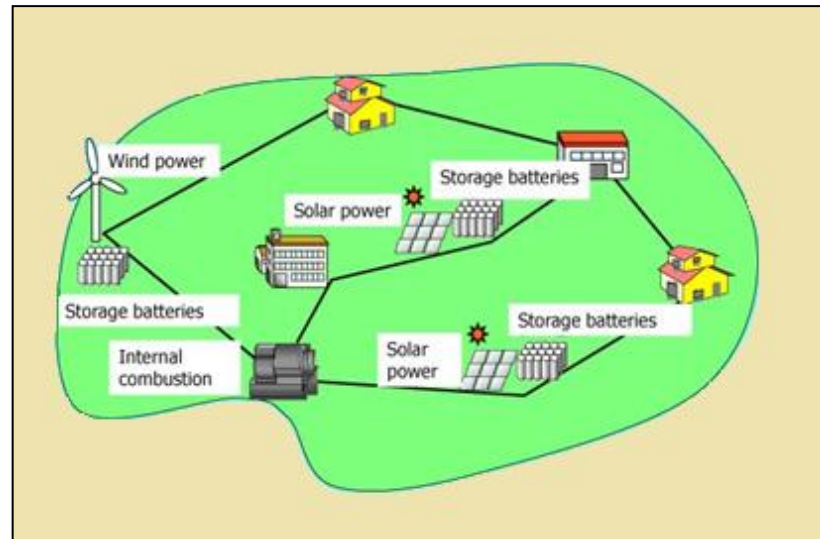


*From grid-connected an islanded modes, it is necessary a smooth transition.  
For both modes, the converters could work as voltage sources!*

# Microgrid operation

## Islanded operation

- Preplanned islanded operation: If any events in the main grid are presented, such as long-time voltage dips or general faults, among others, islanded operation must be started.
- Nonplanned islanded operation: If there is a blackout due to a disconnection of the main grid, the microgrid should be able to detect this fact by using proper algorithms.

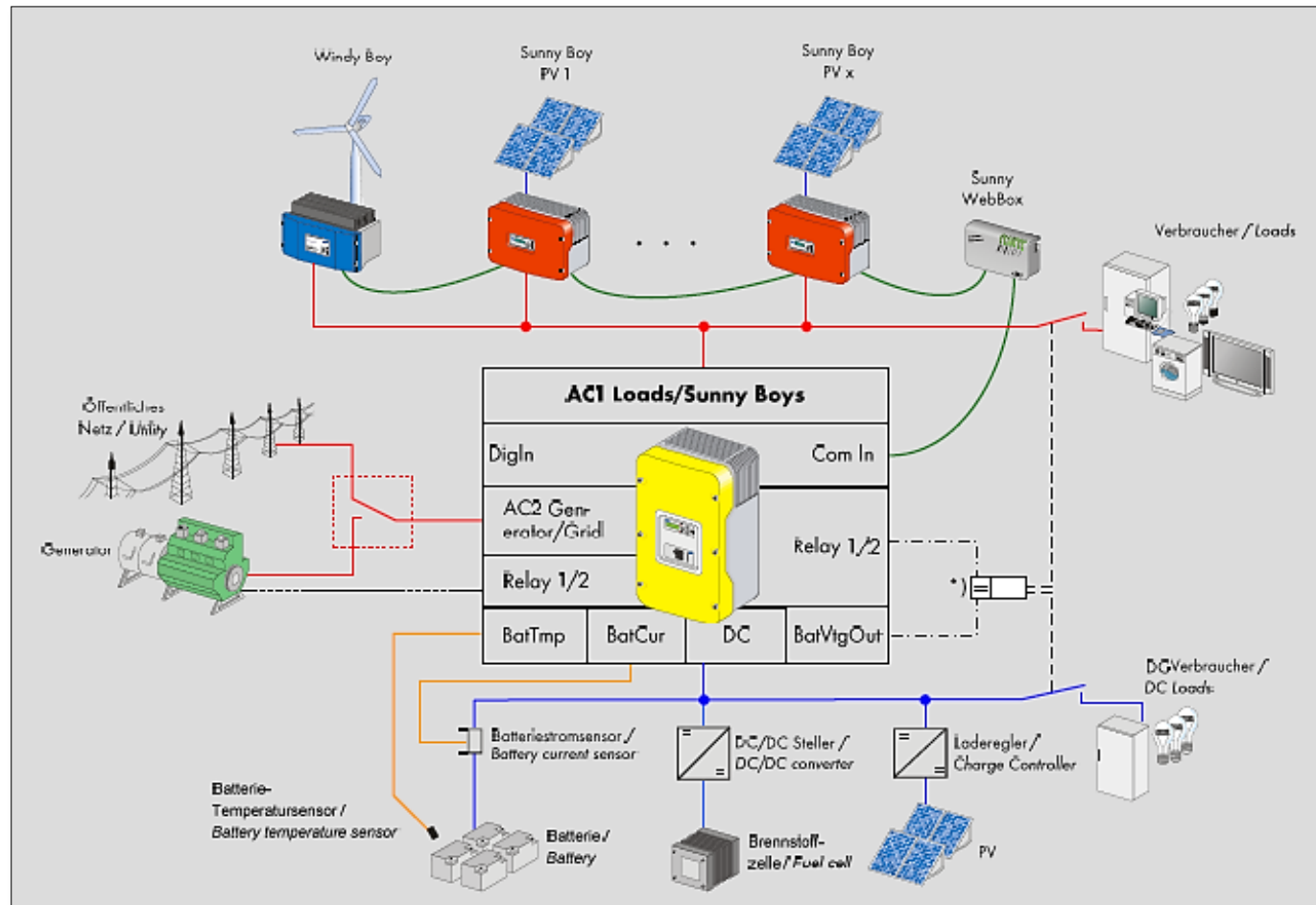


## Islanded operation

- **Voltage and frequency management:** The system acts like a voltage source, controlling power flow through voltage and frequency control loops adjusted and regulated as reference within acceptable limits.
- **Supply and demand balancing:** In grid-connected mode, the frequency of the DG units is fixed by the grid. Changing the setting frequency, new active power set points that will change the power angle between the main grid and the microgrid can be obtained.
- **Power quality:** The power quality can be established in two levels. The first is reactive power compensation and harmonic current sharing inside the microgrid, and the second level is the reactive power and harmonic compensation at the PCC; thus, the microgrid can support the power quality of the main grid.

# Microgrid Configurations

- **AC-DC Hybrid Microgrid**  
*Hierarchy of loads*

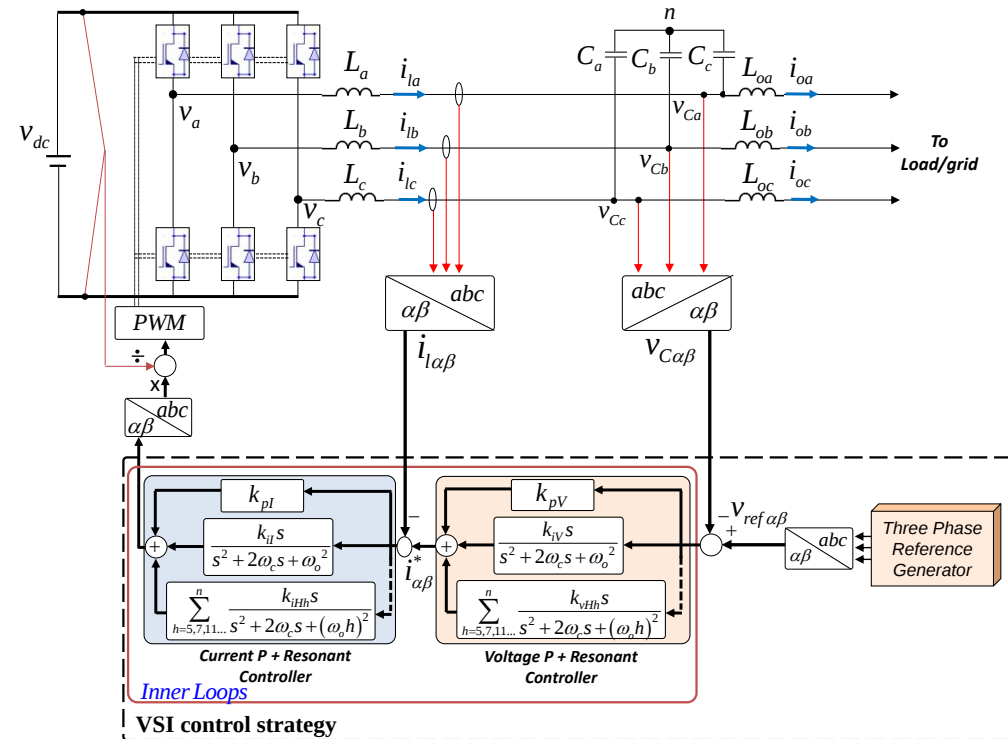


Source: SMA



# Inner control loops

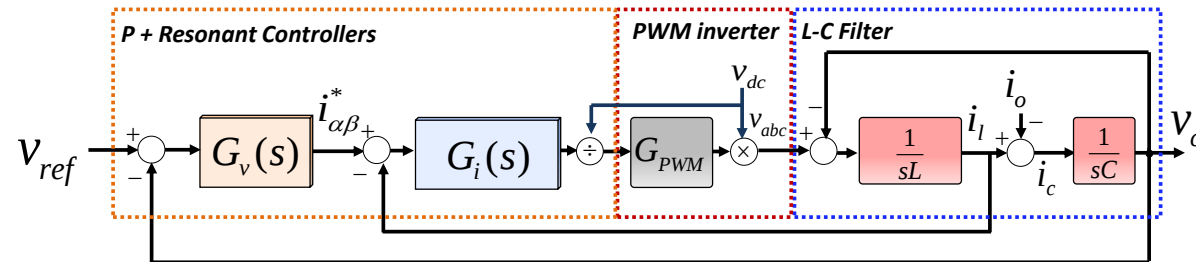
## Power stage and control of a 3 phase VSI with LCL filter



$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{2/3} \cdot \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad \Rightarrow \quad \text{Alpha-beta transformation}$$

# Inner control loops

## Block diagram of the closed-loop VSI.



$$V_c = \frac{G_v(s)G_i(s)G_{PWM}}{LCs^2 + (Cs + G_v(s))G_i(s)G_{PWM} + 1} V_{ref} - \frac{1/Cs}{LCs^2 + (Cs + G_v(s))G_i(s)G_{PWM} + 1} i_o$$

Voltage tracking

**Voltage control loop**

$$G_v(s) = k_{pV} + \frac{k_{rV}s}{s^2 + \omega_o^2} + \sum_{h=5,7,11} \frac{k_{hV}s}{s^2 + (\omega_o h)^2}$$

Output impedance

**Current control loop**

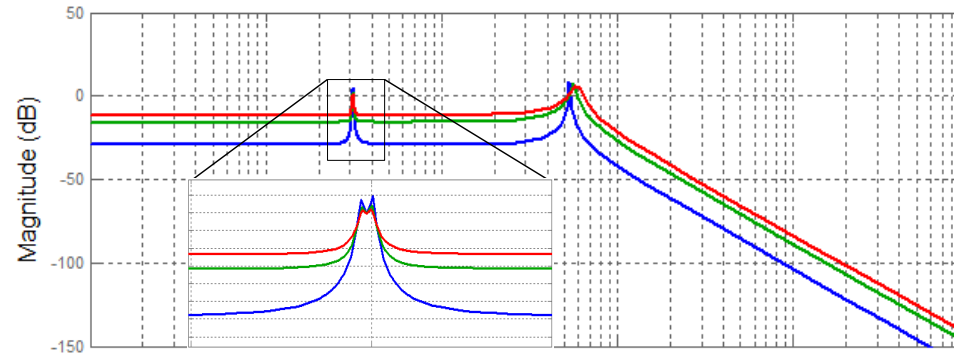
$$G_i(s) = k_{pI} + \frac{k_{rI}s}{s^2 + \omega_o^2} + \sum_{h=5,7,11} \frac{k_{hI}s}{s^2 + (\omega_o h)^2}$$

**Computation delay**  $G_{PWM} = \frac{1}{1 + 1.5T_s}$

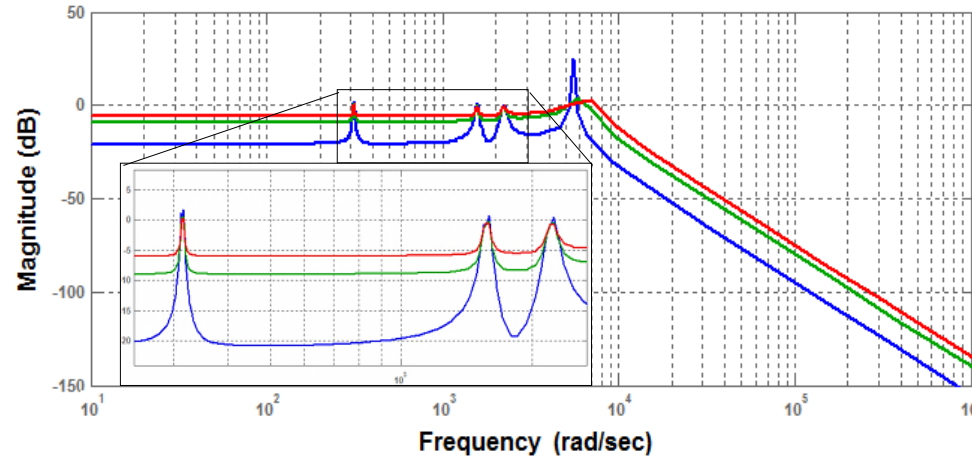
# Inner control loops

Bode diagram of the tracking voltage transfer function  $G_v(s)$

P+R



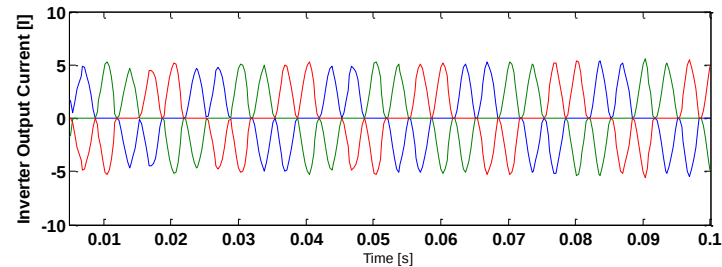
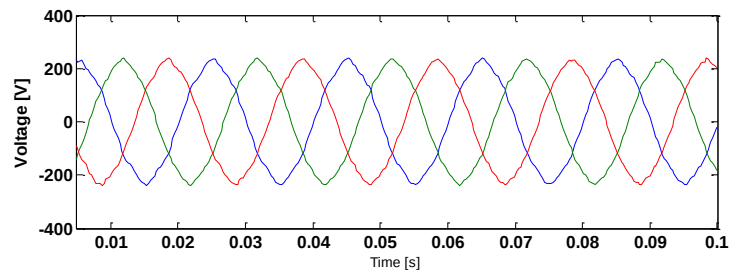
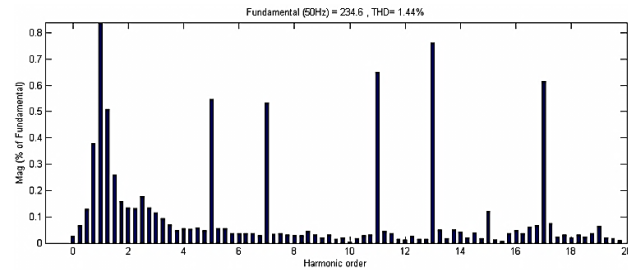
P+R+H



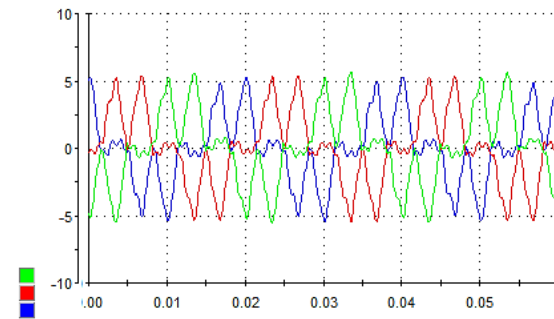
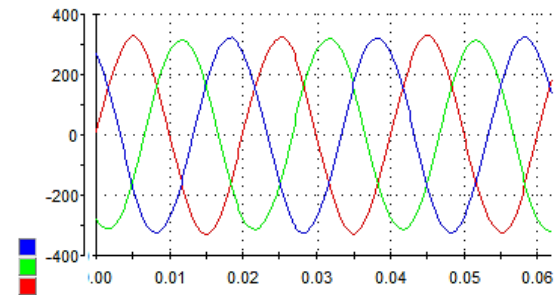
Objective: closed-loop band pass filter characteristics with 0dB, 0°

# Inner contro loops

## Results

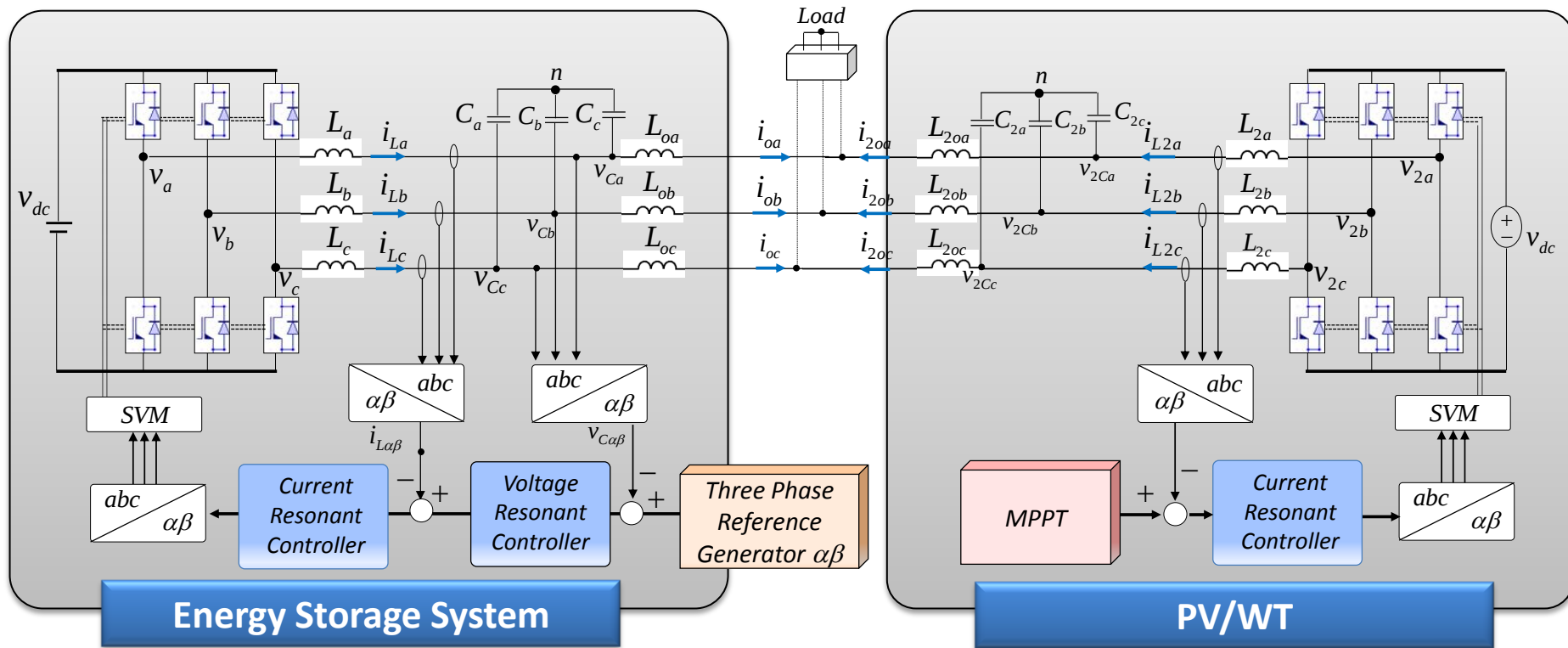


abc-Voltages



abc-Currents

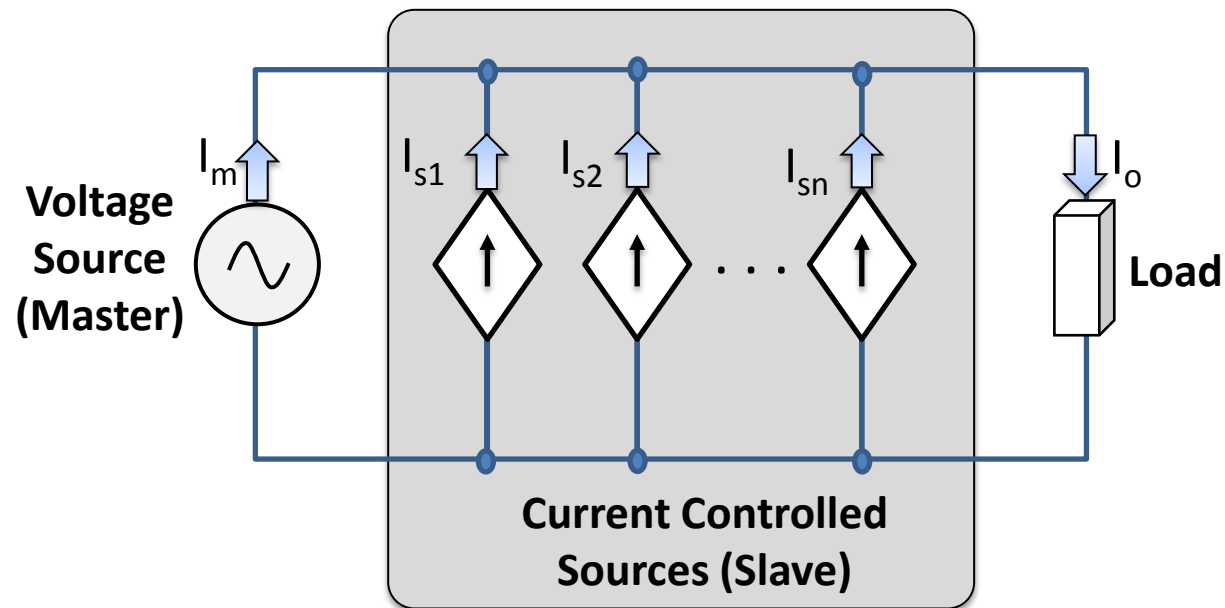
## Master-slave control



- Voltage source: grid forming units
- Current source: MPPT units. WT and PV

In this system is not necessary current sharing!

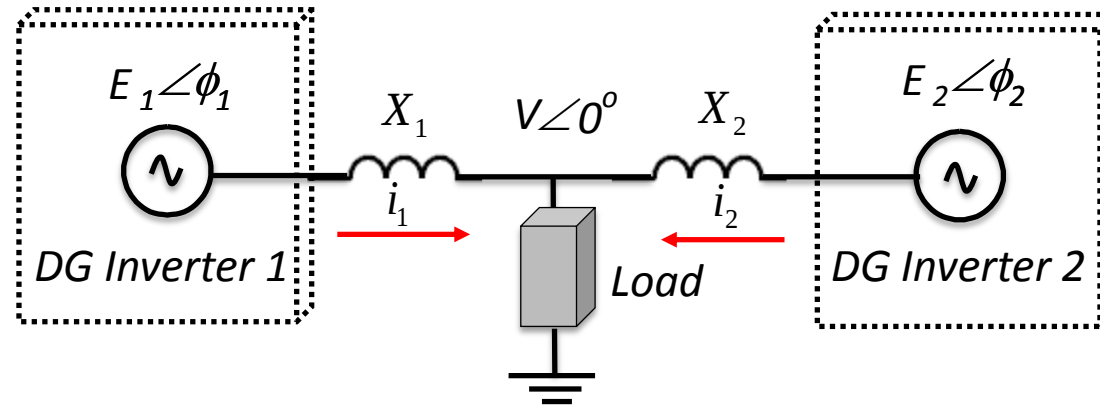
## Master-slave control



**Woo-Cheol Lee** "A Master and Slave Control Strategy for Parallel Operation of Three-Phase UPS Systems with Different Ratings"

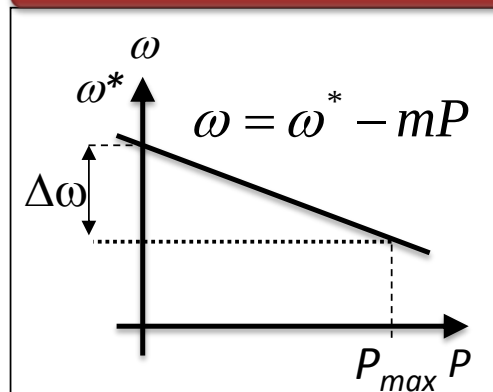
# Droop control for AC MGs

## Droop control of AC systems

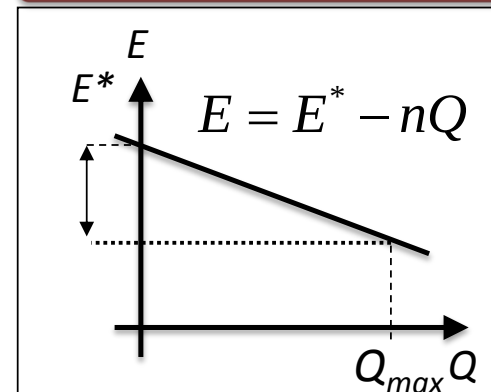


Active power  $P = \frac{VE}{X} \sin \phi$       Reactive power  $Q = \frac{EV \cos \phi - V^2}{X}$

### Frequency droop



### Amplitude droop

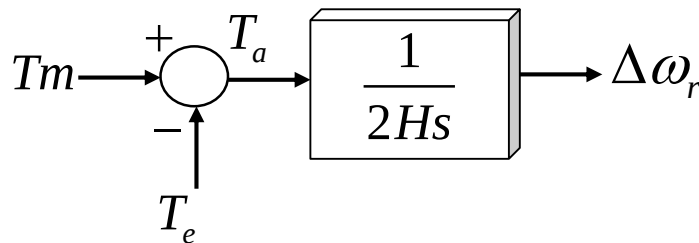


## Inertias in power systems

- Synchronous generator

Equation of motion:  $J \frac{d\omega}{dt} = T_m - T_e$

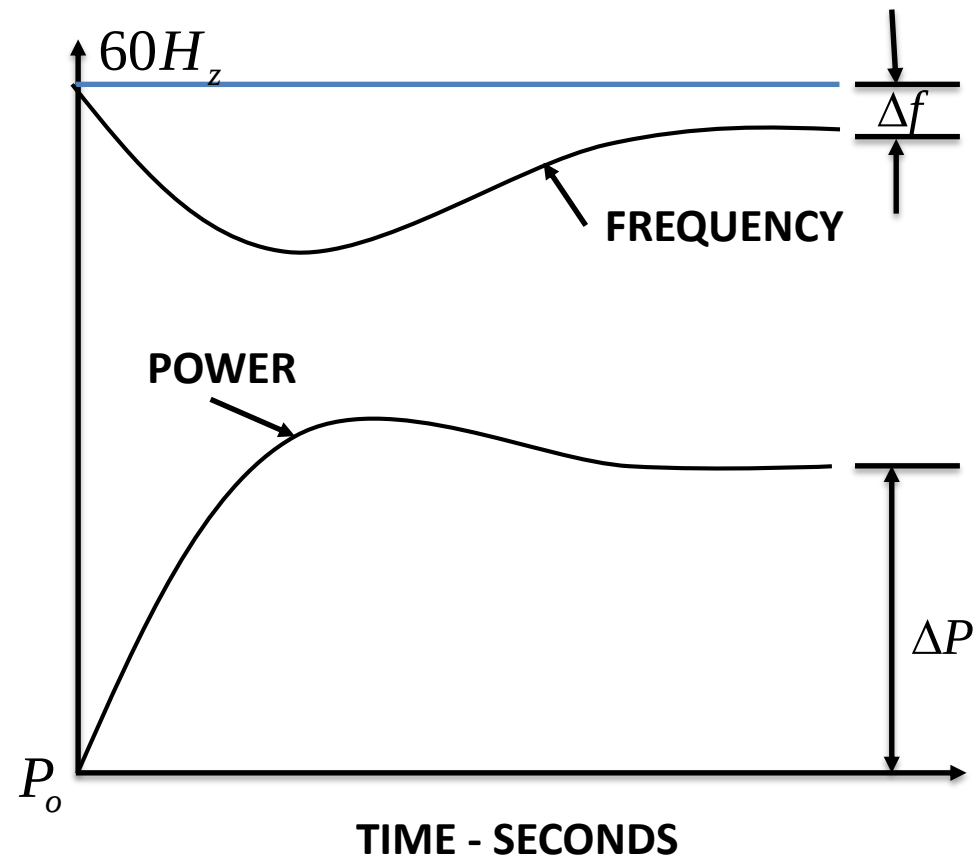
Inertia constant:  $H = \frac{\text{stored energy}}{\text{rating power}} = \frac{E}{P} [s]$  with  $E = \sum \frac{1}{2} J \omega^2$



|                  |                               |
|------------------|-------------------------------|
| $s$              | Laplace Operator              |
| $T_m$            | Mechanical torque (pu)        |
| $T_e$            | Electrical torque (pu)        |
| $T_a$            | Accelerating torque (pu)      |
| $H$              | Inertia constant (MW-Sec/MVA) |
| $\Delta\omega_r$ | Rotor speed deviation (pu)    |

## Inertias in power system

- Synchronous generator transient response



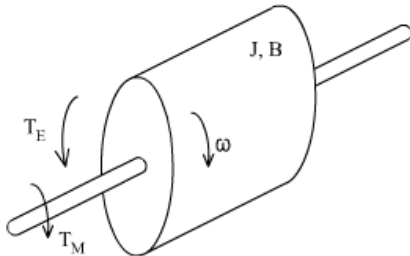
There is a dynamic and a static droop. The static droop coefficient is  $\Delta P / \Delta f$ .

# Virtual synchronous generators

## Synchronous Machine

$$J \frac{d}{dt} \omega = T_m - (T_e + B\omega)$$

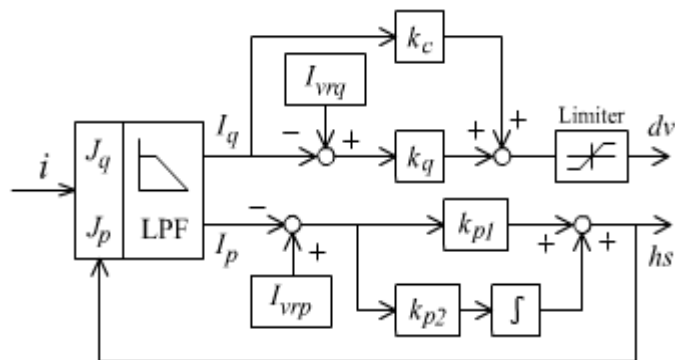
Synchronous Machine Motion Equation



Representation of a synchronous machine

- Inverters that mimic synchronous converters
- Kawamura's approach (2005)

## Independent Control

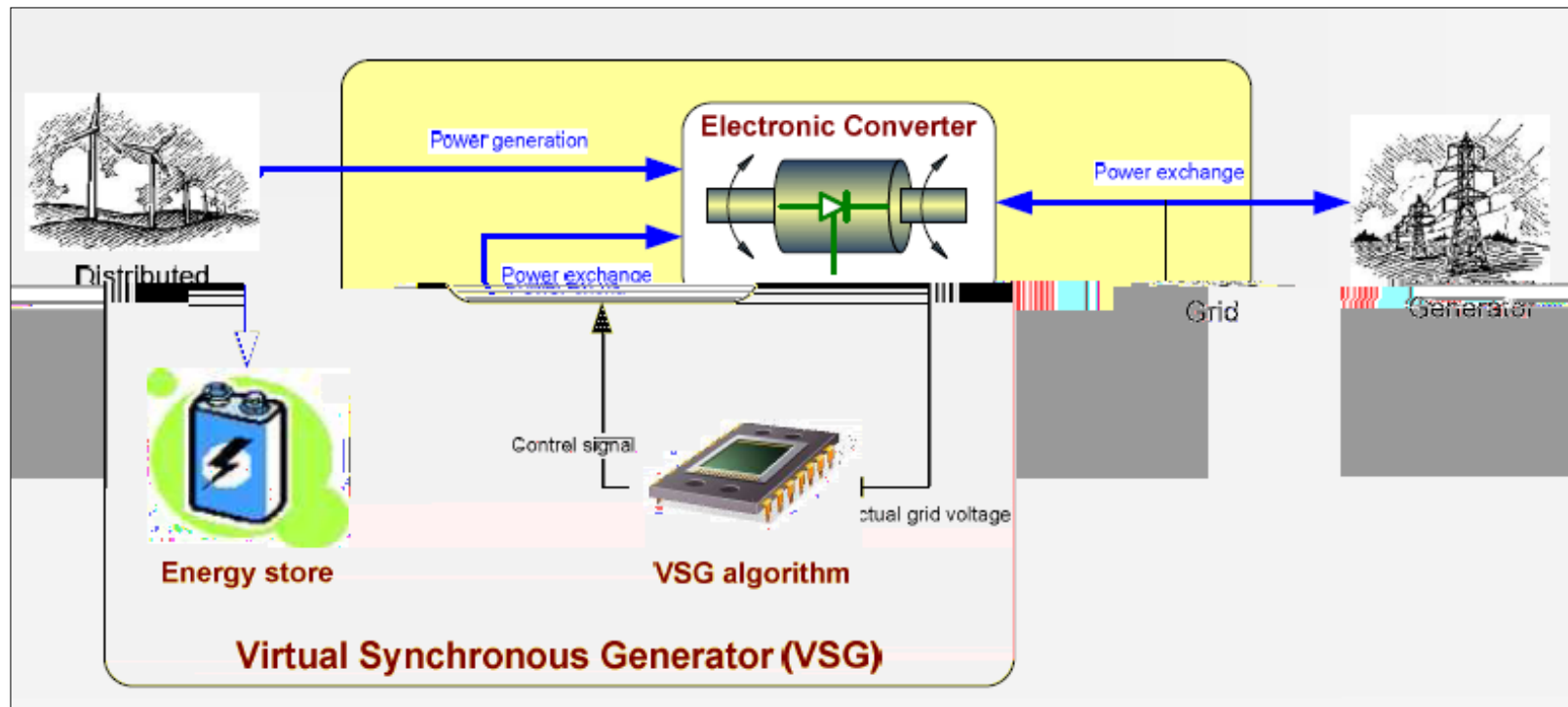


To determine  $dv$  and  $hs$  (amplitude variation and phase angle, respectively), the controller computes the active and reactive components ( $I_p$  and  $I_q$ , respectively) of the output current  $i$ .

High Reliability and High Performance Parallel-Connected UPS System with Independent Control

**Eduardo Kazuhide Sato**

# Virtual synchronous generators



*Inertias means not only load-dependent frequency (droops),  
but also local storage energy system.*

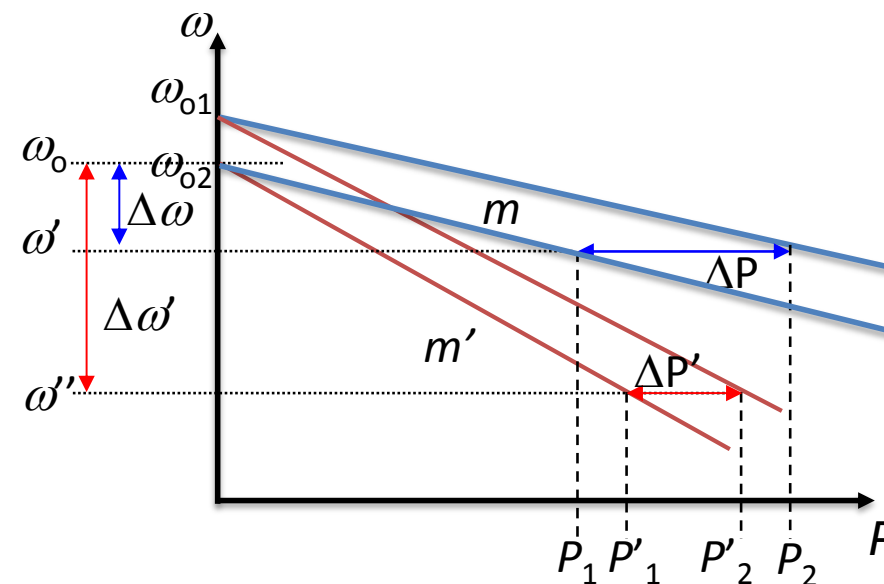
European Project VSYNC: <http://www.vsync.eu>

## Droop control of AC systems

- Trade-off power sharing / amplitude - frequency regulation

$$\omega = \omega^* - mP$$

$$E = E^* - nQ$$



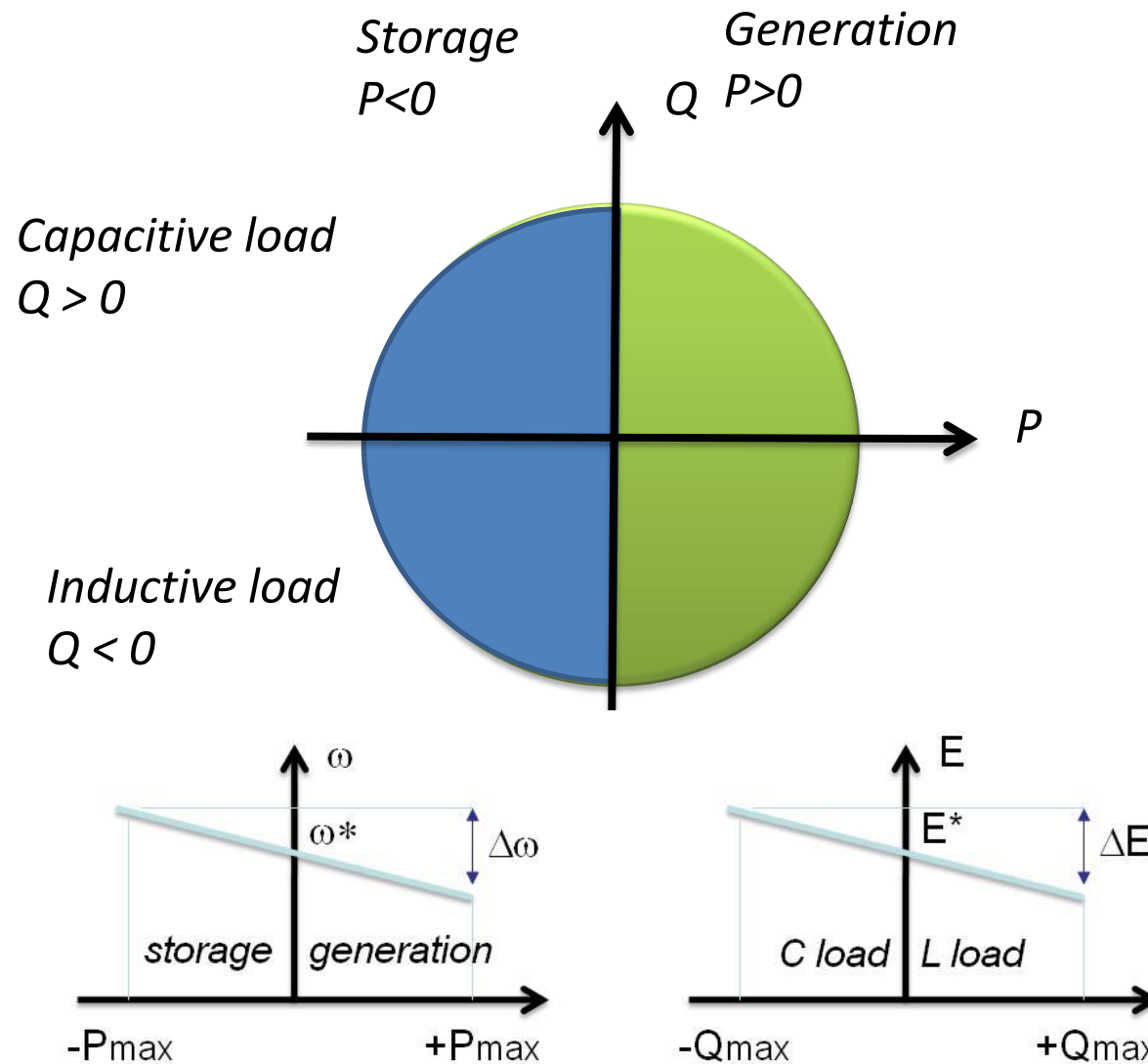
$$\Delta\omega_{\max} = 2\%$$

$$\Delta E_{\max} = 5\%$$

Phase droops are not feasible since the initial phase of each inverter is different!

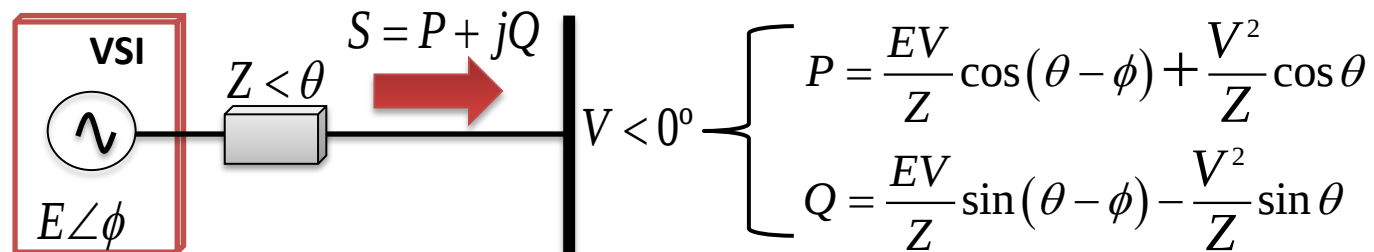
# Droop control for AC MGs

## Droop control of AC systems



## Generalized droop control

- Study of P/Q flow in function of the output impedance



By using the Park transformation, the droop method functions become

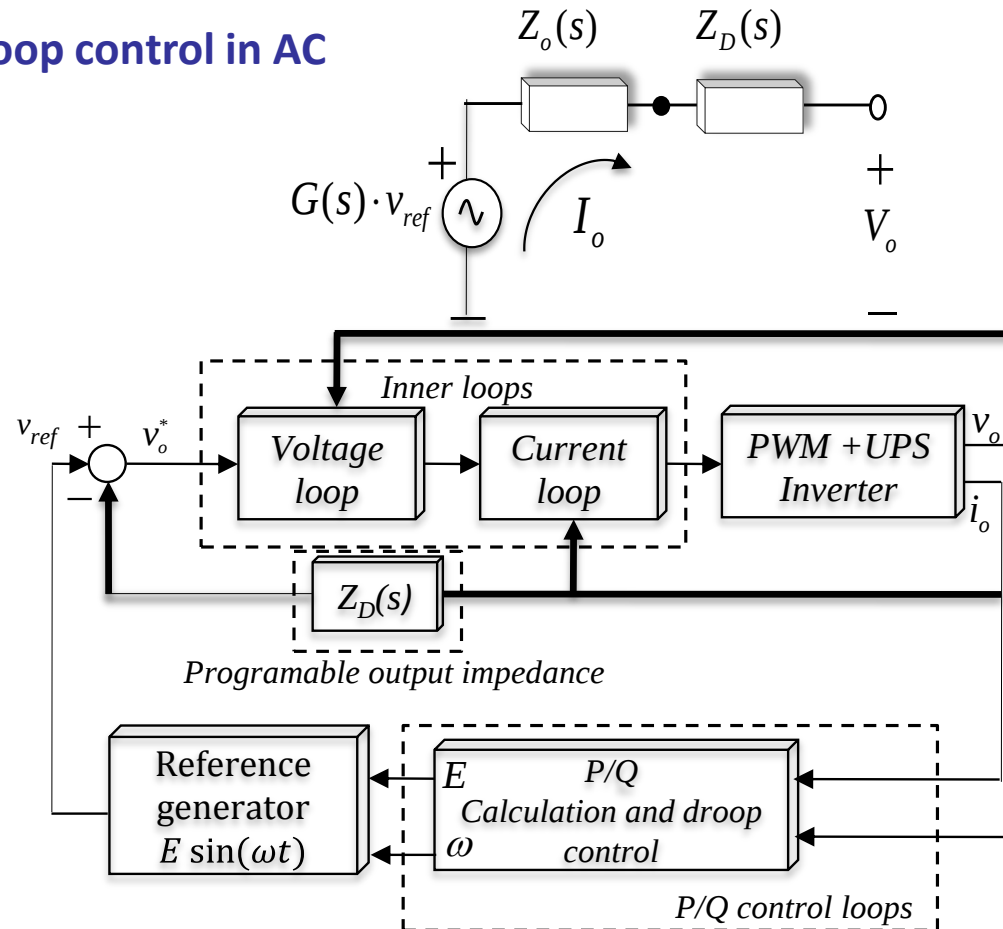
$$\omega = \omega^* - m(P \sin \theta - Q \cos \theta)$$

$$E = E^* - n(P \cos \theta + Q \sin \theta)$$

The R – V virtual resistance in a DC microgrid can be seen as Q – V droop in an inductive AC microgrid. The  $\omega$  – P droop is added to synchronize the system.

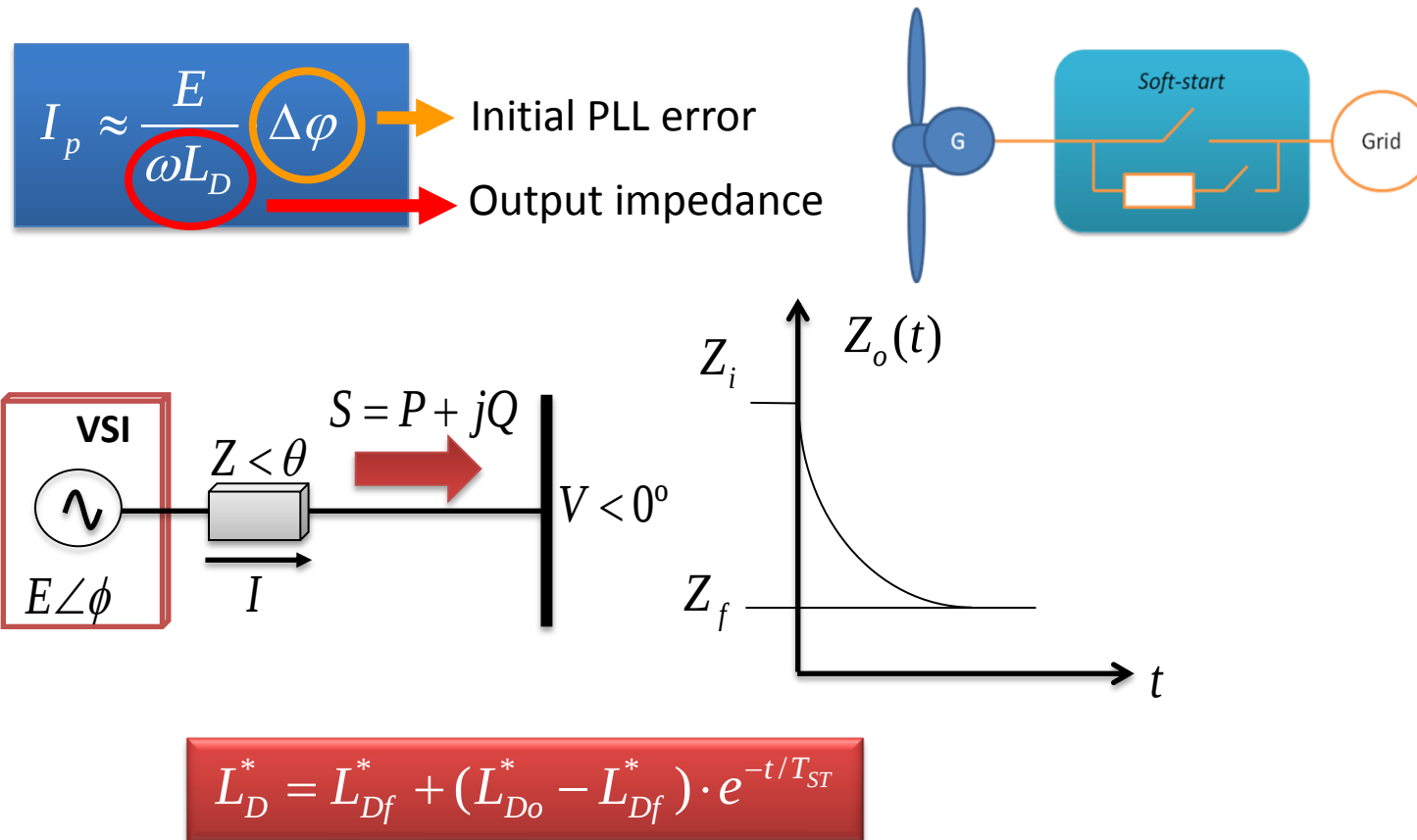
## Virtual Impedance concept

- Droop control in AC



Objective: fix the output impedance

## Soft-start operation

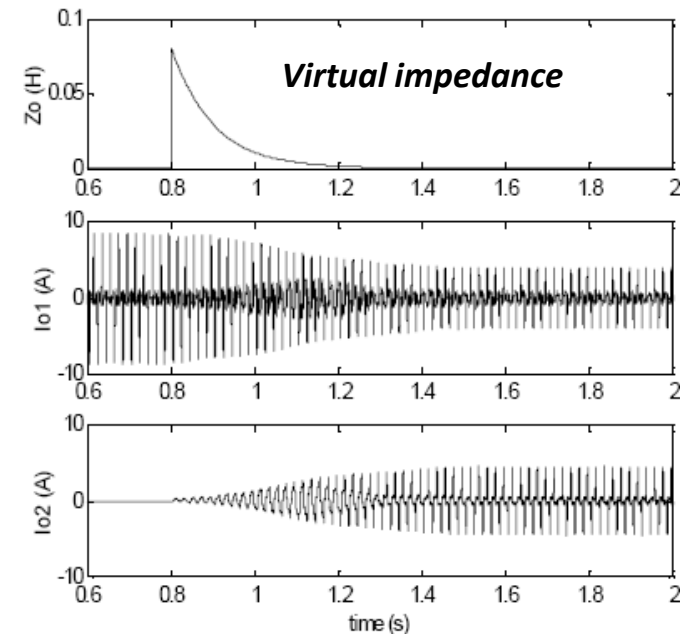
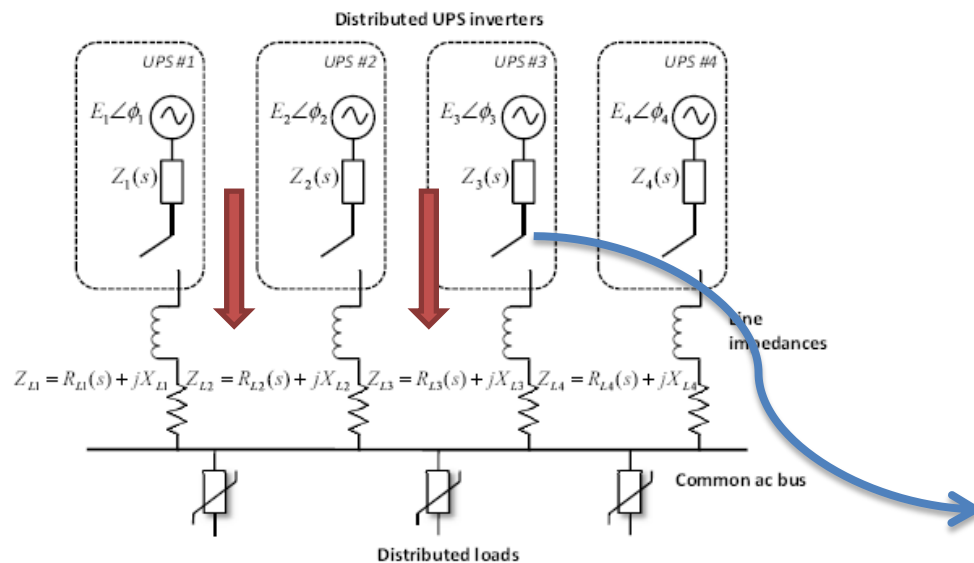


The virtual output impedance is a control variable.

Increasing the output impedance can reduce the initial current peak at the connection

## Hot-swap capability

4 DG units microgrid



**Output currents**

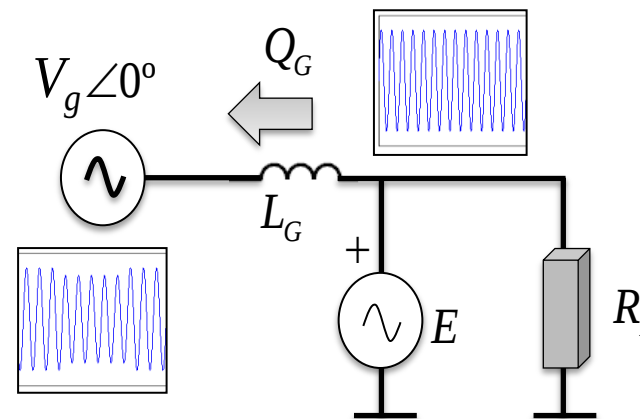
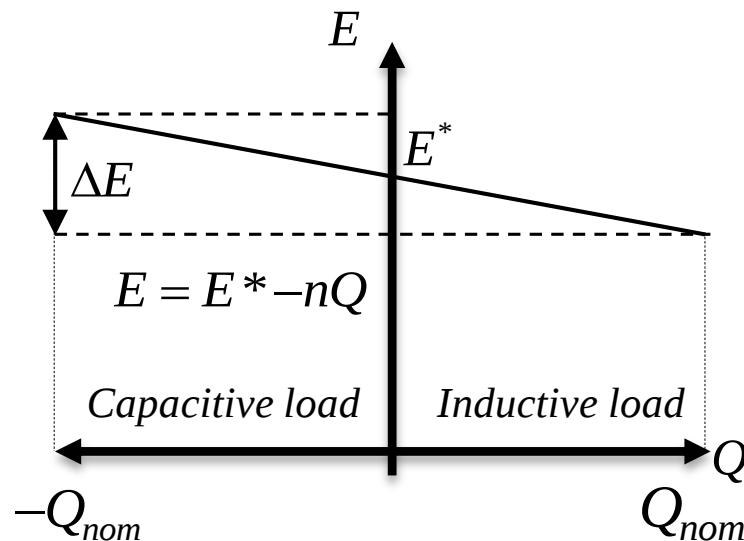
Before the connection,  
a PLL have to synchronize the DG with the MG.

At the connection the virtual impedance is high to reduce the initial current peak.

This capability allow us to connect DGs without stop the microgrid, for maintenance reasons.

## Low voltage ride-through

- Reactive power control of a grid-connected DG.

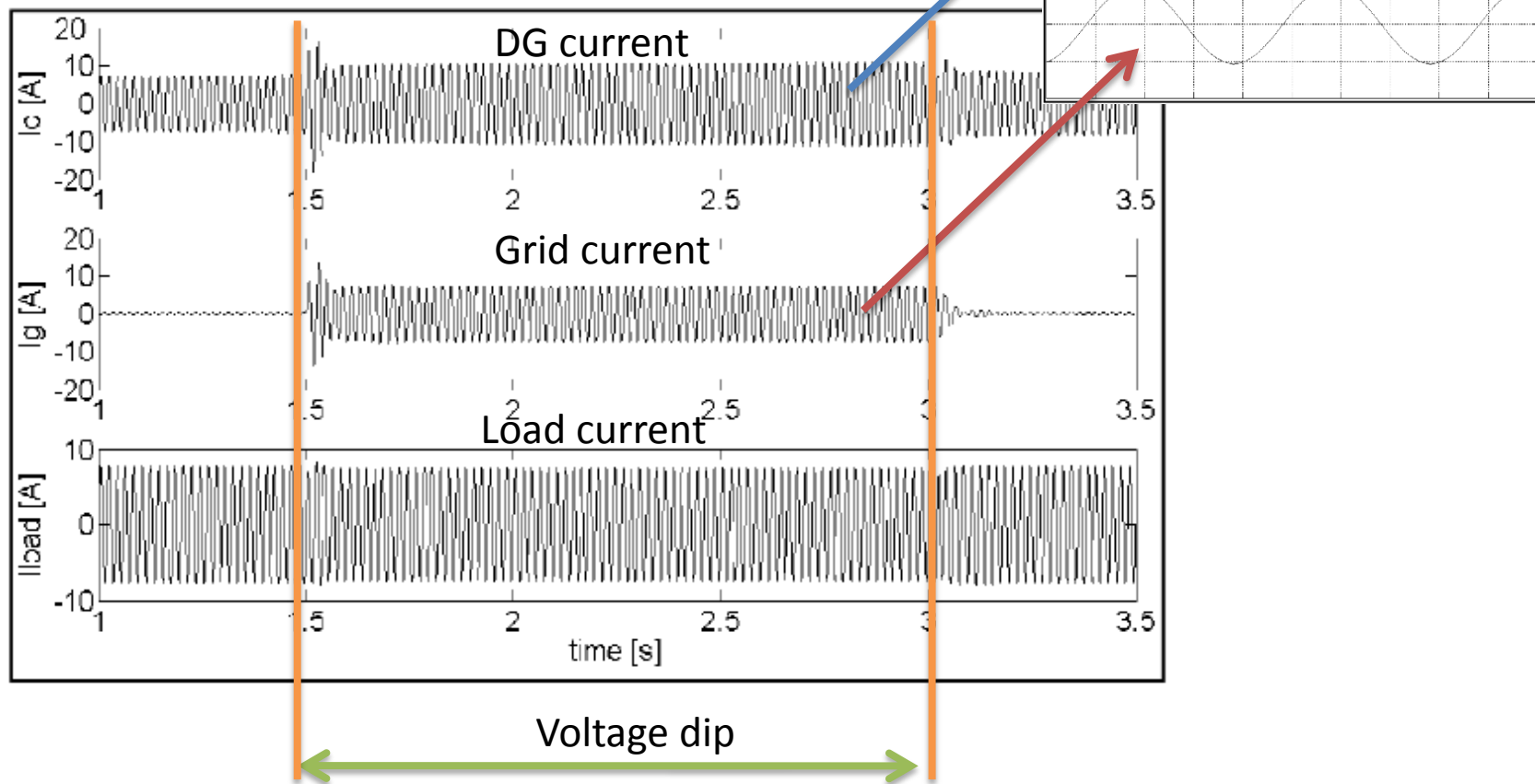


Trade-off during voltage dips: 1) voltage follower ( $Q=0$ ) 2) stiff voltage source ( $Q$  high)

# Low voltage ride-through

## Low voltage ride-through

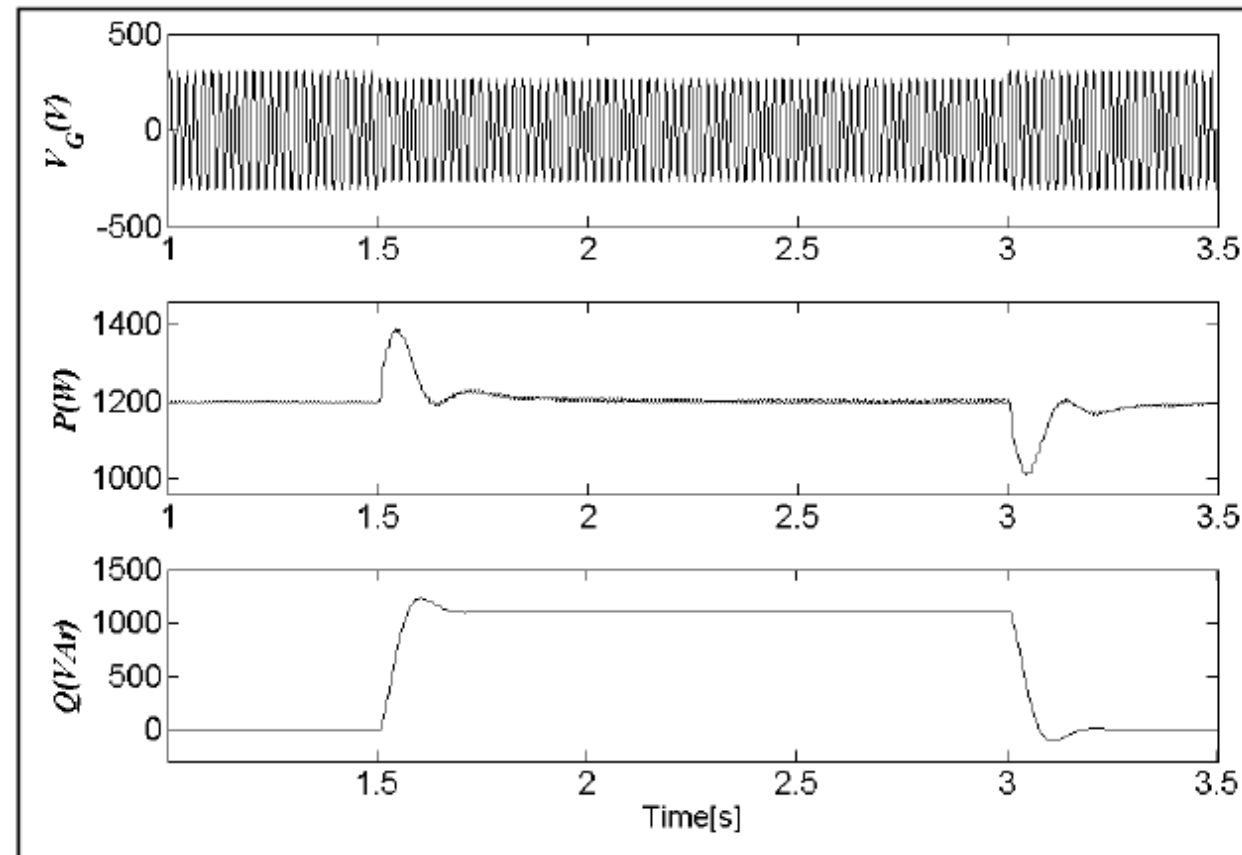
- Reactive power control of a grid-connected DG.



During the voltage grid, the converter injects reactive current ( $90^\circ$ )

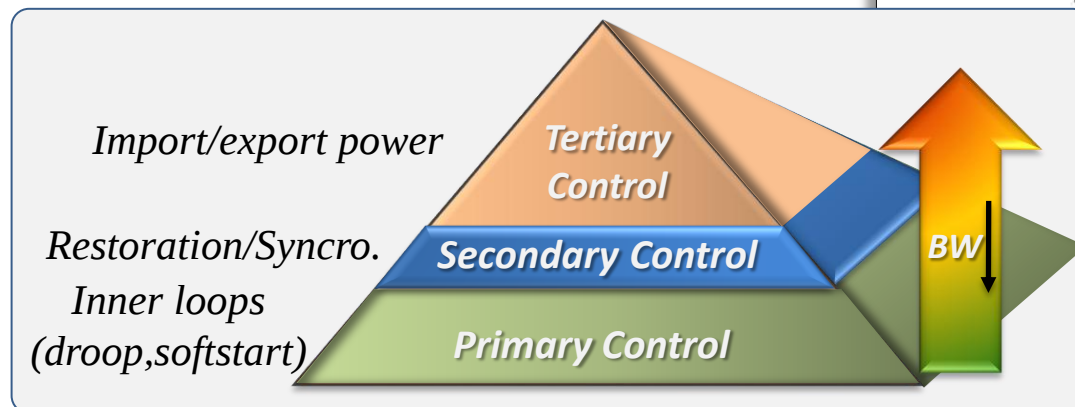
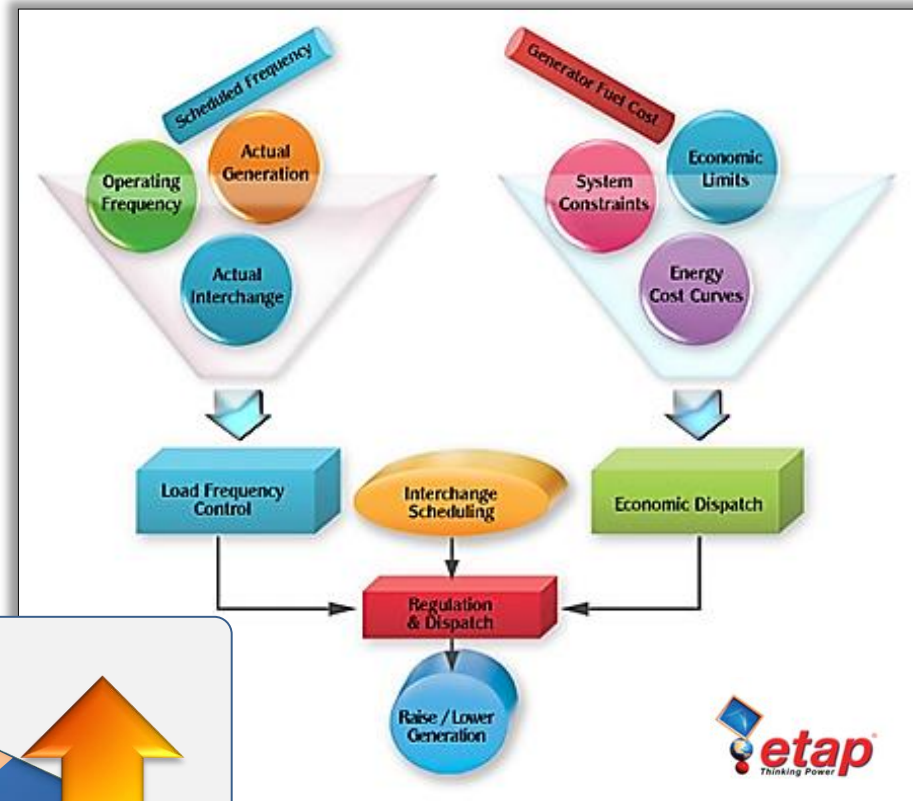
## Low voltage ride-through

- Reactive power control of a grid-connected DG.



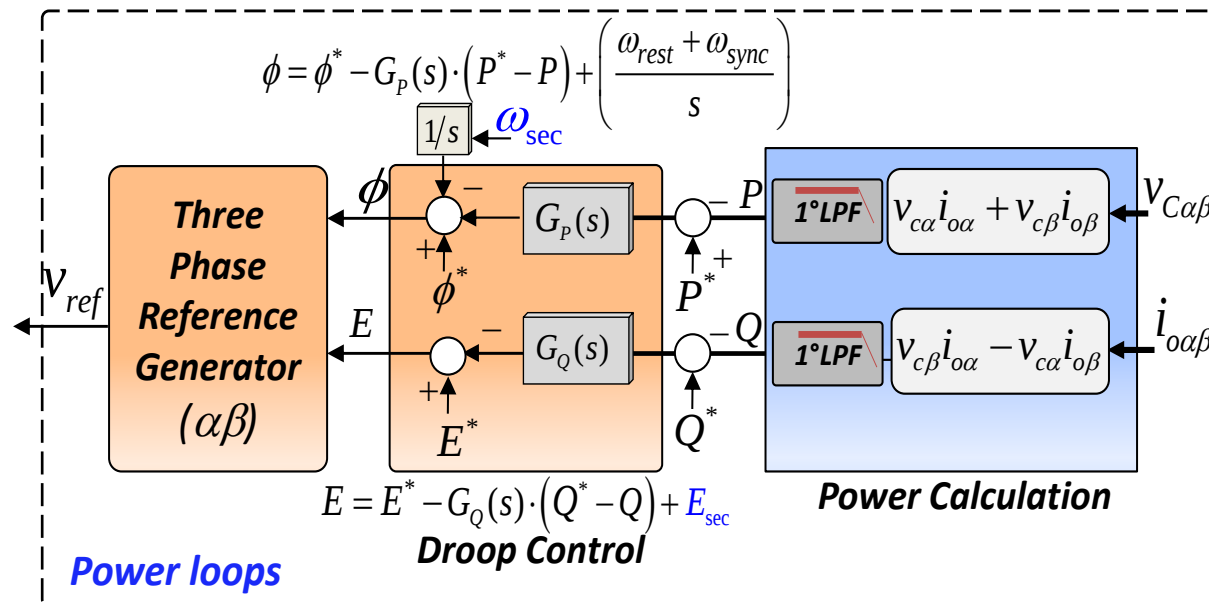
Active power remains constant (to the load). Reactive power is injected to maintain the voltage inside the droop characteristic.

## Hierarchical Control Principle

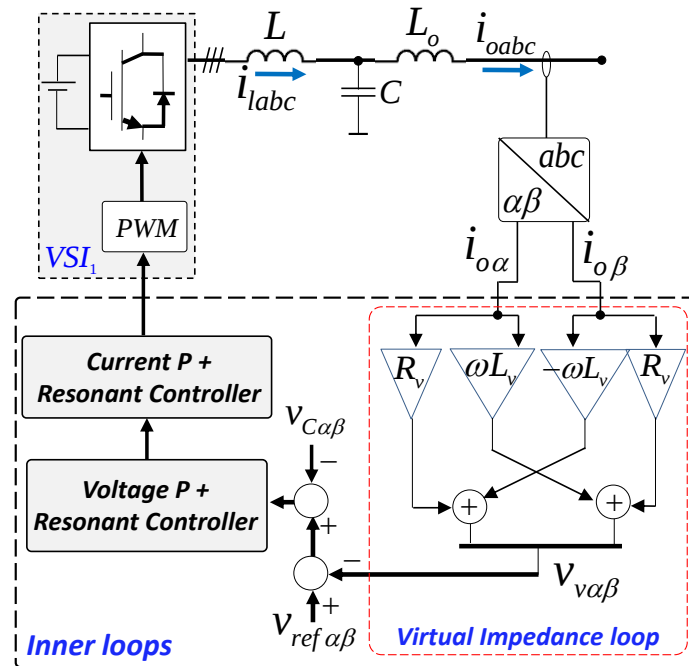


# Hierarchical control

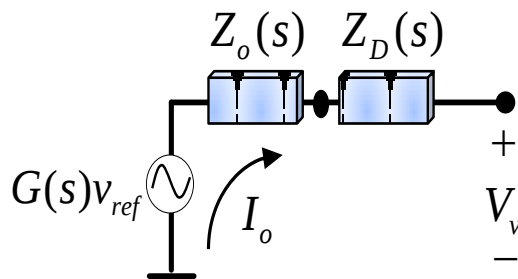
## Droop control for three phase VSIs



## Virtual impedance control for three phase VSIs



$$\begin{cases} V_{V\alpha} = R_v \cdot i_{o\alpha} - \omega L_v \cdot i_{o\beta} \\ V_{V\beta} = R_v \cdot i_{o\beta} + \omega L_v \cdot i_{o\alpha} \end{cases}$$



$$v_{out}(s) = G(s)v_{ref} - Z_o(s)i_o$$

$$Z_o(s) = \frac{\frac{1}{Cs} + G_v(s)G_i(s)G_{PWM}(s)Z_D(s)}{LCs^2 + (Cs + G_v(s))G_i(s)G_{PWM}(s) + 1} + L_o s$$

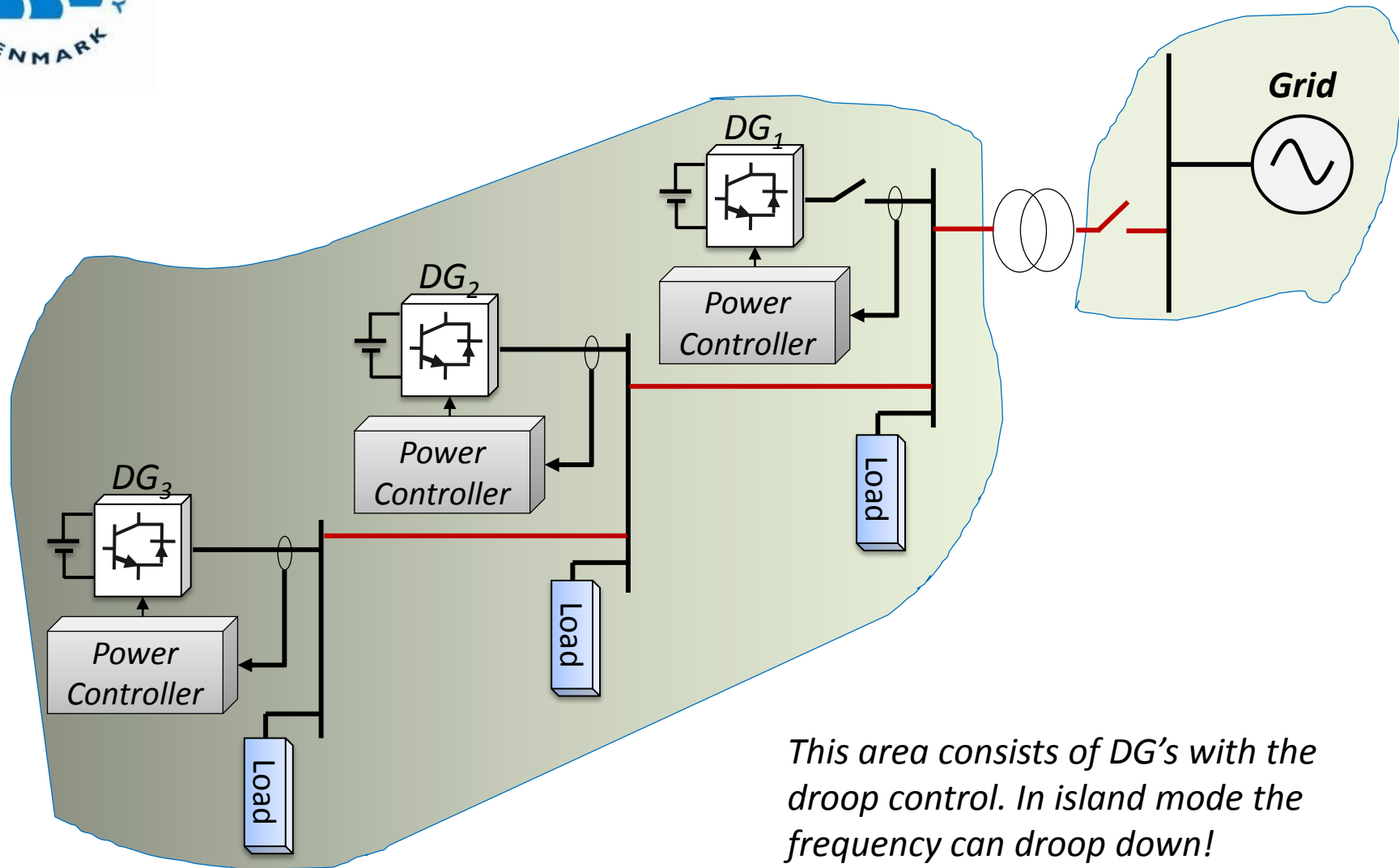
## Islanding microgrids

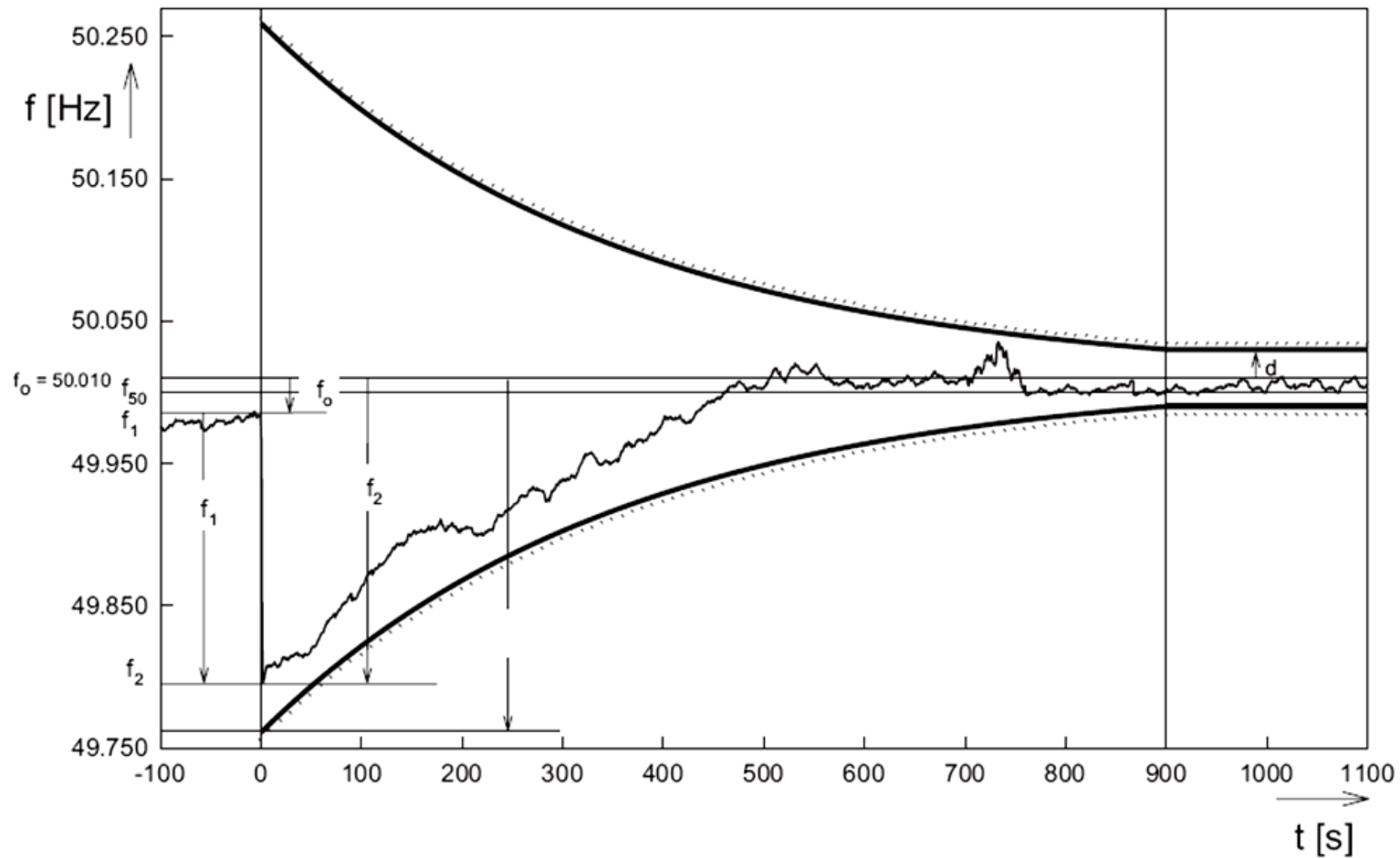
- Grid-connected microgrids operate synchronized with the grid
- Islanded microgrids:
  - Frequency and amplitudes are load-dependent
- Secondary control can contribute to:
  - Frequency restoration
  - Amplitude regulation
  - Power quality (harmonics and unbalance compensation)

Energy management system can be used to:

- Load shedding
- Regulation of the generator's consumption

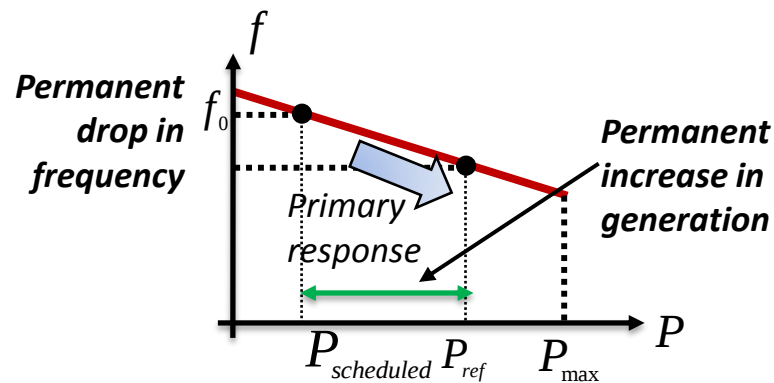
# Secondary Control in Electric Power Systems





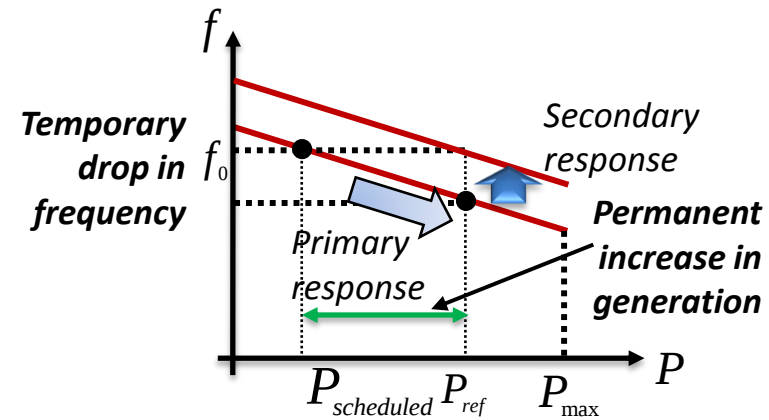
Source: UCTE. A1 – Appendix 1: Load-Frequency Control and Performance

## Secondary control action



a)

No secondary control



b)

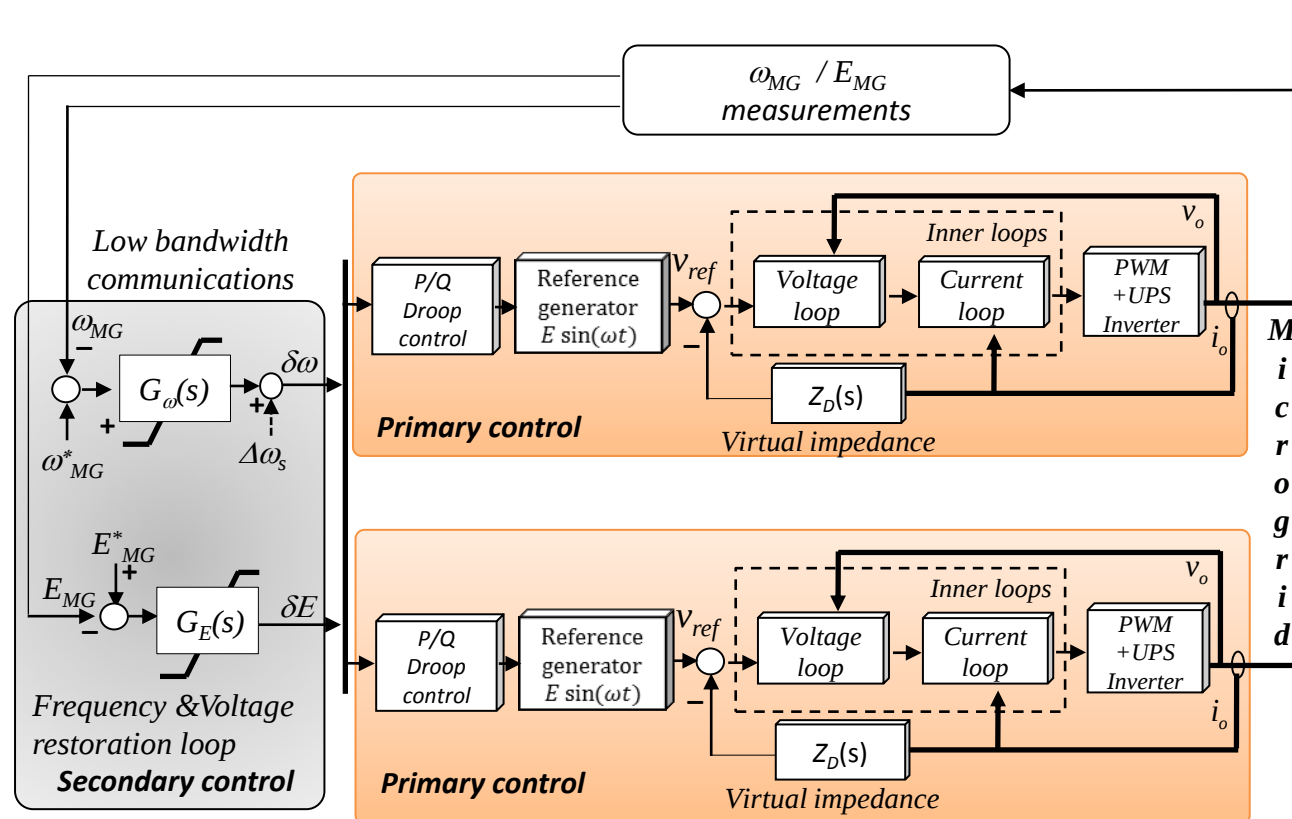
Using secondary control

Primary control ensures  $P$  sharing by drooping the frequency

### Secondary control:

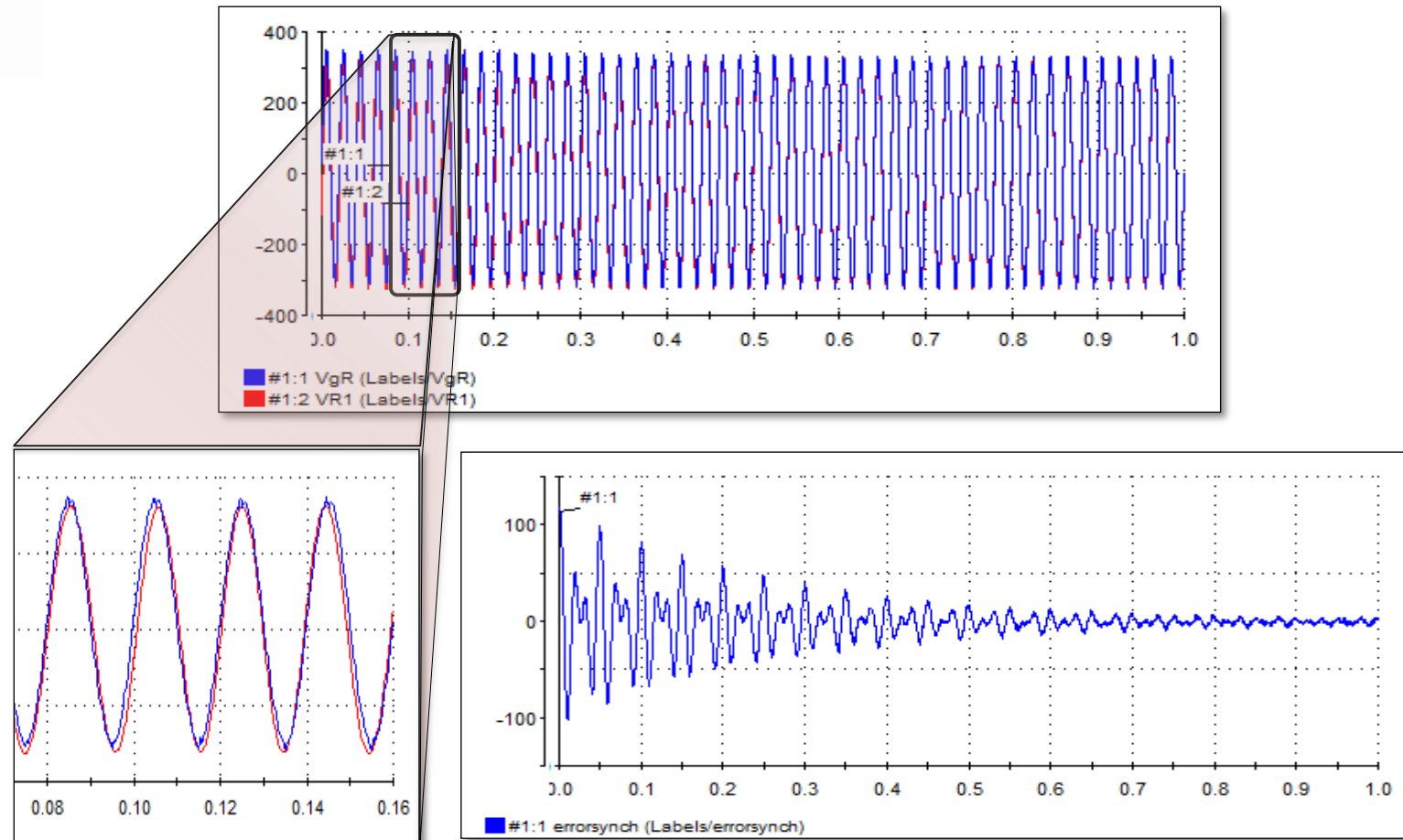
- Restore the nominal frequency
- Cannot work locally, it needs to be centralized.

## Secondary control Implementation



Secondary control is located in the Microgrid Central Controller measure frequency and voltage. The output of the control is send through communications to adjust the reference of the local primary controllers (*droops*).

# Microgrid synchronization with the grid

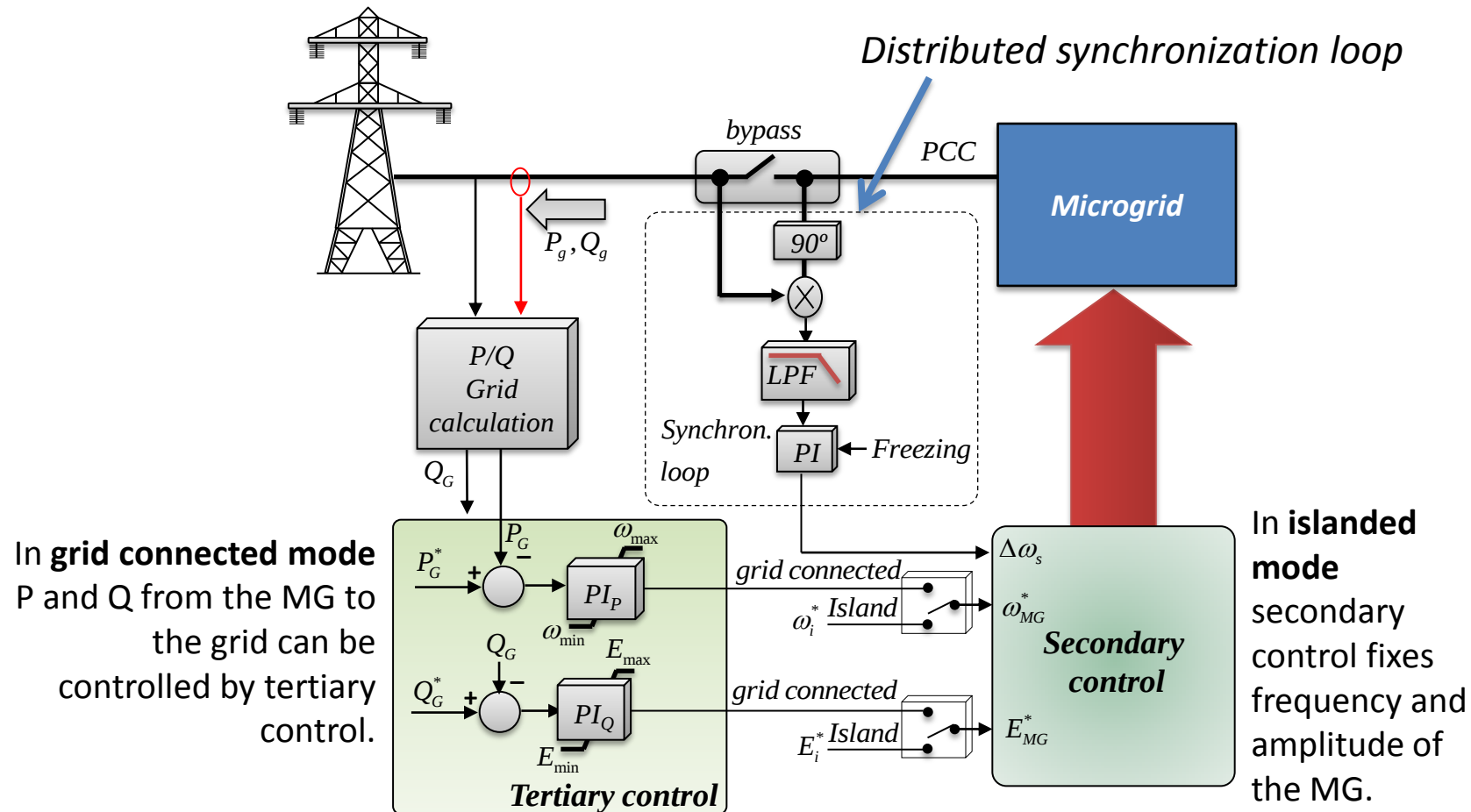


*Synchronization is not necessary to be fast. **Slow** (to avoid instability problems) but well **accurate** (allowing seamless transition to grid-connected mode).*

# Tertiary Control

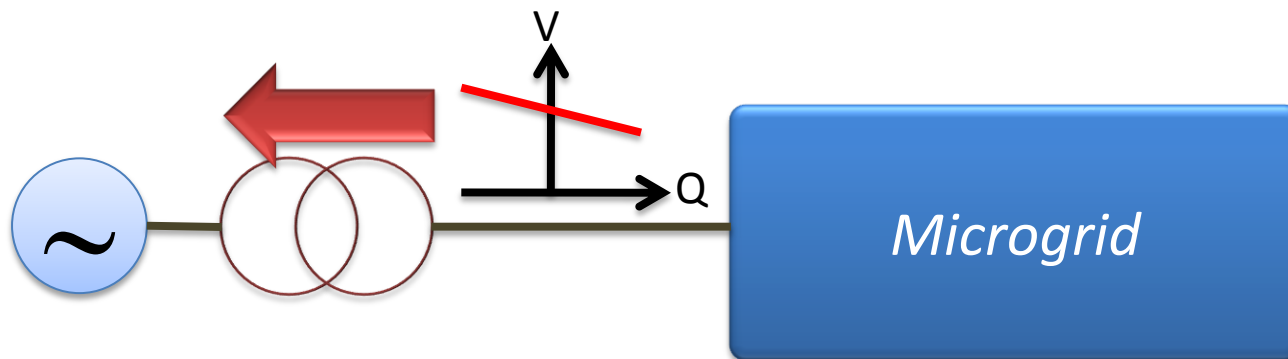
## Tertiary control for AC microgrids

- Tertiary control and synchronization control loops implementation

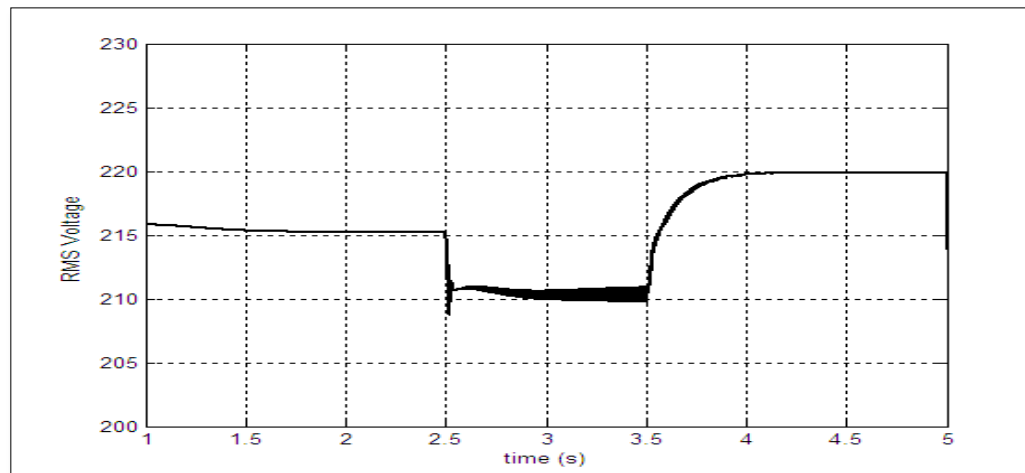
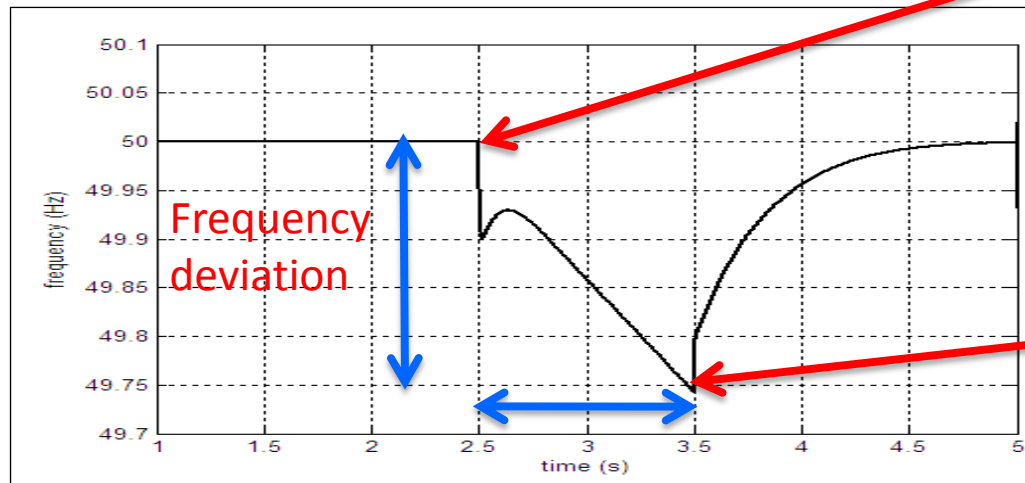


## Tertiary control for AC microgrids

- Low voltage ride-trough of the Microgrid
  - *Freezing or disconnecting the integral term of the  $E - Q$  tertiary control.*
  - *The Microgrid will work like a STATCOM*



## Islanding detection



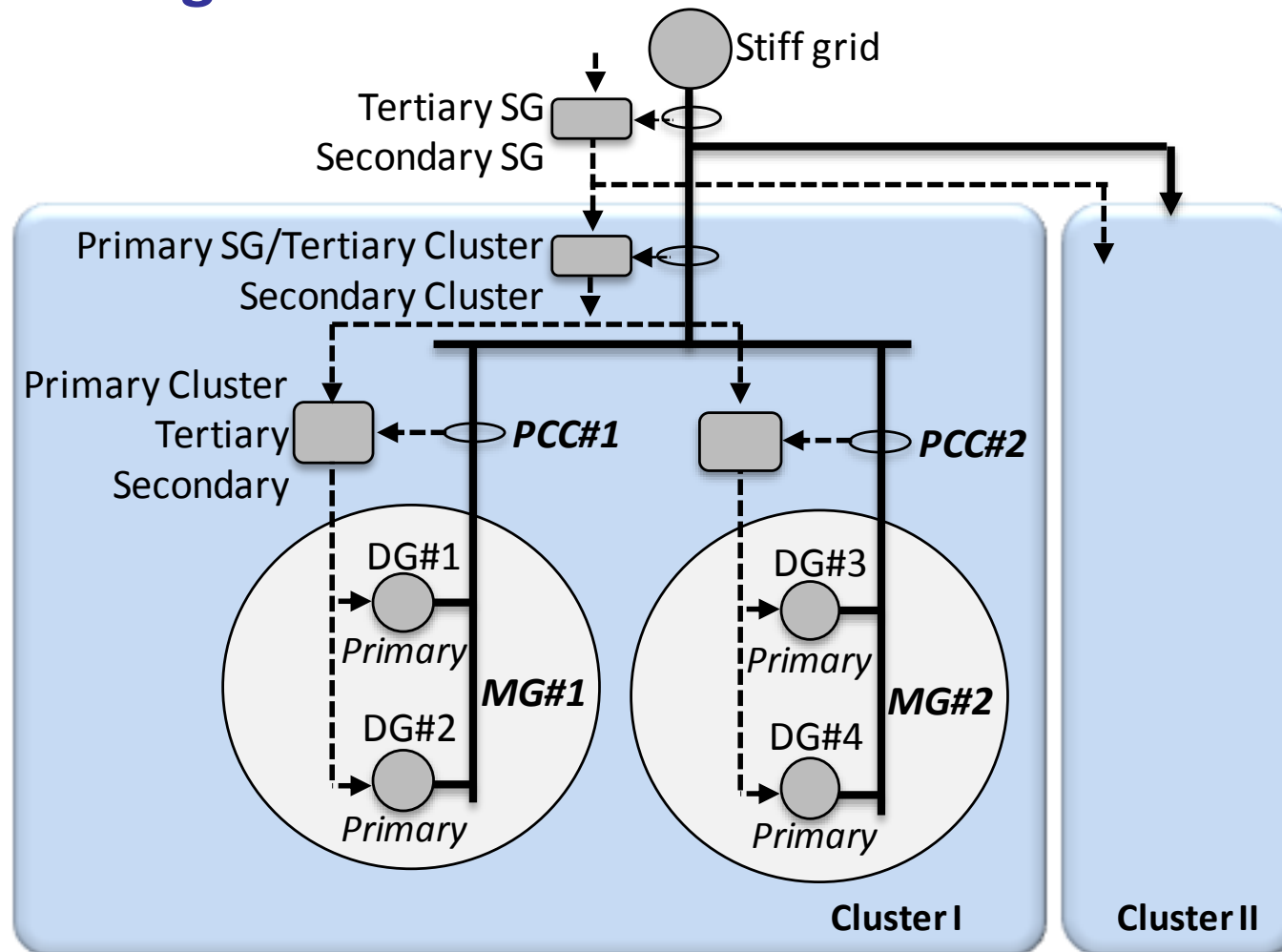
*Non-planning  
Islanding*

*Islanding detection*



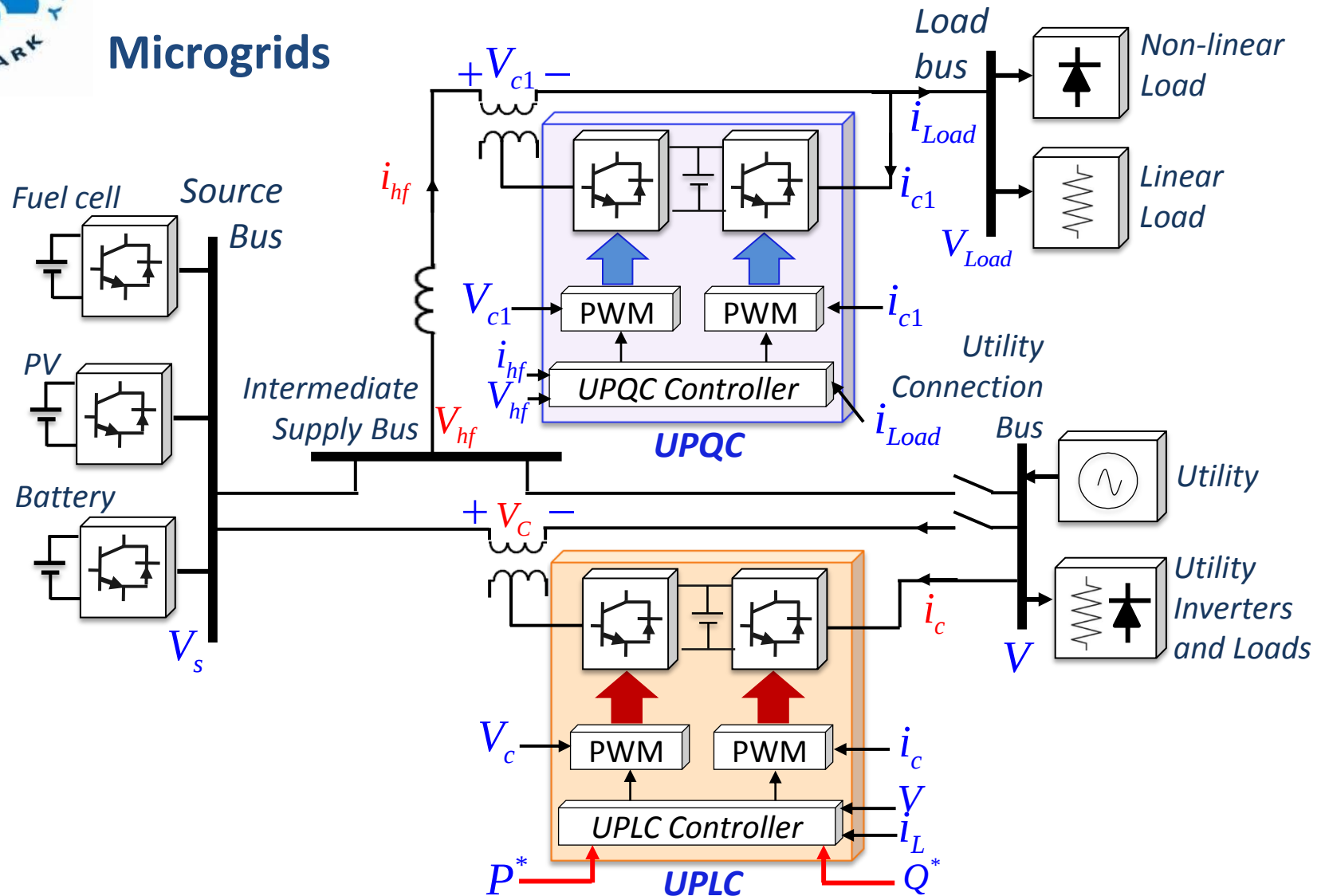
*STS open (protection)  
Q integrators  
disconnected*

## Microgrids interconnection



# Power Quality in Microgrids

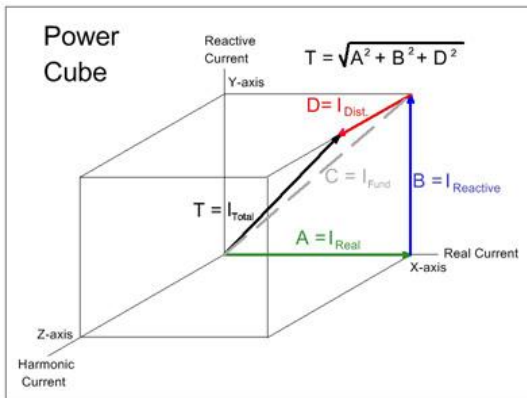
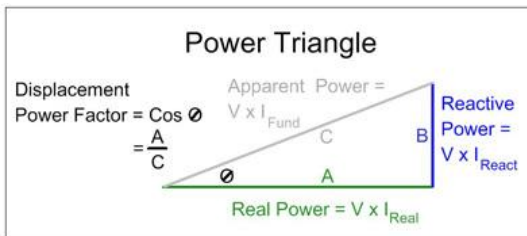
## Microgrids



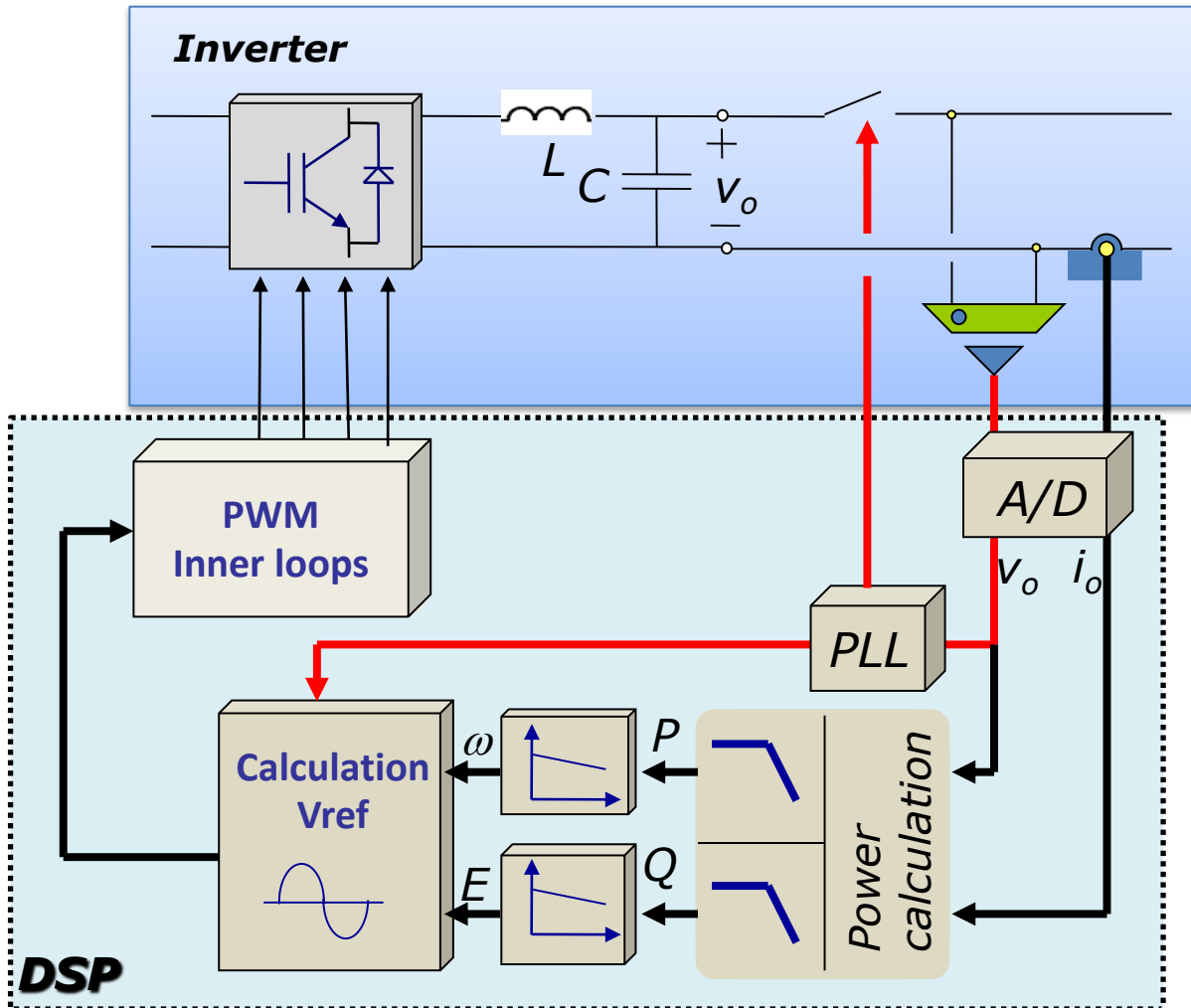
Advanced Active Filtering in a Single Phase High Frequency AC Microgrid - **Sudipta Chakraborty**

## Harmonic current sharing

- ❖ Droop control allows P and Q sharing, averaged over the fundamental frequency.
- ❖ It is not able to guarantee harmonic current sharing!

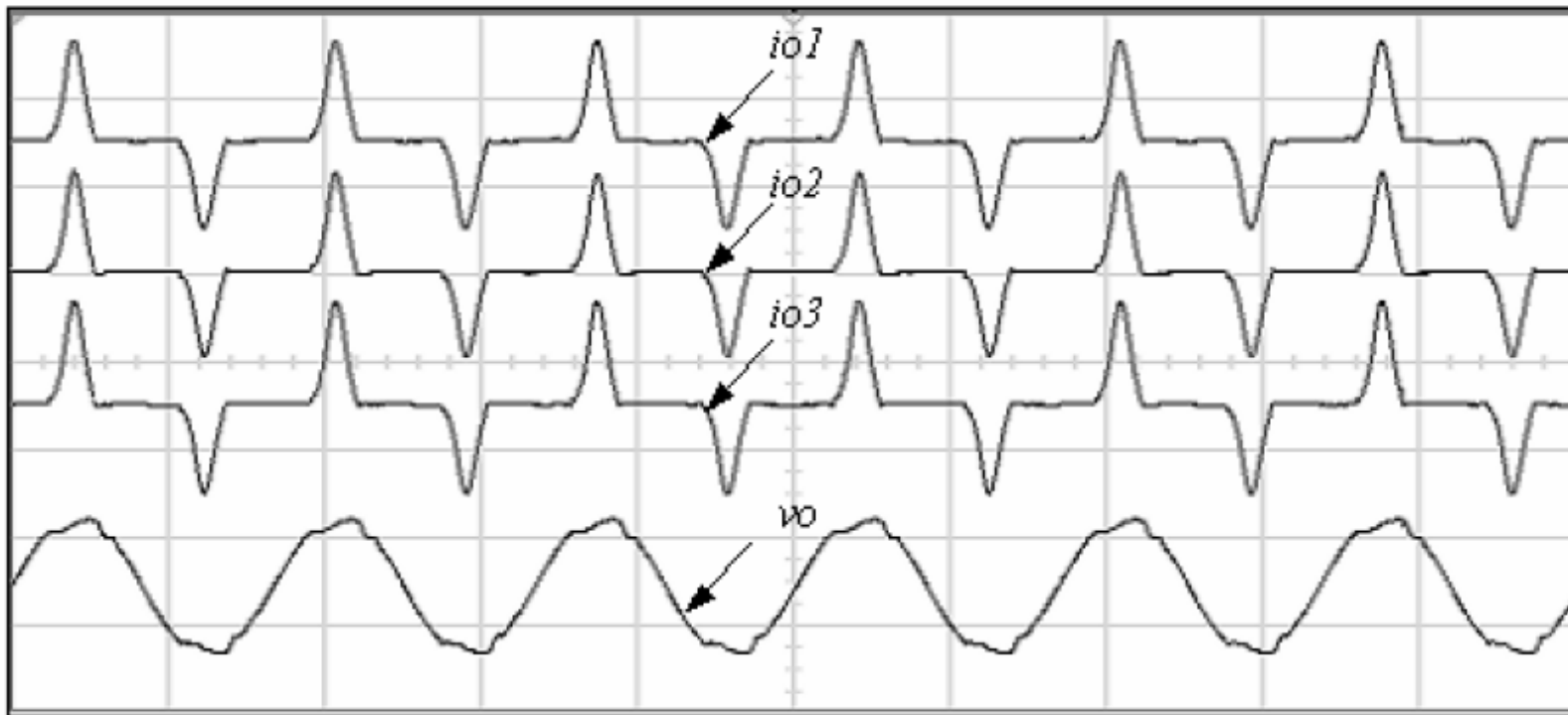


$$D = \sqrt{S^2 - P^2 - Q^2}$$



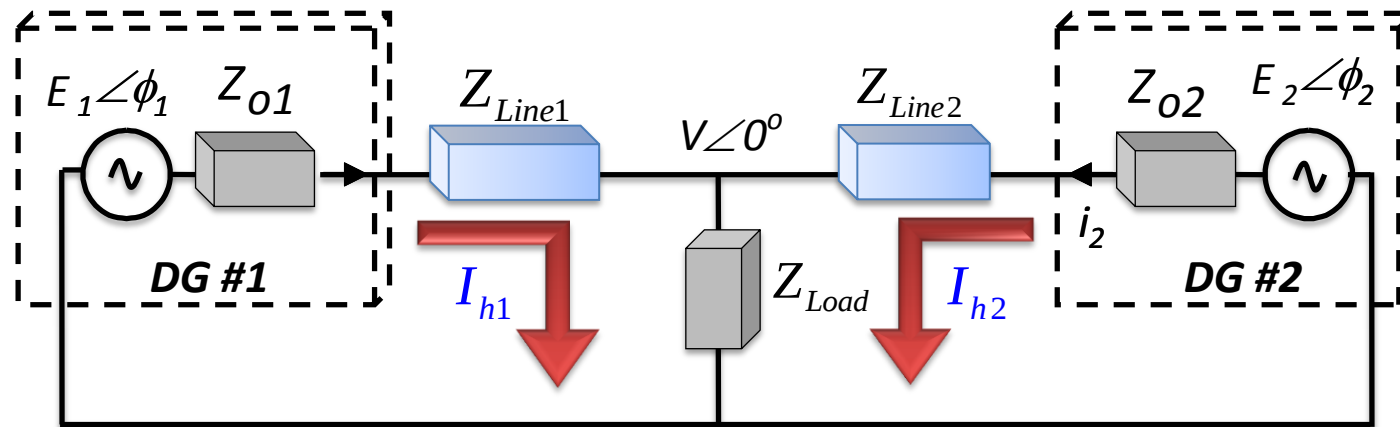
## Harmonics current sharing

- Control objective: Harmonic current sharing proportional to the nominal DG power.
- Trade off: harmonic current sharing/voltage THD



Source: Y. E. Wu

## Harmonics current sharing



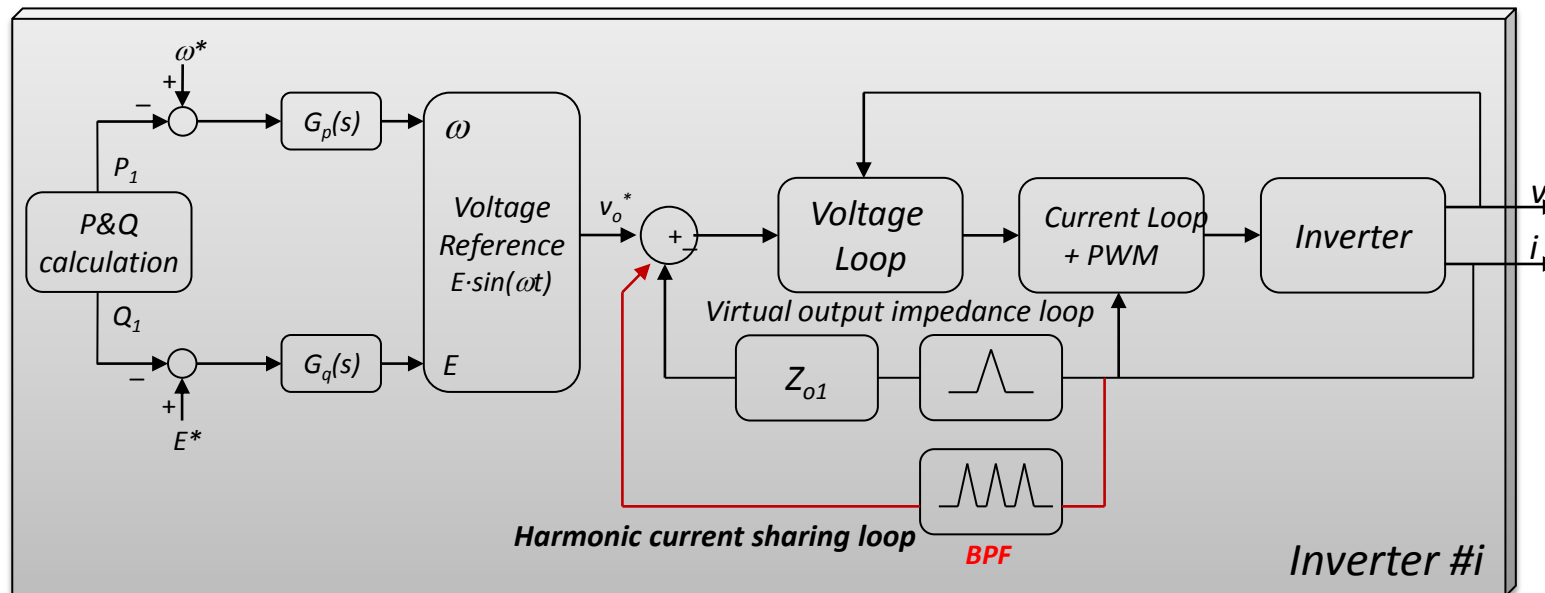
- For  $Z_{line1} \neq Z_{line2}$ , harmonic current sharing is not possible
- Harmonic virtual impedance can enhance sharing

$$Z_h = V_h / I_h$$

- Trade off  $V_{THD}$  and harmonic current sharing.

## Droop control

*Virtual Output Impedance with harmonic current sharing loop*

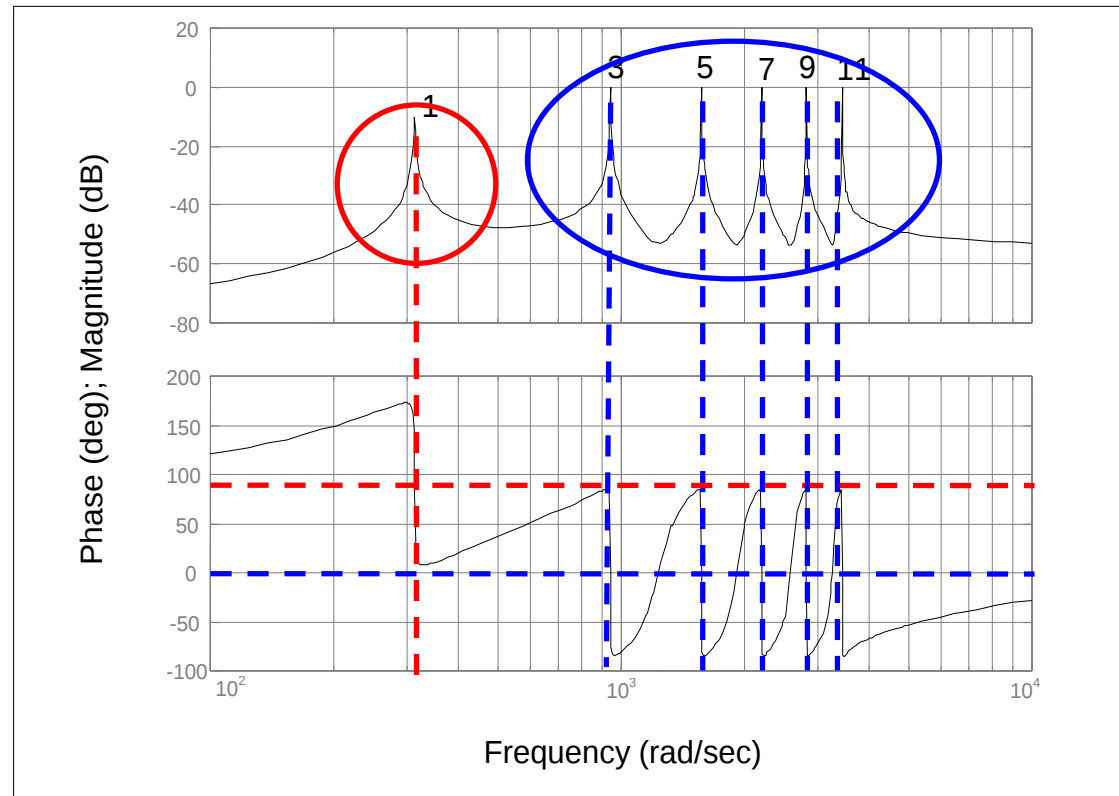


Selective harmonic selection: fundamental and each of the harmonics can have different output impedance.

## Harmonic current sharing

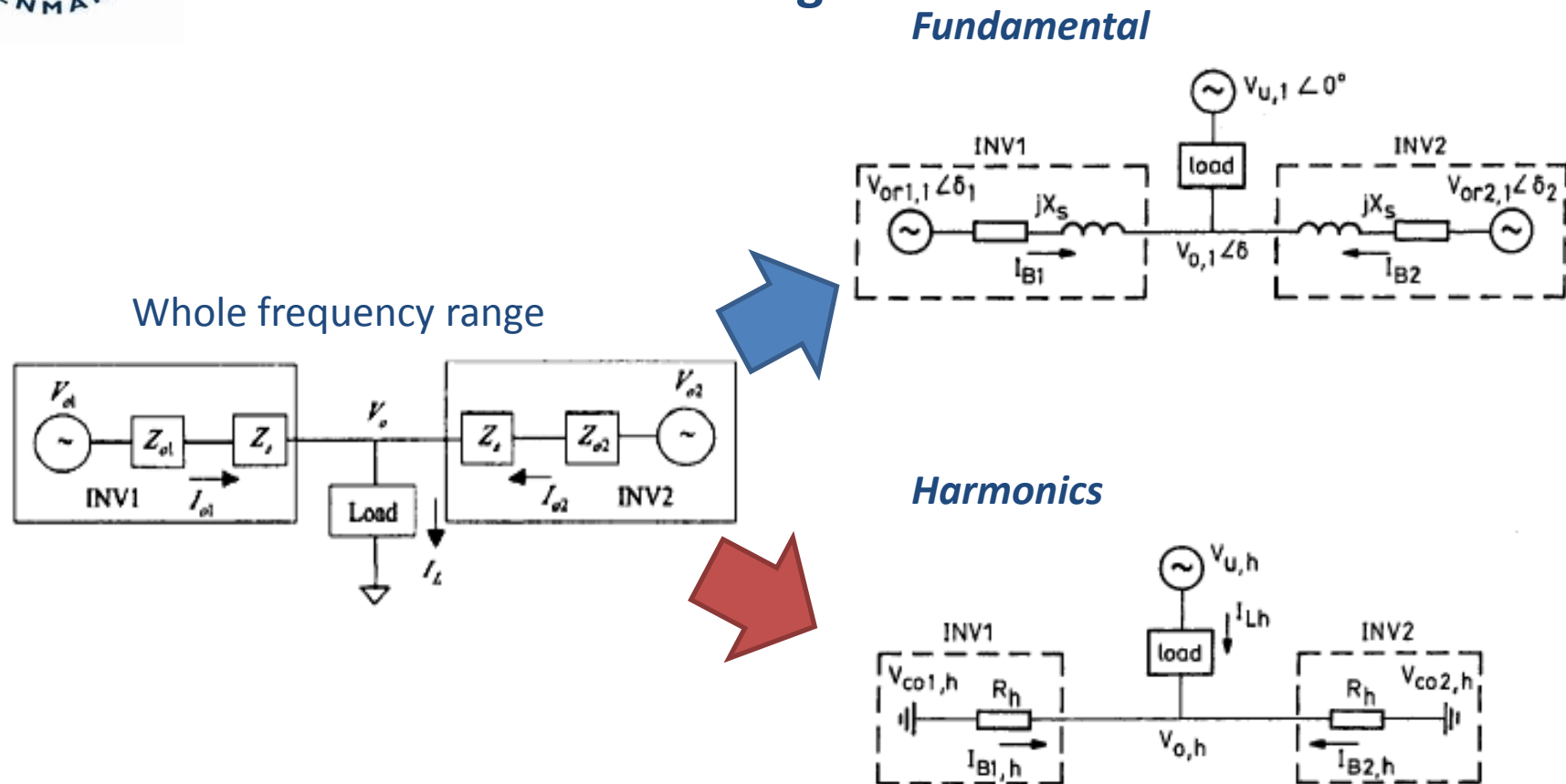
$$H_i(s) = \frac{2k_i s}{s^2 + 2k_i s + \omega_i^2}$$

$$Z_V(s) = L_D \frac{2k_1 s^2}{s^2 + 2k_1 s + \omega_1^2} + \sum_{\substack{i=3 \\ \text{odd}}}^n R_i \frac{2k_i s}{s^2 + 2k_i s + \omega_i^2}$$



# Power Quality in Microgrids

## Harmonic current sharing

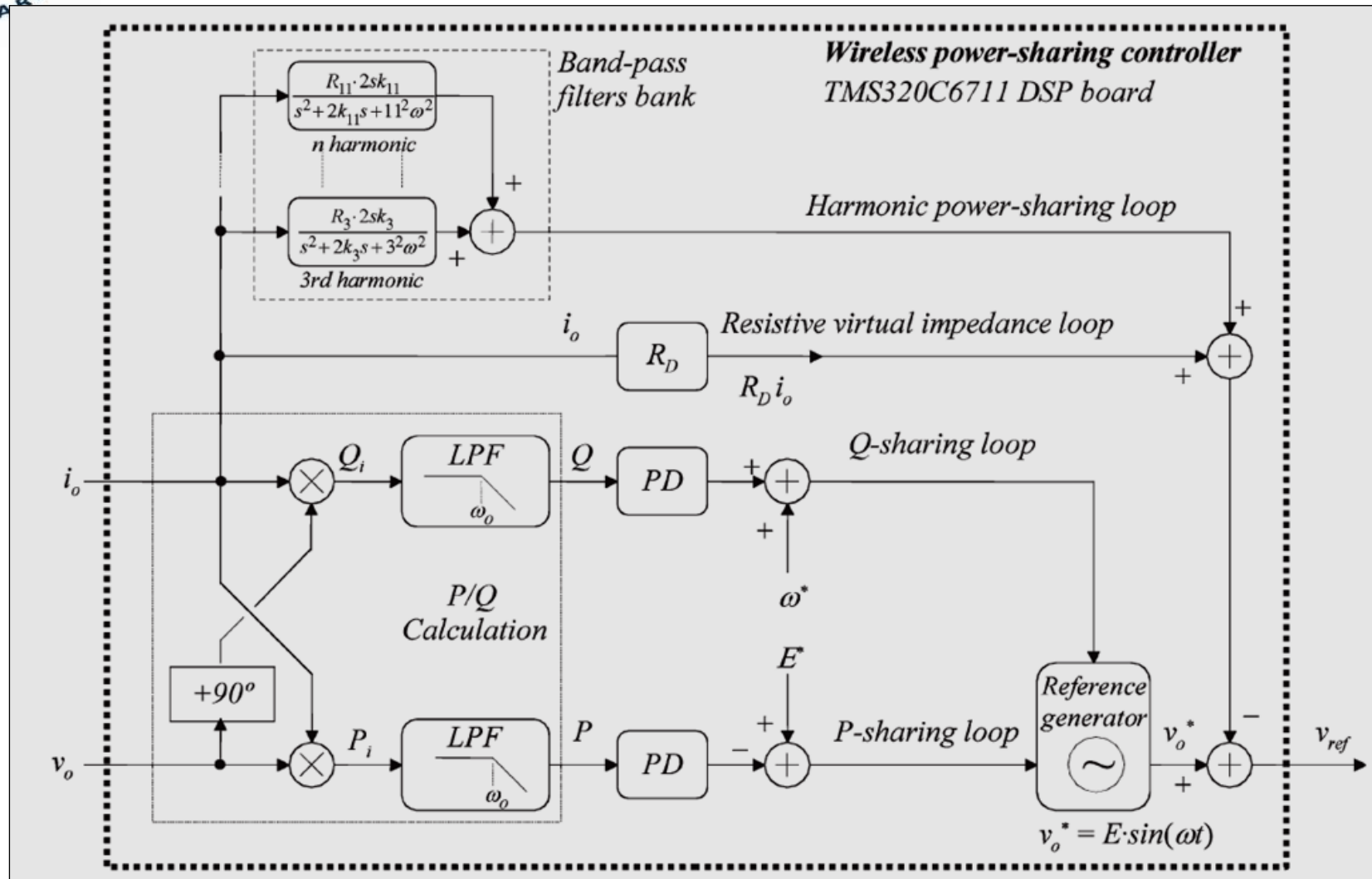


Parallel Control of the UPS Inverters With Frequency-dependent Droop Scheme

*S. J. Chiang and J. M. Chang*

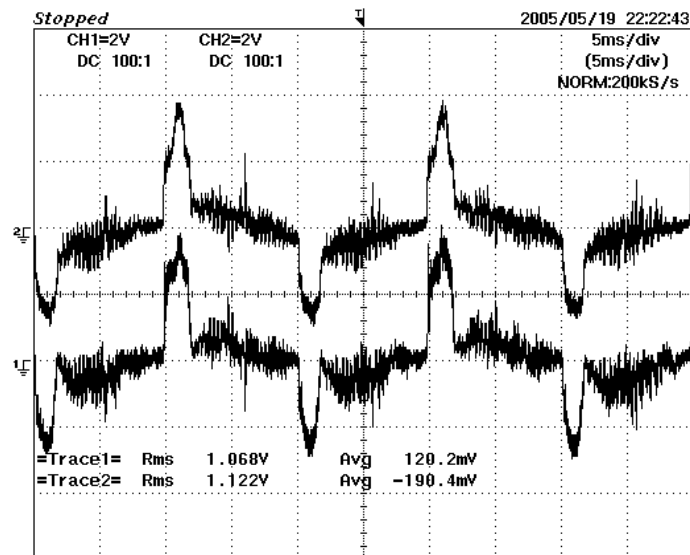
# Power Quality in Microgrids

## Droop method with virtual output impedance and selective harmonic

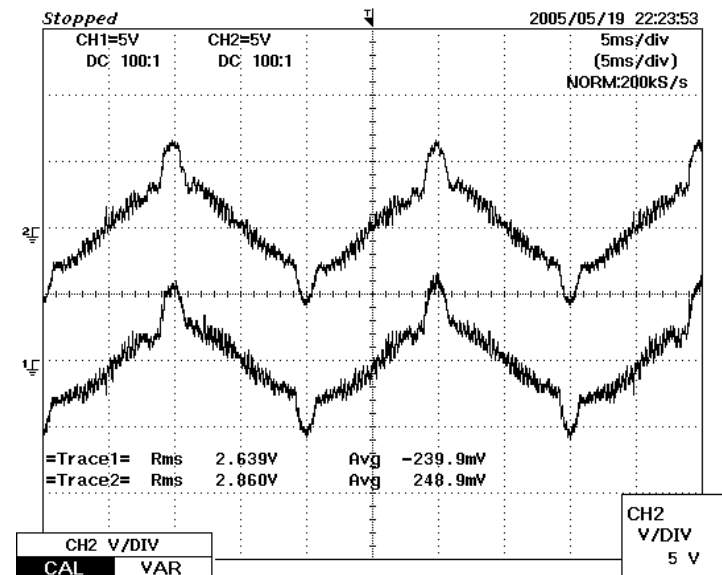


DSP implementation is appropriate for the multi-loop droop framework

## Droop method for resistive output impedance



(a)

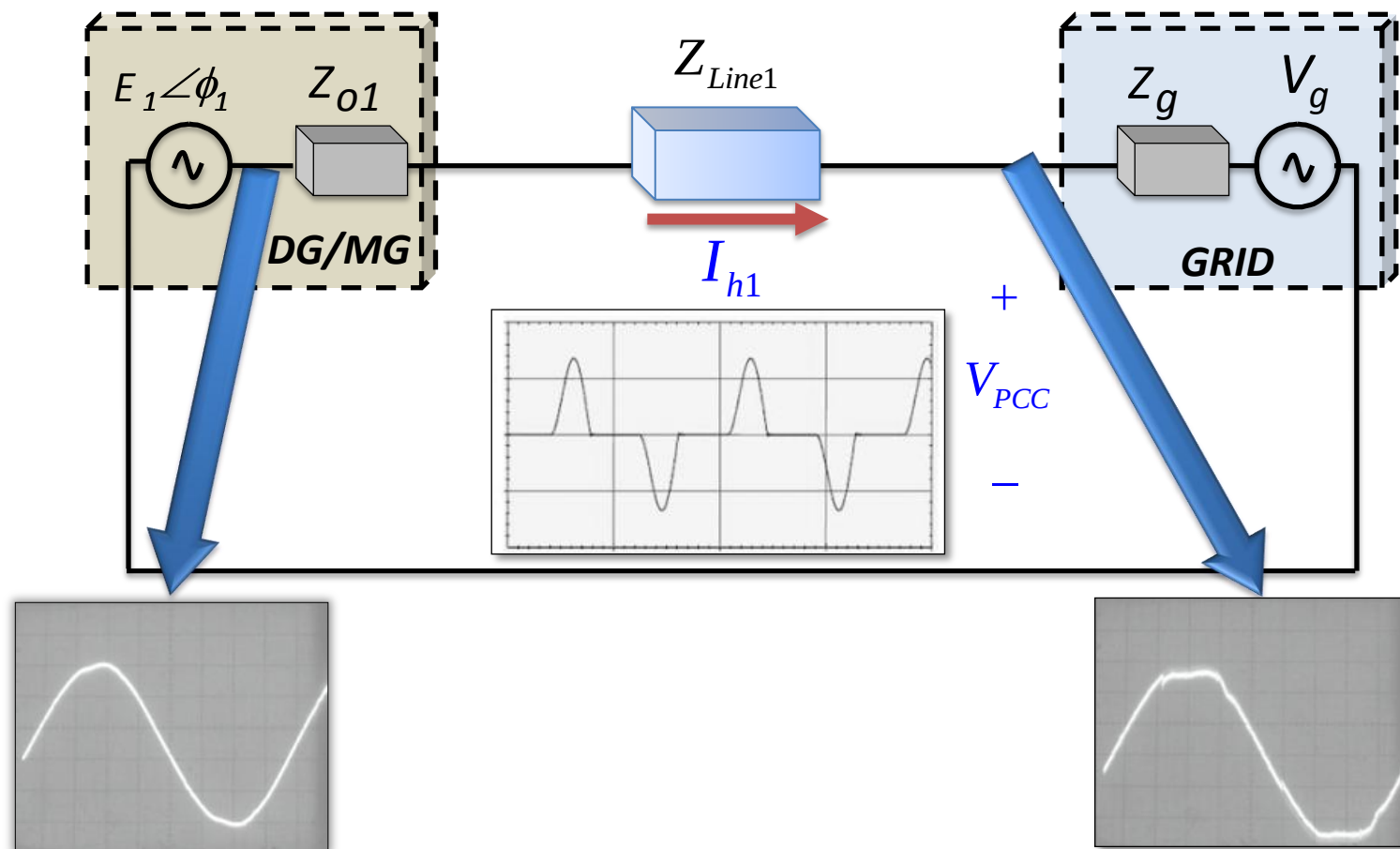


(b)

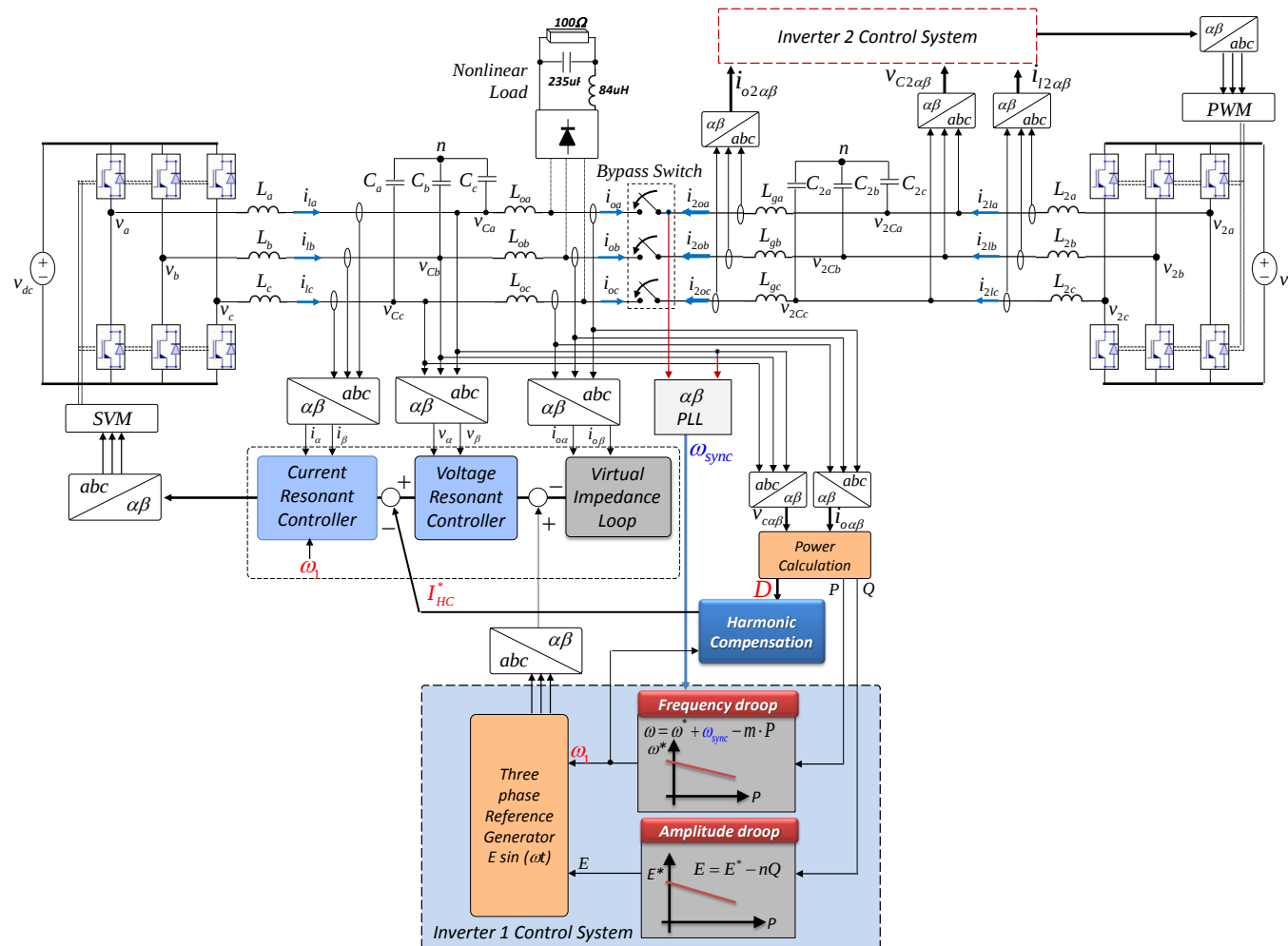
(a) Nonlinear load, Y: 2 A/div, X: 5 ms/div;

(b) Resistive // nonlinear load, Y: 10 A/div, X: 5 ms/div.

## Voltage harmonic reduction by using current harmonics injection



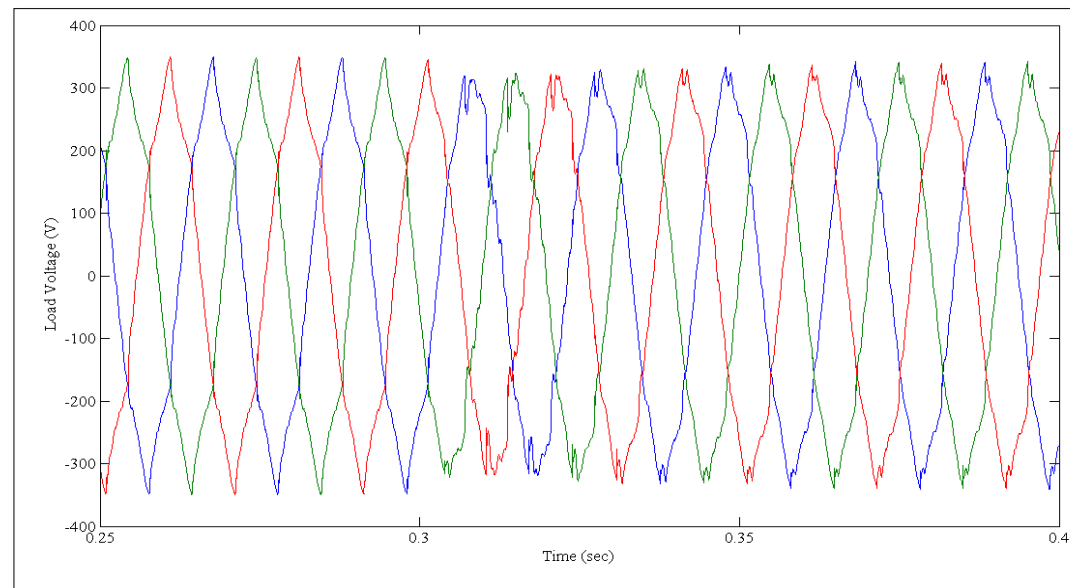
## Decentralized voltage harmonic reduction in an islanded microgrid



# Power Quality in Microgrids

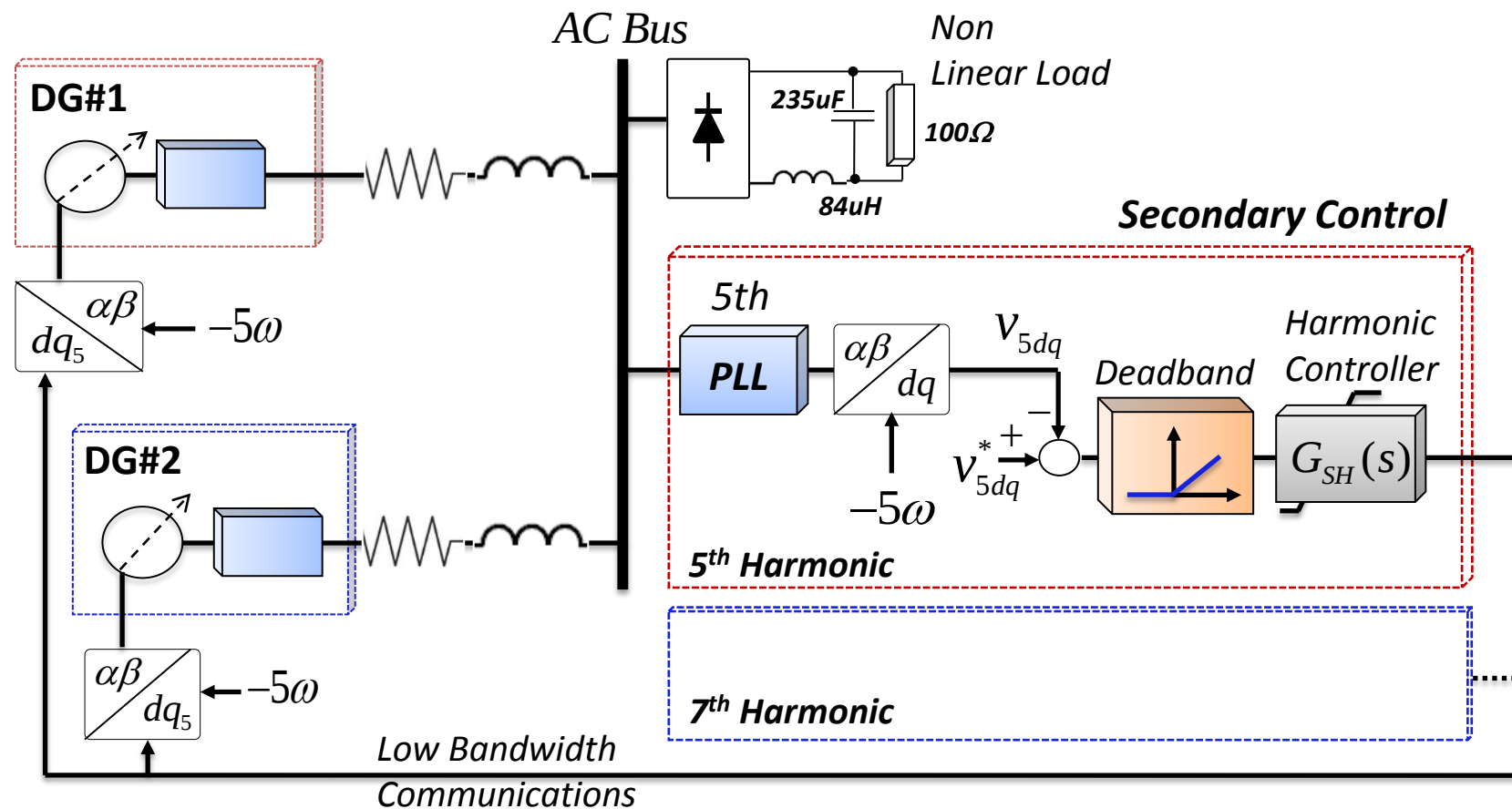
## Decentralized voltage harmonic reduction in an islanded microgrid

|         |      | Before Compensation |                   |                   | After Compensation |                   |                   |
|---------|------|---------------------|-------------------|-------------------|--------------------|-------------------|-------------------|
|         |      | THD%                | 5 <sup>th</sup> % | 7 <sup>th</sup> % | THD%               | 5 <sup>th</sup> % | 7 <sup>th</sup> % |
| Voltage | DG1  | 3.8                 | 2.9               | 2.0               | 1.2                | 0.6               | 0.5               |
|         | DG2  | 2.9                 | 2.1               | 1.5               | 1.1                | 0.5               | 0.4               |
|         | Load | 5.3                 | 4.2               | 2.8               | 3.2                | 2.3               | 2.0               |
| Current | DG1  | 58.6                | 53.7              | 22.9              | 87.6               | 75.2              | 44.1              |
|         | DG2  | 45.8                | 41.5              | 18.8              | 44.5               | 38.1              | 22.5              |
|         | Load | 52.2                | 45.6              | 20.9              | 66.1               | 56.7              | 33.3              |



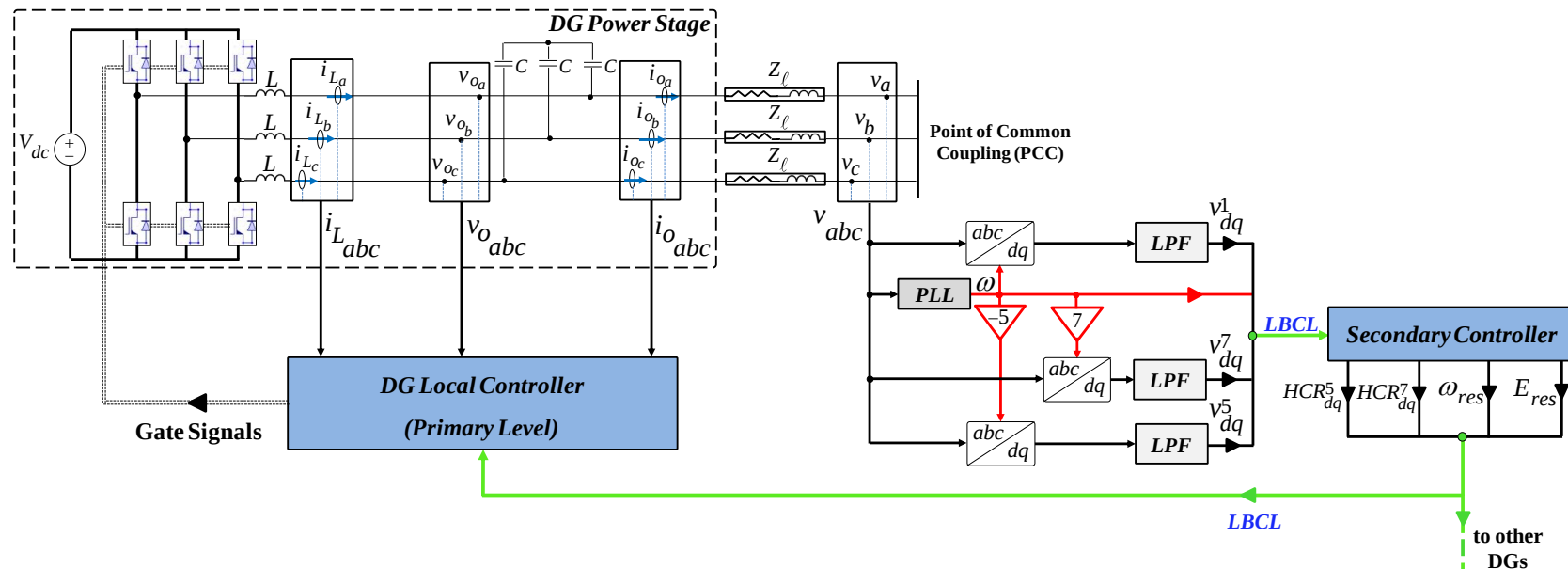
# Power Quality in Microgrids

## Secondary control for voltage harmonic distribution in islanded microgrids



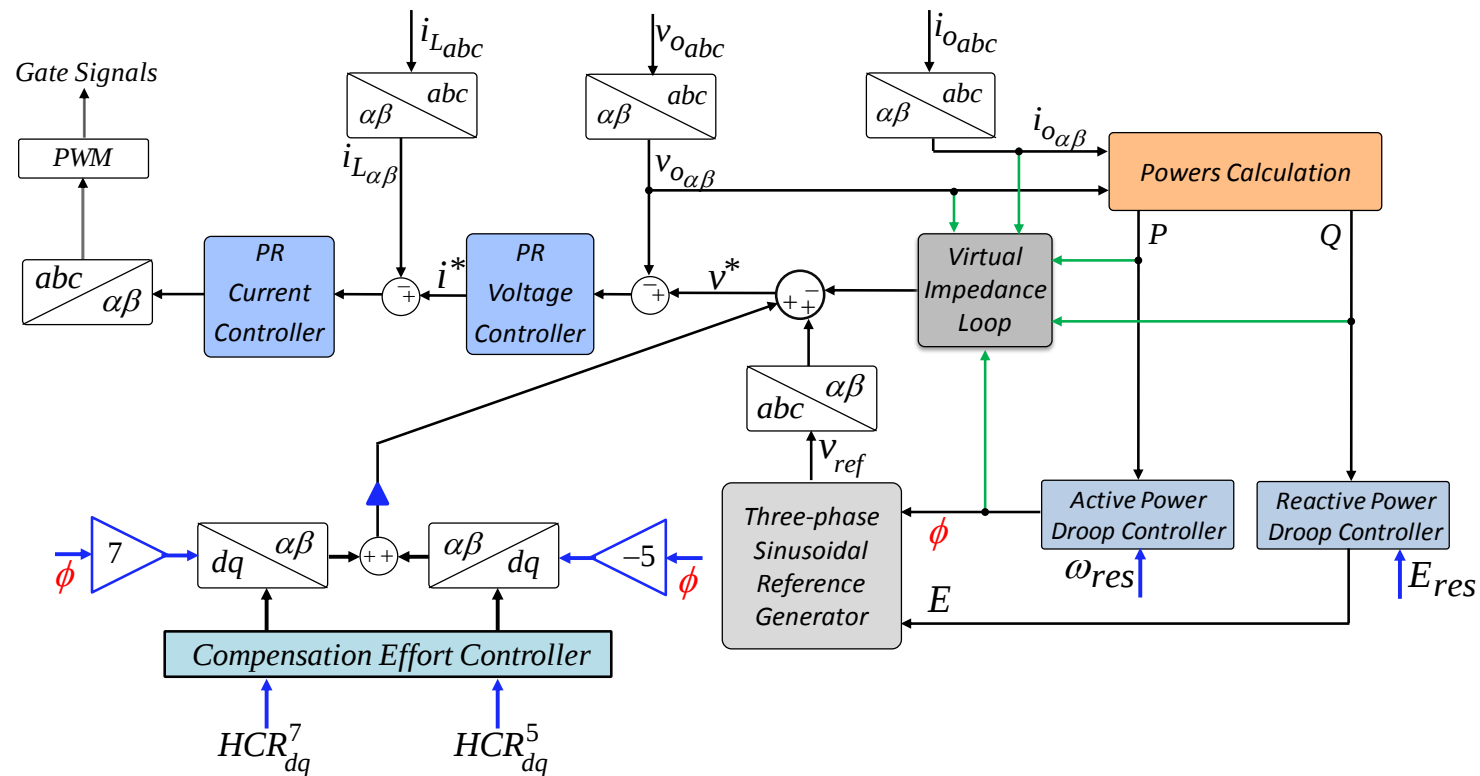
# Harmonics in Microgrids

## Secondary control for voltage harmonic compensation in islanded Microgrids



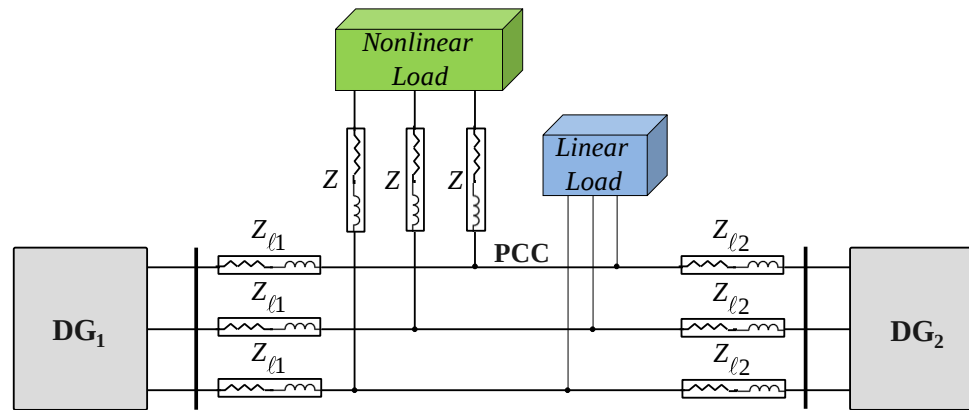
# Harmonics in Microgrids

## DG local controller (primary level)



# Harmonics in Microgrids

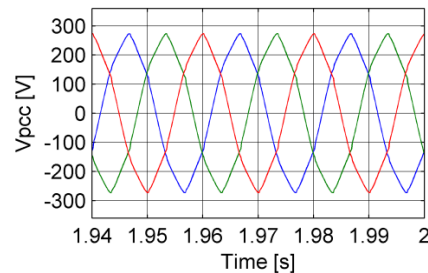
Test system for secondary harmonic compensation



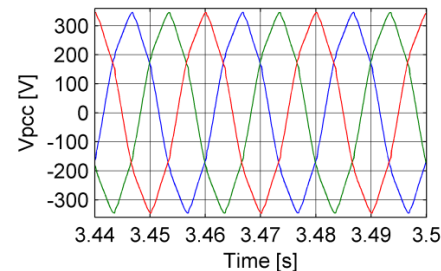
# Harmonics in Microgrids

## Secondary control for voltage harmonic compensation

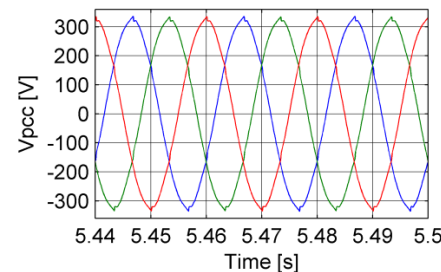
(a) Before amplitude restoration and harmonic compensation



(b) After amplitude restoration (no harmonic compensation)



(c) After amplitude restoration and harmonic compensation



## Voltage unbalance definition

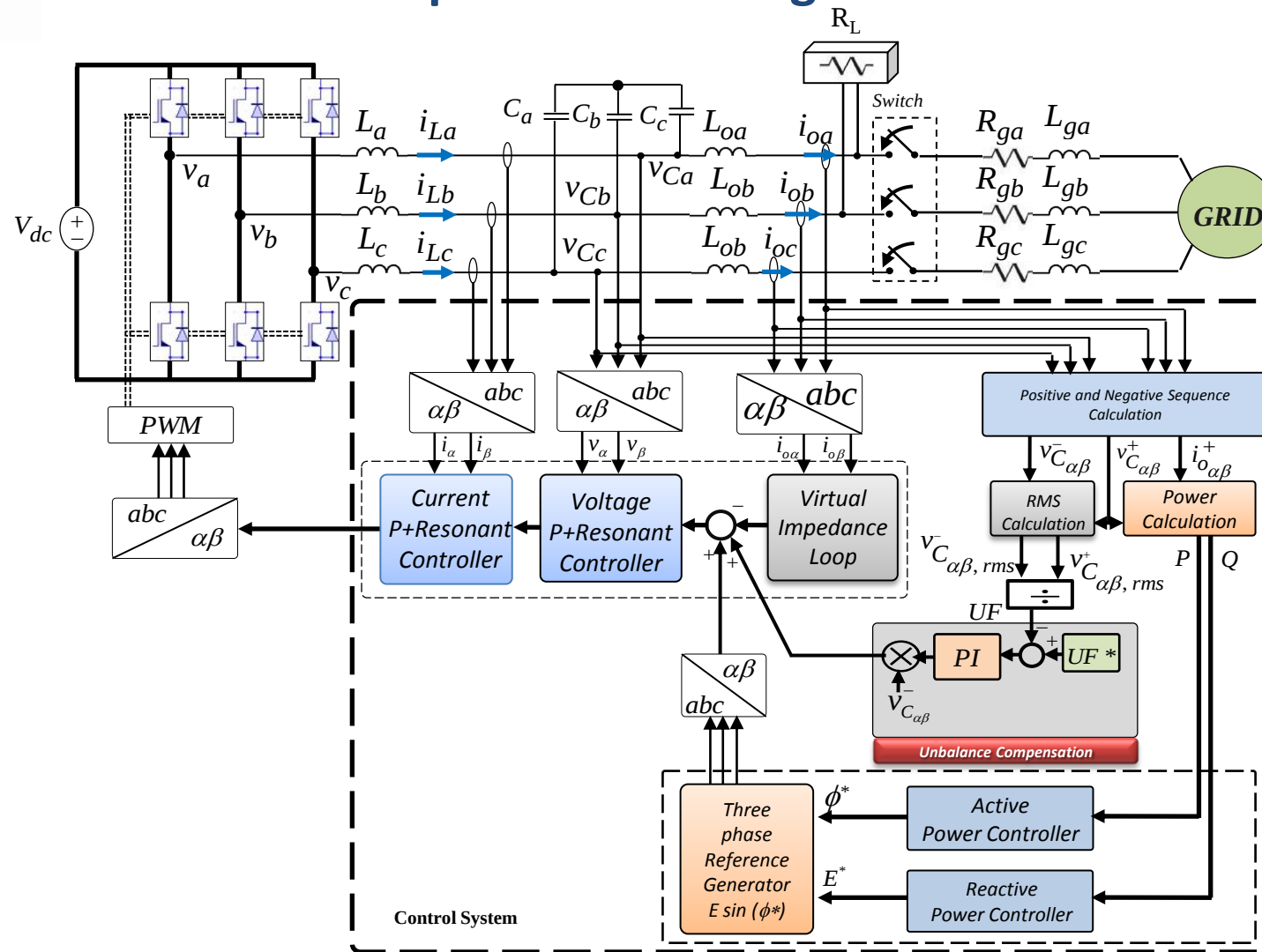
Voltage unbalance factor ( $UF$ ) is considered as the index of unbalance.  
 $UF$  can be defined as follows:

$$UF = \frac{v_{C_{\alpha\beta,rms}}^-}{v_{C_{\alpha\beta,rms}}^+}$$

where  $v_{C_{\alpha\beta,rms}}^-$  and  $v_{C_{\alpha\beta,rms}}^+$  are *rms* values of negative and positive sequences of the DG output voltage.

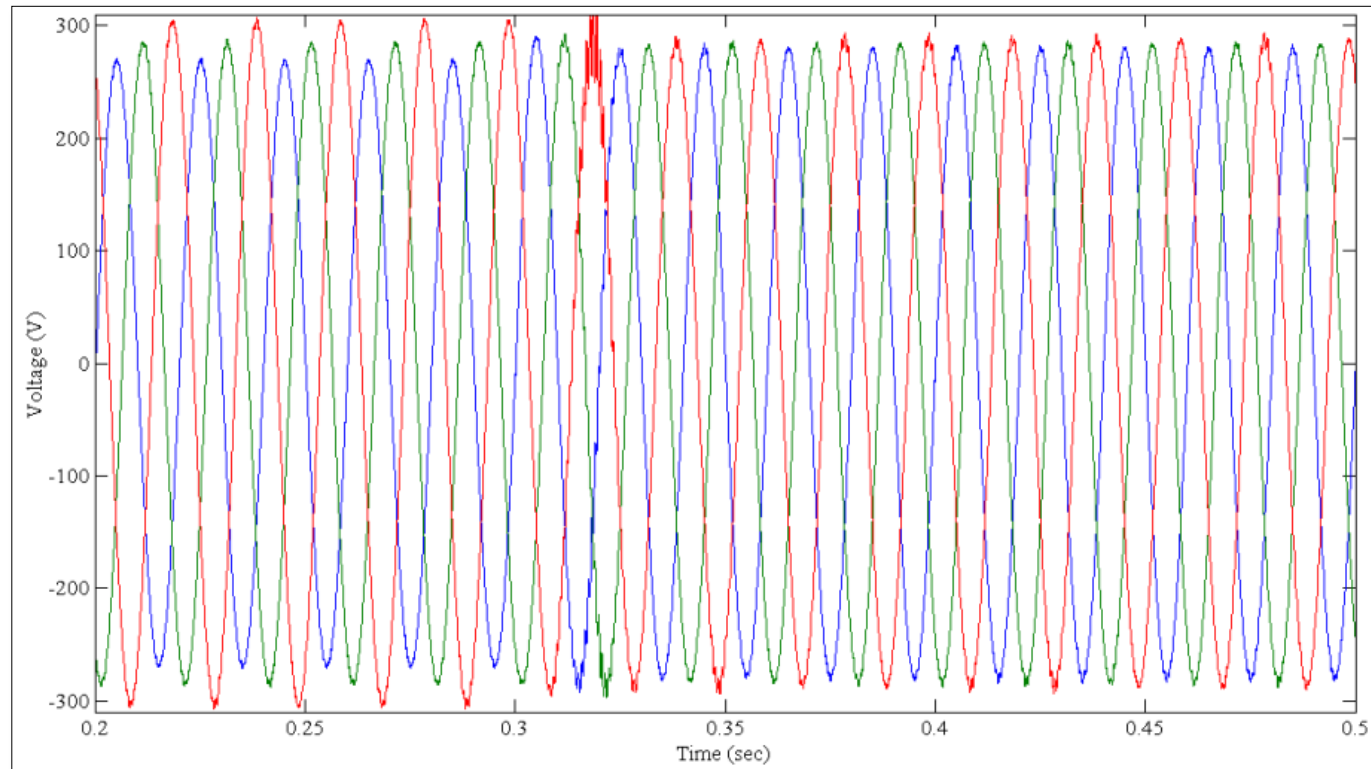
# Unbalance in Microgrids

## Unbalance compensation for a grid-connected DG



# Unbalance in Microgrids

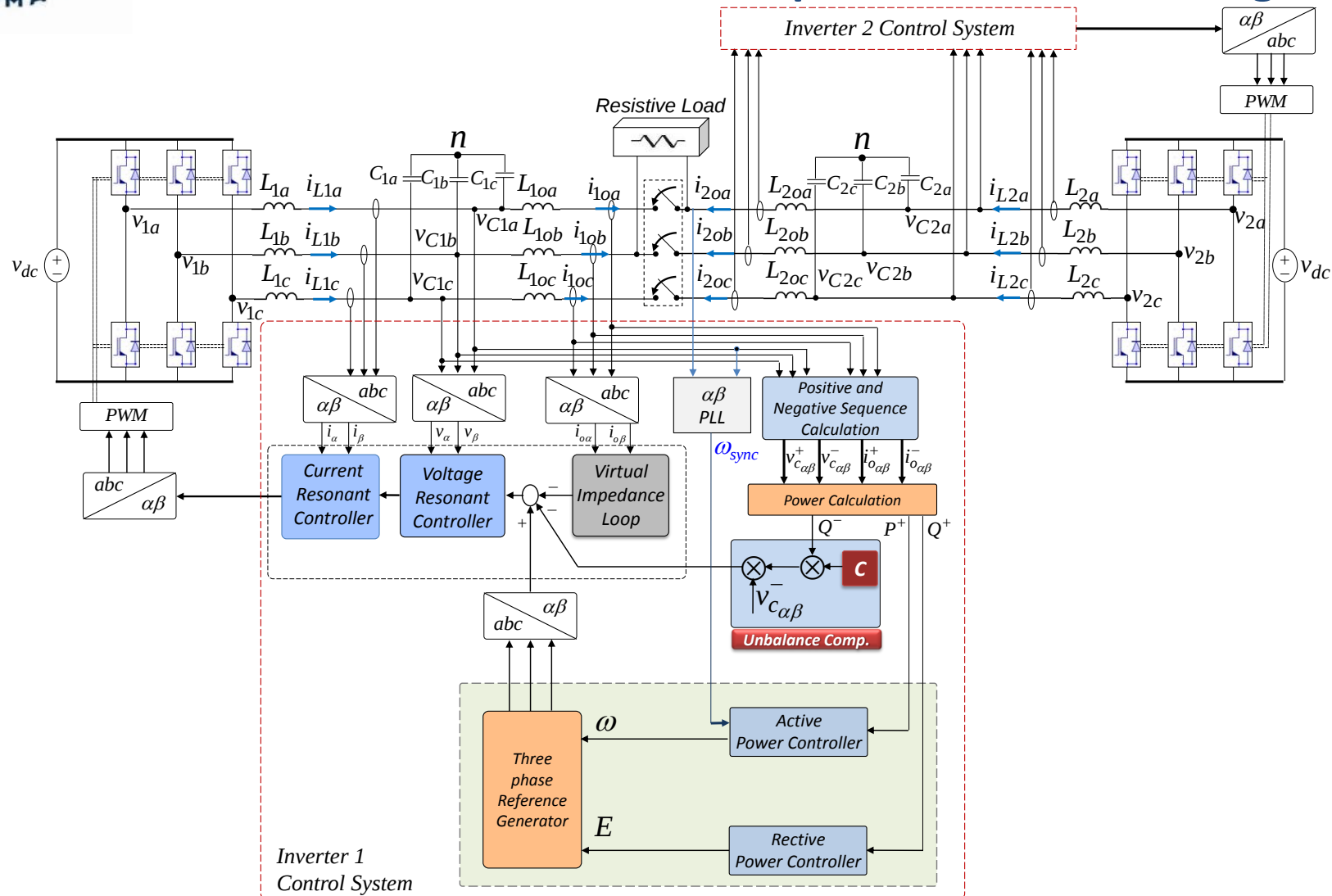
## Unbalance compensation for a grid-connected DG



*DG output Voltage*

# Unbalance in Microgrids

## Decentralized unbalance compensation for a microgrid

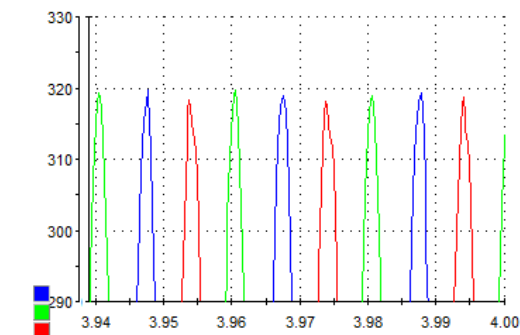
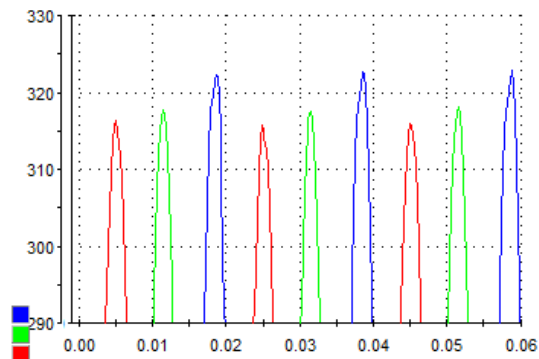
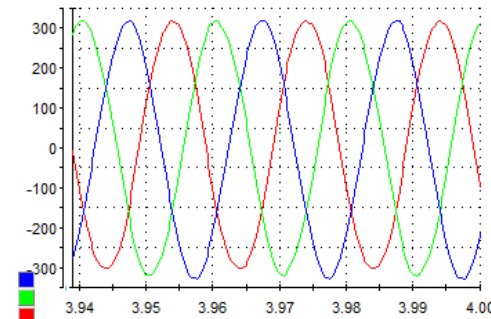
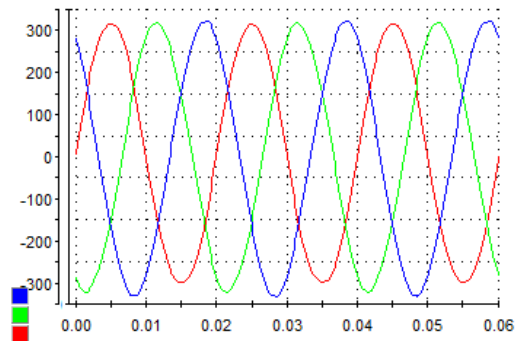


# Unbalance in Microgrids

## Decentralized unbalance compensation for a microgrid

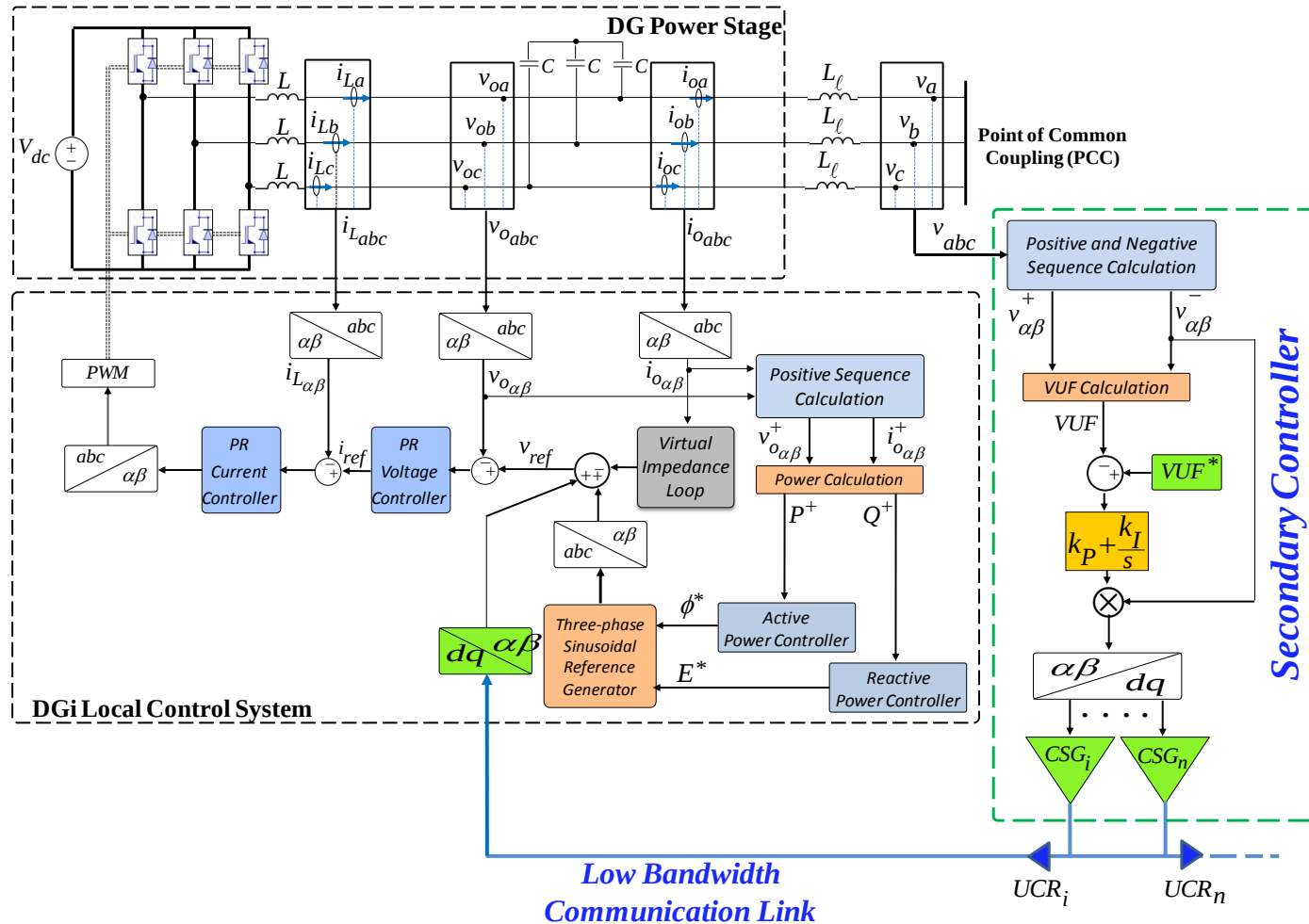
### Unsymmetrical line

Voltage after and before compensation

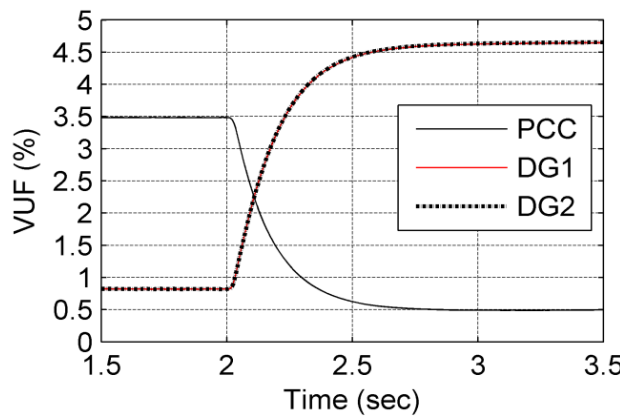
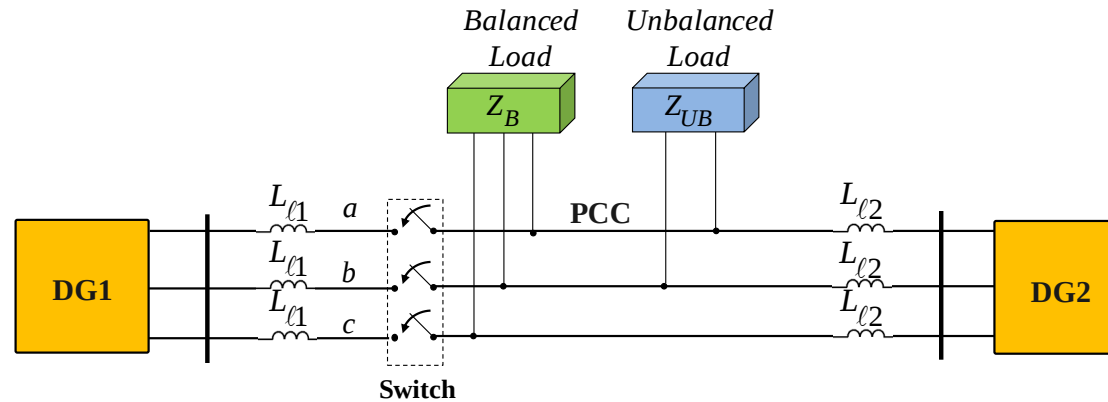


# Unbalance in Microgrids

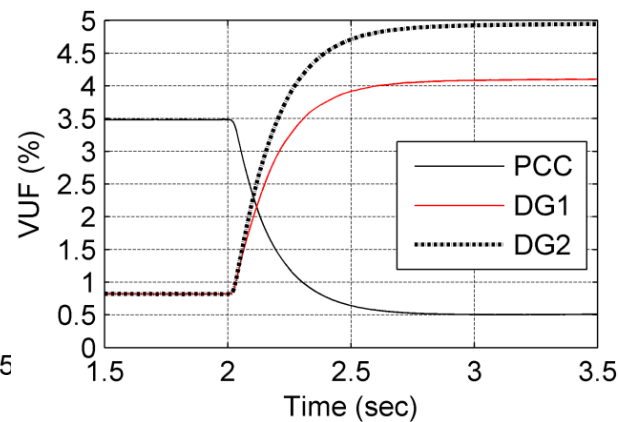
## Secondary control for unbalance compensation in islanded Microgrids



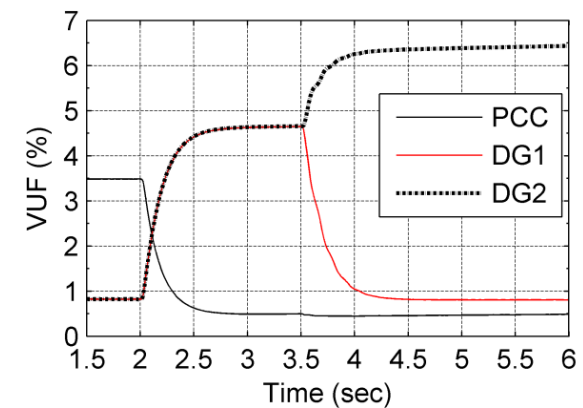
# Unbalance in Microgrids



VUF at PCC and DGs terminal  
( $CSG_1=CSG_2=1$ )



VUF at PCC and DGs terminal  
( $CSG_1=1, CSG_2=1.25$ )

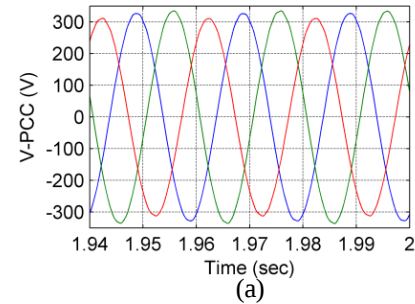


VUF at PCC and DGs terminal  
(DG1 communication link failure  
at  $t=3.5$ sec)

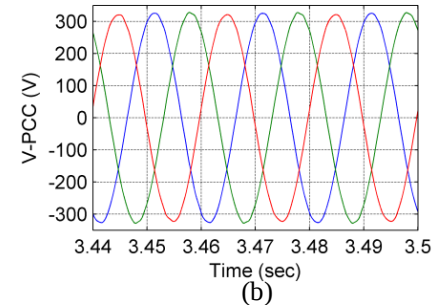
# Unbalance in Microgrids

PCC

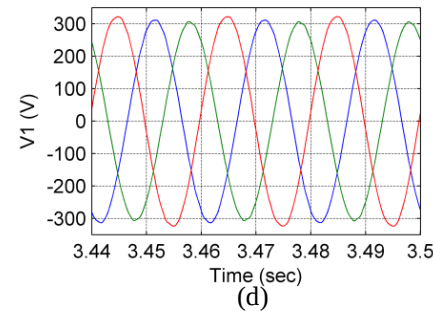
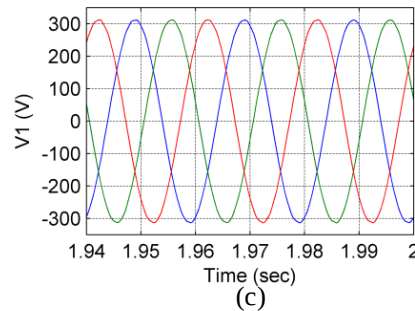
BEFORE COMPENSATION



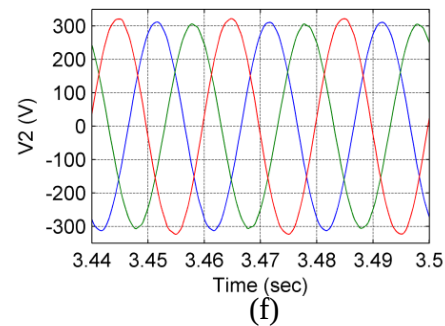
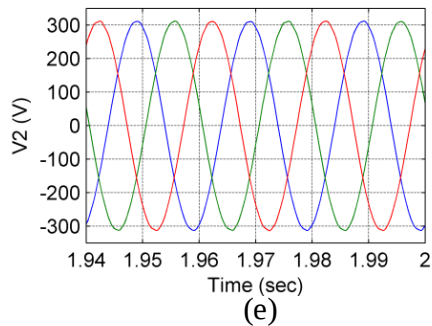
AFTER COMPENSATION



DG1



DG2

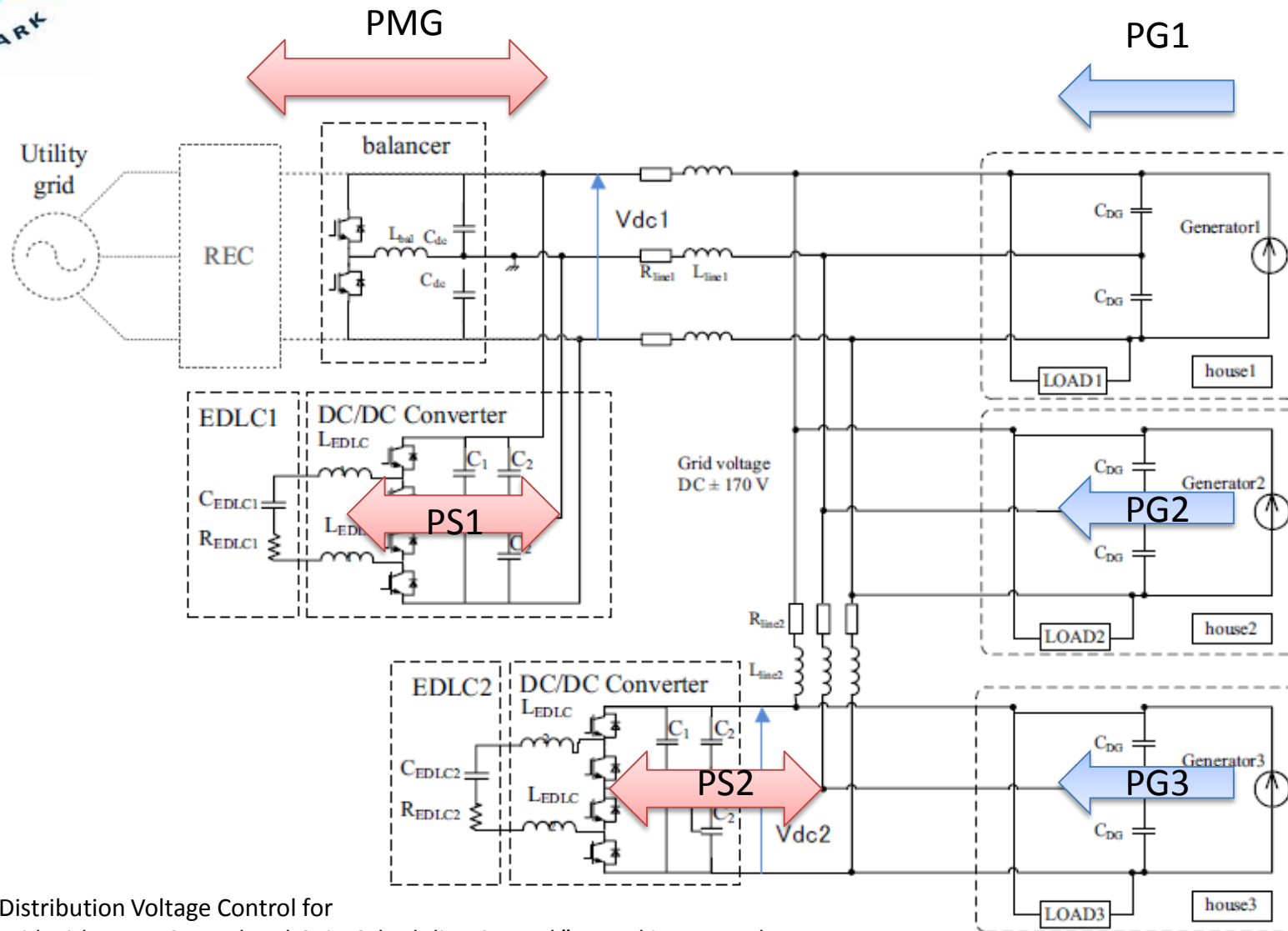


Three-phase voltage waveforms

## Conclusions

- Voltage harmonics in microgrids can be reduced by injecting current harmonic or adjusting harmonic voltage in the DG terminals
- Secondary control can be used to close the loop of the harmonic voltage compensation in the microgrid
- Tertiary control can be used to reduce the current harmonics injected by the microgrid to the grid
- A ponderated trade off between the secondary and tertiary controls have to be designed
- Unbalances in microgrids can be reduced by injecting a voltage negative sequence in the DG proportional to Q negative sequence
- Secondary control and tertiary control for unbalance compensation can be used for islanding and grid-connected microgrids.
- Reactive power have to be limited and ponderated for harmonics and unbalance compensation.

# Distributed Energy Storage in Microgrids



Source: "Distribution Voltage Control for DC Microgrid with Fuzzy Control and Gain-Scheduling Control," H. Kakigano et Al.

# Distributed Energy Storage in Microgrids

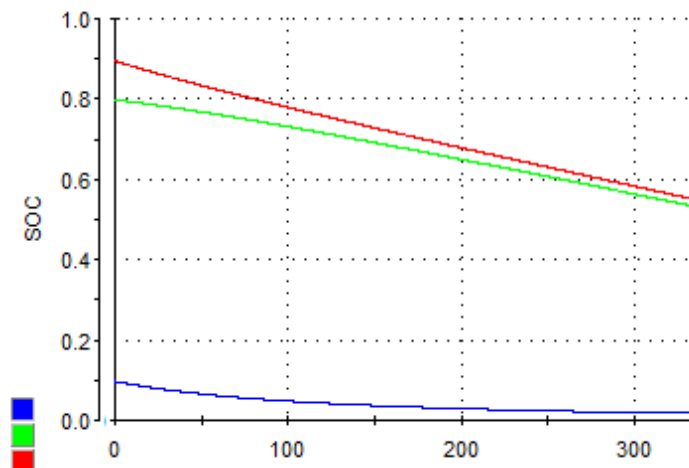
Adaptive droop control:

$$\text{DC: } V = V^* - (k/\text{SoC})I_o$$

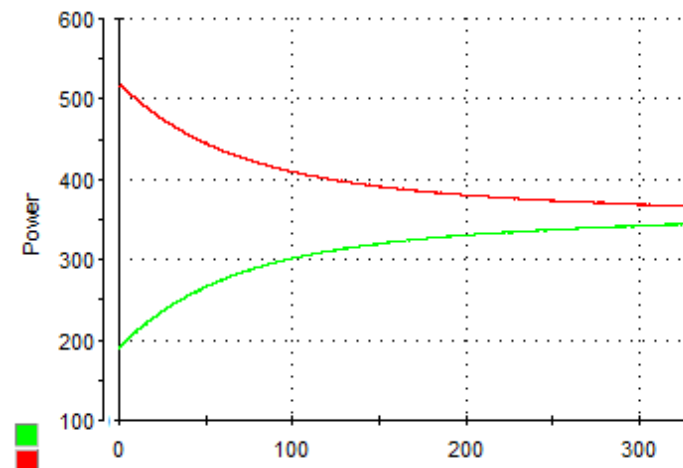
$$\text{AC: } \omega = \omega^* - (k/\text{SoC})P$$

Extended Kalman Filters are used to obtain the SoC of the batteries.

SOC1 – SOC2



PS1, PS2



- [1] J. M. Guerrero, J. C. Vasquez, J. Matas, M. Castilla, etc, "Control strategy for flexible microgrid based on parallel line-interactive UPS systems," IEEE Trans. Industrial Electronics, Vol. 56, No. 3, pp. 726-736, 2009.
- [2] J. M. Guerrero, J. Matas, etc, "Decentralized control for parallel operation of distributed generation inverters using resistive output impedance," IEEE Trans. Industrial Electronics, Vol. 54, No. 2, pp. 994-1004, 2007.
- [3] Y. W. Li and C. Kao, "An accurate power control strategy for power-electronics-interfaced distributed generation units operating in a low-voltage multibus microgrid," IEEE Trans. Power Electronics, Vol. 24, No. 12, pp. 2977-2988, 2009.
- [4] D. M. Vilathgamuwa, P. C. Loh and Y. W. Li, "Protection of microgrids during utility voltage sags," IEEE Trans. Industrial Electronics, Vol. 53, No. 5, pp. 1427-1436, 2006.
- [5] F. Katiraei, M. R. Iravani and P. W. Lehn. "Micro-grid autonomous operation during and subsequent to islanding process," IEEE Trans. Power Delivery, Vol. 20, No. 1, pp. 248-257, 2005.
- [6] H. Gaztanaga, I. Etxeberria-Otadui, S. Bacha and D. Roze, "Real-time analysis of the control structure and management functions of a hybrid microgrid system," in Proc. IECON Conf., 2006, pp. 5137-5142.
- [7] C. Jin, P. C. Loh, P. Wang, Y. Mi, F. Blaabjerg, "Autonomous operation of hybrid AC-DC microgrids," in Proc. ICSET Conf., 2010.
- [8] X. Liu, P. Wang and P. C. Loh, "A hybrid AC/DC microgrid and its coordination control," IEEE Trans. Smart Grid, to be published.
- [9] X. Yu, A. M. Khambadkone, H. H. Wang, etc, "Control of parallel-connected power converters for low-voltage microgrid-Part I: A hybrid control architecture," IEEE Trans. Power Electronics, Vol. 25, No. 12, pp. 2962-2970, 2010.
- [10] C. T. Lee, C. C. Chuang, C. C. Chu and P. T. Cheng, "Control strategies for distributed energy resources interface converters in the low voltage microgrid," in Proc. ECCE Conf., 2009, pp. 2022-2029.

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                     |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| <b>Name</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Josep M. Guerrero (喬瑟輔)                                                                                                                                                                                                                                                                                                                                                                                                       | <b>Photo</b>                                                                        |
| <b>Title</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Full Professor                                                                                                                                                                                                                                                                                                                                                                                                                |  |
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|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Cell: +34652045551                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                     |
| <b>Email</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | <a href="mailto:joz@et.aau.dk">joz@et.aau.dk</a>                                                                                                                                                                                                                                                                                                                                                                              |                                                                                     |
| <b>Website</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | <a href="http://www.et.aau.dk">www.et.aau.dk</a>                                                                                                                                                                                                                                                                                                                                                                              |                                                                                     |
| <b>Educational Background</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | <ul style="list-style-type: none"><li>• 1993 ~ 1997. B.Sc Telecommunications Engineer (Technical University of Catalonia, Barcelona)</li><li>• 1997 ~ 2000. M.Sc Electronic Engineer (Technical University of Catalonia, Barcelona)</li><li>• 2000 ~ 2003. PhD Power Electronics (Technical University of Catalonia, Barcelona)</li></ul>                                                                                     |                                                                                     |
| <b>Work Experience</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | <ul style="list-style-type: none"><li>• Feb 1999 ~Aug 2004 Assistant professor (Technical University of Catalonia, Barcelona)</li><li>• Sept 2004 ~Aug 2008 Lecturer professor (Technical University of Catalonia, Barcelona)</li><li>• Sept 2008~Present Associate Professor (now part time) (Technical University of Catalonia, Barcelona)</li><li>• July 2011~Present Full Professor (Aalborg University, Spain)</li></ul> |                                                                                     |
| <b>Autobiography</b> <p>Josep M. Guerrero (S’01–M’04–SM’08) was born in Barcelona, Spain, in 1973. He received the B.S. degree in telecommunications engineering, the M.S. degree in electronics engineering, and the Ph.D. degree in power electronics from the Technical University of Catalonia, Barcelona, Spain, in 1997, 2000 and 2003, respectively.</p> <p>He is part time Associate Professor with the Department of Automatic Control Systems and Computer Engineering, Technical University of Catalonia, where he currently teaches courses on FPGAs and control of renewable energy systems. From 2011 he is a Full Professor at the Institute of Energy Technology, Aalborg University, Denmark, and responsible of the Microgrid research program. He has been a visiting Professor at Zhejiang University, China, and University of Cergy-Pontoise, France. His research interests include power electronics converters for distributed generation and distributed energy storage systems, control and management of microgrids and islanded minigrids, and photovoltaic and wind power plants control. He is an associate editor of the IEEE Transactions on Industrial Electronics and IEEE Transactions on Power Electronics. He currently chairs of Renewable Energy Systems Technical Committee of IEEE IES. He is an elected IEEE IES Adcom member.</p> |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                     |