Advanced control of PV grid connected converters through the implementation of the Synchronous Power Controller Concept

Pedro Rodriguez

Power Systems Research Area Director
Abengoa Research, Abengoa
Technical University of Catalonia
Spain

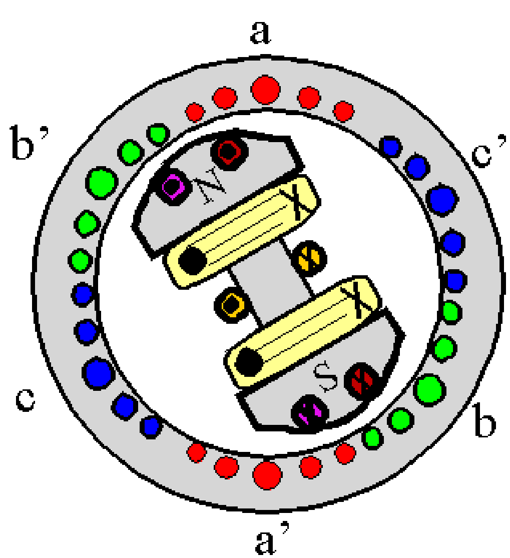
Daniel Remon Rodriguez

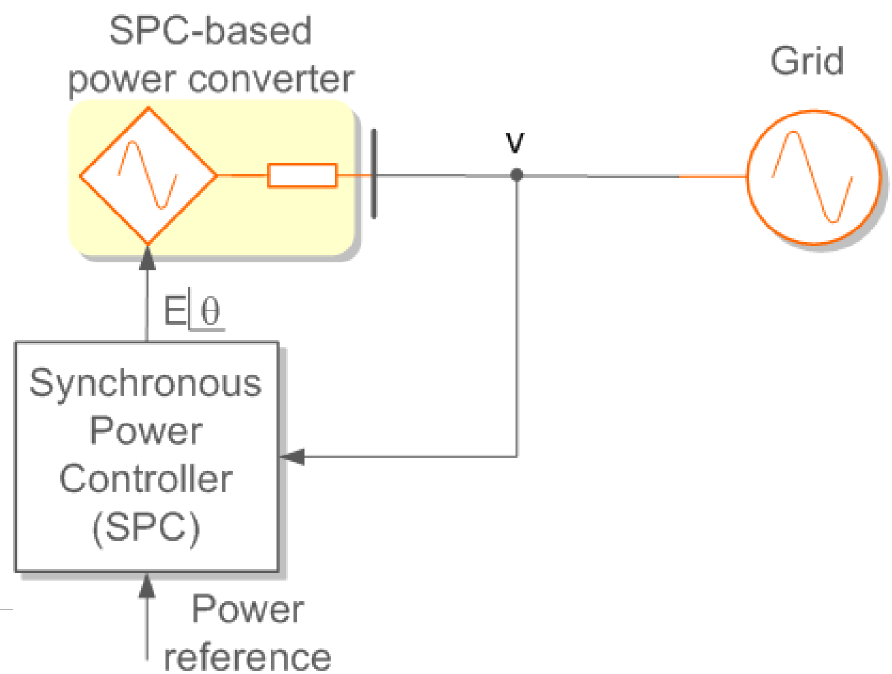
Research Fellow
Technical University of Catalonia
Spain

The Premier Global Event in Applied Power Electronics™
APEC 2016
March 20-24, 2016
Long Beach California
LONG BEACH CONVENTION & ENTERTAINMENT CENTER

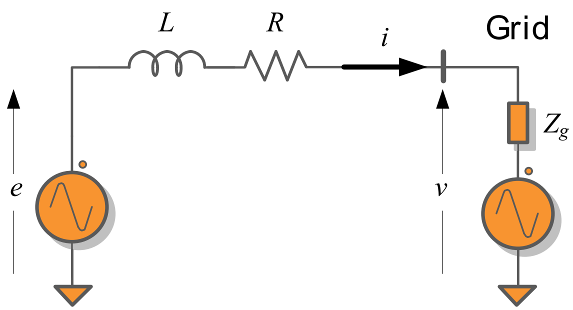
The Synchronous Power Converter

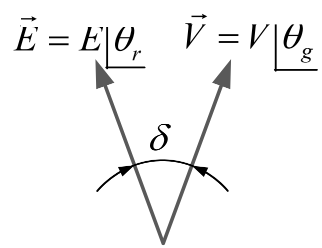
- The Synchronous Power Controller (SPC) stems from the hypothesis that it is possible to develop a new synchronous generator based on power electronics
- The SPC inherits the advantages of conventional synchronous generators, while it fixes many of its drawbacks
- The generators based on SPC have a performance inherently harmonized with the electrical grid, matching thus the grid code requirements in a natural manner





Synchronous Power Converter – Electrical Characteristic





$$v(s) = e(s) - i(s)(R + Ls)$$

$$i(s) = \frac{1}{R + sL}\left(e(s) - v(s)\right)$$

$$P = \frac{EV}{Z}\cos(\phi - \delta) - \frac{V^2}{Z}\cos(\phi),$$

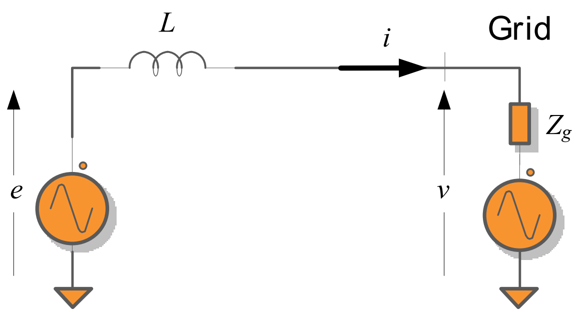
$$Q = \frac{EV}{Z}\sin(\phi - \delta) - \frac{V^2}{Z}\sin(\phi),$$

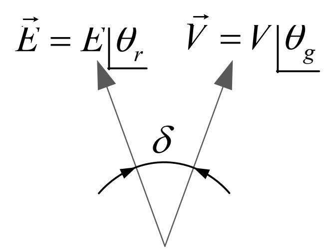
V and E are the rms values of both voltages,

ϕ is the magnitude and phase of the overall impedance

δ is the phase-angle difference between e and v.

Synchronous Power Converter – Electrical Characteristic





if $\omega L = X >> R$

$$\phi = \pi/2$$

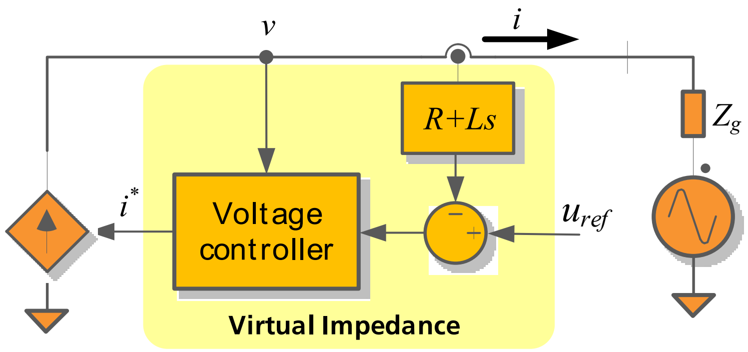
$$P = \frac{EV}{X}\cos\left(\frac{\pi}{2}-\delta\right) - \frac{V^2}{X}\cos\left(\frac{\pi}{2}\right), \quad \Rightarrow \quad P = \frac{EV}{X}\sin(\delta),$$

$$Q = \frac{EV}{X}\sin\left(\frac{\pi}{2}-\delta\right) - \frac{V^2}{X}\sin\left(\frac{\pi}{2}\right), \quad \Rightarrow \quad Q = \frac{EV}{X}\cos(\delta) - \frac{V^2}{X},$$

In high voltage lines or in the interconnection of synchronous generators the impedance is mainly inductive.

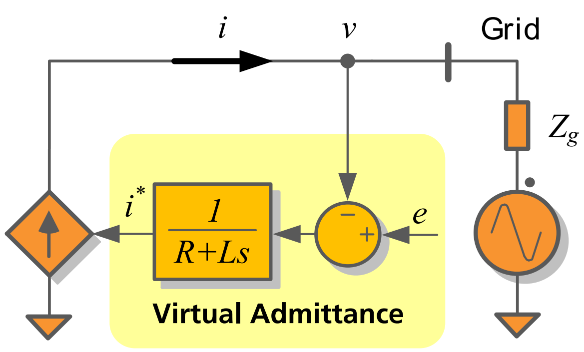
Synchronous Power Converter – Virtual Impedance vs Virtual Admittance

- Implementation of the virtual impedance effect in the controller of a power converter



$$v(s) = e(s) - i(s)(R + Ls)$$

The measured current is affected by a derivative term for calculating the voltage reference, with high noise sensitivity or limited bandwith.

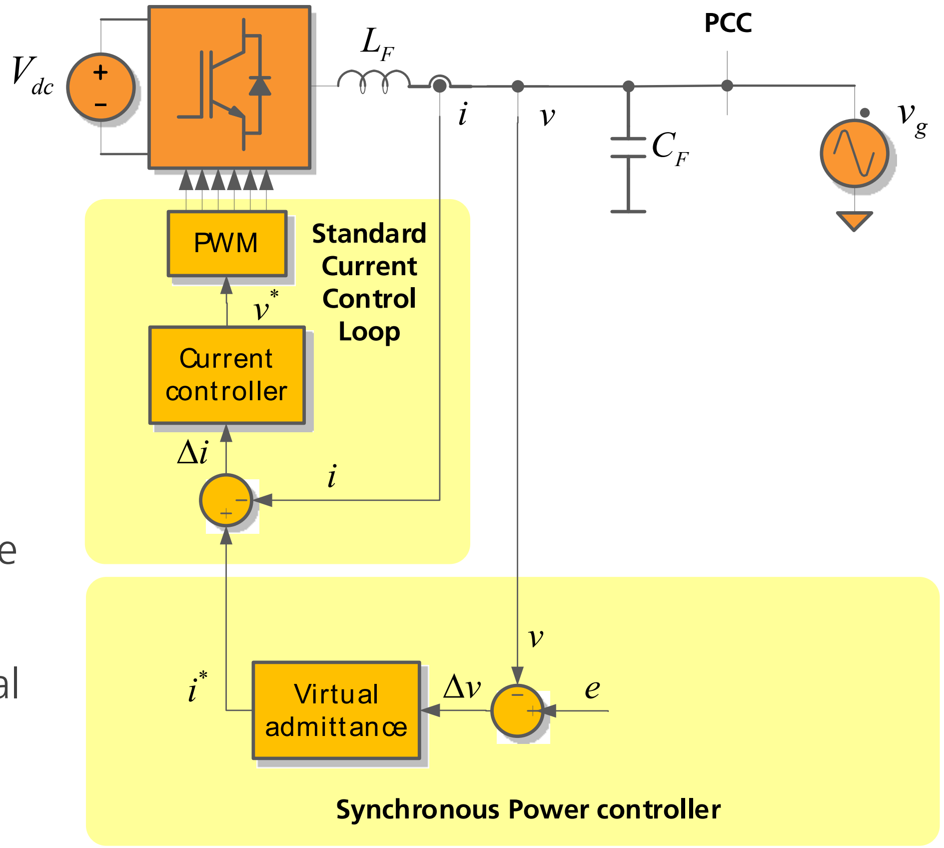


The implementation of virtual impedance needs an additional voltage controller, as a difference with the virtual admittance concept.

$$i(s) = \frac{1}{R + sL}\left(e(s) - v(s)\right)$$

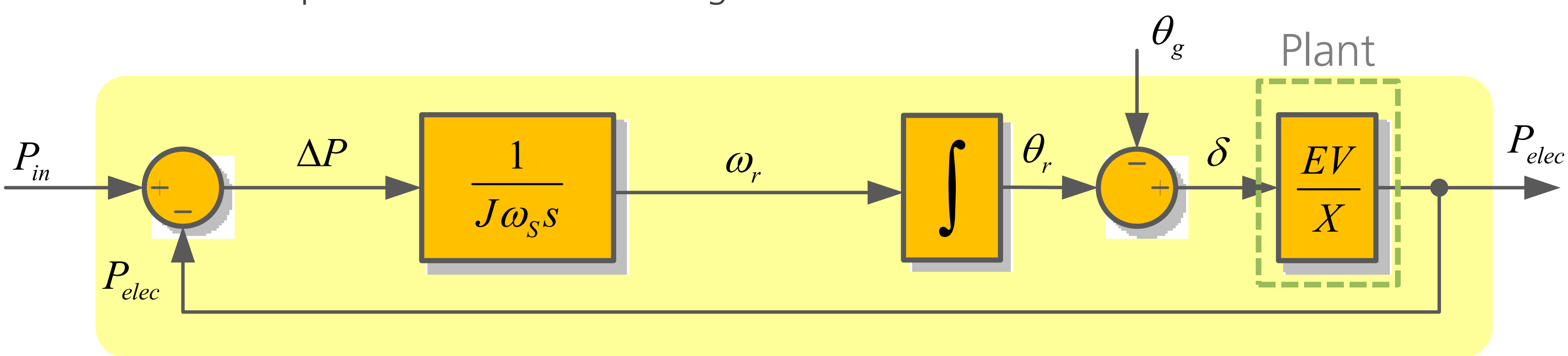
Synchronous Power Converter – Virtual Admittance

- The SPC-based power converter is controlled as a current source.
- The dynamic response of the current loop should be fast enough to match the electrical behavior of the SPC.
- The value of the virtual admittance can be changed according to the operation conditions.
- It is possible to set a predominant inductive behavior in the virtual admittance.
- The SPC does not behave as a conventional grid feeder, but it is a grid forming converter.



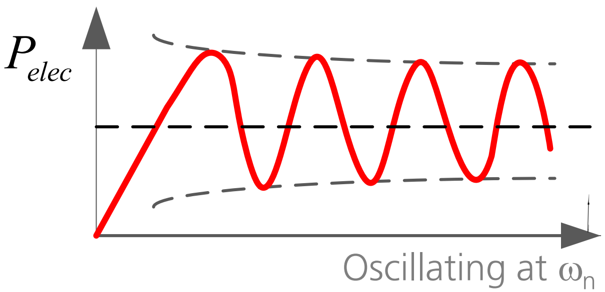
Synchronous Power Converter – Electromechanical Inertia

- Closed-loop electromechanical diagram



$$\frac{P_{out}}{P_{in}} = \frac{\omega_n^2}{s^2 + \omega_n^2}$$

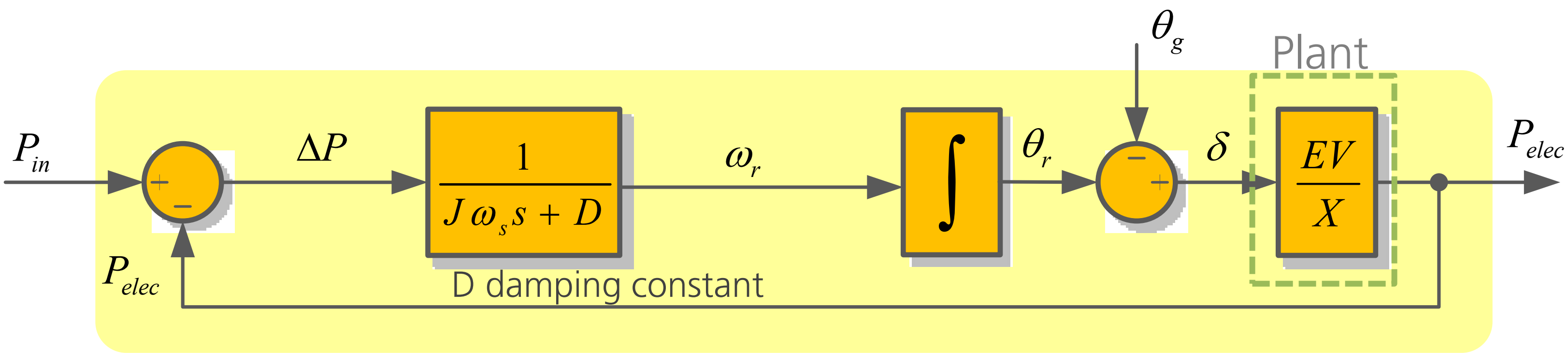
$$\omega_n = \sqrt{\frac{P_{max}}{J\omega_S}}$$



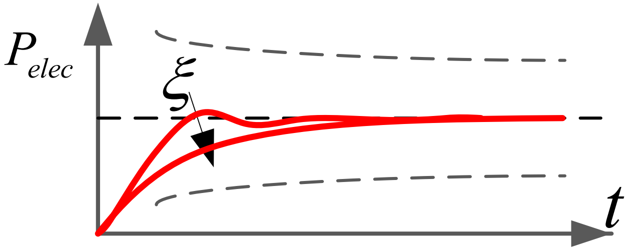
$$P_{\max} = \frac{EV}{X}$$

Synchronous Power Converter – Electromechanical Inertia

- Closed-loop electromechanical diagram with additional damping windings

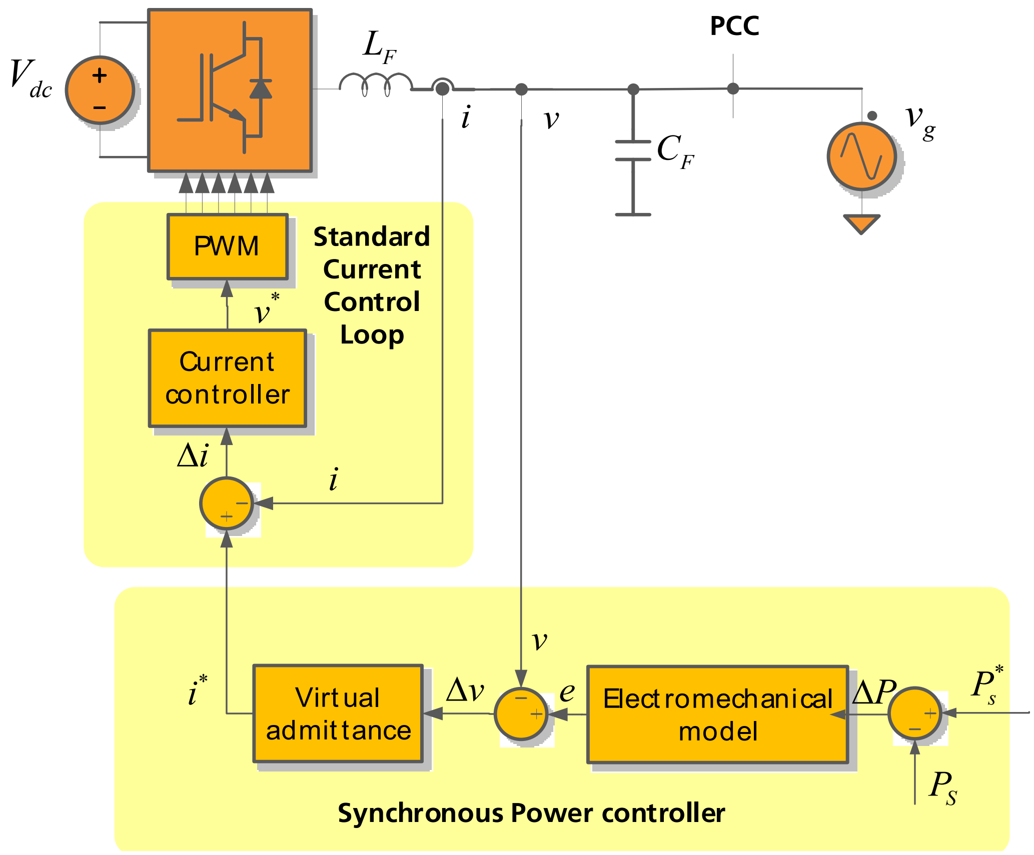


$$\frac{P_{out}}{P_{in}} = \frac{\omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2}$$

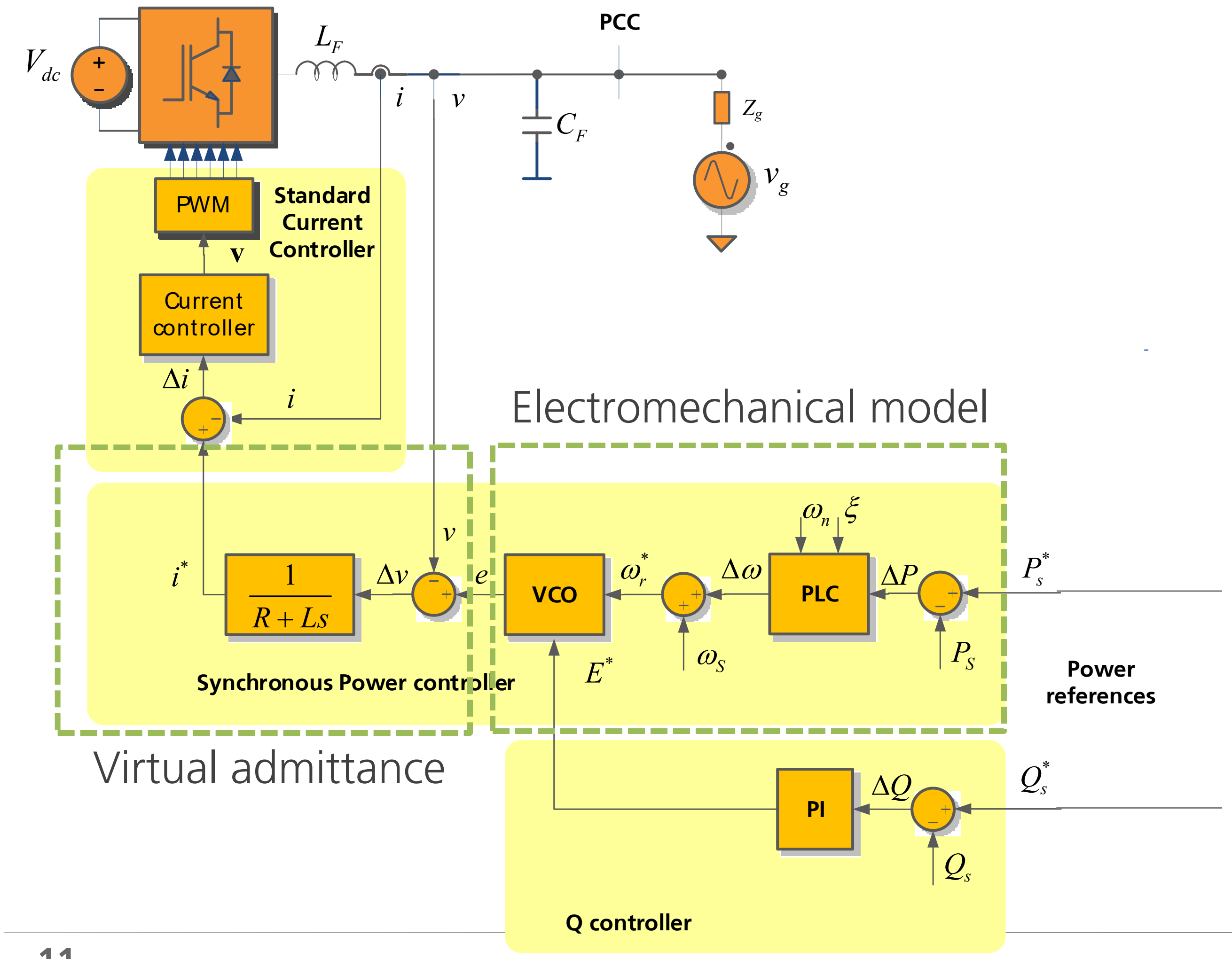


Synchronous Power Converter – Electromechanical Inertia

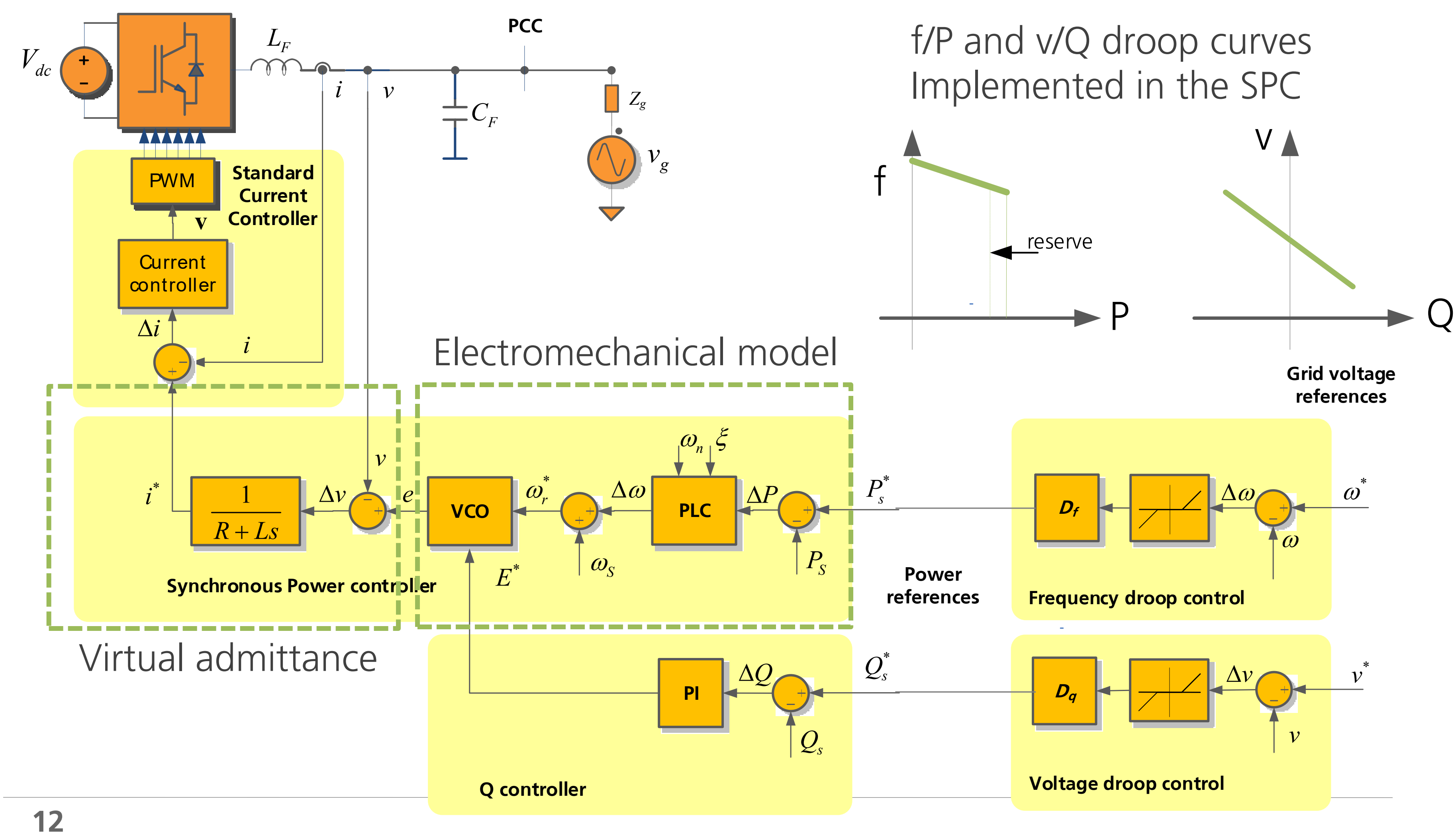
- The electromechanical model is programmed in the digital control system of a power converter.
- The electromechanical response of an SPC-based power converter can be dynamically adapted to the operating conditions.
- Inertia and damping are modifiable variables.
- The SPC does not require any grid synchronization system.



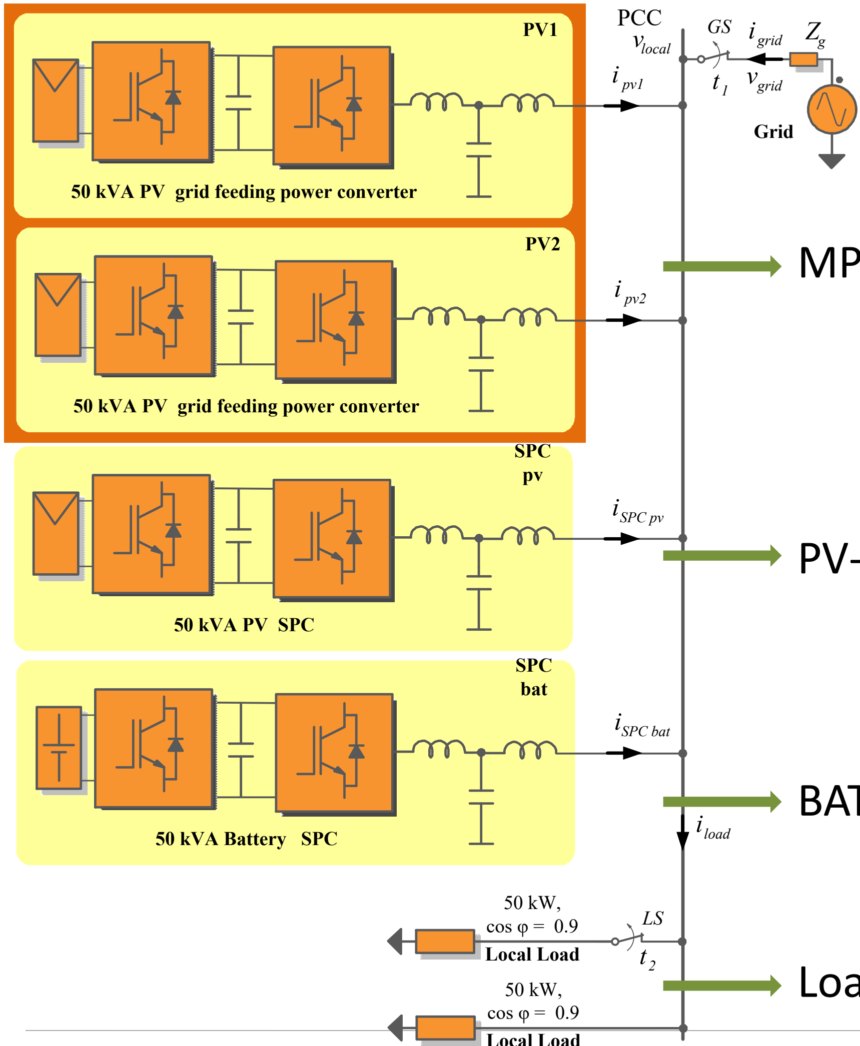
Synchronous Power Converter – Photovoltaic Case



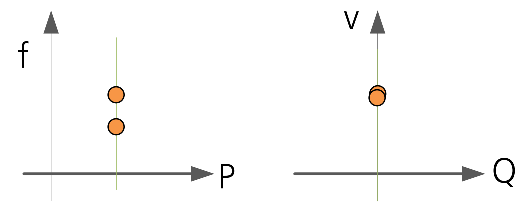
Synchronous Power Converter – Photovoltaic Case



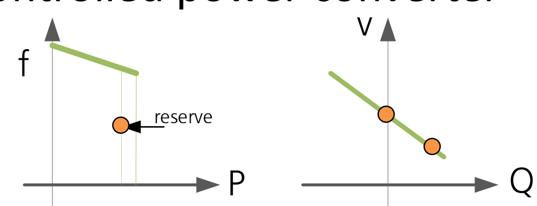
Simulation Test Bench



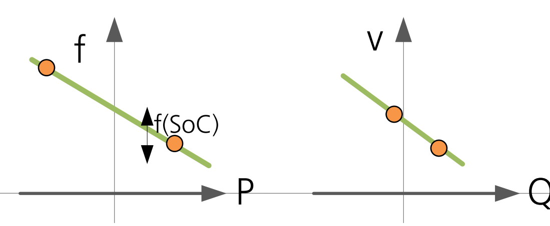
MPPT controlled grid-feeding converters



PV-SPC controlled power converter

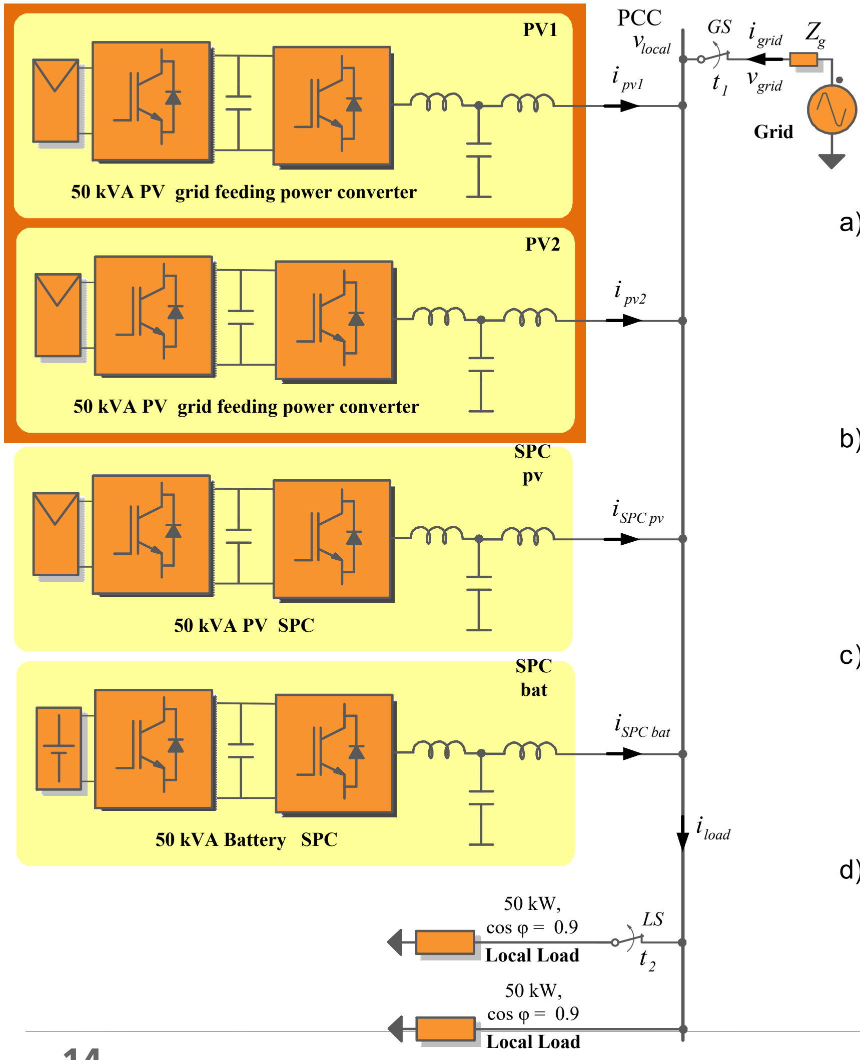


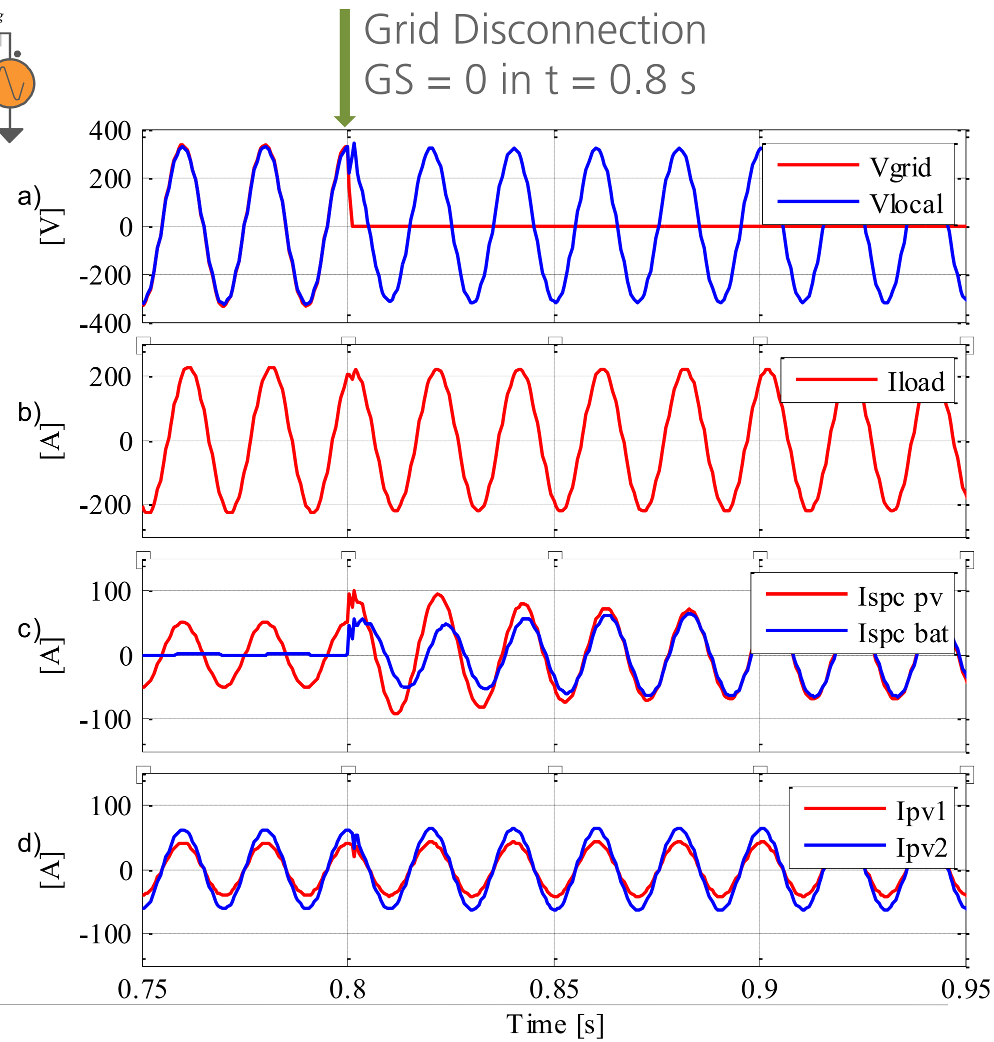
BAT-SPC controlled power converter



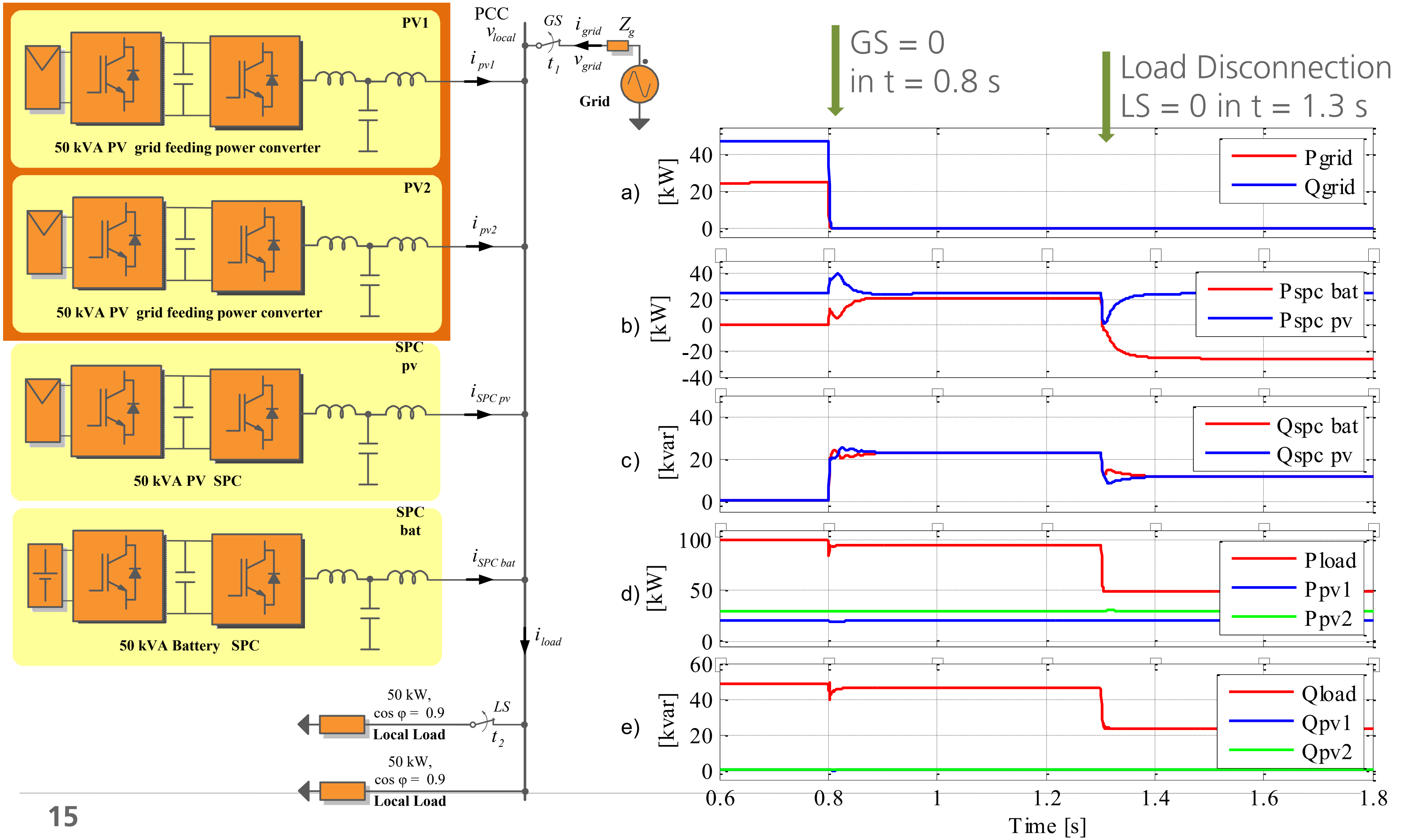
Load

Simulation Results – Grid Disconnection

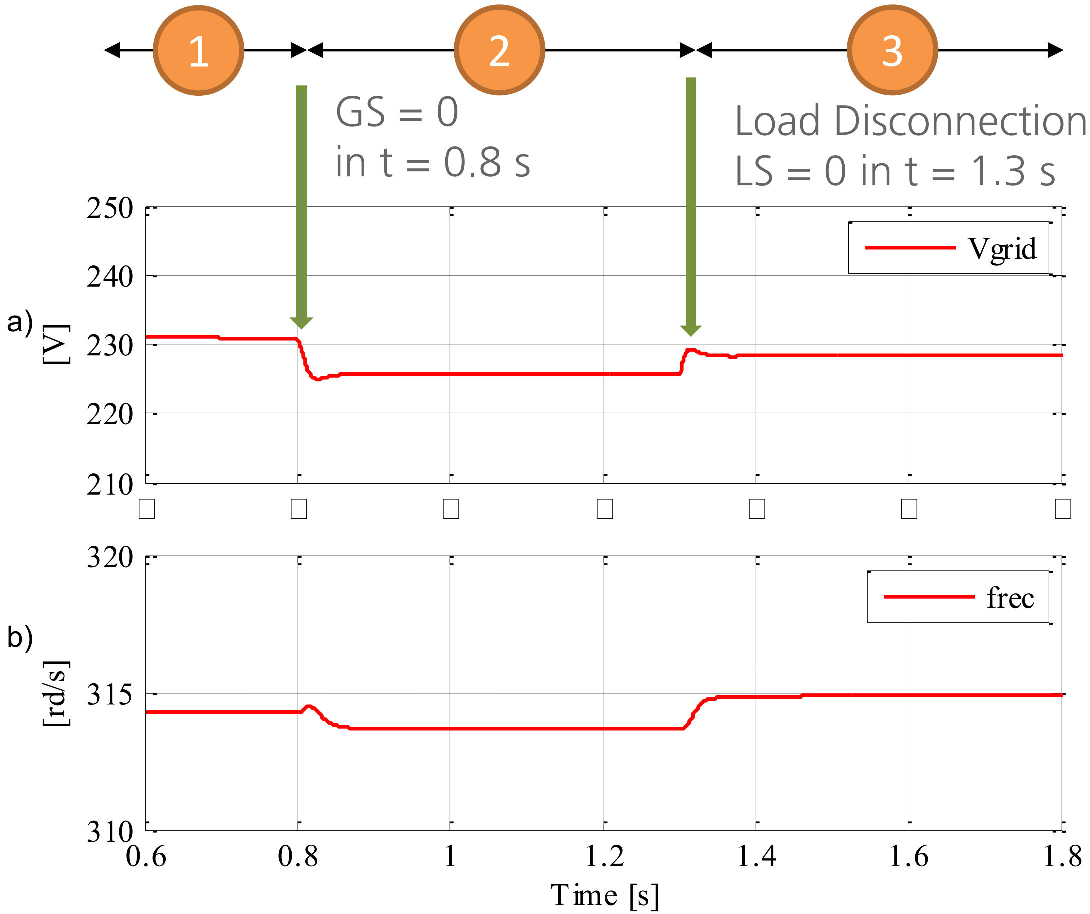


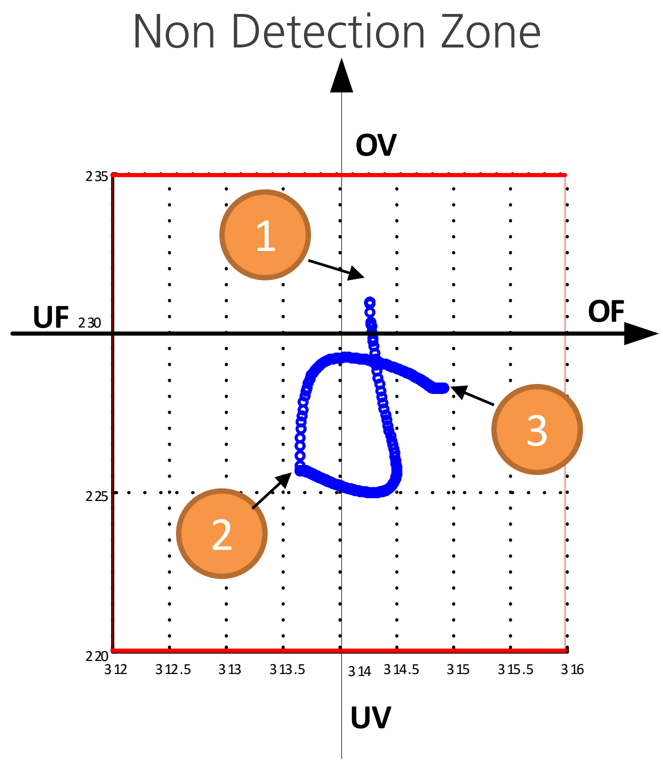


Simulation Results – Grid and load disconnection

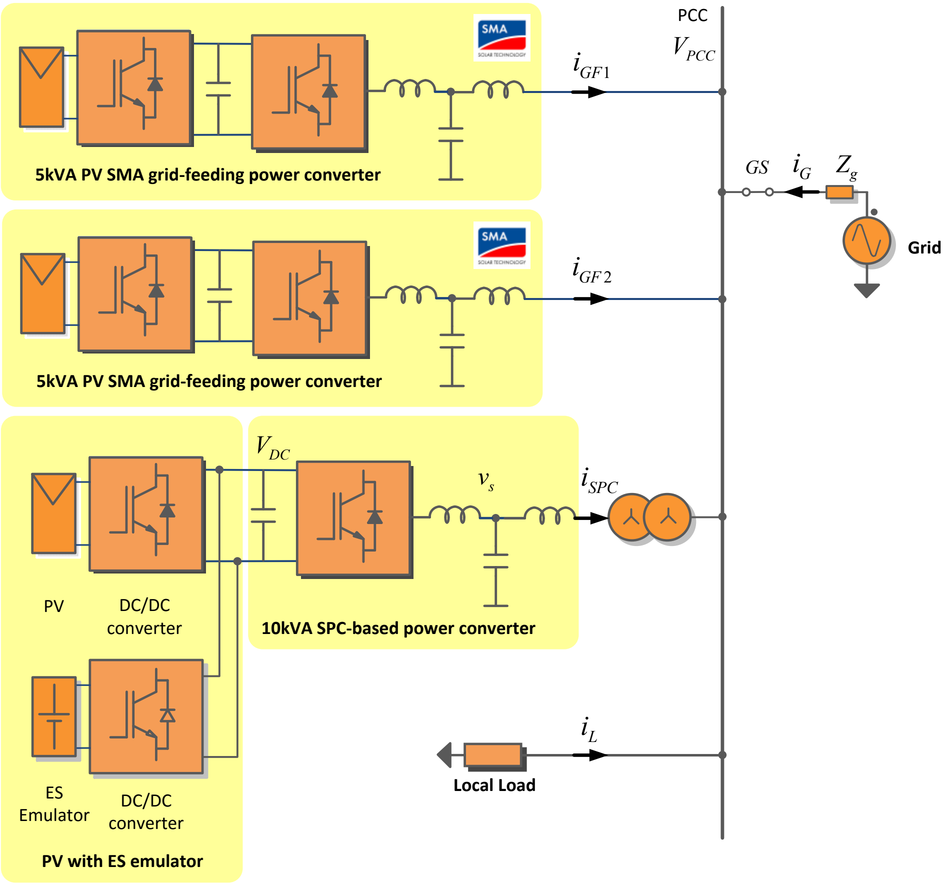


Simulation Results – PCC voltage and frequency transients

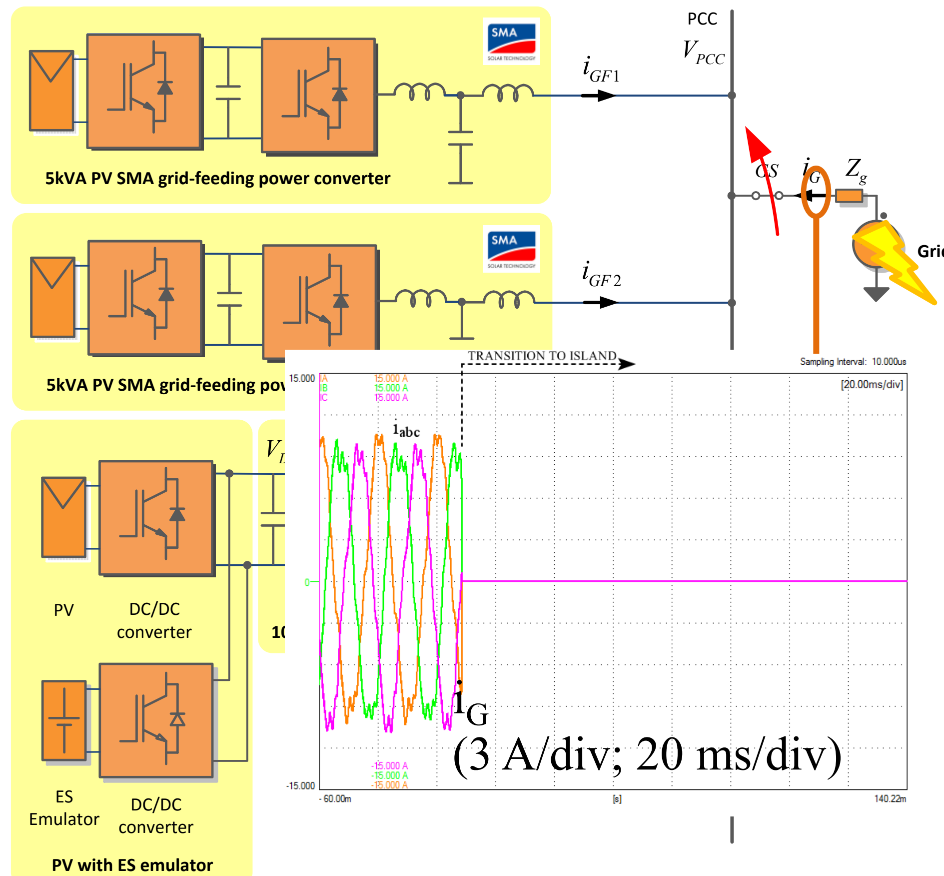




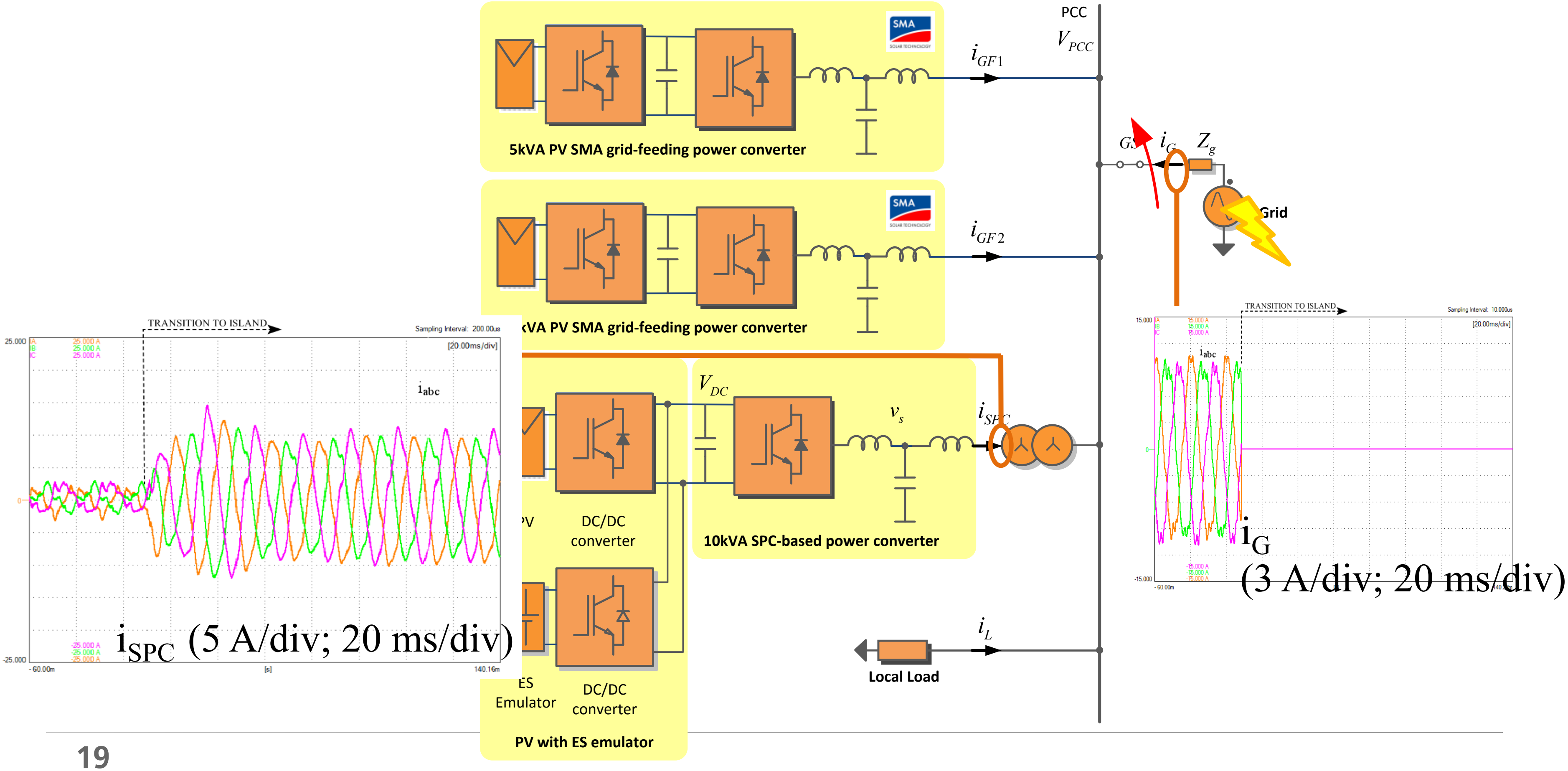
Experimental Test Bench



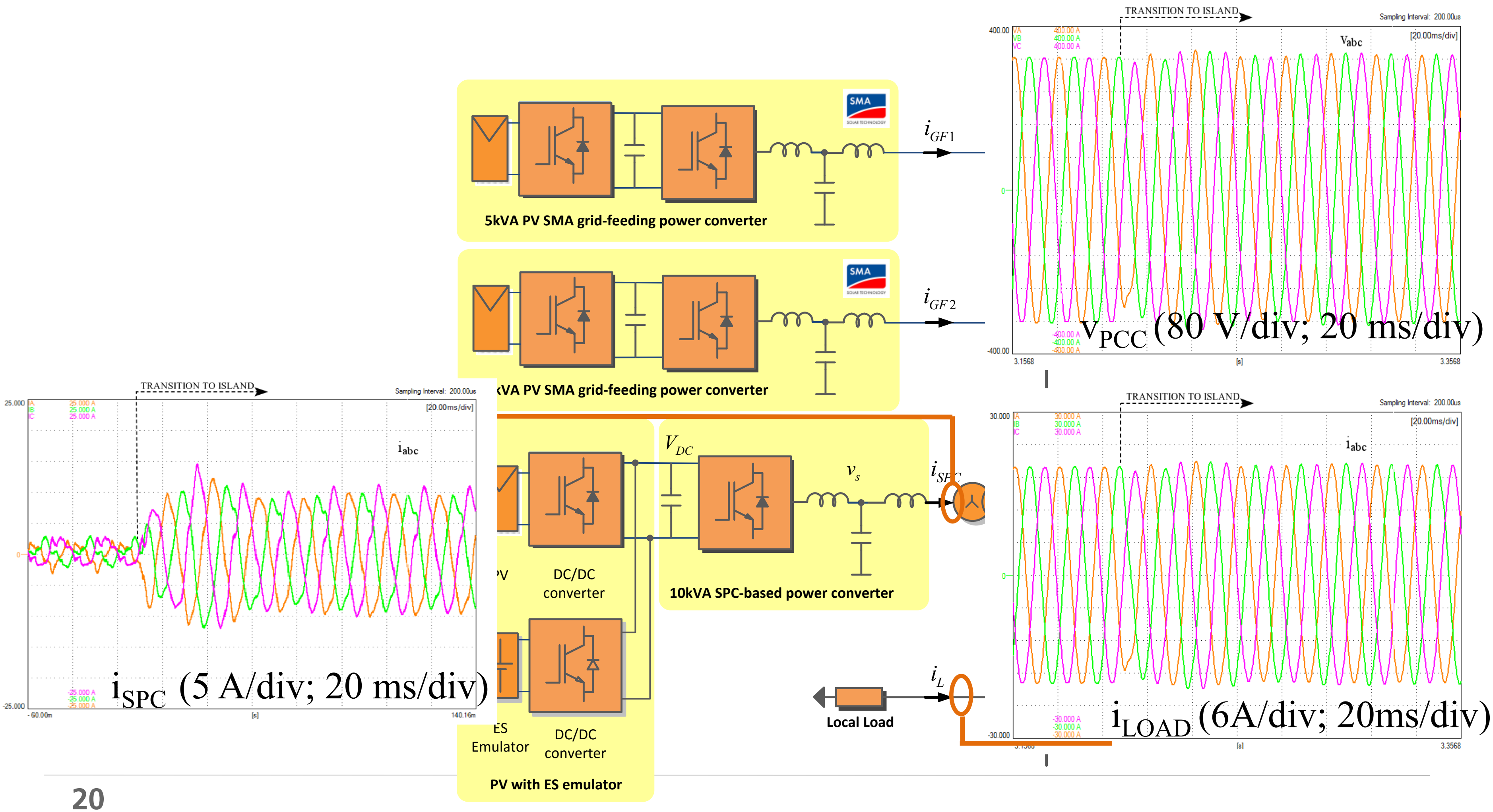
Experimental Test Bench



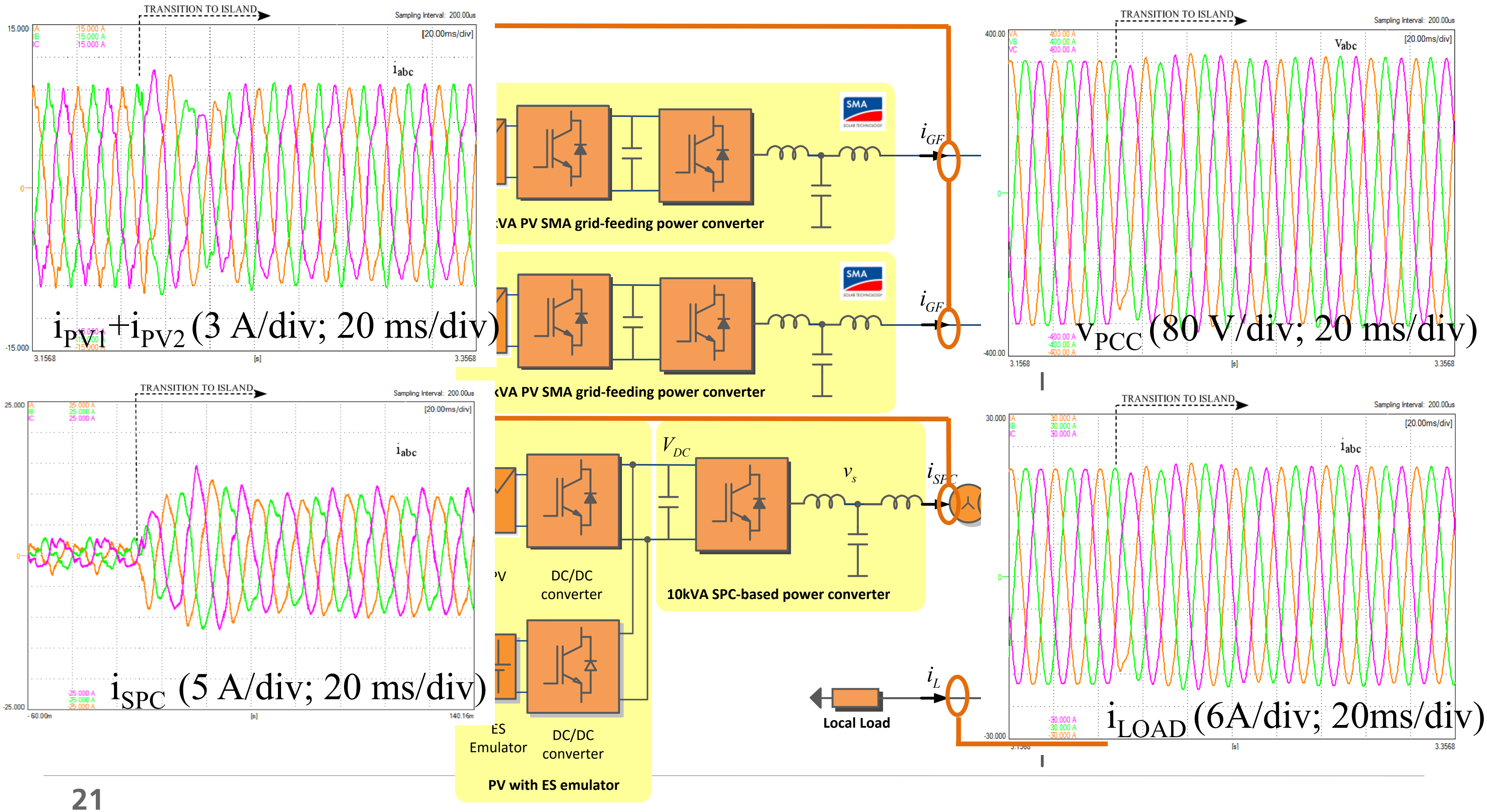
Experimental Results – Grid Disconnection



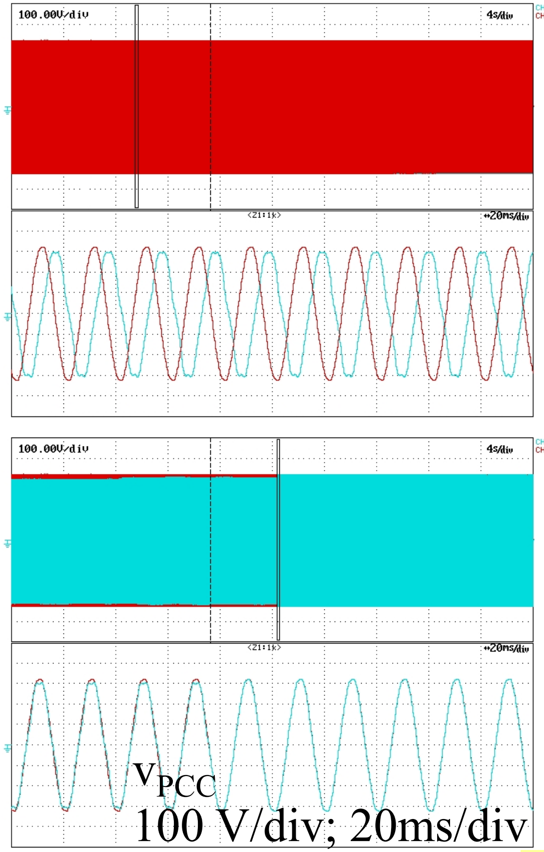
Experimental Results – Grid Disconnection

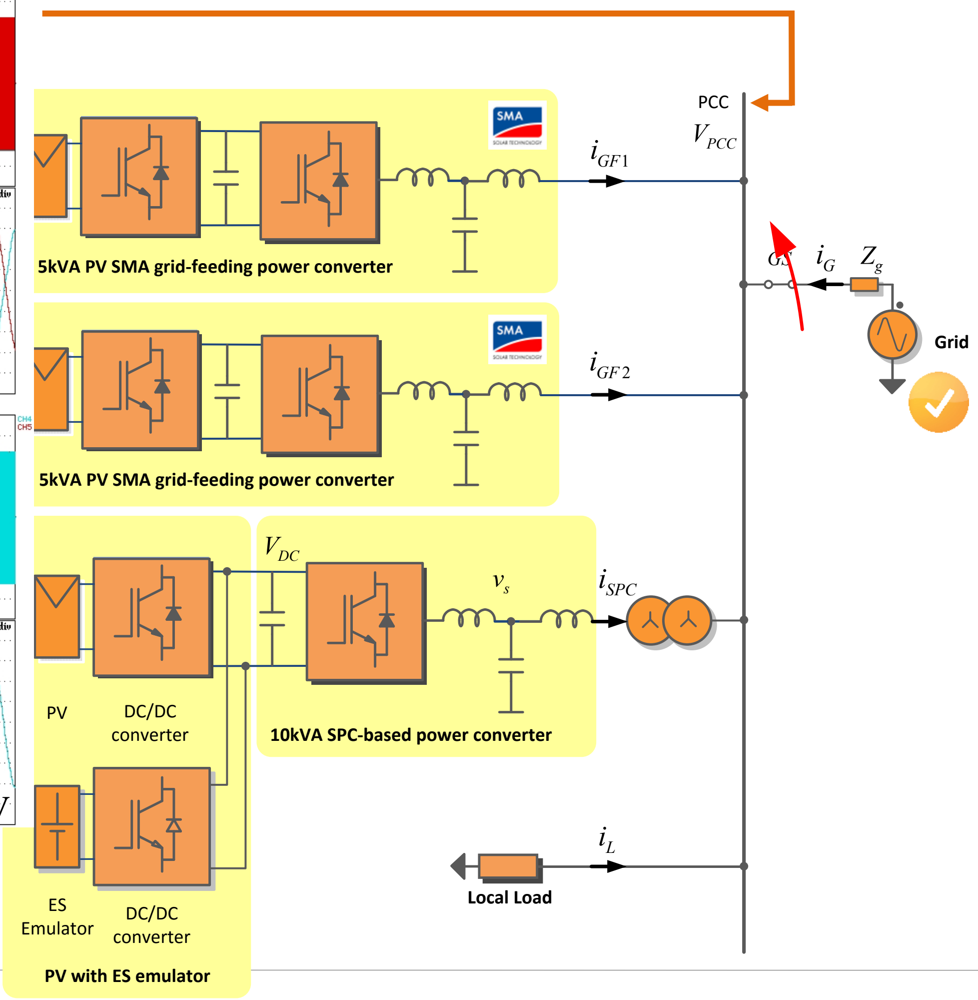


Experimental Results – Grid Disconnection

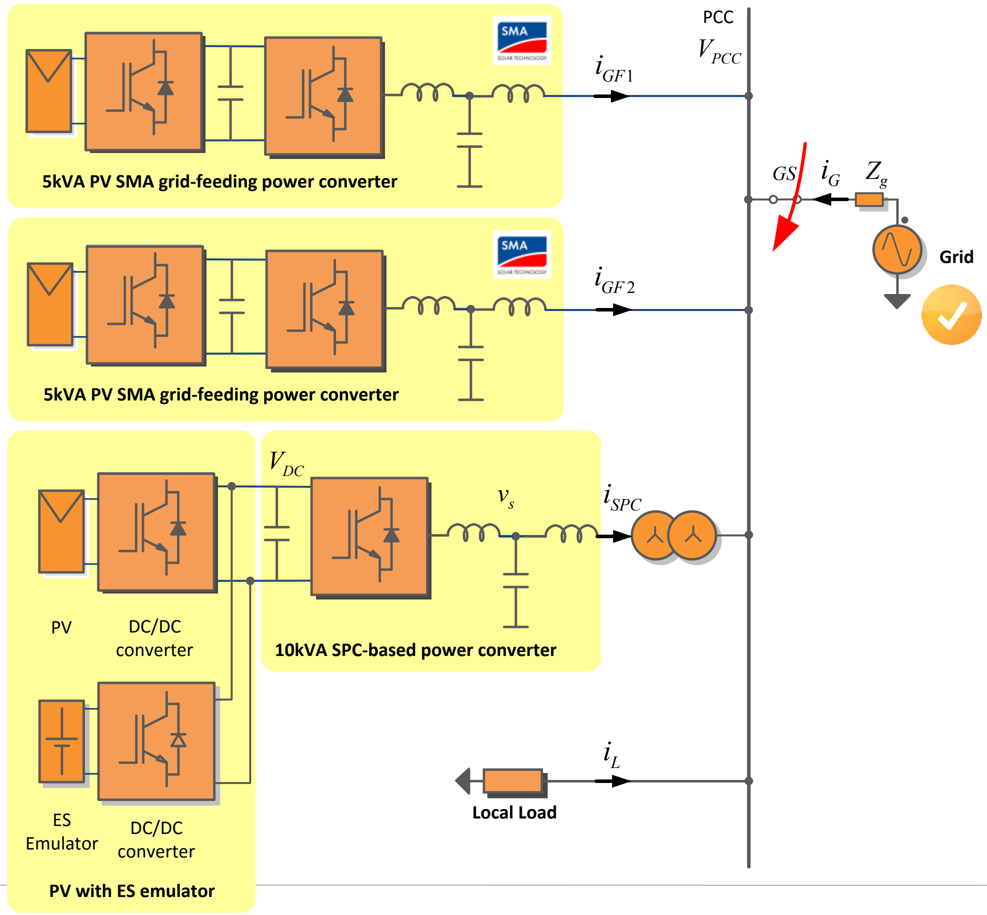


Experimental Results - Resynchronization

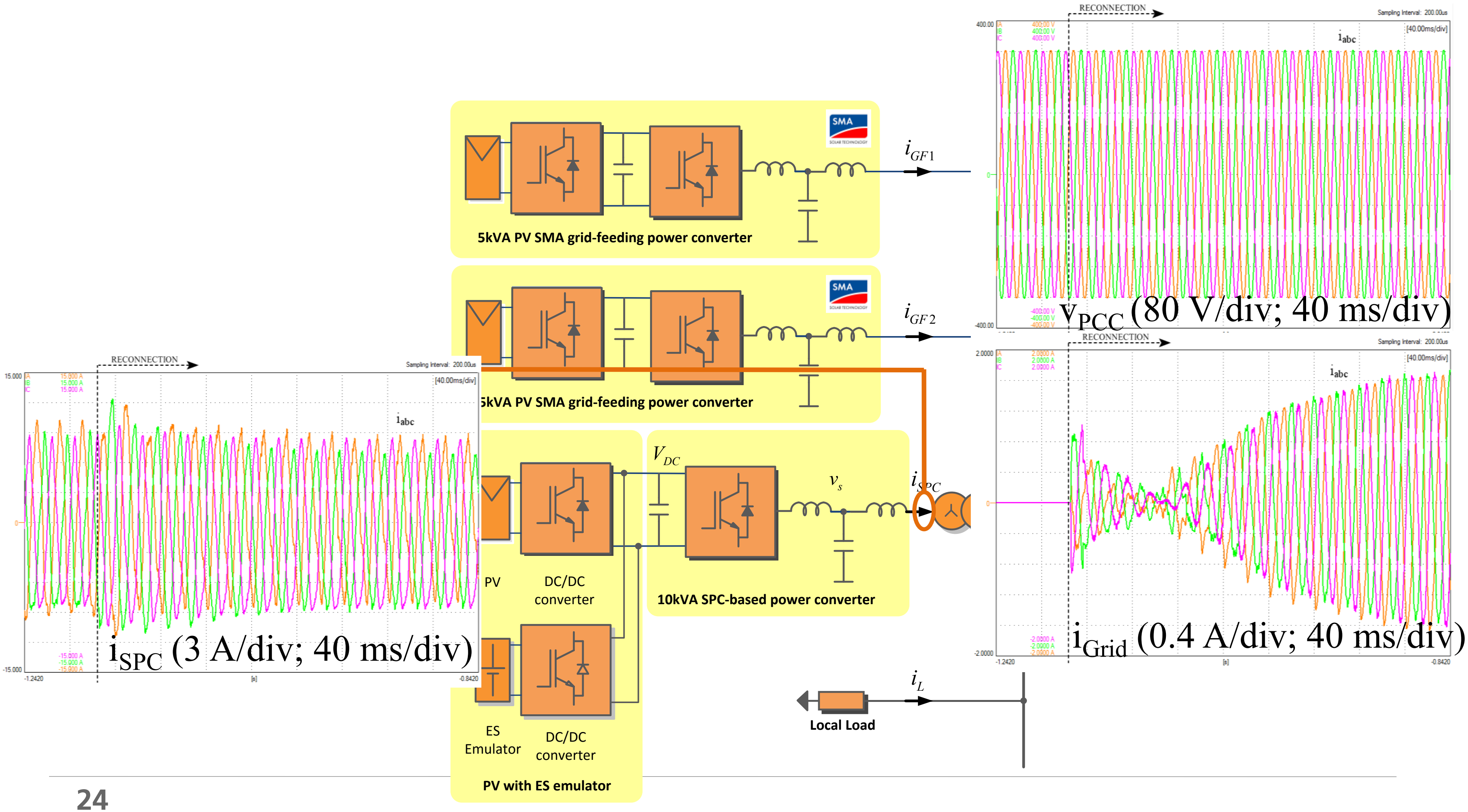




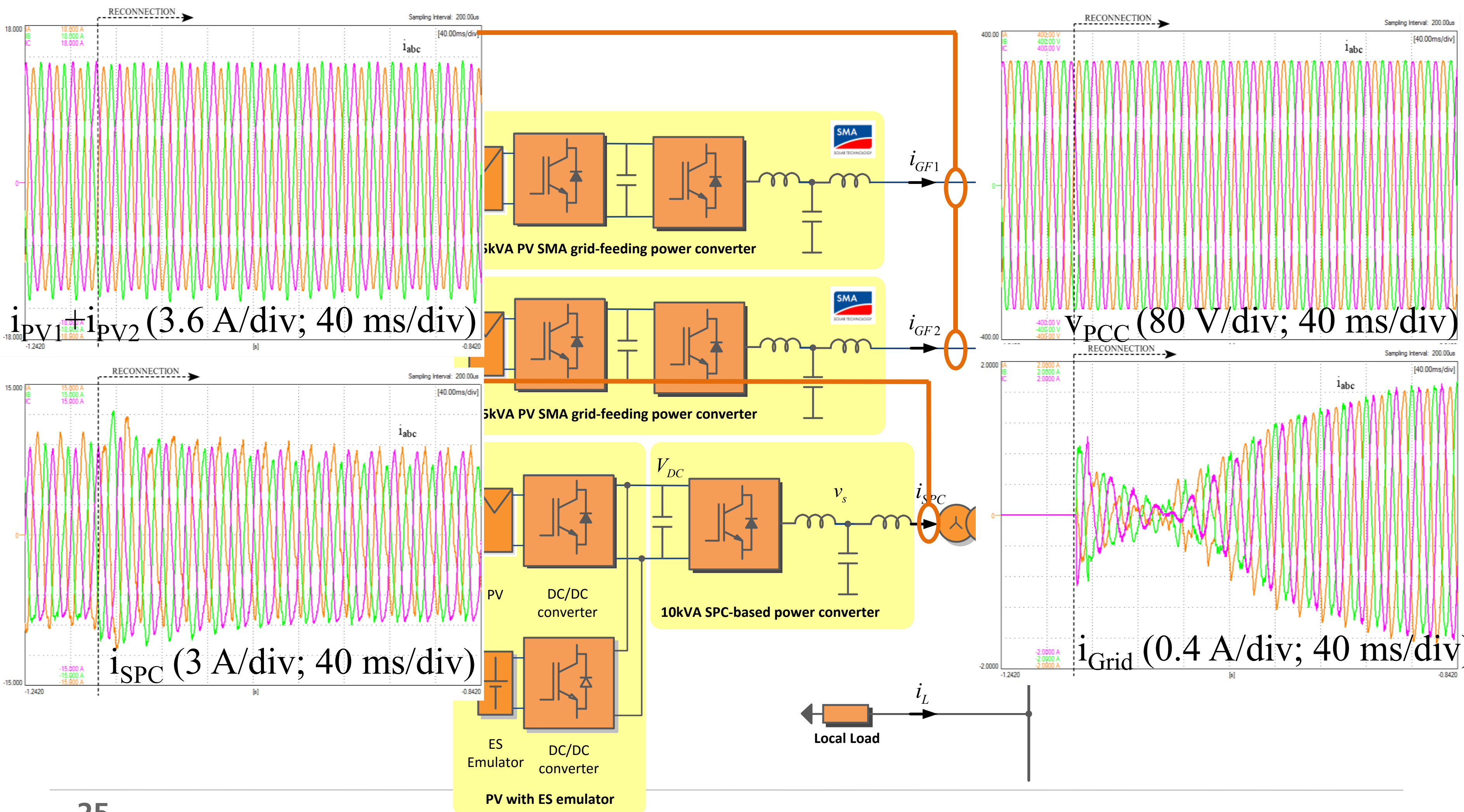
Experimental Results - Reconnection



Experimental Results - Reconnection



Experimental Results - Reconnection



Conclusions

- An advanced control technique based on the Synchronous Power Controller concept has been presented to improve the grid integration of PV or any DG systems.
- A variable virtual connection admittance has been presented to regulate the power transferred between the grid and power converters.
- Digital adjustable inertia and damping have been presented in order to adjust the power performance with the grid operation mode.
- No synchronization loop is necessary to control the power exchanged with the grid.
- Seamless disconnection and reconnection of electrical islands are achieved without creating distortions in the grid giving support to other grid-feeding converters.

The SPC definitely contributes to the large scale integration of distributed generators as it improves both the performance of the power converter and the operation of the grid itself.

Thank you for your attention

Project developed by Abengoa in collaboration with the Technical Universtiy of Catalonia

Project partially funded by the Spanish Research Agency through the project ENE 2013-48428-C02-2-R

Pedro Rodriguez
pedro.rodriguez@abengoa.com

Daniel Remon Rodriguez
daniel.remon@estudiant.upc.edu

GOBIERNO DE ESPAÑA MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

seer Renewable Electrical Energy Systems

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

ABENGOA RESEARCH