International Solar Alliance Expert Training Course

Remote-controlled curtailment options for solar PV system integration / Power plant controllers

In partnership with the Clean Energy Solutions Center (CESC)

Professor Oriol Gomis-Bellmunt

September 2019

Supporters of this Expert Training Series

INTERNATIONAL SOLAR ALLIANCE

CLEAN ENERGY SOLUTIONS CENTER
ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY
An Initiative of the Clean Energy Ministerial

CARBON TRUST

Expert Trainer: Prof Oriol Gomis-Bellmunt

- Professor in the Electrical Power Department of Technical University of Catalonia (UPC)
- Directive board member of the research group CITCEA-UPC, where he leads the group of power systems dominated by power electronics, including renewable energy (PV and wind), HVDC transmission systems and other power converter based systems (energy storage, EV chargers)
- 20+ years of experience in the fields of renewable energy, power electronics and power systems. Involved in a number of research projects and contracts of technology transfer to industry.
- Coauthor of 3 books, 7 patents and > 100 journal publications, mainly in the field of power electronics in power systems and grid integration of renewables.
- Supervision of 18 doctoral theses and >60 Bachelor and Master theses.

Overview of Training Course Modules

This Training is part of Module 4, and focuses on the issue of remote-controlled curtailment options for solar PV system integration and power plant controllers

Outline

Remote control of PV power plants

Structure of power plant controllers

PPC for reactive power control

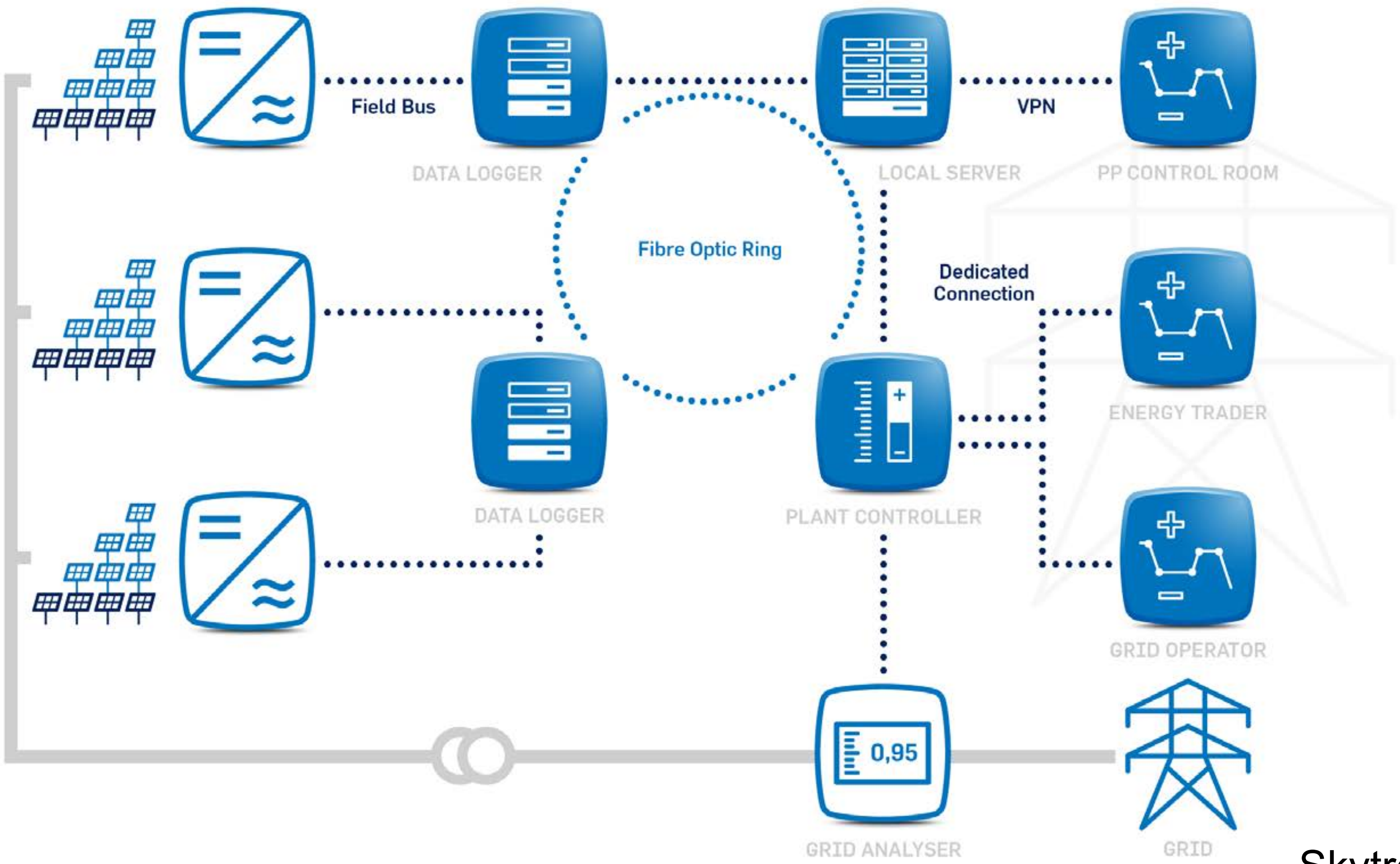
PPC for active power control

Examples

Context

- Power plant controllers are the overall plant controllers that ensure grid-friendly integration of the PV power plant.
- The PPC control the overall plant considering the distributed nature of the system.
- The PPC dispatches active and reactive power set-points to all the inverters and additional equipment to ensure the grid requirements in the point of connection.

System operation communication with PV power plants

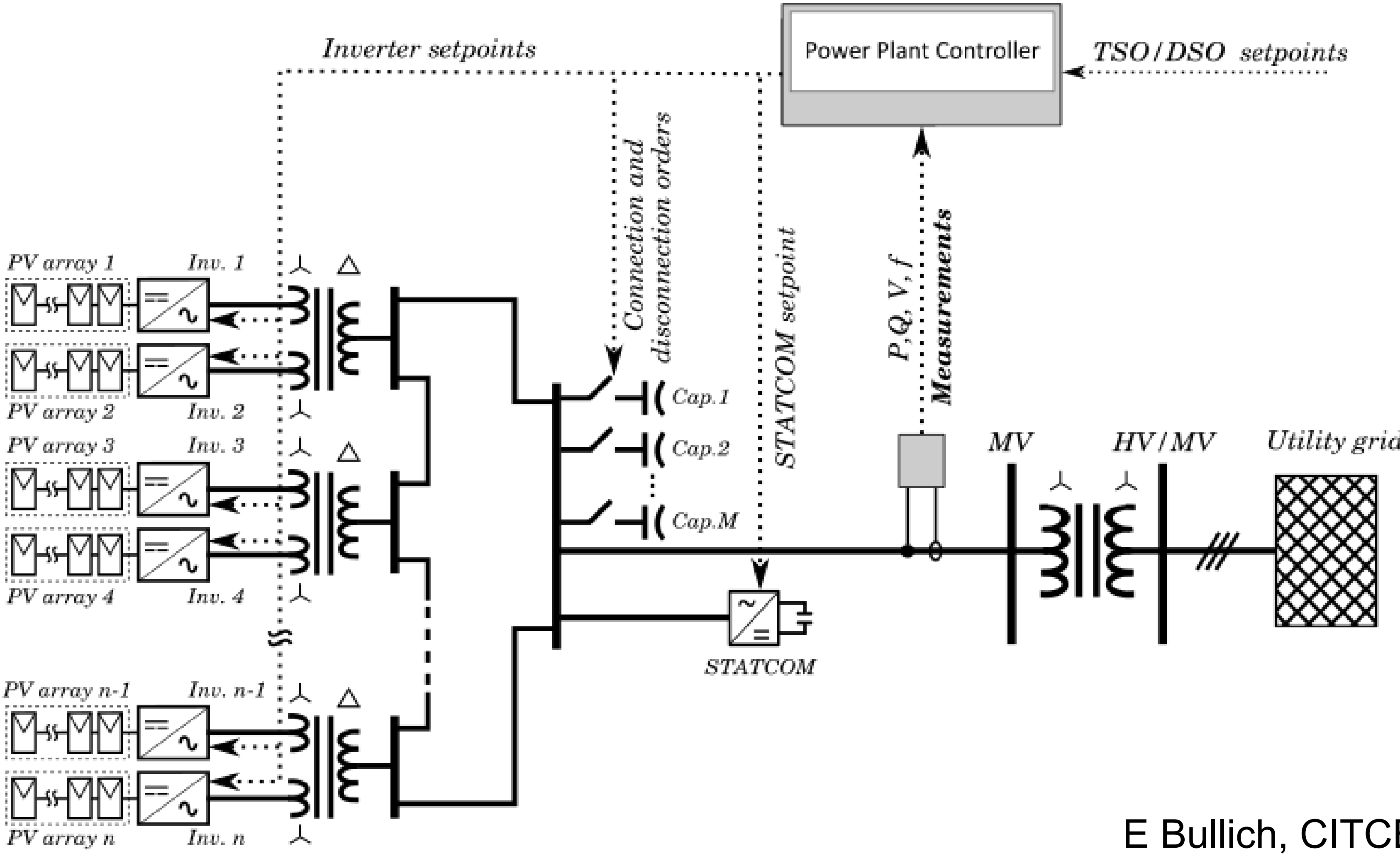


Skytron

System operation communication with PV power plants

- The system operator receives information on the PV power plant state and sends set-points related to active and reactive power exchange.
- A typical example is a command of active power curtailment, to avoid congestions in the power system.
- The set-points of the grid-code requirements can be also adjusted through this communications channel.
- The power plant controller of the PV power plant is the responsible to coordinate the required actions internally in the plant.

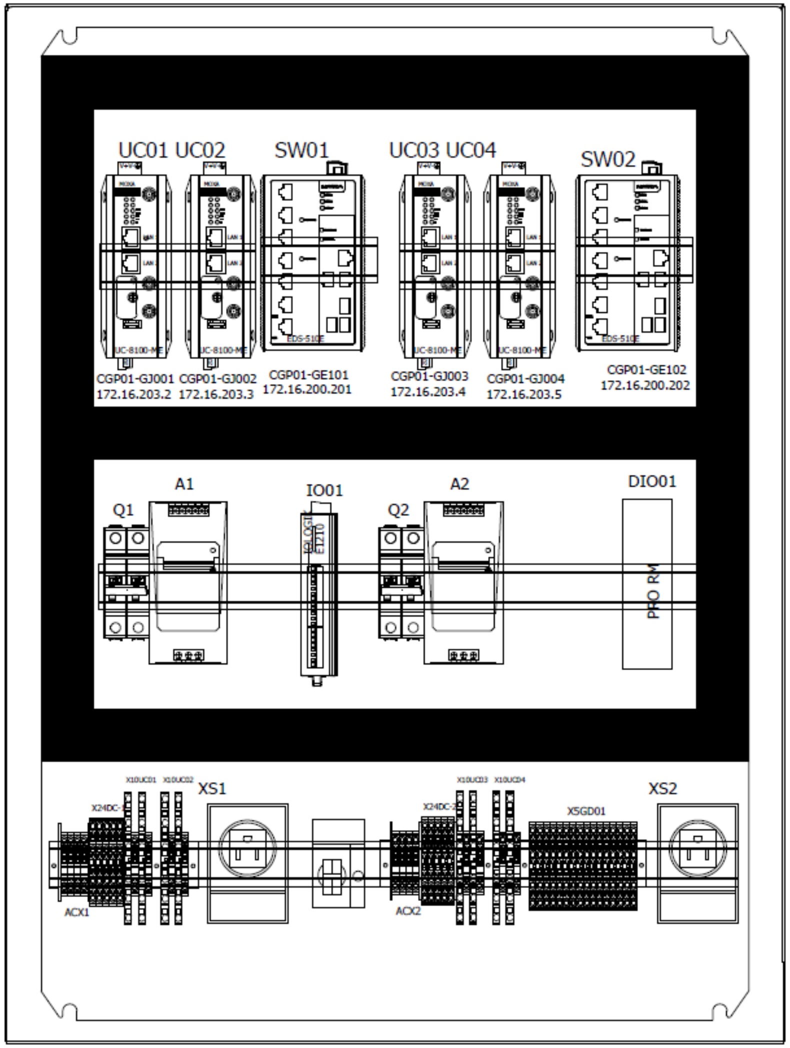
Power plant controller



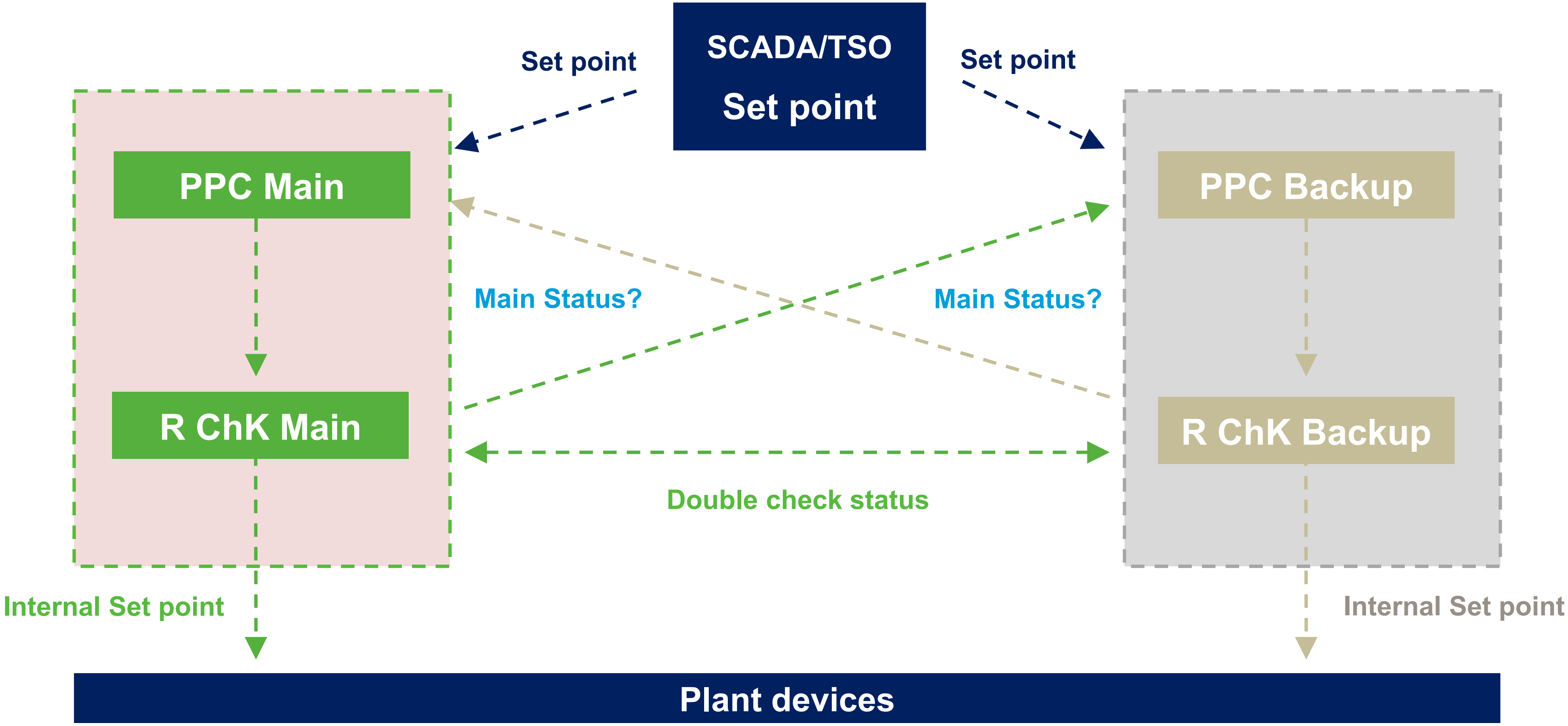
E Bullich, CITCEA

Physical implementation

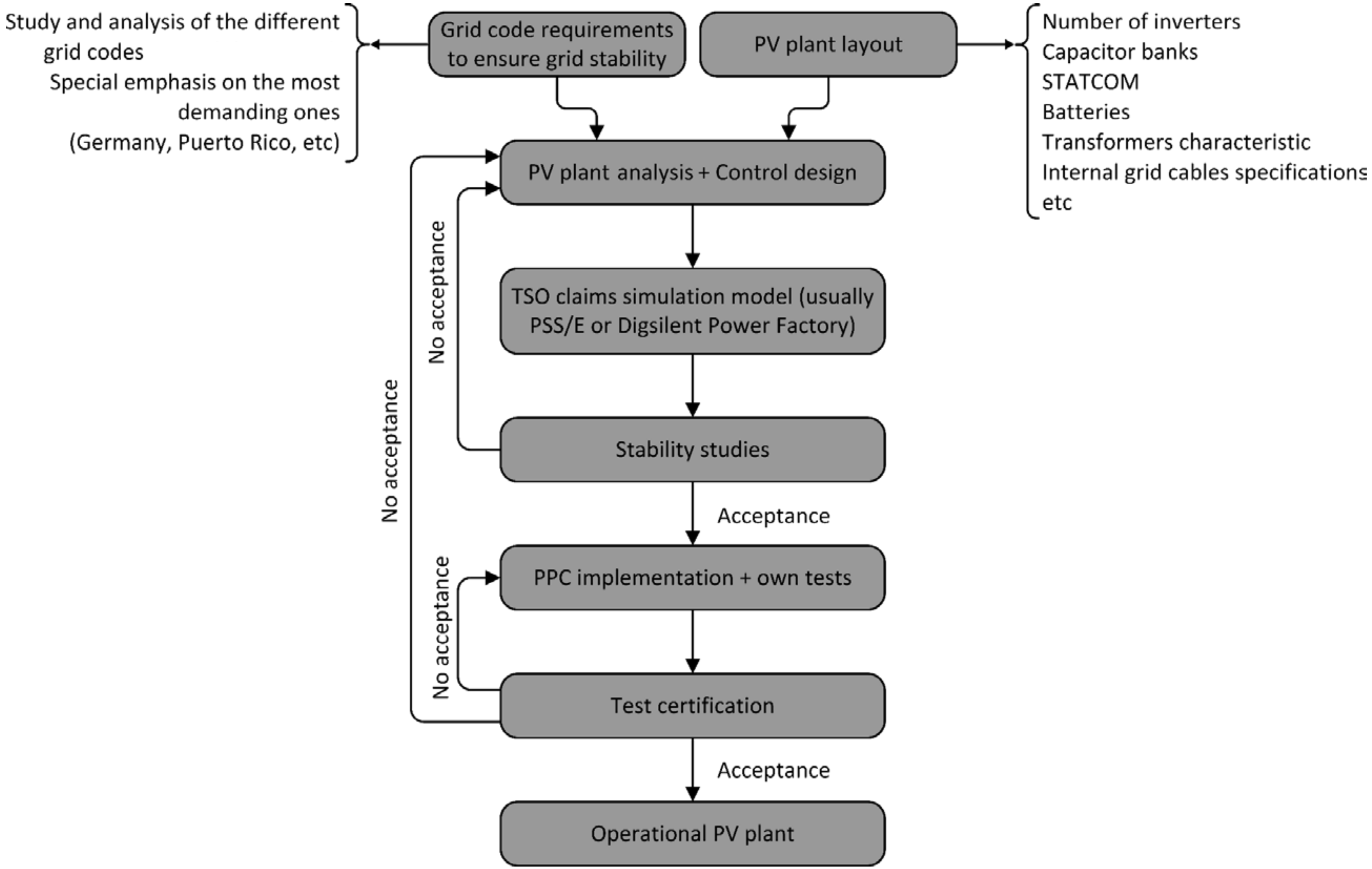
GreenPowerMonitor
a DNV GL company



Redundancy


SCADA/TSO
Set point
Set point
Set point
PPC Main
R ChK Main
PPC Backup
R ChK Backup
Main Status?
Main Status?
Double check status
Internal Set point
Internal Set point
Plant devices

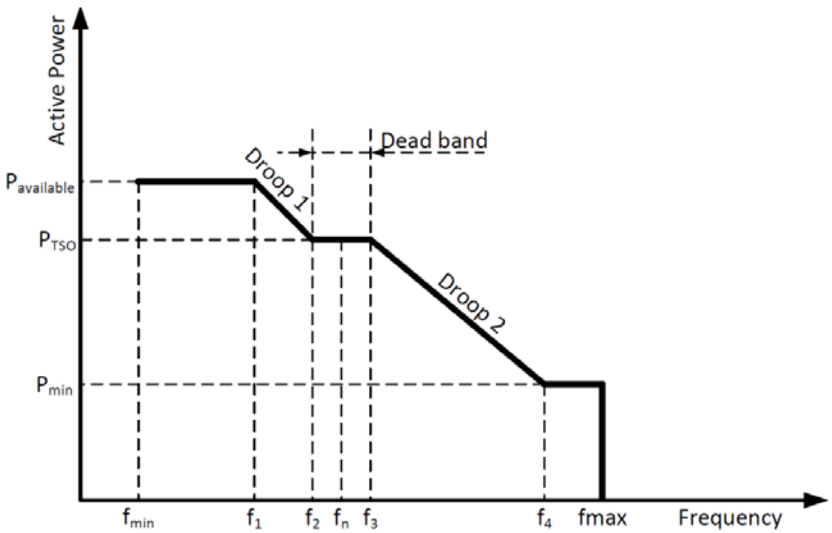
Power plant control design process



Grid code requirements

Grid code requirements

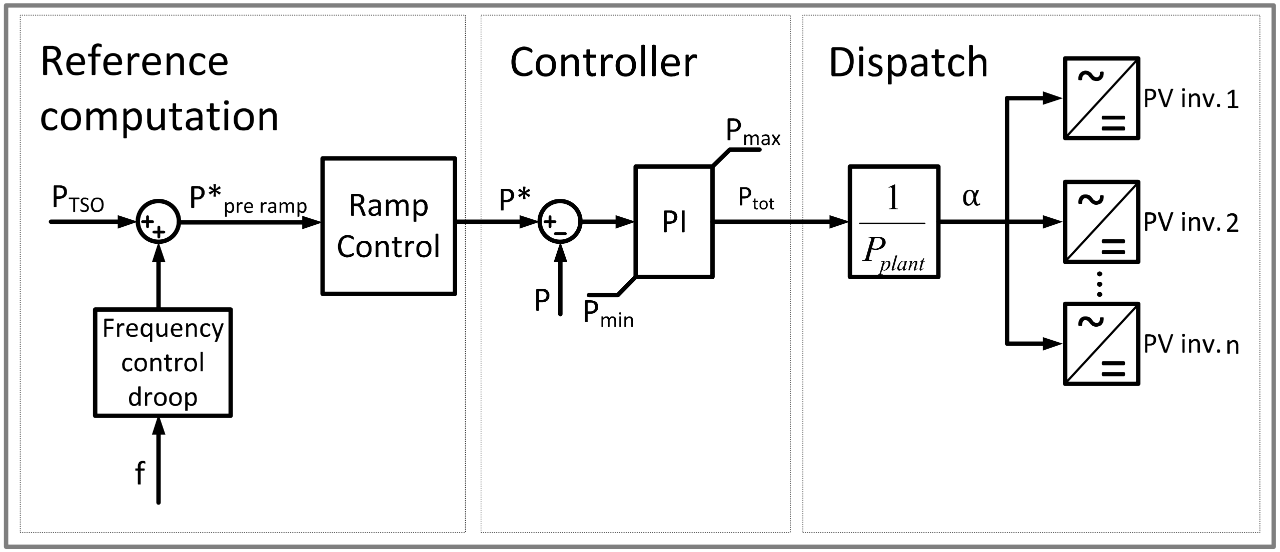
- Voltage regulation
  - Reactive power set-point
  - Droop Curve
  - Power Factor set-point
- Frequency regulation
  - Active power curtailment
  - Droop Curve
- Active and reactive ramp rate restrictions
- Fault ride through (inverter local controls)



Frequency Droop curve
South Africa Grid Code

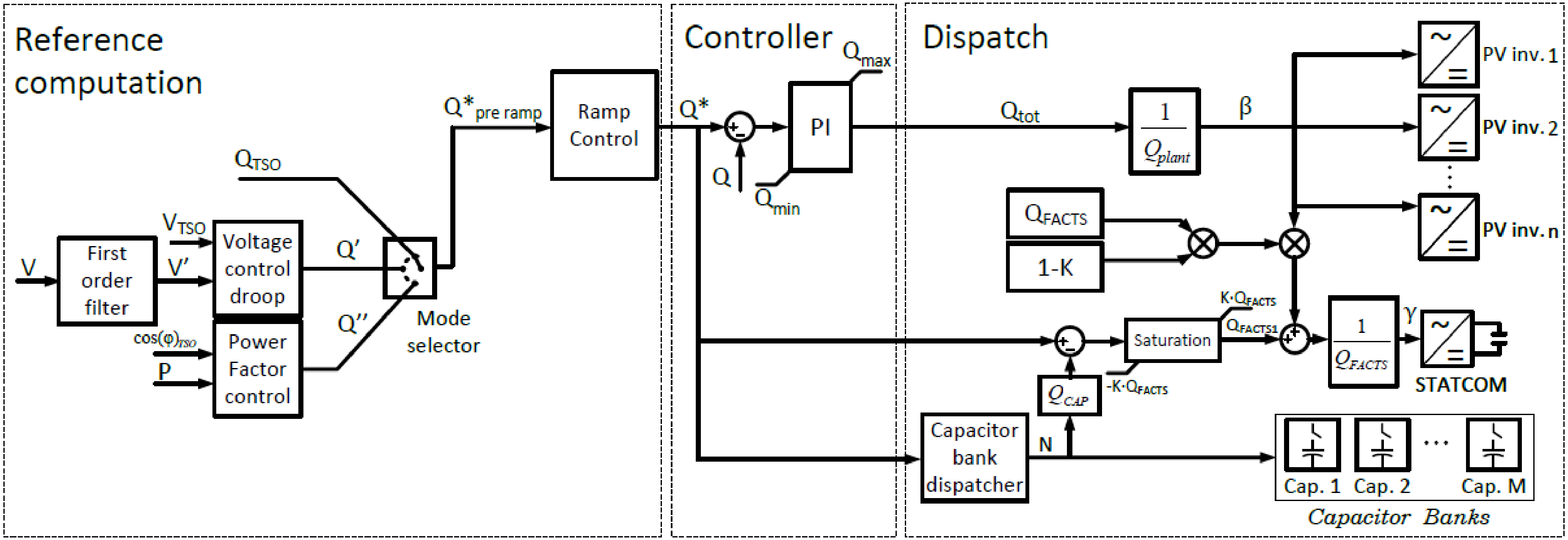
PV Power plant control

- Active power control



  - Power curtailment and frequency droop are applied together
  - Ramp rate limitation only applied to the curtailment contribution
  - A PI controller computes the total power that PV inverters must generate
  - Possible optimization

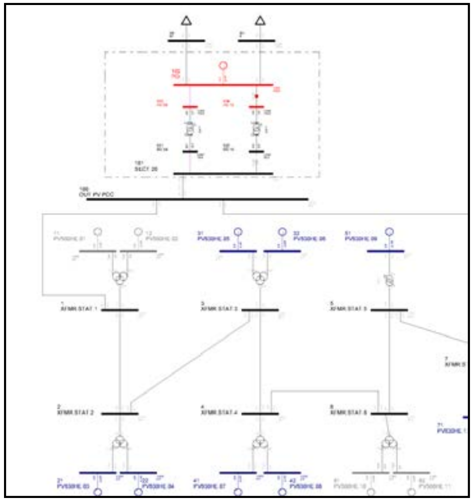
PV Power plant control – Reactive power



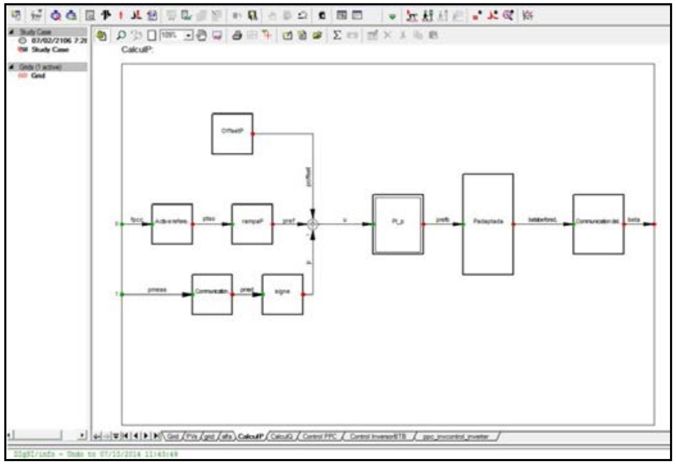
- Similar method compared to active power control
- Considering capacitor banks and FACTS devices a priority criteria is established
- If the plant is equipped with capacitor banks a filter is required before performing the voltage droop control
- Possible optimization (losses minimization)

Modelling and simulation

- Software used: PSS/E® ,DIgSILENT Power Factory ®, EMTP-RV® or others
- Typical software used by distribution and transmission companies
- Mandatory in some cases
- Inverter manufacturers provide a model
- Plant modelling:
  - Short circuit power at PCC
  - Cables, transformers and PV plant protection
  - Inverter models
  - Internal grid configuration
  - Power Plant Control model

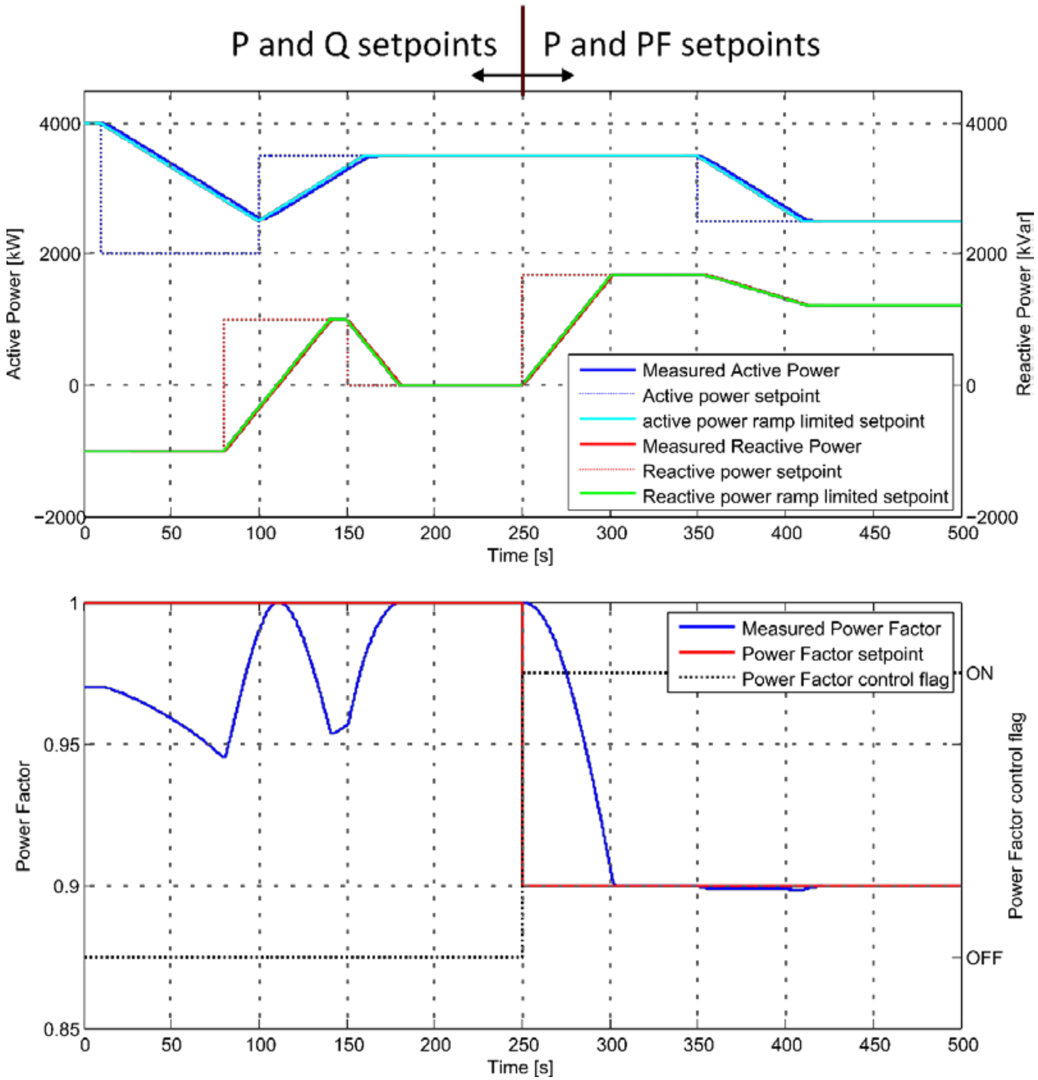


PSS/E. Fraction of a PV plant layout



DIgSILENT Power Factory. Active Power control scheme

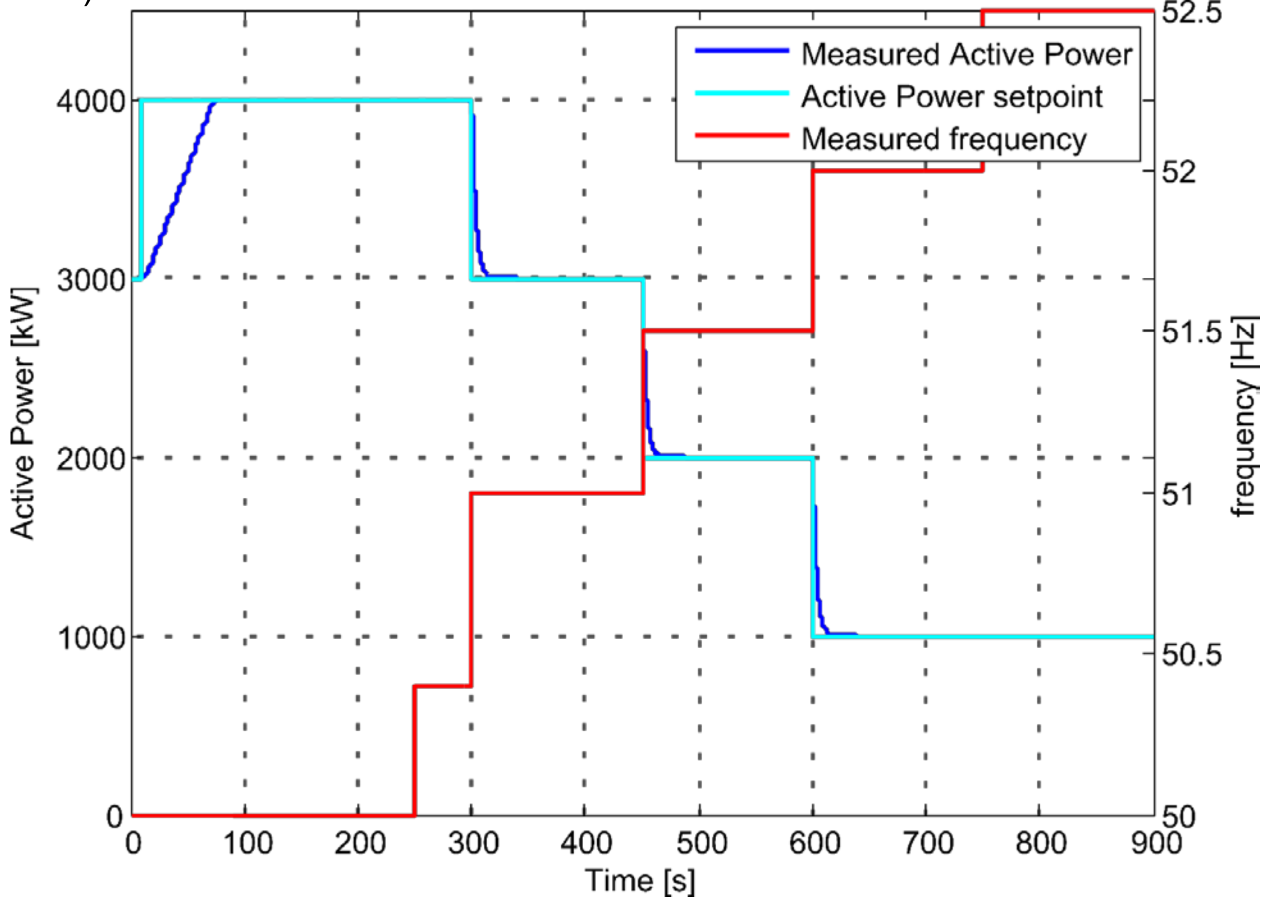
Modelling and simulation



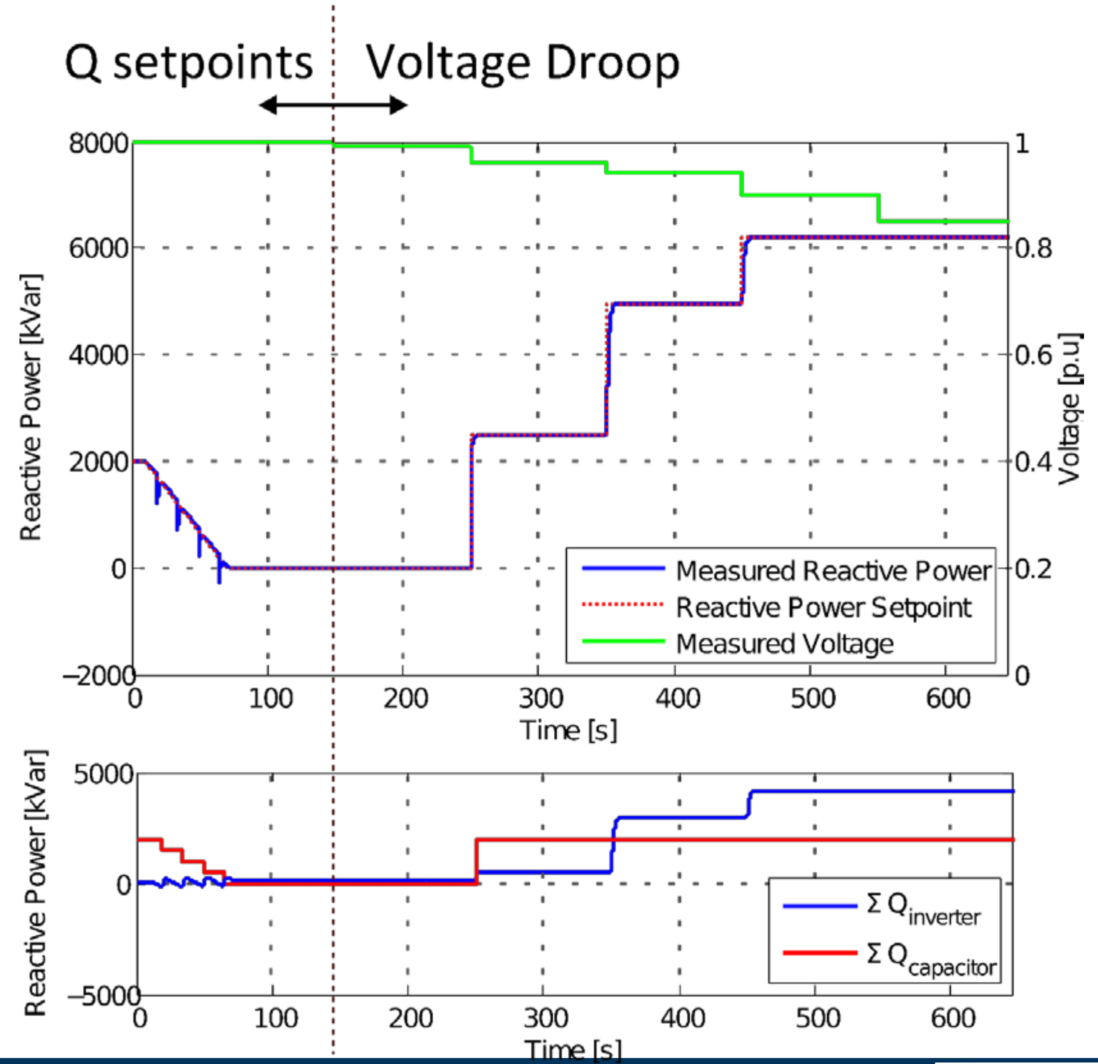
Modelling and simulation

Frequency Droop

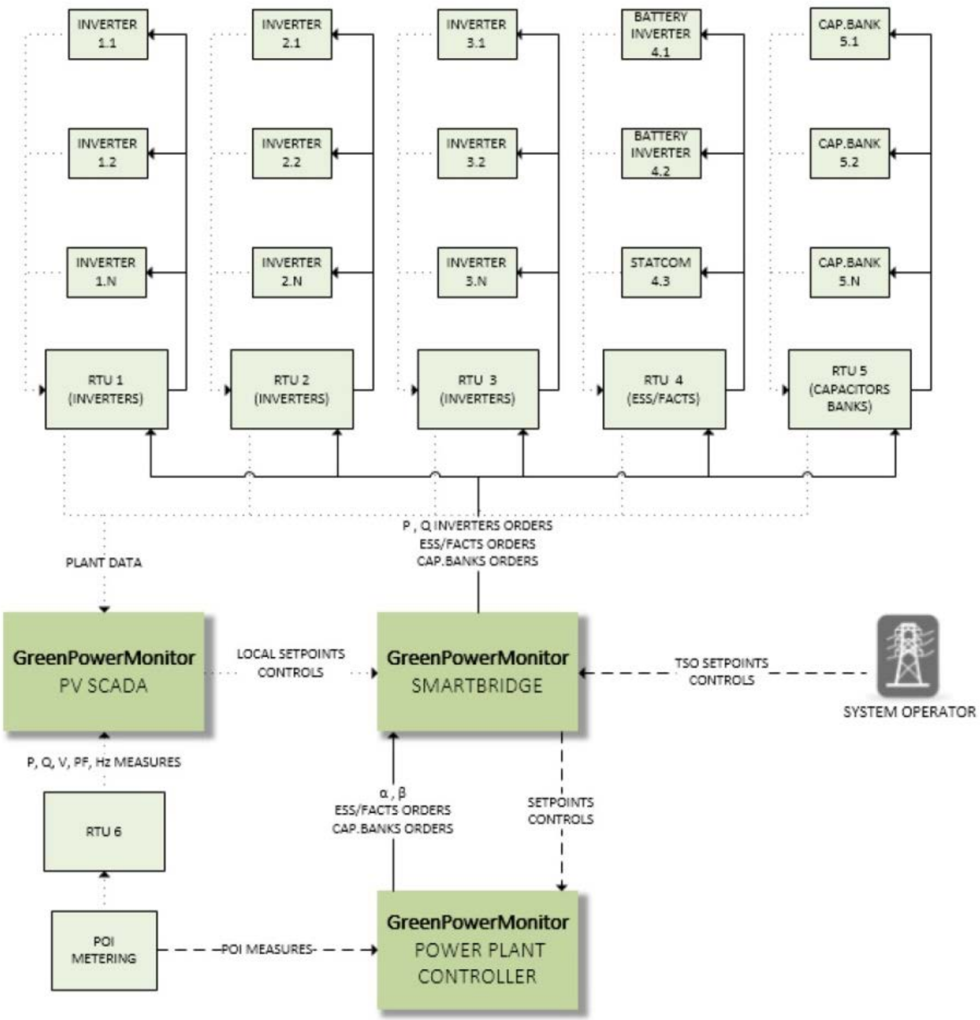
(activated at t=200s)



Modelling and simulation



Implementation



Scheme of Power Plant Control implementation

- PV SCADA
  - Display PV plant status in real time
  - Set control mode and local setpoints
- Smart Bridge
  - Receives data from GPM PV SCADA and from TSO
  - Interacts with PPC controller
  - Sends all PPC orders (inverters, capacitor banks, etc.)
- Power Plant Controller
  - Receives setpoints (from SCADA or TSO)
  - Receives measurements from PCC
  - Executes the control algorithm

Example real results

GreenPowerMonitor
a DNV GL company

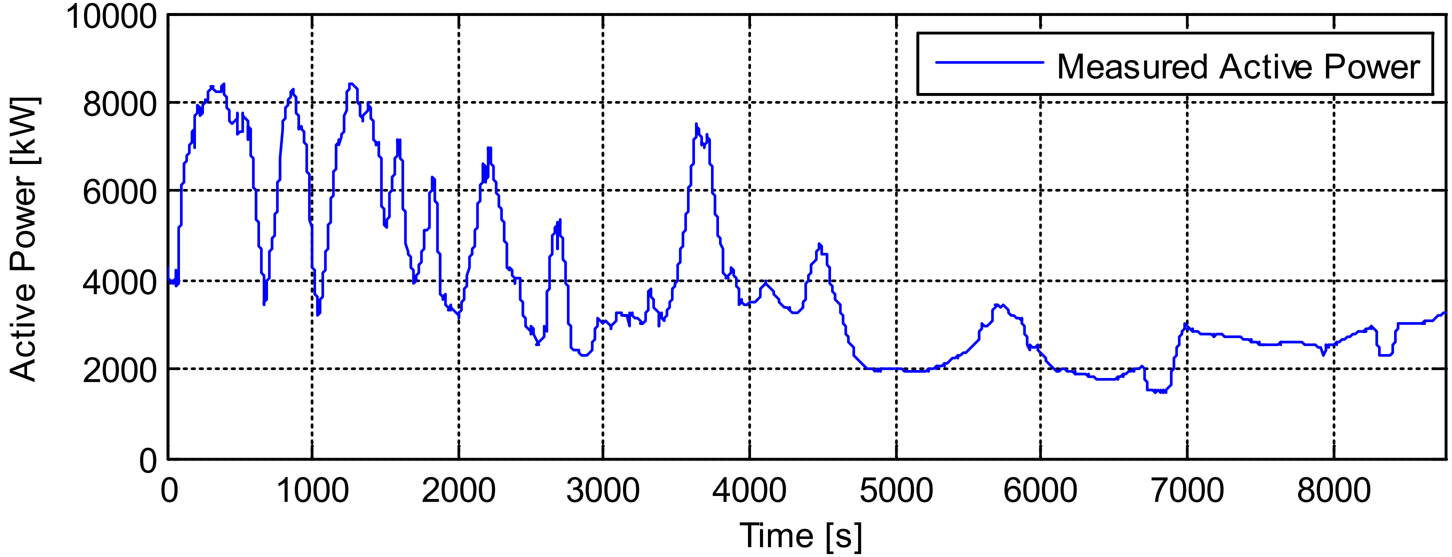
Example PV Plant

- 9.6 MW
- 15 inverters (SMA)
- Ramp rate: +/-1 MW/min
- Grid Code Requirements:
    - Power Curtailment
    - Q setpoint
    - PF setpoint
- Loop time: 1 second
- Communication delays: 200 ms
- Without Capacitor Banks, STATCOMS or batteries

9.6 MW PV power plant

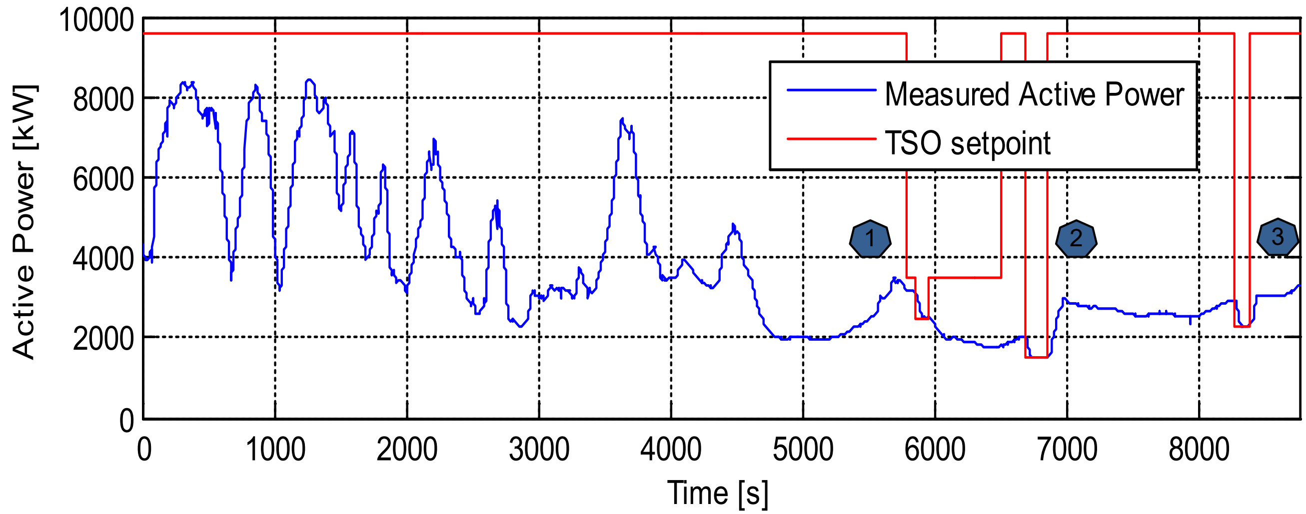
Results - Active Power Output

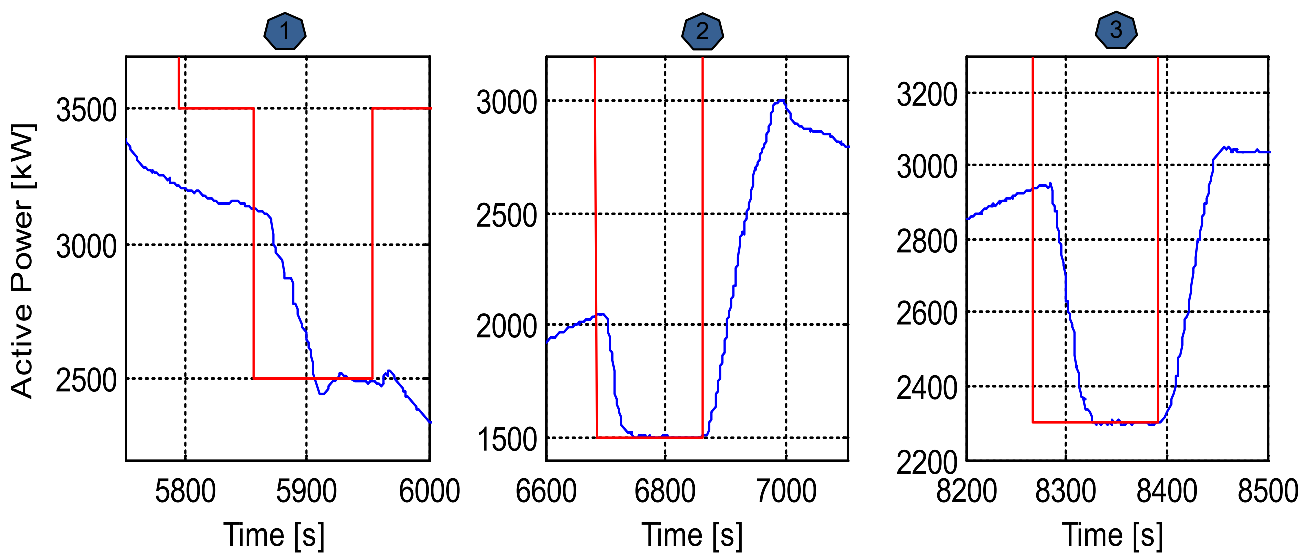
GreenPowerMonitor
a DNV GL company



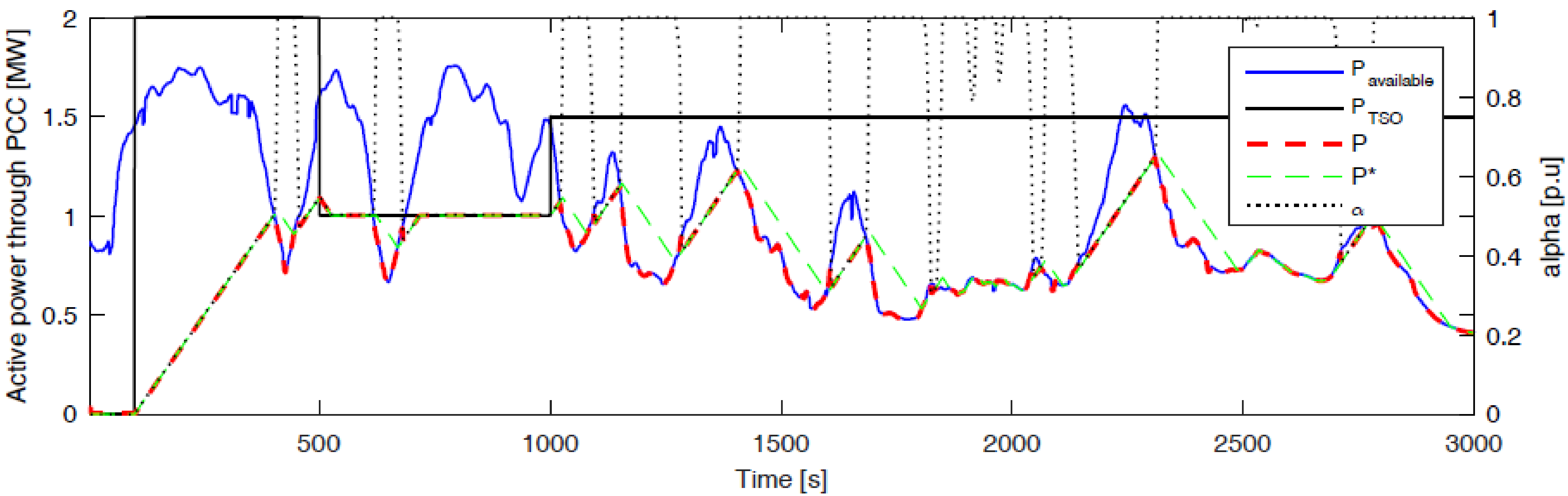
GreenPowerMonitor
a DNV GL company

Results - Active Power Output



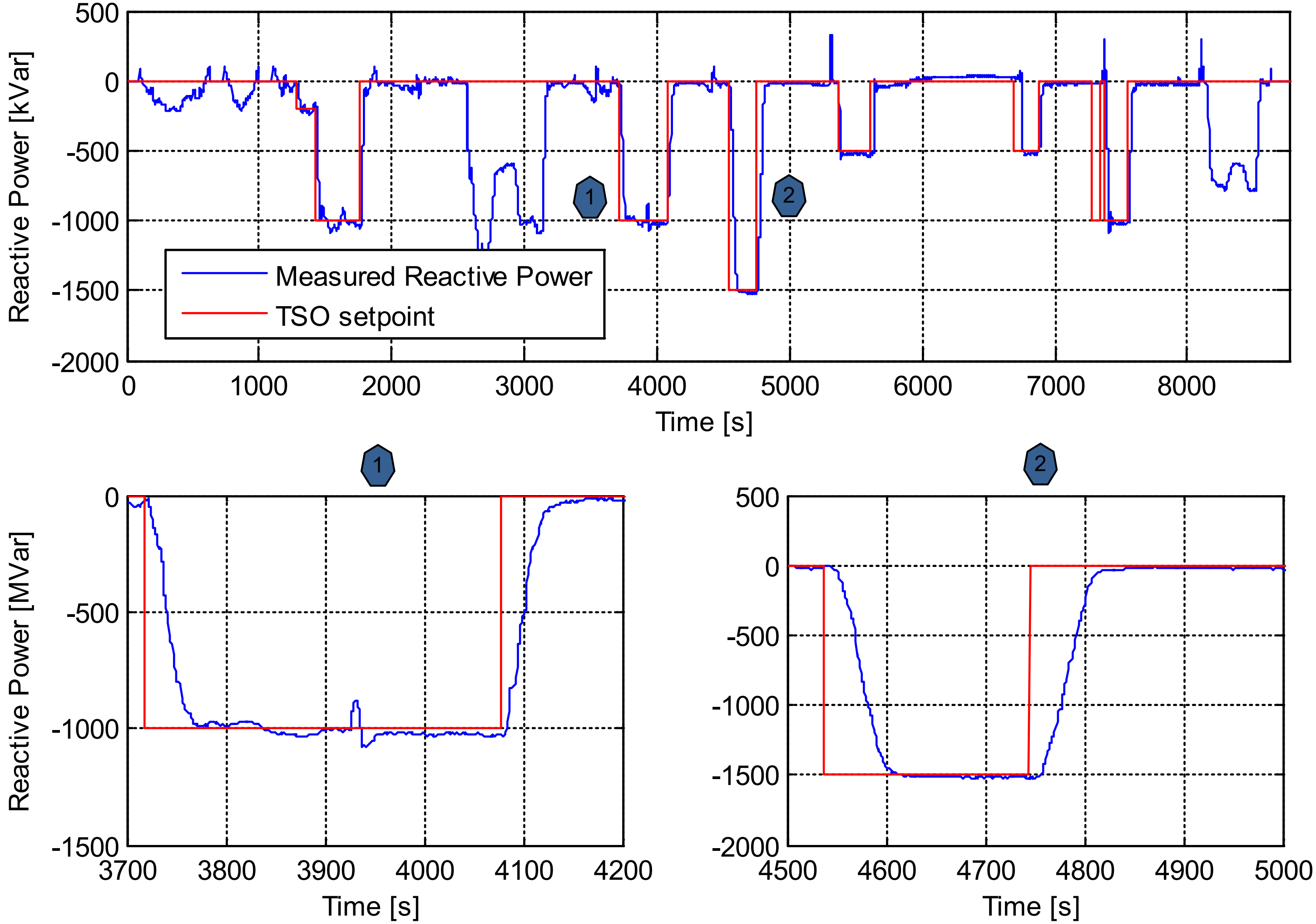


Results - Active Power Output

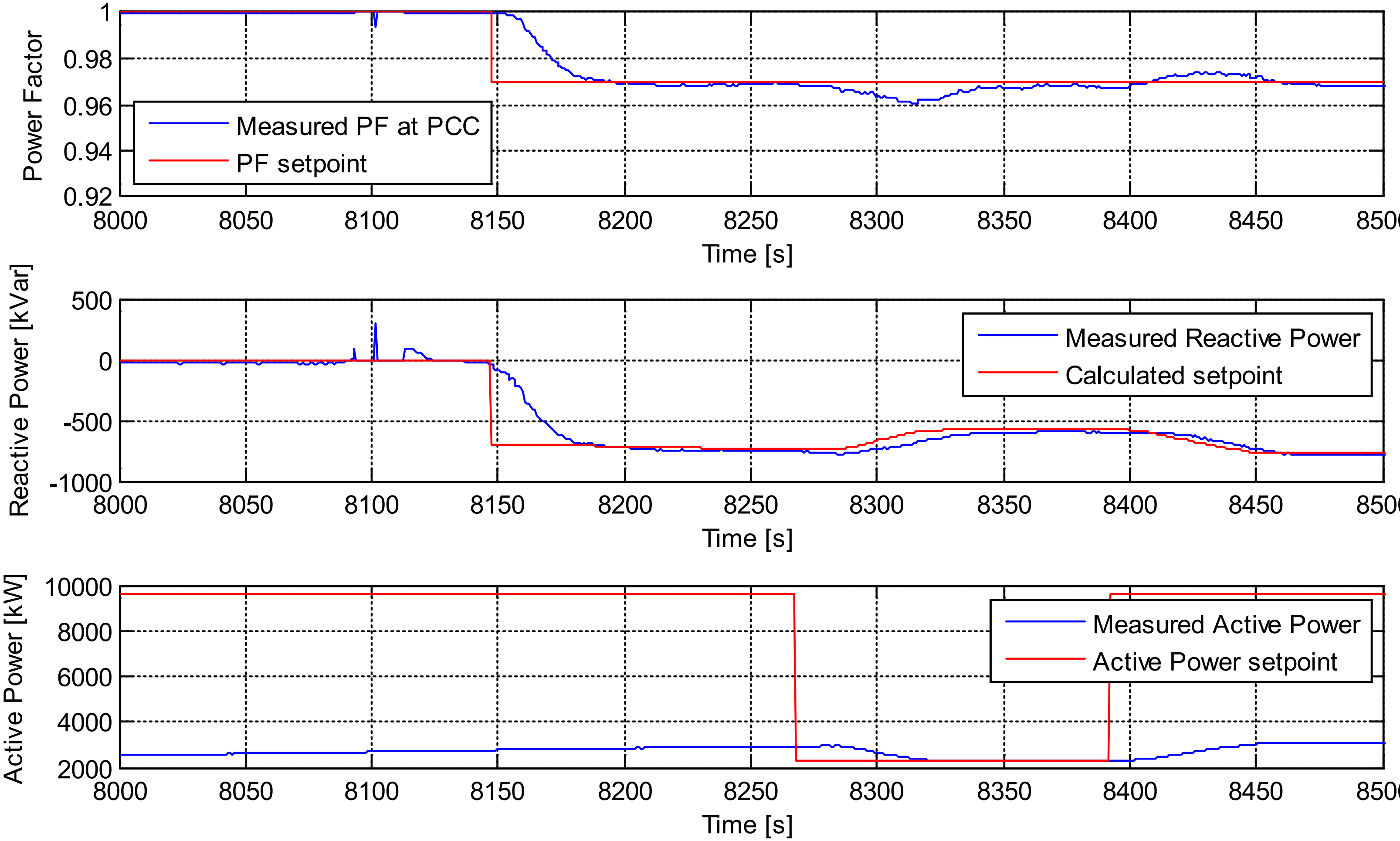


GreenPowerMonitor
a DNV GL company

Results - Reactive Power

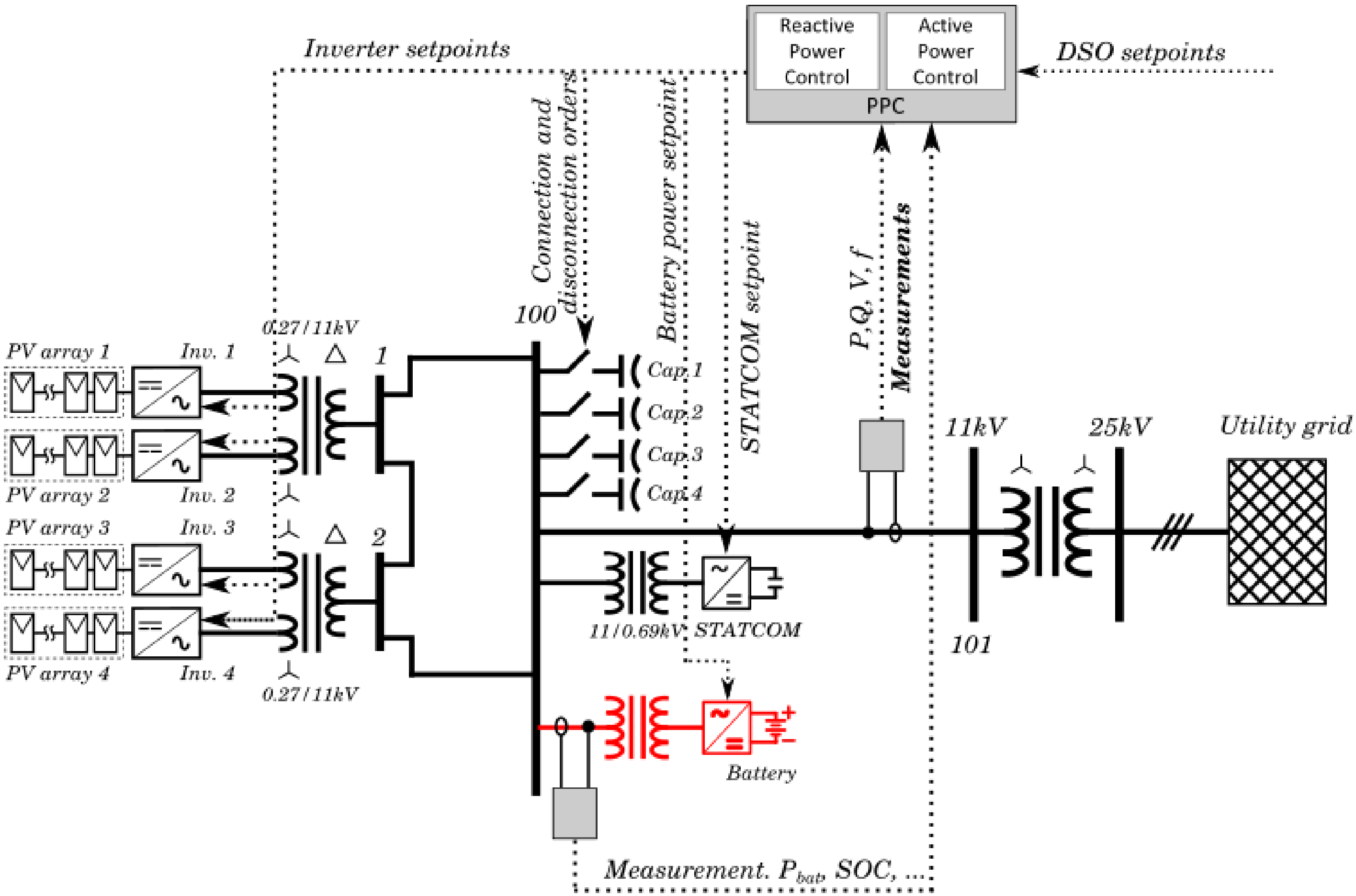


Results – Power factor



Power plant control with energy storage

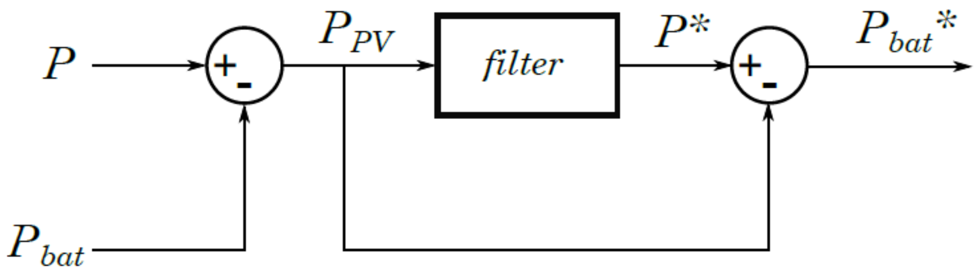
- Energy storage systems allow more flexible power regulation



Power plant control with energy storage

- Ramp rate control strategies

1. Power filtering with a low pass filter



2. Direct ramp control
   1. Ramp-rate calculation
   2. Battery set-point definition

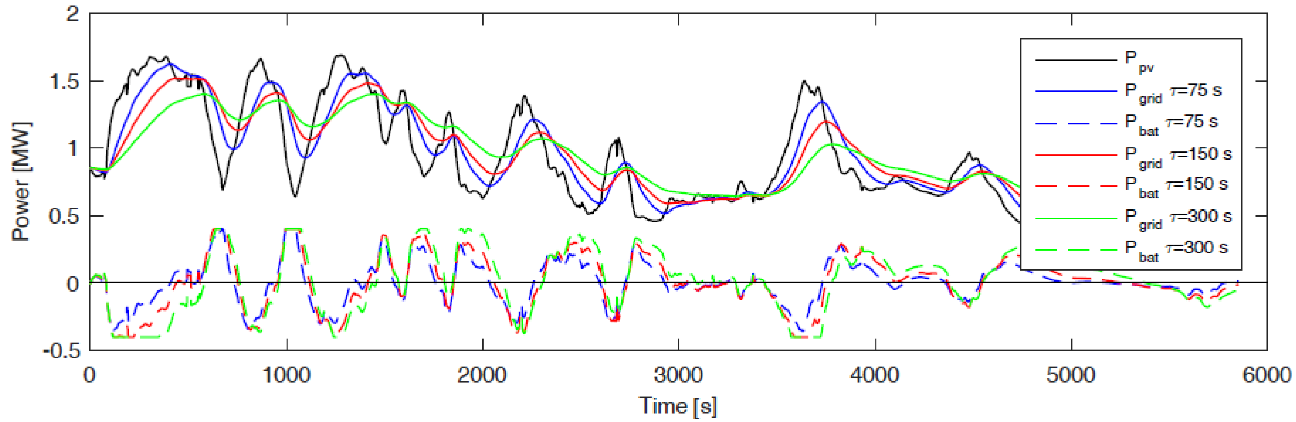
$$R_r = \frac{P_{PV}(t) - P(t-\Delta T)}{\Delta T}$$

$$P^*_{bat} = \begin{cases} 0 & \text{if } R_{r-down} < R_r < R_{r-up} \\ (R_{r-down} - R_r)\cdot \Delta t & \text{if } R_r < R_{r-down} \\ (R_{r-up} - R_r)\cdot \Delta t & \text{if } R_r > R_{r-up} \end{cases}$$

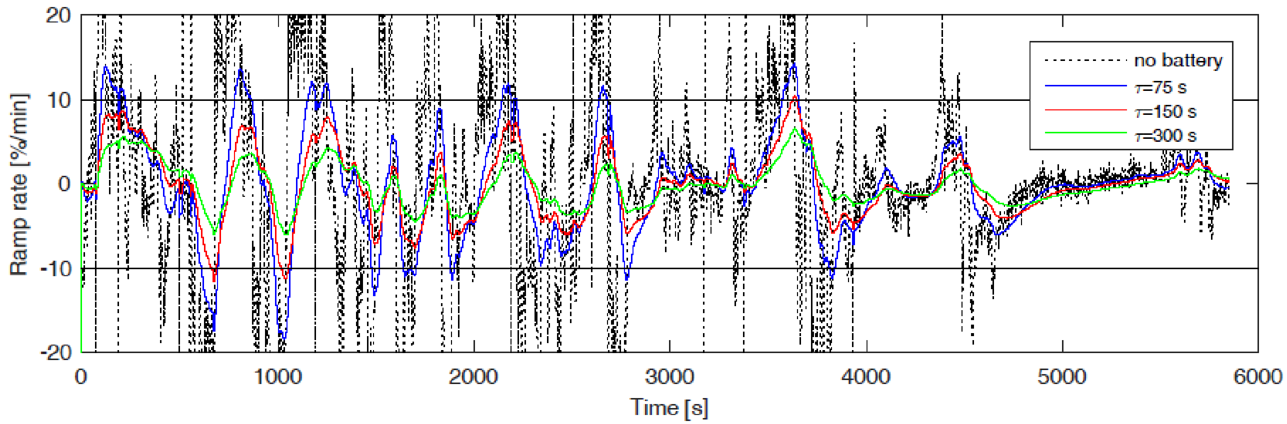
$R_{r\text{-}up}$ y $R_{r\text{-}down}$ ramp rate limits

Power plant control with energy storage

- Power filtering example



(a) PV, PCC and battery active power



(b) Ramp rate

Example of AES Ilumina PV Power Plant

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Single-line diagram of Ilumina's 20-MVA utility interconnection

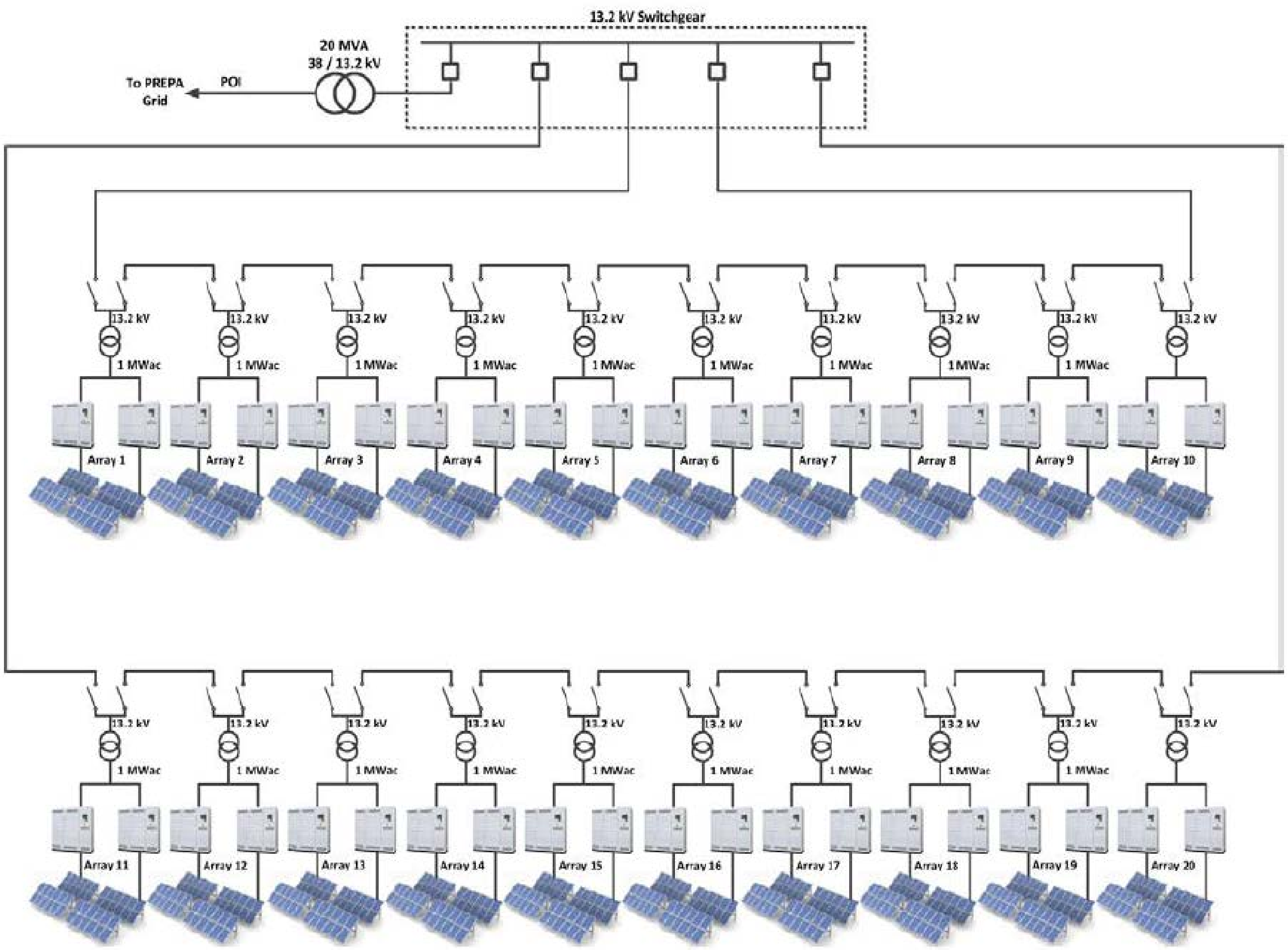

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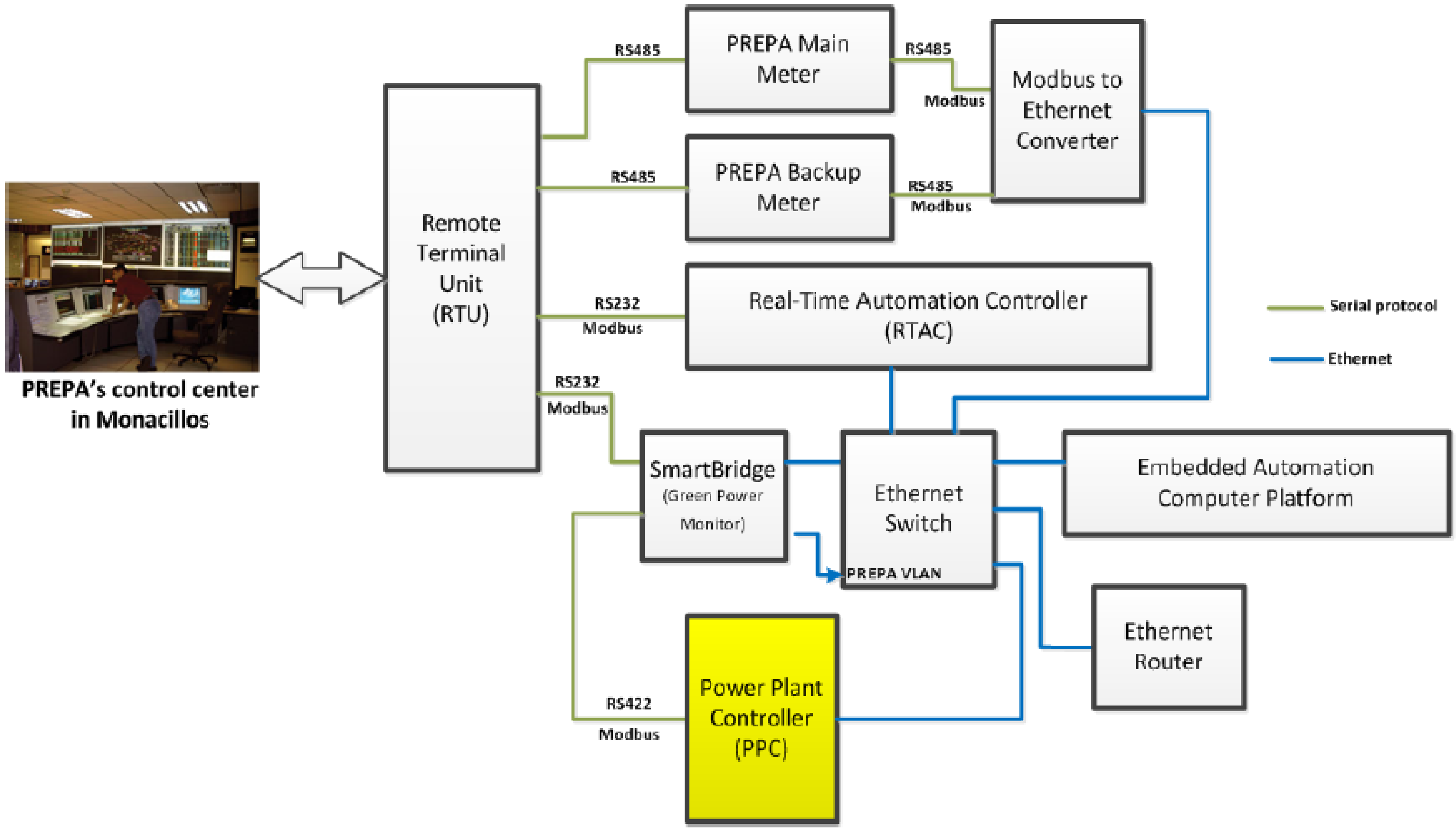
Diagram of the Ilumina PV power plant's remote terminal unit communications



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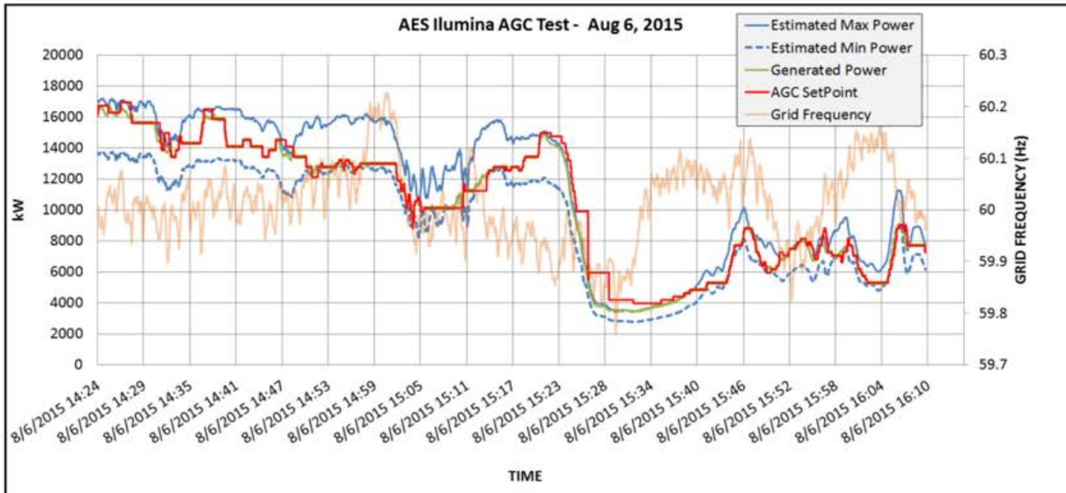
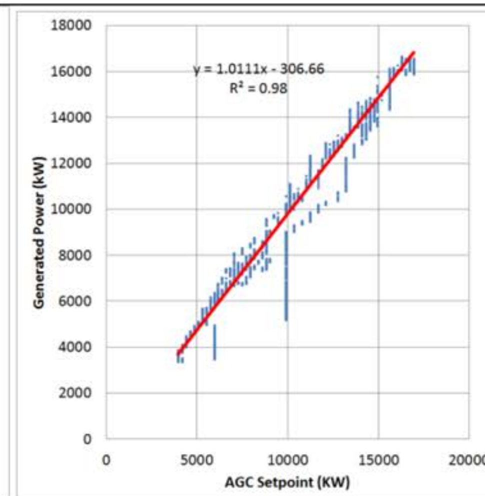
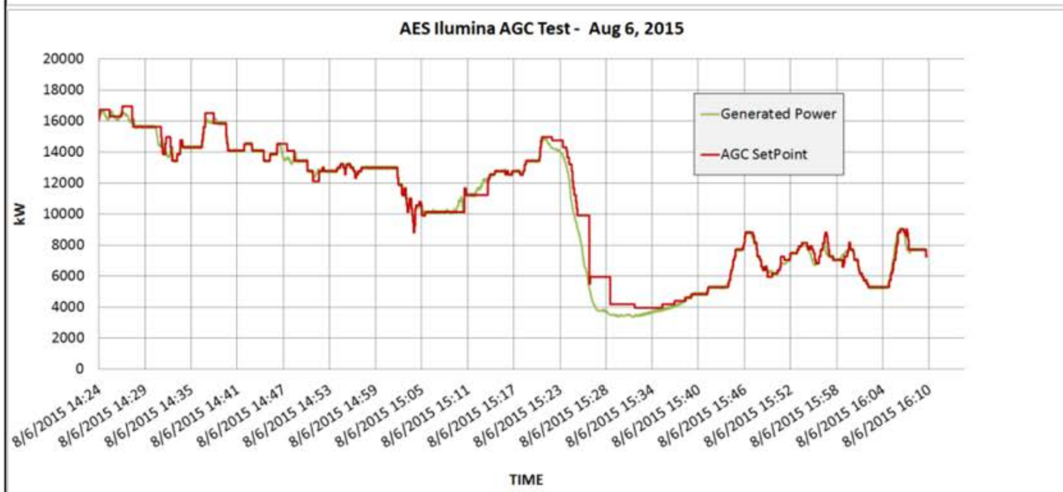
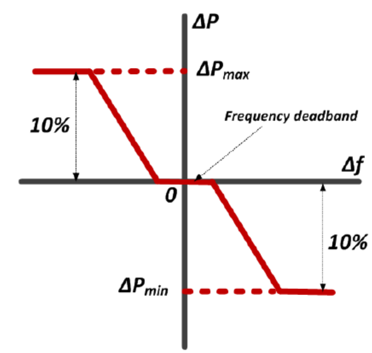
Tests on frequency control









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Example of Pecos Barilla PV power plant. Controls and interfaces.

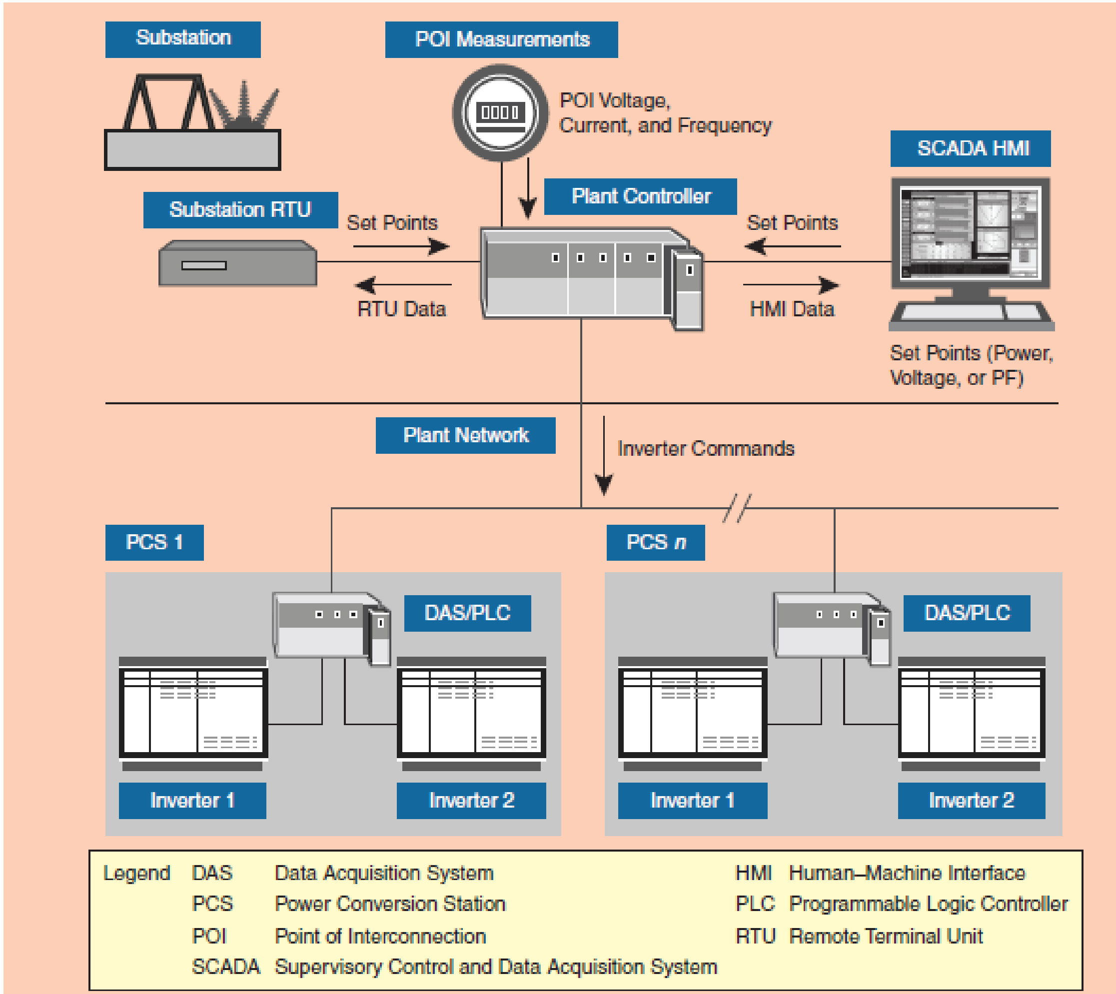

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Image from First Solar

Example of Pecos Barilla PV power plant. Controls and interfaces.

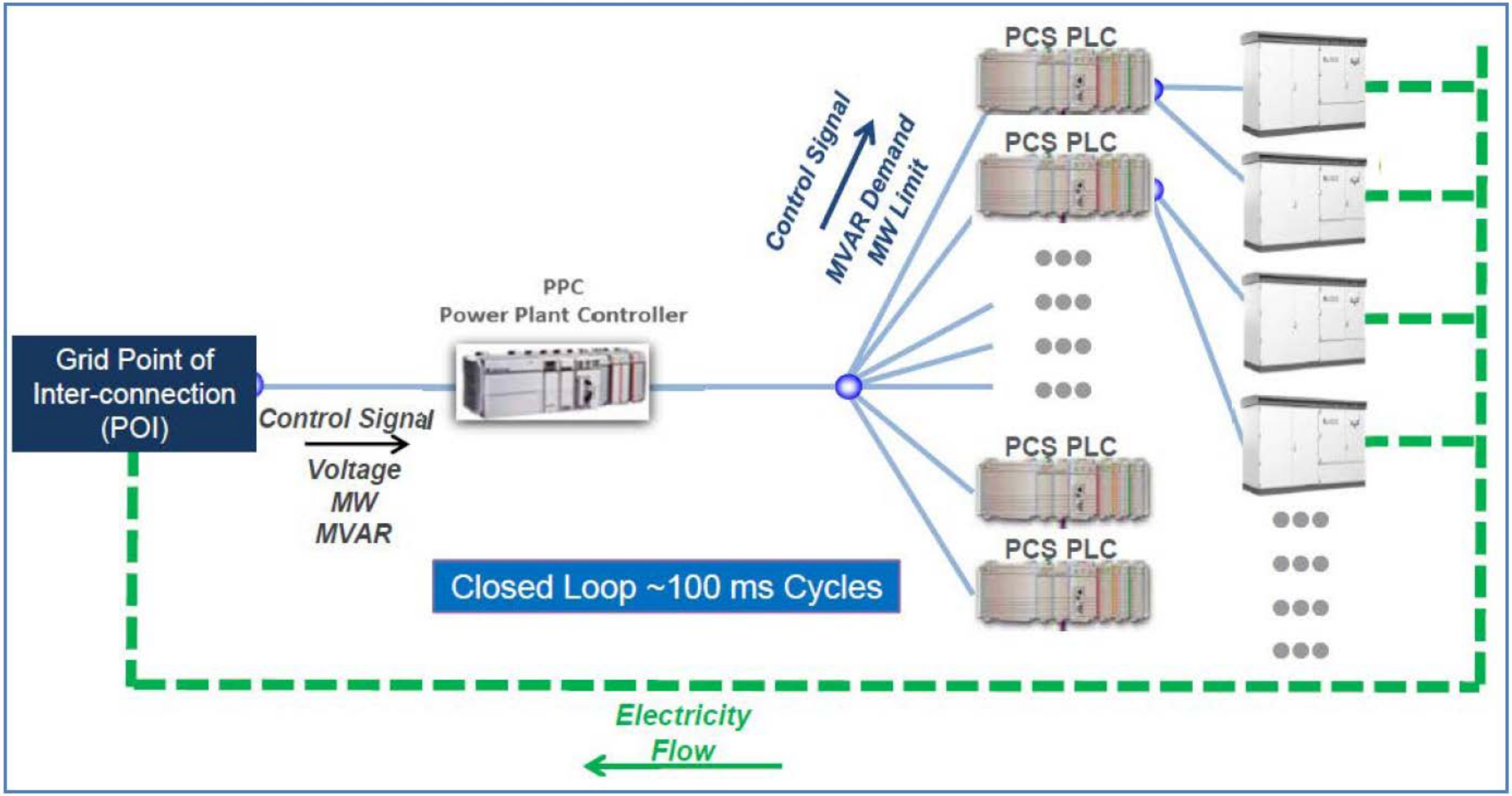

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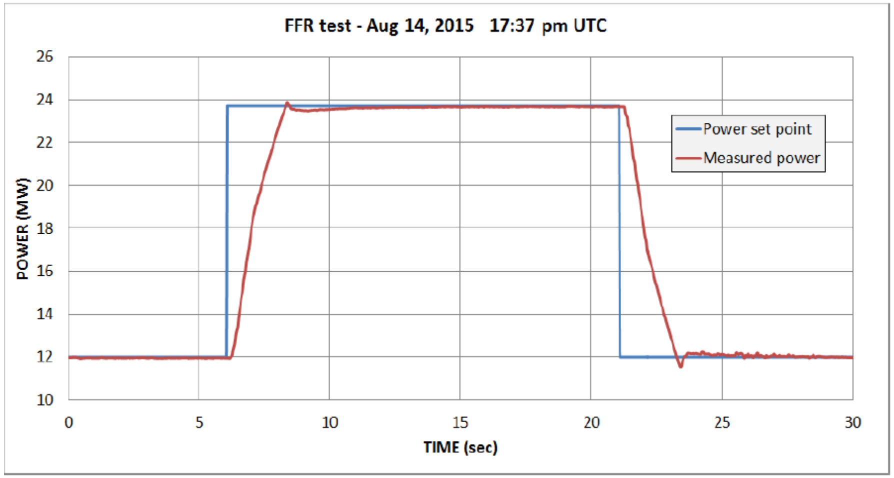
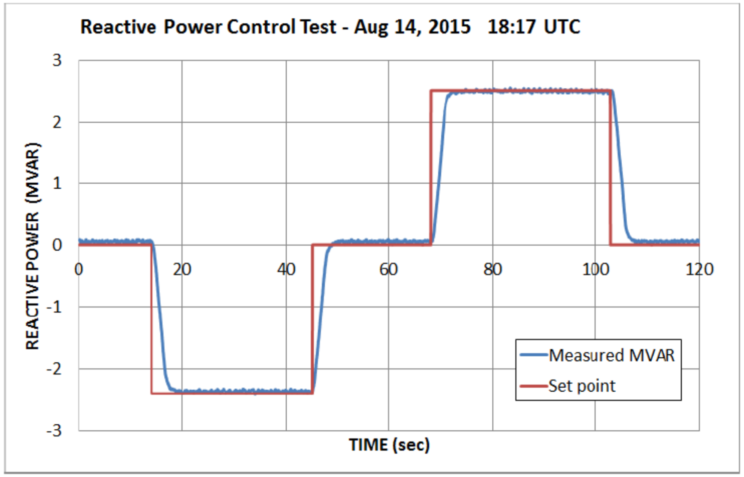
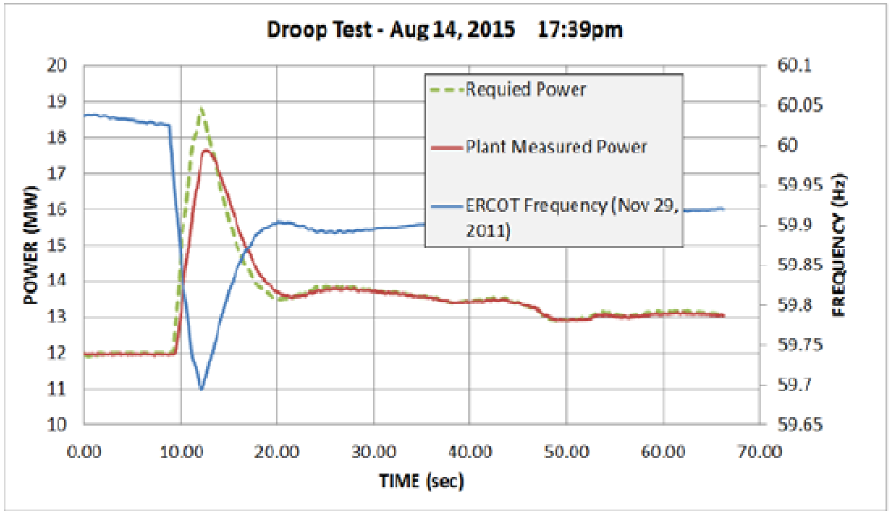
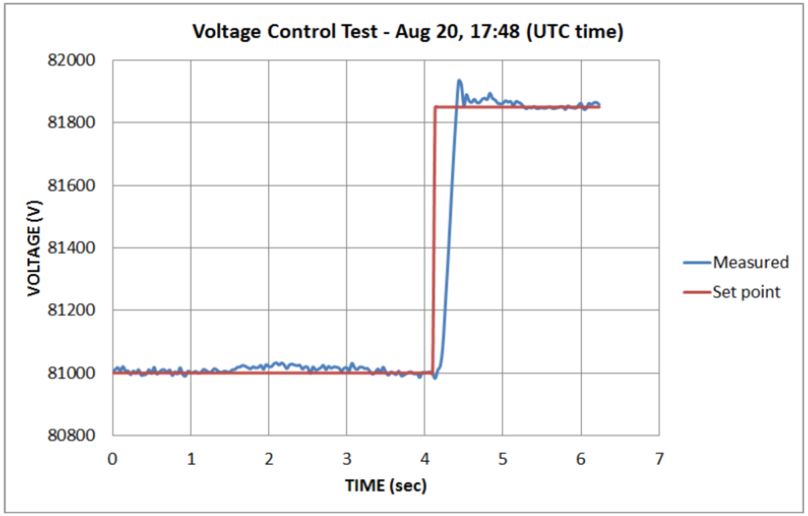
Image from First Solar

Example of Pecos Barilla PV power plant. Test results.









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Summary

- The operator receives information on the PV power plant state and sends set-points related to P and Q exchange.
- Power plant controllers are employed to control a number of different inverters and additional equipment to ensure that the overall power plant behaves as established in the grid codes.
- Active and reactive controllers are implemented centrally and the set-points are dispatches to the different equipment.
- Energy storage is managed when needed.

Thanks for your attention!

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tta Trama TecnoAmbiental