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)

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Supporters of this Expert Training Series

[Logos of ISA, Clean Energy Solutions Center, and 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.
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
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
Redundancy

**Plant devices**

- PPC Main
- R ChK Main
- PPC Backup
- R ChK Backup

Set point

**Main Status?**

Double check status

**Internal Set point**

**SCADA/TSO Set point**

**GreenPowerMonitor**
a DNV GL company

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Power plant control design process

- Study and analysis of the different grid codes
  Special emphasis on the most demanding ones (Germany, Puerto Rico, etc)

- Grid code requirements to ensure grid stability
  → PV plant layout

- PV plant analysis + Control design
  → TSO claims simulation model (usually PSS/E or Digsilent Power Factory)

- Stability studies
  - No acceptance
  - Acceptance

- PPC implementation + own tests
  - No acceptance

- Test certification
  - No acceptance
  - Acceptance

- Operational PV plant

- Number of inverters
- Capacitor banks
- STATCOM
- Batteries
- Transformers characteristic
- Internal grid cables specifications etc
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)
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
– 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

- **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

Scheme of Power Plant Control implementation
Example real results

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
Results - Active Power Output

Measured Active Power

Active Power [kW]

Time [s]
Results - Active Power Output

![Graph showing active power output over time, with markers indicating different time intervals.](image)

**Graph Details:**
- **Measured Active Power** line
- **TSO setpoint** line
- Time [s] axis from 0 to 8000
- Active Power [kW] axis from 0 to 10000

**Time Intervals:**
1. [5800, 5900] s
2. [6600, 7000] s
3. [8200, 8500] s
Results - Active Power Output
Results - Reactive Power
Results – Power factor

- **Power Factor**
  - Measured PF at PCC
  - PF setpoint

- **Reactive Power [kVar]**
  - Measured Reactive Power
  - Calculated setpoint

- **Active Power [kW]**
  - Measured Active Power
  - Active Power setpoint
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

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

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

R_{r\text{up}} y R_{r\text{down}} ramp rate limits
Power plant control with energy storage

- Power filtering example
Example of AES Ilumina PV Power Plant

Advanced Grid-Friendly Controls Demonstration Project for Utility-Scale PV Power Plants
Vahan Gevorgian and Barbara O’Neill, National Renewable Energy Laboratory
Single-line diagram of Ilumina’s 20-MVA utility interconnection

Advanced Grid-Friendly Controls Demonstration Project for Utility-Scale PV Power Plants
Vahan Gevorgian and Barbara O’Neill, National Renewable Energy Laboratory
Diagram of the Ilumina PV power plant’s remote terminal unit communications

Advanced Grid-Friendly Controls Demonstration Project for Utility-Scale PV Power Plants
Vahan Gevorgian and Barbara O’Neill, National Renewable Energy Laboratory
Tests on frequency control

Advanced Grid-Friendly Controls Demonstration Project for Utility-Scale PV Power Plants
Vahan Gevorgian and Barbara O’Neill, National Renewable Energy Laboratory
Example of Pecos Barilla PV power plant. Controls and interfaces.

Advanced Grid-Friendly Controls Demonstration Project for Utility-Scale PV Power Plants
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Image from First Solar
Example of Pecos Barilla PV power plant. Controls and interfaces.
Example of Pecos Barilla PV power plant. Test results.

Advanced Grid-Friendly Controls Demonstration Project for Utility-Scale PV Power Plants
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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!