

Control Measures for Smoothing PV Power Fluctuations in Madeira Power System

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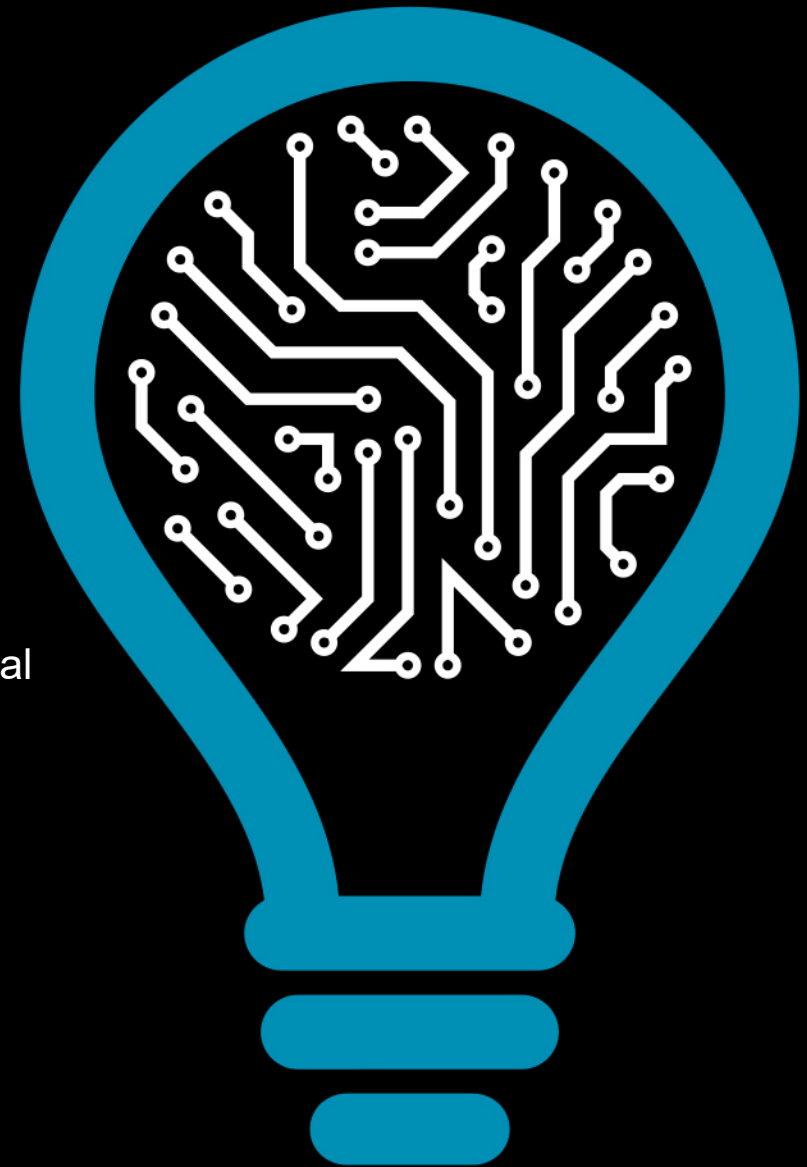


Madeira, Portugal

26 April 2022



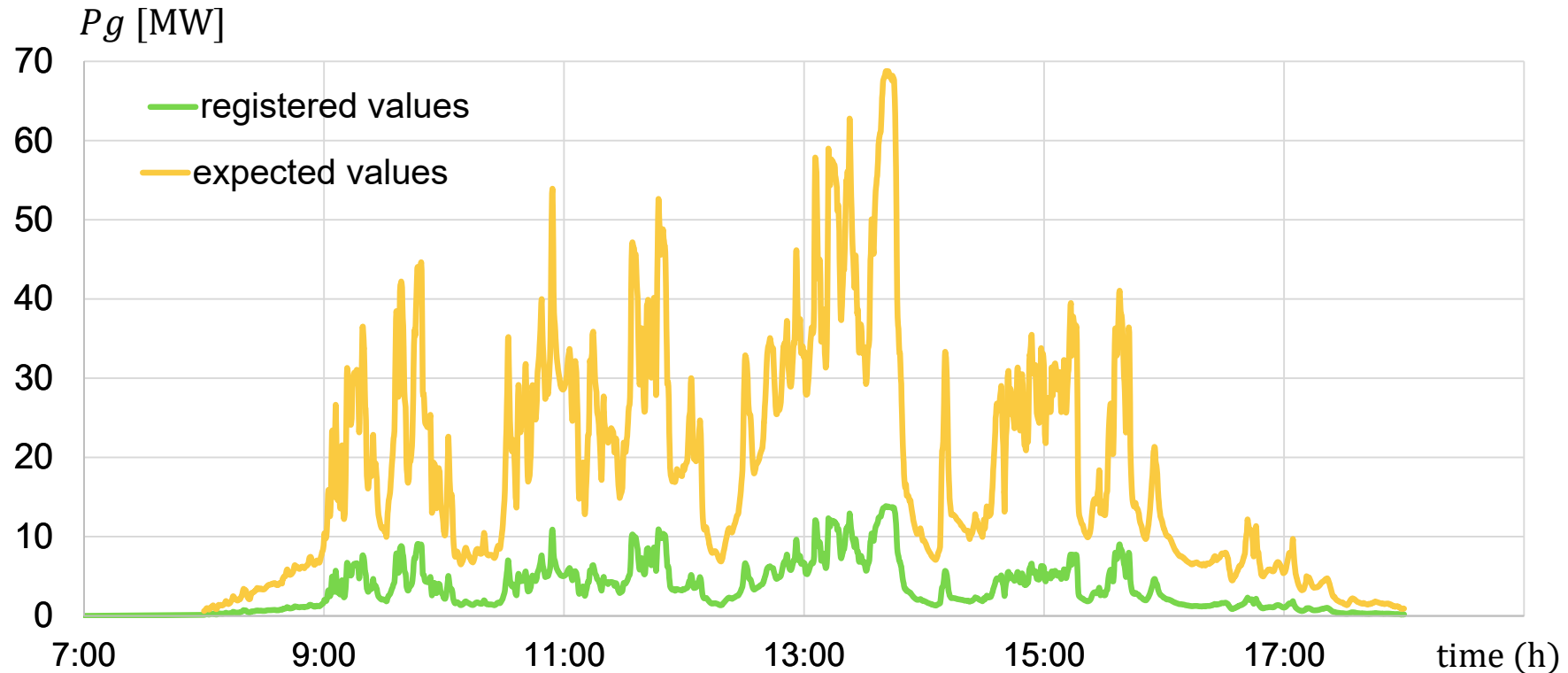
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Madeira island - Expected scenario of PV power production

PV installed capacity: PRESENT **15 MW** → FUTURE **75 MW**
FOR A PEAK LOAD ≤ 140 MW

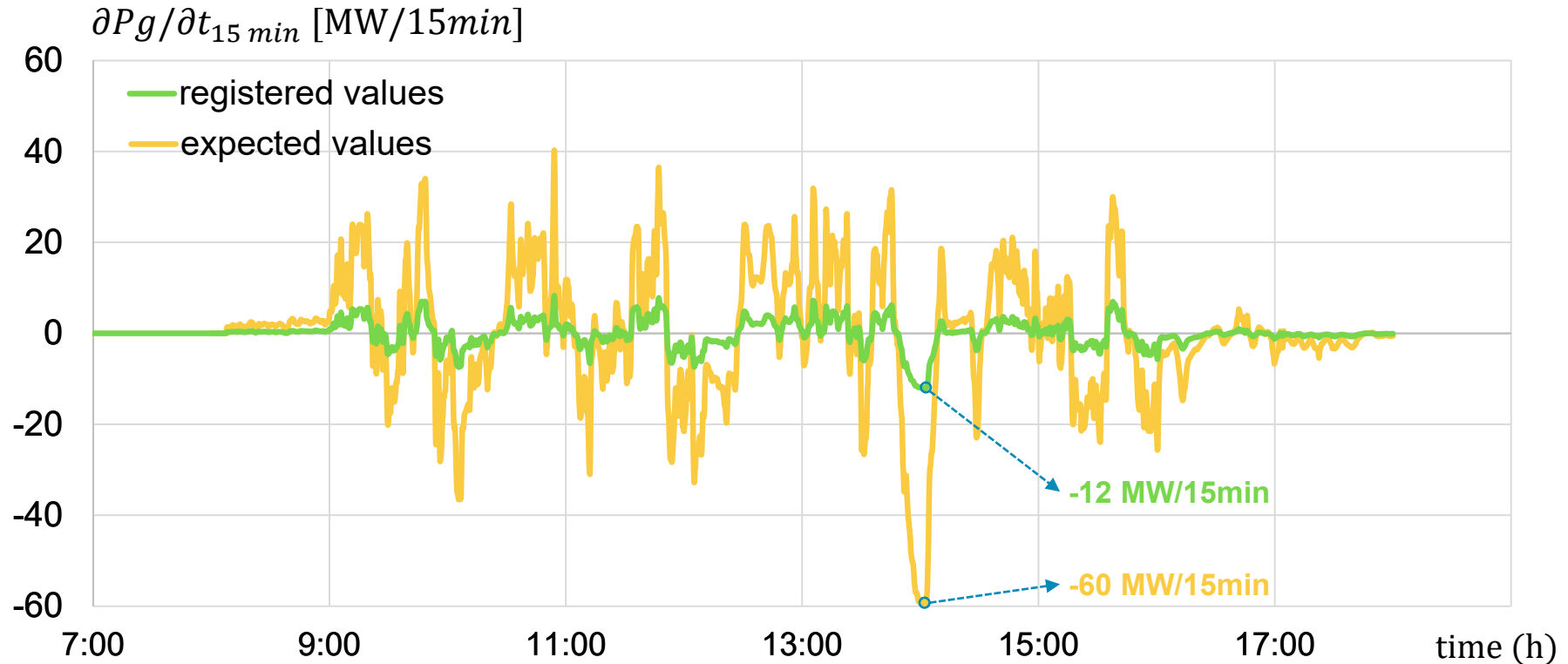
Total PV production in a disturbed day of 2016



Madeira island - Expected scenario of PV power production

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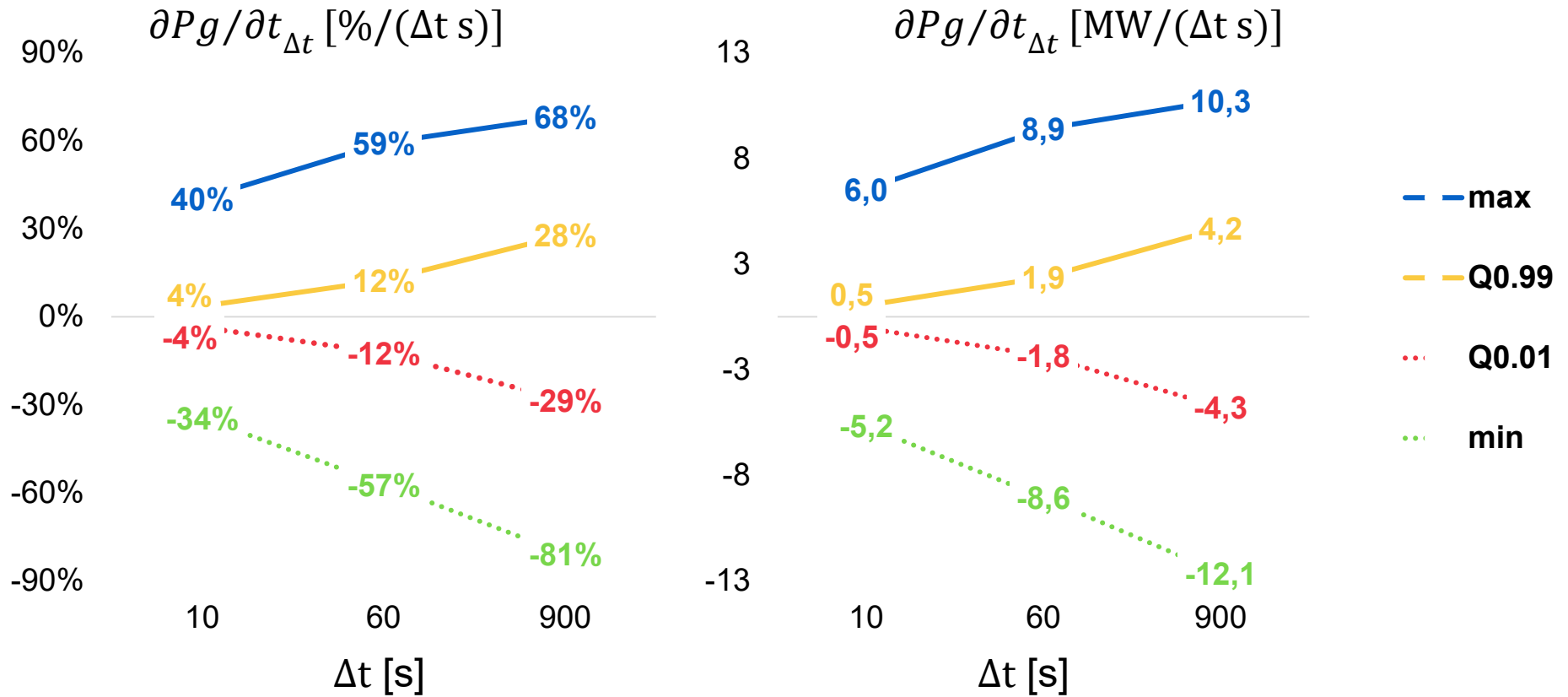
15 min PV ramp-rates in a disturbed day of 2016



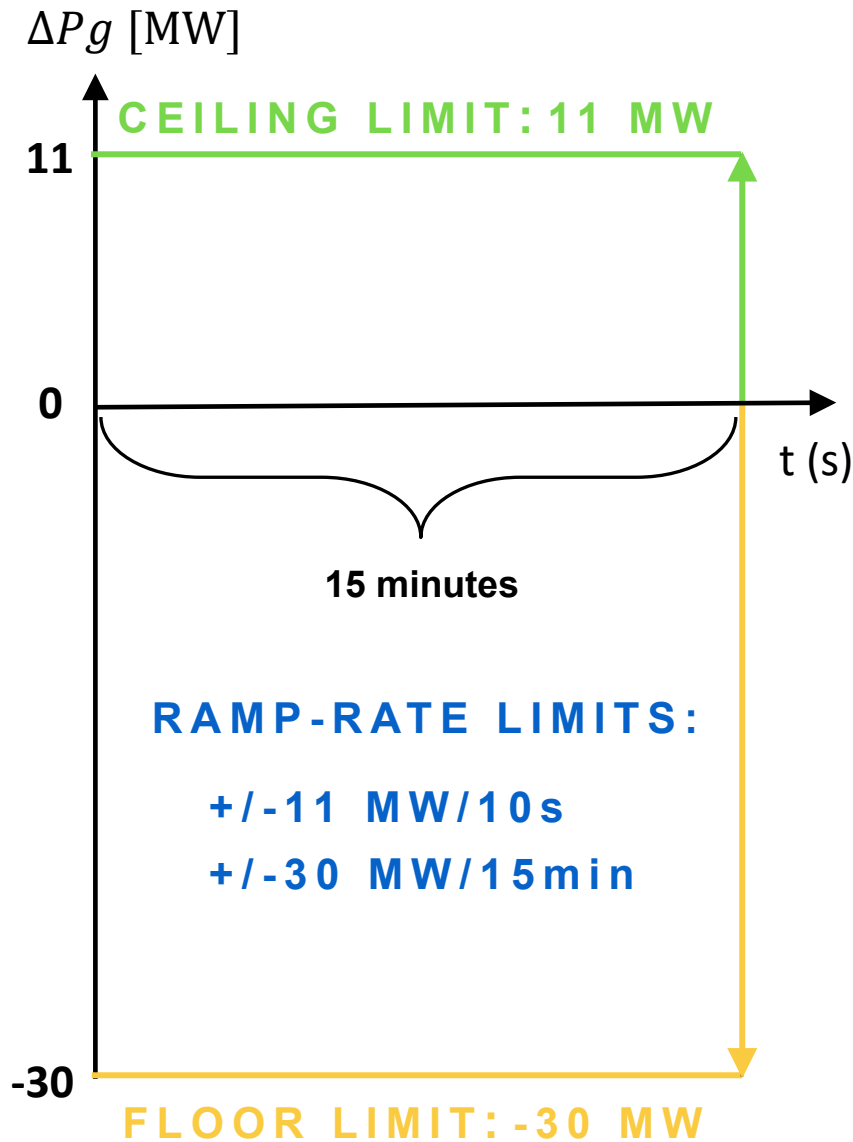
Madeira island - Expected scenario of PV power production

Registered ramp-rate values

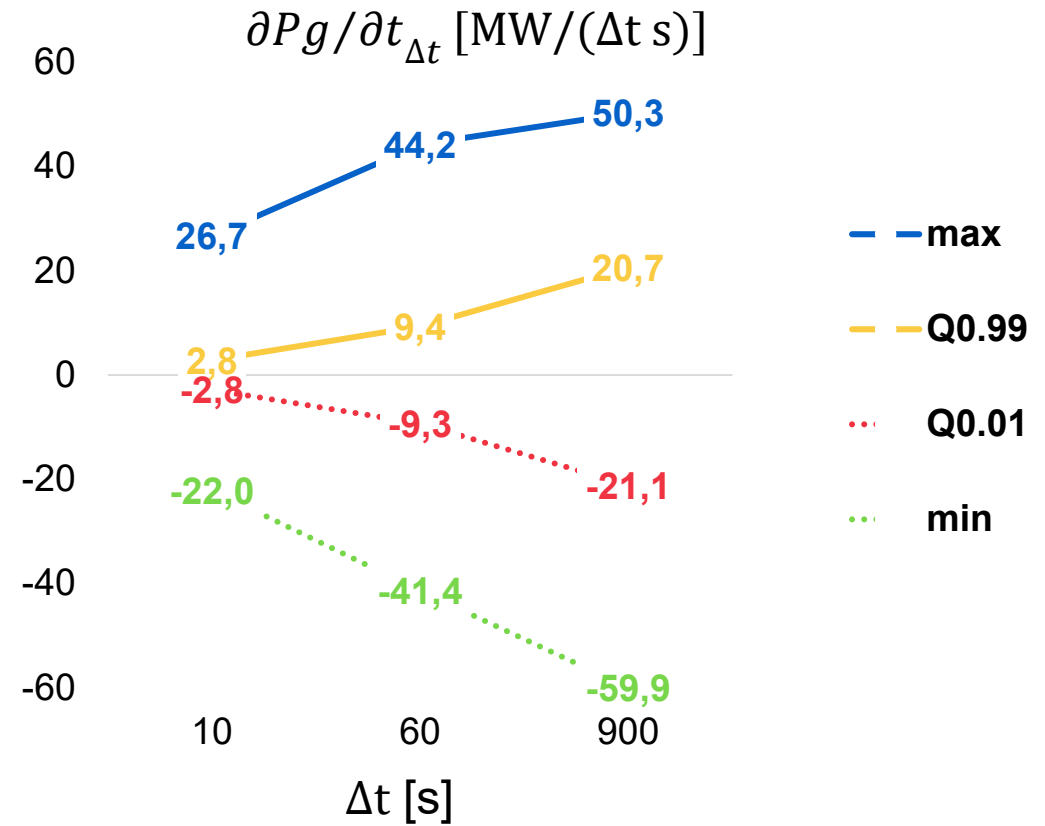
IN 2016 WITH 15 MW



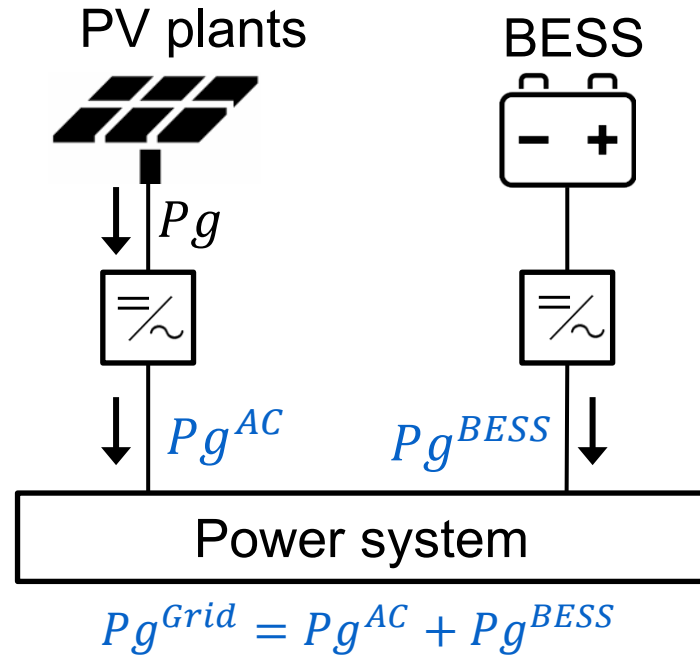
Acceptable limits for PV fluctuations



EXPECTED RAMP-RATE VALUES with 75 MW



Proposed control strategy to mitigate PV power fluctuations



➤ Maximum Power Point Tracking (MPPT) control

- direct control of PV power increases

control parameters

$\Delta P_{g_{max}}$: ceiling limit within each 15 min

$\partial P_g / \partial t_{max}$: ramp-up limit

➤ Battery Energy Storage System (BESS)

- to reduce the PV energy curtailment caused by MPPT control
- direct control of PV power decays

control parameters

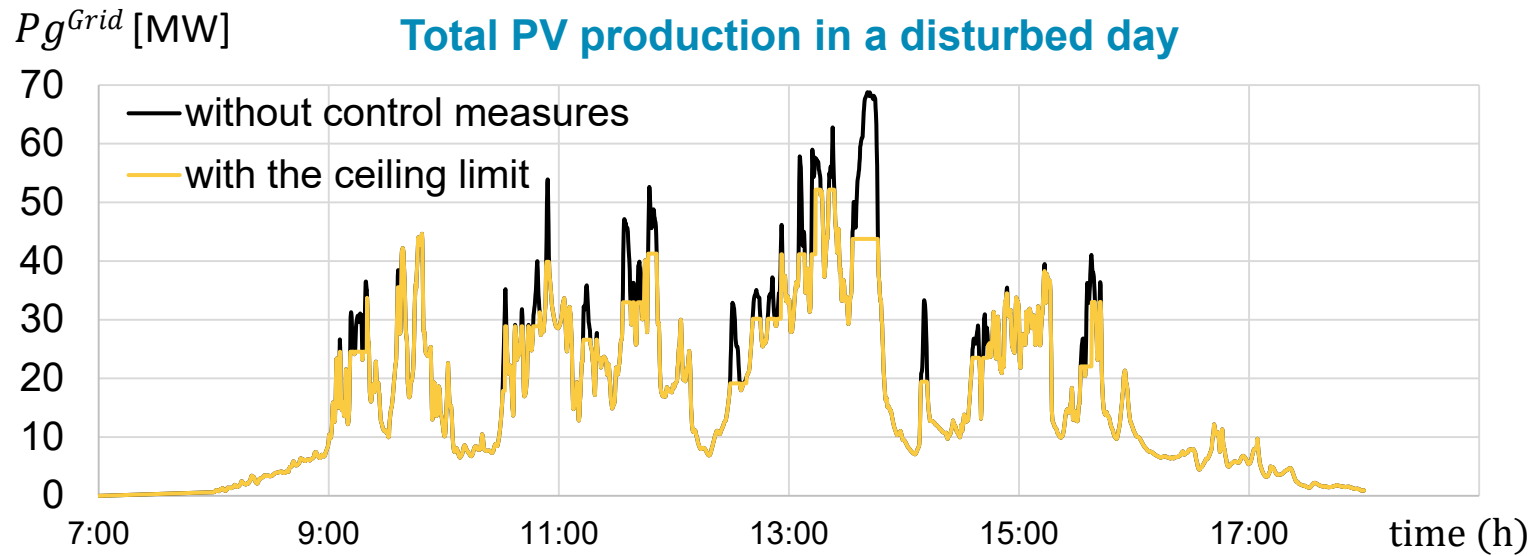
$\partial P_g / \partial t_{min}$: ramp-down limit

SOC_{ini} : battery SOC at sunrise

Parameters tuning and BESS sizing

- Trade-off between the **required BESS power and energy** and **expected PV energy curtailment**

Expected results with the ceiling limit



control parameters
 $\Delta P g_{max}$: 11 MW
 $\partial P g / \partial t_{max}$: ---
 $\partial P g / \partial t_{min}$: ---

control actions applied only to the new PV

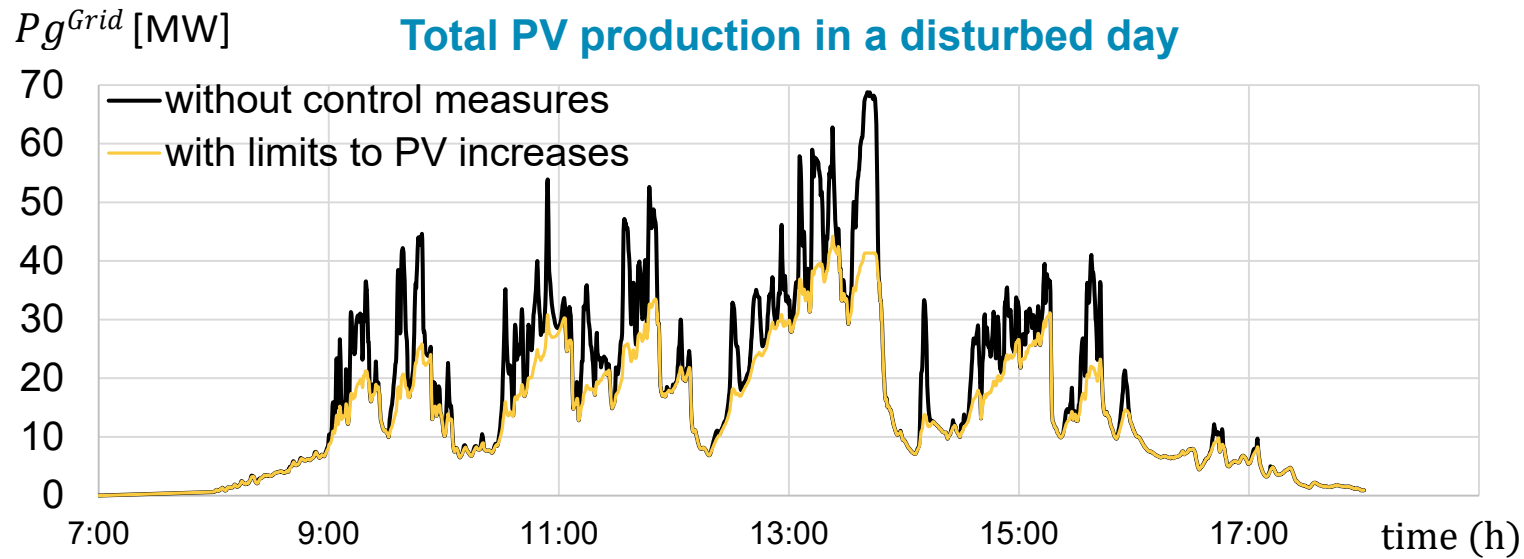
Annual PV energy curtailment: **0.8%**

| | Required limits | Obtained min/max |
|---------------------------------|-----------------|------------------|
| ramp-rates in 10 s (MW/10s) | 11 | 15,2 |
| ramp-rates in 15 min (MW/15min) | -22 | 48,4 / 30 |
| variations within 15 min (MW) | -30 | -50,2 / -40 |

#instants/year outside the limits: **266**

#days/year outside the limits: **68**

Expected results with the ceiling and ramp-up limit



control parameters
 ΔPg_{max} : 11 MW
 $\partial Pg / \partial t_{max}$: +1%/min
 $\partial Pg / \partial t_{min}$: ---

control actions applied only to the new PV

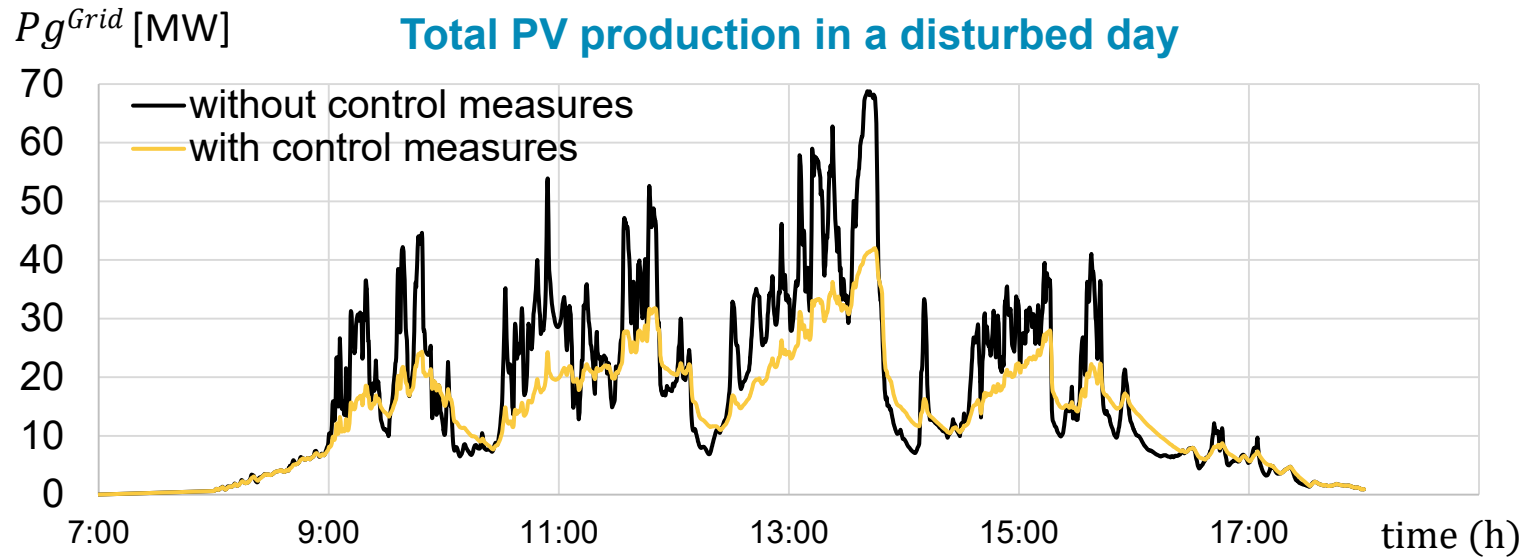
Annual PV energy curtailment: **6.1%**

| | Required limits | Obtained min/max |
|---------------------------------|-------------------------|------------------|
| ramp-rates in 10 s (MW/10s) | 11 5,2 -11 -13 | 30 18,8 |
| ramp-rates in 15 min (MW/15min) | -30 | -39,2 |
| variations within 15 min (MW) | -11 | -35,9 |

#instants/year outside the limits: **2**

#days/year outside the limits: **15**

Expected results with the ceiling and ramp-up limit + 5 MW/10 MWh BESS



control parameters

$\Delta P g_{max}$: 11 MW
 $\partial P g / \partial t_{max}$: +0.5%/min
 $\partial P g / \partial t_{min}$: -0.5%/min

control actions applied only to the new PV

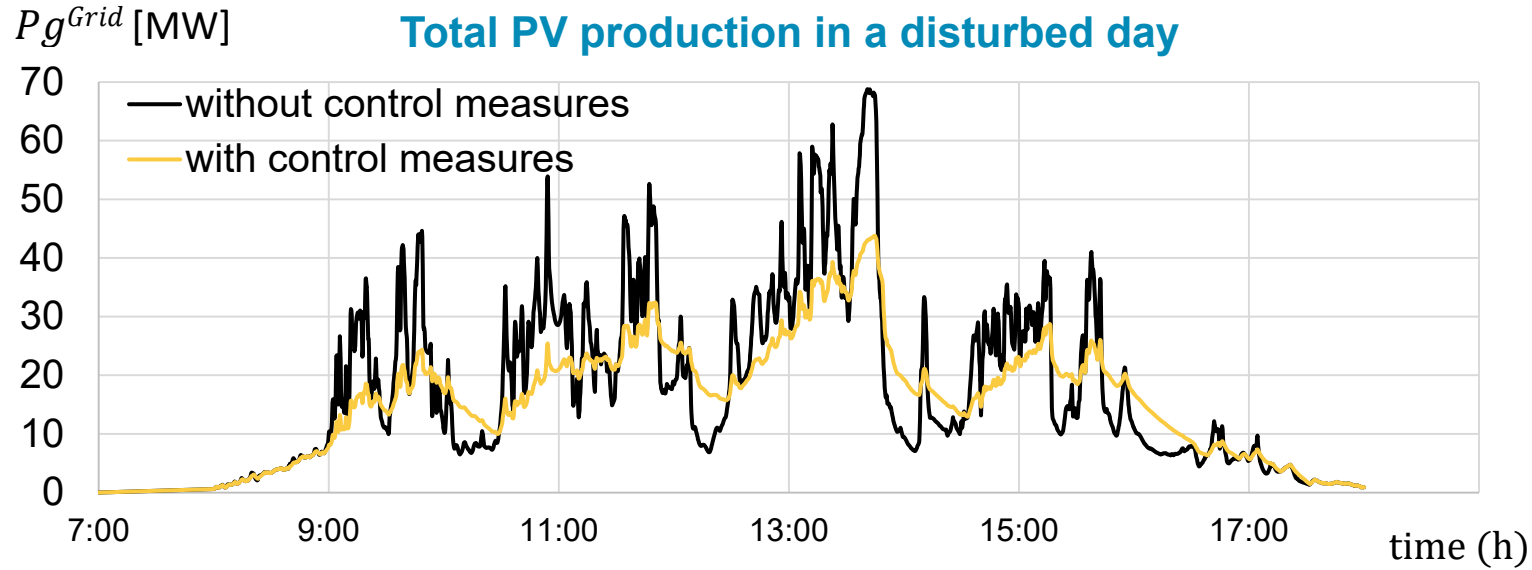
Annual PV energy curtailment: **3.5%**

Estimated time for battery end of life: **15 year**

| | Required limits | Obtained min/max |
|---------------------------------|-----------------|------------------|
| ramp-rates in 10 s (MW/10s) | 6,1 / -8,7 | 11 / -11 |
| ramp-rates in 15 min (MW/15min) | -30 | 30 / -34,3 |
| variations within 15 min (MW) | -30 | 11 / -30,6 |

#days/year outside the limits: **3**

Expected results with the ceiling and ramp-up limit + 10 MW/20 MWh BESS



control parameters
 $\Delta P g_{max}$: 11 MW
 $\partial P g / \partial t_{max}$: +0.5%/min
 $\partial P g / \partial t_{min}$: -0.5%/min

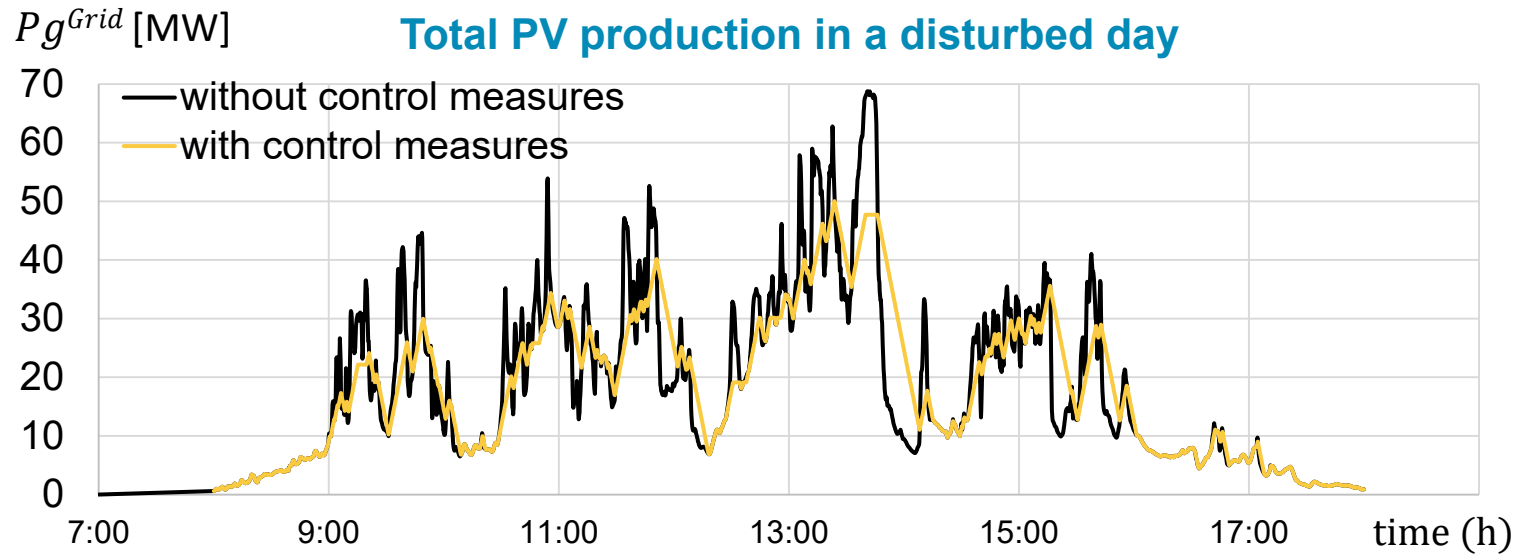
control actions applied only to the new PV

Annual PV energy curtailment: **1.7%**

Estimated time for battery end of life: **20 year**

| | Required limits | Obtained min/max |
|---------------------------------|-----------------|------------------|
| ramp-rates in 10 s (MW/10s) | 6,1 -9,7 | 11 -11 |
| ramp-rates in 15 min (MW/15min) | | 30 -29.4 |
| variations within 15 min (MW) | | 13,8 -30 |
| | | 11 -25.9 |

Expected results without MPPT control → 40 MW/30 MWh BESS



control parameters

$$\Delta P_{g_{max}}: 11 \text{ MW}$$

$$\partial P_{g} / \partial t_{max}: +2.7\% / \text{min}$$

$$\partial P_{g} / \partial t_{min}: -2.7\% / \text{min}$$

control actions applied to all PV

Required limits Obtained min/max

| | | |
|--------------------------------|------------------------------------|----------------------------------|
| | 30 | |
| 0,3 -0,3 | 27,2 | 11 |
| 11 -11 | -30 | -29.7 -30 |
| ramp-rates in 10 s (MW/10s) | ramp-rates in 15 min (MW/15min) | variations within 15 min (MW) |

Annual PV energy curtailment: **0.5%**

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