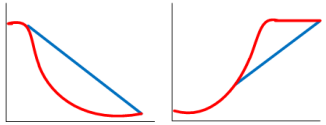
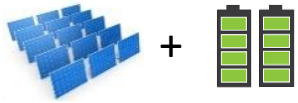
Sizing of batteries for PV power rate control

Aitor Makibar
Solar Energy & Energy Storage Engineer, PhD

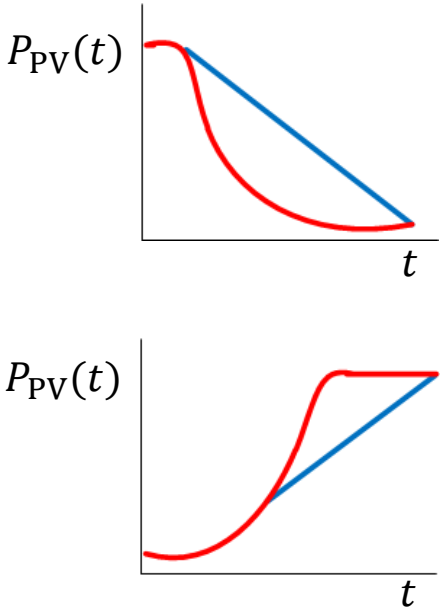
Freelance
Researcher (Solar Energy Institute IES-UPM)

Contents

1. PV power fluctuations & ramp rate control 
2. Battery sizing for PV power ramp rate control 
3. Techniques for reducing battery requirements 
4. Conclusions 

PV power fluctuations

Some grid-codes require storage systems to limit PV power ramp rate

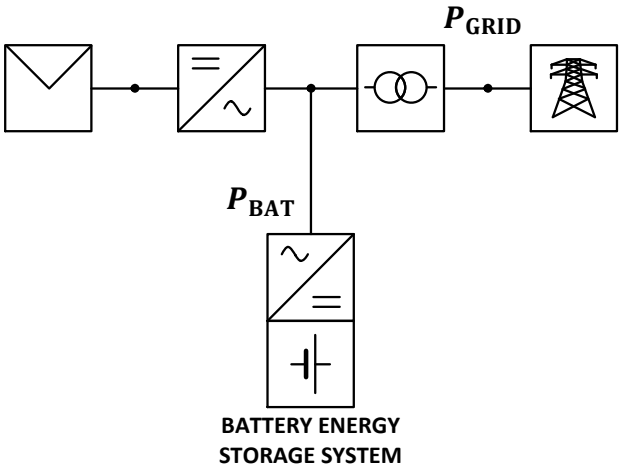


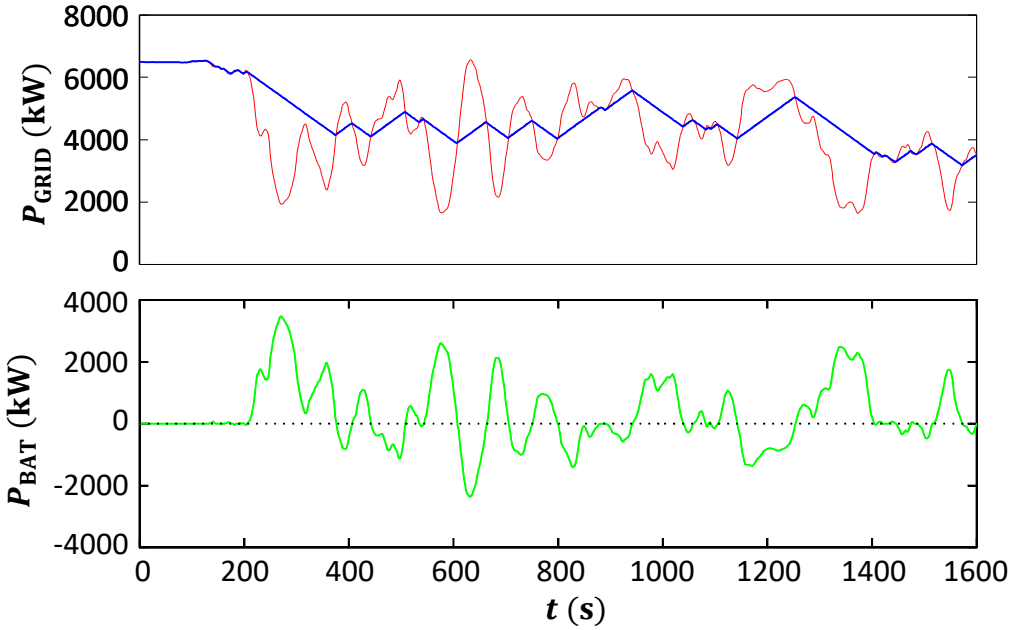
Data for modelling: Milagro PV plant (Spain)

$S = 52$ ha $\qquad P^* = 9{,}5$ MWp $\qquad P_{\mathrm{N}} = 7{,}2$ MW

PV power ramp rate limitation

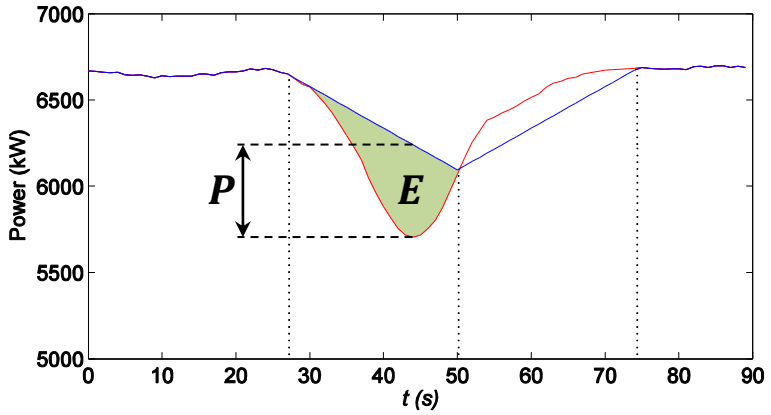
***Ramp-rate*:** $RR = \dfrac{[P_{\mathrm{PV}}(t) - P_{\mathrm{PV}}(t - \Delta t_{\mathrm{R}})]/P_{\mathrm{N}}}{\Delta t_{\mathrm{R}}} \rightarrow \boldsymbol{RR_{\mathrm{LIM}} = 10\ \%P_{\mathrm{N}}/\mathrm{min}}$



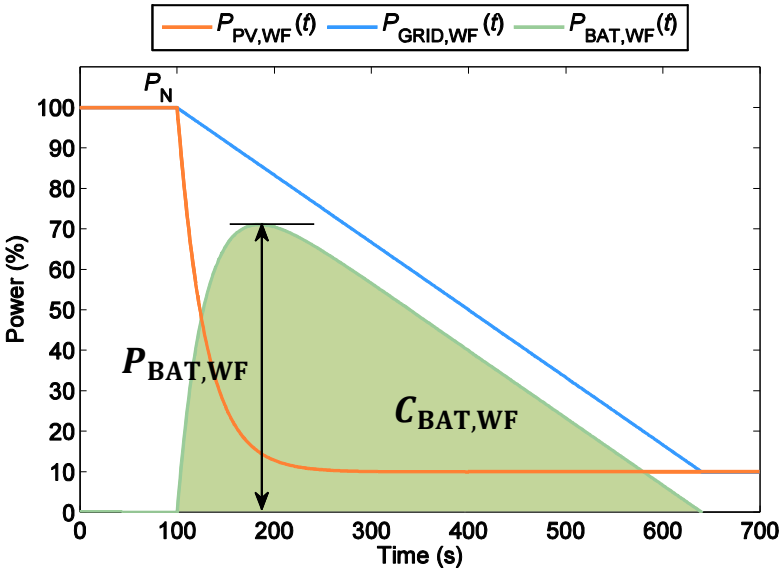


Battery sizing: Power and capacity requirements

Statistical analysis



Worst Fluctuation Model



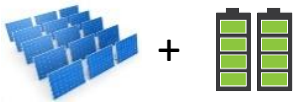
Milagro $RR_{LIM} = 10\%$ /min

$P_{BAT,WF}$	$C_{BAT,WF}$
5148 kW	437kWh
(71.1 % P_N)	*(3.6 min)*

Cost of battery is high

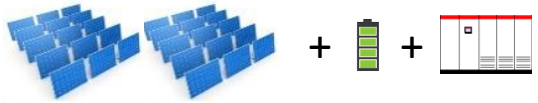
Techniques for reducing the battery size for ramp rate control

1. **Basic**



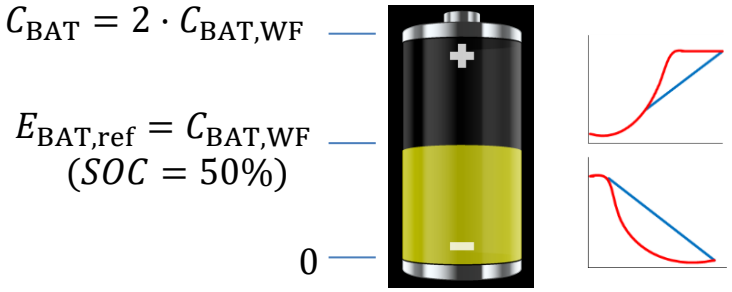
2. **PV inverters power limitation**

3. **PV array oversizing**

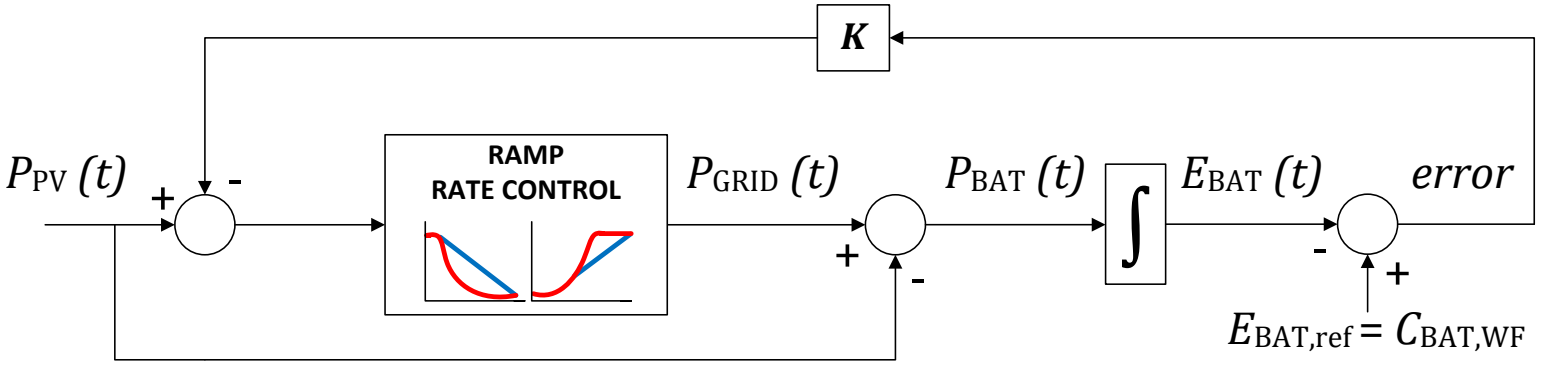


Basic technique: SOC50 strategy

Double $C_{\mathrm{BAT,WF}}$:



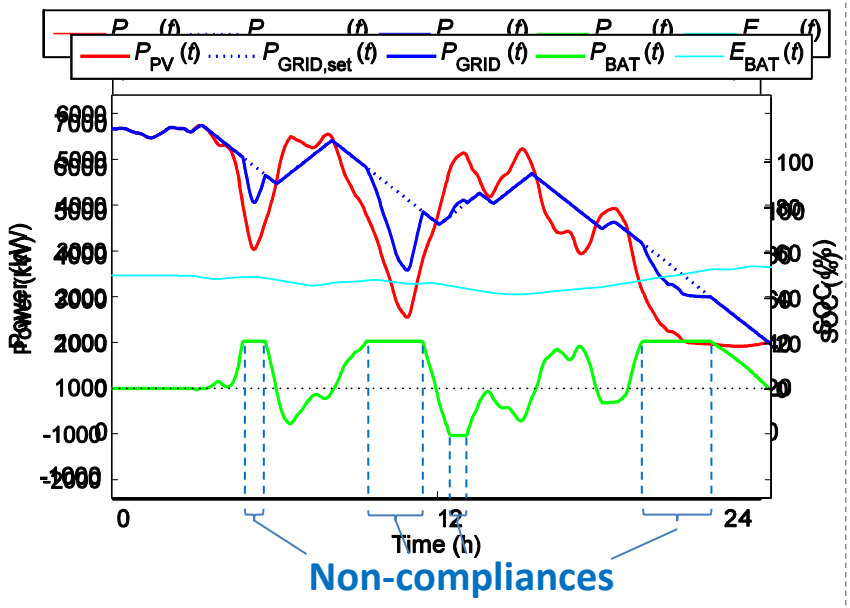
SOC50 control strategy:



Size reduction for a specific grid-code: Puerto Rico (PREPA)

- Power monitored every 2 s
- Weekly RR compliance index ➔ $\boldsymbol{RRC}$
- Penalty: $\boldsymbol{Cu}$ (P_{GRID}limitation)

k_p = 0,2

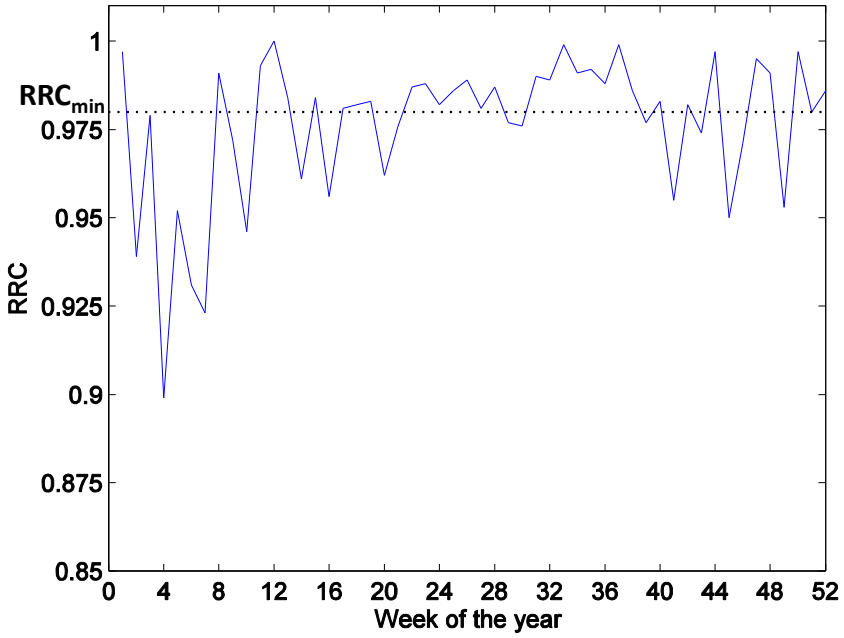


$$Cu_w = (Cu_{w-1} - (RRC_{\min} - RRC_{w-1}))$$

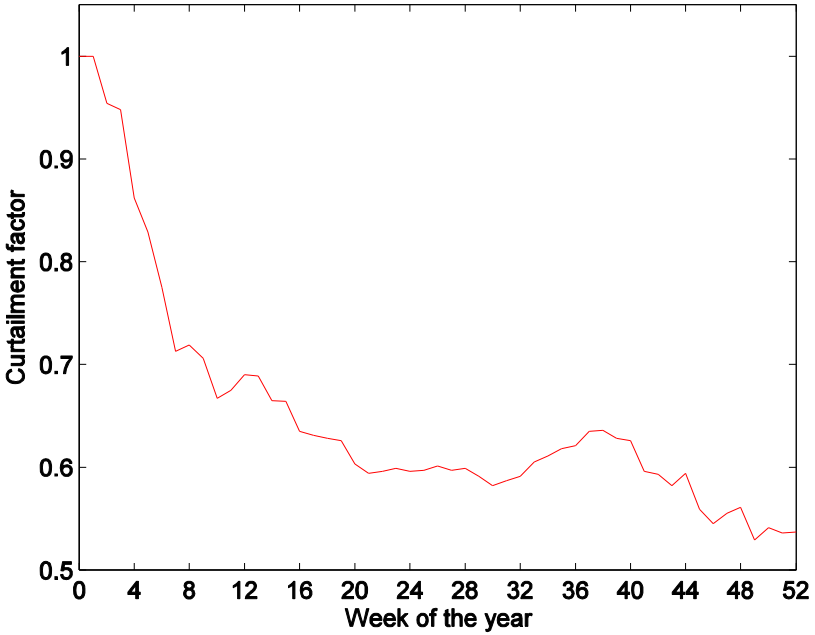
Penalty vs. Size reduction

Battery reduced in power : $k_p = 0, 1$

Compliance index



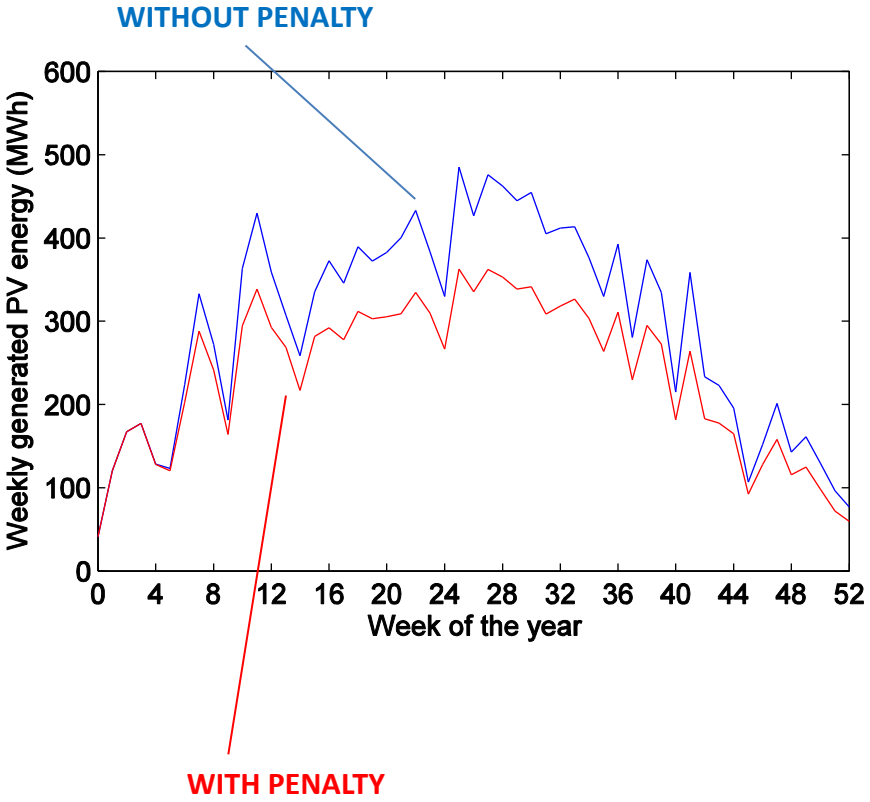
Penalty



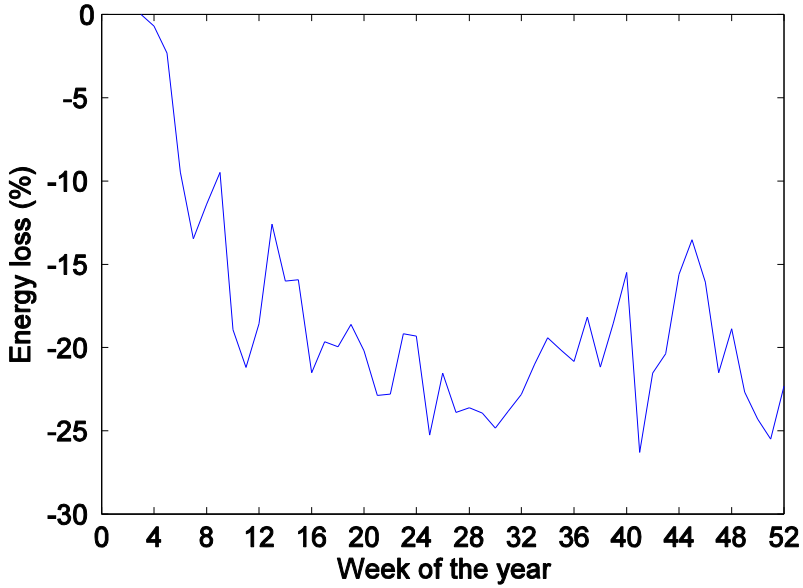
Penalty vs. Size reduction

Battery reduced in power : $k_p = 0,1$

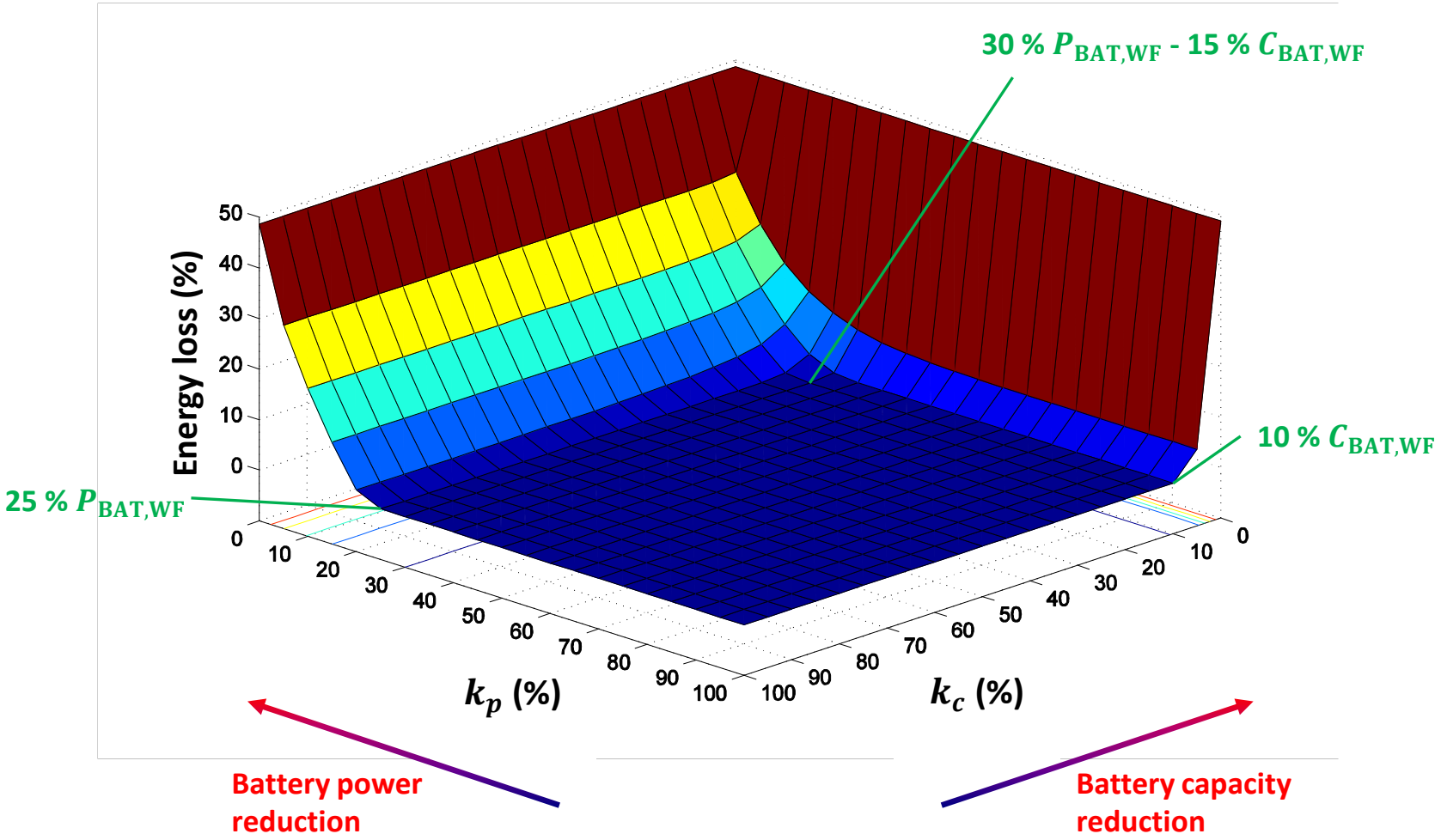
Weekly PV production



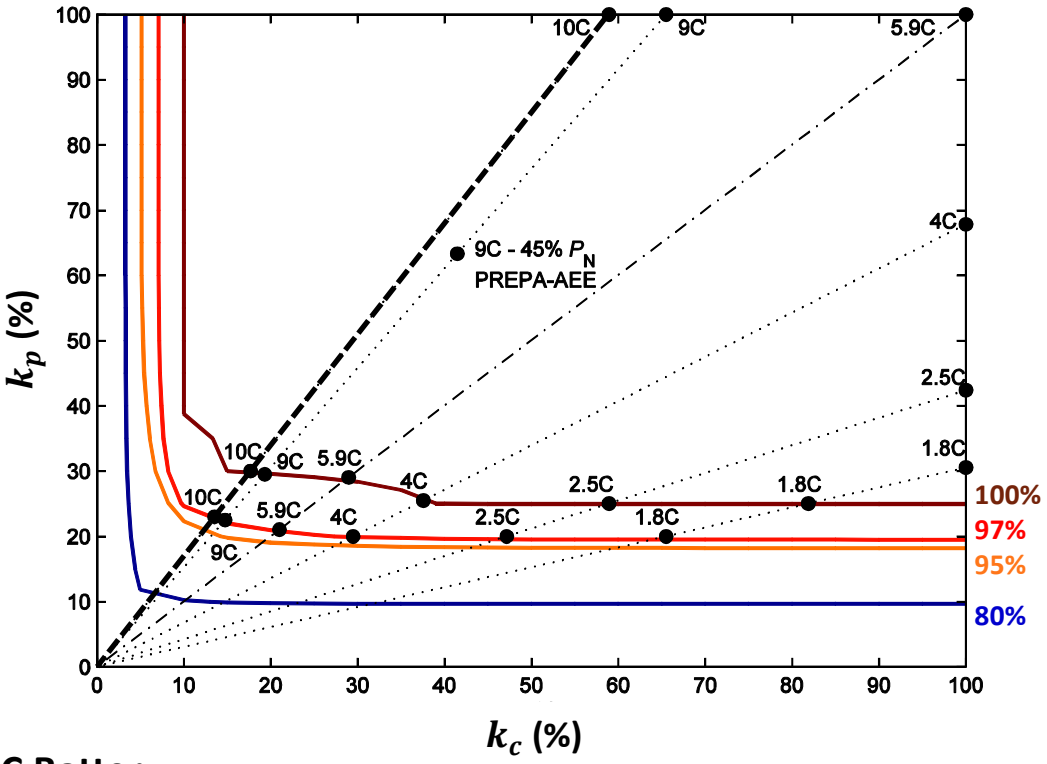
Energy loss



Reduced batteries sizing tool



Reduced batteries sizing tool



10C Battery

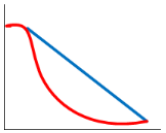
E_{GRID}	k_p	Power kW (% P_N)	k_c	Capacity kWh (*min*)
100%	**0,33**	1544 (*21.3*)	**0,18**	155 (*1.3*)
97%	0,23	1184 (*16.3*)	0,14	119 (*1.0*)

2nd Technique: PV inverters power limitation

SOC100_PVCurt control strategy:

$E_{\mathrm{BAT,ref}} = C_{\mathrm{BAT,WF}}$
$(SOC = 100\%)$

0

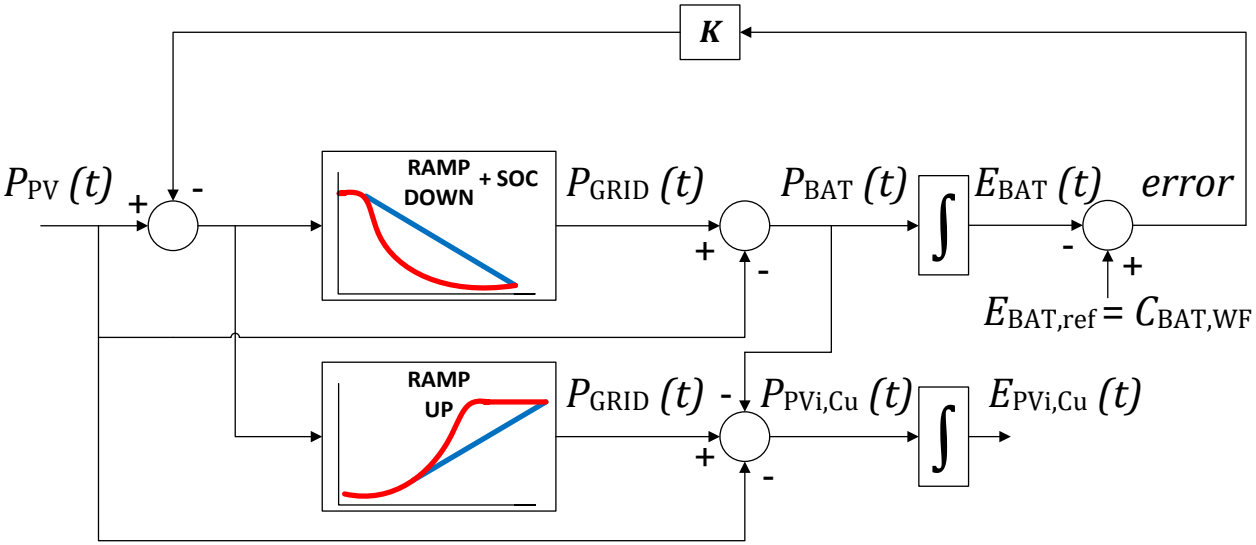


Advantages

$C_{\mathrm{BAT}} = \cdot C_{\mathrm{BAT,WF}}$

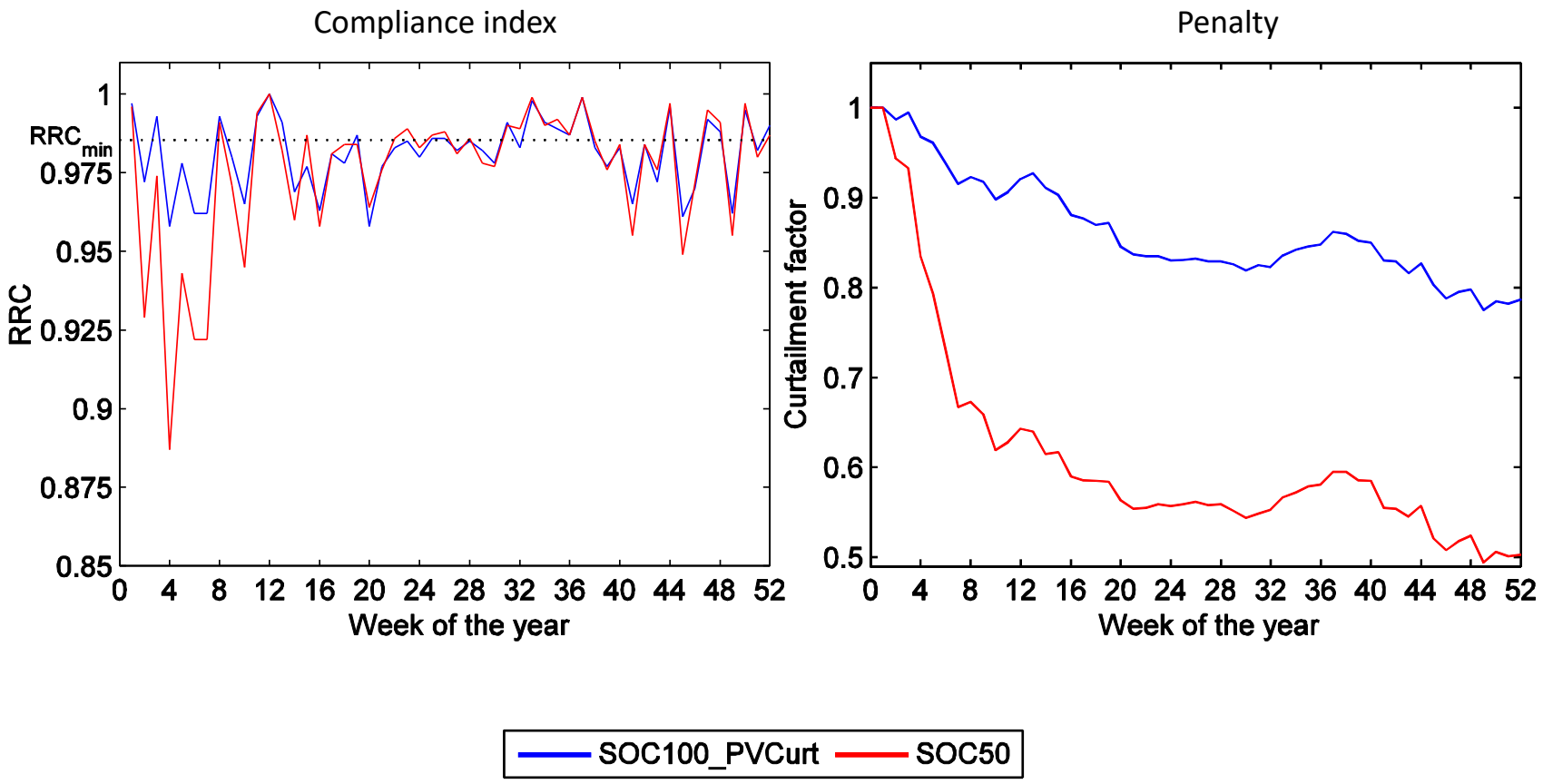
Disadvantages

Loss due to inverters limitation

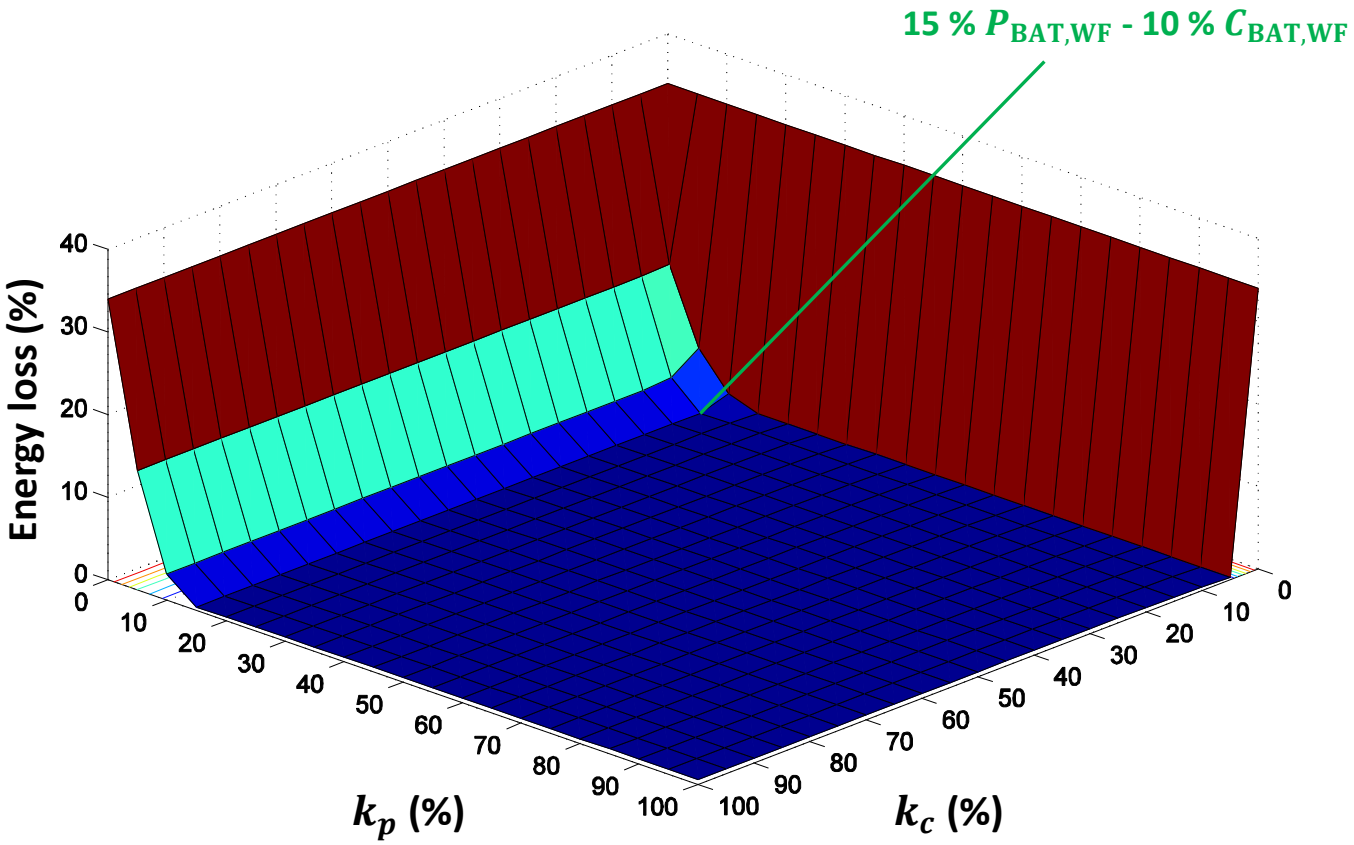


SOC50 vs. SOC100_PVCurt

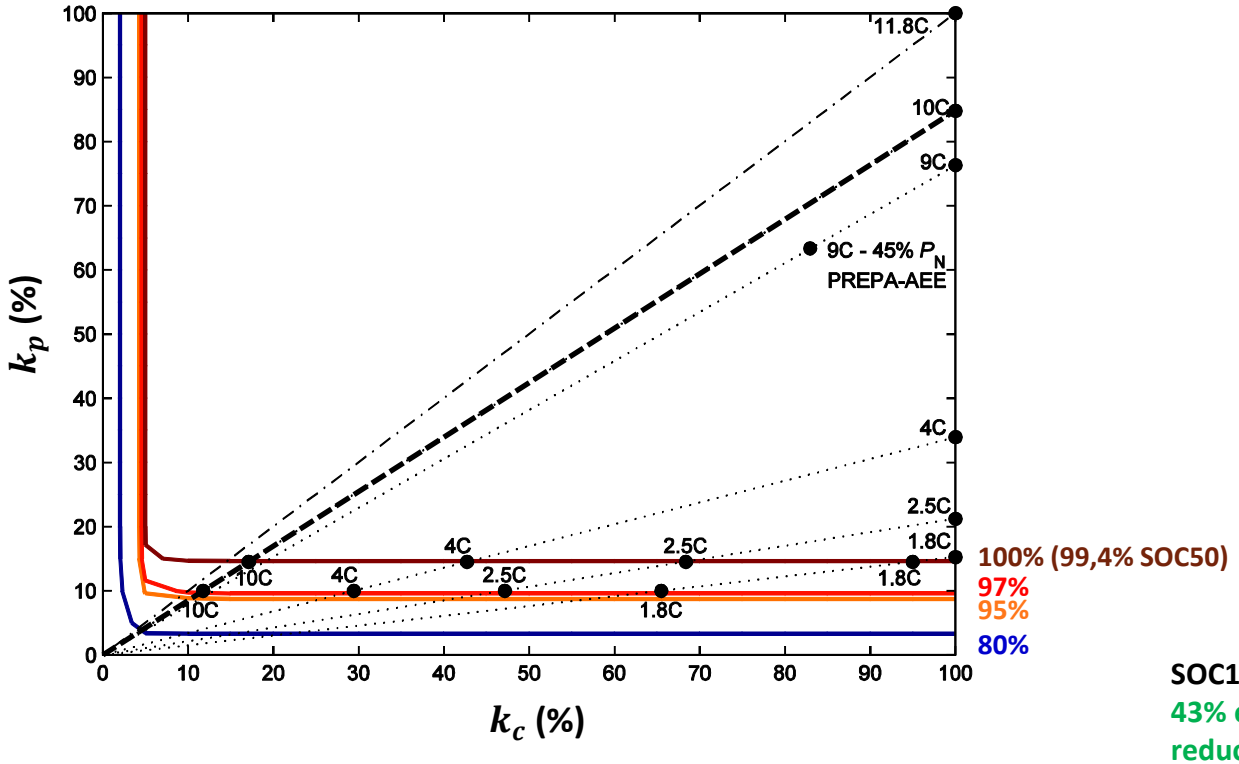
Battery reduced in power : $k_p = 0, 1$



Reduced batteries sizing tool for PV inverters limitation



Reduced batteries sizing tool for PV inverters limitation

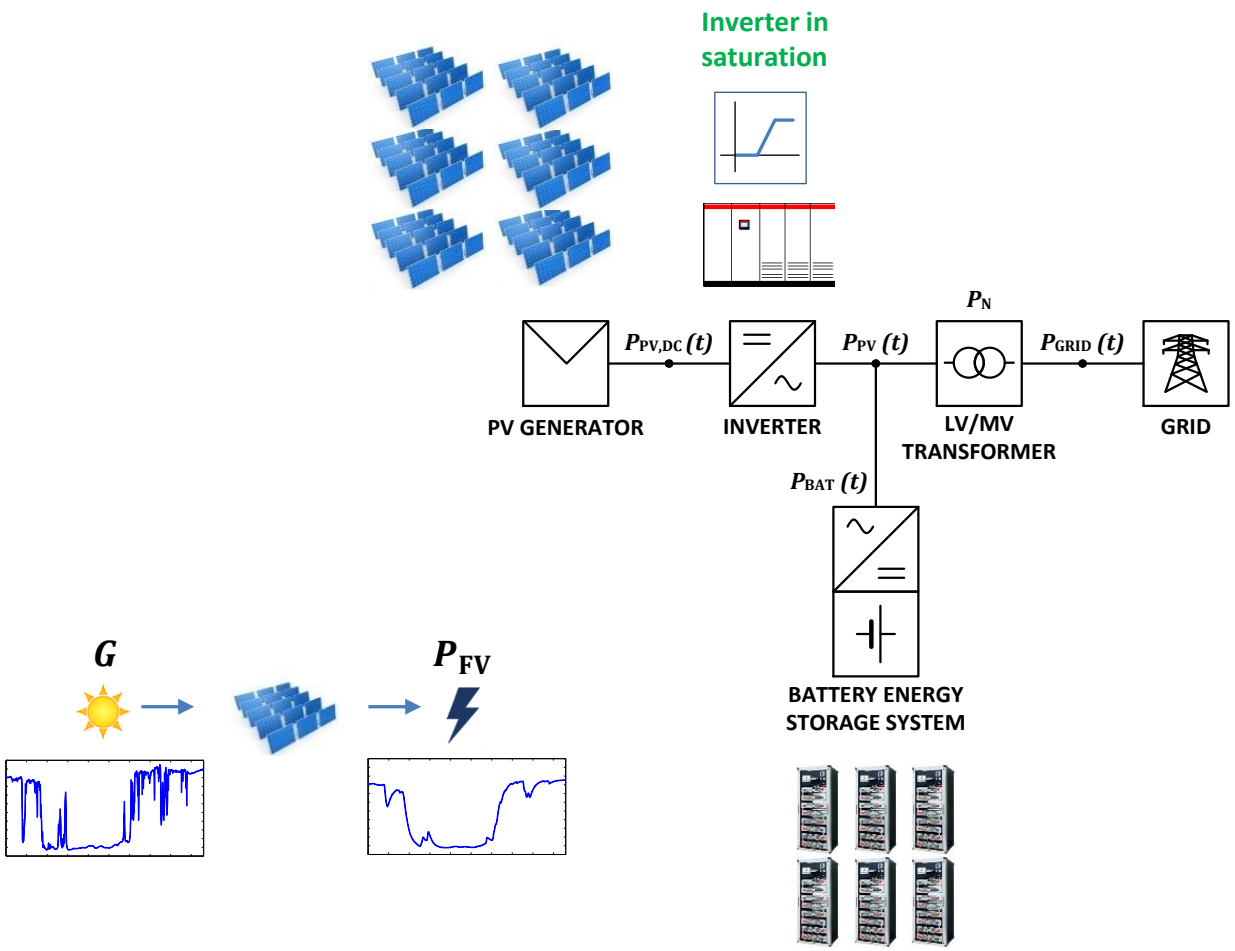


10C Battery:

SOC100_PVCurt:
43% extra reduction

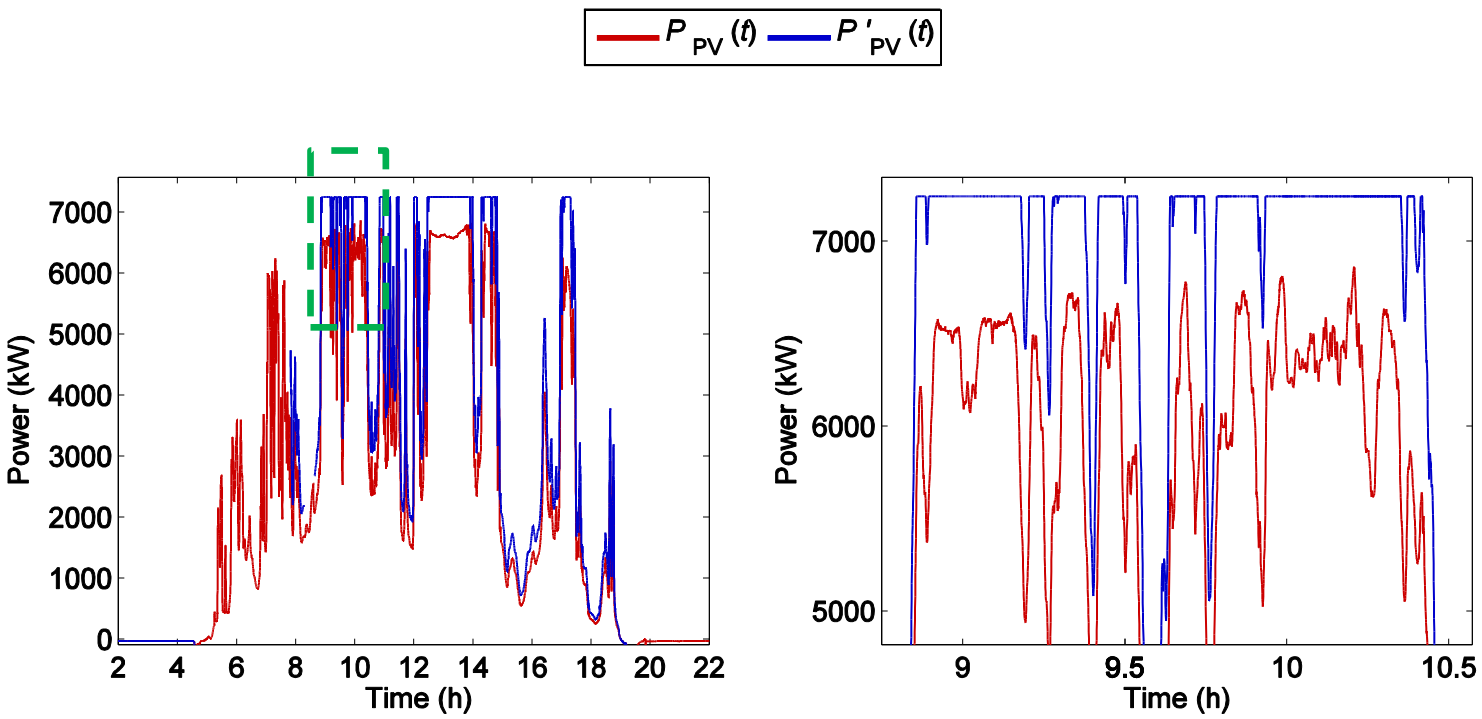
E_{GRID} limit	SOC100_PVCurt				SOC50			
	k_p	Power kW (% P_N)	k_c	Capacity kWh (*min*)	k_p	Power kW (% P_N)	k_c	Capacity kWh (*min*)
SOC100_PVCurt: 100% (*SOC50*: 99.43%)	0,15	**747** (*10.3*)	0,17	**75** (*0.6*)	0,26	**1313** (*18.1*)	0,15	**132** (*1.1*)

3rd Technique: Reduced batteries with PV array oversizing



3rd Technique: Reduced batteries with PV array oversizing

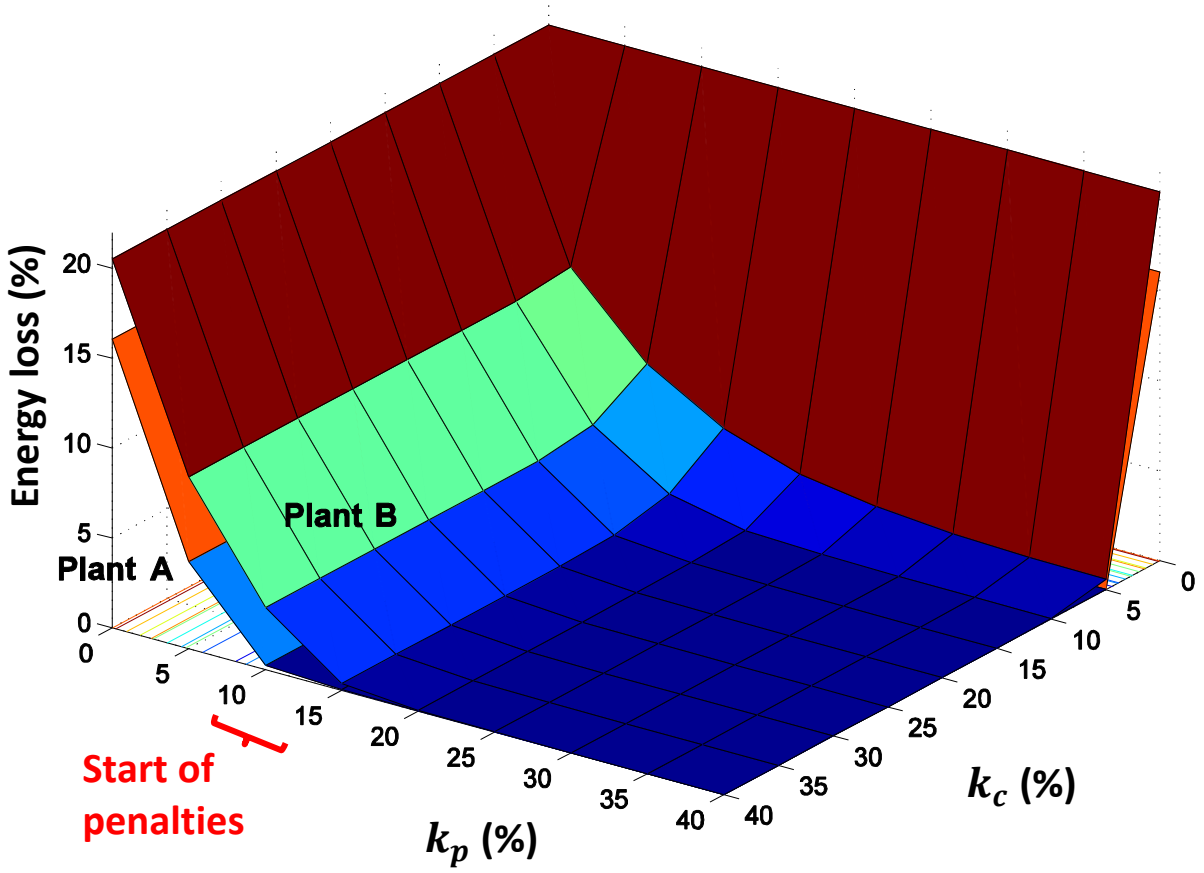
Output power of a PV plant with equilibrated / oversized array



Batteries sizing tool for an oversized PV array

Plant A: Original $S = 52$ ha

Plant B: Oversized $S' = 78$ ha **(50% oversizing)**



Comparison

Benefits of PV array oversizing

Reduction of 10C battery

Non-oversized			Oversized (50%)		
Power kW (*% P_N*)	Capacity kWh (*min*)	E_{GRID} MWh	Power kW (*% P_N*)	Capacity kWh (*min*)	E_{GRID} MWh
721 (*10.0*)	72 (*0.6*)	14 930	216 (*3.0*)	22 (*0.2*)	16 529

→ **70% reduction**
10% E_{GRID} ↑

Production vs. same 10C battery

Power kW (*% P_N*)	Capacity kWh (*min*)	E_{GRID} MWh	
		Non-overs.	Oversized (50%)
721 (*10.0*)	72 (*0.6*)	14 930	18 784

→ **25% E_{GRID} ↑**

Conclusions

Battery is **sized** for full compliance with **RR limitation** of each **grid code**.

Given the **low ocurrence of critical fluctuations**, battery size must be reduced.

We developed a method to **evaluate the battery size reduction potential**. Three techniques:

1. **Basic: 30%**.
2. **PV inverters limitation: 40-50% extra**.
3. **PV array oversizing: 70% reduction**.

The combination of the three techniques arises **multiple decision factors**, useful to find the optimal *battery size-PV array-inverter power* ratios.

Thanks for your attention

Aitor Makibar

Solar Energy & Energy Storage Engineer, PhD

aitor.makibar@gmail.com

www.linkedin.com/in/aitormakibar/en