Electricity price arbitrage in utility-scale PV-plus-battery systems

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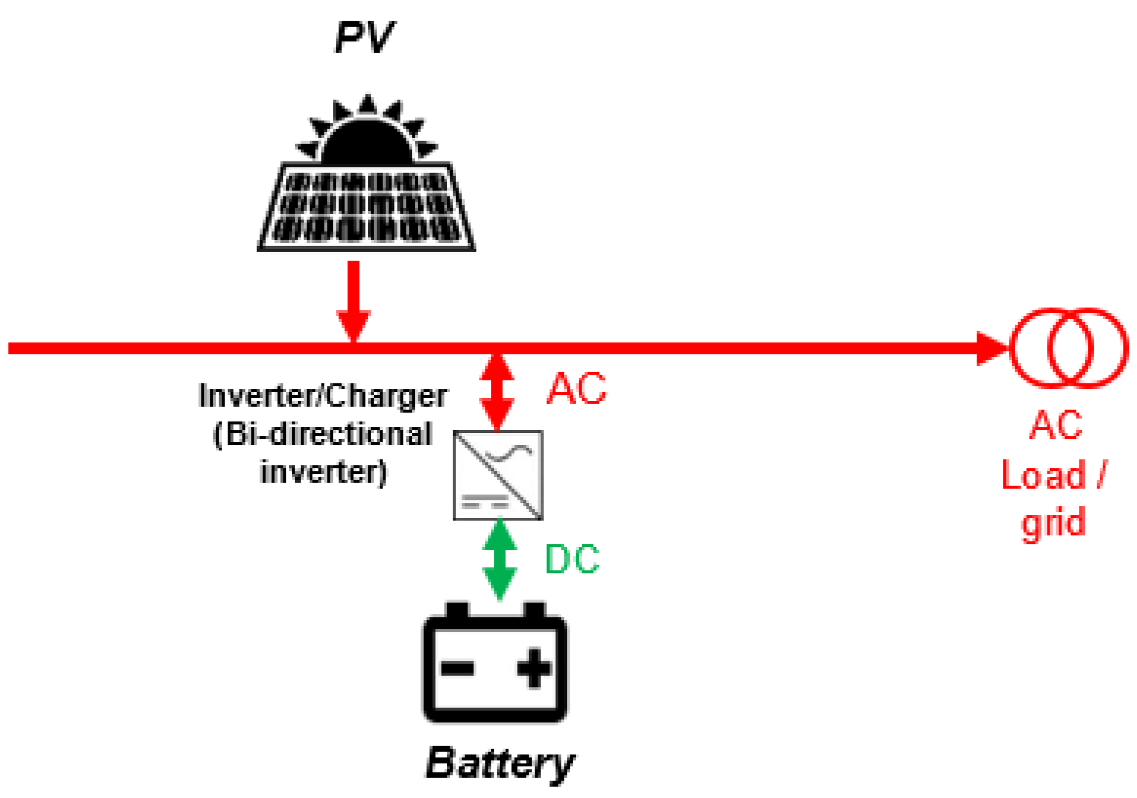
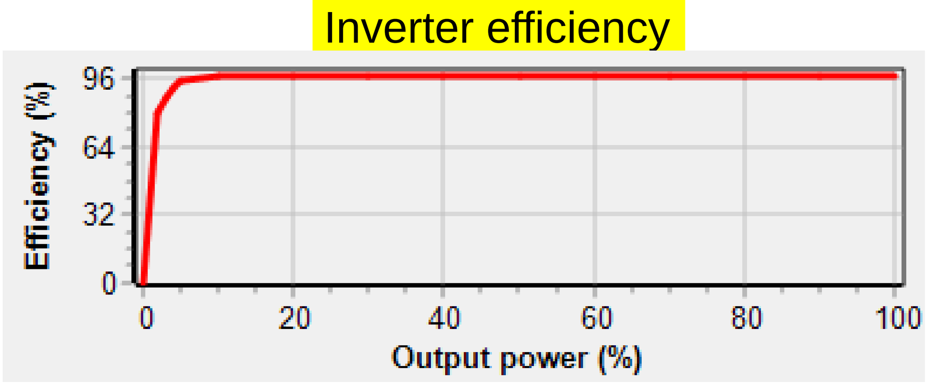
Optimization of an AC-coupled utility-scale PV-plus-battery system. Batteries are used for price arbitrage, being charged with the PV generation during hours of low electricity price and discharged during hours of high price. Advanced models for estimating the Li-ion battery lifetime (considering cycle and calendar ageing) are used. With present components costs, considering the Spanish SPOT price of 2021 with an expected increase of 1% annual, the AC coupled utility-scale PV-plus-battery isn't economically viable comparing to the PV-only system. If electricity hourly price was multiplied by two, in certain cases adding battery to the PV system would be profitable.



Inverter efficiency



SIMULATION AND OPTIMIZATION OF THE SYSTEM

- Location: near Zazarogza (latitude 41.66º, longitude 0.86º).
- SPOT hourly electricity prices of 2021 with expected annual increase of 1%
- PV: 10 to 100 MWac in 10 MW steps.
- Batteries: 0 to 50 MWh in 5 MWh steps.
- Inverter/chargers: 0 to 20 MWac in 5 MW steps.
- 3 cases for control variables:
  - Case 1: X=0.05 €/kWh, Y=10%
  - Case 2: X=0.1 €/kWh, Y=10%
  - Case 3: X=0.15 €/kWh, Y=10%
- Two cases for electricity prices:
  - A): SPOT prices 2021
  - B): 2x SPOT prices 2021.

Simulation of three consecutive days, optimal system, A) Case 1 (September 18th-20th)

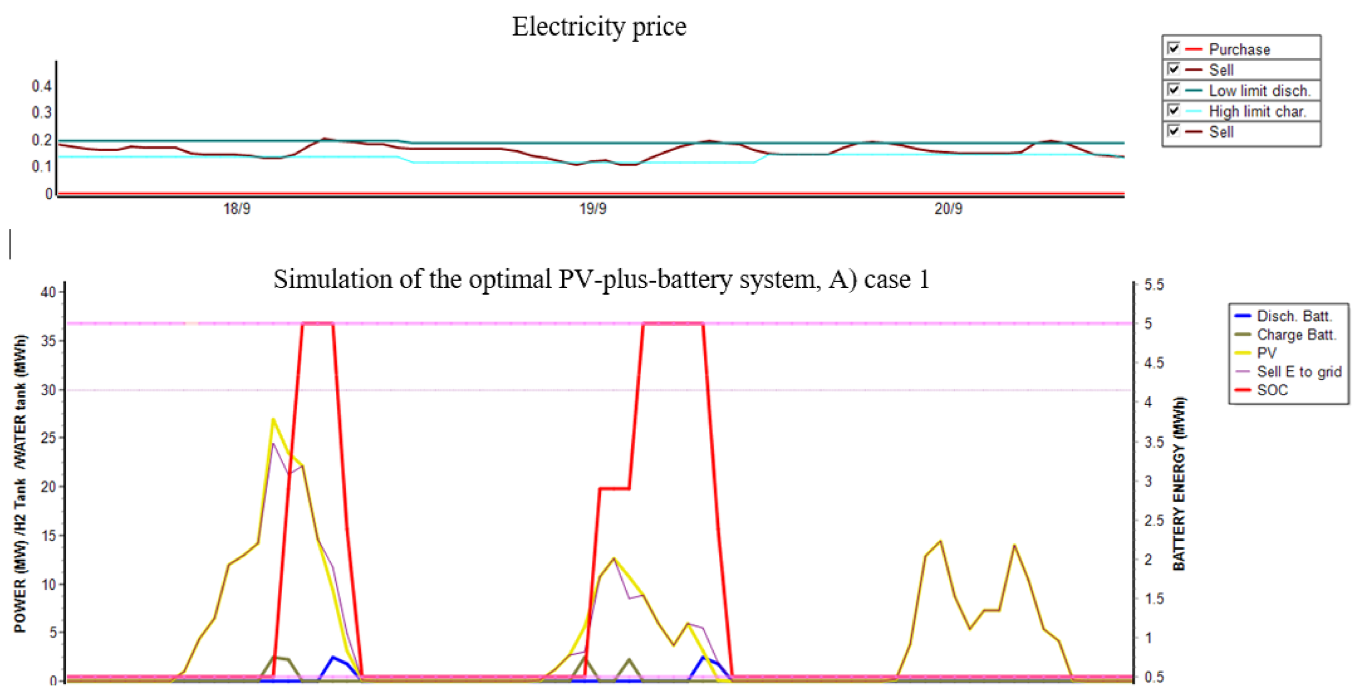


Fig. 9. Electricity price with charge and discharge limits (up) and simulation of the optimal system for case 1 for three consecutive days (18th to 20th September). Optimal PV-plus-battery system, A) case 1.

Hourly values during one year, optimal system, A) Case 1 (September 18th-20th)

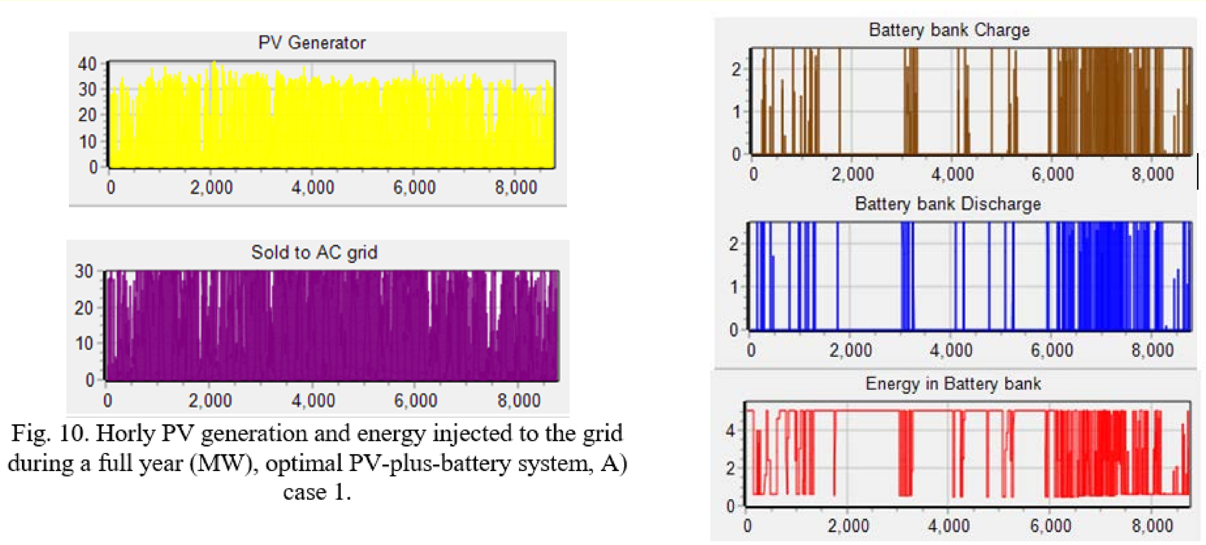


Fig. 10. Horly PV generation and energy injected to the grid during a full year (MW), optimal PV-plus-battery system, A) case 1.

REMARKS

- Optimization (maximization of NPV) of the utility-scale AC-coupled PV-plus-battery size and the control strategy variables for arbitrage. System lifetime: 25 years.
- Comparison with PV-only system.
- Variable PV inverter and inverter-charger efficiencies
- First, optimization of the PV-only system
- Second, optimization of the PV-plus-battery: size of PV, battery and inverter/charger
- Different values for the control strategy (X: minimum difference of max-min price of the day; Y: percentage for charge/discharge)
- Li-ion battery ageing model: Naumann et al., 2018 and 2020
- Simulations and optimizations performed by MHOGA software (MegaWatt Hybrid Optimization by Genetic Algorithms).

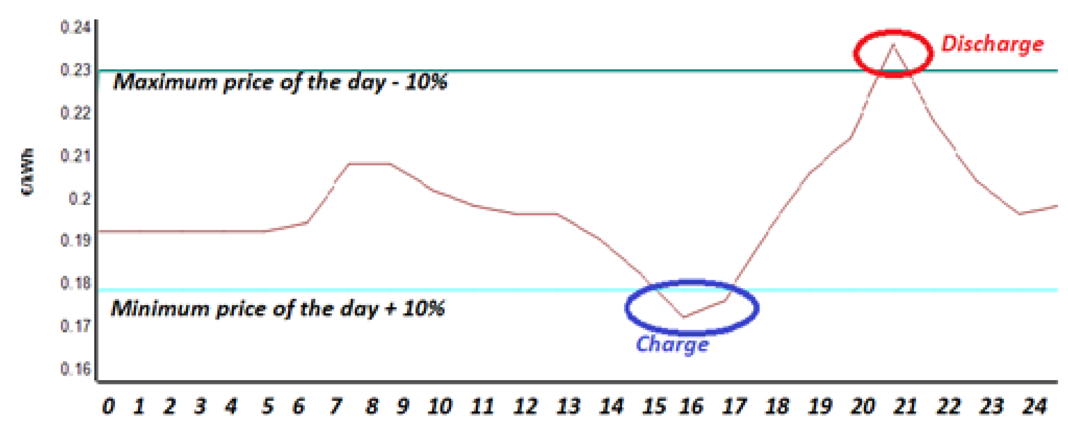


Fig. 8. Battery management for a specific day with X = 0.05 €/kWh and Y = 10%.

OPTIMAL SYSTEMS:

	A: SPOT PRICES 2021				B: SPOT PRICES 2021 x 2			
	PV-only	Case 1	Case 2	Case 3	PV-only	Case 1	Case 2	Case 3
PV (MW)	40	40	40	40	60	60	60	60
Battery (MWh)	-	5	5	5	-	45	25	0
Inverter-charger (MW)	-	5	5	5	-	20	10	0
NPV (M€)	**17.26**	15.44	15.24	15.12	121.04	127.04	121.27	**120.41**
Investment cost (M€)	67.5	69.22	69.22	69.22	101.25	113.9	108.44	101.97
IRR (%)	9.59	9.28	9.25	9.23	17.92	17.28	16.36	17.72
LCOE (€/kWh)	0.078	0.08	0.08	0.08	0.094	0.103	0.100	0.096
PV generation (GWh/yr)	69.21	69.21	69.21	69.21	103.82	103.82	103.82	103.82
Bat. charge energy (GWh/yr)	-	0.39	0.09	0.03	-	9.29	2.44	0.29
Bat. disch. energy (GWh/yr)	-	0.36	0.09	0.03	-	8.59	2.27	0.27
Hours of bat. charge per year	-	135	20	6	-	224	106	38
Hours of bat. disch. per year	-	181	43	15	-	511	283	134
Battery lifetime (years)	-	12.07	15	15	-	8.27	12.21	15
Sell energy (GWh/yr)	67.76	67.93	67.82	67.78	84.21	90.84	86.01	84.45
Sell incomes, 1st year (M€)	7.19	7.23	7.21	7.19	18.19	20.30	18.98	18.31
Sell incomes, NPV (M€)	92.45	93.00	92.67	92.54	233.82	260.97	244.06	235.42
PV costs, NPC (M€)	61.86	61.86	61.86	61.86	92.53	92.53	92.53	92.53
Batt. costs, NPC (M€)	-	1.37	1.37	1.37	-	17.06	7.53	1.37
Inv-ch costs, NPC (M€)	-	0.52	0.52	0.52	-	1.56	1.04	0.52

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CONCLUSIONS
MHOGA software used for the optimization of an AC-coupled utility-scale PV-plus-battery system, using the battery for energy arbitrage to maximize the benefits. The software uses advanced models for estimating the battery lifetime (considering cycle and calendar ageing), which has great influence in the optimization. With present components costs, considering the Spanish SPOT price of 2021 with an expected increase of 1% annual, it is not worth to add batteries to the PV-only system. However, with prices twice of those, AC coupled utility-scale PV-plus-battery can be economically viable comparing to the PV-only system