Energy arbitrage in PV-PHS systems

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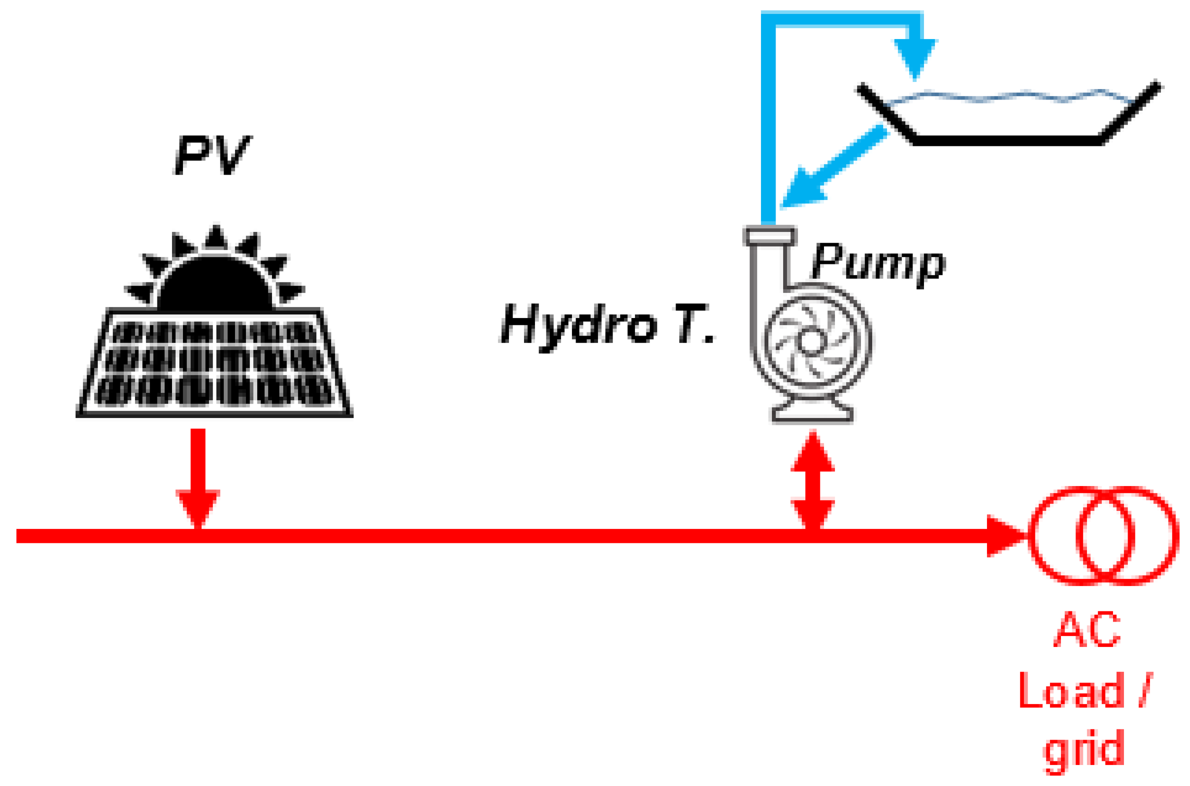
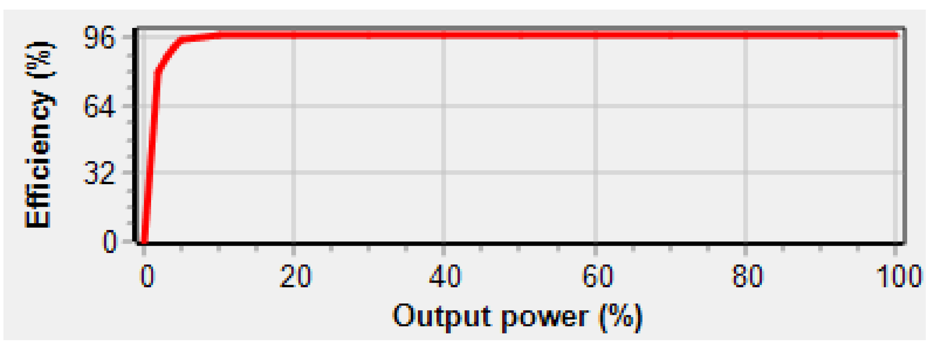
Optimization of utility-scale PV systems with pumped hydro storage (PHS). PHS is used for electricity price arbitrage, pumping water from the lower reservoir to the upper reservoir with the PV generation during hours of low electricity price and generating electricity by means of the stored water with the turbine during hours of high price (during these hours the PV generator also injects its production to the grid). Comparison of PV-PHS system with PV-only system.



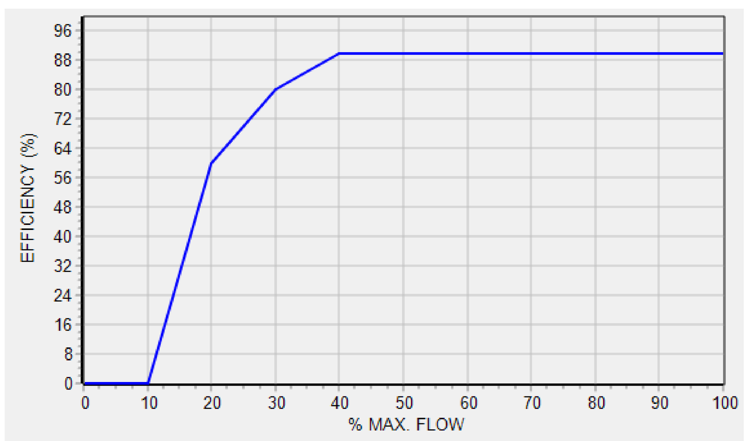
REMARKS

- Evaluated the economical viability of adding PHS storage (PV-PHS system).
- Optimization (maximization of NPV) of the pump-turbine size and the control strategy variables for the use of the pump and the turbine, trying to obtain the maximum benefits. System lifetime: 25 years.
- Variable pump-turbine efficiency
- Variable PV inverter efficiency
- First, optimization of the PV-only system
- Second, optimization of the PV-PHS system
  - Optimal pump-turbine size
  - Optimal control variables (X1, X2, X3)
- Simulations and optimizations performed by MHOGA software (MegaWatt Hybrid Optimization by Genetic Algorithms).

Inverter efficiency



Pump-Turbine efficiency



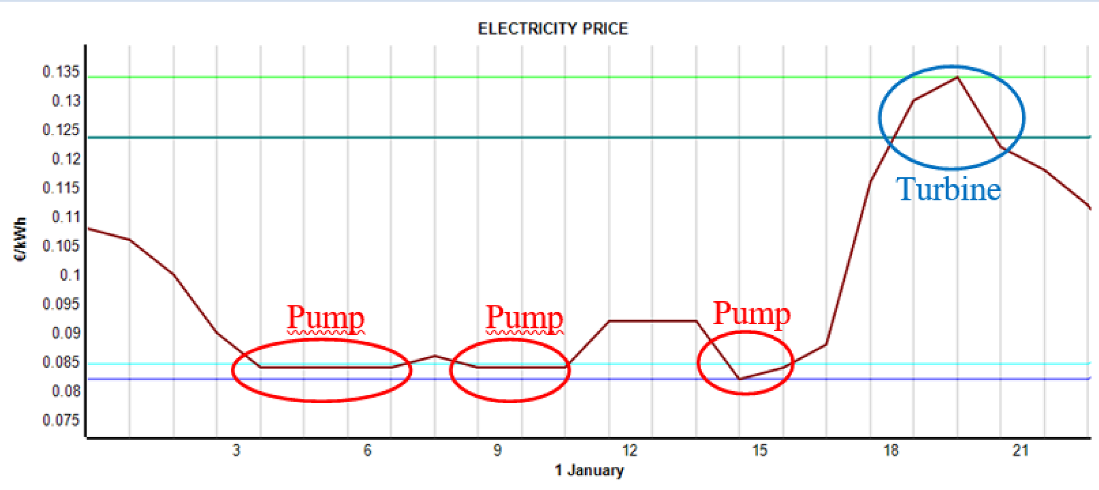
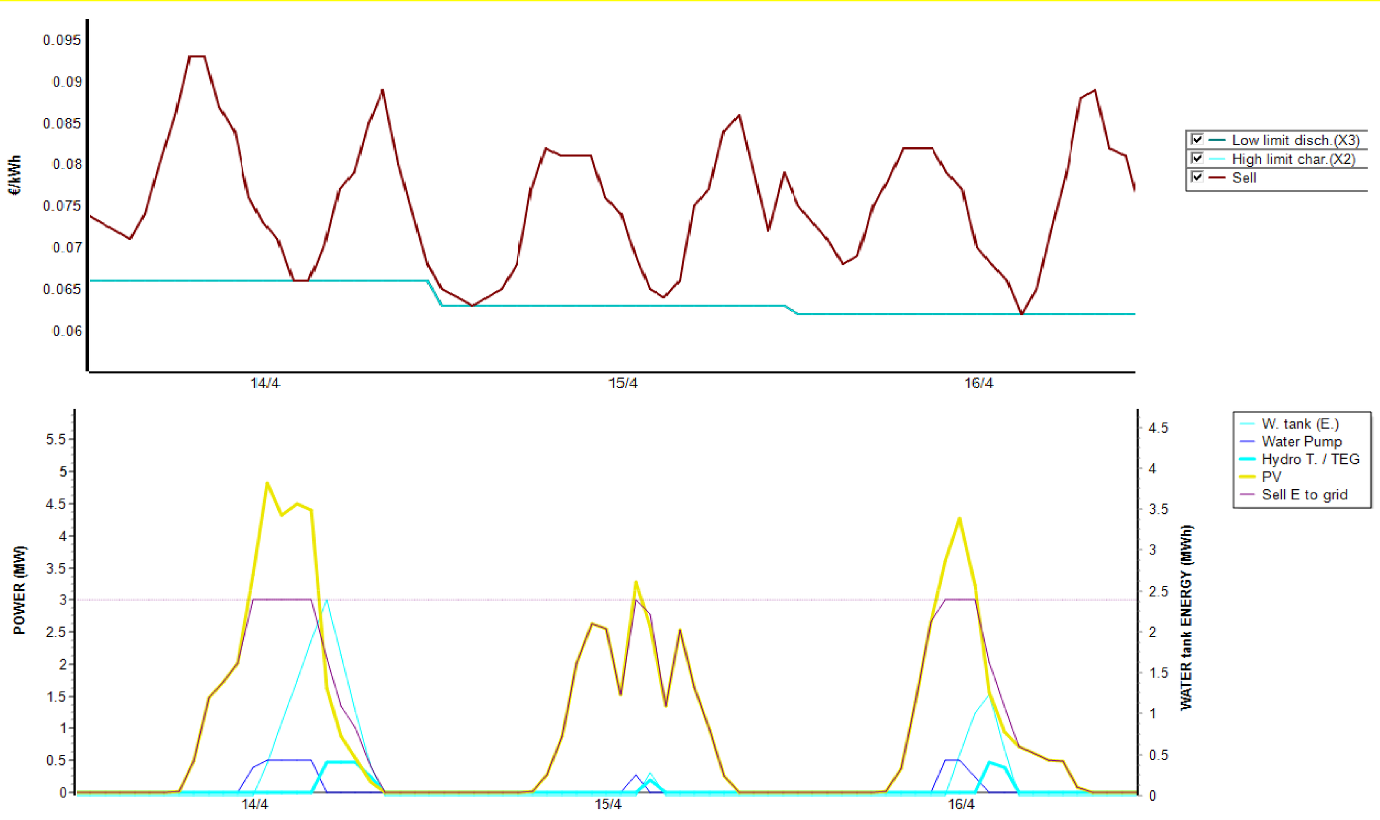


Fig.7. PHS management for a specific day with X1 = 0.06 €/kWh, X2 =5%, X3 = 20%.

SIMULATION AND OPTIMIZATION OF THE SYSTEM

- Location: Pyrenees of Huesca, Spain (latitude 42.52º, longitude -0.37º).
- SPOT hourly electricity prices of 2021 with expected annual increase of 1%
- PHS: 6 different possibilities, from 0.5 to 3 MW (2 to 12 m^3/s max. flow) reversible pump/turbines, in steps of 0.5 MW (costs from 1,500 €/kW to 1,000 €/kW in steps of 100 €/kW)
- Reservoir of 130 dam^3 (net volume). 3 to 20 h storage duration.
- Available head of 30 m. Friction losses 4%.
- When the upper reservoir is full, water stored energy (MWh) will be E = 10.2 MWh

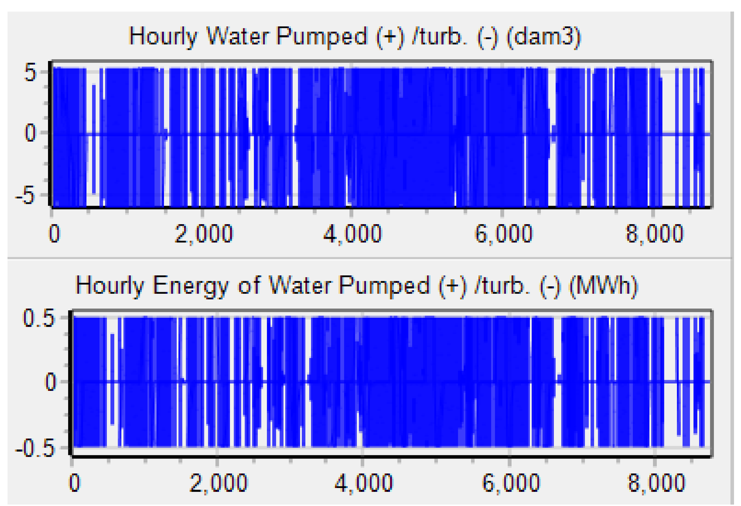
Simulation of three consecutive days, optimal PV-PHS system (April 14th-16th)

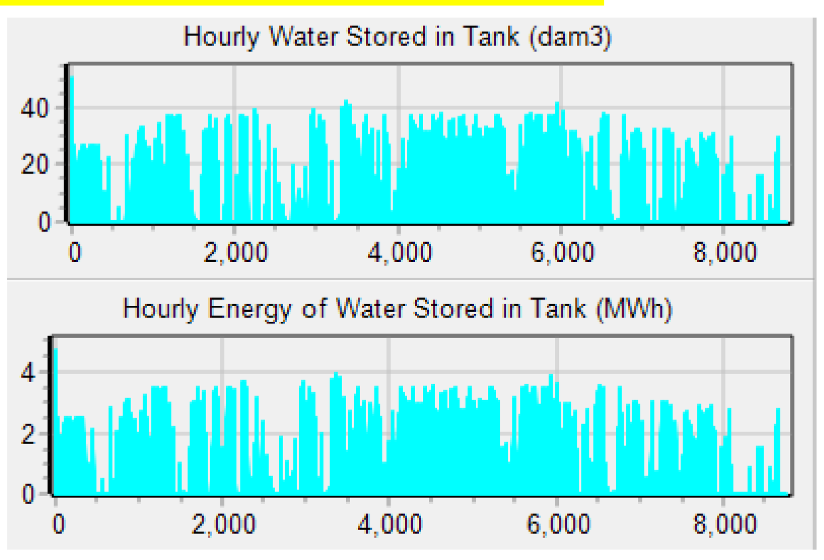


OPTIMAL SYSTEMS:

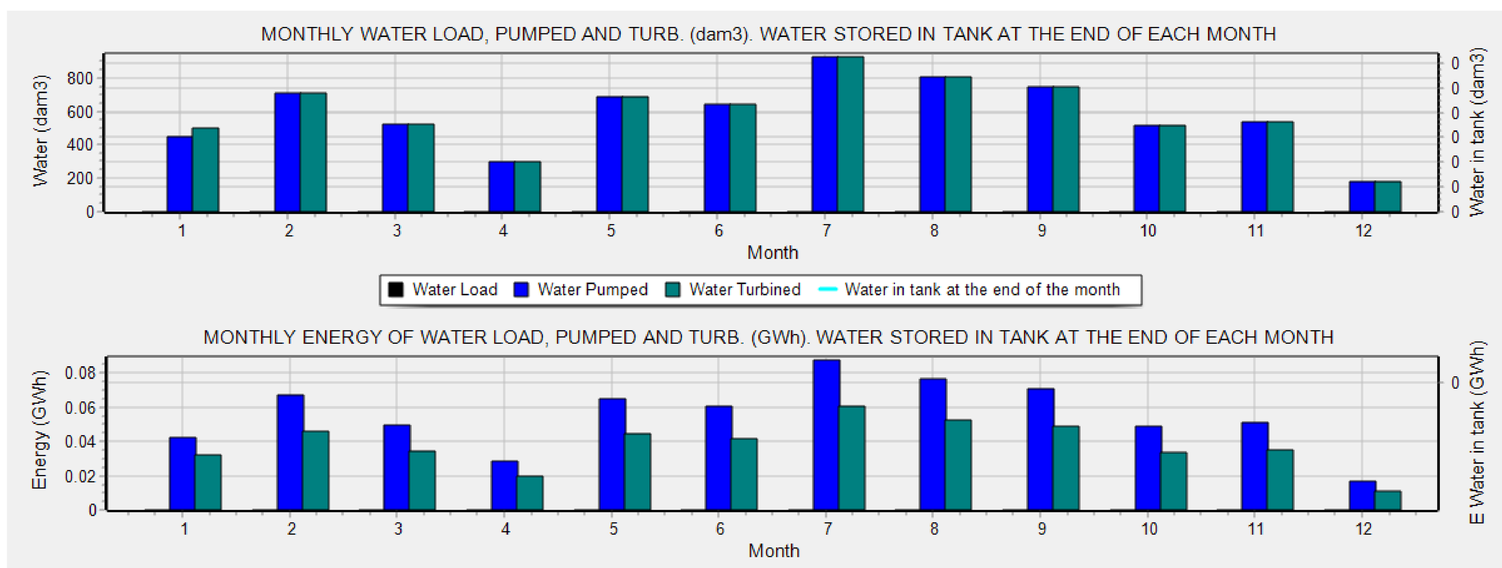
	PV-only	PV-PHS
PV (MW)	6	6
PHS (MW)	0	0.5
PHS management strategy: X1 (€/kWh), X2(%), X3(%)	-	0.003 €/kWh, 0%, 100%
NPV (M€)	4.01	3.55
Investment cost (M€)	6	6.94
IRR (%)	13.4	12
Capacity factor (%) (defined as Sell energy divided Pmax_grid·8760)	29.9	31.6
LCOE (€/kWh)	0.060	0.066
PV generation (GWh/yr)	9.59	9.559
Pump energy (GWh/yr)	-	0.663
Hydro turb. energy (GWh/yr)	-	0.459
Pumping hours per year	-	1,468
Turbine running hours per year	-	1,157
Sell energy (GWh/yr)	7.86	8.32
Sell incomes, 1st year (M€)	0.83	0.88
Sell incomes, NPV (M€)	10.69	11.38
PV costs, NPC (M€)	5.48	5.48
PHS costs, NPC (M€)	-	0.96

Hourlyh Water pumped / turbined and stored during one year, optimal PV-PHS system





Monthly Water pumped / turbined and stored during one year, optimal PV-PHS system



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CONCLUSIONS

The PV-only system is compared to the optimal PV-PHS, evaluating different options for PHS, from 3 to 20 h storage duration and optimizing the PHS size and its management strategy in order to maximize NPV. In the case evaluated, considering SPOT electricity prices of 2021 with expected annual increase of 1% and PHS cost of 1,400 €/kW (for the case of 1 MW, 10.2 h storage duration, which was obtained the optimal one), the PV-PHS system is not economically viable compared to the PV-only, as its NPV is lower than the NPV of the PV-only system. Also PV-PHS has higher LCOE and lower IRR. However, the capacity factor of the PV-PHS system is higher than PV-only system.