ESR 03: Virtual Power Plant for Operation, both Isolated and Connected

SMARTGYsum Result Presentation Badajoz, Spain

Anas Abdullah Alvi
University of Extremadura

Supervisor: Enrique Romero-Cadaval

ETN 955614
Marie Skłodowska-Curie Actions (MSCA)
Innovative Training Networks (ITN)
H2020-MSCA-ITN-2020

Research and Training Network for
Smart and Green Energy Systems and Business Models

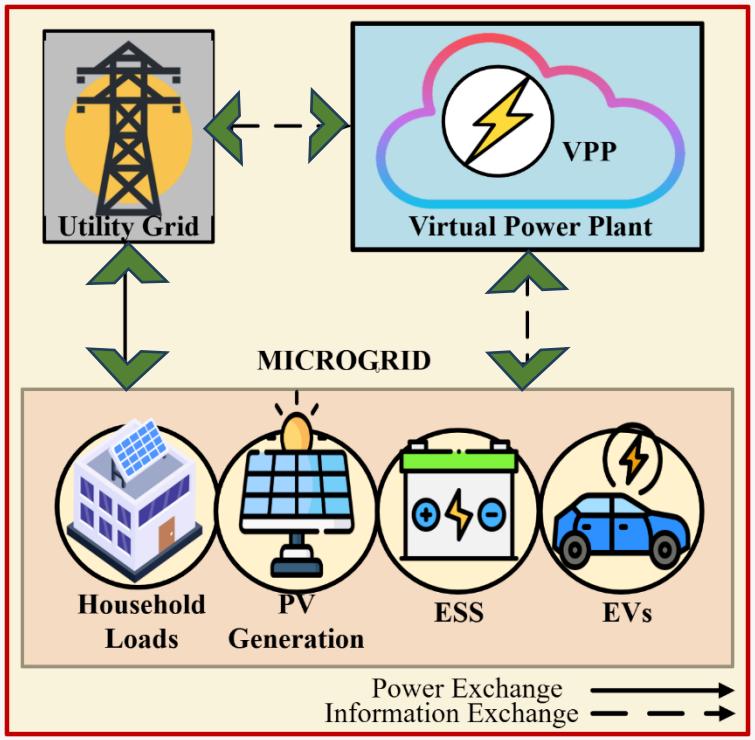
Introduction

- **Growing number** of renewable energies based distributed energy resources
- **Increase** in new types of loads such as electric vehicles
- **Creating** uncertainty and instability in the grid
- **Rising** cost of electricity

Increasing the demand of Energy Management Systems (EMS) in Virtual Power Plant (VPP)

VPP Definition

- Integration of Distributed Energy Resources
- Interconnected network
  - Solar Panels
  - Wind Turbines
  - Energy Storage Systems
  - Manageable Loads



Overview of VPP interactions

Objectives of this work

General objectives:

- ❑ To create and evaluate a VPP for a MG
- ❑ To define optimization functions and constraints
- ❑ To obtain new operation set-points
- ❑ To create a graphical interface of the VPP

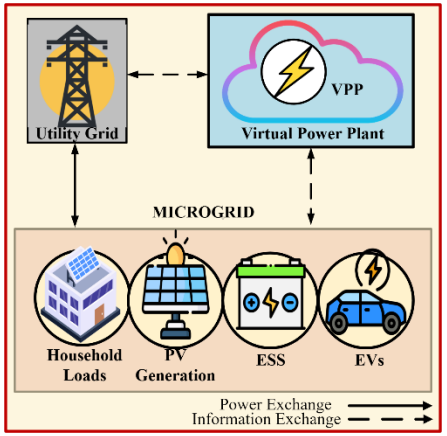
Specific objectives for the VPP:

- ❑ Economical optimization
- ❑ Technical optimization
- ❑ Grid congestion constraints
- ❑ Simulation time reduction
- ❑ **Improvement of GA for VPP**

Case Study Description

- The VPP under study encompasses:
  - Households: **8 houses** with different demand profiles
    - 4 houses were modelled with a medium level of annual electricity use.
    - 4 houses responded to a high and low demand profile.
  - A **PV power plant** rated at a 15-kW peak.
  - An **VPP** with a capacity of 24 kWh, maximum charge/discharge power of ±6 kW and a SoC range of 20–100%.
  - **Four EVs**, each with a battery capacity of 7.5 kWh.

Elements of the VPP under study



González-Romera, E.; Romero-Cadaval, E.; Roncero-Clemente, C.; Milanés-Montero, M.-I.; Barrero-González, F.; Alvi, A.-A. A Genetic Algorithm for Residential Virtual Power Plants with Electric Vehicle Management Providing Ancillary Services. *Electronics* **2023**, *12*, 3717.

Study Procedure

START

Load power profiles
- Household loads
- PV Generation
- Costs of electricity

Determine set-points
- Set objective functions
- Set contraints
- Perform optimization **by GA**

Run simulation
- Time resolution: hours
- Add uncertainties
- Obtain new ESS set-points
- Obtain new EV set-points

Evaluate
- Analysis results.
- Calculate performance indexes
- Draw evaluation figures

END

The VPP power balance is defined as:

$$P_{grid}(h) = P_{PV}(h) - P_{LD}(h) - P_{ESS}(h) - P_{EV}(h)$$

The objective function is defined as:

$$f = \sum_{h=1}^{24} \left[\left(I_{pur}(h) \cdot p_{pur}(h) - I_{sel}(h) \cdot p_{sel}(h) \right) \cdot \left| P_{grid}(h) \right| \right]$$

EVs charging from 0 to 8 h

$$-P_{EVmax} \cdot n_{EV}(h_{EV}) \leq P_{EV}(h_{EV}) \leq P_{EVmax} \cdot n_{EV}(h_{EV}),\ h_{EV} \in nh_{EV}$$

$$P_{EV}(h) = 0, h \notin nh_{EV}$$

$$\sum_{h_{EV}} P_{EV}(h_{EV}) = E_{EVtotal}.$$

$$-P_{ESSmax} \leq P_{ESS}(h) \leq P_{ESSmax}$$

$$SoC_{lo} \leq SoC(h) \leq SoC_{up}$$

$$|SoC_{in} - SoC(24)| \leq 10\%$$

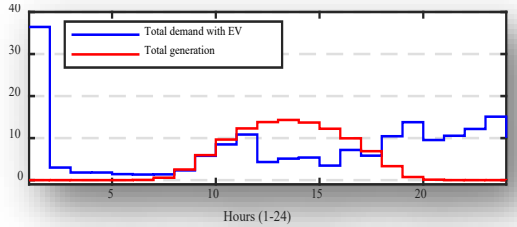
where:

$$SoC(h) = SoC_{in} + \sum_{i=1}^{h} \left(I_{ESSch}(i) \cdot P_{ESS}(i) \cdot \eta_{ch} + I_{ESSdi}(i) \cdot \frac{P_{ESS}(i)}{\eta_{di}} \right)$$

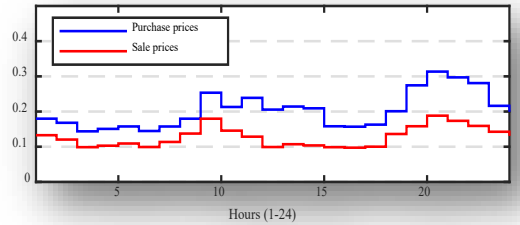
Results (Cost Minimization)

Initial Condition without optimization and ESS

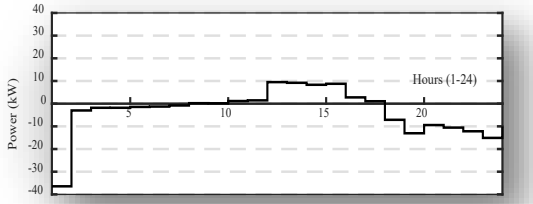
Accumulated demand and generation (kWh)



Prices of energy (€/kWh) for prosumers



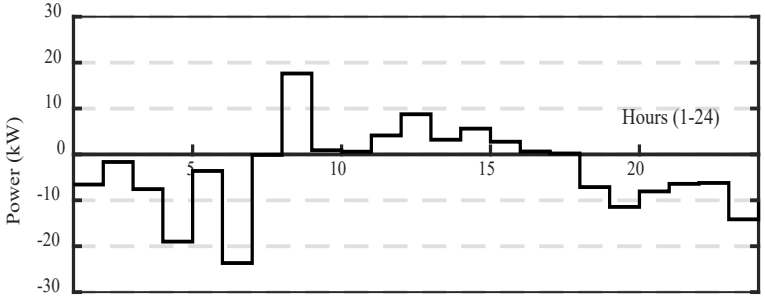
Power interchange with distribution grid



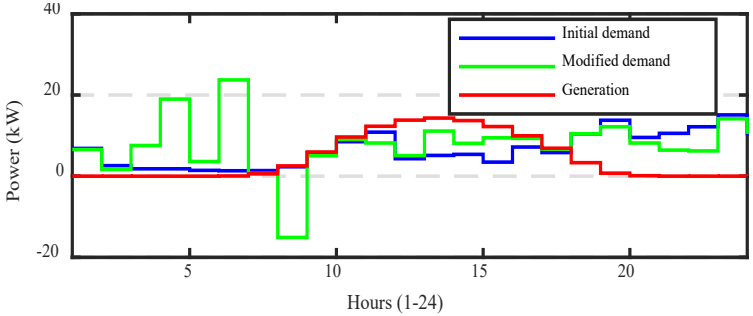
Initial Cost per day: 23.47 €

Results after optimization with ESS

Power interchange with distribution grid



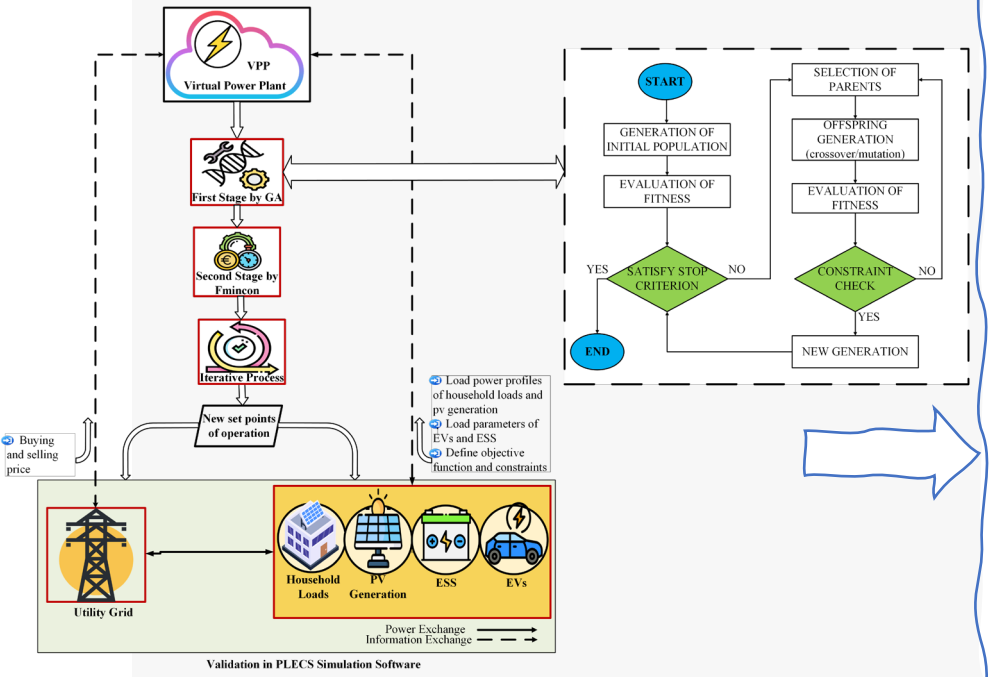
Accumulated demand and generation after scheduling



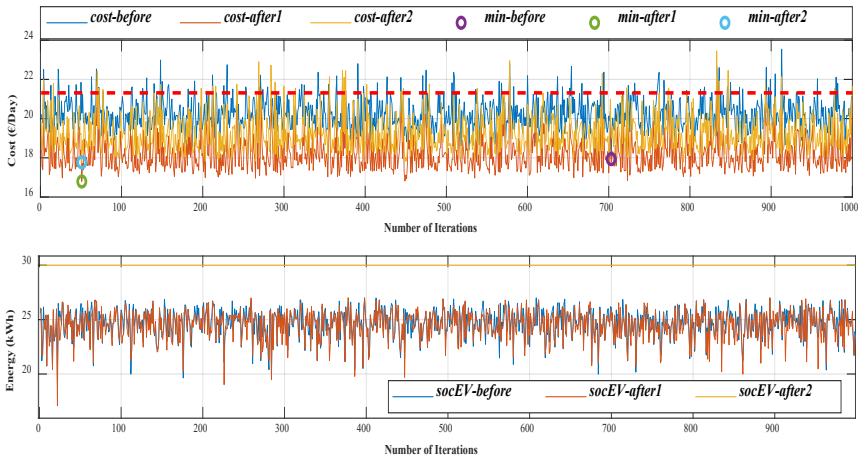
Cost per day: 19.95 €
Reduction of 15 %

Improvement of GA in VPP

A 2-stage iterative GA is proposed combining GA and F_{mincon} and adjusting SoC constraint of EVs.



Results after optimization with ESS

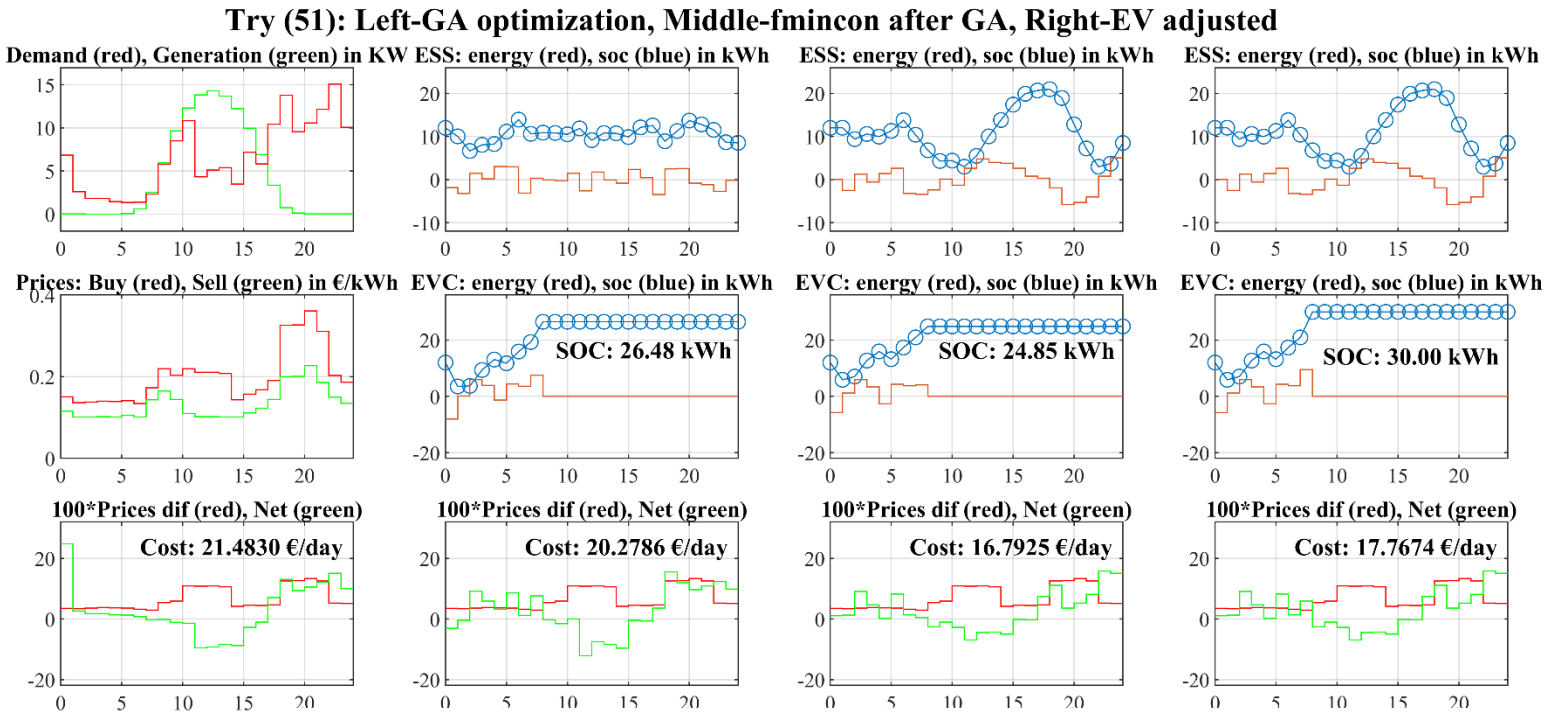


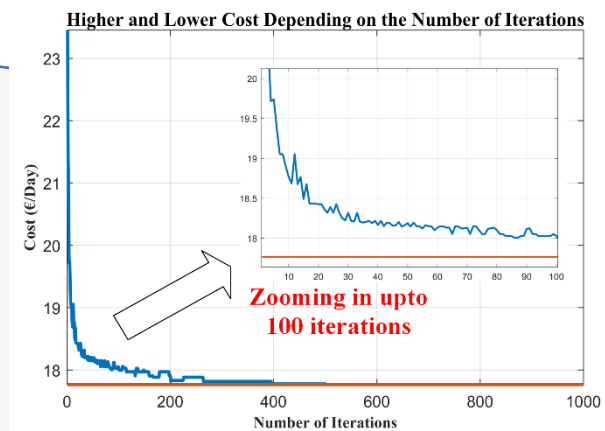
Number of iterations versus change in cost

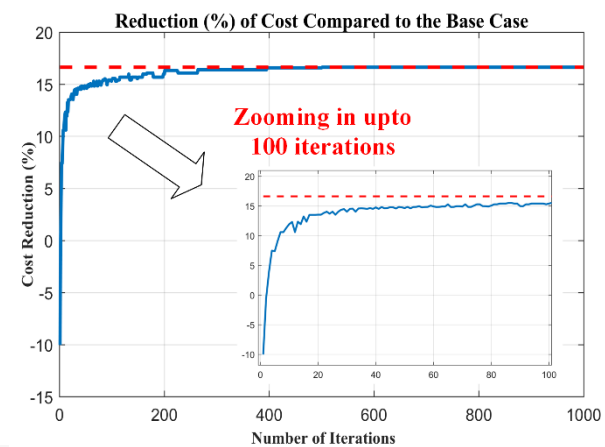
- **Before (Only GA):**
  17.9375 euros (on iteration 703).
- **After 1st Stage (GA + F_{mincon}):**
  16.7925 euros (in iteration 51).
- **After 2nd Stage (GA + F_{mincon} + SoC Adjustment):**
  17.7674 euros (in iteration 51).

Alvi, A.A.; Martínez-Caballero, L.; Romero-Cadaval, E.; González-Romera, E.; Malinowski, M. Iterative Genetic Algorithm to Improve Optimization of a Residential Virtual Power Plant. Energies 2025, 18, 5377.

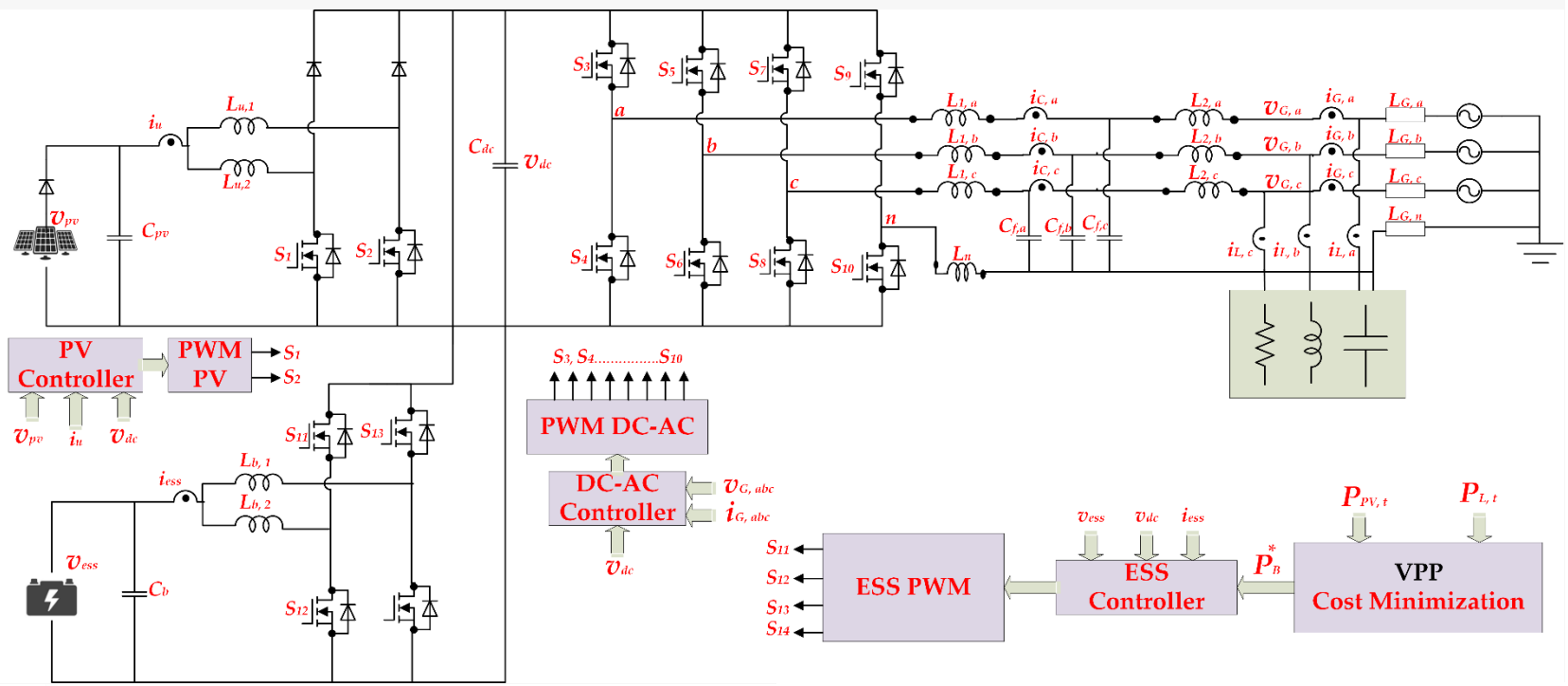
Improvement of GA in VPP (Contd.)

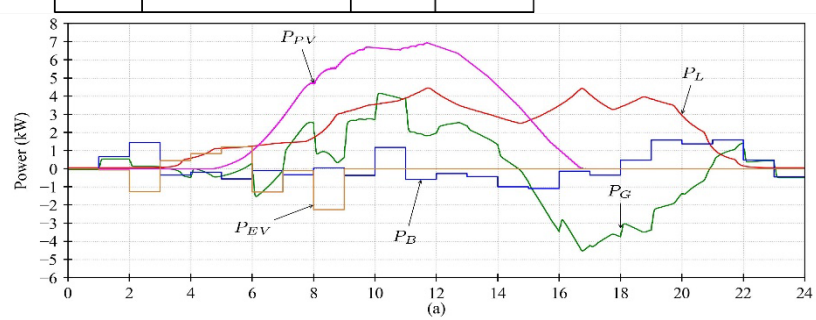


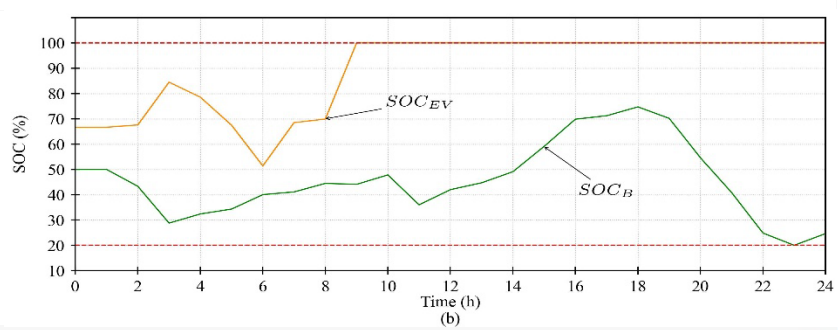




Validation using PLECS Simulation Model



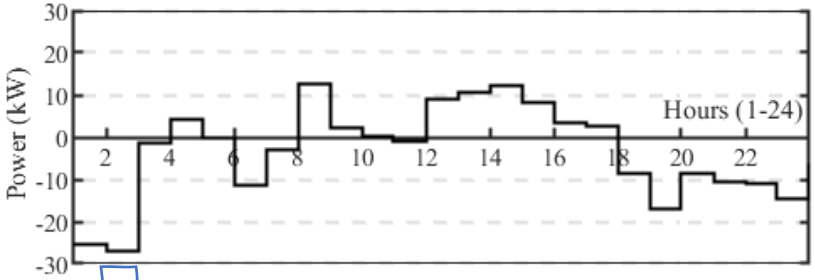




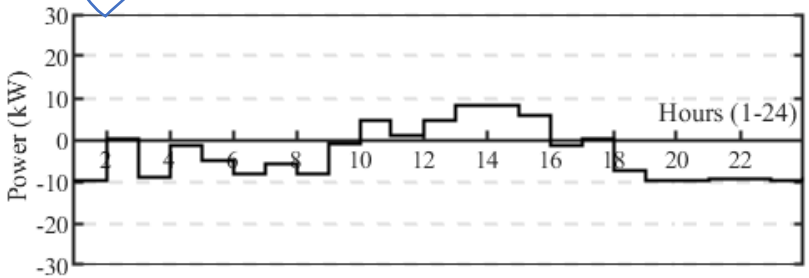
The total cost of energy obtained in this way deviated by only 3.85%

Results (Peak Shaving Constraint)

Compensation Payment of 50 €/MW/h



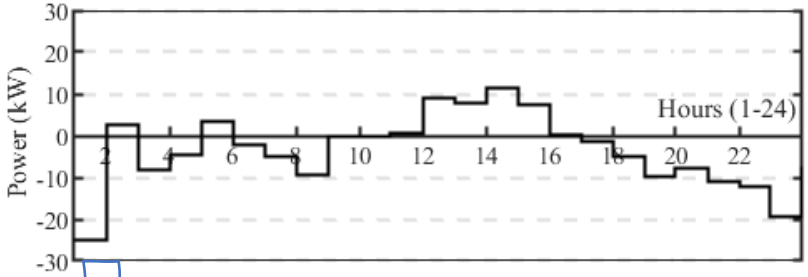
Power Interchange after adding Peak Shaving Constraint



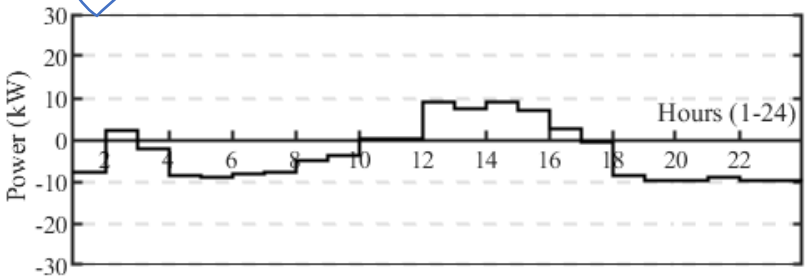
P_{AS_up} = 0.09 kW
P_{AS_down} = 0.76 kW

Cost per day 20.1 €
Reduction of 14.36 %

Compensation Payment of 250 €/MW/h



Power Interchange after adding Peak Shaving Constraint



P_{AS_up} = 0.87 kW
P_{AS_down} = 0.58 kW

Cost per day 13.13 €
Reduction of 44.1 %

65.28 €/day

Penalty Cost:

$$Cost_{max}, P_h = K_p \cdot t_{ep}\sqrt{(P_h - P_c)^2}$$

56 €/day

A. A. Alvi, E. González-Romera, E. Romero-Cadaval, D. Vinnikov, M. I. Milanés-Montero and F. Barrero-González, "An Economical Optimization for the Participation of a Residential Microgrid in Flexibility Markets Providing Ancillary Services," *2024 IEEE 18th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG)*, Gdynia, Poland, 2024, pp. 1-6.

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Publications

Journals –

1. González-Romera, E.; Romero-Cadaval, E.; Roncero-Clemente, C.; Milanés-Montero, M.-I.; Barrero-González, F.; Alvi, A.A. A Genetic Algorithm for Residential Virtual Power Plants with Electric Vehicle Management Providing Ancillary Services. Electronics 2023, 12, 3717.

2. Alvi, A.A.; Martínez-Caballero, L.; Romero-Cadaval, E.; González-Romera, E.; Malinowski, M. Iterative Genetic Algorithm to Improve Optimization of a Residential Virtual Power Plant. Energies 2025, 18, 5377. https://doi.org/10.3390/en18205377.

3. González-Romera, E., Roncero-Clemente, C., Romero-Cadaval, E., Milanés-Montero, M. I., Barrero-González, F., & Alvi, A. A. (2025). Two-stage optimization for energy management and power allocation in a Virtual Power Plant of residential microgrids. *Renewable Energy and Power Quality Journal*, *23*(3), 160-165.

Conferences –

1. A. A. Alvi, E. Romero-Cadaval, E. González-Romera, D. Vinnikov and J. Hassan, "Performance Evaluation of a Three-Phase PV Power Plant under Unbalanced Conditions with Islanding Detection Reliability Test," 2023 IEEE 17th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG), Tallinn, Estonia, June 2023, pp. 1-6.

2. A. A. Alvi, E. González-Romera, E. Romero-Cadaval, D. Vinnikov, M. I. Milanés-Montero and F. Barrero-González, "An Economical Optimization for the Participation of a Residential Microgrid in Flexibility Markets Providing Ancillary Services," 2024 IEEE 18th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG), Gdynia, Poland, 2024, pp. 1-6, doi: 10.1109/CPE-POWERENG60842.2024.10604394.

3. A. A. Alvi, L. Martínez-Caballero, E. Romero-Cadaval, E. González-Romera, R. Kot and M. Malinowski, "Guidelines for the Application of Genetic Algorithm in Energy Management System," *IECON 2024 - 50th Annual Conference of the IEEE Industrial Electronics Society*, Chicago, IL, USA, 2024, pp. 1-6, doi: 10.1109/IECON55916.2024.10905264.

4. A. A. Alvi, E. Romero-Cadaval, E. González-Romera, M. I. Milanés-Montero, F. Barrero-González and L. Martínez-Caballero, "A Novel Iteration Based Two-Stage Optimization in Energy Management Systems Application For Cost Minimization," *2025 IEEE 19th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG)*, Antalya, Turkiye, 2025, pp. 1-6, doi: 10.1109/CPE-POWERENG63314.2025.11027217.

Book Chapter –

1. Alvi, A.A., Romero-Cadaval, E., González-Romera, E., Hassan, J., Vinnikov, D. (2023). An Overview of the Functions of Smart Grids Associated with Virtual Power Plants Including Cybersecurity Measures. Technological Innovation for Connected Cyber Physical Spaces. IFIP Advances in Information and Communication Technology. Springer 2023, ISBN: 978-3-031-36006-0.

Thank You

Questions?