Optimal Management of a Hybrid and Isolated Microgrid in a Random Setting

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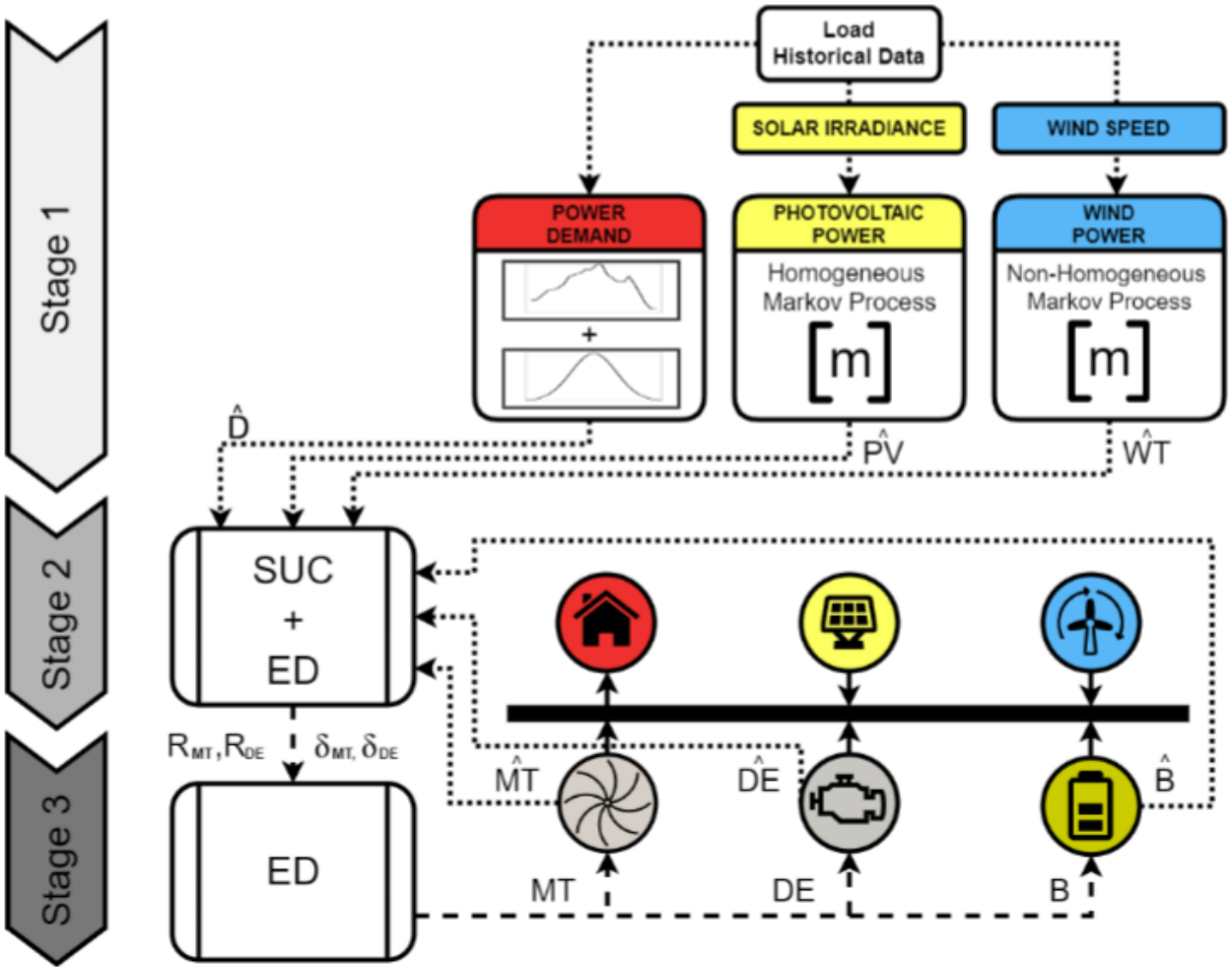
1. INTRODUCTION

- The goal of this work is to solve an optimization problem which aims at covering demand while minimizing the operating costs
- Purposes of the microgrid:
  - to distribute and to exploit more zero emission sources
  - to satisfy the demand
  - to manage a photovoltaic plant (PV), a wind turbine (WT), a microturbine (MT), a diesel generator (DE) and a battery (BESS)
- Application of **non-homogeneous and homogeneous Markov processes to model the uncertainties of WT and PV powers** in a **Stochastic Unit Commitment** (SUC) and **Economic Dispatch** (ED) problem
- Comparative analysis with the study in Alvarado-Barrios et al. (2020)*, where the renewable sources are considered fixed

*Alvarado-Barrios, L., del Nozal, A. R., Valerino, J. B., Vera, I. G., & Martínez-Ramos, J. L. (2020). Stochastic unit commitment in microgrids: Influence of the load forecasting error and the availability of energy storage. *Renewable Energy*, *146*, 2060-2069.

2. PROPOSED ENERGY MANAGEMENT SYSTEM

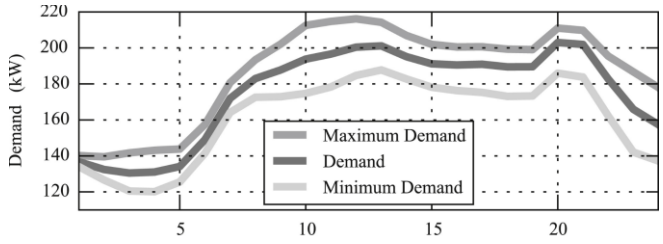
- Flowchart of the problem



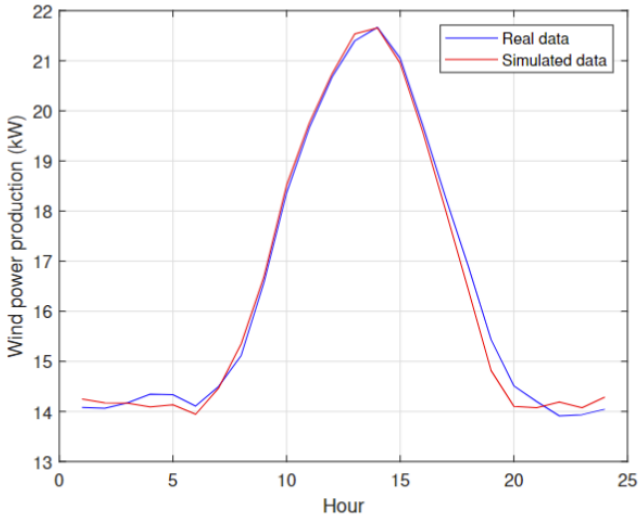
3. SYSTEM MODELING

- Demand ➡
  - ARMA model

$$D(t) = \sum_{i=1}^{p} \phi_i D(t-i) + \sum_{j=0}^{q} \theta_j \varepsilon(t-j)$$



- Wind generation ➡
  - **Non-homogeneous Markov reward process** (each transition from an hour to the next one is governed by a different transition probability matrices)



- E^{WT} ={1,2,3,4,5} is the set of the different levels of generated wind power (state 1 between 0 and 16 kW, state 2 between 16 and 32 kW, state 3 between 32 and 48 kW, state 4 between 48 and 64 kW, state 5 between 64 and 80 kW)
- J_n^{WT} indicates the state of system at the n-th transition

$$P[J_{n+1}^{WT} = j \mid J_n^{WT} = i_n, J_{n-1}^{WT} = i_{n-1}, \ldots, J_1^{WT} = i_1, J_0^{WT} = i_0] = P[J_{n+1}^{WT} = j \mid J_n^{WT} = i_n] = p_{i_n j}(n+1)$$

3. SYSTEM MODELING

- Example:

$$\begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{array} \begin{array}{c} \begin{array}{ccccc} 1 & 2 & 3 & 4 & 5 \end{array} \\ \begin{pmatrix} 0.98 & 0.02 & 0 & 0 & 0 \\ 0.10 & 0.80 & 0.10 & 0 & 0 \\ 0 & 0.16 & 0.73 & 0.10 & 0.01 \\ 0 & 0 & 0.27 & 0.64 & 0.09 \\ 0 & 0 & 0.01 & 0.10 & 0.89 \end{pmatrix} \end{array}$$

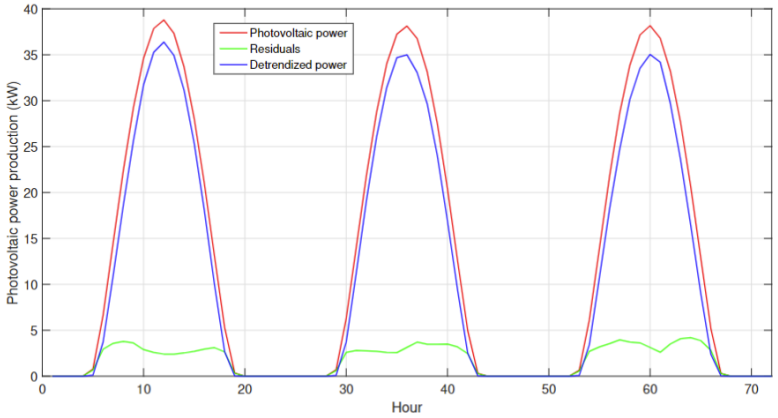
Hours 2:00 – 3:00 a.m.

$$\begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{array} \begin{array}{c} \begin{array}{ccccc} 1 & 2 & 3 & 4 & 5 \end{array} \\ \begin{pmatrix} 0.94 & 0.05 & 0.01 & 0 & 0 \\ 0.15 & 0.63 & 0.20 & 0.02 & 0 \\ 0.01 & 0.13 & 0.57 & 0.24 & 0.05 \\ 0 & 0 & 0.07 & 0.43 & 0.50 \\ 0 & 0 & 0 & 0.05 & 0.95 \end{pmatrix} \end{array}$$

Hours 8:00 – 9:00 a.m.

3. SYSTEM MODELING

- Photovoltaic generation ➡



- PV power is detrended
- Residuals are modeled using a homogeneous Markov reward process
- E^{PV} ={1,2,3} is the set of the different levels of generated wind power
- J_n^{PV} indicates the state of the system at the n-th transition

$$P[J_{n+1}^{PV} = j \mid J_n^{PV} = i_n, J_{n-1}^{PV} = i_{n-1}, ..., J_1^{PV} = i_1, J_0^{PV} = i_0] = P[J_{n+1}^{PV} = j \mid J_n^{PV} = i_n] = p_{ij}$$

4. OPTIMIZATION AND CONTROL STRATEGY

- Production = Demand

$$D(t) = PV(t) + WT(t) + B(t) + \delta_{MT}(t) \cdot MT(t) + \delta_{DE}(t) \cdot DE(t)$$

- Objective function

$$\min_{\substack{\delta_{MT},\delta_{DE},\\ B,MT,DE}} \sum_{j=0}^{N-1} \left(C_{MT}(\delta_{MT}(j), MT(j)) + C_{DE}(\delta_{DE}(j), DE(j)\right) + C_{R_{DE}} R^u_{DE}(j) + C_{R_{MT}} R^u_{MT}(j)$$

- System constraints ➡ SOC, P_{max} and P_{min} of each power unit

- Spinning reserve: the difference between the maximum power the generator can deliver, and the power that it is generating at a given instant t. In 99.73% of the cases, the prediction error of the demand is within the interval [μt − 3σt, μt + 3σt] (3σ criteria). The total spinning reserve must be at least greater than three times the standard deviation, to satisfy, with the described uncertainty, the power demanded.

$$R^u_{DE}(t) = DE_{max} - DE(t) \qquad R^d_{DE}(t) = DE(t) - DE_{min} \qquad R^u_{DE}(t) + R^u_{MT}(t) \geq 3\sigma_t$$

$$R^u_{MT}(t) = MT_{max} - MT(t) \qquad R^d_{MT}(t) = MT(t) - MT_{min} \qquad R^d_{DE}(t) + R^d_{MT}(t) \geq 3\sigma_t$$

5. RESULTS

- We use 10 years of hourly wind speed and solar irradiation data, precisely from 01/08/2008 to 01/08/2018, which refer to a location in Sardinia
- Parameters of each device of the microgrid

Source	$P_{max}(kW)$	$P_{min}(kW)$
MT	20	5
DE	150	15
WT	80	0
PV	40	0

- We consider 2 scenarios in which we modify the characteristics of the BESS

Source	$P^c_{max}(kW)$	$P^d_{max}(kW)$	$SOC_{min}(kWh)$	$SOC_{max}(kWh)$
Scenario 1	80	80	70	280
Scenario 2	120	120	0	280

The two scenarios have the same system configuration of the ones considered in Alvarado-Barrios et al. (2020)

5. RESULTS (SCENARIO 1)

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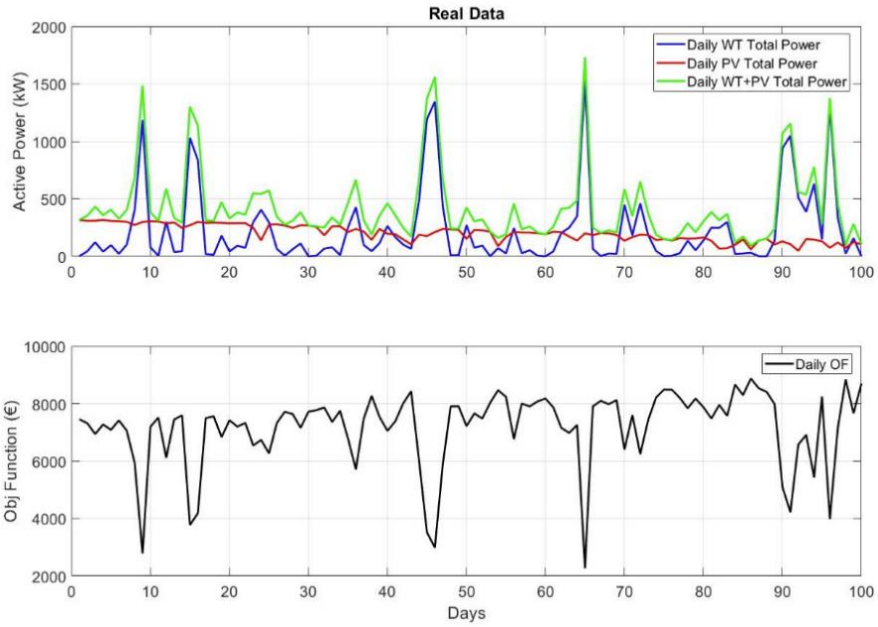
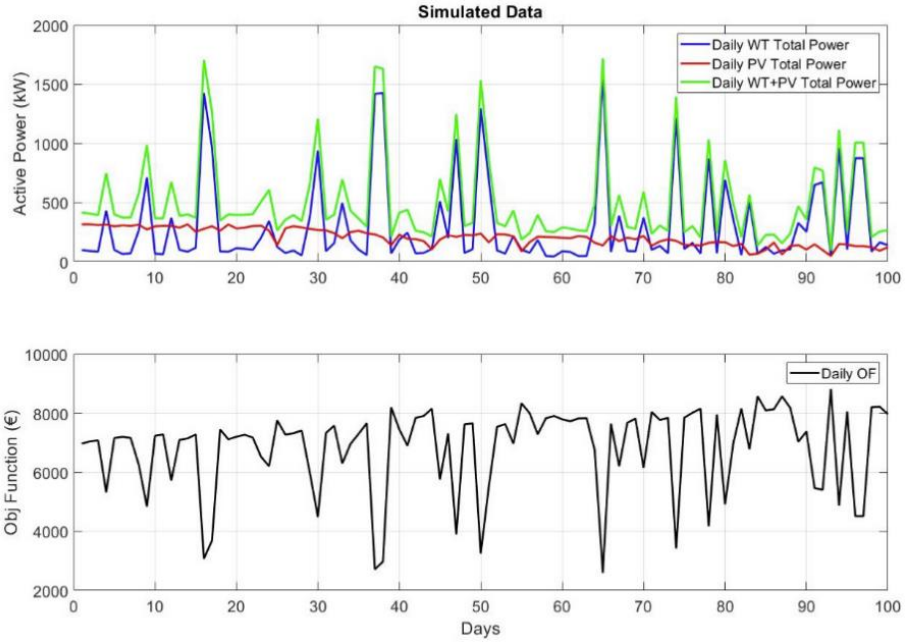
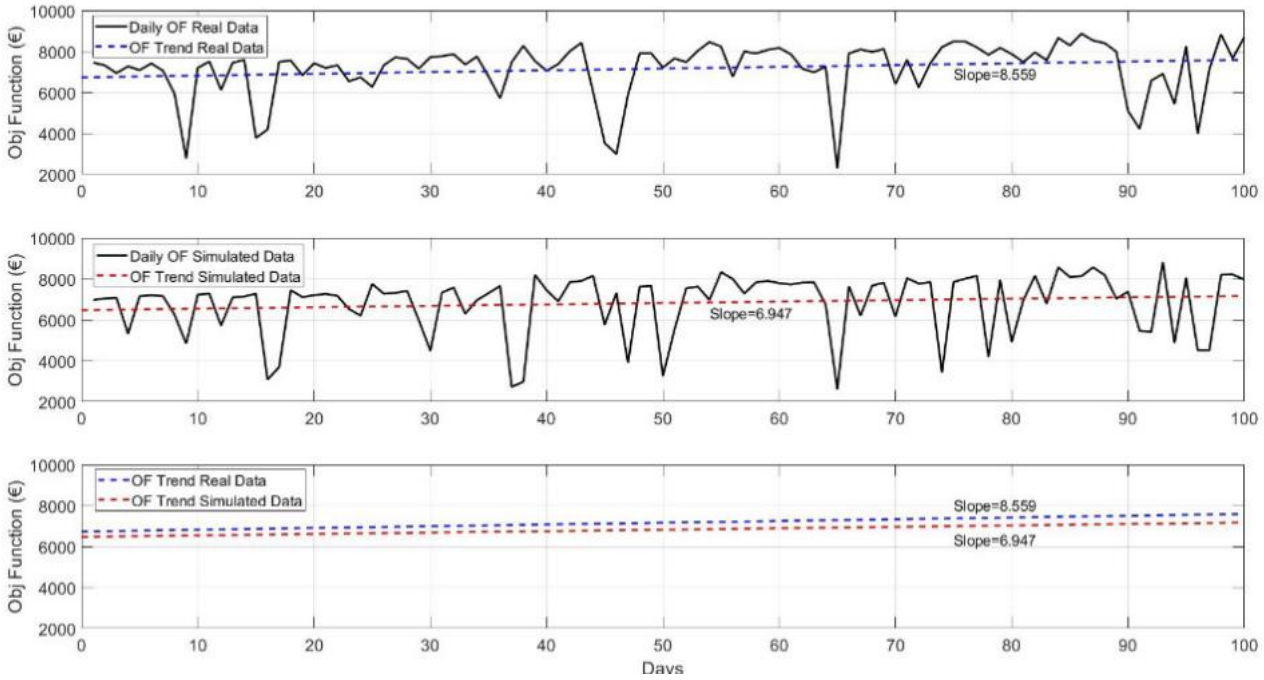
- 100-day real data sample



- 100-day simulated sample



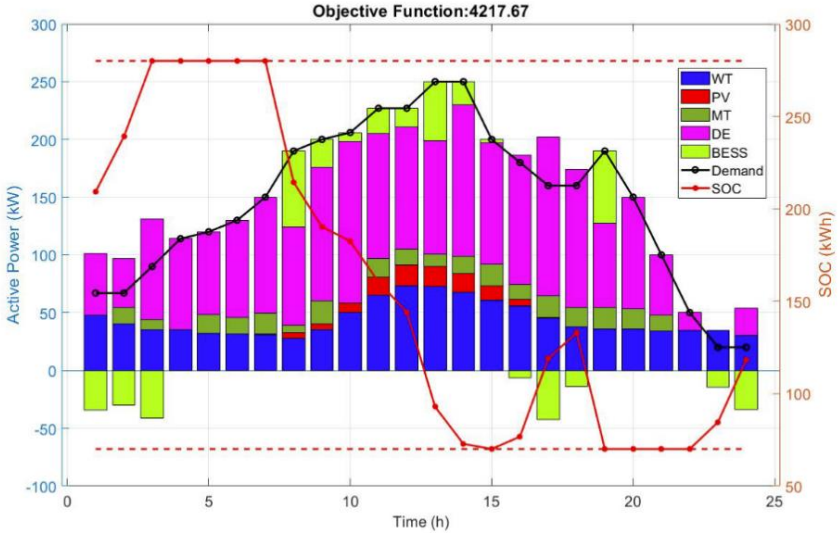
5. RESULTS (SCENARIO 1)



Objective function average of real data = € 7164,60

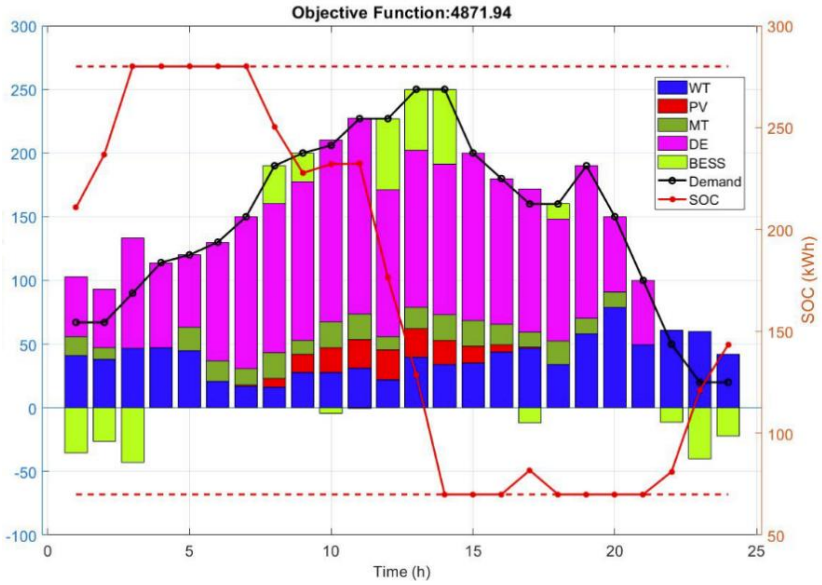
Objective function average of simulated data = € 6841,10

5. RESULTS (SCENARIO 1)



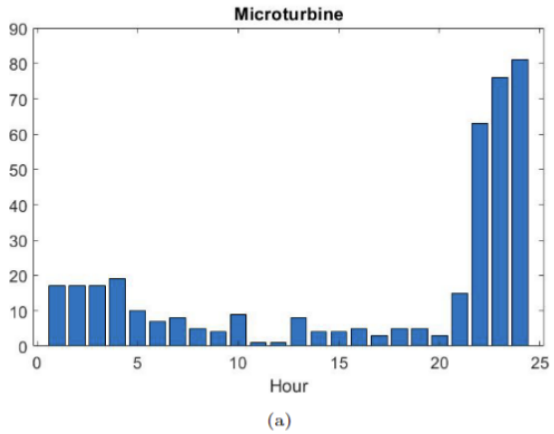
- Coverage curve of 1-day sample for real data

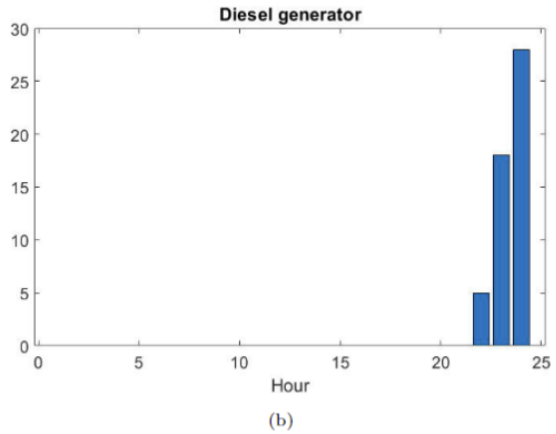
- Coverage curve of 1-day sample for simulated data



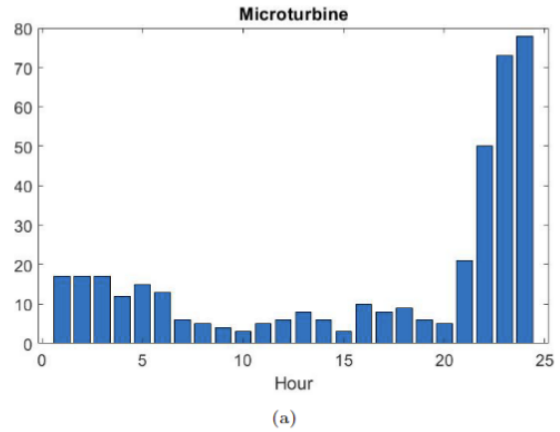
5. RESULTS (SCENARIO 1)

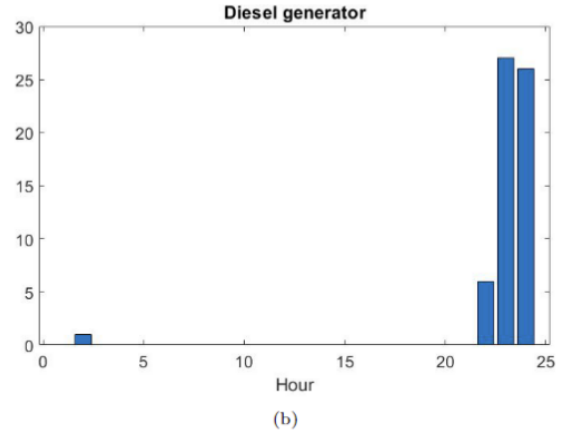
- Hourly off-status histograms of MT (a) and DE (b) for the real 100-day sample





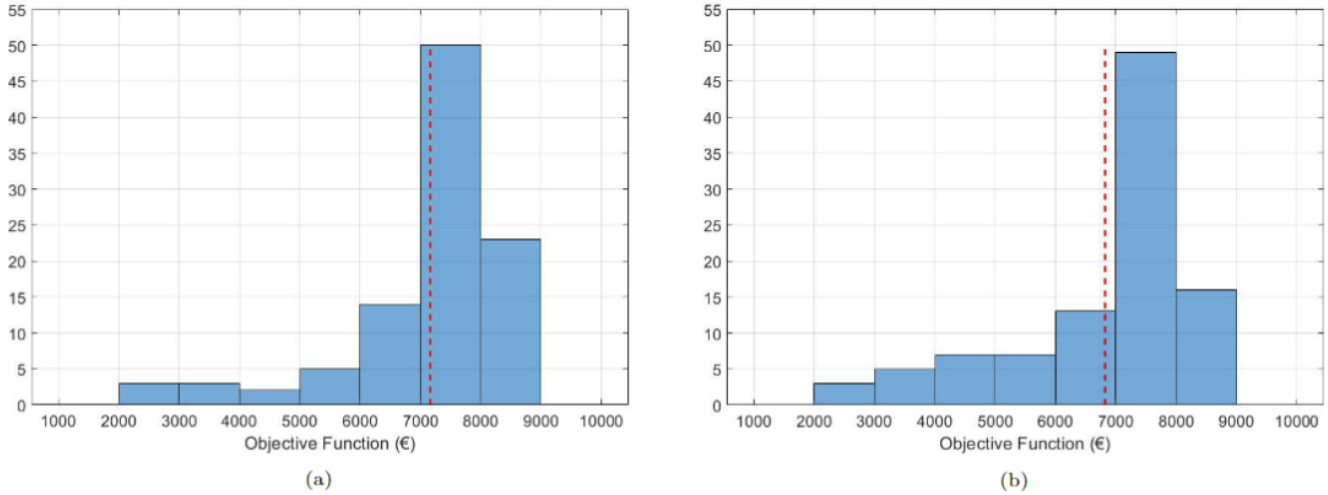
- Hourly off-status histograms of MT (a) and DE (b) for the simulated 100-day sample





5. RESULTS (SCENARIO 1 – COMPARISON STUDY*)

- Objective function histograms of real (a) and simulated data (b) with the indication of the mean value



- OF average = € 7164,60
- OF in Alvarado-Barrios et al. (2020) = € 3159,38

Scenario 2

- OF average = € 6779,60
- OF in Alvarado-Barrios et al. (2020) = € 2884,80

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5. CONCLUSIONS

- The stochastic models used in this work adequatly simulate the behaviour of the renewable energy sources (RESs)

- The homogeneous and non-homogeneous Markov processes are applied to model the uncertainty in a scheduling problem (SUC + ED) for the management of a hybrid and isolated microgrid

- This study highlights the importance of correctly considering and modeling the stochastic nature of RESs

- Further improvements of this study: modeling the renewable energy production with different stochastic models, testing different settings of the system, and changing the length of the time horizon and the time scale.

*This work is under review after «minor revision» for the journal Energy reports.

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5. CONCLUSIONS (SECOND STUDY)

- As extension of this first work, we led a second study

Optimal Management of Unbalanced Active Distribution Networks using Model Predictive Control in a Stochastic Environment

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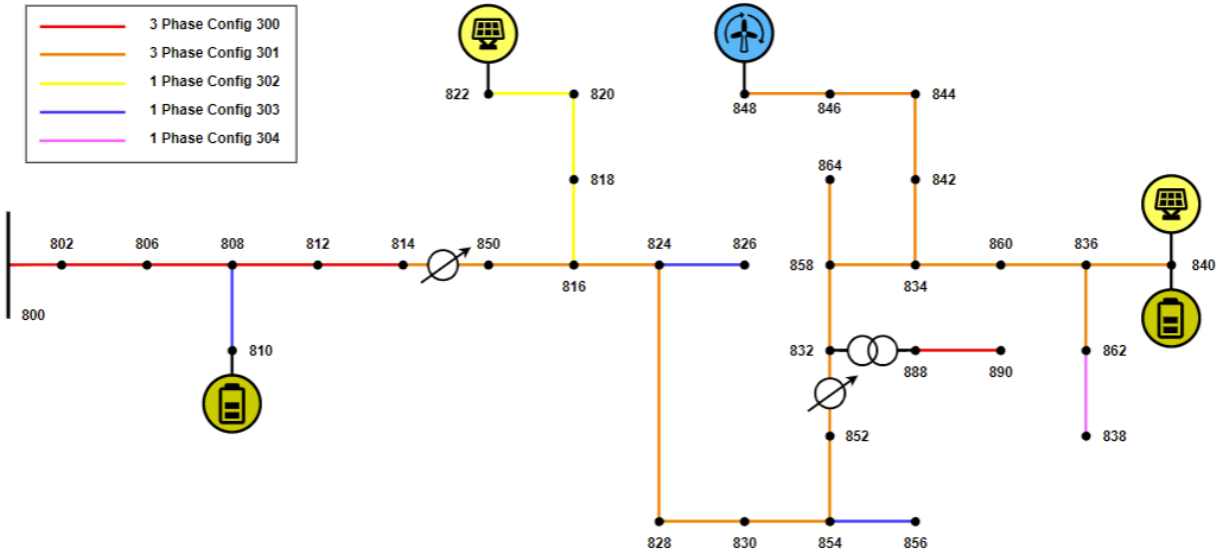

- A two-level optimization problem is implemented with the objective of minimizing the total active power losses of an active distribution system (ADS)
- 34-node grid

5. CONCLUSIONS (SECOND STUDY)

- A Model Predictive Control framework based on Markov reward process predictions (time horizon = 24 hours)
- The 24-hour predictions are generated at each time step (hour) considering the current wind and photovoltaic powers

Day	2^{nd} of August	3^{nd} of August	6^{nd} of August	7^{nd} of August
		Case 1		
Myopic Scenario	1.6172	1.4880	1.9222	1.6120
Ideal Scenario	-0.0348	-0.0409	-0.0448	-0.0538
MPC Scenario	-0.0380	-0.0475	-0.0353	-0.0282
		Case 2		
Myopic Scenario	1.5805	1.4606	1.8855	1.5903
Ideal Scenario	-0.0374	-0.0421	-0.0424	-0.0514
MPC Scenario	-0.0241	-0.0358	-0.0418	-0.0344
		Case 3		
Myopic Scenario	1.5719	1.4584	1.8805	1.5848
Ideal Scenario	-0.0555	-0.0809	-0.0798	-0.0811
MPC Scenario	-0.0368	-0.0689	-0.0899	-0.0715

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THANK YOU FOR YOUR TIME!