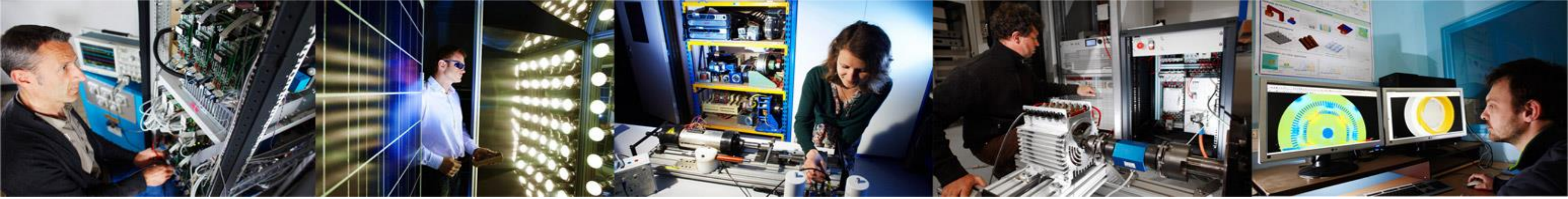

Réunion du Groupe de travail sur les microréseaux

Tuesday, November 15, 2016

Operating Reserve Quantification Considering System Uncertainties and Day-ahead Optimal Dispatching of a Microgrid with Active PV Generators

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Contents

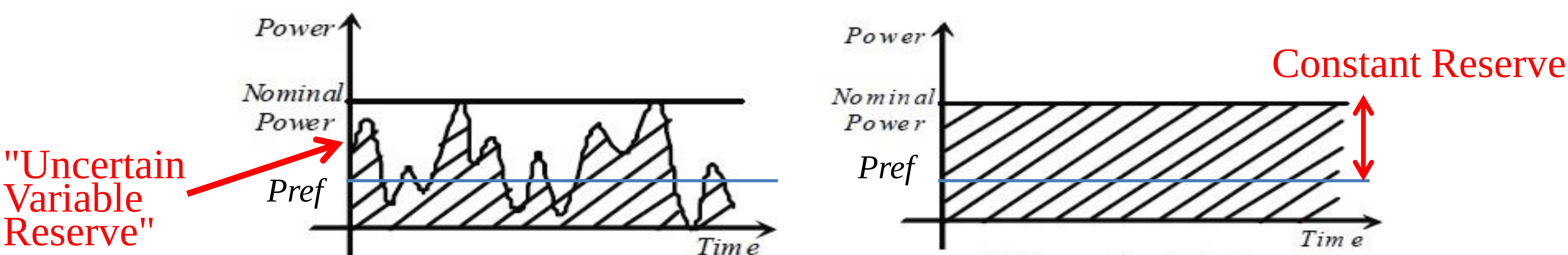
I.1 Problem: Uncertainty and Power Reserve

Uncertainty: Intermittent renewable energy sources (RES) power is difficult to predict.

To cover the risk: Additional Operating Reserve (OR) is needed.

Massive RES increases the uncertainty in power system and OR is mandatory to **maintain the system security level**.

- Today the consumption/production balancing and OR provision are performed by conventional generators.



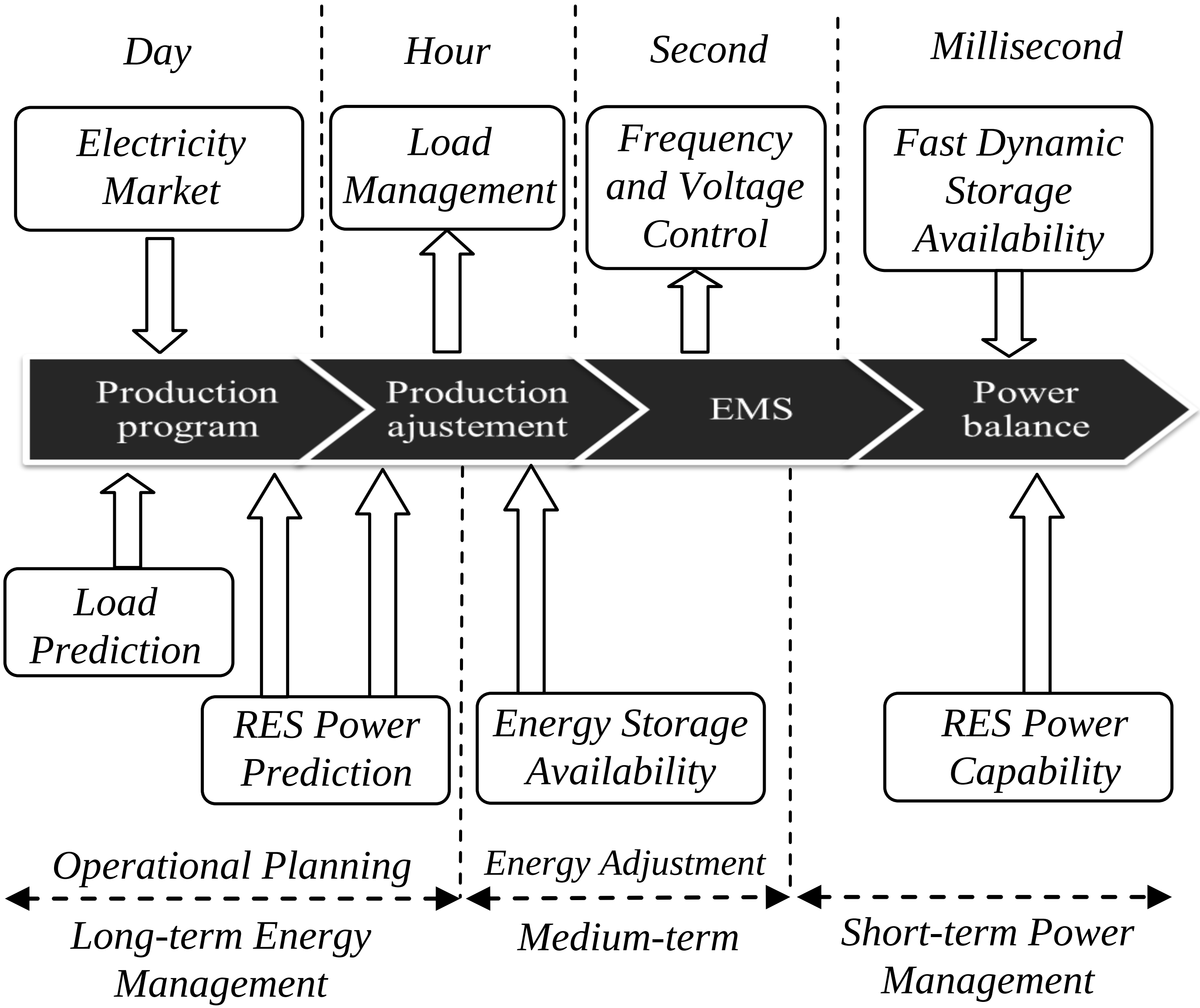
(a) No dispatchable renewable energy source (b) Conventional plant

Pref is given by the system operators (power dispatch)

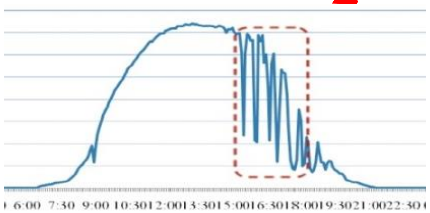
- **Problem:** how to precisely quantify the OR and locate it into the generators, without losing the system security level.

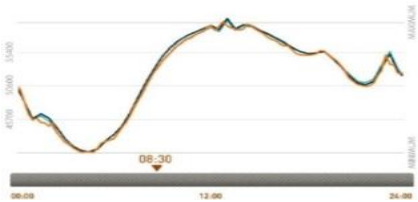
I.2 General Organization of Energy Management System (EMS)

- Microgrid supervision can be analyzed and classified in different timing scales and functions.



I.3 Objectives and Methods





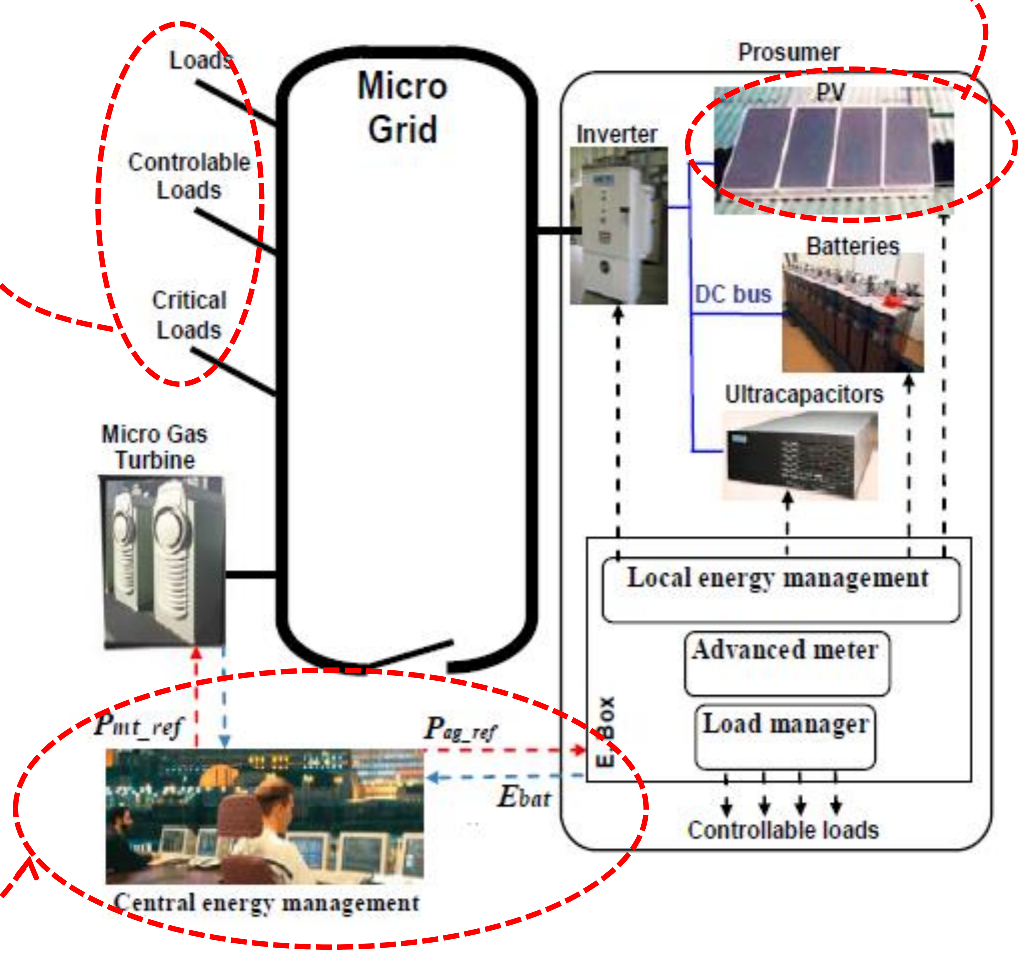
Predictive Analysis for Uncertainty: PV power and load forecasting

Operating Reserve Quantification: Loss of load probability (LOLP)

OR Dispatching Strategies on Generators

Day-ahead Optimization Planning: Unit commitment problem with dynamic programming

A User-friendly EMS and Operational Planning Supervisor



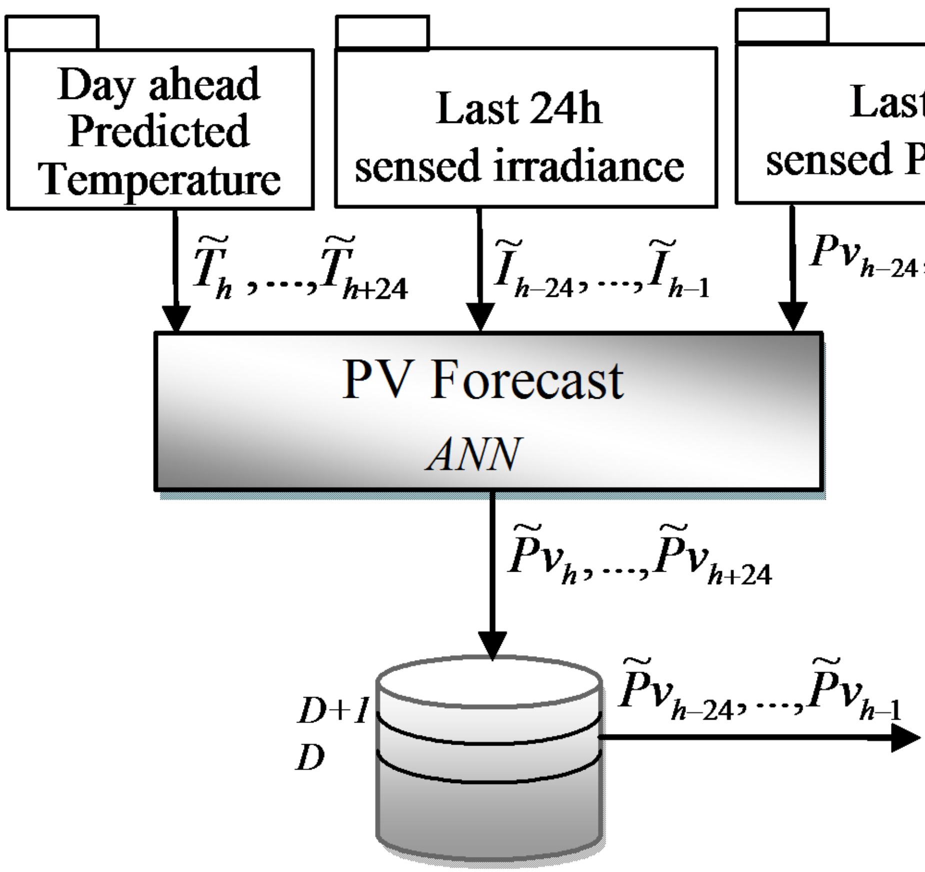
Microgrid with PV Active Generator (AG)

PV Active Generator (**PV AG**): PV panels combined with a storage system to provide ancillary services.

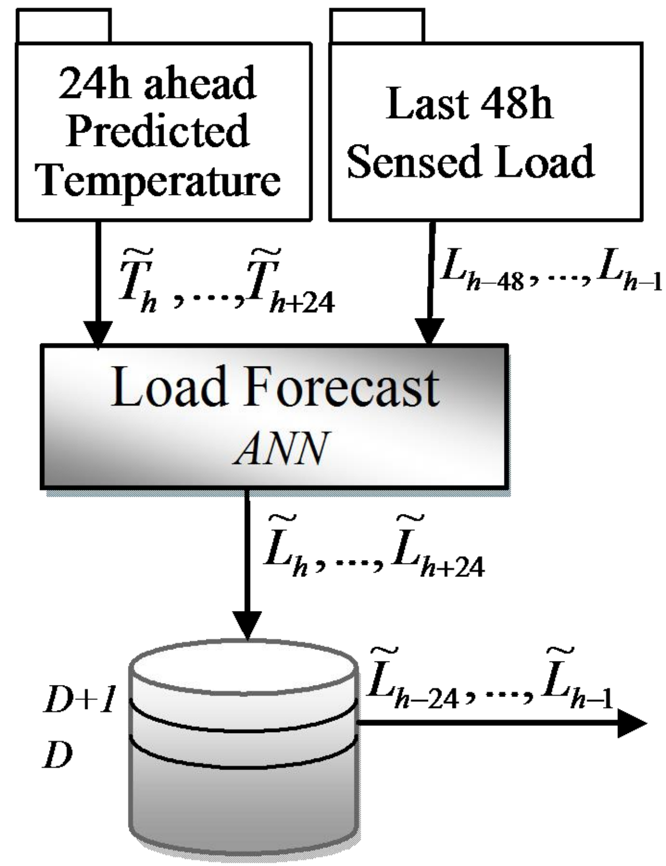
II.1 Data Predictive Analysis and Forecasting

- Data management: Collect, Mining, and Predictive Analysis
- PV Power and Load Forecasting with ANN

PV power forecasting With Artificial Neural Networks (ANN)

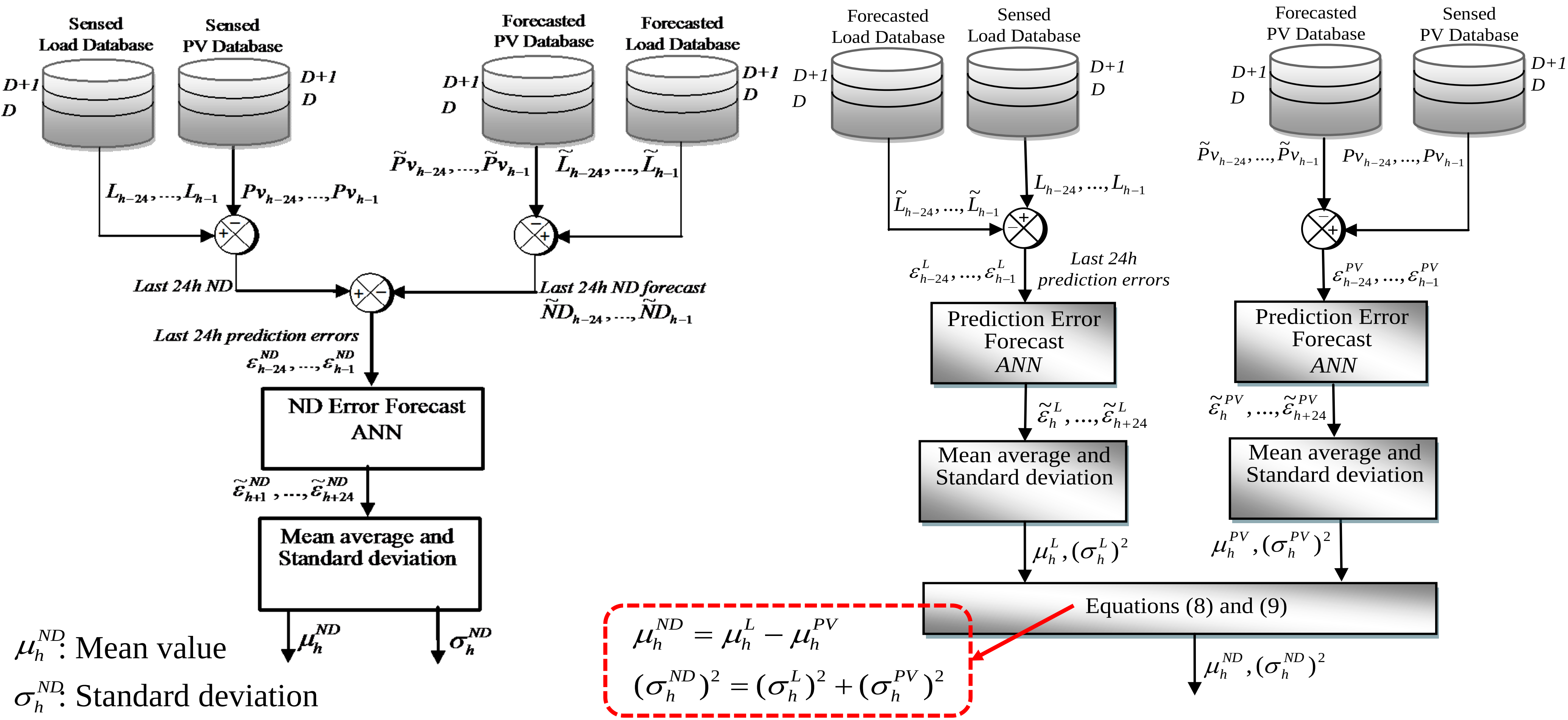


Load forecasting with ANN



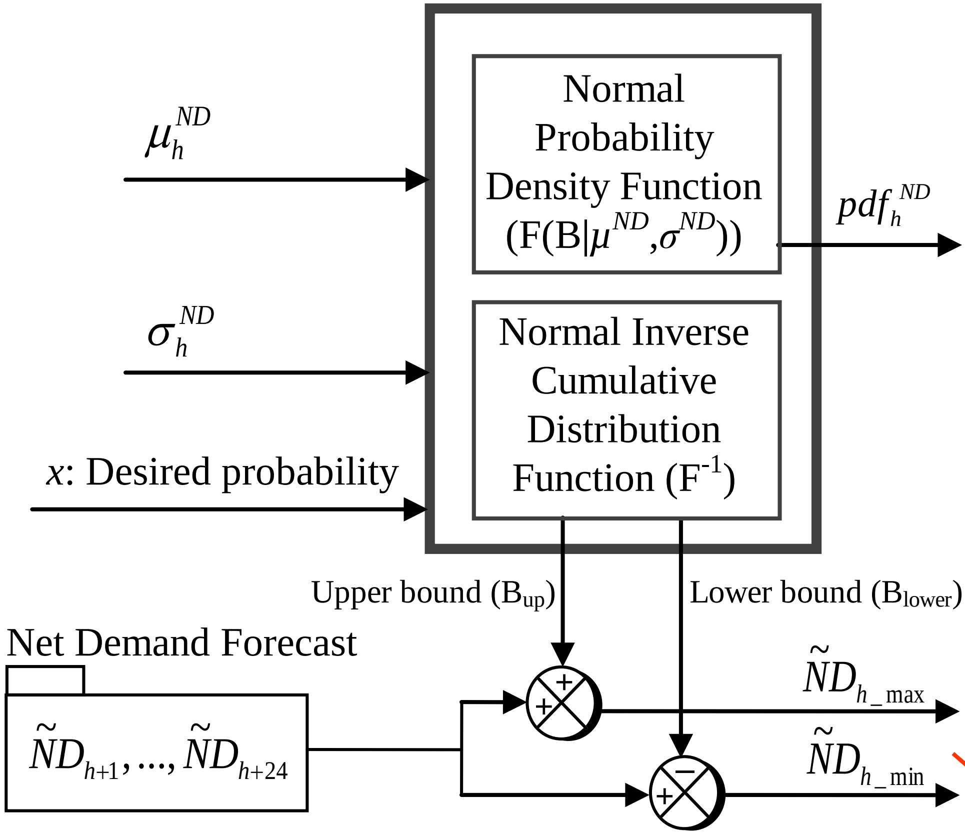
II.2 Net Demand (ND) Uncertainty Analysis

- The real ND is composed of the forecasted ND and an error: $ND_h = \widetilde{ND}_h + \varepsilon_h^{ND}$ (ND forecasting errors)
- First Method: Day-ahead Net Demand Errors Forecast;
- Second Method: Calculation from the PV Power and the Load Forecast Errors Estimation.



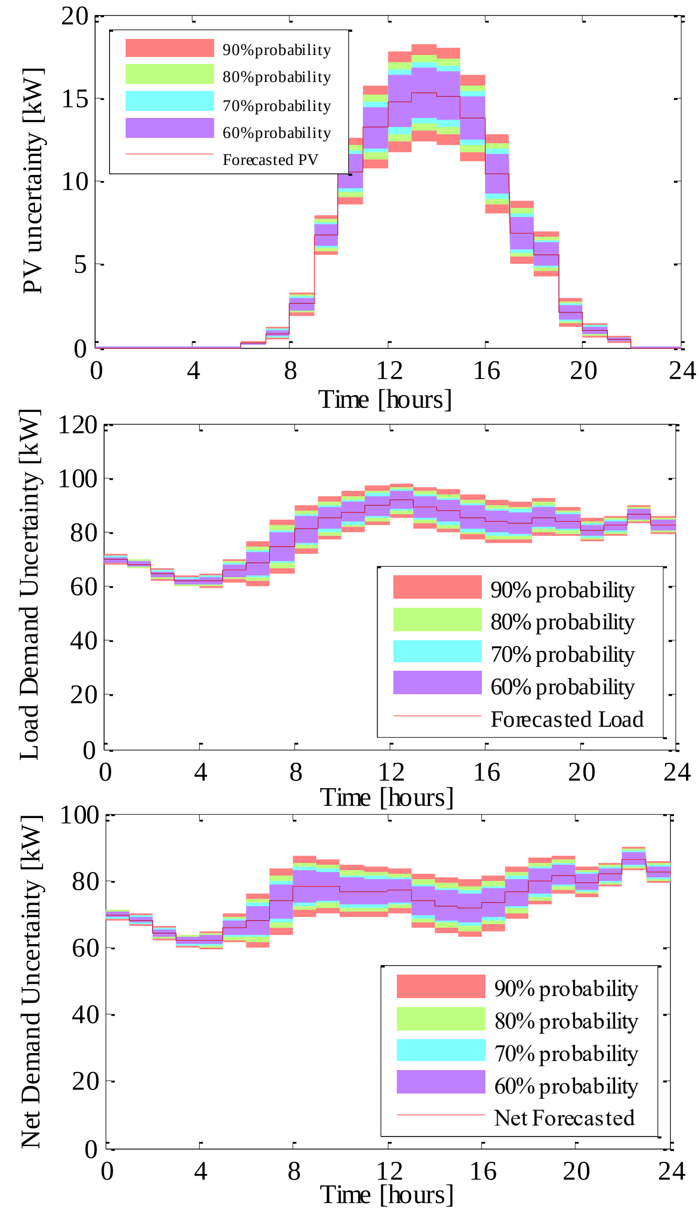
II.3 Uncertainty Assessment and Power Reserve Quantification

- ND uncertainty assessment for each ½ hour



$$B = F^{-1}(x|\mu_h^{ND}, \sigma_h^{ND}) = \{B : F(B|\mu_h^{ND}, \sigma_h^{ND}) = x\}$$

$$x = F(B|\mu_h^{ND}, \sigma_h^{ND}) = \frac{1}{\sigma_h^{ND}\sqrt{2\pi}} \int_{-\infty}^{B} e^{\frac{-(\tau-\mu_h^{ND})^2}{2(\sigma_h^{ND})^2}} d\tau$$

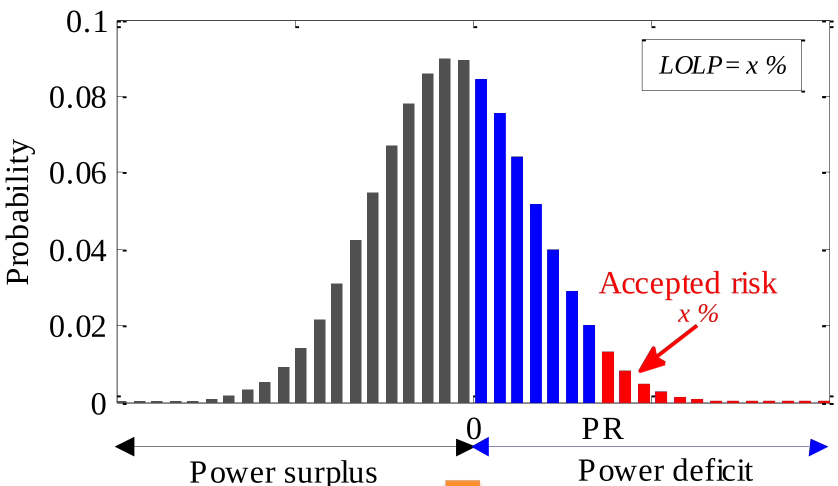


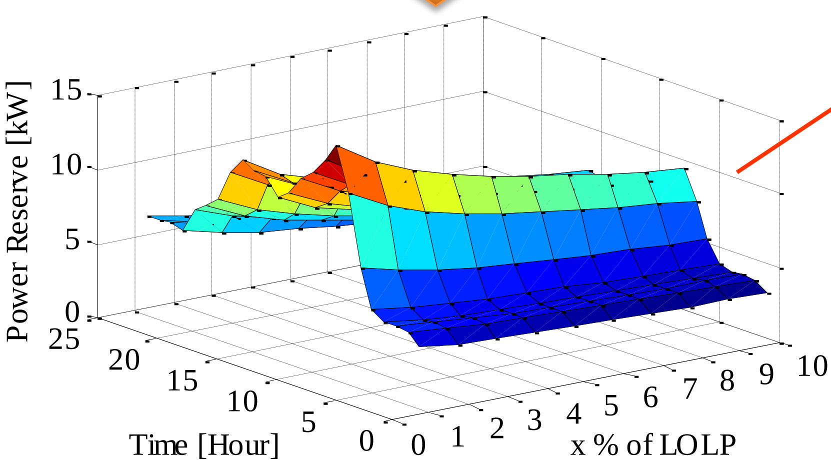
II.4 Operating Power Reserve Quantification

❑ Power reserve quantification

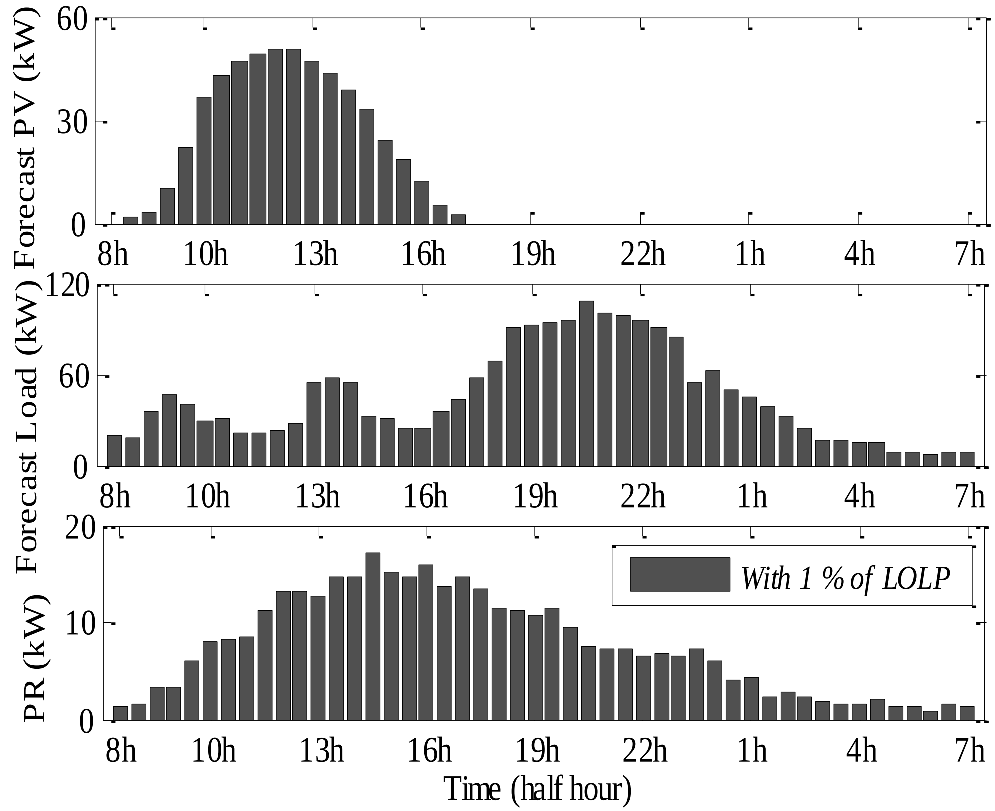
LOLP represents the probability that load exceeds PV power.

$$LOLP_h = prob(L_h - P_h > 0) = \int_{PR}^{+\infty} pdf(\tau)\,\mathrm{d}\tau$$





❑ Day-ahead forecasted PV, load and power reserve

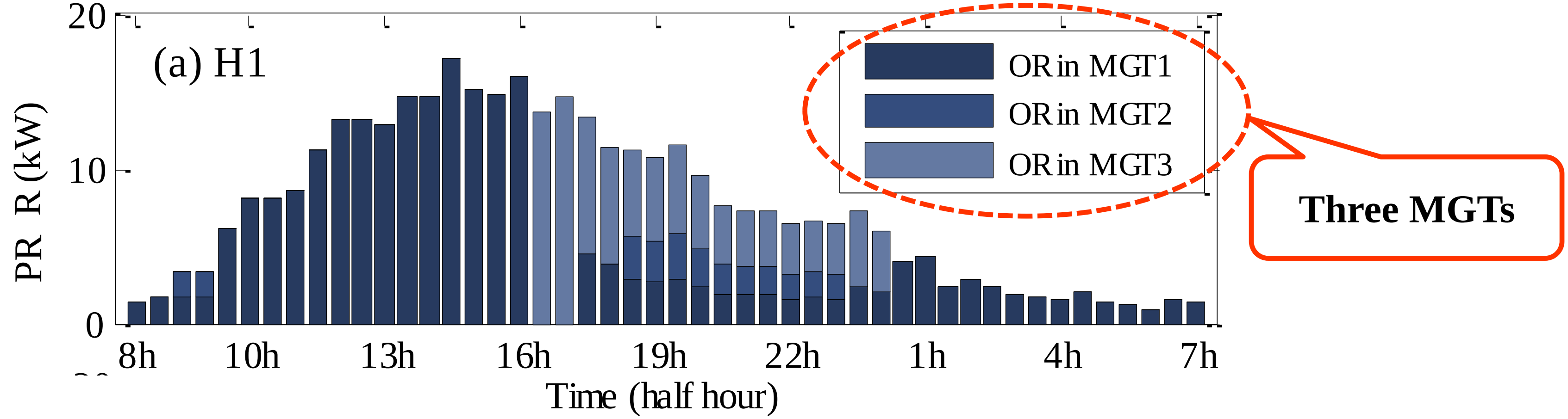


❑ Targets

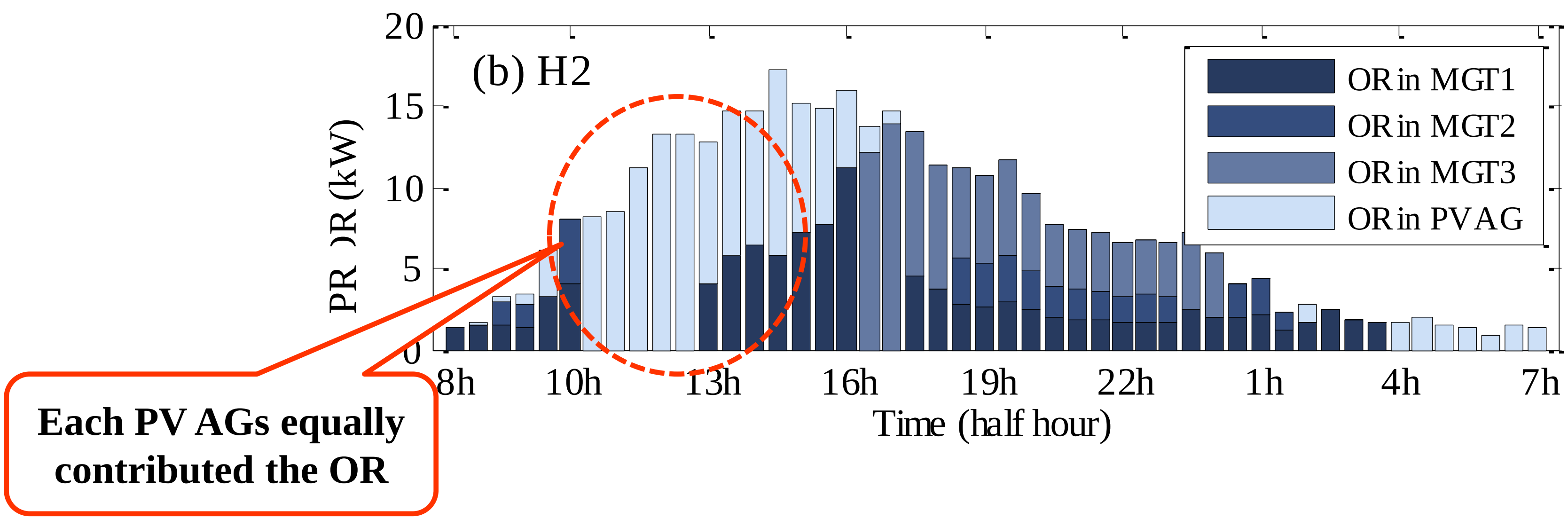
✔ Day-ahead dynamic power reserve quantification.

III. Strategies: OR Provision by MGT and PV AG

- Strategy 1: OR on three **MGTs only**

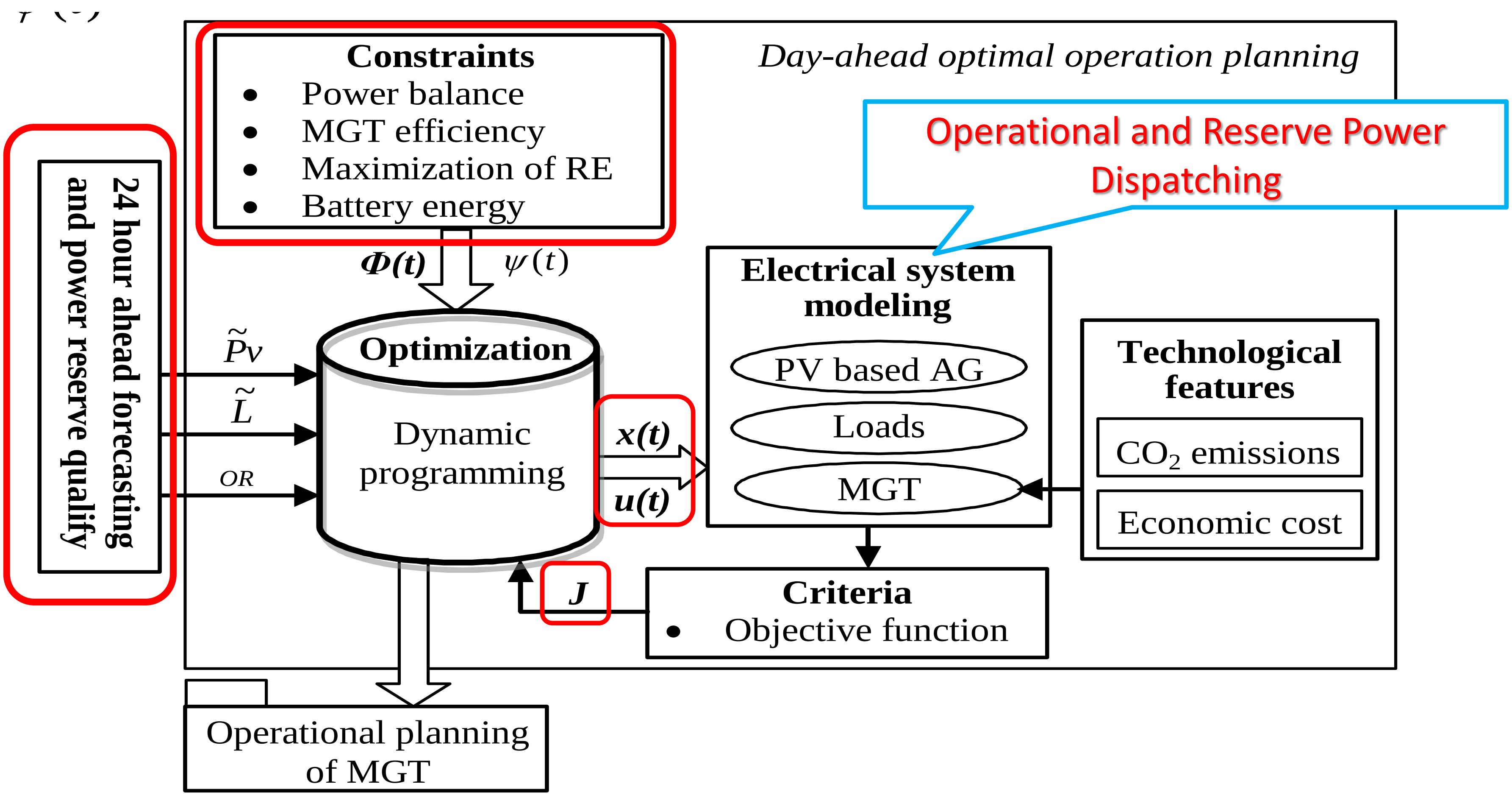


- Strategy 2: OR on three MGTs **and thirteen PV AGs**



More details can be found here: *X. Yan, D. Abbes, B. Francois, and Hassan Bevrani "Day-ahead Optimal Operational and Reserve Power Dispatching in a PV-based Urban Microgrid," EPE 2016, ECCE Europe, Karlsruhe/ Germany.*

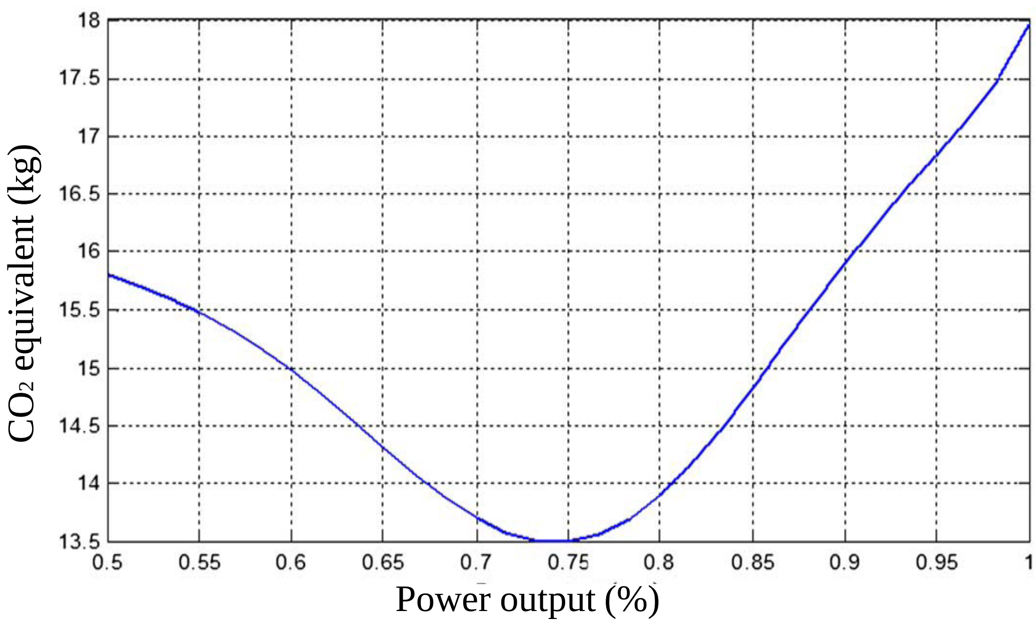
IV.1 Scheme of Day-ahead Optimal Power Reserve Planning

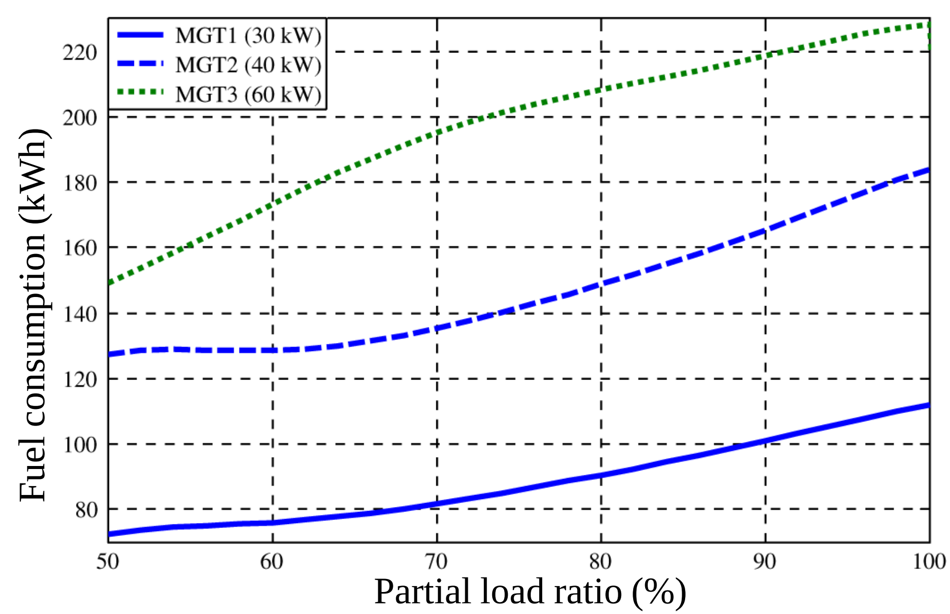


- Focus on the design of the MCEMS under particular constraints.
- Uint commitment problem (UCP) with dynamic programming (DP) is developed in order to reduce the economic cost and CO_2 equivalent emissions.

IV.2 Non-linear Constraints

- Security: Reserve power assessment with *x* % of LOLP;
- Power balancing: $\psi(t) = P_L(t) + P_{res}(t) - \sum_{n=1}^{N} P_{AG\_n}(t) - \sum_{i=1}^{M} (\delta_i(t) \bullet P_{MGT\_i}(t)) = 0$
- Maximization of renewable energy usage: considering the battery capacity limitation (more PV power, larger battery storage !)
- MGT corresponding inequality constraint: $50\% P_{M\_\max\_i}(t) \le P_{M\_i}(t) \le 100\% P_{M\_\max\_i}(t)$



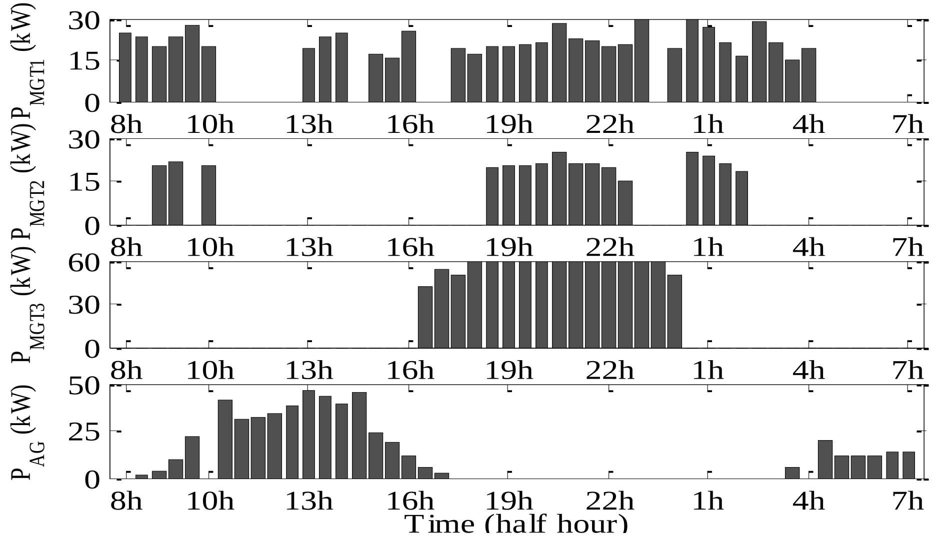


IV.3 Unit Commitment Problem (UCP) with Dynamic Programming

- UCP: Optimal Operational of a cluster of MGTs (since the PV power is prior source)

$$x(\mathrm{t}) = \left[P_{MGT\_1}(t), P_{MGT\_2}(t), \ldots, P_{MGT\_i}(t)\right]$$

$$u(\mathrm{t}) = \left[\delta_1(t), \delta_2(t), \ldots, \delta_i(t)\right]$$

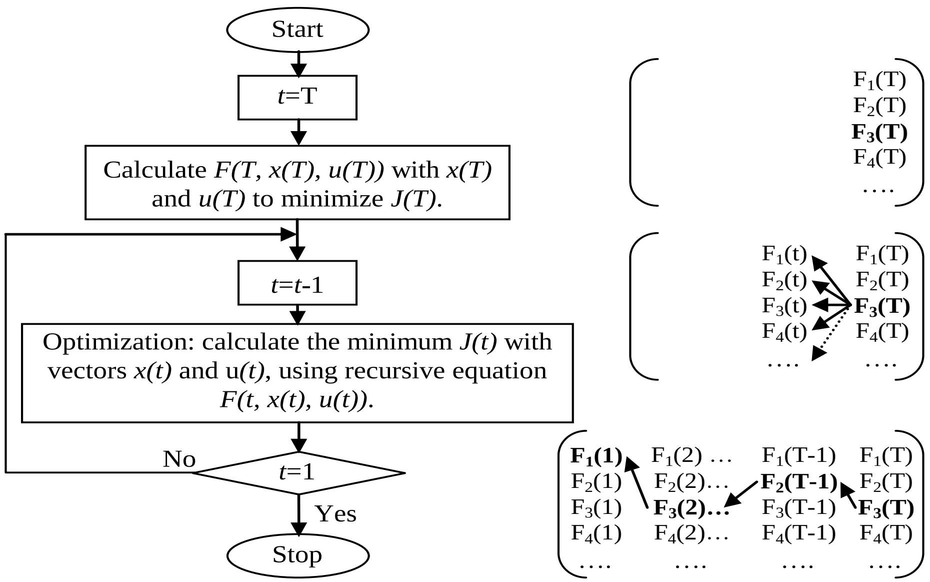


- Optimization Objectives:

1. Economic criteria: minimize total fuel cost;
2. Environmental criteria: minimize CO_2 emission;
3. Best compromise criteria: make a compromise.

- Dynamic Programming (DP)

Systematically evaluates a large number of possible decision in a multi-step problem considering the "transition costs".



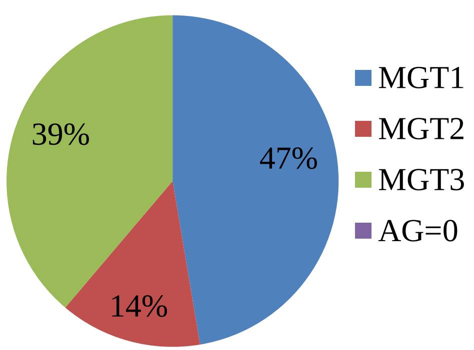
IV.4 Case Study and Simulation Results (1)

In this case: rated load (110 kW), rated PV power (55 kW) and the OR (with 1 % of LOLP) coming from the net demand uncertainty assessment.

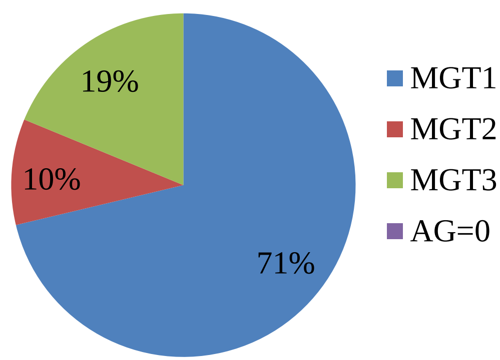
Scenario	Optimized criteria	Cost (€)	Pollution (kg)	OR on AG (%)	$E_{battery—Max}$ (kWh)
Without PV Power	None	219	1392	0	0
	Environmental	212	1196	0	0
	Economic	210	1263	0	0
Strategy 1:	None	183	1156	0	80.2
	Environmental	181	1067	0	80.2
	Economic	178	1120	0	80.2
Strategy 2:	None	182	1098	**40**	**54.1**
	Environmental	179	991	**40**	**54.1**
	Economic	177	1061	**40**	**54.1**

- Power reserve dispatching, one day ahead

Without PV power

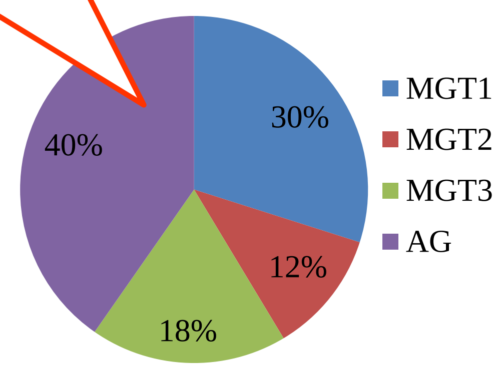


Strategy 1



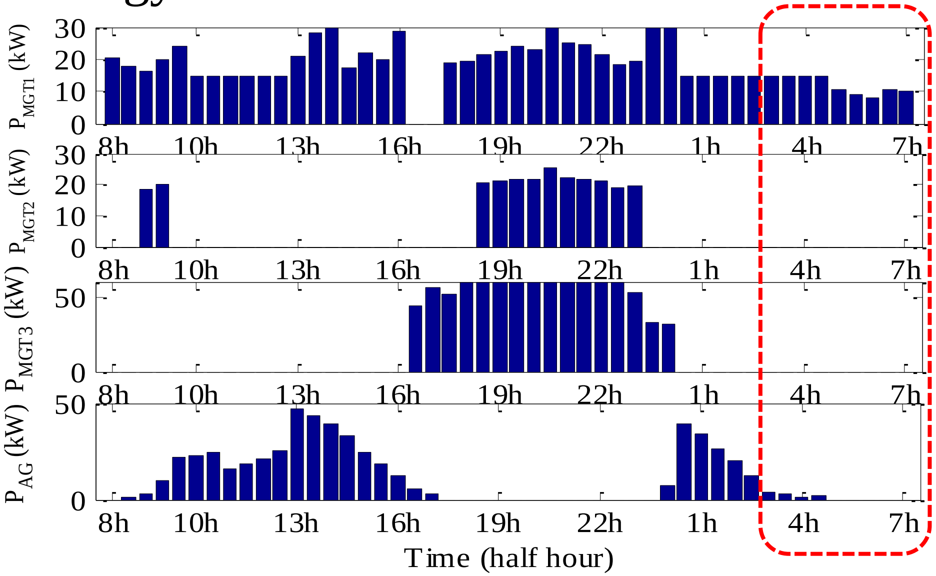
40% of OR is on PV AG !

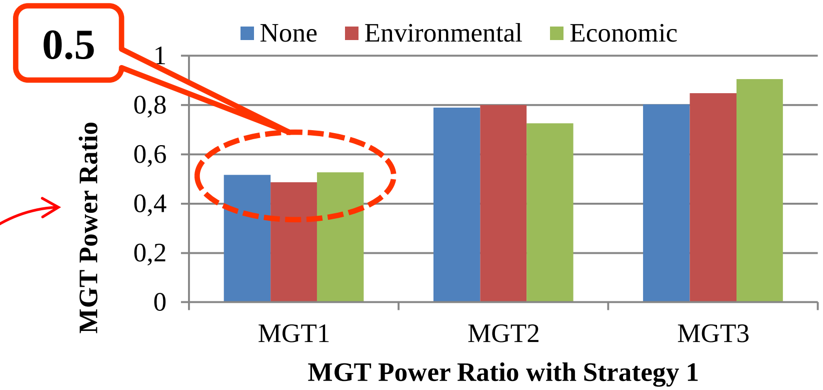
Strategy 2

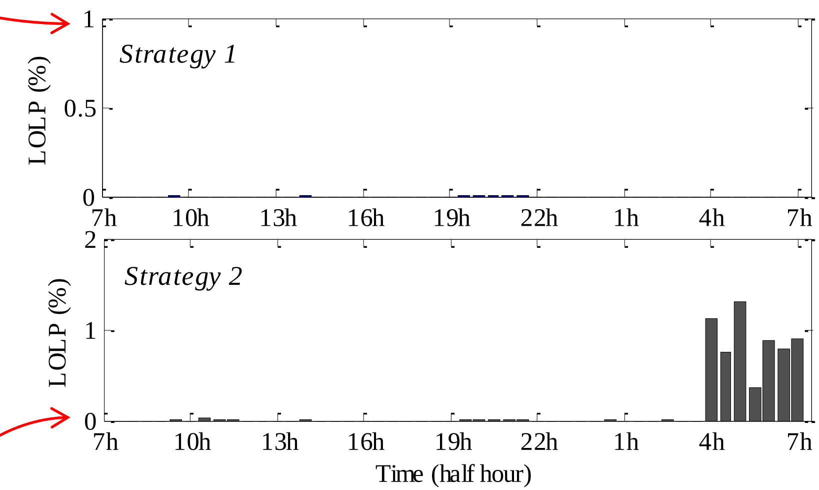


IV.4 Results (2): MGTs Load Ratio and System Security

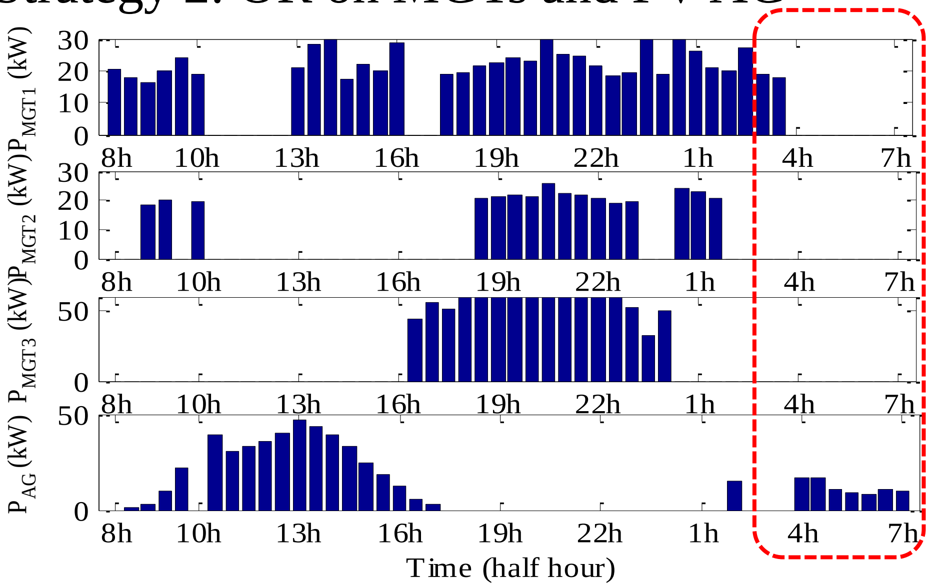
Strategy 1: OR on MGTs

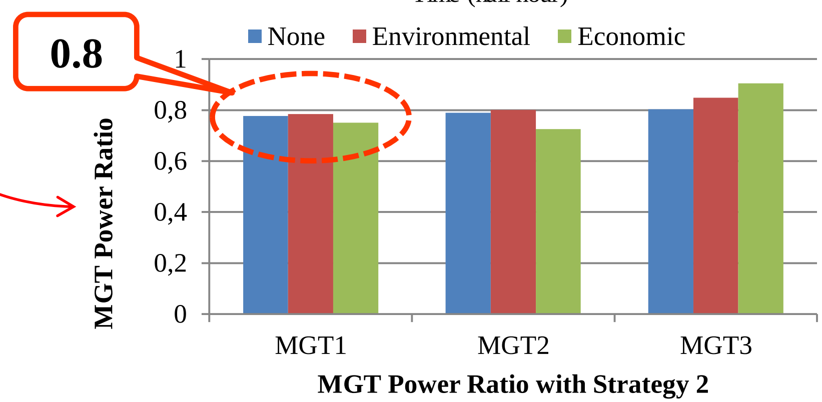






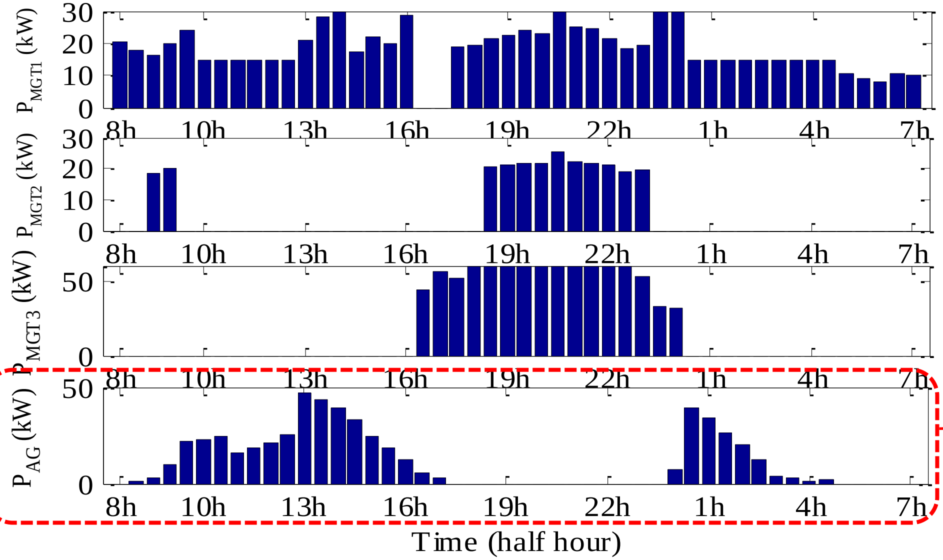
Strategy 2: OR on MGTs and PV AG

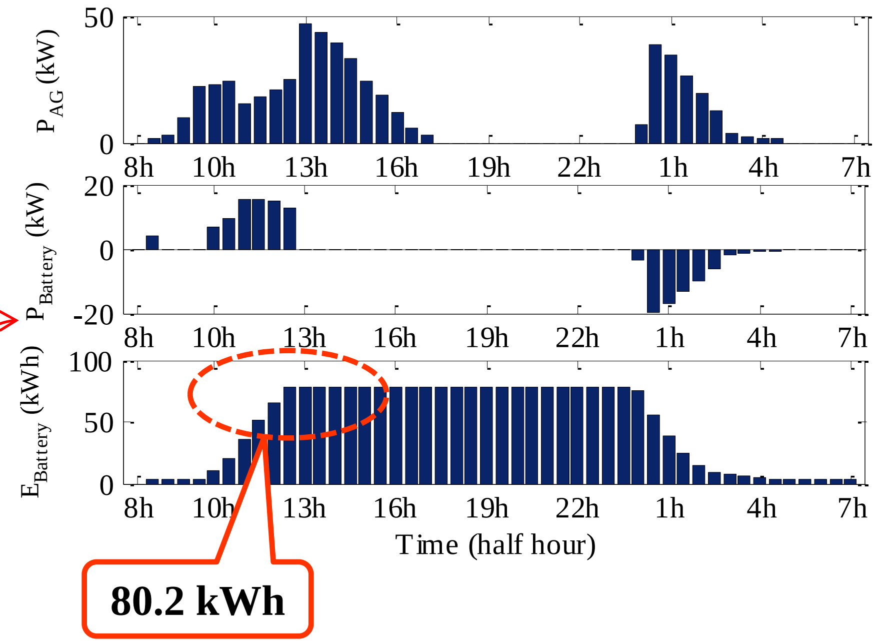




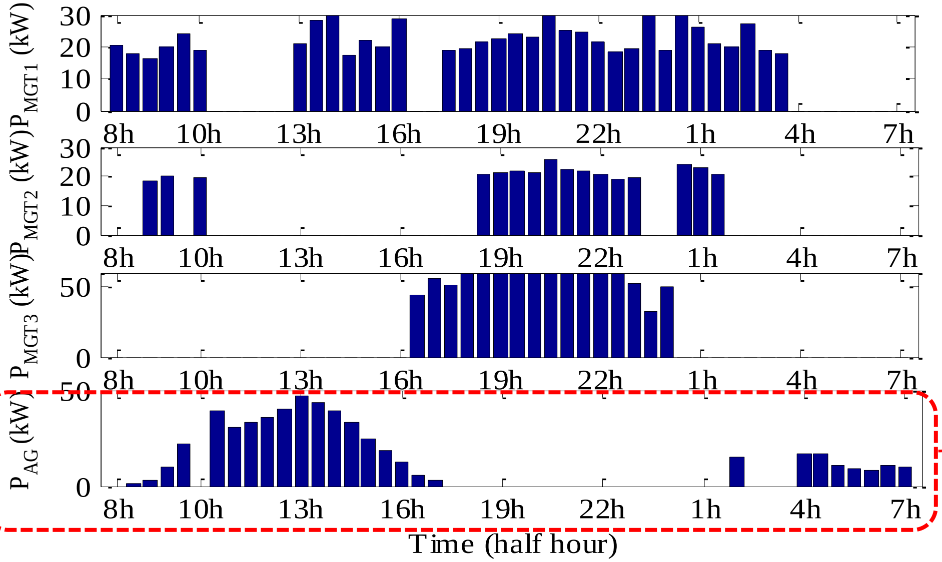
IV.4 Results (3): Battery State of Charge

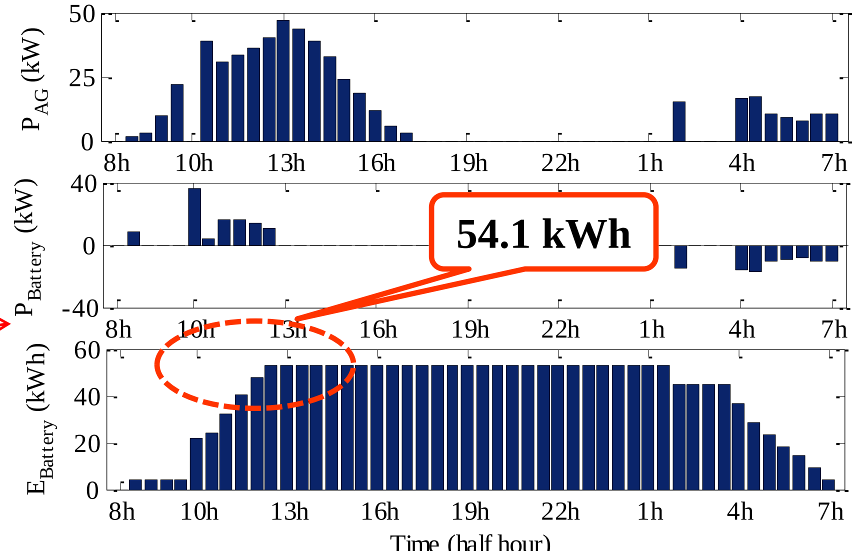
❑ Strategy 1: OR on MGTs





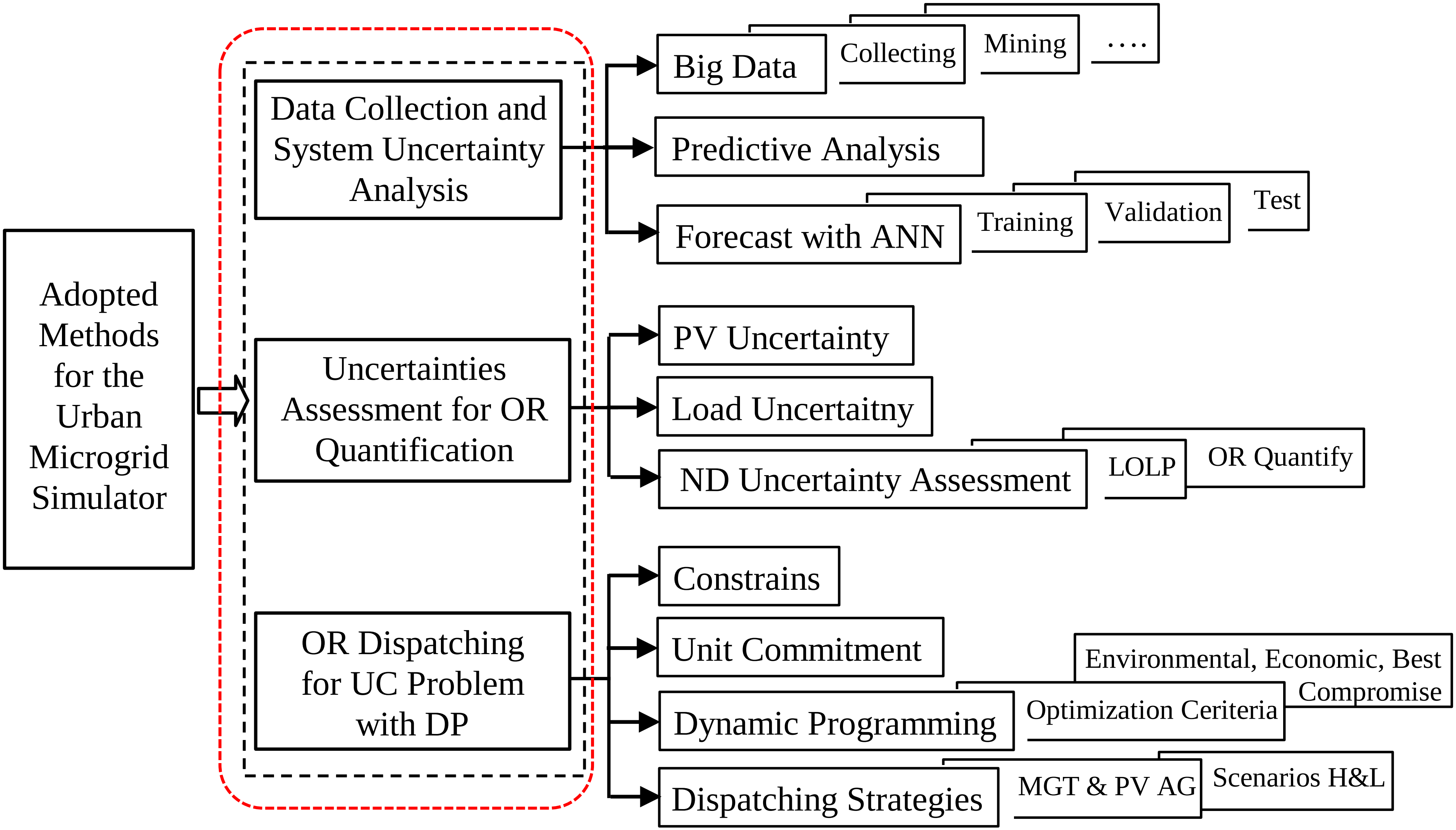
❑ Strategy 2: OR on MGTs and PV AG





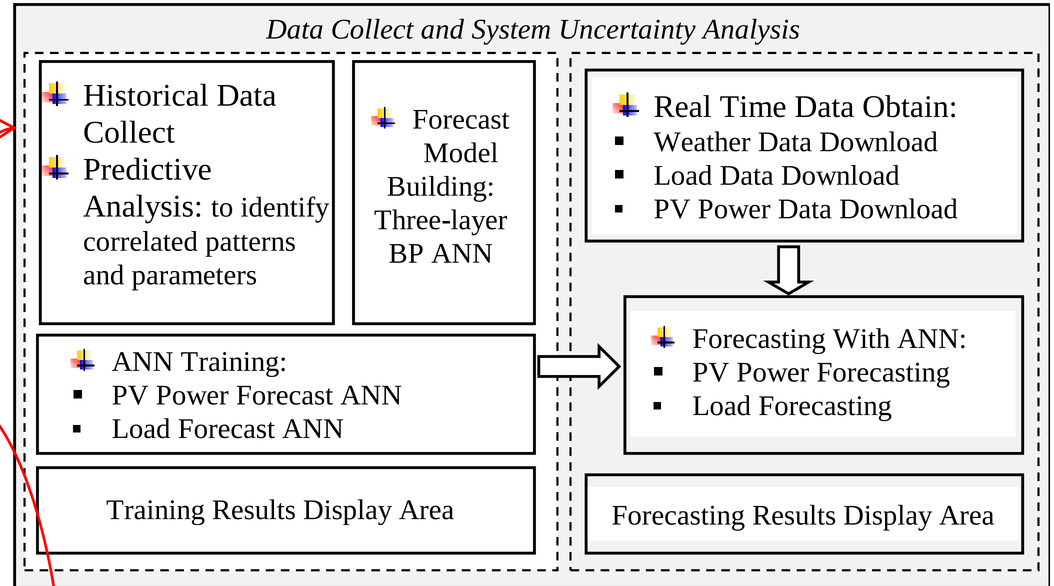
V.1 General Framework

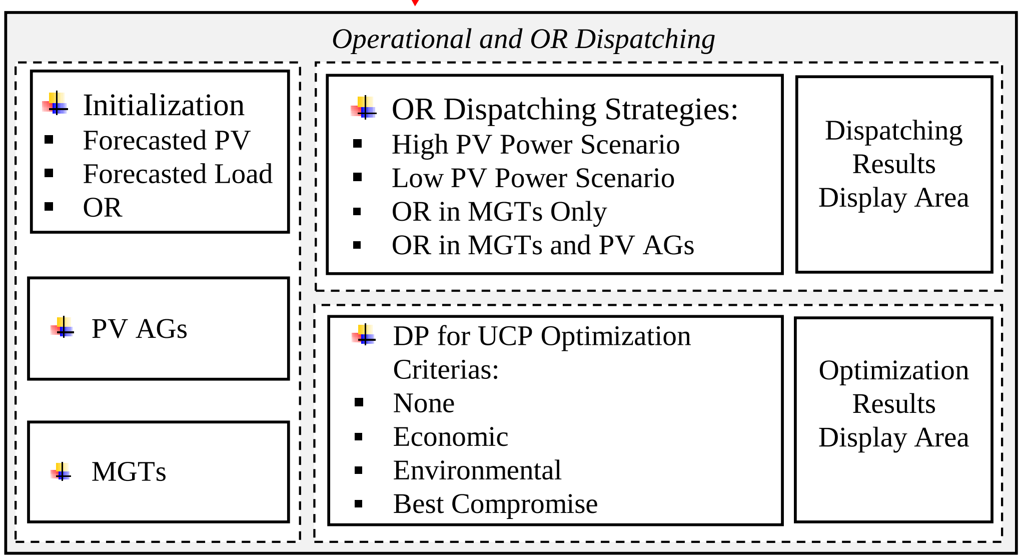
- **Objective:** to conceptualize the overall system operation and to provide a complete set of user-friendly GUI to properly model and study the details of PV AG, load demand, and MGTs.

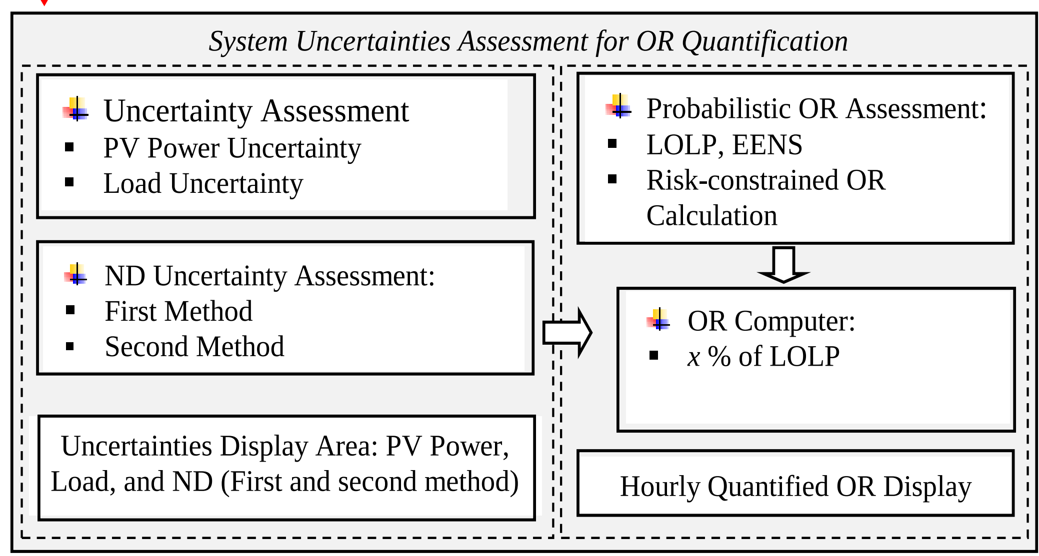


V.2 Microgrid Simulator Frame Design

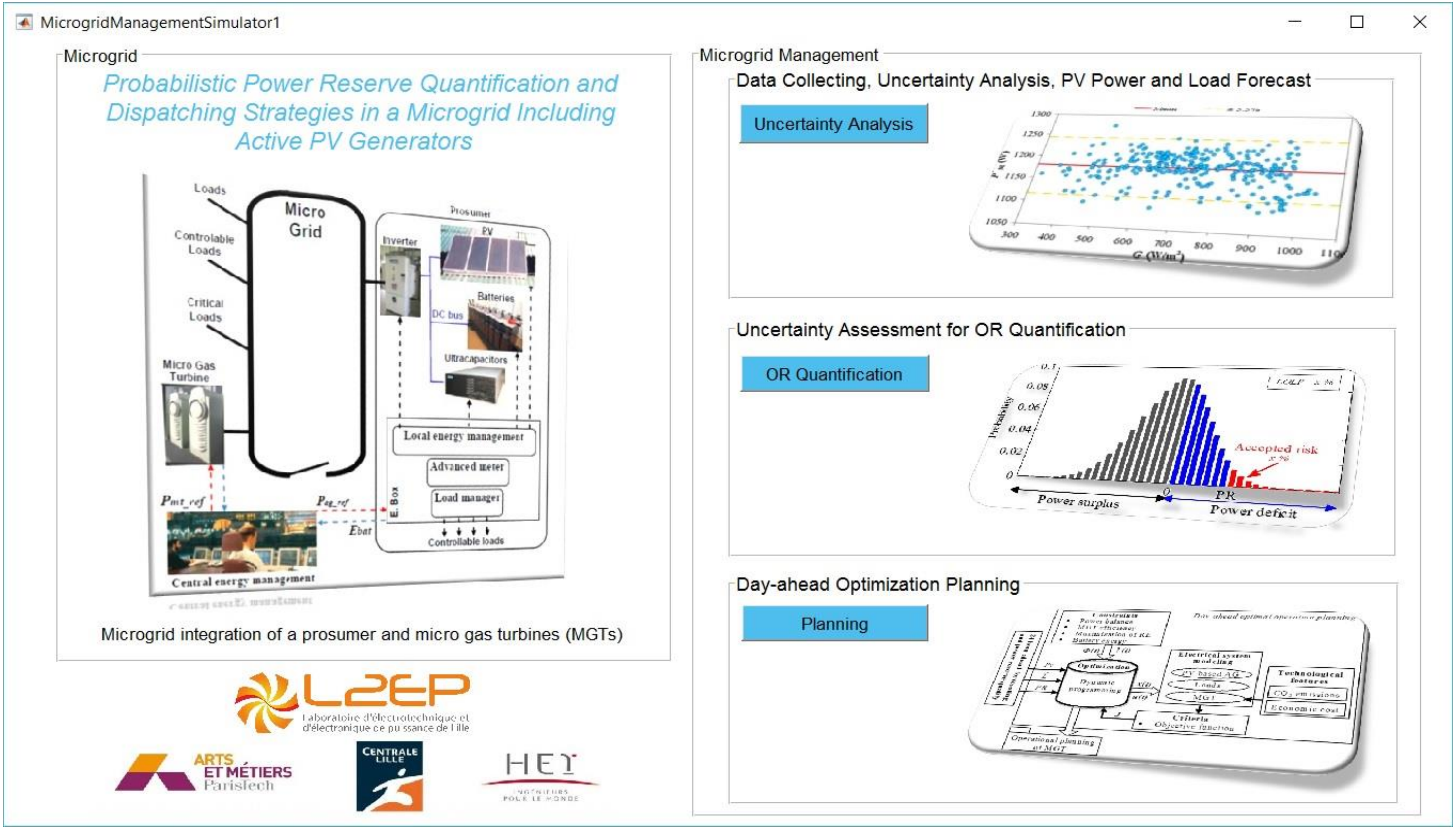
Main Interfaces	Individual Modules
Data Collect and System Uncertainty Analysis	• Historical Data Collect for ANN Training • Day-ahead Data Download: Weather Information, Load, and PV Power Data • PV Power and Load Demand Forecast by Using Well Trained ANN
System Uncertainties Assessment and OR Power Quantification	• PV Power Uncertainty • Load Demand Uncertainty • Net Demand Uncertainty • OR Quantification
Operational and OR Dispatching	• Dispatching Strategies • PV AGs and MGTs Power References







❑ Demonstration

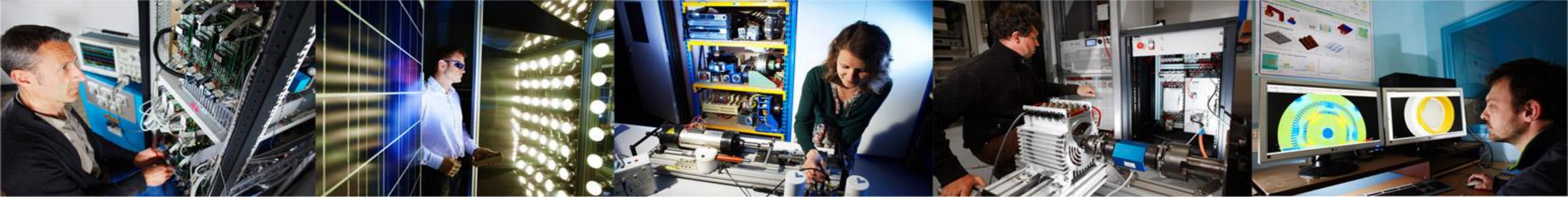


❑ Conclusions

- ❑ PV power variability and load demand variability are analyzed.
- ❑ The ANN algorisms are developed for the PV power and the load forecast.
- ❑ A probabilistic method for the OR calculation based on two different kind of ND forecasted uncertainty assessment methods is proposed.
- ❑ The dynamic joint operational and OR dispatching strategies are developed.
- ❑ Day-ahead optimal operational and OR planning with DP is proposed by considering different constraints and different optimization strategies.
- ❑ **A User-friendly EMS and Operational Planning Supervisor** is developed.

❑ Prospects

- ❑ "Big data" for distributed RES uncertainty analysis and a better forecasting results
- ❑ Optimization method to improve the battery efficiency
- ❑ Build a global EMS to incorporate the predicted uncertainty ranges into the scheduling, load following, and into the regulation processes.



Related Publications

1. X. Yan, B. Francois, and D. Abbes, ”Solar radiation forecasting using artificial neural network for local power reserve,” in Electrical Sciences and Technologies in Maghreb (CISTEM), 2014 International Conference, pp. 1-6.
2. X. Yan, B. Francois, and D. Abbes, “Operating power reserve quantification through PV generation uncertainty analysis of a microgrid,” in PowerTech, 2015 IEEE Eindhoven, 2015, pp. 1-6.
3. X. Yan, D. Abbes, B. Francois, and Hassan Bevrani “Day-ahead Optimal Operational and Reserve Power Dispatching in a PV-based Urban Microgrid,” EPE 2016, ECCE Europe, Karlsruhe/ Germany.
4. X. Yan, B. Francois, and D. Abbes, “Uncertainty Analysis for Power Reserve Quantification in an Urban Microgrid Including PV Generators”, **Elsevier, Renewable Energy, under review.**
5. X. Yan, B. Francois, and D. Abbes, “Operating Reserve Quantification and Day-ahead Optimal Dispatching of a Microgrid with Active PV Generators,” **IET, under review**.

Thank you for your attention !

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