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MAESHA

The MAESHA innovations for island energy market evolution

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MAESHA

Demonstration of smart and flexible solutions for a decarbonised energy future in Mayotte and other European islands

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Agenda

- The MAESHA project and context
- Procurement and management of distributed flexibilities
- Flexibility market & product design
- Island-scale energy system modelling

Flexibility market & product design

Aleksei Mashlakov

centrica

Content

- Objectives
- Methodology
- Market framework design
- Frequency control products
- Frequency stability requirement
- Market clearing options for frequency control
- Conclusions and outlook

Challenges & goals of market design

➢ **Market design** aims to **maximize social welfare** under conditions of:

- **Extremely low market liquidity**
  - *applying mechanisms to detect and prevent abuse of market power*
  - *increasing technology neutrality by lowering entry barriers for DERs via VPPs*
- **Rigid energy market structure**
  - *coexistence of independent flexibility market and vertically integrated utility*
- **Limited inertia in the power system**
  - *improving system frequency stability with faster response times*
- **Costly and CO_2 intensive electricity supply mix**
  - *limiting the use of less inefficient peak diesel generators*
  - *Increasing hosting capacity of renewable sources (beyond 36%)*

Methodology

Technical analysis | *Literature review* | *Regulatory state* | *Use cases*

- Frequency control
- Voltage control
- Peak demand reduction

Market & product design options

Design criteria:
- Operational security
- Environmental benefits
- Regulatory compatibility
- Market liquidity impact
- Costs and complexity

Use-case-specific qualitative and/or quantitative analysis

+

Utility feedback

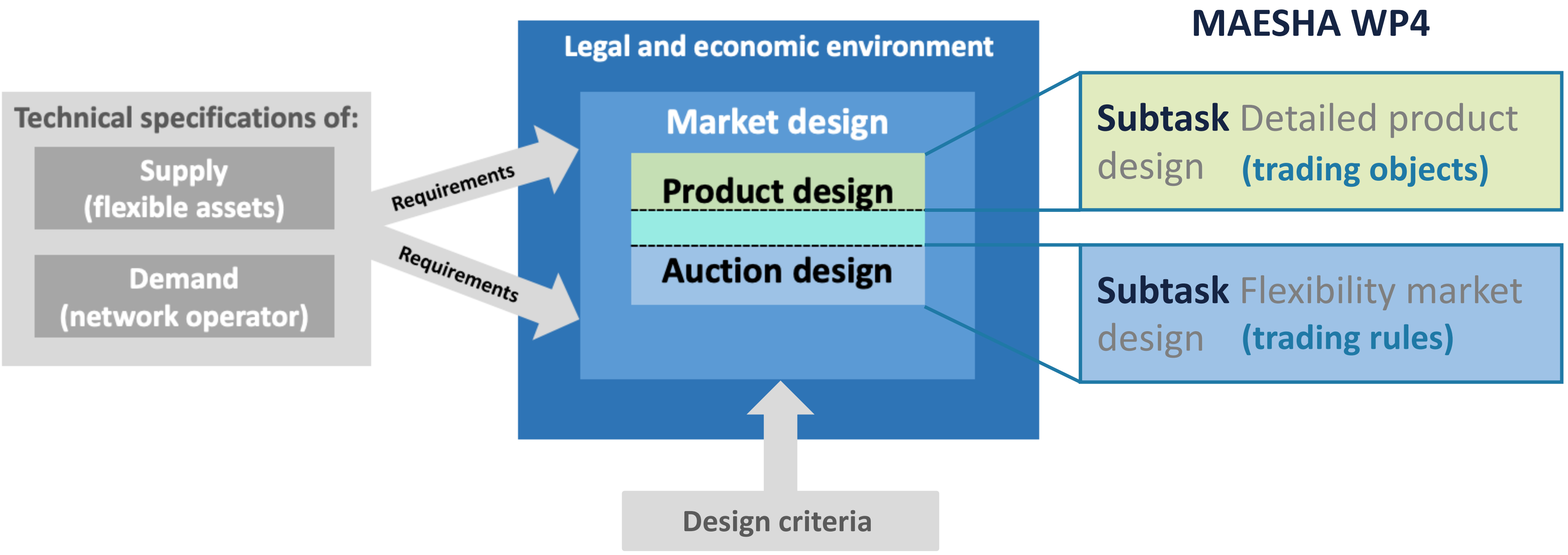
Technology feedback:
- Power system dynamics
- Peak demand analysis
- RES sensitivity analysis
- Residential demand response
- Industrial demand response

Product and market composition

1. Base-case design for pilot demonstration — *low complexity, solid benefits (2025)*
2. Innovative design options — *higher complexity, maximum benefits (2030)*
3. Recommendations for follower islands — *range of possible options with related costs*

Market framework design (1)

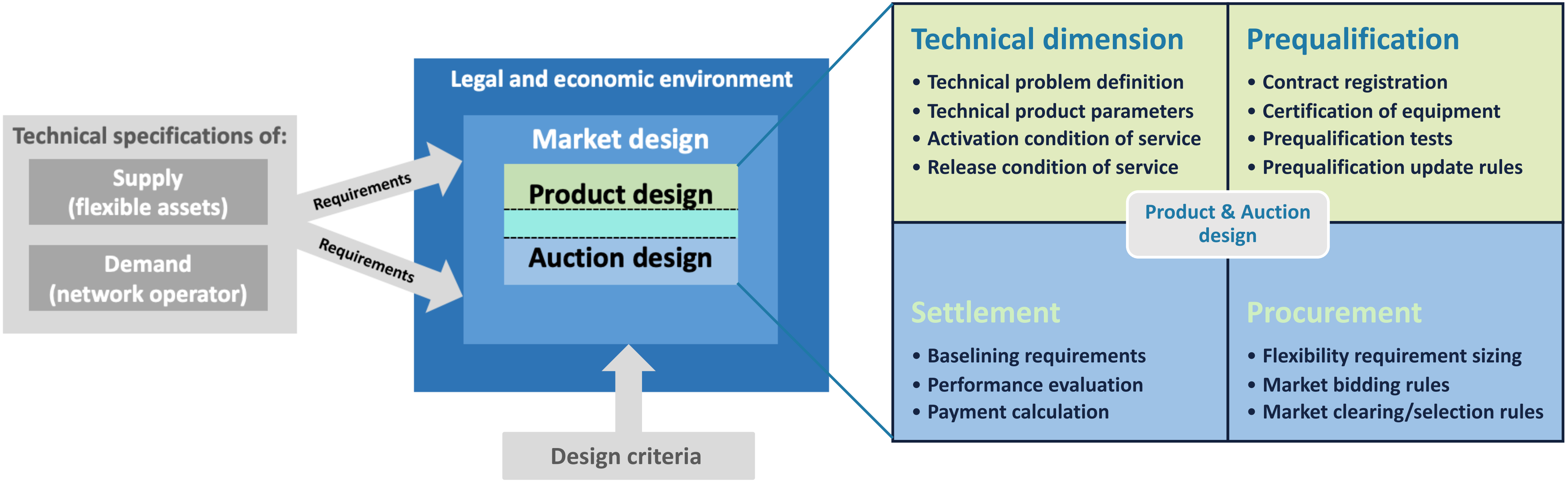
➢ Market design of flexibility markets in MAESHA



Modified from (Heilmann et. al.)

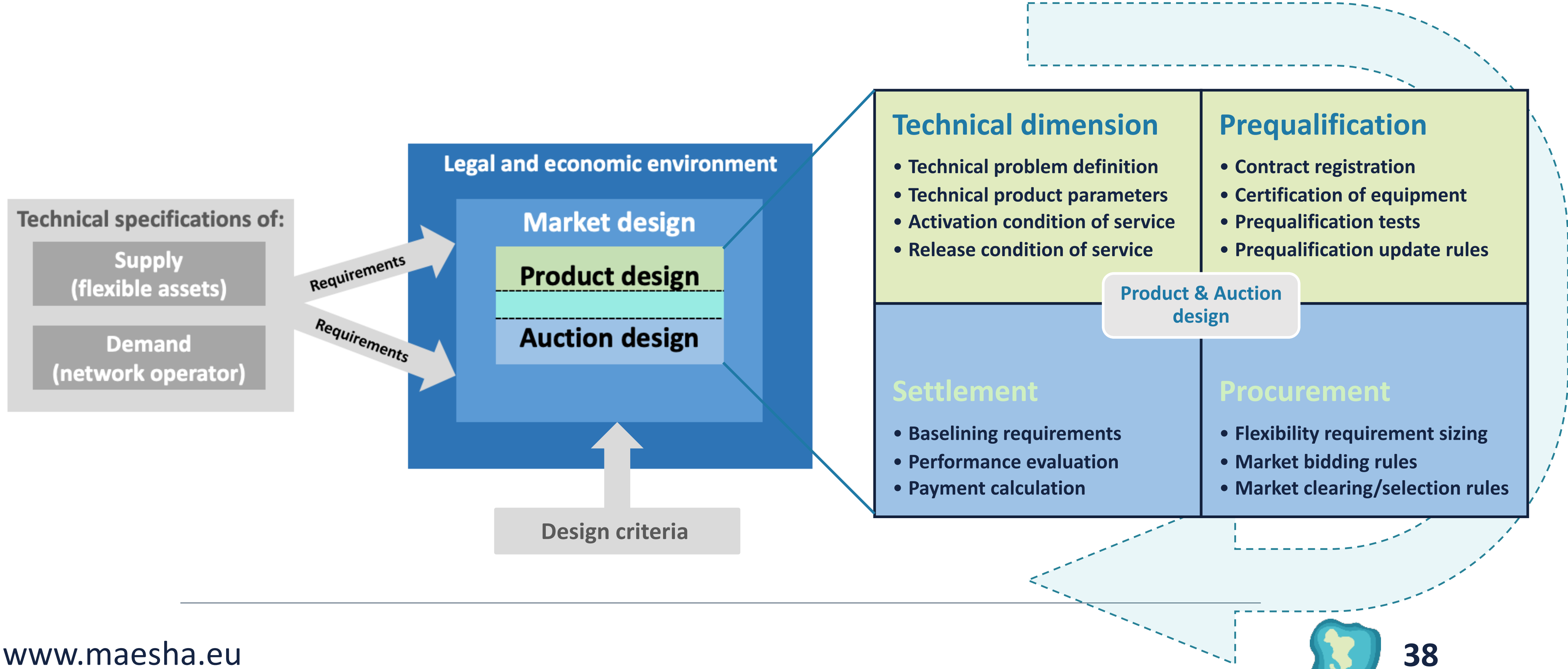
Market framework design (2)

- Market design of flexibility markets in MAESHA

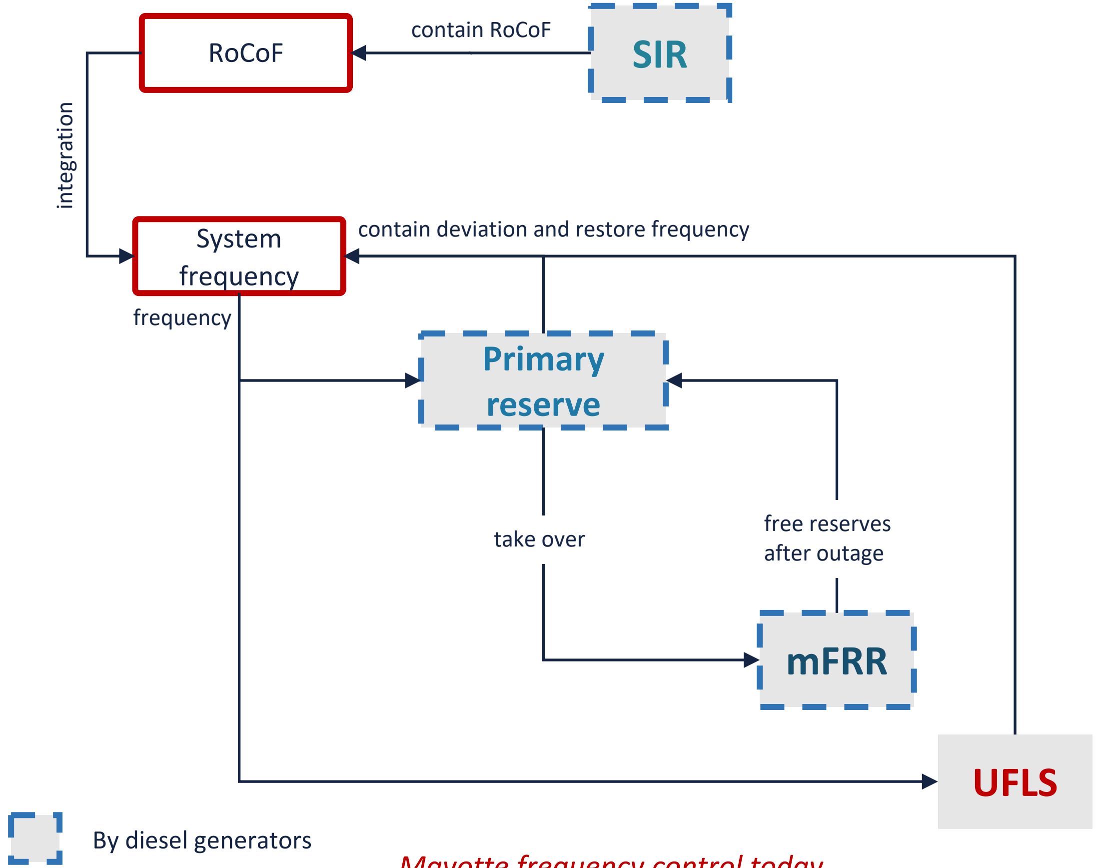


Market framework design (2)

➢ Market design of flexibility markets in MAESHA

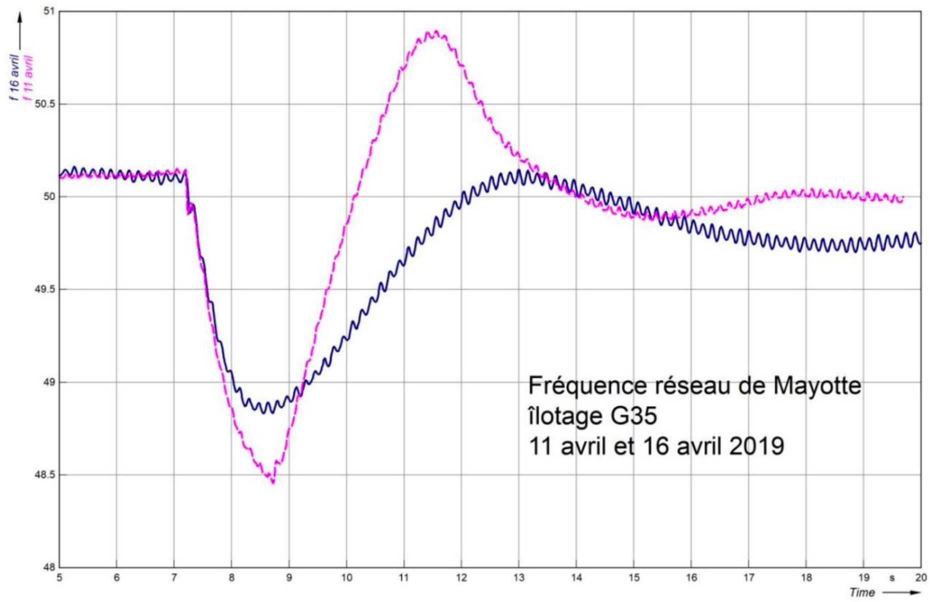


Frequency control products (1)



Mayotte frequency control today

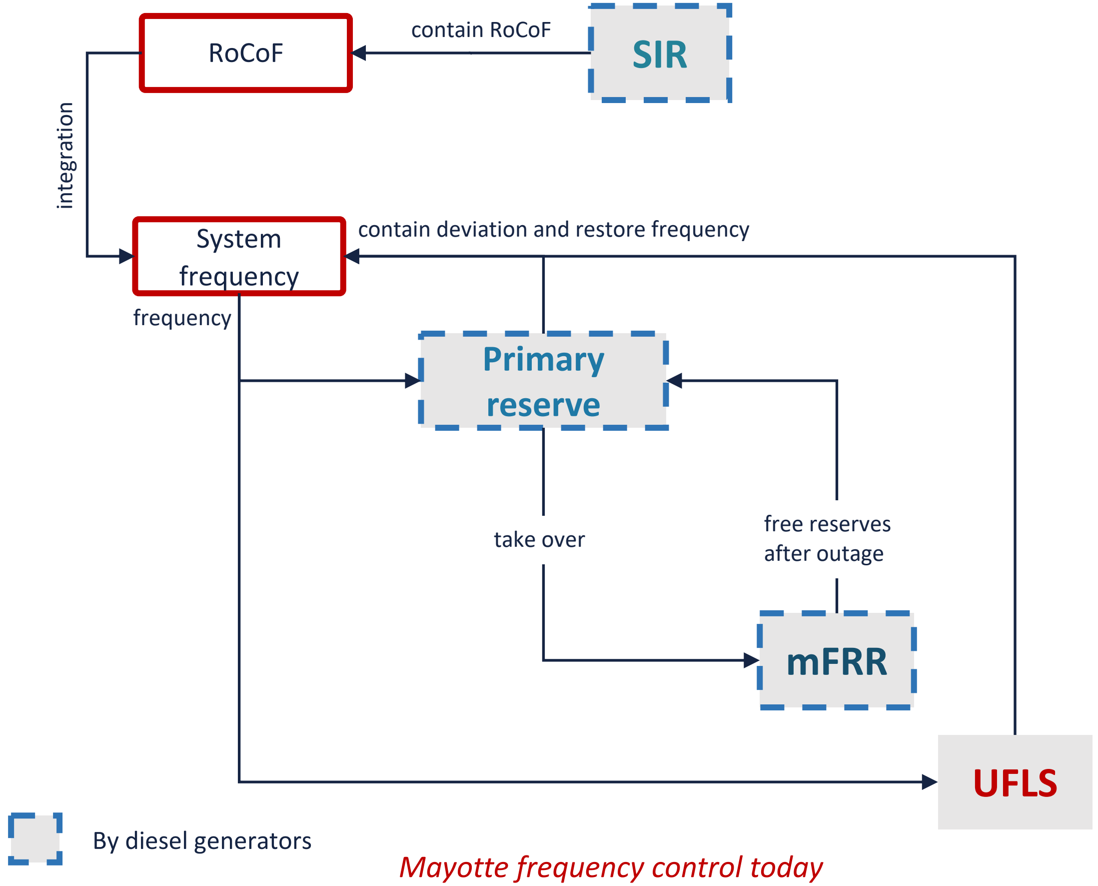
➢Experiment-based stability assessment



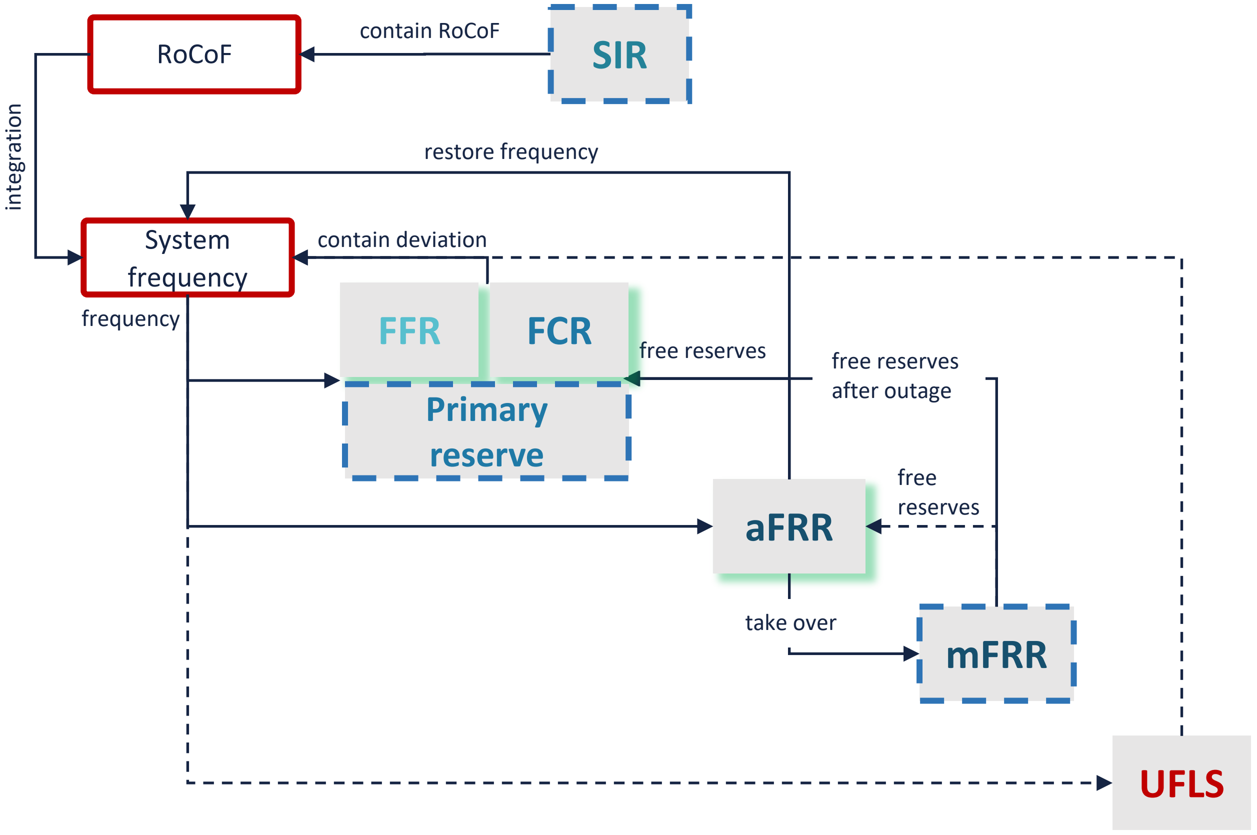
Real-life stability testing of Mayotte power system

- Normal frequency 50.15 Hz
- High RoCoF ~ 1.9 Hz/s

Frequency control products (1)

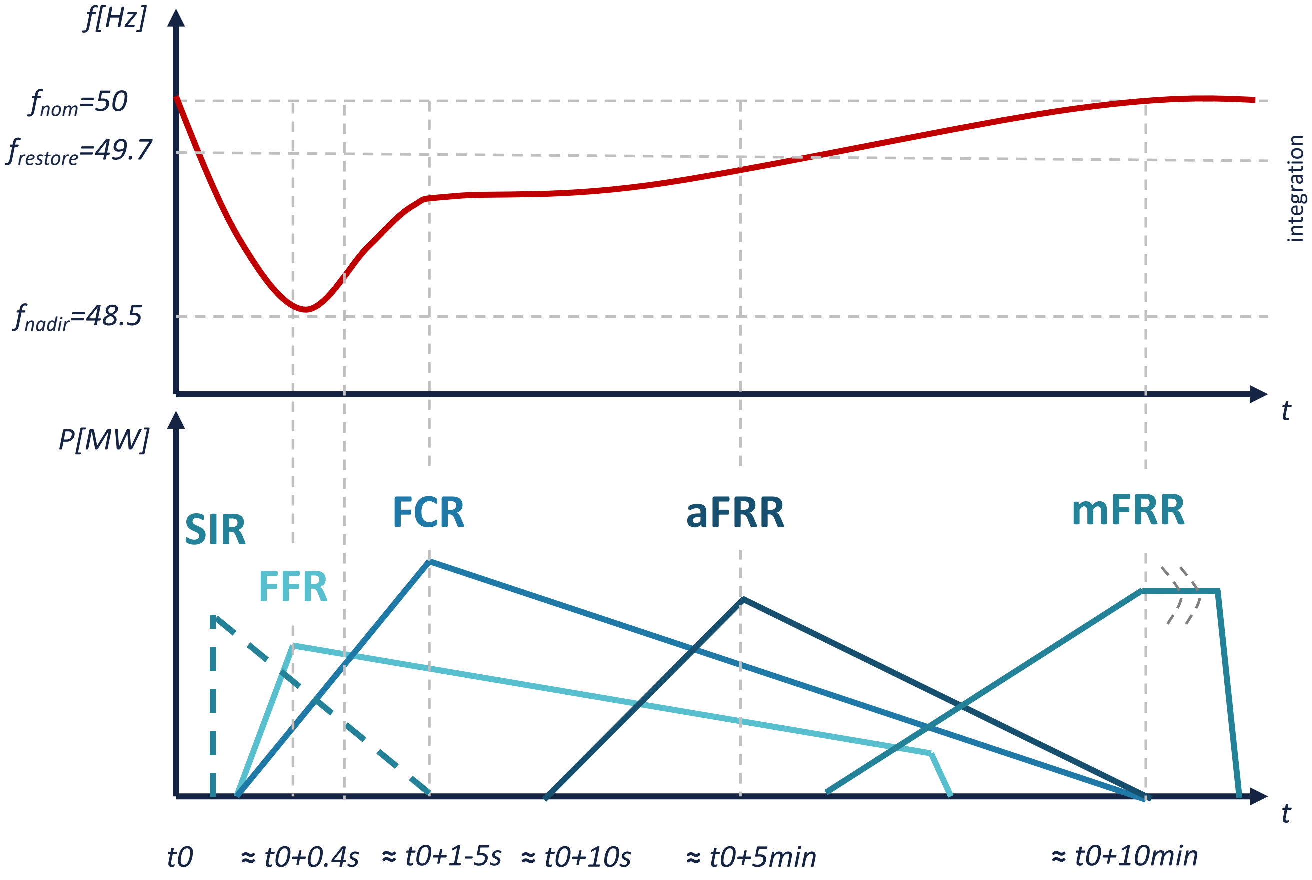


Mayotte frequency control today

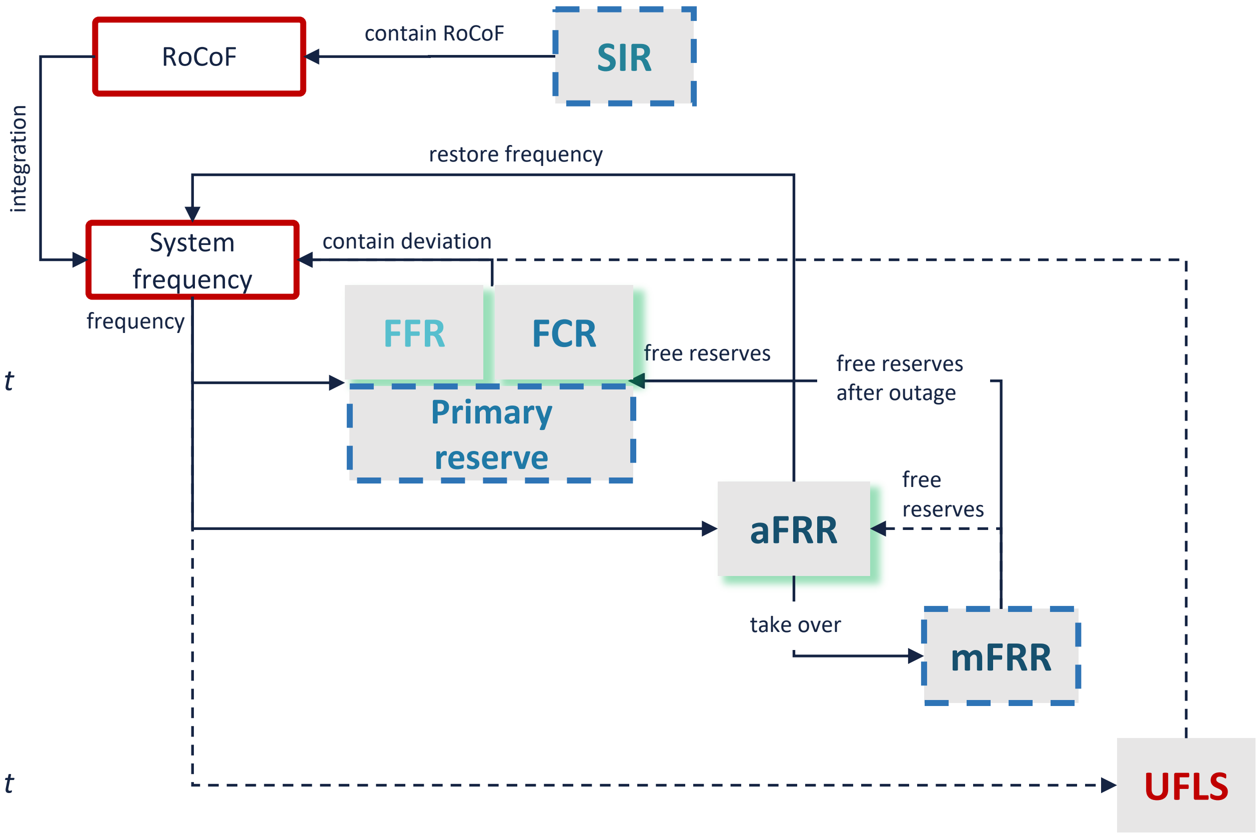


Mayotte frequency control of today + FMTP

Frequency control products (2)

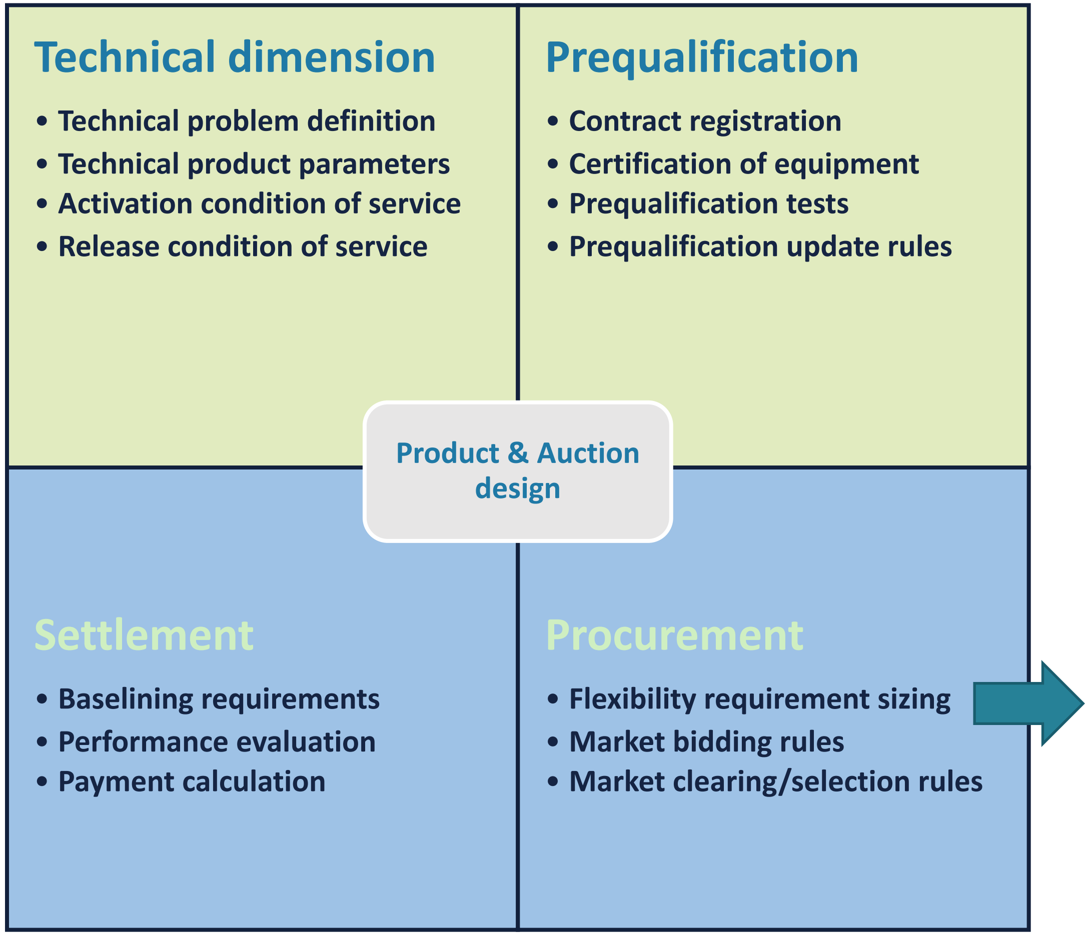


Loss of largest generator



Mayotte frequency control of today + FMTP

Technical specification: Frequency stability (1)



➢ Reserve requirements sizing (RRS) -

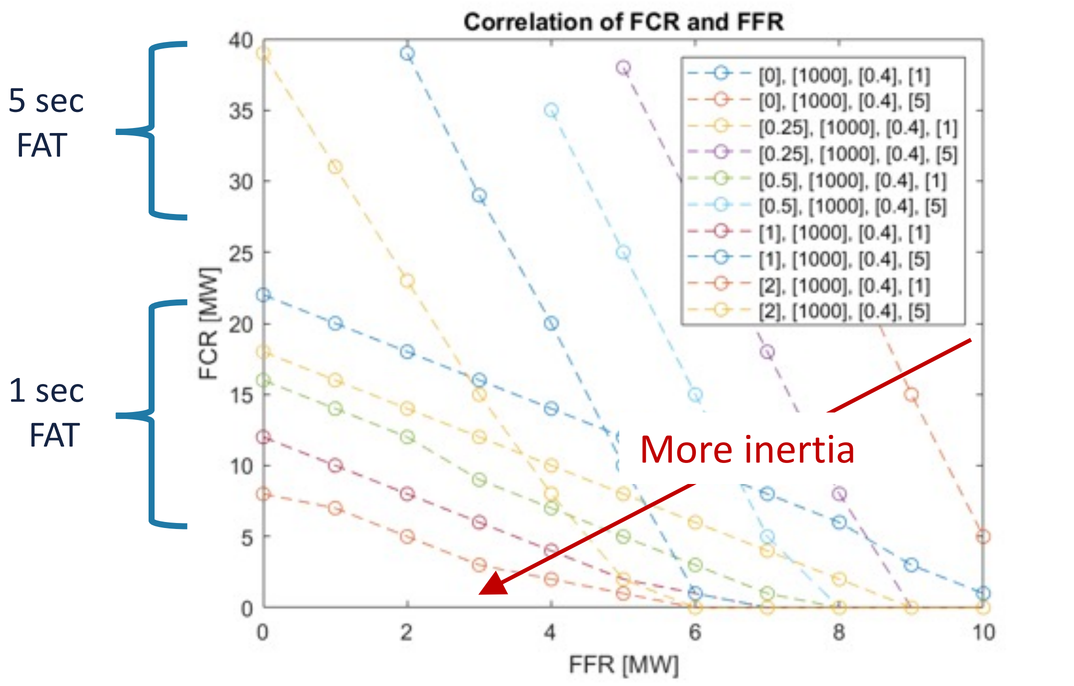
- Dimensioning of **Minimum Reserve Requirement (MRR)** to be contracted in advance to maintain security of supply

➢ Sizing methods

Deterministic (reference incident)	**Probabilistic** (Convolution of probability of normal imbalance + probability of forced outages and disturbances)	**Simulation of system dynamics**

- Now operating reserve is defined deterministically as ~16% of total demand
  - *However, N-1 criteria is necessary but not sufficient criteria for frequency stability.*

Technical specification: Frequency stability (2)



System stability simulation of Mayotte power system. SOURCE: TUB

- MRR is affected by a set of available reserve products and inertia level
  - Products with faster response time provide more value to the system dynamics
- Static MRR is not sufficient to guarantee system stability as
  - It disconnects the system state and market clearing results
- How to **enable a single-market clearing** that would couple interdependent inertia, FFR and FCR response products and satisfy stability requirement?

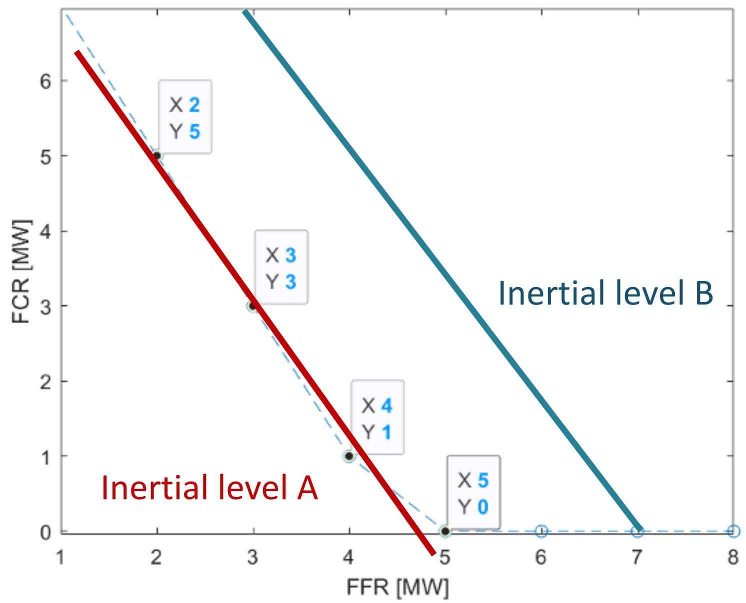
Market clearing

➢ **Option 1:** Use **Product Scalar** to reward providers that can offer products with enhanced technical performance (i.e., **a faster delivery time**)

- Utilized by EirGrid for FFR service or on PJM' Marginal Rate of Technical Substitution for RegA and RegB products

1. Simulate MRR for a set of inertia levels
2. Approximate the total MRR with regression

$$P_{MRR} = P_{FCR} - Product\ Scalar \cdot P_{FFR}$$



3. Clear the market on scalar-adjusted capacity

$$Scalar-adjusted\ MW = Offered\ MW \cdot Product\ Scalar$$

Garcia, M., & Baldick, R. (2021). Requirements for interdependent reserve types providing primary frequency control. IEEE Transactions on Power Systems, 37(1), 51-64.

Market clearing

- **Option 2:** Allow different availability/reliability levels for reserve providers to increase the market liquidity

- The availability can be estimated with historic performance. Then, based on PJM' MRTS for RegA and RegB products:

$$Effective\ MW = Offered\ MW\ \cdot \boldsymbol{Historic\ Performance\ Score}\ \cdot Product\ Scalar$$

$$Performance - adjusted\ price\ (euro) = \frac{Capacity\ Offer\ Price\ \left(\frac{euro}{MW}\right)}{\boldsymbol{Historic\ Performance\ Score}}$$

- Performance-based remuneration gives incentive to better service provision and enables transparent performance-based clearing of the market.

Herre, L., Pinson, P., & Chatzivasileiadis, S. (2022). Reliability-aware probabilistic reserve procurement. Electric Power Systems Research, 212, 108345.

Market clearing

➢ **Option 3:** Allow all units to bid in the market on equal footing via **ideal tender**
- optimizing the system response dynamics **not based on the service requirements** but **on the available response profiles** with unit-specific droop rates, energy content, and reaction times
  - *their performance evaluation is tailored to their expected capabilities*

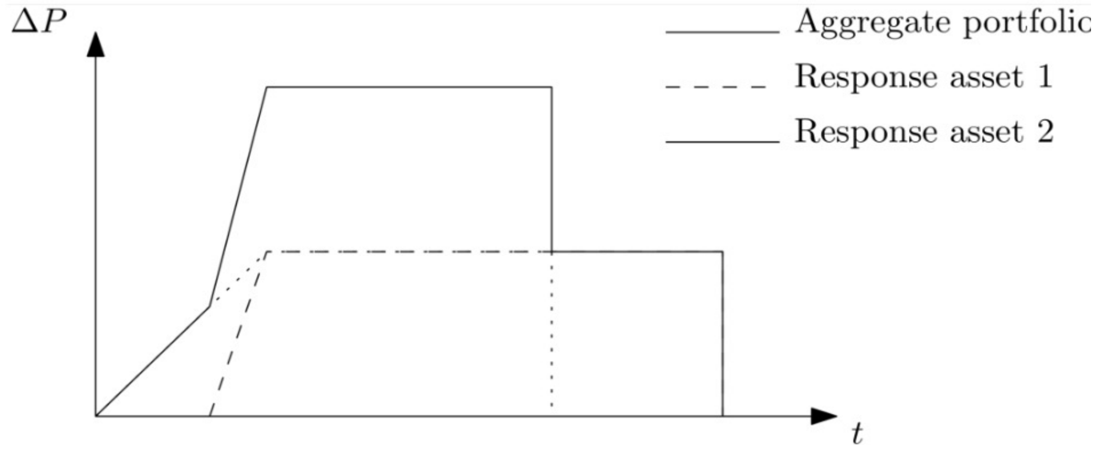
➢ Overall approach:
- Minimize total cost of asset responses:

$$\min \sum_{j=1}^{m} \delta_j \pi_j$$

- System dynamics is defined by swing equation:

$$2H\frac{df}{dt} = \Delta P = -\Delta P_{dist} + \Delta P_m - D\Delta f.$$

- Subject to RoCoF, frequency nadir and quasi-steady-state frequency requirements



Bondy, D. E. M. (2017). Demand response for a secure power system operation. *English. PhD thesis*.

Conclusions and outlook

- We **went through the goals of market design** on Mayotte island
- We **explored** the market design **methodology** and **framework** in MAESHA
- We **identified the need of single-market clearing** for frequency response products
- Several **options** were shown **for the single-market clearing**:
  - Use of product scalars to reward fast reacting reserves
  - Use of historical performance scores to allow different availability
  - Use of ideal tender to mitigate the product requirement differentiation and enable technology neutrality

- More research on the response-based market clearing in the end of the presentation
  - **Dynamic Virtual Power Plants** as response matching approach on all time scales
  - **Joint energy-reserve markets** as the target market design on islands

Questions/Reactions from the floor?

Further literature on market clearing

- Chávez, H., Baldick, R., & Sharma, S. (2014). Governor rate-constrained OPF for primary frequency control adequacy. *IEEE Transactions on Power Systems*, *29*(3), 1473-1480.
  - The PFR adequacy conditions are expressed as a function of individual unit governor response ramp rates and system inertia
- Teng, F., Trovato, V., & Strbac, G. (2015). Stochastic scheduling with inertia-dependent fast frequency response requirements. *IEEE Transactions on Power Systems*, *31*(2), 1557-1566.
  - MILP formulation for stochastic unit commitment that optimizes system operation by simultaneously scheduling energy production, standing/spinning reserves and inertia-dependent fast frequency response
- Jomaux, J., Mercier, T., & De Jaeger, E. (2016, April). A methodology for sizing primary frequency control in function of grid inertia. In *2016 IEEE International Energy Conference (ENERGYCON)* (pp. 1-6). IEEE.
  - Presents a linear programming problem to select the most cost-efficient FCR providers to sustain disturbance while respecting static and dynamic constraints
- Badesa, L., Teng, F., & Strbac, G. (2019). Simultaneous scheduling of multiple frequency services in stochastic unit commitment. *IEEE Transactions on Power Systems*, *34*(5), 3858-3868.
  - Novel frequency stability constraints that, for the first time, allow to simultaneously cooptimise the provision of synchronised and synthetic inertia, PFR, EFR and a dynamically-reduced largest power infeed.

Further literature on market clearing

- Badesa, L., Teng, F., & Strbac, G. (2020). Optimal portfolio of distinct frequency response services in low-inertia systems. *IEEE Transactions on Power Systems*, *35*(6), 4459-4469.
  - Shows that droop control services can be accurately and conservatively approximated by a power ramp with an activation delay; formulates the frequency-security conditions as chance constraints for any finite number of FR services with distinguished characteristics, such as different delivery times and activation delays.
- Liang, Z., Mieth, R., & Dvorkin, Y. (2022). Inertia pricing in stochastic electricity markets. *IEEE Transactions on Power Systems*.
  - Simultaneous procurement of energy, reserve and inertia providing services.
- Liang, Z., Mieth, R., Dvorkin, Y., & Ortega-Vazquez, M. A. (2022). Weather-Driven Flexibility Reserve Procurement. *arXiv preprint arXiv:2209.00707*.
  - Weather-driven flexibility reserve sizing and allocation for large-scale wind power installations
- Björk, J., Johansson, K. H., & Dörfler, F. (2022). Dynamic virtual power plant design for fast frequency reserves: Coordinating hydro and wind. *IEEE Transactions on Control of Network Systems*.
  - The controllers rely on dynamic participation factors (DPFs) and are designed so that all devices collectively match the Bode diagram of a design target, specified by the SO's requirements.