H2020 FLEXGRID Project

A novel smart grid architecture that facilitates high RES penetration through innovative markets towards efficient interaction between advanced electricity grid management and intelligent stakeholders

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FLEXGRID R&I motivation

- **Need for high and distributed RES penetration**
  - How to deal with RES intermittency, non-dispatchability, stochasticity, etc?
  - How to deal with new challenges in the distribution network management (i.e. local congestion, voltage control)?
  - How can small energy prosumers participate in emerging energy/flexibility markets in order to facilitate bottom up investments?

- **Need for energy markets' liberalization**
  - How to deal with the various roles and conflicting interests of many energy market stakeholders (RES producers, flexibility service providers/aggregators, flexibility market operators, system operators)?
  - How to incentivize equal market participation, ensure market liquidity and efficiency (i.e. avoid market's temporal and special fragmentations) ?
  - How to develop economically sustainable business models for the new emerging energy ecosystem (i.e. B2B) and individual market stakeholders?

- **Need for sustainable investments and optimal exploitation of flexibility**
  - How can system operators (TSO/DSO) utilize efficiently flexibility provided by distributed FlexAssets to guarantee network's stability/robustness/cost efficient operation (avoid expensive grid reinforcements)?
  - How can FlexSuppliers optimally invest on/operate their FlexAssets to maximize their profits?
  - How to incentivize small energy prosumers/RES cooperatives/RES communities to buy and utilize distributed FlexAssets (e.g. batteries, EVs, demand side management units)?

Main innovative research idea

Advanced mathematical models and algorithms

To enhance the operation of the grid in order to be able to facilitate high RES penetration through flexmarkets' operation.

Market-aware distribution grid operation

For the existing and emerging flexmarkets' operation in order to take into account the complex operation of the grid.

Network-aware flexibility market operation

Integrating intelligence in an Automating Trading Platform (ATP) with digital tools for:

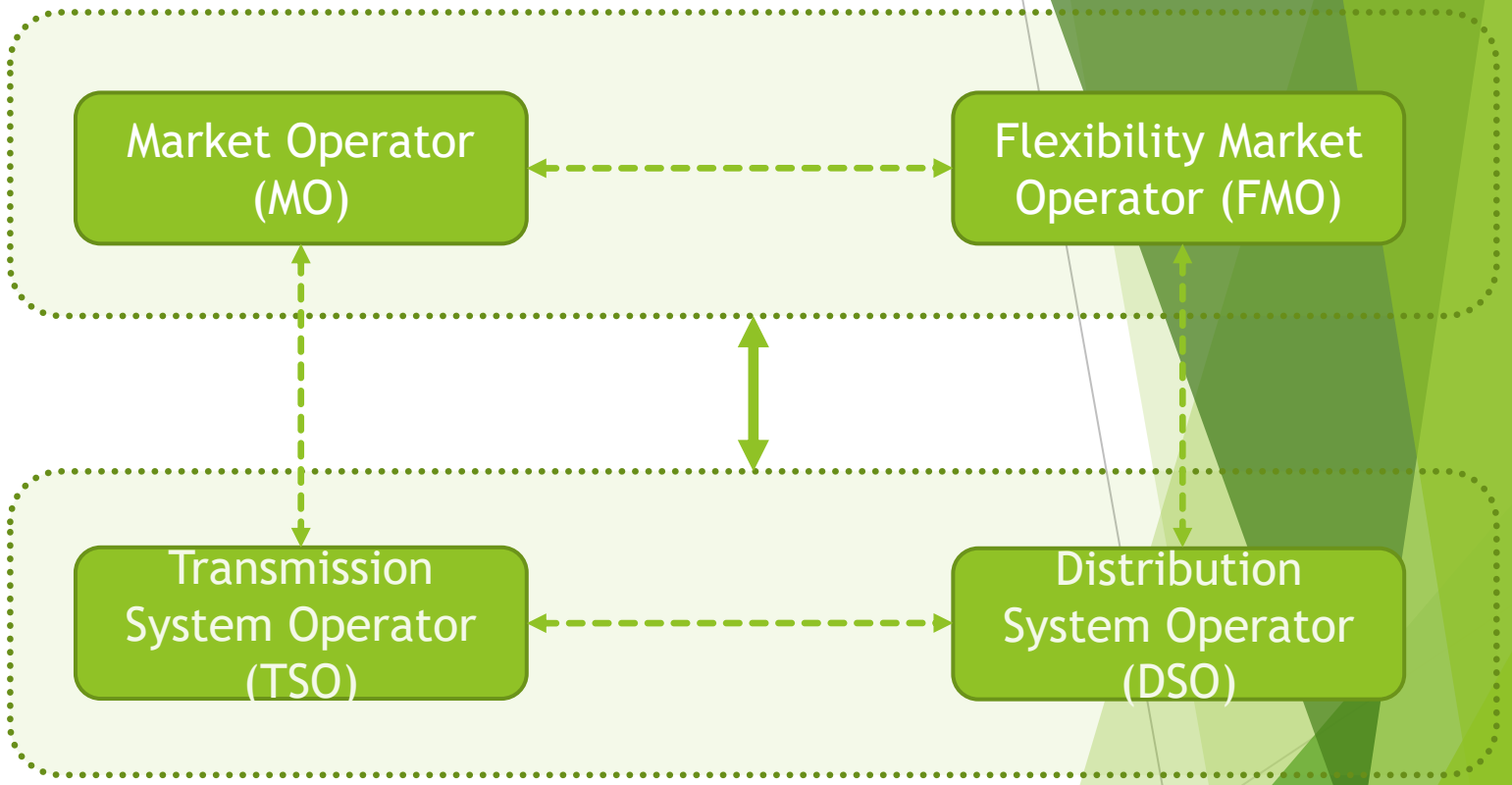
- Flexibility Market Operator (FMO) user
- Distribution System Operator (DSO) user
- Energy/Flexibility Service Provider (ESP/FSP) user
- Independent aggregator user

FLEXGRID holistic energy and AS market architectures (interaction between market and network domains at both TN and DN levels)

Market domain

FLEXGRID goal: Optimal interaction between market and network operations (economic efficiency vs. reliability under high RES)

Network domain



- MO operates day-ahead (and intra-day) energy markets at the TN level.
- FMO operates day-ahead (and intra-day) energy markets at the DN level.
- TSO operates the day-ahead reserve and balancing energy market at TN level.
- DSO operates the day-ahead reserve and balancing energy market at DN level.
- **MO-FMO coordination for better market efficiency outcomes in high RES scenarios.**
- **TSO-DSO coordination for better network operation outcomes in high RES scenarios.**

We follow the Nord Pool paradigm (as EU baseline)

- **Day-ahead energy market** gate closure: 12:00 of D-1

- **Day-ahead market clearing results**: 14:00 of D-1 (auction-based trading, uniform pricing). MO informs the TSO about the day-ahead dispatch (DAD).

- **Day-ahead reserve market** takes place by TSO in the afternoon of D-1 (TN-aware DAD). In other countries, it is also called Integrated Scheduling Process (ISP) undertaken by the TSO.

- **Intra-day energy market** opens: 15:00 of D-1 (continuous bi-lateral electronic trading)

- **Intra-day energy market** gate closure: ~23:00 of D-1 (depends on the country)

- **Balancing market** gate closure: 23:15 for delivery of 00:00-01:00 of D, 00:15 for delivery of 01:00-02:00 of D, etc.

(as close as possible to real time, not before the intra-day gate closure time, sufficient time for the necessary balancing processes by the TSO should be ensured)

Conclusion:

Let us assume 3 main markets operating at both TN and DN levels (i.e. a total of 6 markets), namely:

OK, but what are exactly the inputs and outputs of these 6 markets? And why do we need each one of them? Which are the alternative options to avoid market fragmentation?

FLEXGRID holistic energy market architectures

1) Market Operator (MO) operates the day-ahead energy market at the Transmission Network (TN) level
- Input: Bids from all market participants and power flow constraints at the TN level.
- Output: Market clearing results (TN-aware day-ahead dispatch – energy quantity and price €/MWh per participant) → DN assumed as "copper plate"

2) TSO operates the day-ahead reserve market at the TN level
- Input: Bids from all market participants at TN level + DAD schedules from MO + RES/demand forecasts + maintenance-related info from assets and grid
- Output: Reserve market clearing results at TN level (available power capacity reserved and price €/MW per participant)

3) Flexibility Market Operator (FMO) operates the day-ahead energy market at the distribution Network (DN) level.
- Input: Bids from all market participants at DN level (incl. FlexAsset) + (DAD schedule from MO at all TSO-DSO coupling points) + DN constraints
- Output: Market clearing results (DN-aware day-ahead dispatch – energy quantity and price €/MWh per participant)

4) DSO operates the day-ahead reserve market at the DN level
- Input: Bids from all market participants at DN level + DAD schedules from FMO + RES/demand forecasts + maintenance-related info (if any)
- Output: Reserve market clearing results at DN level (available power capacity reserved and price €/MW per participant)

5) TSO operates the balancing energy market at the TN level.
- Input: Bids from all market participants at TN level (incl. DER aggregators) + updated RES/demand forecasts + updated data from SCADA
- Output: Balancing energy market clearing results at TN level (i.e. Up/Down activation energy quantities and prices €/MWh per participant)

6) DSO operates the balancing energy market at the DN level
- Input: Bids from all market participants at DN level + updated RES/demand forecasts
- Output: Balancing energy market clearing results at DN level (i.e. Up/Down activation energy quantities and prices €/MWh per participant)

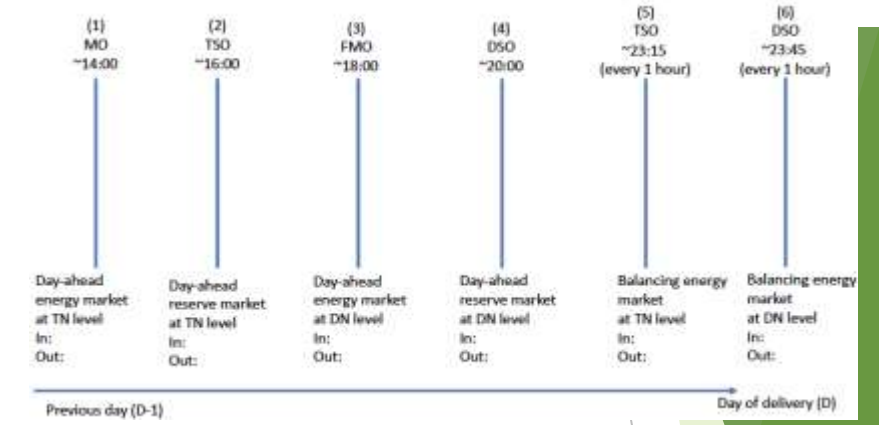
OK, but which is the timing (sequence) of these markets? And how does this timing affect the market architecture model (i.e. how inputs/outputs change)? What happens if we eliminate/merge one or more of these 6 markets to avoid market fragmentation phenomena?

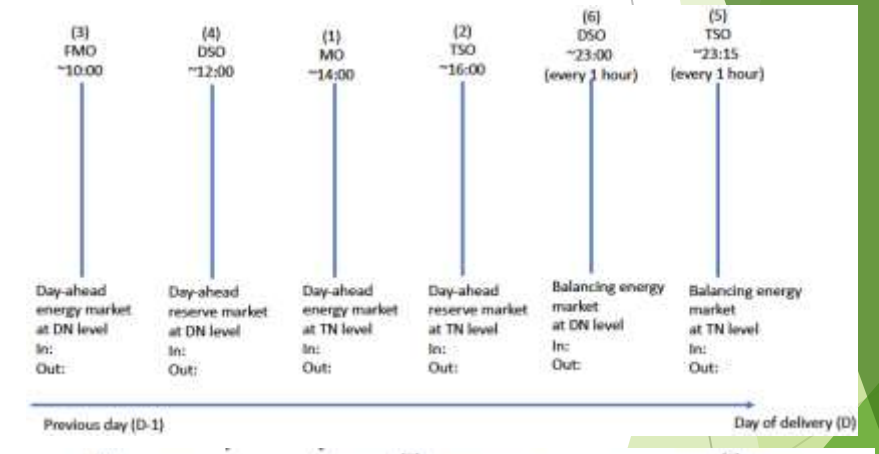
Reactive, Proactive & Interactive energy market architectures

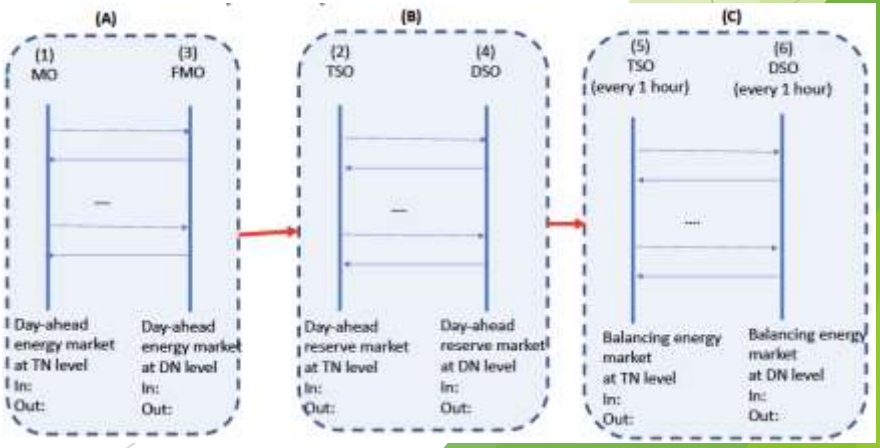
- **Reactive Distribution Level Flexibility Market (DLFM):**
  - **Distribution Network (DN) markets follow up the market clearing results of the respective Transmission Network (TN) markets**
  - **Compatible with existing regulatory framework but not optimal.**

- **Proactive DLFM:**
  - **DN-level markets precede the respective TN markets to proactively avoid DN-level problems (i.e. local congestion, voltage control)**

- **Interactive DLFM:**
  - **Iterative processes** (e.g. via decomposition techniques) until MO-FMO and TSO-DSO converge to an optimal dispatch for both TN and DN levels
  - **Difficult to implement in reality, but provides optimal results**

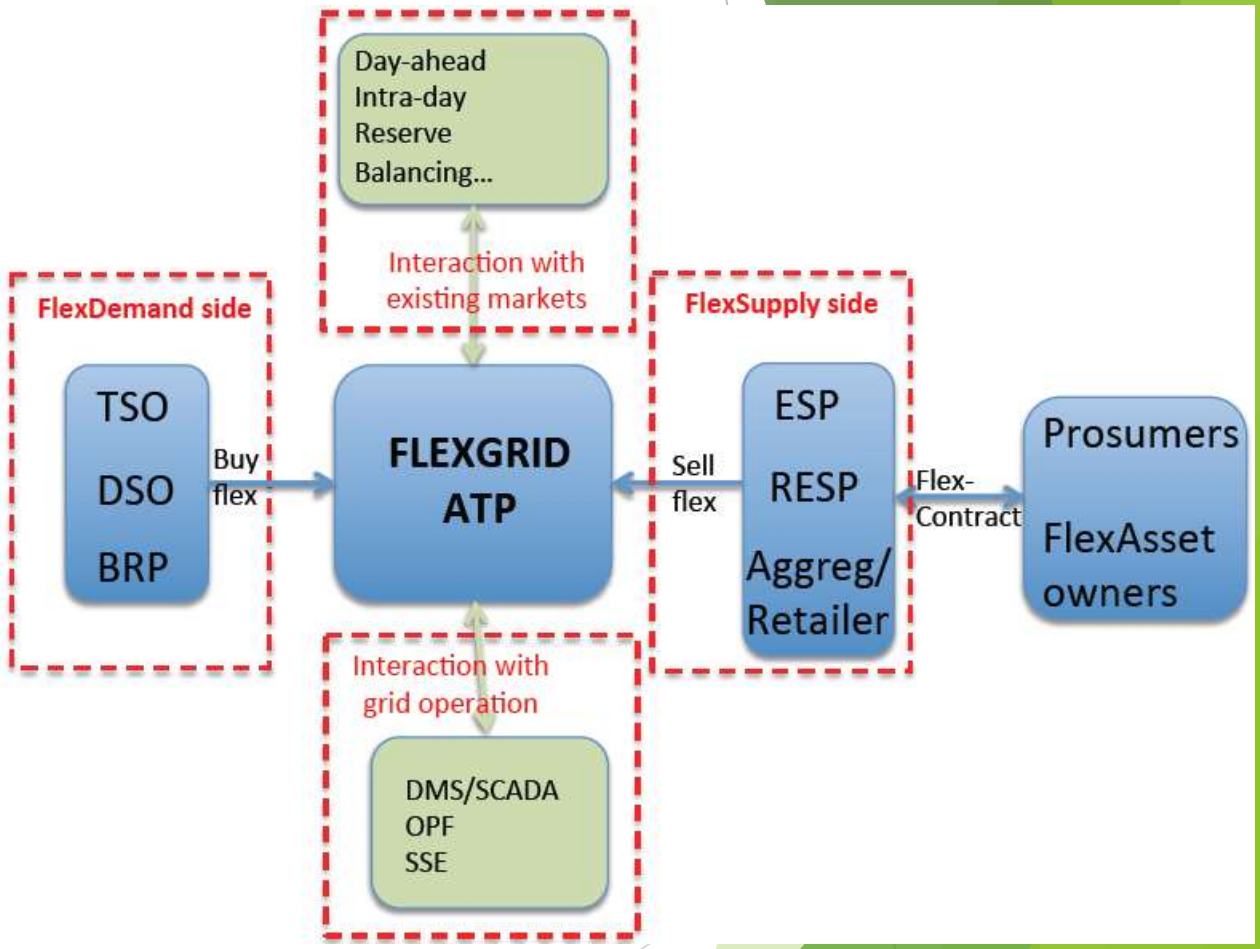




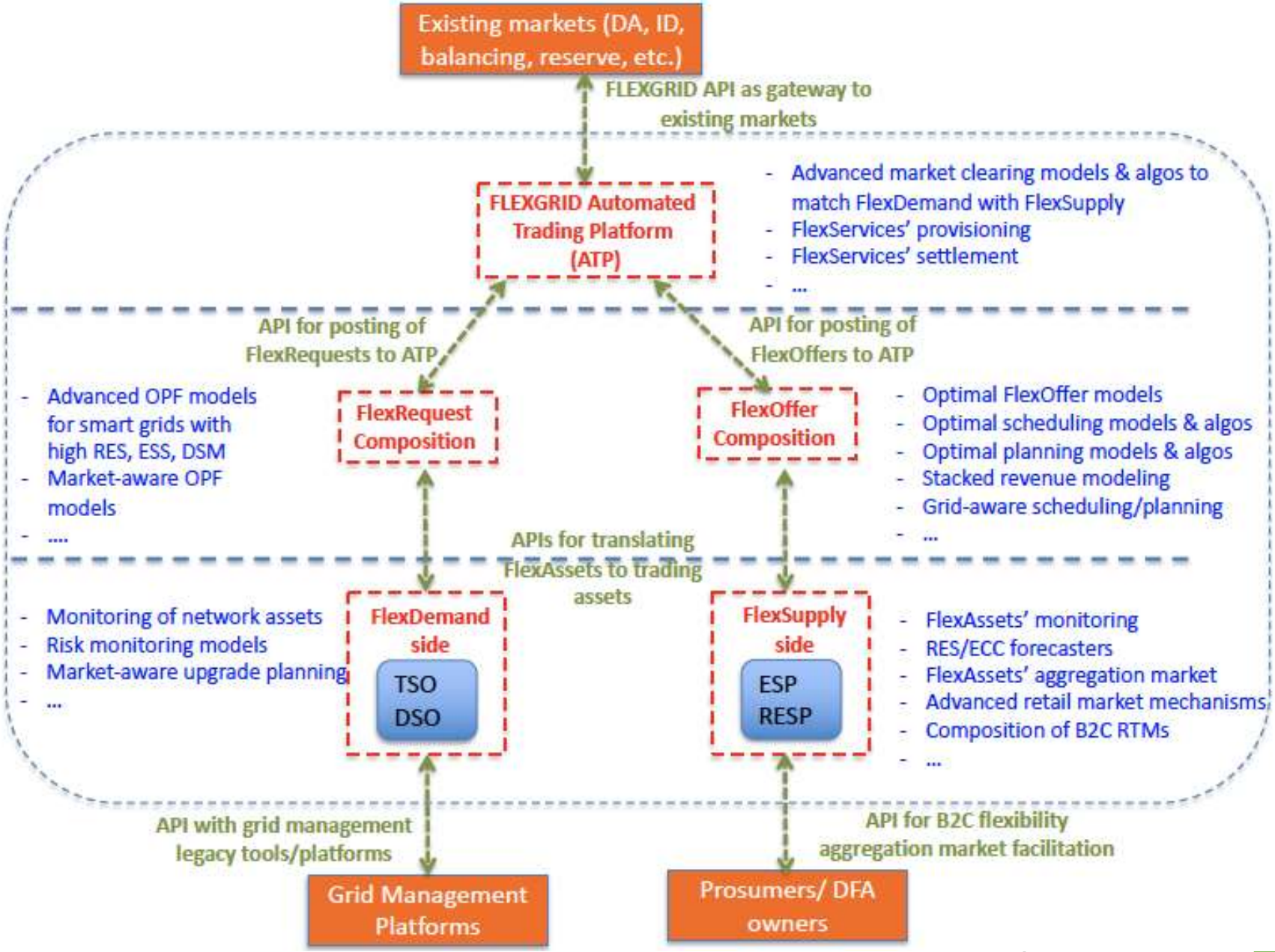


FLEXGRID ecosystem design

- Looks like NODES marketplace (https://nodesmarket.com/)
- Multi-sided and modular-by-design S/W platform
- FLEXGRID ATP facilitates the automated, online and optimal trading of FlexAssets, realizing "win-win" business contexts for energy market stakeholders at both FlexSupply and FlexDemand sides.
- FLEXGRID ATP may be owned by an independent Flexibility Market Operator (FMO) legal entity, who will realize revenues in the form of license fees paid by all involved FLEXGRID actors.
- Through FLEXGRID's innovative energy market architectures facilitates innovative Energy Services (ESs) that highly enhance the management efficiency of the various market stakeholders' internal business portfolios.



FLEXGRID S/W architecture

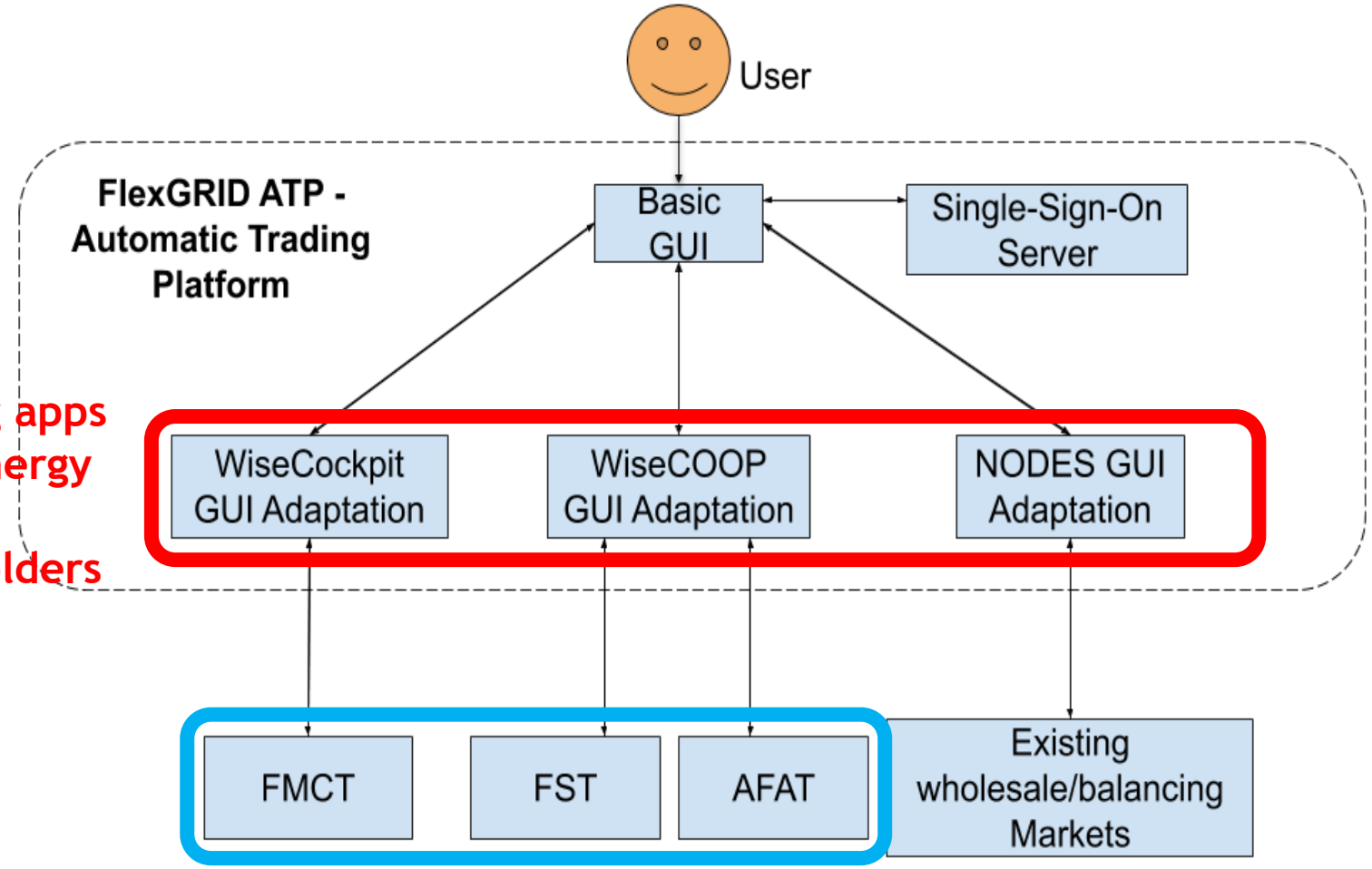


FLEXGRID Automated Trading Platform (ATP)

AFAT: Automated Flexibility Aggregation Toolkit → aggregator user

FST: FlexSupplier's Toolkit → ESP/FSP user

FMCT: Flexibility Market Clearing Toolkit → FMO/DSO user



Existing apps from energy market stakeholders

FLEXGRID S/W toolkits to integrate beackend intelligence

Flexibility Market Clearing Toolkit (FMCT)

- **FMCT GUI tabs (FMO user):**
  - Interact with TN-level market in order to operate the proposed energy market architecture (proactive, reactive, interactive)
  - Operate DN-aware “pay-as-bid” market management algorithm (match FlexRequests with FlexOffers)
  - Operate DN-aware “pay-as-clear” market algorithms (i.e. AC-OPF)
  - Visualize the TSO-level decisions (R-DLFM case) that should be respected at DN level.
  - Visualize the DN-level FlexOffers and possibly forward them (if not matched at DN level) to the wholesale (MO)/balancing markets (TSO) at TN-level.
  - Visualize and store all FlexRequests and FlexOffers (both accepted and rejected ones).

- **FMCT GUI tabs (DSO user):**
  - Run a (convexified) AC-OPF algorithm to:
    - Dynamically identify flexibility needs per DN node (both local congestion and voltage control)
    - Determine DN-level nodal prices for active (d-LMPs) and reactive power (q-LMPs)
    - Automatically create a FlexRequest and submit it in ATP

FlexSupplier's Toolkit (FST)

FST GUI tabs (ESP/FSP user):

- **Minimize ESP/FSP's OPEX**
  - Run an optimal FlexAsset scheduling algorithm (cf. consumption, production and storage assets)
  - Define the dispatch per FlexAsset
- **Minimize ESP/FSP's CAPEX**
  - Run an optimal FlexAsset planning algorithm
  - Offline operation (i.e. simulating exhaustive "what-if" scenarios for future FlexAsset investment)
- **Maximize ESP's/FSP's stacked revenues**
  - Run a stacked revenue maximization algorithm
  - Define the FlexOffers for co-optimized participation in several energy/flexibility markets according to the innovative energy market architectures that FLEXGRID proposes

Automated Flexibility Aggregation Toolkit (AFAT)

AFAT GUI tabs (Aggregator user):

- **Manage a B2C flexibility market (end energy prosumers compete)**
  - Run fair behavioral real-time pricing algorithms in order to incentivize end users (bottom up flexibility investors/operators to participate in the aforementioned energy markets)
  - Run various “what-if” simulation scenarios (offline operation) to determine more beneficial FlexContracts with end energy prosumers in the future
- **Manage a FlexRequest:**
  - Run an automated flexibility aggregation algorithm to optimally respond to a given FlexRequest published in ATP
  - Informs the ATP about the dispatch per end energy prosumer
- **Create a FlexOffer**
  - Run an automated flexibility aggregation algorithm to determine/ create an optimal FlexOffer that best represents aggregator’s portfolio
  - Submit the FlexOffer in ATP

FLEXGRID

Thank you for your attention!

Round-table discussion