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ISGAN –
International Smart Grid Action Network

Smart4RES Project

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ISGAN in a Nutshell

ISGAN
INTERNATIONAL SMART GRID
ACTION NETWORK

International Smart Grid Action Network is the only global government-to-government forum on smart grids.

Created under the auspices of:

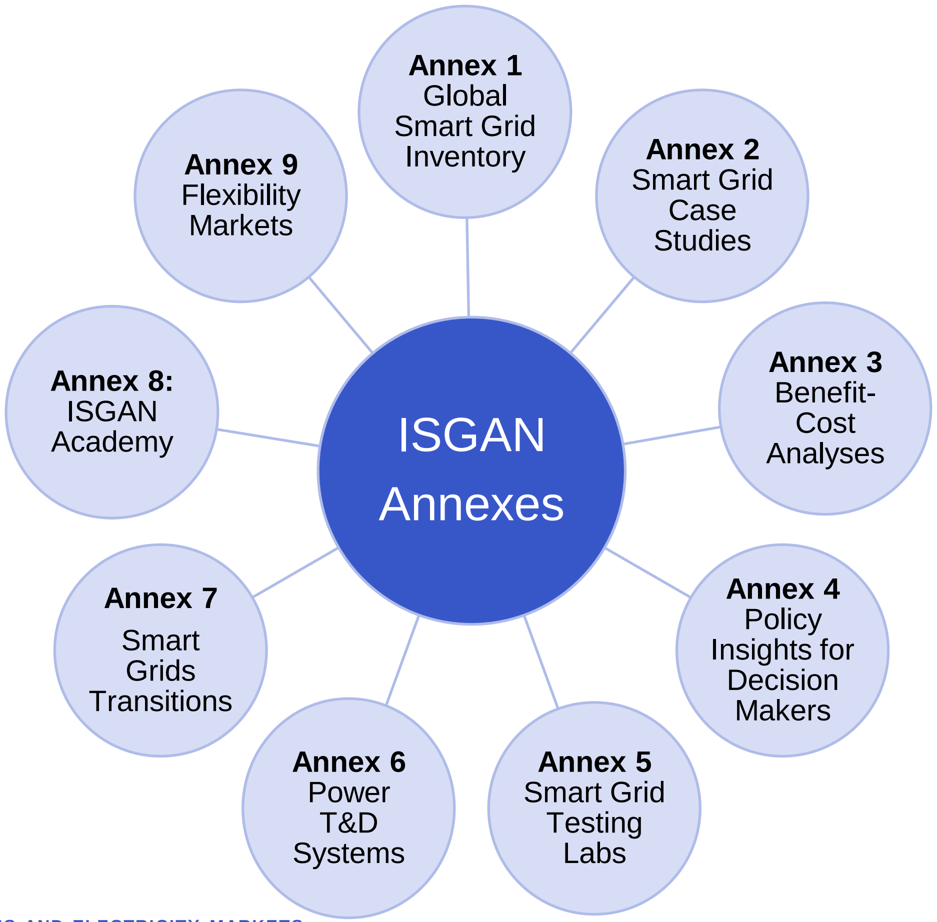
iea Energy Technology Network

the Implementing Agreement for a Co-operative Programme on Smart Grids

CLEAN ENERGY MINISTERIAL
Accelerating the Transition to Clean Energy Technologies

an initiative of the Clean Energy Ministerial (CEM)

Strategic platform to support high-level government knowledge transfer and action for the accelerated development and deployment of smarter, cleaner electricity grids around the world

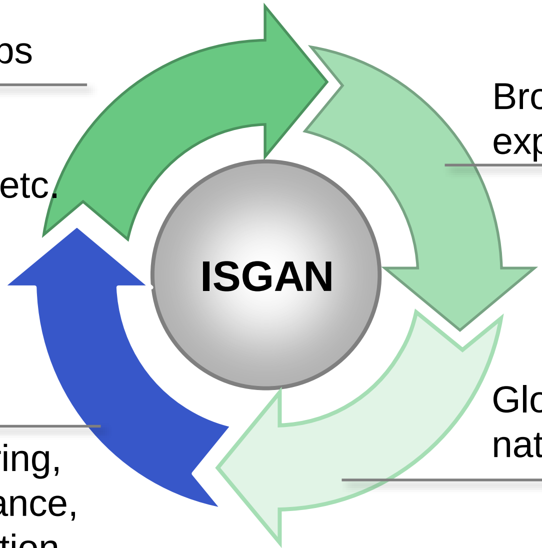


ISGAN's worldwide presence

Value proposition

Strategic partnerships

IEA, CEM, GSGF, Mission Innovation, etc.



Broad international expert network

Global, regional & national policy support

Knowledge sharing, technical assistance, project coordination

Visit our website:
www.iea-isgan.org

Optimizing the value of storage in power systems and electricity markets

Agenda

- Smart4RES in a nutshell
- Industrial view on the problematic and role of storage – utilities needs and expectations (Maria Inês Marques, EDP)
- Optimization of storage operation in power systems with high RES penetration (Dimitrios Lagos, ICCS-NTUA)
- Optimization of storage and RES participation in electricity markets (Simon Camal, ARMINES-MINES ParisTech)

Smart4RES in a nutshell

Smart4RES Consortium & Vision

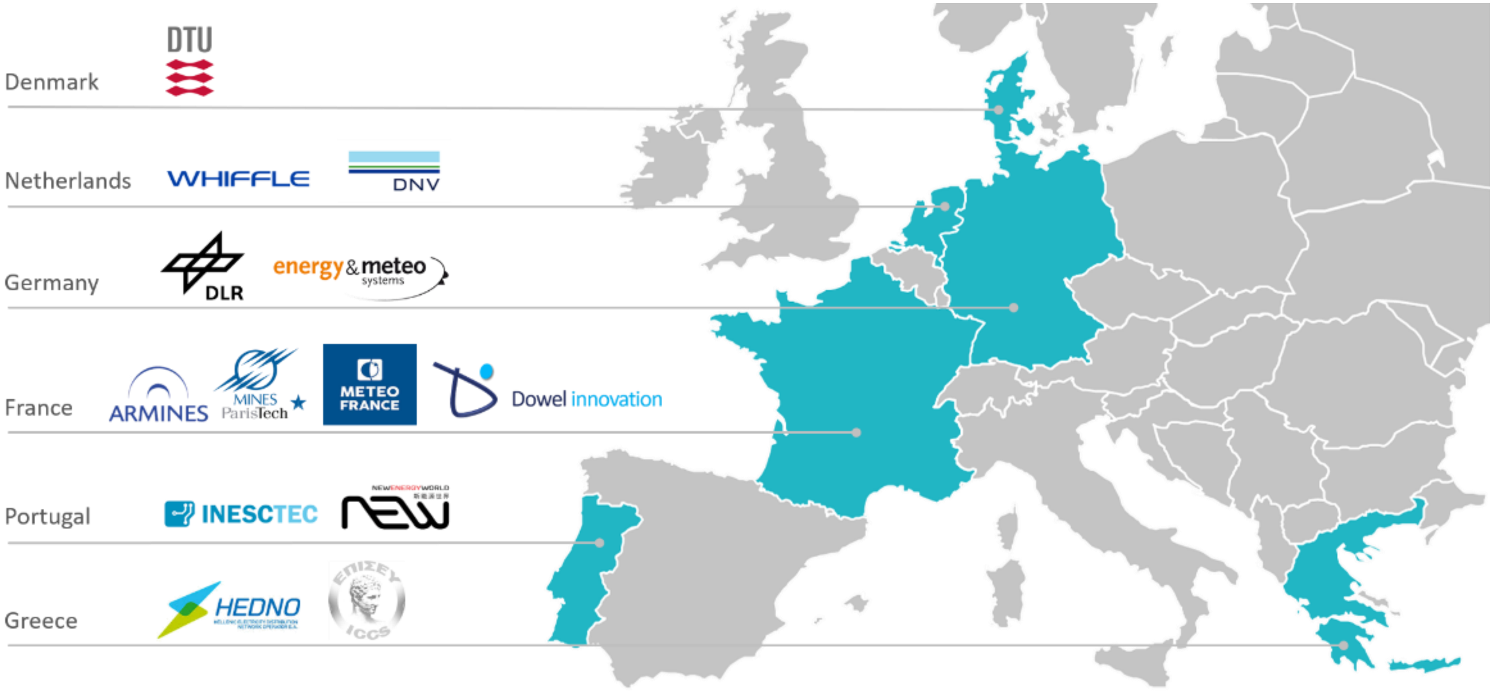
ISGAN
INTERNATIONAL SMART GRID ACTION NETWORK

6 countries
12 partners

End-users
Industry
Research
Universities
Meteorologists

Funds: H2020 programme
Budget: 4 Mio€
Duration: 3.5 years

11/2019-4/2023



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www.smart4res.eu

Science and industry closely co-operate to achieve outstanding improvements of RES forecasting by considering the whole model and value chain.

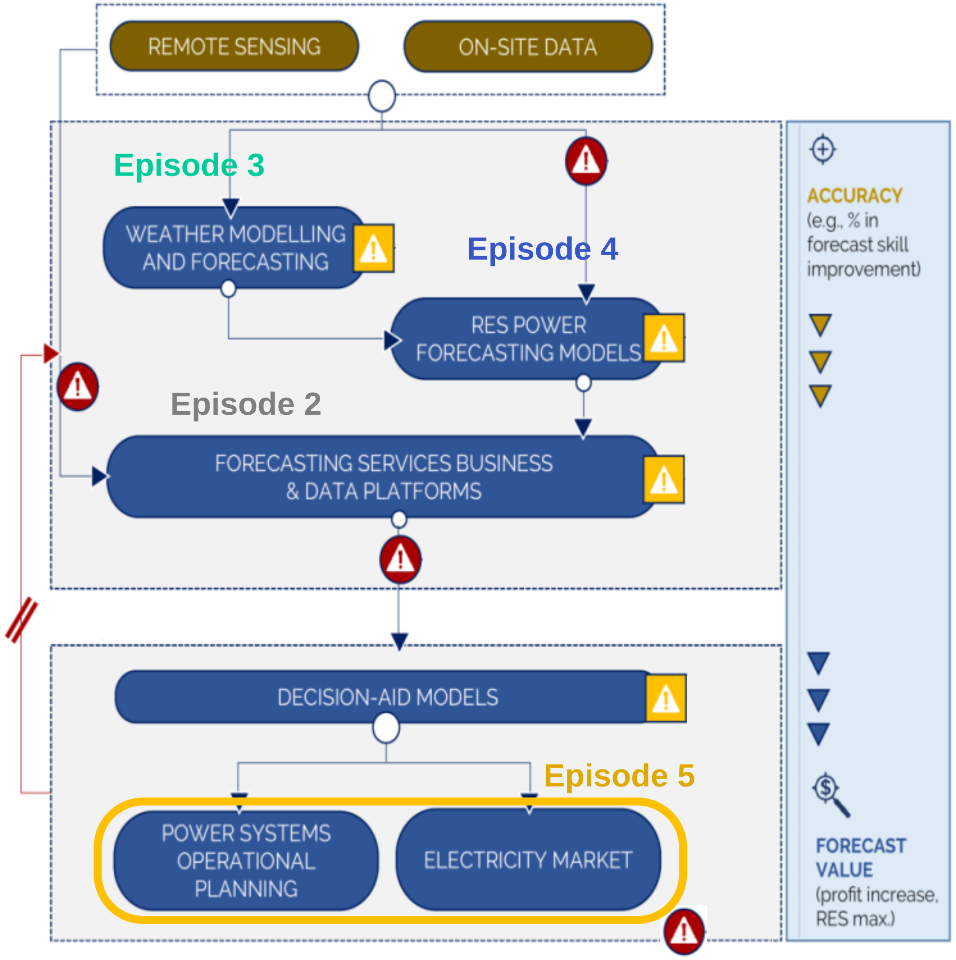
Smart4RES

Smart4RES in a nutshell

Objectives:

1. Requirements for **forecasting solutions** to enable **100% RES penetration**
2. RES-dedicated **weather forecasting with 10-15% improvement** using various sources of data and very high-resolution approaches
3. New generation of **RES production forecasting** tools enabling **15% improvement** in performance
4. Streamline the process of getting optimal value through **new forecasting products**, **data marketplaces**, and novel **business models**
5. New **data-driven optimisation** and decision aid tools for **power system management** and **market participation**
6. Validation of new models in **living labs** and assessment of forecasting value vs remedies

Storage related objectives



Objectives of the webinar

INDUSTRIAL DEPLOYMENT OF STORAGE ASSETS

01 **What are the problematics faced today by industrial actors?**

Example of EDP, targeting 1GW of capacity by 2026 on energy storage.

HOW SMART4RES CAN HELP?

02 **Forecasting and optimization solutions to facilitate the integration of storage into the grid**

03 **Forecasting and optimization solutions to optimize market participation**

Industrial view on the problematic and role of storage
Utilities needs and expectations (EDP)

EDP developments on storage

EDP Renewables is targeting 1 GW of capacity by 2026 on energy storage

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EU-SysFlex

Coordinated use of flexibility for integration of RES, using VPP's and local markets.
(1MW/1,4MWh storage)

XFLEX

Enhance hydropower's flexibility services and potential impact in power markets.
(950MW pumped storage)

Dominoes

Development of local community markets with flexibility and energy assets management.
(600kW/481kWh storage)

Sensible

Analyse the benefits of storage technologies (BESS, thermal) with consumption and local PV.
(600kW/481kWh storage)

Storage solution for B2C

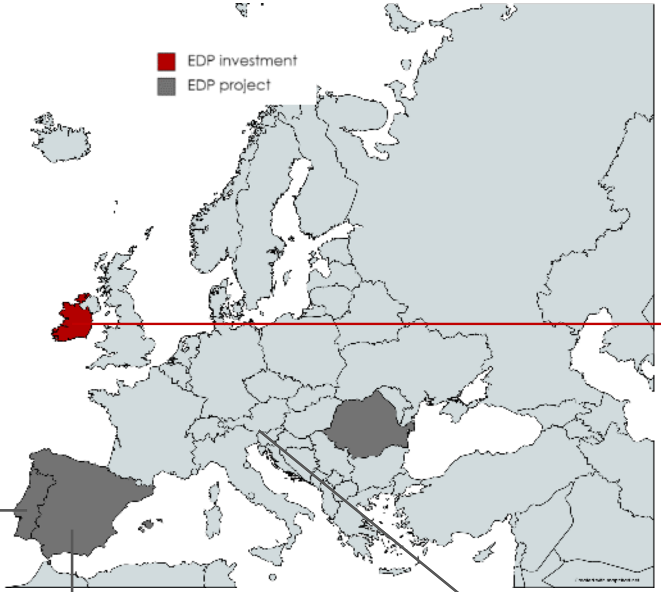
Development of battery management solution for residential clients.

Siestorage

Large scaled demonstration of battery energy storage solutions for MV/LV grids.
(480kW/360kWh storage)

Floating PV

Integrated BESS (aprox. 1 MW) in Alqueva Hydro + floating PV plant (4 MW).
(1MW/1,4MWh storage)



Gridbeyond

Connects industrial demand, generation and storage, to manage energy flexibility and provide ancillary services.

Aboño

EDP España is developing a project to install a Li-ion battery system in Aboño power station.
(255MW storage, to be)

Cobadin

Wind power plant (26 MW) combined with an AC-coupled Li-ion battery.
(1.26MW/1,37MWh storage)

Bailesti

DC-Coupled Li-Ion batteries and solar PV Generation.
(630kW/710kWh storage)

Smart4RES

Industrial view on the problematic and role of storage

A HIGH-RENEWABLE SYSTEM INCREASES THE NEED FOR FLEXIBILITY AND RELIABILITY

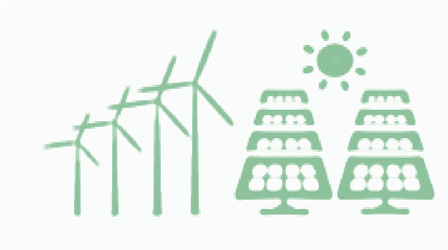
>> HOLISTIC APPROACH
Challenge: To enable near 100% RES penetration
Need: Improve forecasting accuracy and further integrate RES in market processes

>> PERFORMANCE
Challenge: Improve battery performance and system operation
Need: Minimize battery degradation and have the best operational performance possible

>> DISPATCH
Challenge: How to dispatch into different power sources
Need: Storage as a resource of flexibility to support a high share of variable RES

>> ISOLATED power systems
Challenge: Requirements for the storage and Virtual Power Plants (VPP) in islands
Need: Integrated solutions for decarbonization and smartification of islands

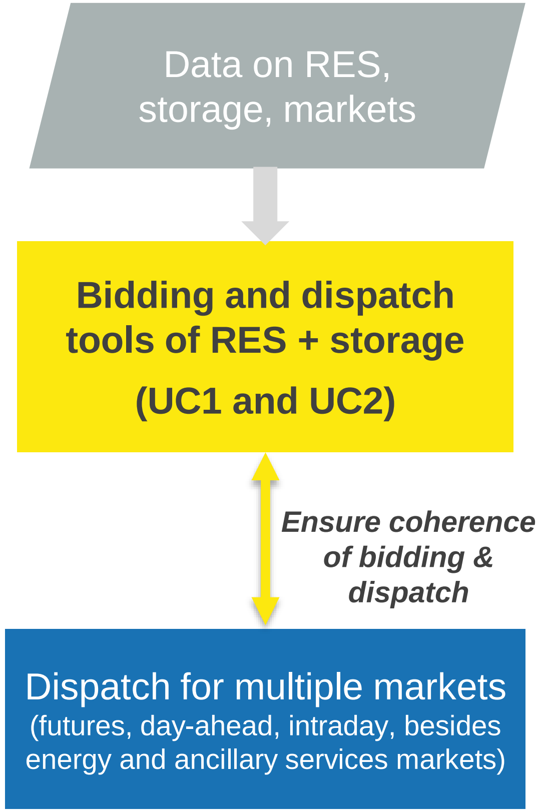
Enable near 100% RES penetration



Challenges	Needs	How EDP is addressing it
Forecasting errors	Improve forecasting accuracy	• (Co)developing solutions that match EDP's needs (e.g. more accurate forecasting, optimal storage operation) • Developing tools to optimize the management of a hybrid system: Battery Energy Storage Systems (BESS) in Cobadin Wind Power Plant
Undispatchable	Further integrate RES in market processes	
Variable	Coupling RES and storage	

Smart4RES: Bidding and dispatch of RES + storage

https://www.smart4res.eu/concept-methodology/use-cases/



- Challenges being addressed by these Use Cases (UC):

- Currently, the use of dedicated storage systems to compensate for RES imbalances on energy markets **does not pay back** the storage investment.

- Forecasts are still **not reliable** to allow the RES production deviation compensation through cost-effective storage systems.

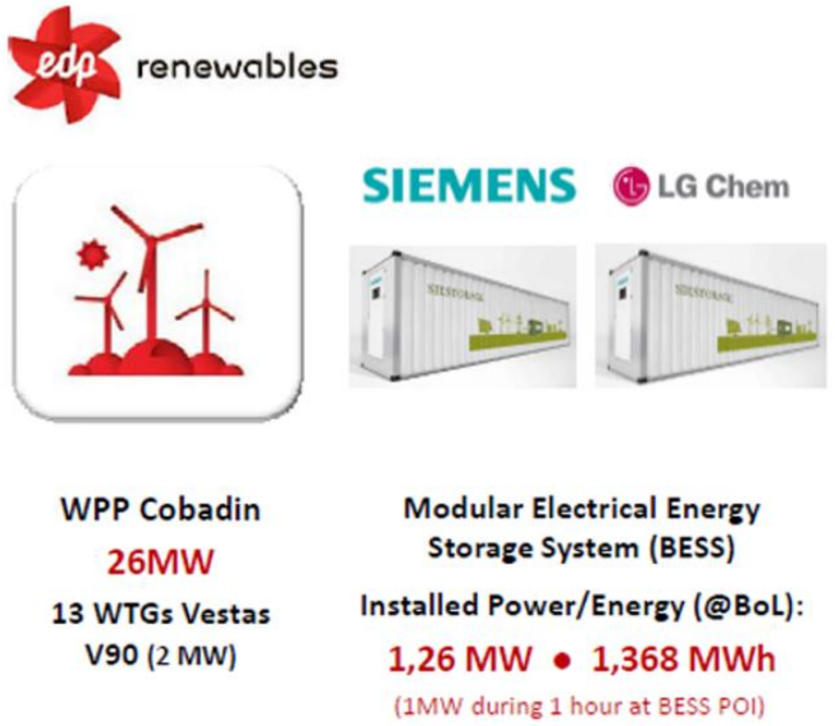
- KPIs:

- Intelligent storage dispatch system to **maximise market revenue** and **minimise deviations penalties;**

- Revenue increased by +20-25% multiple markets vs bidding on a single market.

Managing the Cobadin wind farm

BESS embedded in Cobadin Wind Power Plant, operated by EDP in Romania



- **STOCARE** project:

EDP Renewables aims to study and test applications for **energy storage in combination with wind power generation**:

- Energy management (reduce forecast errors and energy losses)
- Ancillary services (frequency stability, voltage stability and reactive power compensation)

- **Smart4RES** project:

- Study the system capacity to provide multiple products (energy deviation and ancillary services)

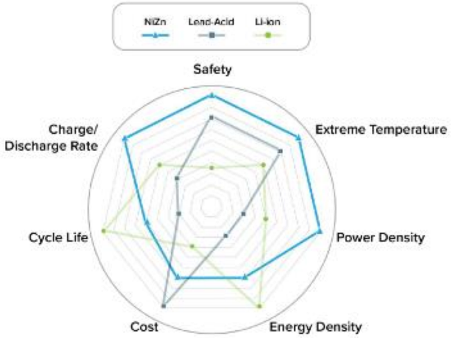
- Minimize energy deviations between the market bids and real-time generation.

Main lessons learned from Cobadin

- Battery Manufacturer **restrictions and limitations should be clear**, about operation and data handling.
- Energy Management System (**EMS**) **detailed definition is critical. Batteries and system behaviour mostly depends on commands & control.**
- It is essential to perform different **cost/benefit analysis** to estimate the optimal theoretical **sizing of the system**

Improve battery performance and system operation

Challenges	Needs	How EDP is addressing it
Battery degradation	Minimize battery degradation	• Developing a novel and promising battery chemistry – a rechargeable Nickel-Zinc battery – having very high energy and power densities and low costs
Electrochemical batteries constraints	Have the best operational performance possible	
When hybrid systems are not available	Electrochemical batteries needed (ex. no hydro everywhere)	



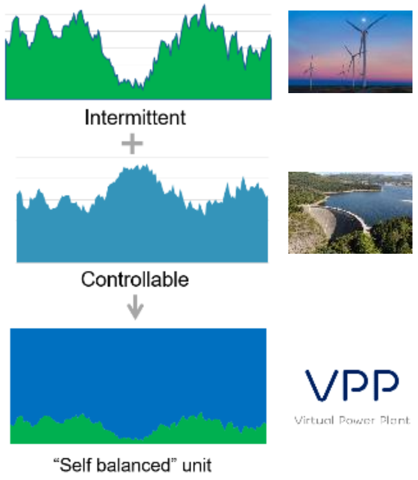
How to dispatch into different power sources

Challenges	Needs
Link with European markets, regulation and developments	Help BU to promote changes on regulation
Undispatched RES	VPP additional flexibilities & the value of storage
High share of variable RES	Supported by Storage as a resource of flexibility

How EDP is addressing it

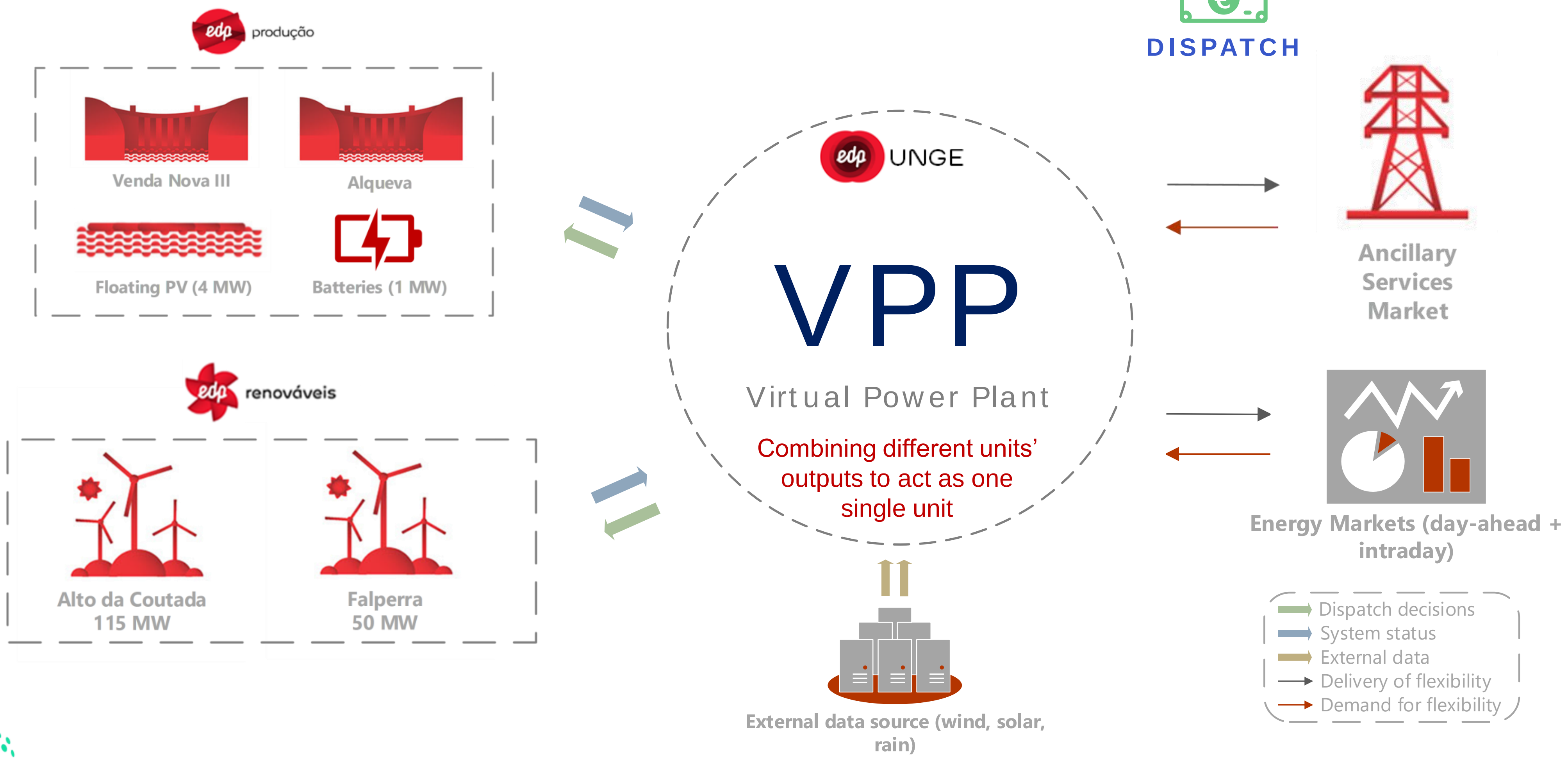
- Coordinating the flexibility resources (Storage / Other resources / System integration) and finding the right blend of flexibility and system services to support secure, resilient transmission system operation

EU-SysFlex

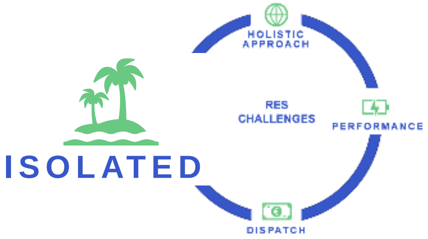


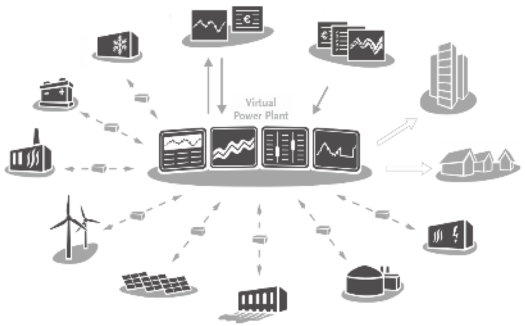
Smart4RES

VPP Portuguese demo

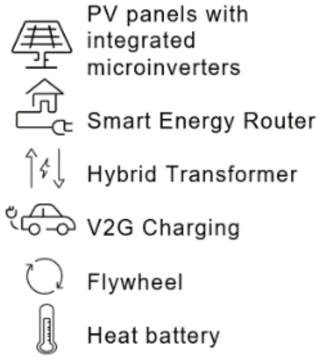


Requirements for the storage and VPP in islands



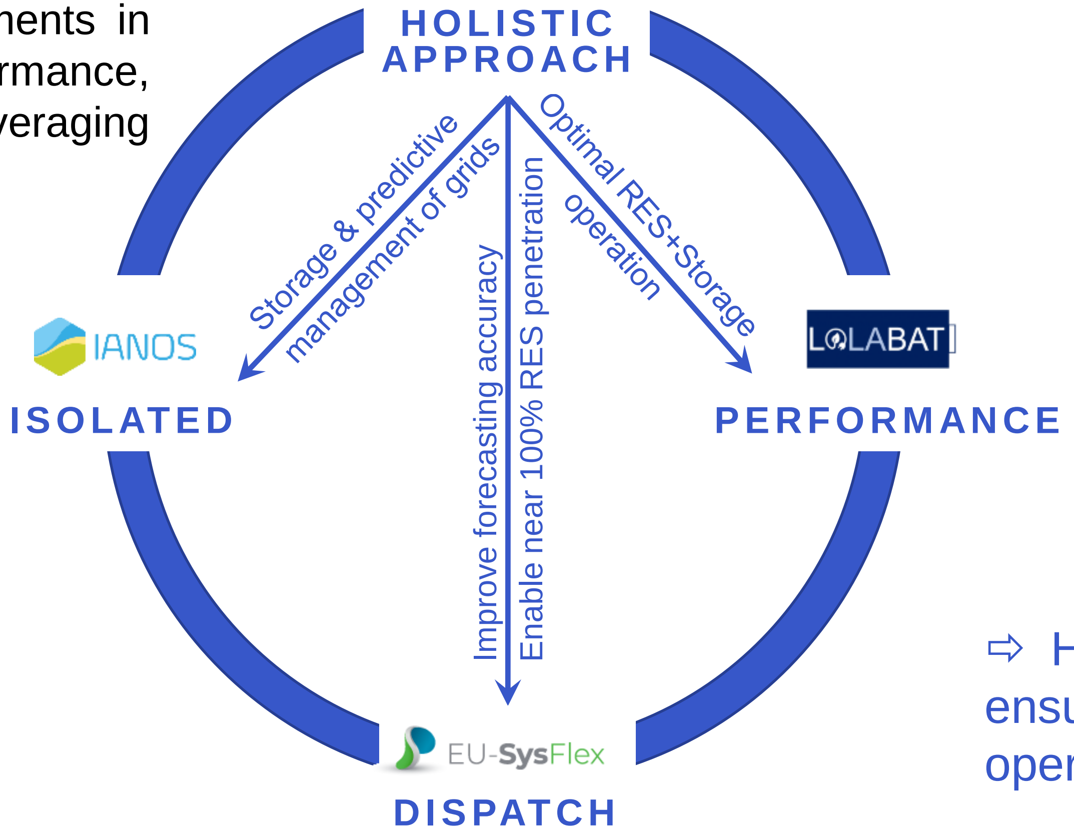


Challenges	Needs	How EDP is addressing it
Decarbonization and smartification of islands	New contributions of storage to predictive management of grids	• Developing integrated solutions for decarbonization and smartification of islands and increasing islands’ energy and resource efficiency
Requirements for storage and VPP in islands	Implementation of large-scale storage solutions for RES in islands	
Specific conditions: fossil fuels, seasonality non-controllable RES	Address distinct market characteristics, policies and regulations	



Delivering knowledge & solutions to EDP's RES challenges

- Smart4RES is using a holistic approach, leading to developments in the other vectors (Performance, Dispatch and Isolated) and leveraging the results of other projects



⇨ How to optimise storage to ensure safe systems operation?

Optimization of storage operation in power systems with high RES penetration (ICCS/NTUA)

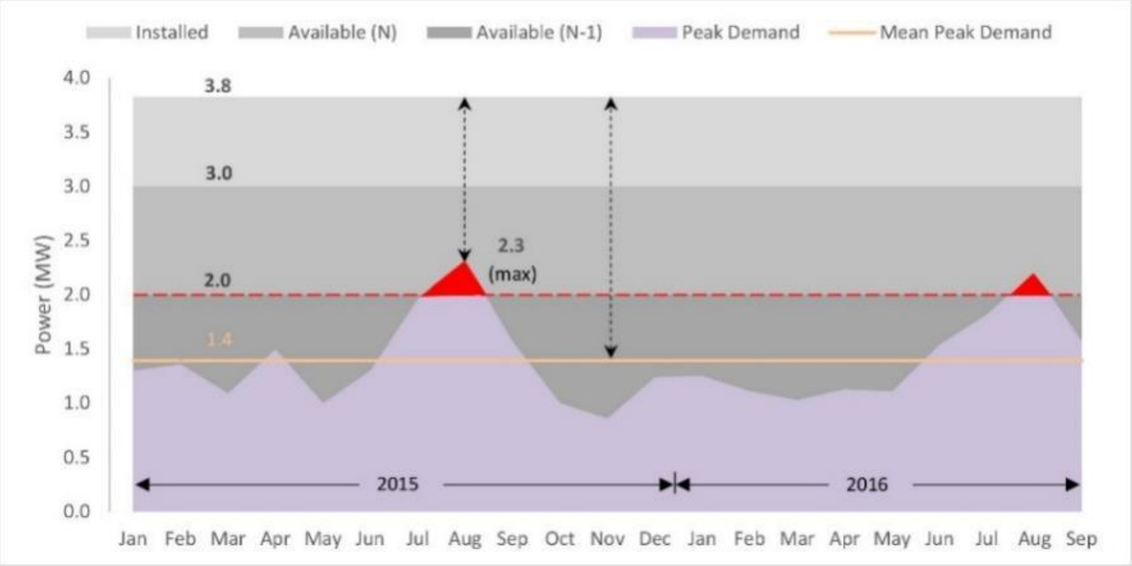
- Focus on non-interconnected islands
- Mitigate security concerns with storage and RES ancillary services
- Minimise costs and ensure security against RES under uncertainty

Dimitrios Lagos – ICCS/ NTUA (National Technical University of Athens)

Greek Non interconnected islands' characteristics

- Host 15% of the Greek population and account for almost 14% of the total national annual electricity consumption
- 60 Islands
  - 32 Electrical Systems (ES)
    - Classification (2009/72/European Union (EU) Directive)
    - 31 micro isolated System (500 GWh annual consumption year 1996)
    - 1 Small Isolated System (Crete) (≤ 3000 GWH annual consumption year 1996)

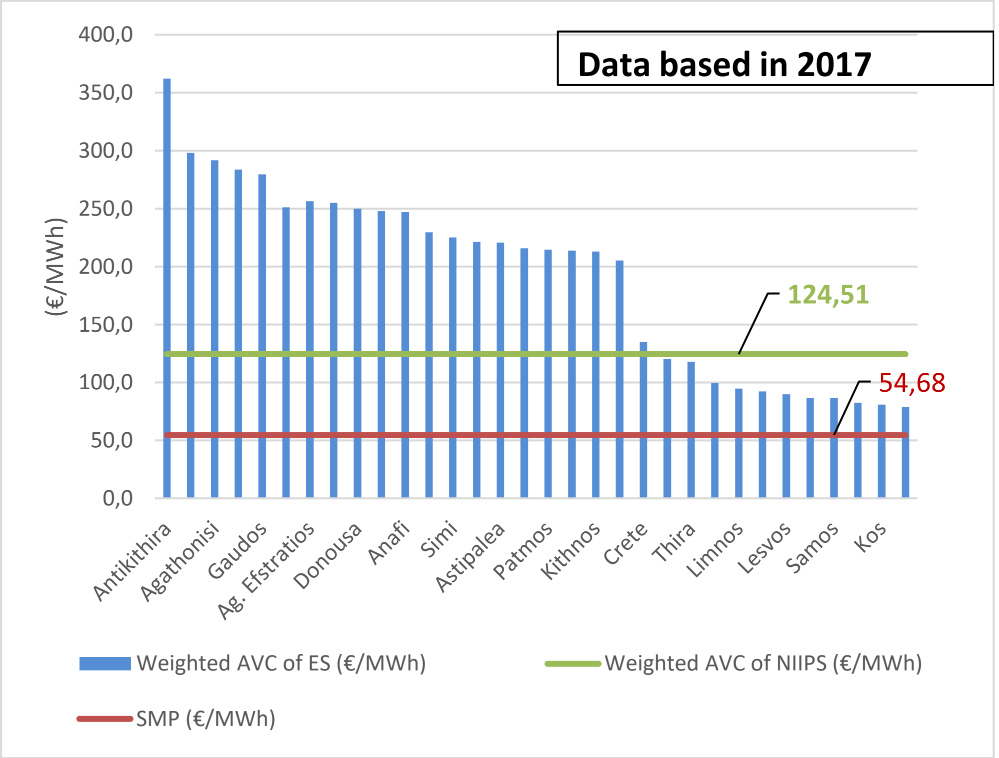
- High seasonal variability in load demand (peak demand in summer due to tourism).



Economic Drivers for decarbonization of islands

Power Generation characteristics

- Supplied by autonomous power stations
- Generators running on Light Fuel Oil (LFO) or Heavy Fuel Oil (HFO)
- High Operational Costs
- Severe constraints on the exploitation of the significant Renewable Energy Sources (RES) potential
    - **technical minima** of thermal units could cover significant portion of load in low demand periods.
    - **penetration level limit**, applied for frequency security purposes



“Smart” island projects under developement

- Installation of battery storage technologies
- Increase RES penetration beyond 60%
- Ensure security of power supply
- Minimize impact on thermal production

Security concerns in islands with very high penetration of RES

- Short Circuit Concerns
  - Protection schemes with Fault Ride-Through (FRT) coordination
  - Less short circuit current levels
- Frequency Stability Concerns:
  - Further reduce of inertia
  - Frequent and severe power imbalances due to:

1. High variability in production of RES
2. Higher probability of RES units disconnection (e.g. FRT, wind speed exceed the Wind Turbine (WT) cut out speed)

BESS ancillary services are important to system security under high RES penetration levels.

Impact of BESS in high RES penetration

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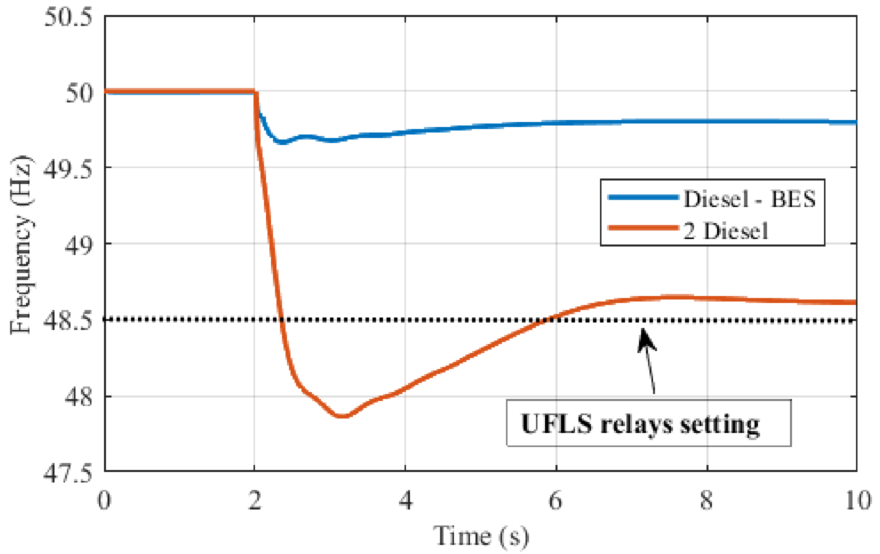
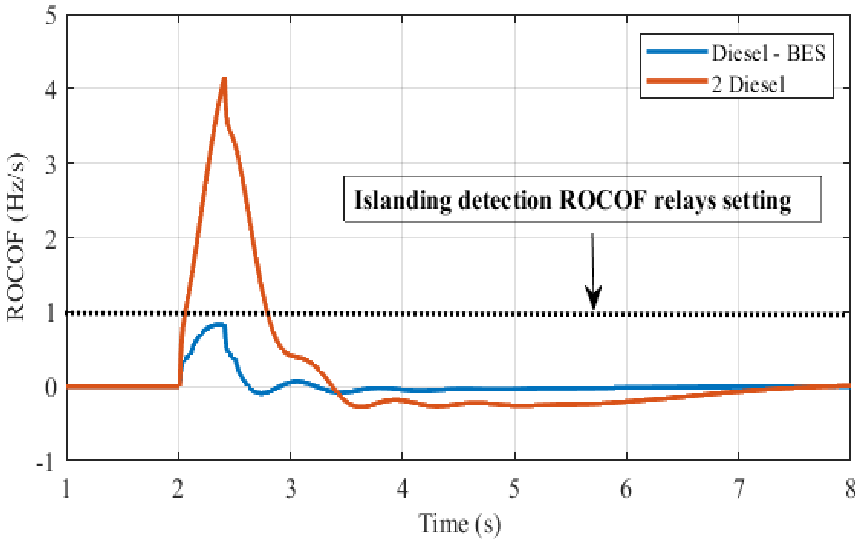
- Dynamic Model of Astypalaia island
- 60% Penetration scenario (2MW Load – 1.2MW WT production)
- Contigency: WT disconnection
- 2 cases
  - 2 Diesel
  - Diesel –BESS (Frequency Containment Reserve FCR + Emulated Inertia)



Frequency transients comparison



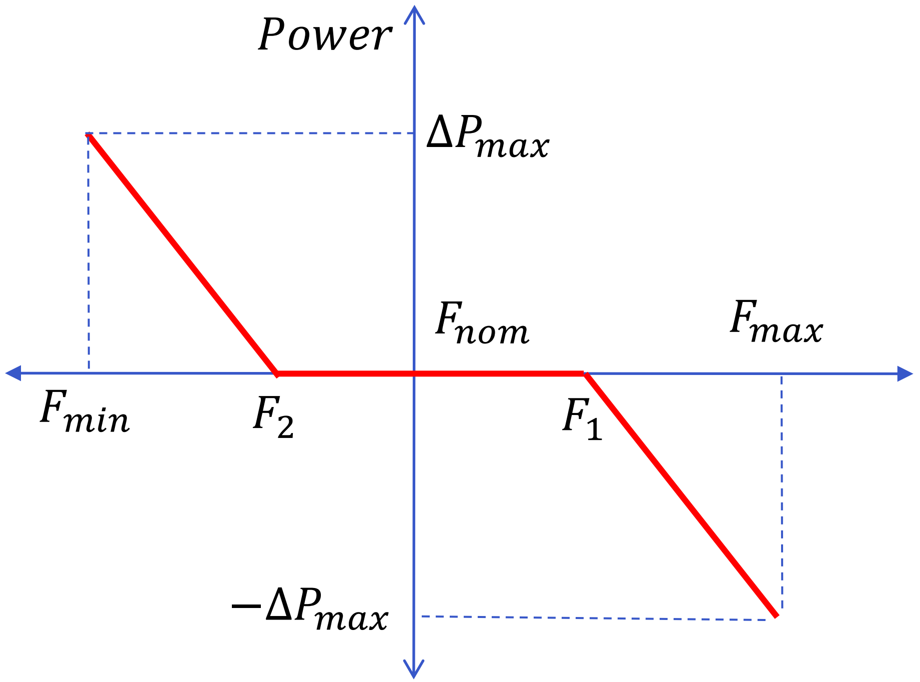
Rate Of Change Of Frequency transients comparison

BESS ancillary services ensure security under high levels of RES penetration

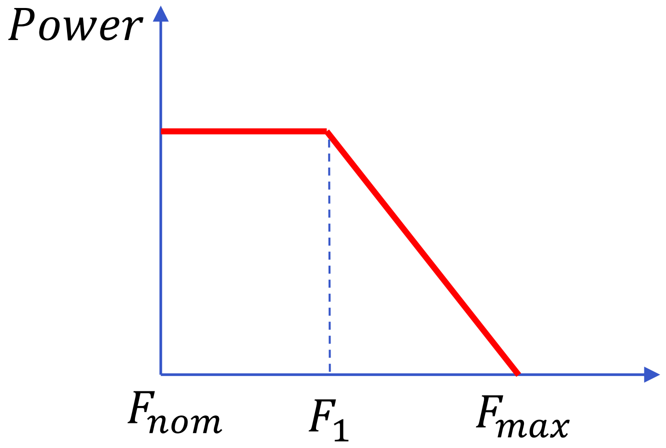
Smart4RES

Frequency Containment Reserve Services (1/2)

- Inverter based generation, mainly battery storage can mitigate the frequency transients, providing fast frequency containment reserves (FCR).
- RES units (e.g. PV, WT) can assist in frequency transient mitigation. FCR for under-frequency events require power curtailment. They can provide downward FCR by curtailing power.



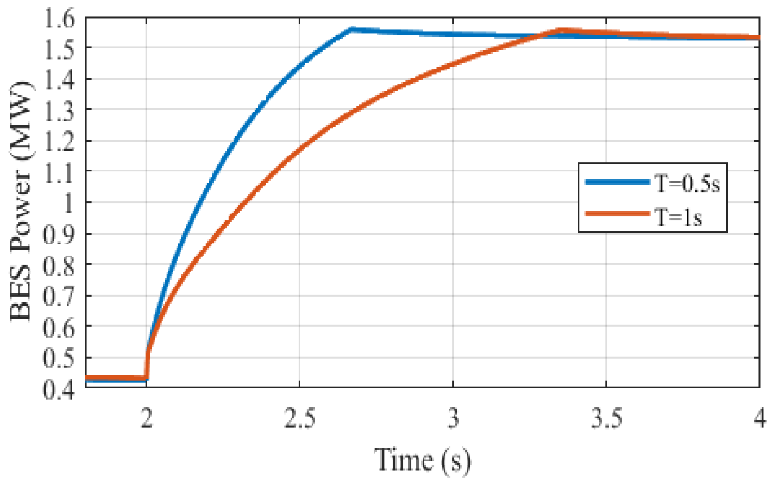
BESS dynamic FCR



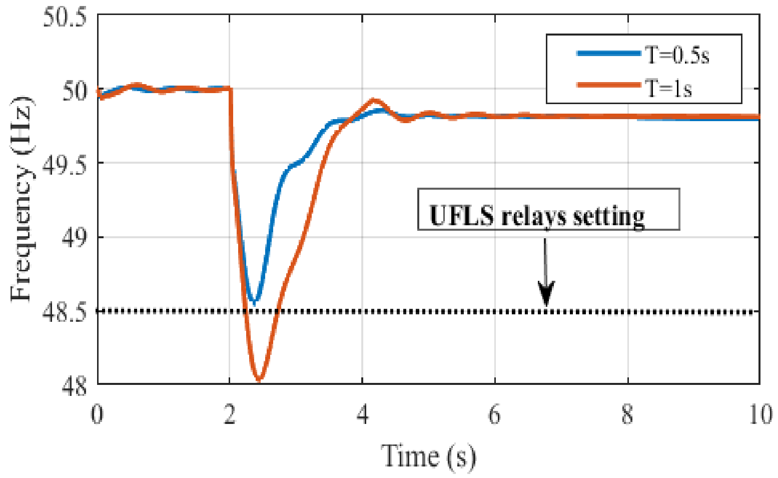
RES dynamic FCR

Frequency Containment Reserve Services (2/2)

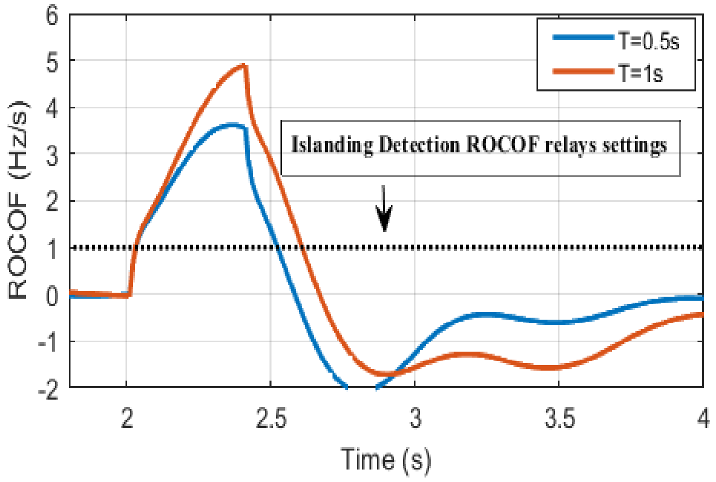
- The speed of the reserve provision affects the frequency transients.
- 1s response defined in several grid codes (e.g. Great Britain) might not be adequate for isolated systems
- Same high RES penetration scenario different time responses from BESS unit



Power reserves provision transients comparison



Frequency transients comparison

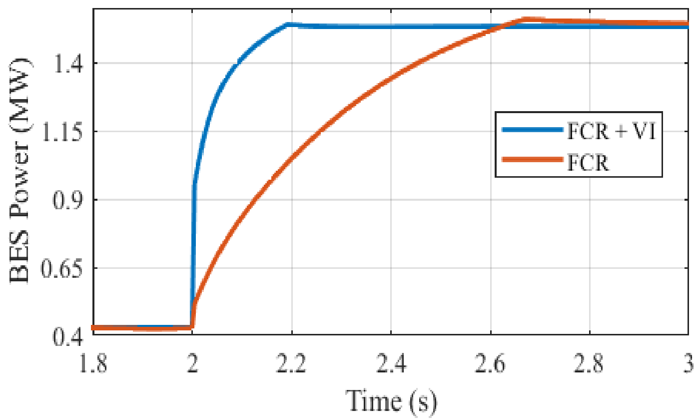


ROCOF transients comparison

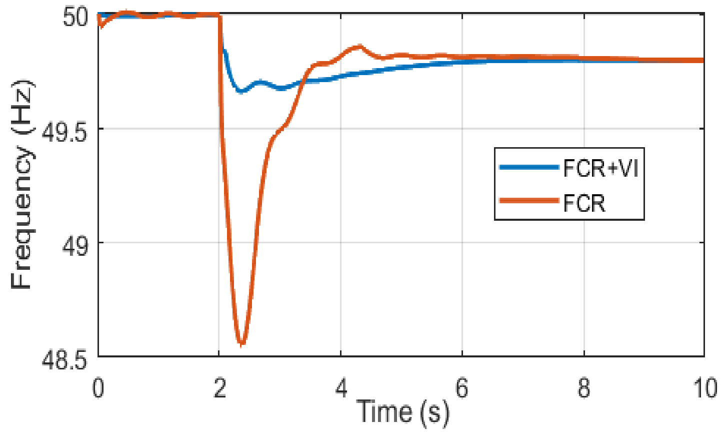
- ***Higher speed response in FCR improve frequency transients***
- ***Still high ROCOF events are expected***

Emulated Inertia Service

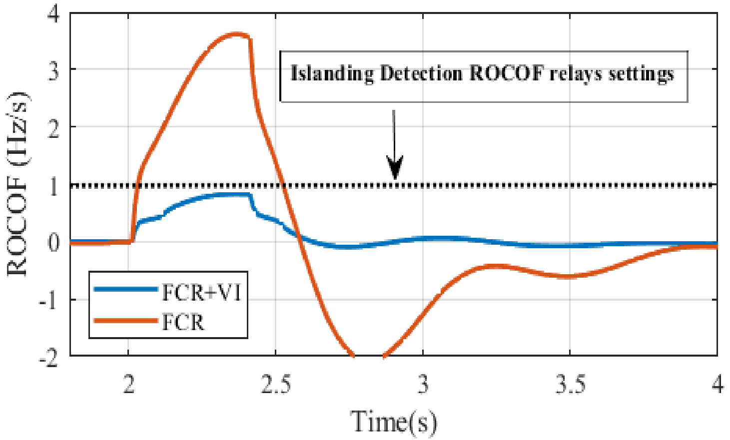
- The lack of inertia in isolated systems is the reason severe frequency transients (especially high ROCOF).
- The inverter interfaced units can emulate the inertia of the system (Virtual Inertia – VI) by modifying their power according to the Rate of Change of Frequency (ROCOF). **Flywheels** can be used also to increase the inertia of the system.
- Virtual Inertia can be provided by RES units when their power is curtailed or by using stored energy (e.g. kinetic in WTs) but it is also of uncertain nature.
- Same high RES penetration scenario different services by BESS unit.



Power reserves provision transients comparison



Frequency transients comparison

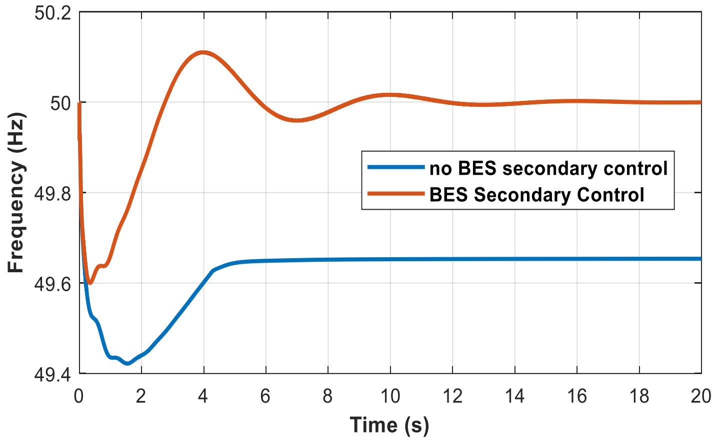


ROCOF transients comparison

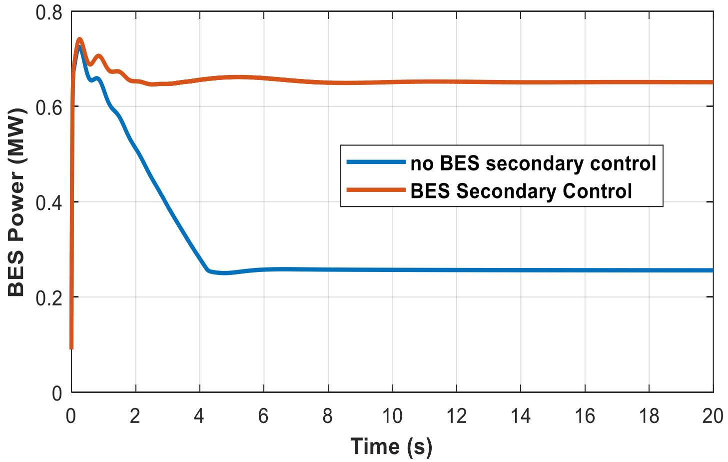
ROCOF and frequency nadir are improved

Storage FRR services

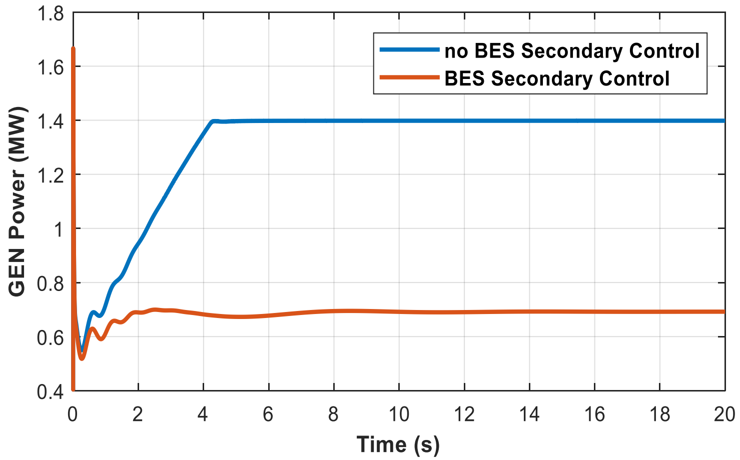
- The **Frequency Restoration Reserves (FRR)** kicks in to restore the frequency to the nominal value.
- BESS units must provide also FRR since the existing FRR by conventional units might be insufficient to restore the frequency and might lead to overload.
- Same high RES penetration case with and without BESS providing FRR (secondary control)



Frequency transients comparison



BESS Power transients comparison



Diesel Generator power transients comparison

BESS FRR are important to restore frequency to 50Hz and avoid diesel generator overload.

How to integrate these services characteristics in economic dispatch?

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Current practice for system security in economic dispatch in small non-interconnected islands:

- Dynamic penetration level limit of RES, applied for stability purposes (e.g. 20-35% of the total demand).
- Upward FCR levels in small isolated islands are specified according to each island characteristics (e.g. PV,WT variability)
- Downward FCR as a percentage of load

Do not include:

- BESS/RES services different characteristics compared to conventional thermal units
- Impact of RES production uncertainty in BESS/RES ancillary services

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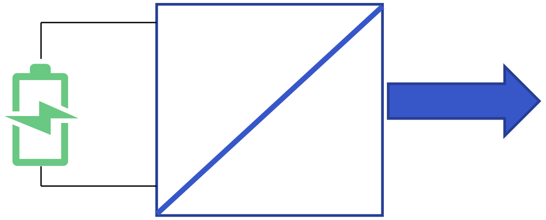
From storage services to economic dispatch constraints



$fast\ FCR\ (\overline{{}_{f}FCR})$

$Synthetic\ Inertia\ (SI)$

SI $\qquad$ $\overline{{}_{f}FCR}$

$$H_{sys} = SI + \sum_{i=1}^{n_{gen}} H_i S_i x_{i,t}$$

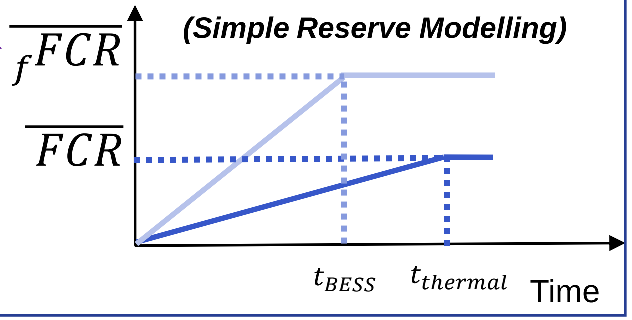
(System Inertia calculation)

H_{sys}

$$\frac{2H_{sys}}{f_{nom}} \frac{d\Delta f(t)}{dt} + D \cdot Load \cdot \Delta f(t) = FCR(t) + {}_{f}FCR(t) - P_{dis}$$

(Swing equation)

${}_{f}FCR(t)$



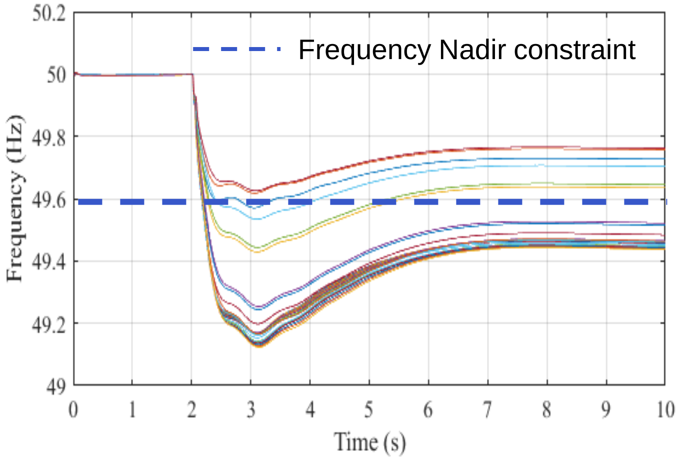
- Use simple physics representation
- Integrate inverter controller dynamics
- Extraction of linear rules for economic dispatch that constraint frequency (nadir, ROCOF, steady state frequency) [1]

[1] L. Badesa, F. Teng and G. Strbac, "Simultaneous Scheduling of Multiple Frequency Services in Stochastic Unit Commitment," in IEEE Transactions on Power Systems

Evaluation of analytic calculation of security rules in economic dispatch

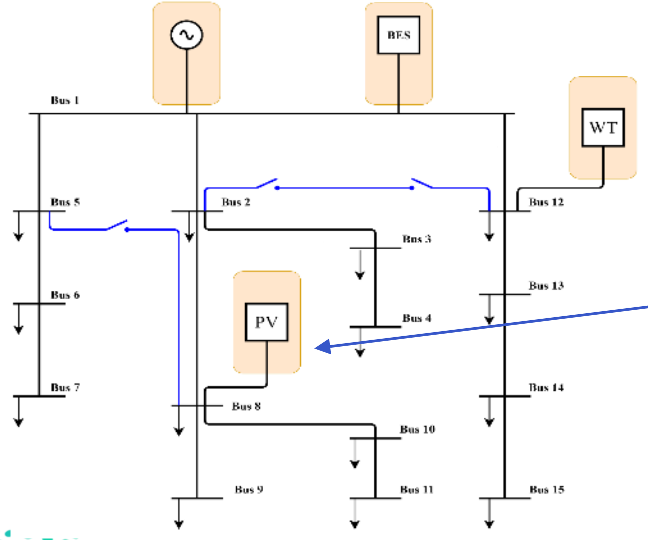
1. Extraction of operating scenarios

- 3 days, 20 minutes Economic Dispatch
- Calculation of reserves in ED
  - current practice (BES+Diesel reserves ≥ max (P_{WT}, P_{PV})
  - Analytic calculation

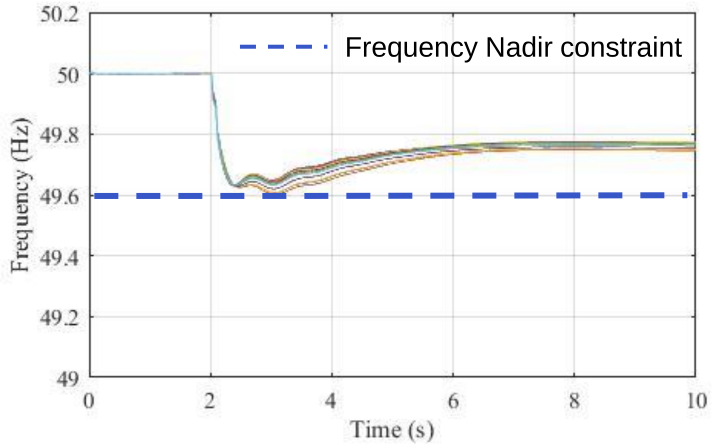


Frequency transients with current reserve calculation practice

2. Dynamic Simulation of scenarios in EMT



Disconnection of max (P_{WT}, P_{PV}) for every scenario



Frequency transient with analytic calculation of reserves

Integration of RES production and Load uncertainty

- Non-interconnected islands are small systems with RES generation located in close areas.
- They also supply limited amount of customers.
- Accumulative load and RES forecasts errors can be greater compared to larger interconnected systems.

Reduce forecast accuracy can lead to:

- Lower RES acceptability by the isolated system.
- Under/over estimation of the reserves (FCR, FRR) requirements.
- Sub optimal use of the battery storage.
- Increased costs.

Smart4RES targets to**:**

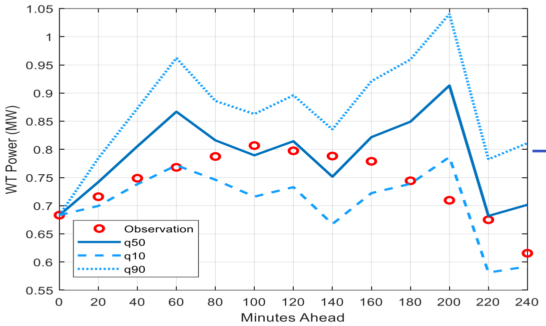
- Improve RES and Load forecast with novel forecast techniques.
- Study their impact in small isolated systems operating in high RES penetration levels**.**

Application of probabilistic RES and Load forecast in stochastic Economic Dispatch (ED)

$$\min \sum_{i=1}^{P} p_i \left(Cost_{prod,i} + Curtailment_{RES} \right)$$

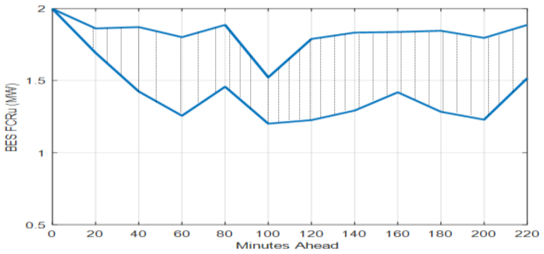
s.t. system constraints (SOC, power balance FCR) for every scenario

Probabilistic Forecasts of RES and Load



Stochastic Frequency Constrained Economic Dispatch

Ensure system constraints (e.g. BESS SOC, FCR) for every scenario



Impact of advanced forecasting modules:

- 4.5% decrease in cost with Probabilistic Forecast/ED.
- Increase in RES penetration ~1%

Cost Comparison (3 days with high RES production, low demand)

Forecast/ED	Deterministic	Probabilistic
Cost (€)	4736	4520
RES Penetration (%)	81.5	82.4

Conclusions on operation of non-interconnected islands in high RES penetration levels

- Pilot projects with battery storage and high RES penetration in non interconnected islands has been considered or already utilized in several islands.

- Battery storage ancillary services are crucial for islands operational security.

- Inverter based generation services characteristics should be considered in the economic functionalities of the system (e.g. economic dispatch).

- RES and Load forecasts in isolated system could have increased errors and should be addressed with novel techniques in their forecast and in power system functionalities.

- Multiple provision of services are also important in larger systems where market participation needs to be optimized.

Optimization of storage and RES participation in electricity markets (ARMINES – MINES ParisTech)

- The role of forecasting
- Maximize RES and storage value under uncertainty
- Control storage with minimized degradation

A typical modelling chain for RES with storage

Step 0 - Investment:
Sizing storage operating with RES

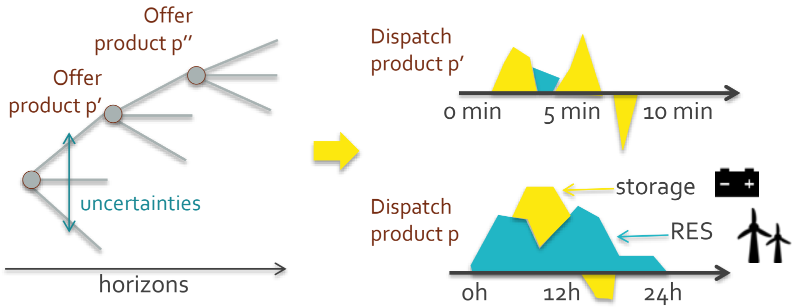
Renewable Forecast

Market Forecasts & Data

Step 1 - Day-ahead, Intraday:
Optimize offer or schedule over multiple horizons

Step 2 – Near Real-time:
Optimize dispatch of RES and Storage

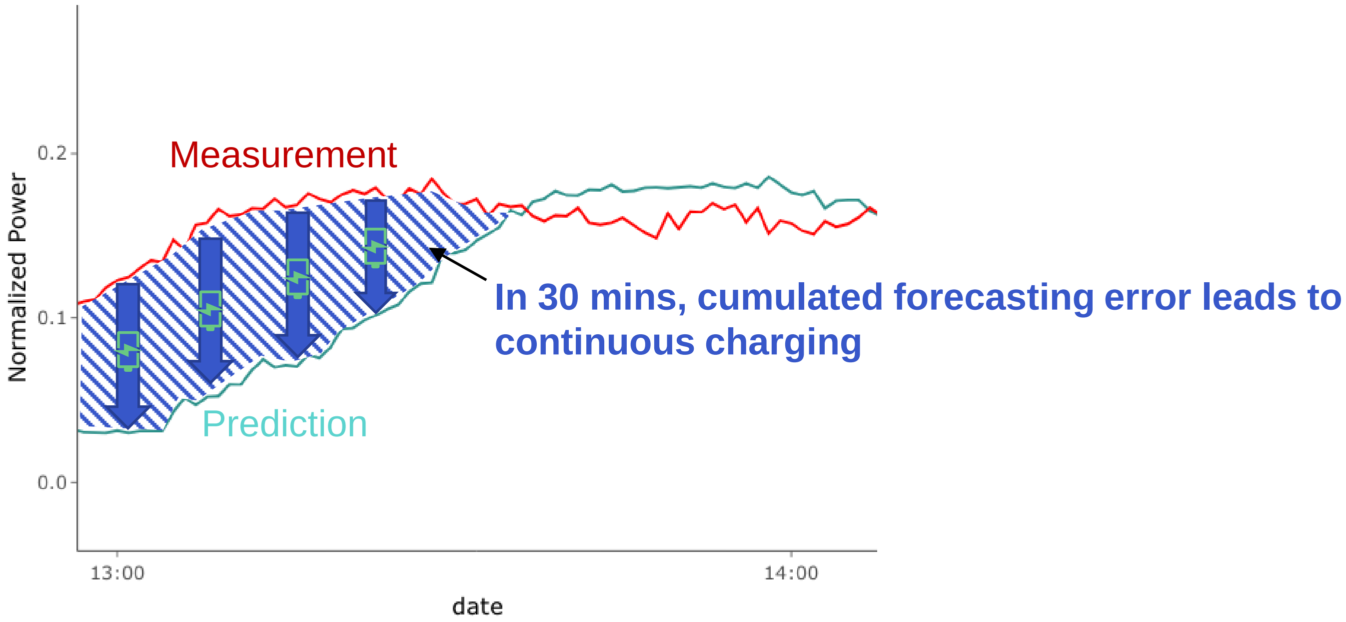
Operation



Step 3 – Ex post:
Continuous performance evaluation & feedbacks

RES forecasting error impacts storage sizing

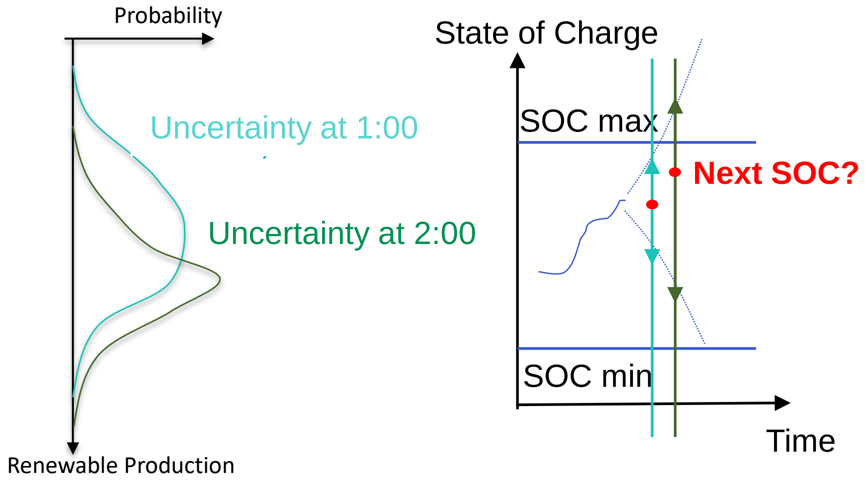
RES forecasting error is **autocorrelated,** i.e. shows correlations in successive timesteps

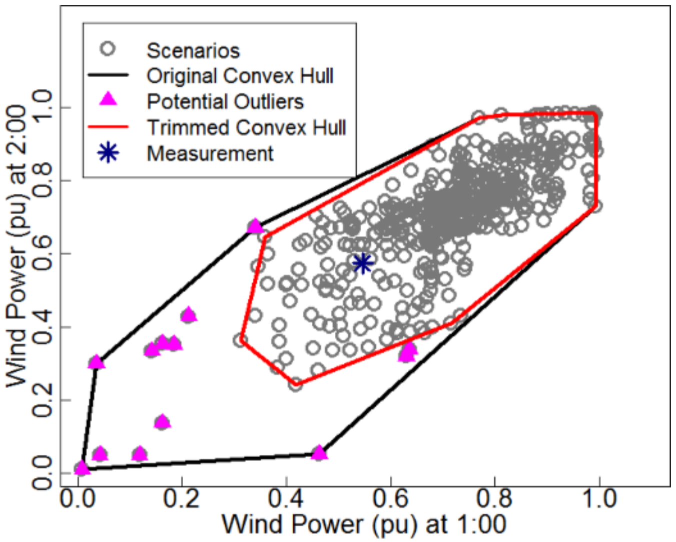


In a hybrid system RES+BESS: **larger cumulated errors contribute to larger storage size** [1]

Temporally coherent RES forecasts are needed for storage

In decision problems with storage, **temporal correlation** in renewable uncertainty is important





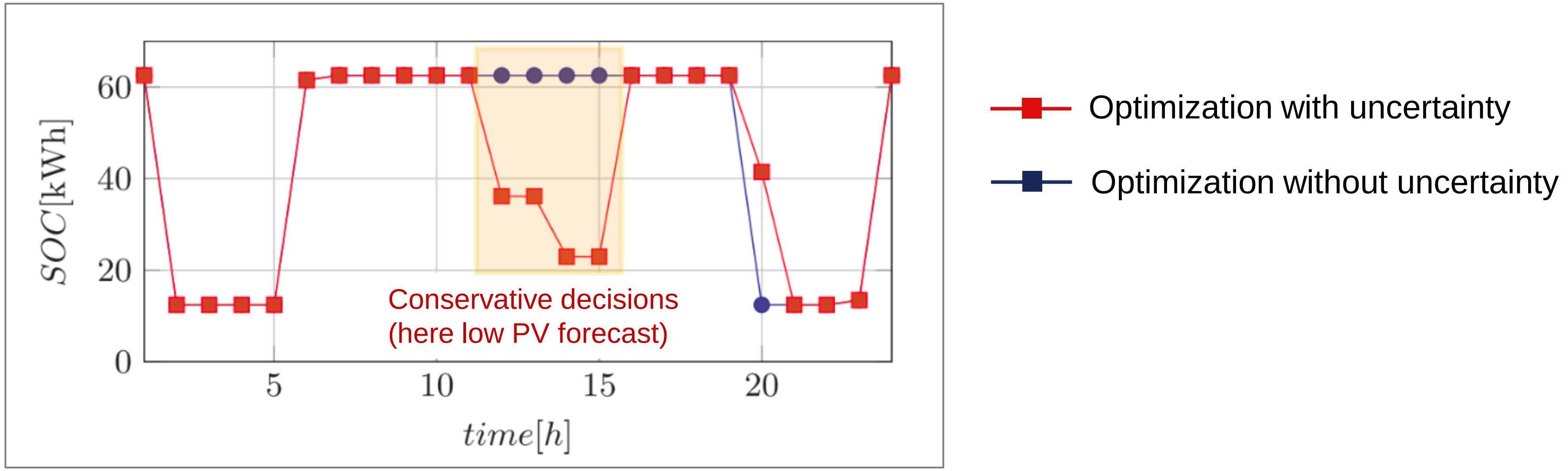
- Independent probability distributions at each time steps don't inform on the sequence of possible events
- This is why scenarios and uncertainty regions have been proposed [2]

Storage trading strategies should consider RES uncertainties

In many decision problems with storage, integrating the distribution of the uncertain variables ξ in the optimization model leads to decisions that adapt better to different weather/market conditions x

$$\min_{Decisions} \mathbb{E}_{\xi \sim P(x)} \left[\sum_{t \in T} cost(Decisions_t | \xi_t) \right]$$

Example: energy purchase and flexibility provision by a prosumer community [3]

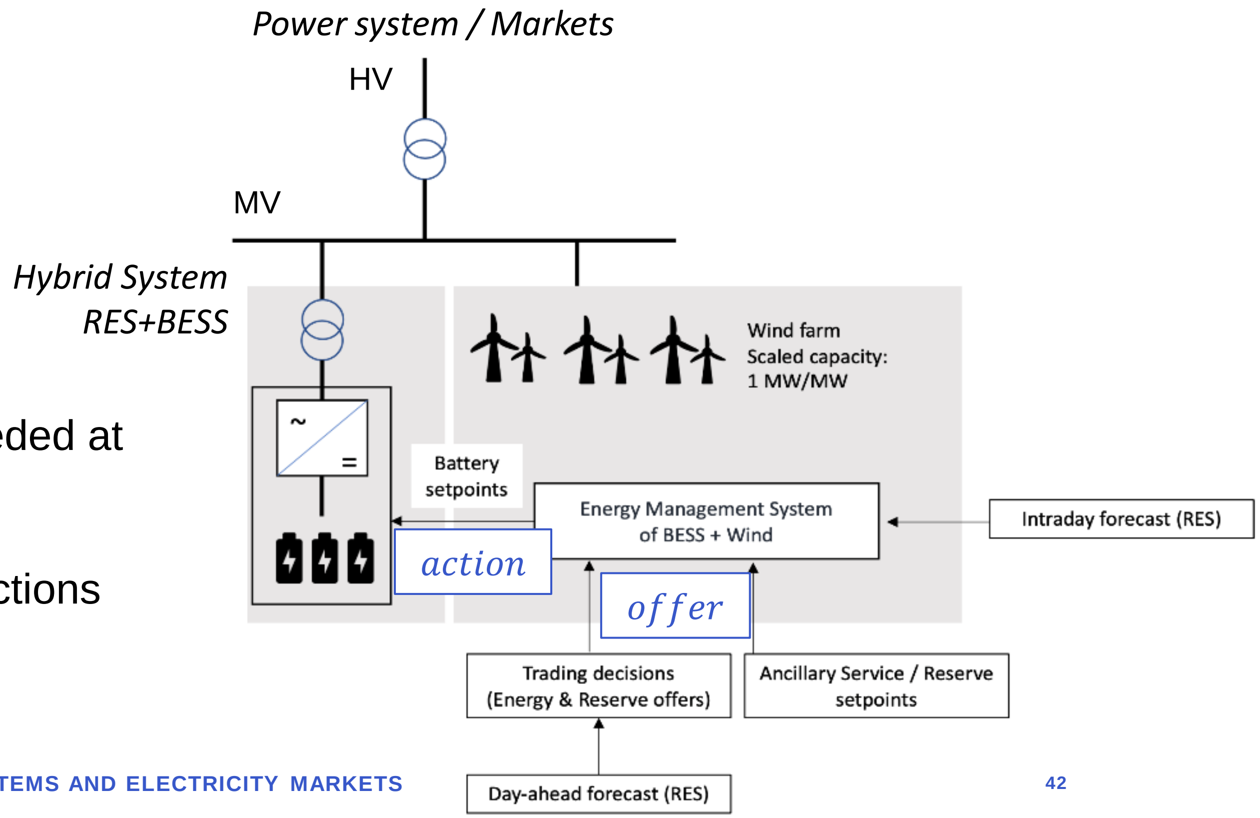


Maximize storage value and minimize degradation?

Optimize multiple objectives costs of market participation and battery degradation

$$\min_{\text{offer},action} \mathrm{w}_{offer} cost_{Energy,AS}(offer, action) + \mathrm{w}_{\text{BESS}} cost_{Degradation,BESS}$$

s.t. storage constraints, RES & price forecasts



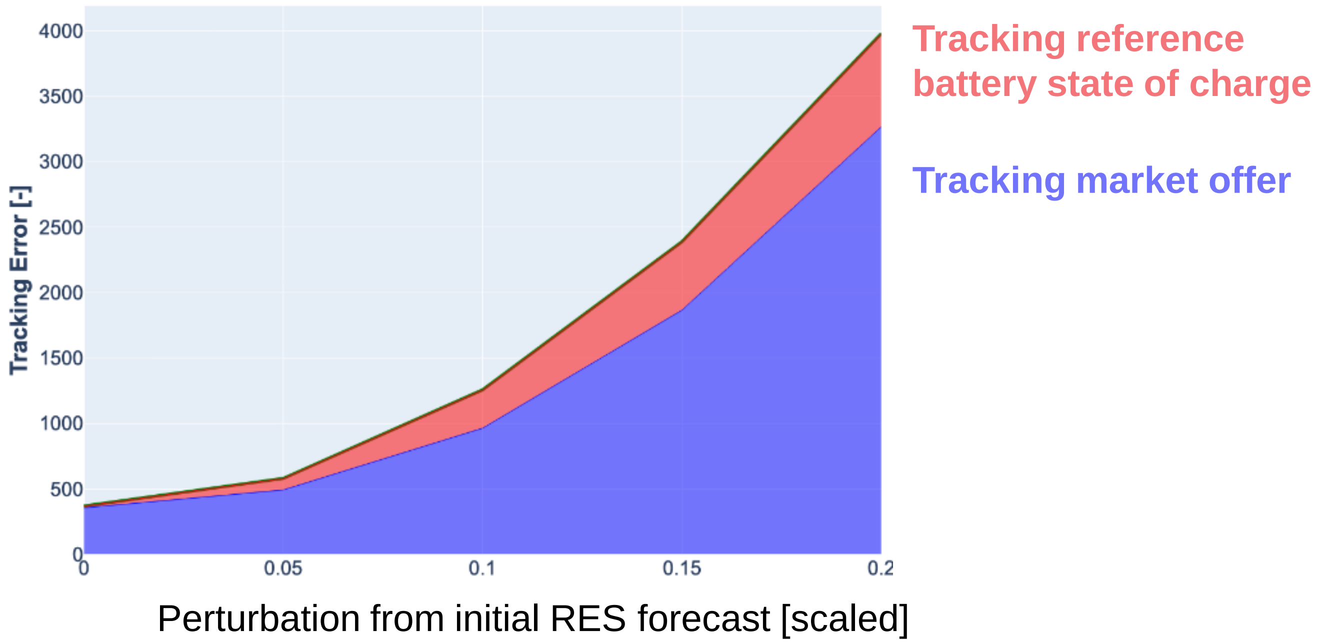
In this type of problem, probabilistic forecast of RES is needed at multiple timescales:

- Day-ahead horizon for offering/scheduling
- Intraday horizon (minutes to hours ahead) for control actions

Maximize storage value and minimize degradation?

High RES forecasting error leads to more difficult control of the storage system

- The control error increases with higher RES forecasting error [4]



Perspective: data-driven approaches for trading/control

Simplification of the trading modelling chain: forecasts are bypassed or **integrated into a single tool**

Data on RES, storage, markets

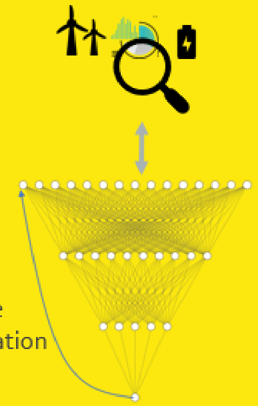
Forecast RES production

Forecast energy market quantities

Forecast ancillary service market quantities

Trading strategy including storage constraints

Data-driven bidding tool



Observation of emulated environment: RES uncertainties, storage constraints and market quantities are implicitly considered

Machine learning solutions learn optimal bids through interactions with the emulated environment

Revenue optimization

Multiple bids

Bids on energy + Ancillary Services (AS) markets

Take-home messages

- Utilities implement storage as a key player providing flexibility in coordination with RES
- **RES forecasting accuracy matters for storage sizing and trading strategies**
- **Minimizing battery degradation** is a major challenge to be addressed by improved materials and optimized control
- **Storage is able to provide multiple ancillary services in order to stabilize isolated power systems with high RES**

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[1] A. Michiorri, J. Lugaro, N. Siebert, R. Girard, and G. Kariniotakis, “Storage sizing for grid connected hybrid wind and storage power plants taking into account forecast errors autocorrelation,” *Renew. Energy*, vol. 117, pp. 380–392, 2018, doi: 10.1016/j.renene.2017.10.070.

[2] F. Golestaneh, P. Pinson, and H. B. Gooi, “Polyhedral Predictive Regions for Power System Applications,” *IEEE Trans. Power Syst.*, vol. 34, no. 1, pp. 693–704, 2019, doi: 10.1109/TPWRS.2018.2861705.

[3] C. A. Correa-Florez, A. Michiorri, and G. Kariniotakis, “Robust optimization for day-ahead market participation of smart-home aggregators,” *Appl. Energy*, vol. 229, no. April, pp. 433–445, 2018, doi: 10.1016/j.apenergy.2018.07.120.

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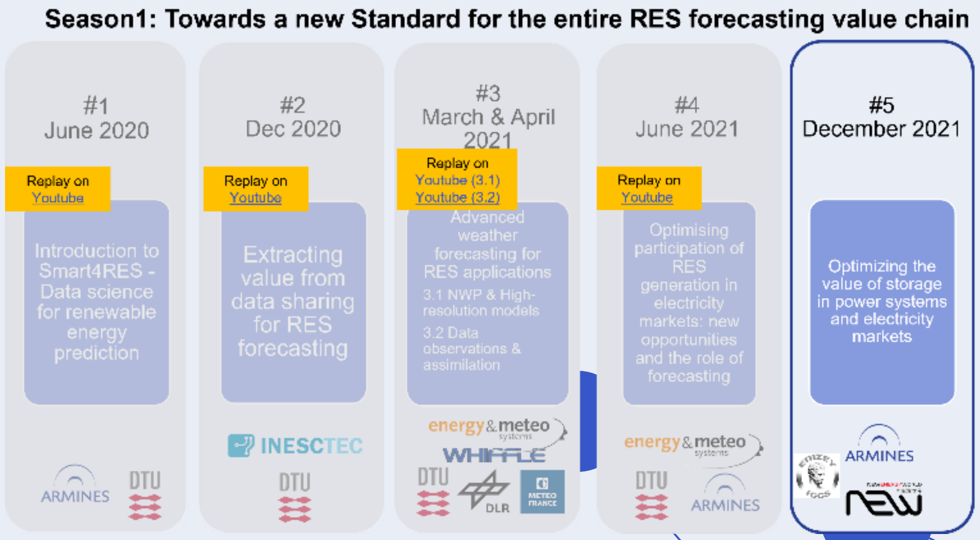

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