THE HORIZONTAL ELECTRICITY SYSTEM THINK TANK

06 June, ‘25

1. **Elia** – voltage management optimisation algorithms

2. **Virya Energy** – Hyoffwind project

3. **Huawei** – Grid forming aspects for batteries

1. **Elia** – voltage management optimisation algorithms
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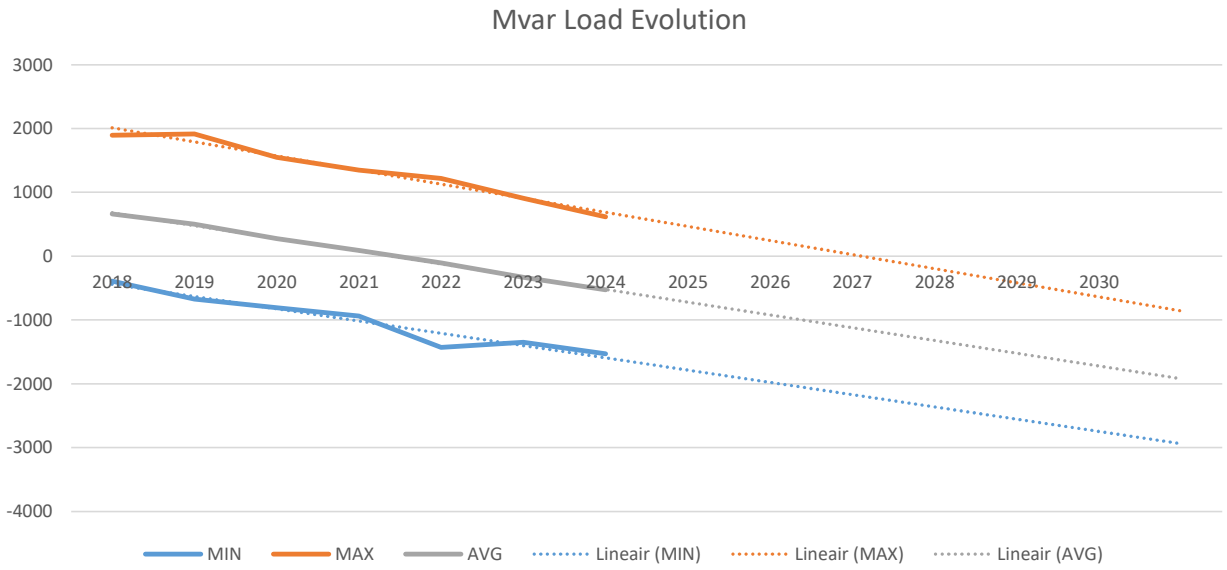
Voltage Management

Think Tank

September 2025 | Joachim Van Erps

Load



- The Mvar load, coming mainly from the DSO's, is quickly becoming more capacitive at a rate of 200 Mvar/year.
- Main Drivers:
  - More and heavier cables in the DSO grids
  - Less electrical motors and more power electronics

➡ The load is quickly becoming more capacitive +/- 200 Mvar/year

Elia cable projects

PRESS RELEASE | August 30, 2024

Elia orders 945 km of cables from NKT, Nexans and Prysmian to meet new connection requests and strengthen its grid

Elia is also massively investing in underground cable projects, which produce a lot of Mvar

⇒ Together with capacitive load, very high need for compensation!

Some examples:

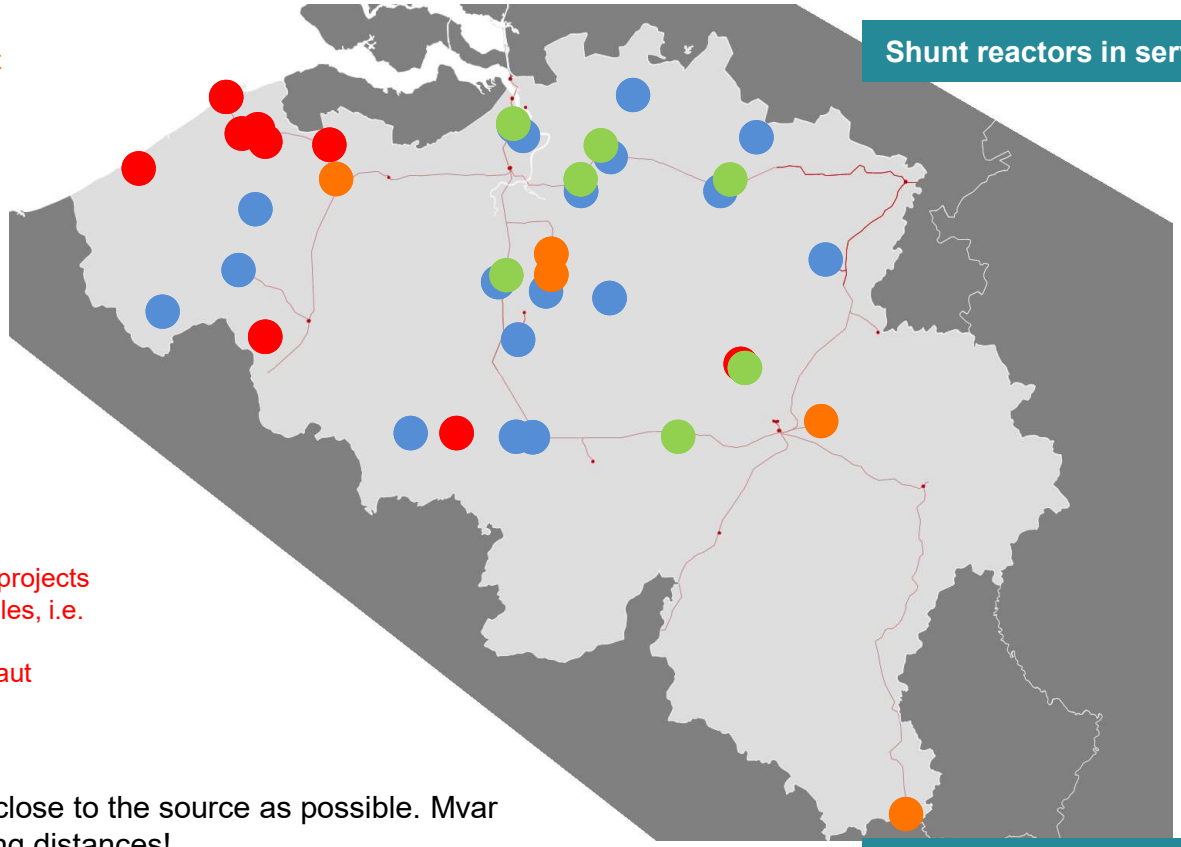
• Stevin axis 380 kV cables:	4 * 10 km	400 Mvar
• Hainaut reinforcement 150 kV cable:	27 km	55 Mvar

Overview all planned SHRs since 2018

Voltcontrol I focused on guaranteeing import capacity with capacitor banks (no shunt reactors)

Voltage Control II	**0.5 Gvar**
Voltage Control III	**1.0 Gvar**
Voltage Control IV	**1.6 Gvar**
Project specific	

Project specific compesantion foreseen for projects with a significant length of underground cables, i.e. Stevin project in the past,
and upcoming Ventilus and Boucle de Hainaut projects



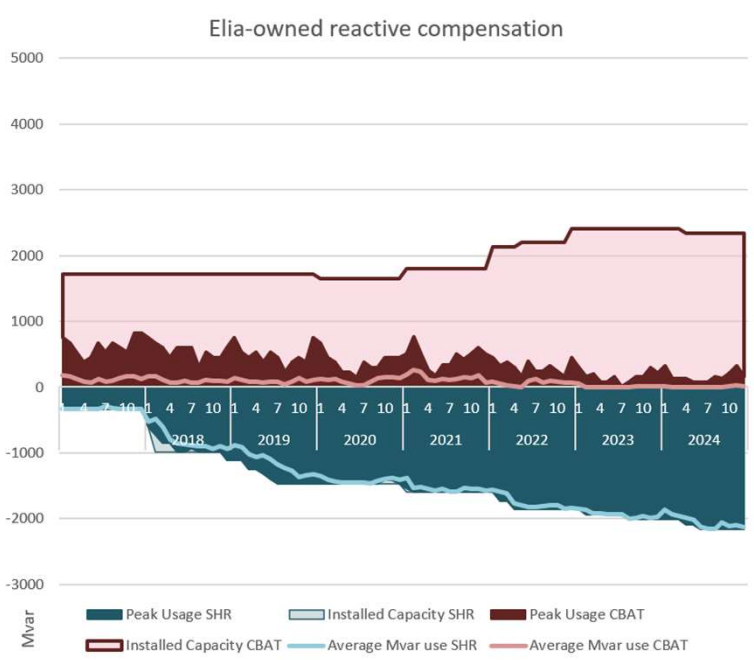
Shunt reactors in service today: 2.3 Gvar

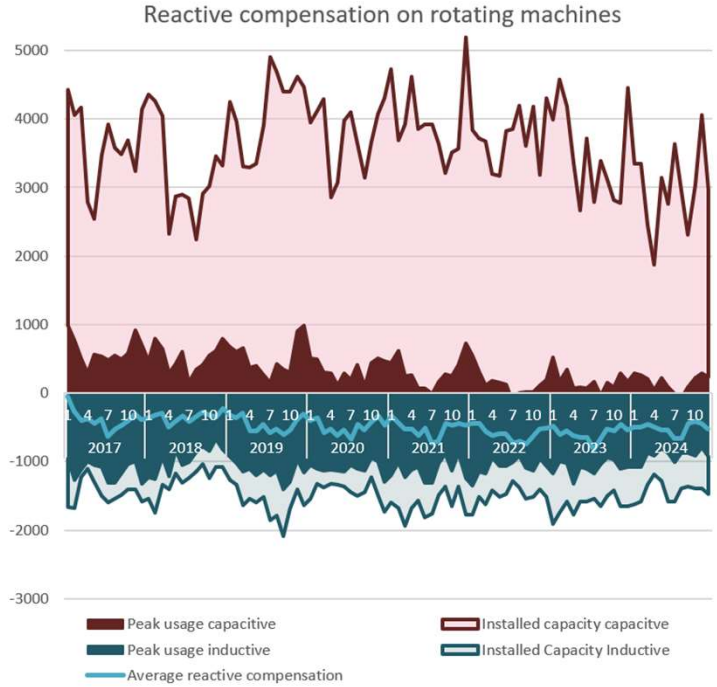
x 2
in ~4 years

Planned today-2029: 2.2 Gvar

Reactive compensation needs to be as close to the source as possible. Mvar cannot be transported efficiently over long distances!

Utilisation rate of shunt reactors, capacitors and power plants





The utilization rate of shunt reactors is >99%, indicating a clear saturation of our available assets

Cables, Load & Shunt reactors

AS IS:

2024 Mvar situation at most critical time:

- Load: -1500 Mvar
- Q Elia grid: -2400 Mvar
- Shunt reactors: 2100 Mvar
- Voltage service providers: 800 Mvar
- **Sum** **-1000 Mvar**

=> There is a Q gap of 1 Gvar, which needs to be covered with measures of last resort (de-energization of cables & PST circulation)

TO BE:

Trend for the coming years for shunt reactors, Elia cable projects, and load:

	Shunt Reactors	Cables	Load	Net effect	**Cumulative net effect at end of period (compared to 01/01/2025)**
2025	560	-62.4	-200	298	**298**
2026	225	-206.38	-200	-181	**116**
2027	1155	-49.5	-200	906	**1022**
2028	545	-60.56	-200	284	**1306**
2029	150	-64	-200	-114	**1192**

Slight improvement of situation in 2025 & 2026, but still a global deficit. However major “game-changer” commissioning of shunt reactors is expected only by early 2027 when we will close the gap

Regulating units

Decommisioning and revisions

- There are significant outages of large regulating assets, making voltage management more difficult especially during the summer of 2026

Large regulating assets - Revisions		2026											
		jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Doel 4	01/04 - 01/11												
Tihange 3	01/04 - 01/11												
Coo 1	22/03 - 01/04												
Coo 2	12/04 - 22/04												
Coo 3	18/02 - 31/12												
Coo 4	01/03 - 11/03												
Coo 5	21/06 - 02/07												
Coo 6	07/12 - 17/12												
Nemo HVDC	21/09 - 27/09												
Alegro HVDC	13/04 - 24/04												

- This is on top of decommissioning of Doel 1, Doel 2 and Tihange 1 during 2025

New assets

- CRM power plants will be in service during the winter of 25-26
- Battery energy storage systems (BESS) are coming online, bringing much needed 24/7 voltage control services. Important to keep in control permanently as much as possible (compensator mode)!

Trends

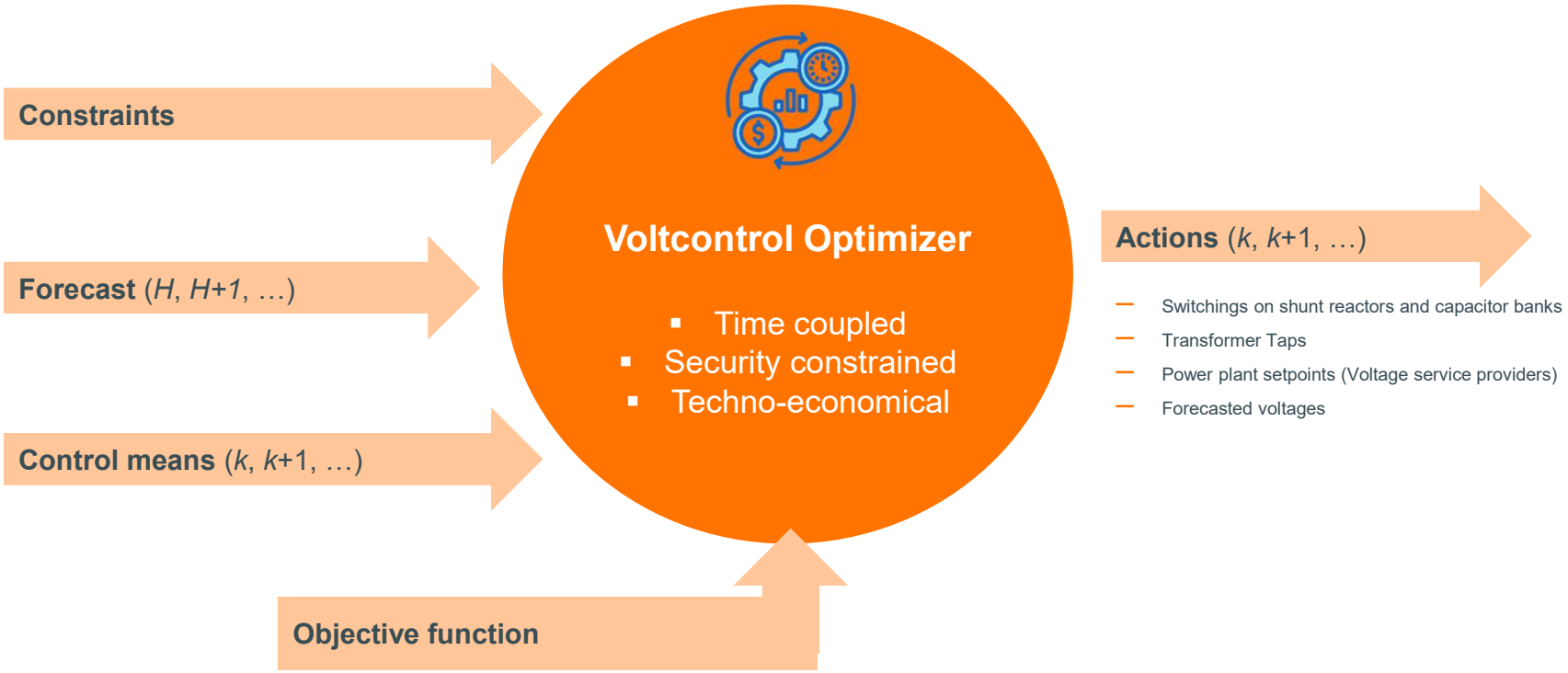
The days of the centralized grid, with big nuclear power plants doing the heavy lifting are about to end

The future grid contains more decentralized production, and many small units

At the same time the variability increases greatly, with power flows reversing depending on wind and sun conditions in Europe

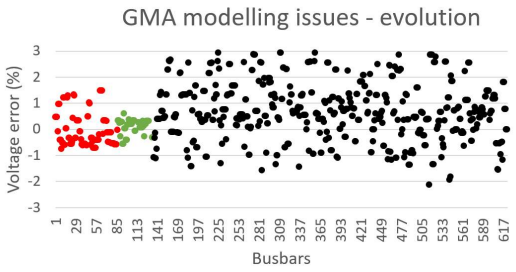
=> Human control will become infeasible, need for automatic optimisation

Voltcontrol: An intraday optimalisation

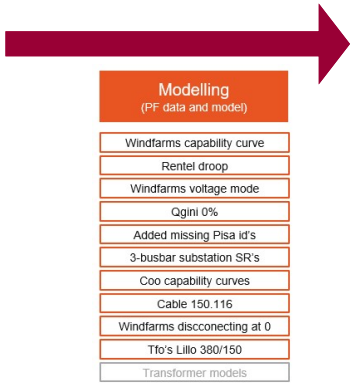


The importance of Grid Model Alignment

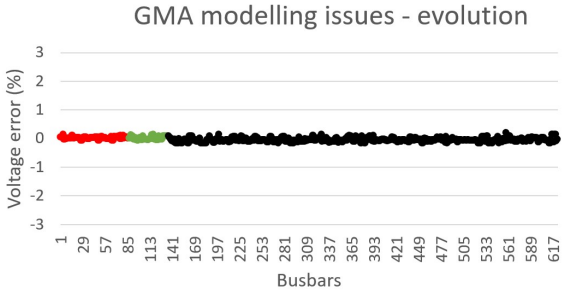
1) Initial grid model errors



2) Model corrections

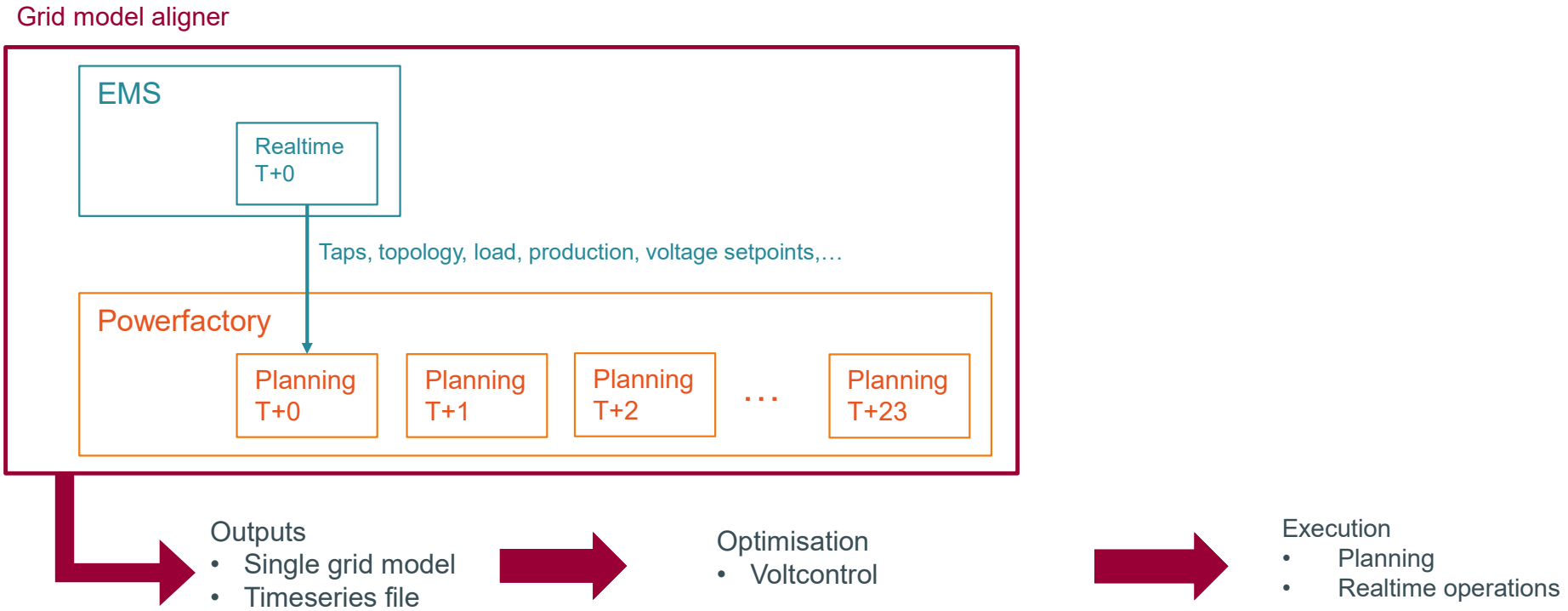


3) Final grid model errors



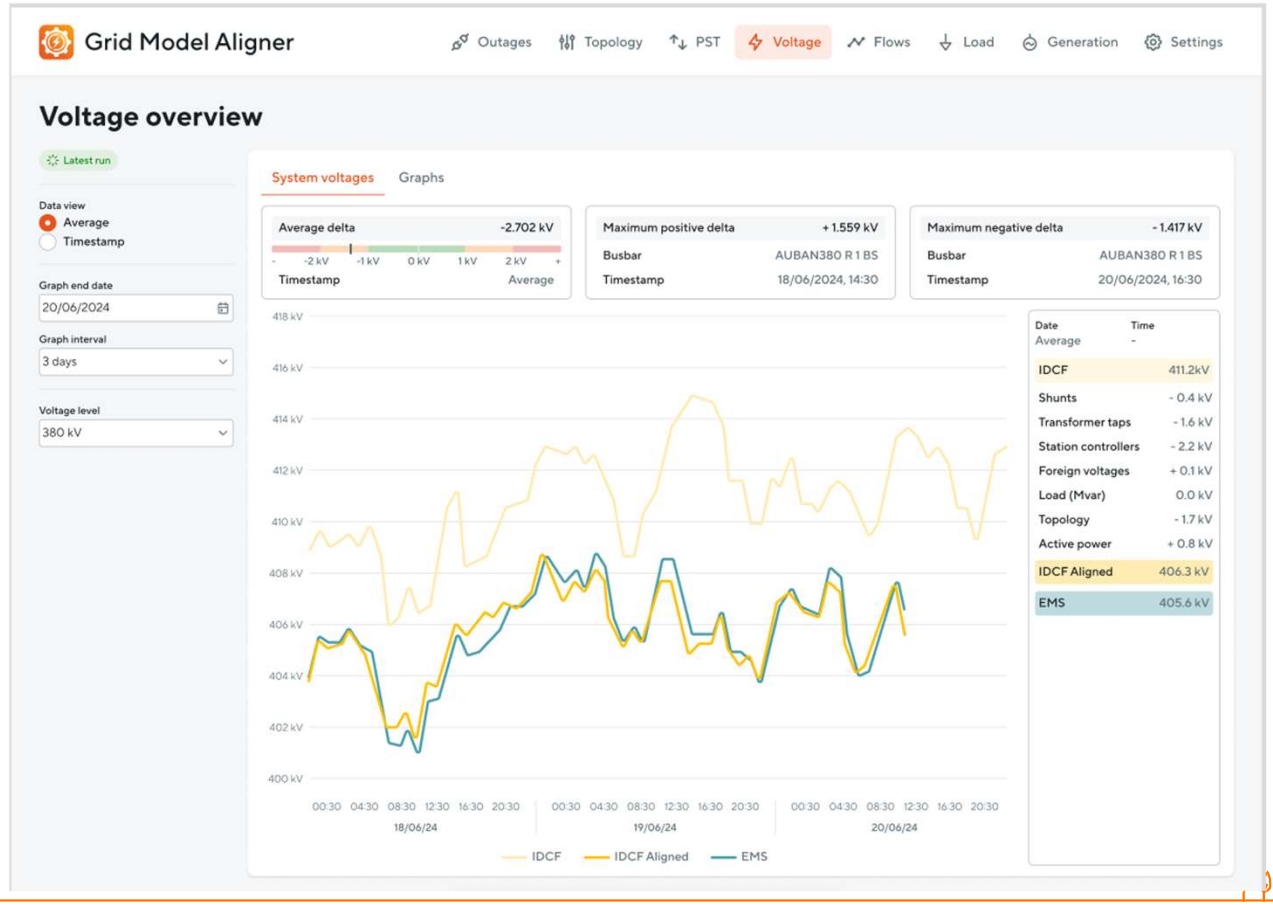
A project was launched to correct and align our grid models, with massive improvements, so our real-time and planning models are matching better

Matching real-time and planned grid models



Monitoring of successful alignment

Quality of the model alignment is visualized in realtime. If successful, data is ready for optimisation

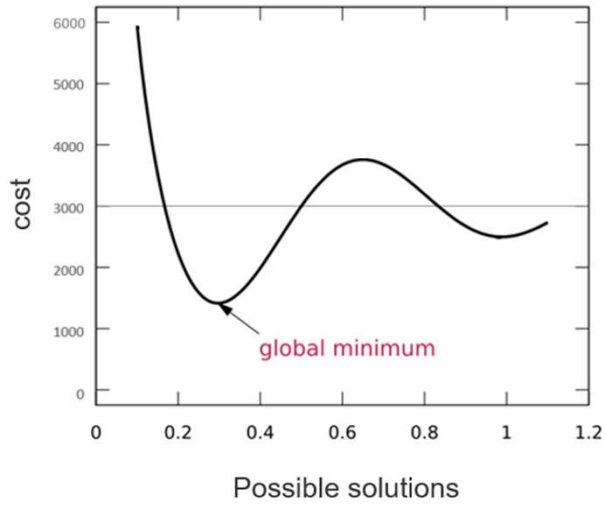


Solver searches the point of lowest cost

1) Define all costs, penalties, controls and constraints

- Manual actions:
  - # of transformer tap changes
  - # of generator setpoint change request
  - # of Shunt reactor/Capacitor bank switching
- Starting up of generators
- Load balancing on parallel transformers
- Voltage targets
- Generator deviation from neutral

2) Use of a specialized solver to find the best solution with a **mixed-integer nonlinear (MINLP)** approach

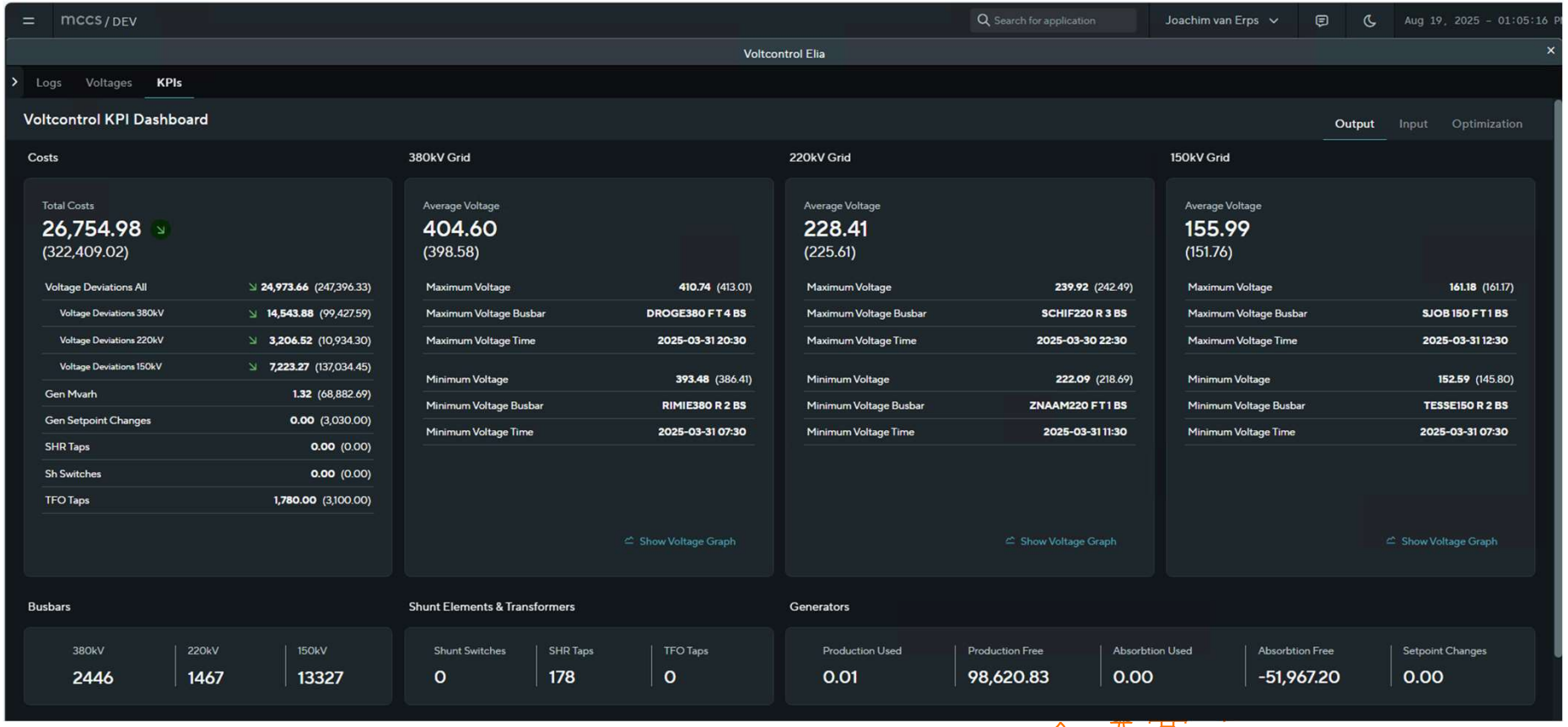


Voltcontrol optimisation

Voltages screen: Displaying the values of the optimised voltages

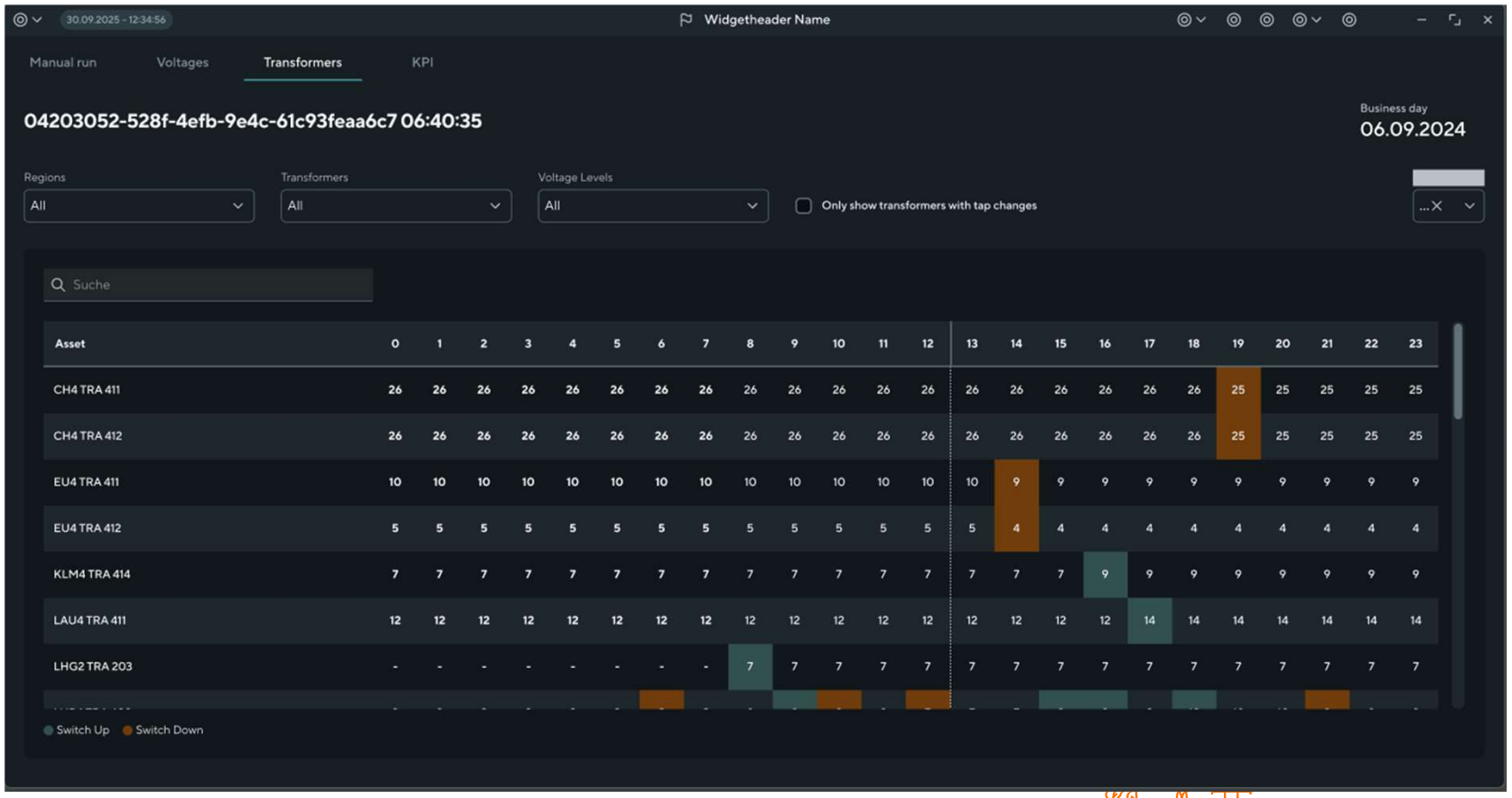
Voltcontrol optimisation

KPI screen: to asses and quantify the techno-economical improvements



Voltcontrol optimisation

Transformer screen: visualizing actions to be performed



Bringing into operations

Decision-support

1. Actions are presented visually to operators
2. All actions need to be performed manually

This allows a galvanic protection between the decision and the grid, by always going via a human operator (implicit quality check)

Operator in the lead

Support in decision-making

Semi-automate

1. Actions are presented visually to operators
2. Operator validates, and then confirms execution of commands via a single button

Relies more on operator taking proper care in the validate step. Therefore more confidence in tooling is needed

Operator in the lead

Support in decision-execution

Automate

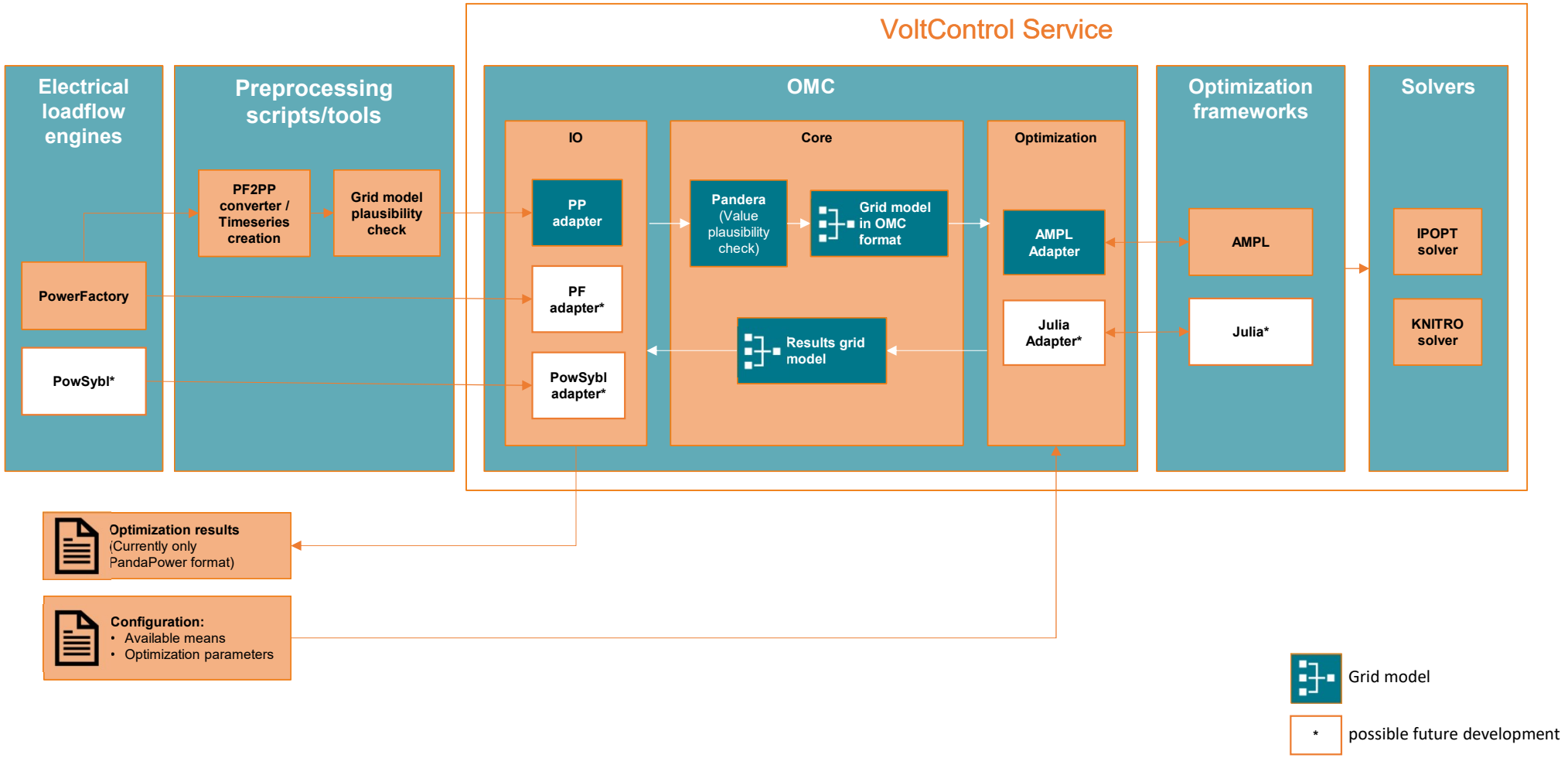
1. Actions are presented visually to operator
2. Actions will be executed, unless operator cancels or modifies the proposed actions

This achieves the auto-pilot status, while still allowing for easy override by the operator

Tool in the lead “Auto-pilot”

Operator can override

Optimization approach - Overview



Questions?

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3. **Huawei** – Grid forming aspects for batteries

Hyoffwind

ELIA think tank

26/09/2025

virya energy

Convinced that sustainable hydrogen is a critical key to the next stage of decarbonization, Virya capitalizes on its expertise and builds a hydrogen ecosystem for mobility

Energy transition | **Virya Vision** | **Virya Development Capabilities**

virya H2 energy

Why hydrogen?

- Initial hydrogen experimentation initiatives stemmed from Colruyt's **internal need to decarbonize its logistical chain**
- Early recognition of **wider societal needs and convinced that sustainable hydrogen holds a key to the next stage of decarbonization,** Virya decided to explore opportunities in the sustainable hydrogen space

Since 2007, Virya and its shareholders have experimented with H2 related technologies and engaged in collaborative partnerships

2007 – First experience with forklifts – deployment of 75 fuel cell forklifts

2011 – First electrolyser (Alkaline)

2016 – 20 fuel cell company cars in Colruyt Group Fleet

2018 – 1st multi fuel HRS (700 bar) and start development of 25MW electrolyser in Zeebrugge

2020 – Colruyt group pioneers in heavy duty applications – first fuel cell trucks in EU

2021 – 5 hydrogen refuelling stations in BE and 1 heavy duty truck

2022 – Investment in Dhyve

2023 – Further investments in Hiringa, additional refuelling stations, Taxis Verts, etc.

virya energy

The Hyoffwind case study, the most advanced electrolyser project in Belgium

1

- Flanders **first electrolysis plant** to produce **sustainable hydrogen from wind and solar energy** on a large scale, with a focus on industry, transport and injections into the Belgian network
- Secured partnerships with **John-Cockerill and BESIX** as technology partners and as partners for the design and construction of the facility
- **Government support** since 2020, the project contributing to the Flemish hydrogen strategy:
  - In 2023, the project secured a €30m capex GBER ("General Block Exemption Regulation") subsidy[1]

2

Zeebrugge's facility will act as an energy hub for gas and electricity, having the potential to become a logistics hub for hydrogen linked applications:

- **12% of the gas import capacity in Europe** (physical interconnection points with Norway, UK and presence LNG terminal)
- Possibility to inject large amounts of sustainable H2 in the natural gas grid without exceeding the limit of 2% H2 in the blend

3

- Hyoffwind plans to start operations in 2026 as part of its first phase comprising an electrolysis facility with a capacity of **25 MW. It is expected to be expanded subsequently by two additional phases, following the market uptake**
  - Second phase represents an upscale opportunity to 37 MW, by utilizing the building's capacity that can accommodate 2 additional electrolyser stacks of 6 MW each
  - Third phase would enable the project to upscale to 100MW
- **Max output of 3.7 kton sustainable hydrogen/year** for phase 1

virya energy

Note: (1) GBER aims to facilitate green investments, including hydrogen projects and carbon capture and storage or usage initiatives

Actual status

Actual status

VALLHYÈGE (VALLée HYdrogène liÈGE)

PRODUCTION & DISTRIBUTION (BE)

Virya Energy et John Cockerill develop a local hydrogen ecosystem in Liège (B). The Vallhyège project has been selected for public funding by the Walloon Region in 2024, which further supports the viability of the anticipated ecosystem.

With their partners, Virya et John Cockerill have the ambition to:

- Design, build and operate a 15MW production unit
- Design, build and operate a HRS filling station in the Port of Liège
- Retrofit a barge (inland waterway logistics between Antwerp and Liège)
- Deploy 16 hydrogen trucks

NINATRANS

TRAFUCO MEMBER OF ALTREA LOGISTICS

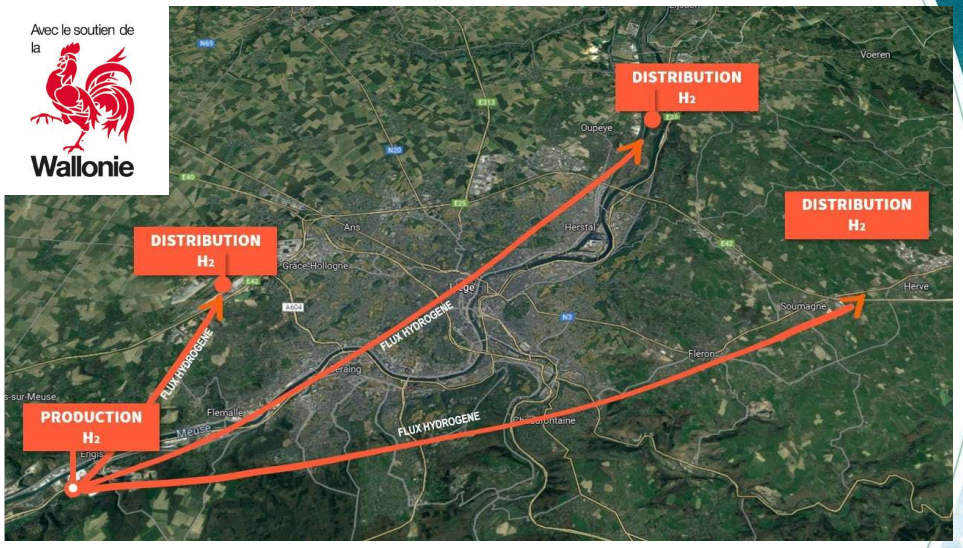
GROUP BEYERS INTERNATIONAL

JOST life in motion

COLRUYT GROUP

SNEL

Avec le soutien de la Wallonie



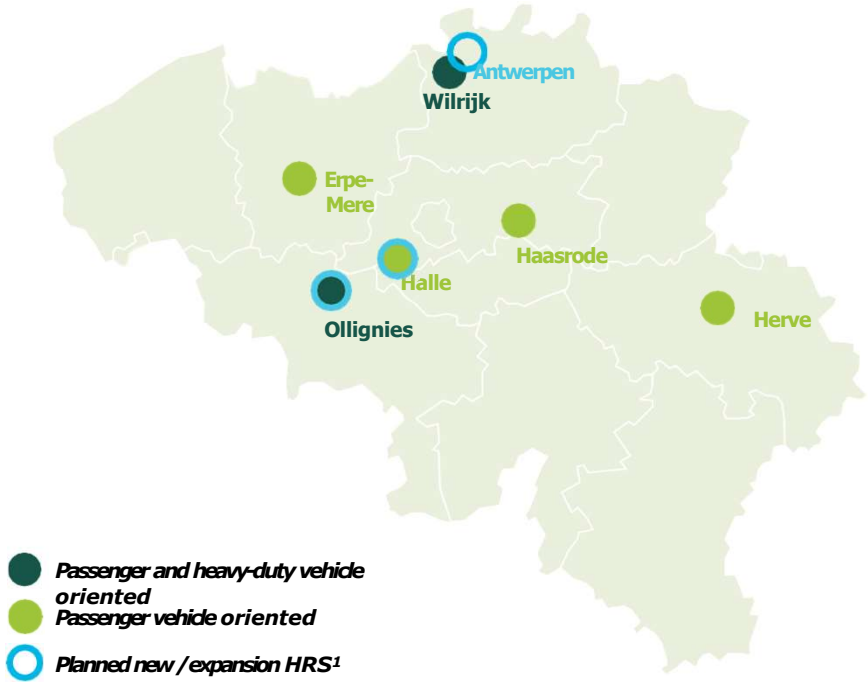
virya energy

John Cockerill

DATS 24's H2 assets offer a route to the mobility market

Pioneer in hydrogen

DATS 24 H_2 Operates largest hydrogen network in Belgium, compromising 6 HRS

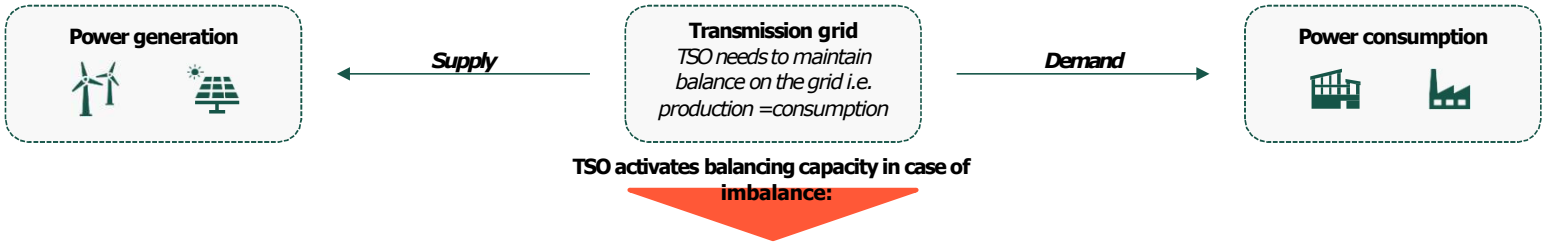


- DATS 24 is an experienced **energy supplier and trusted fuel specialist**
- Supplies both conventional fuels and alternative forms (CNG[2], H2) throughout Belgium and distributes the electricity Colruyt Group generates from wind and biomass to households in Flanders and Wallonia
- It operates the **largest hydrogen network in Belgium**, fulfilling its leading role in the energy transition
- 2 of the Hydrogen Refuelling Stations (Ollignies and Halle) will be reformed to integrate **heavy-duty refuelling capabilities**, with another **expansion** planned in Antwerpen towards heavy duty vehicles
- Works closely together with WaterstofNet, as part of the "H2Benelux" and "Waterstofregio 2.0", two projects to **integrate more hydrogen pumps into the Benelux**

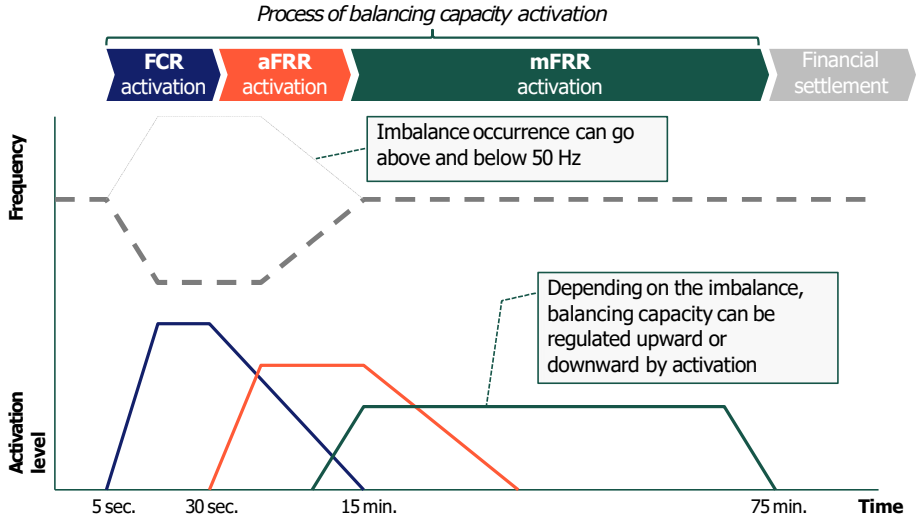
Notes: (1) All planned HRS expansions are heavy duty oriented, (2) Compressed Natural Gas

Hyoffwind has a certain flexibility in the timing of its production. Hence, it foresees to play into TSO's demand for grid balancing capacity, mostly through providing aFRR

Flexibility services



TSO activates balancing capacity in case of imbalance:



Keeping the balance and activation of flexibility though 3 types of balancing products:

1. FCR:

- **"Primary reserve"** with **initial activation to smoothen out any temporary glitches** in the (international) system. Activation is through automatic frequency measurements by BRPs. Required capacity to be available is set by ENTSO-e[1]

2. aFRR:

- **"Regulating power"** reserved to **correct national imbalances via automated activation ramping up after 30 seconds**. Steering is done through automated signals at 4-second intervals. Required capacity is based on historical imbalances and total grid capacity

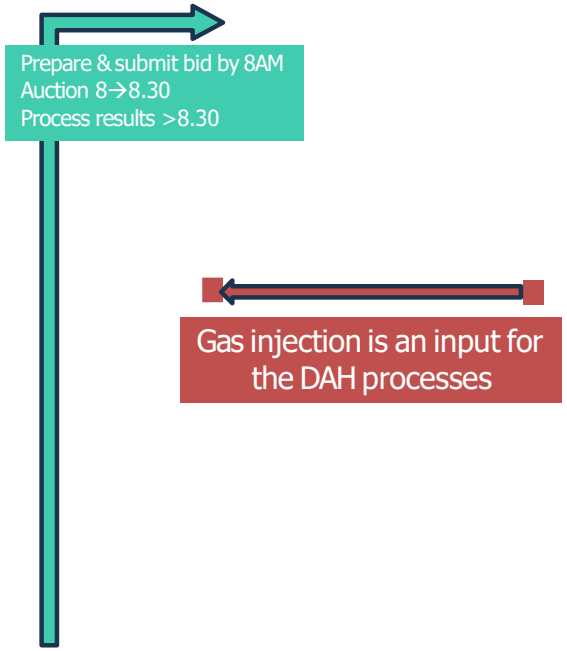
3. mFRR:

- "Incident reserve" **or "emergency reserve"** is **activated manually when there is a longer system imbalance or in case of larger imbalances**. Activation is done manually by telephone. Required capacity is based on historical imbalances and total grid capacity

virya energy

Note: (1) European Network of Transmission System Operators for Electricity (ENTSO-e)
Source: TenneT

A real life case of sector coupling (complexity)



Flex
Power
Nat Gas
Production

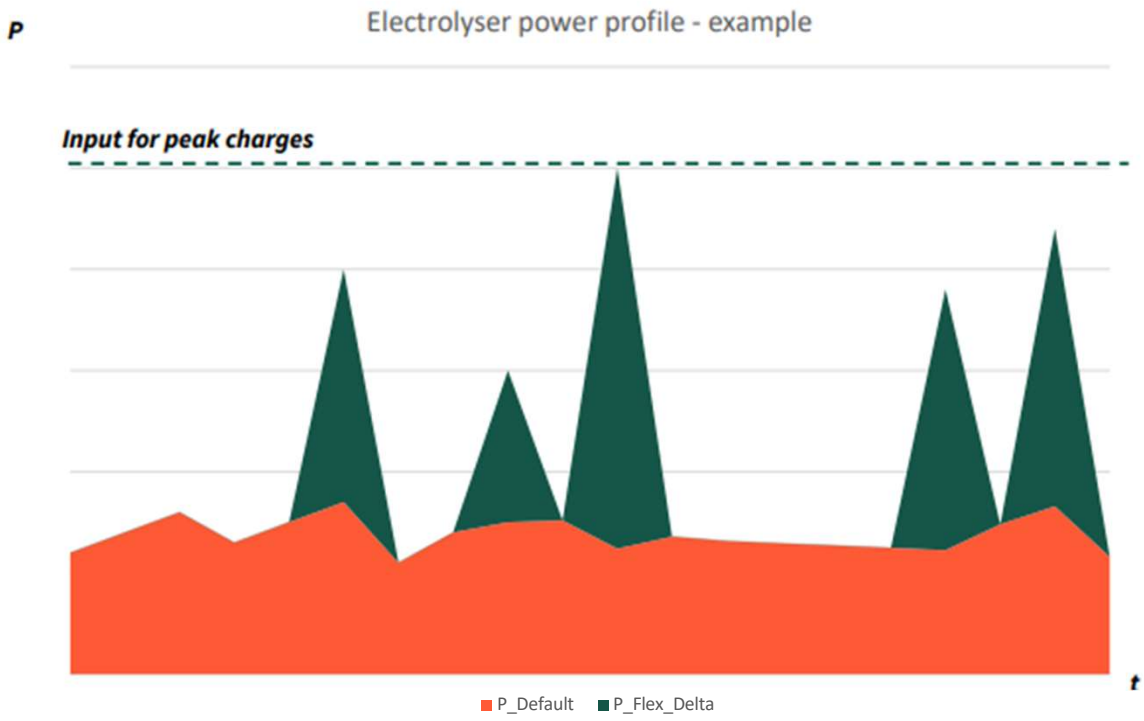
Offering Flex value is a function of planned production and offtake, plant availability, logistic planning, power prices, gas prices and the gas grid injection potential of which each element has its own timelines

Grid costs, peaks and & flexibility

Electrolyser grid costs & flexibility

- With its capacity to produce H2 in a flexible manner with fast ramp rates, electrolysers can provide balancing support towards the Belgian grid in different markets
- While providing balancing services, energy is stored as a different energy carrier
- However, the current grid cost structure, heavily determined by peak based elements, impacts the incentive for Electrolysers to provide downward flexibility to the power grid
- … although we could consider them to be desired peaks

Graphical example

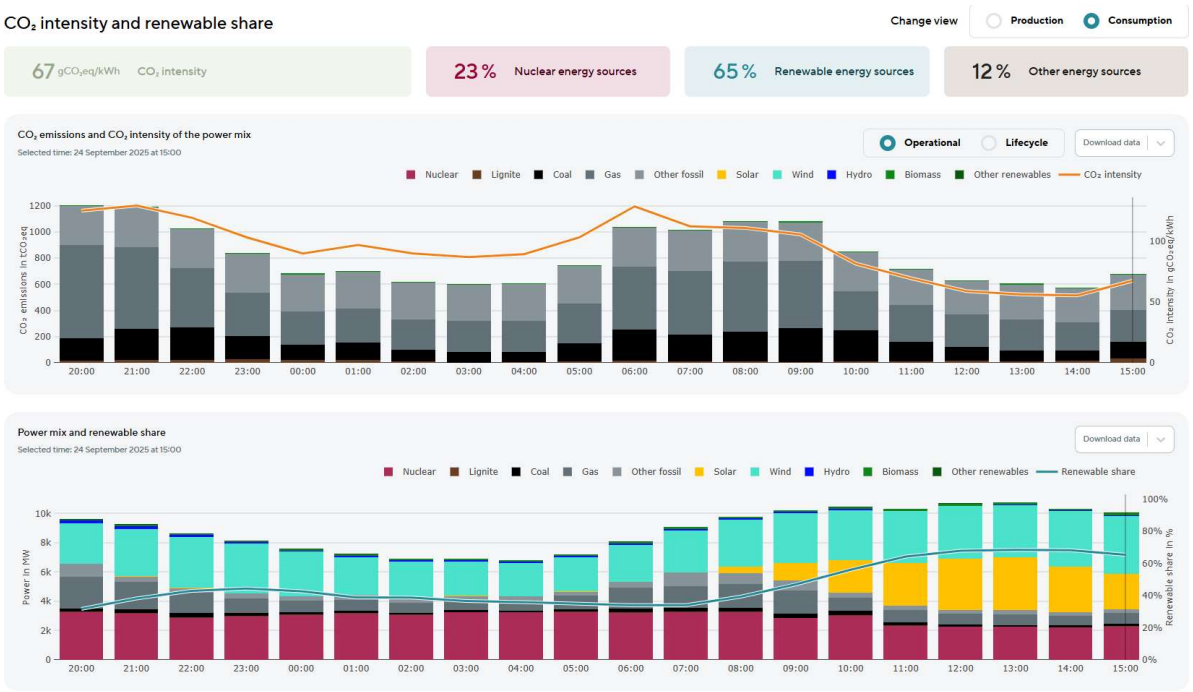


CO_2 Intensity — *Electrolysers have the potential to sync H2 production with low CO_2 emission power consumption*

Flexibility & CO_2 intensity

- Flexibility of electrolyser allow to sync H2 production with power consumption of low CO_2 emission content
- Elia Green Grid compass provides real-time CO_2 intensities and renewable power shares
- This kind of innovative and data driven initiatives could help alleviate the strict and rigid constraints of the RFNBO DA's

Greengrid compass – graphical example



Conclusion

- By means of this project the shareholders of Hyoffwind Infrastructure, Elia and Fluxys are pioneering and create a vision for future integrated grids. Hyoffwind will be a fine functioning example of system integration.

- The plant will be offering long-duration storage potential for renewable electricity

- But (not surprisingly) there is still room to reduce complexity

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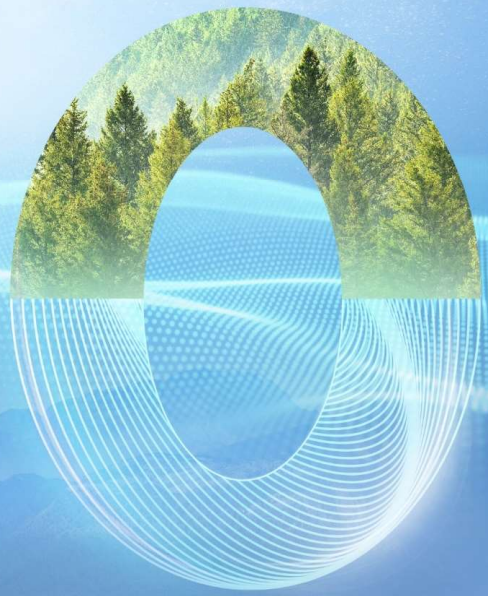
HUAWEI

Build a fully connected, Intelligent world

Grid Forming Power Converters

Unleashing the full potential of renewable energy



Huawei: A trusted long-term partner

Vision & mission

Bring digital to every person, home and organization for a fully connected, intelligent world

170+
countries and regions

207,000
employees

55.4%
of employees work in R&D

No. 4
in global R&D investment

120,000+
active patents held globally
(*Huawei has one of the world's largest patent portfolios.)

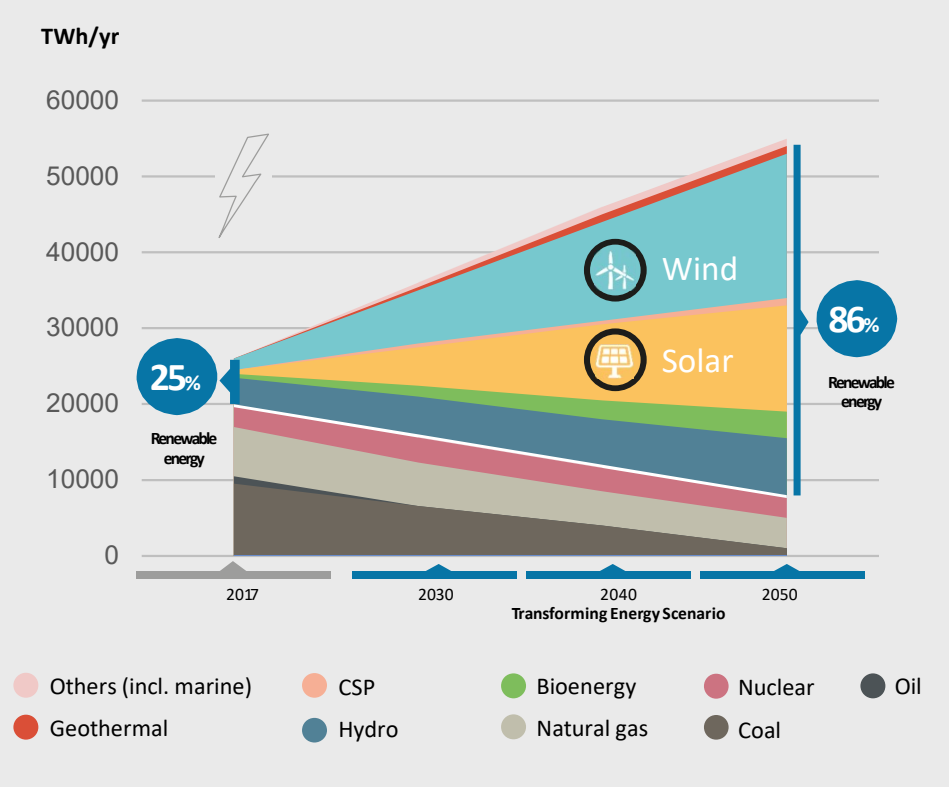
HUAWEI

Why is GFM needed?

World Energy Strategy Transformation

Promoting Solar & Wind to Become the Major Energy

PV – The Major Energy Supply for Power Plant Installation



The Government & Large Corporation specify low carbon targets continuously

China

Carbon neutral realized **in 2060**

Peak value **by 2030**, 20% renewable energy

EU

Carbon neutral realized **in 2050**

GHG emission reduced 60% **by 2030**, 32% renewable energy

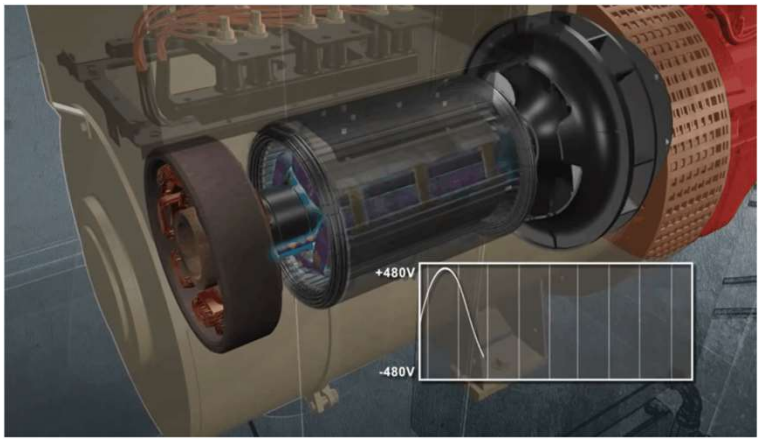
Strategic transformation of energy giants

Accelerate Carbon Neutral realized

Various Power consumption companies join RE100

Promised to achieve 100% renewable energy power consumption

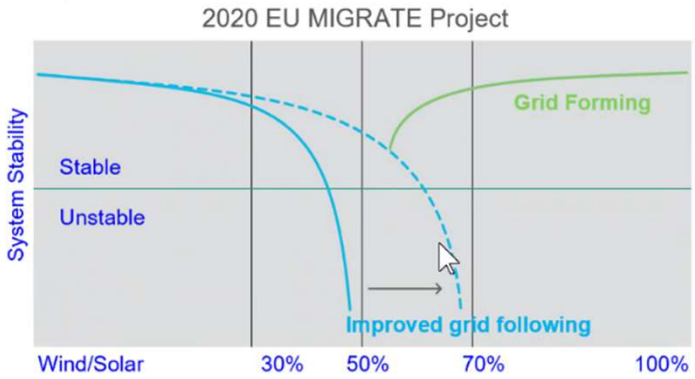
As the energy transition progresses, we will continue to decommission classical generators.



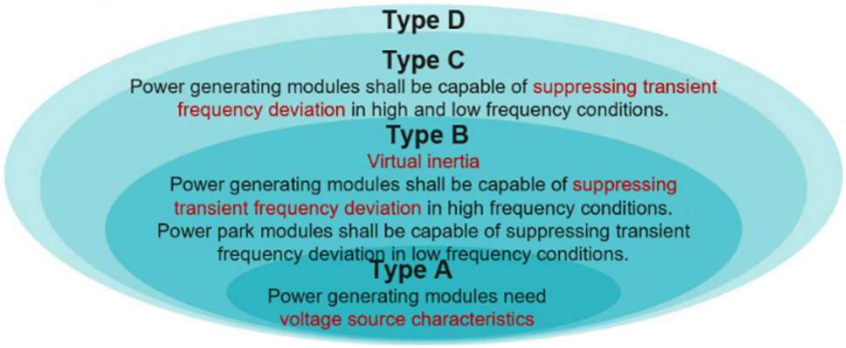
HUAWEI

Grid Forming is considered a vital technology for weak power systems

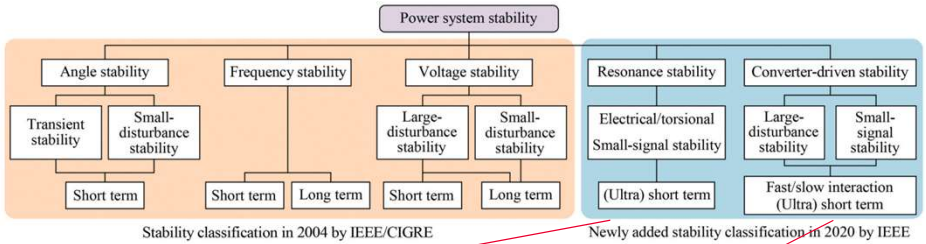
Renewable energy vs Power systems stability



The European Power Grid Code (RfG) raised requirements of Grid Forming for Type A-D power generating modules



Modern power systems stability challenges



Stability classification in 2004 by IEEE/CIGRE

Newly added stability classification in 2020 by IEEE

Refers to active damping capabilities against low frequency power oscillations

(0.5 – 30Hz)

Requires design considerations at plant level (Plant Controller)

Refers to voltage step response behavior and harmonic oscillation damping
(kHz range)

Requires design considerations at the power converter level (PCS)

What do we need?

Grid forming - Necessary Enabling Technology

Promoting Renewable Energy from Grid Following to be Grid Forming

Grid-forming Converters (GFC) are power electronics devices designed in control and sizing in order to support the operation of an AC power system under normal, disturbed, and emergency conditions without having to rely on services from synchronous generators.
Future capabilities of GFC, in order to allow up to 100% penetration of power park modules (PPM) can be classified exhaustively as follows:

1. Creating system voltage,
2. Contributing to Fault Level,
3. Contributing to Total System Inertia (limited by energy storage capacity),
4. Supporting system survival to allow effective operation of Low Frequency Demand Disconnection (LFDD) for rare system splits,
5. Acting as a sink to counter harmonics & inter-harmonics in system voltage,
6. Acting as a sink to counter unbalance in system voltage,
7. Prevent adverse control system interactions.

entsoe

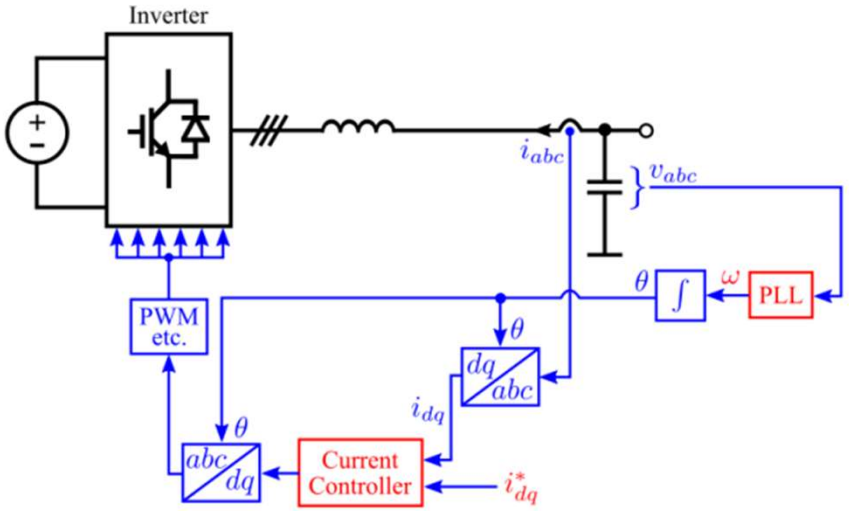
HUAWEI

Grid forming - Necessary Enabling Technology

Promoting Renewable Energy from Grid Following to be Grid Forming

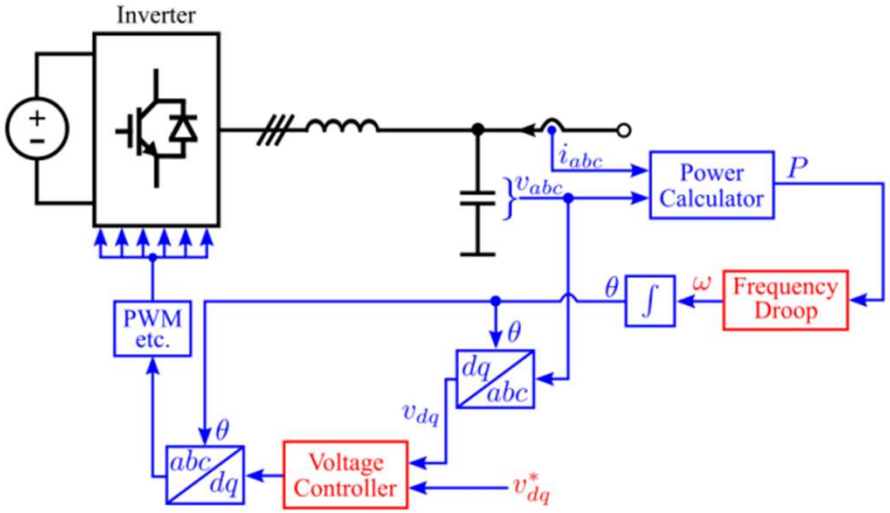
Grid following basic function:

Current source
Grid voltage dependent
Current time response range: 20-40 ms



Grid forming basic function:

Voltage source
Grid voltage independent
Current time response: instantaneous - 5 ms



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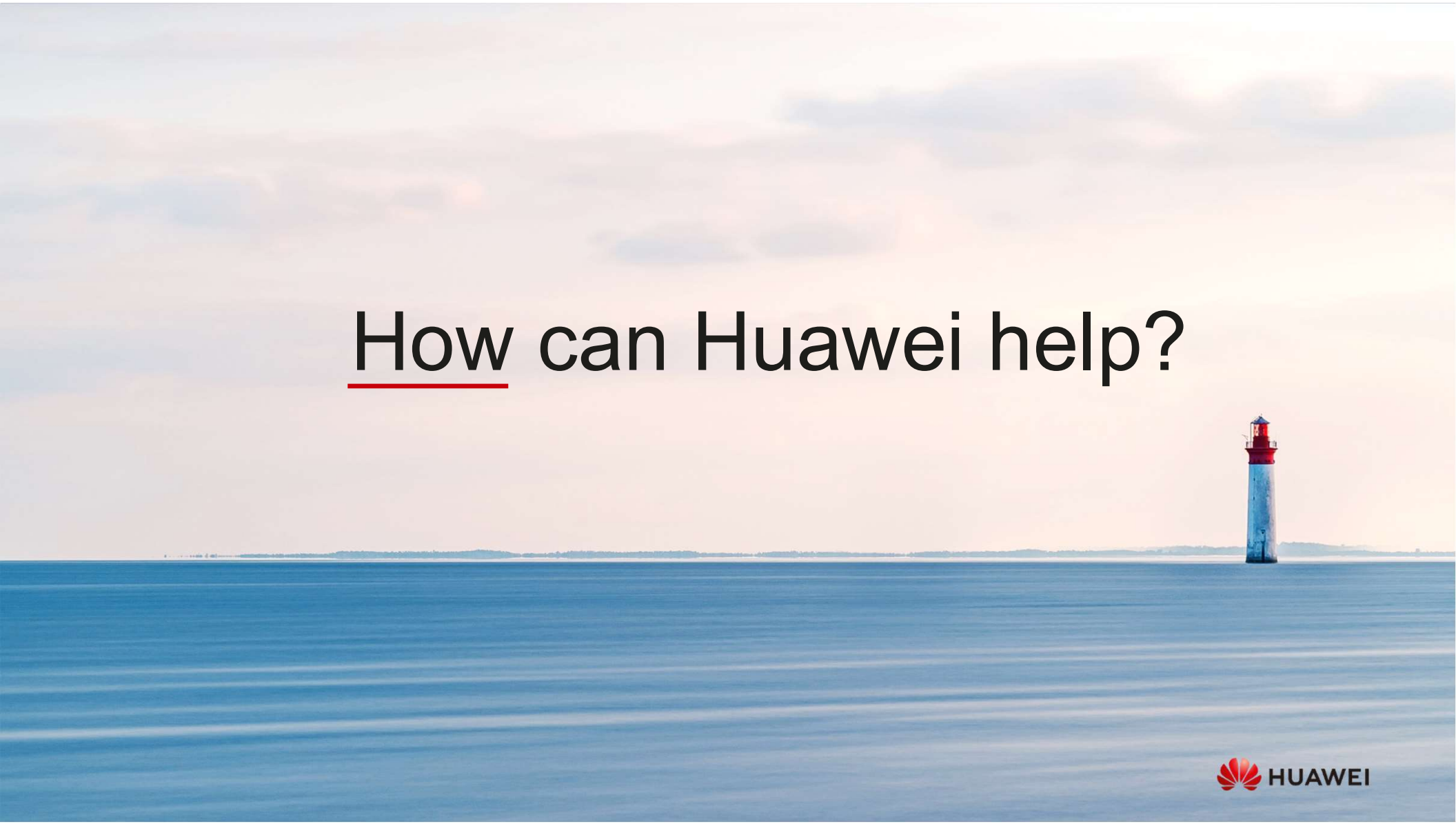
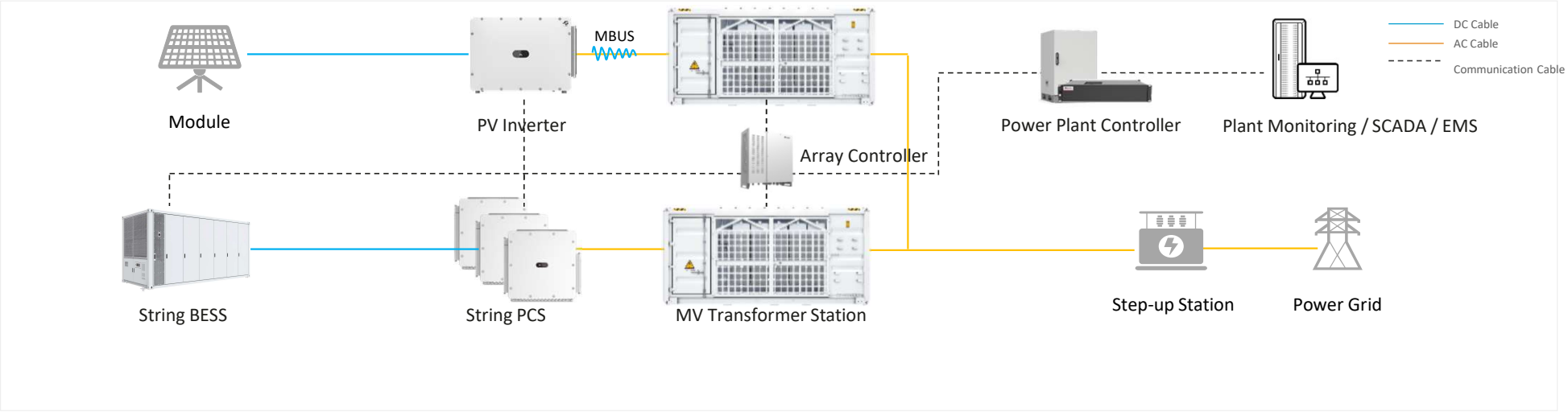
How can Huawei help?



Huawei GFM BESS solution for enhancing grid strength



Optimal LCOS

- Pack-level optimization, rack-level optimization
- **Constant output power @ 0~100% full SOC range**
- Optimal RTE up to **90.3%**
- Up to **99.9%** higher system availability

Ultimate Safety

- Cell to Grid **five layers safety** protection
- Pack-level fault isolation for higher safety
- 100+ cell performance test stricter than the industry, Pack-level Hi-Fuse design, active protection for fault isolation

Smart O&M

- Pack-level **real-time** active balancing, no need onsite balancing
- Smart BMS for 10+ battery faults pre-alarm
- Automatic fault analysis and identification.
- Compatible with offshore wind application.

Grid Forming

- Adaption to extremely weak grid, SCR low to 1.1 during grid connected mode
- Higher power quality: THDi < 1%(rated)
- Plant-level E2E frequency regulation response time**<200ms**

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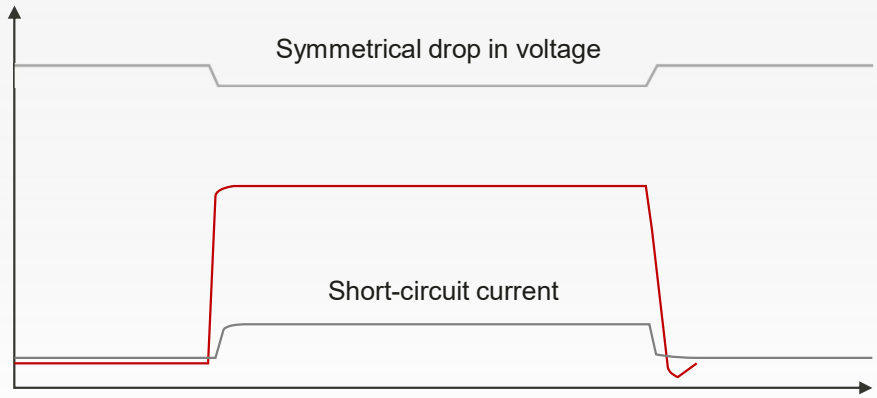
Grid Forming/Grid-connected – Redefine Voltage Stability

Short-circuit capacity support

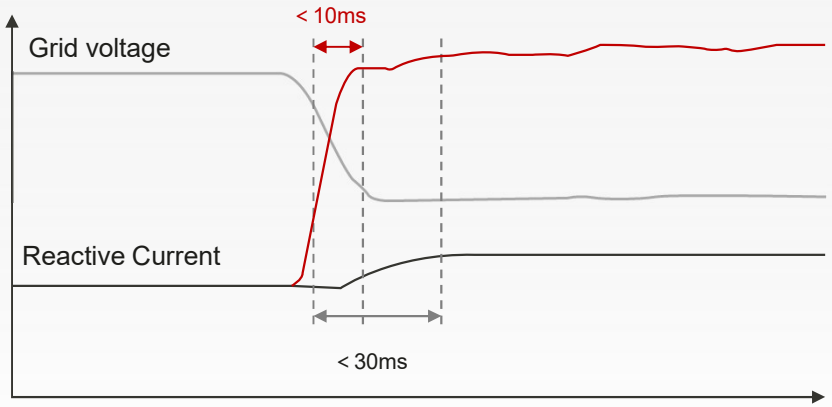
Smart PV & ESS Generator : 3 times VS Traditional solution: 1.04 times



Traditional Solution Smart PV & ESS Generator

Dynamic reactive current response

Smart PV & ESS Generator < 10ms VS Traditional solution < 30ms



Traditional Solution Smart PV & ESS Generator

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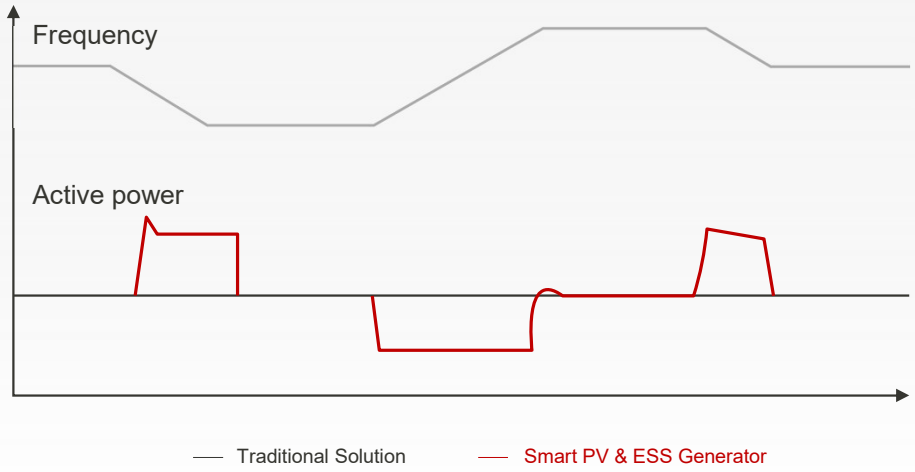
Grid Forming/Grid-connected– Redefine Frequency Stability

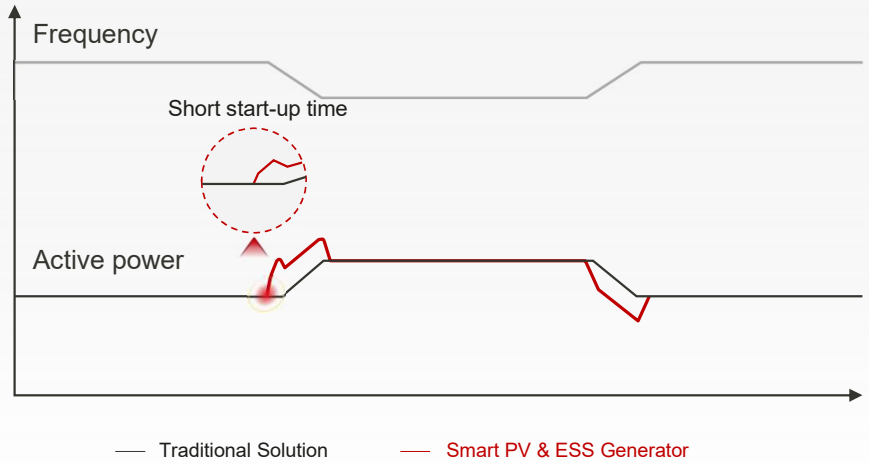
Virtual inertia

Smart PV & ESS Generator **support** VS Traditional solution **not support**



Frequency adjustment start time (by active power)

Smart PV & ESS Generator **< 50ms** VS Traditional solution **< 250ms**



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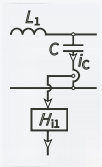
Grid Forming/Grid-connected– Redefine Phase Angle Stability

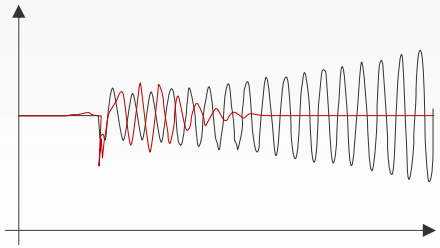
Wide frequency oscillation suppression

Smart PV & ESS Generator with wide range (0.1Hz~100Hz) vs Traditional solution no suppression capability

POD



Virtual Impedance Remodeling Algorithm



Traditional Solution

No suppression capability

Smart PV & ESS Generator

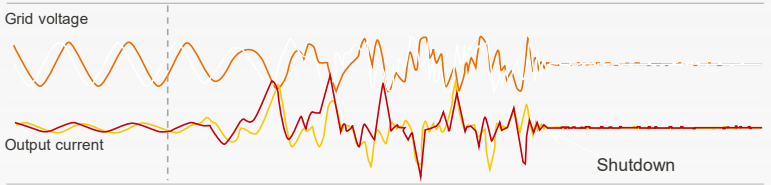
Fast suppression and stable active power

Continuous HVRT and LVRT capability on weak grid

Smart PV & ESS Generator support VS Traditional solution not support

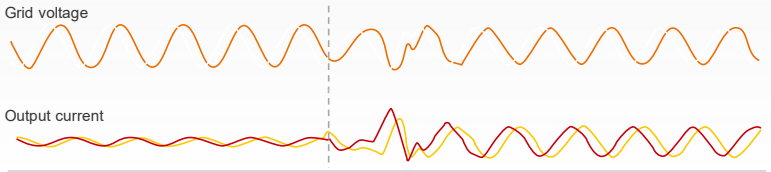
Fast detection + Effective suppression

Traditional Solution: shutdown due to oscillation caused by weak grid fault



VS

Smart PV & ESS Generator: stable operation on weak power grids after faults



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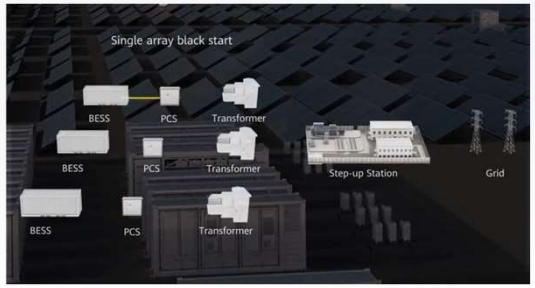
Grid Forming/Islanding:Whole grid black start enabling minutes level power recovery

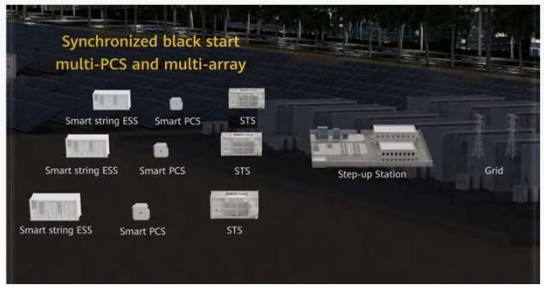
Traditional solution: black start for single PV array in sequence, takes several hours - days



Whole grid recovery

several hours - days

Smart PV & ESS Generator: Synchronous black start of multi-PCS and multi-PV array



Whole grid recovery

Minutes level

Multi-PCS in parallel soft-start synchronous ramp

Multi-arrays in parallel soft-start synchronous ramp

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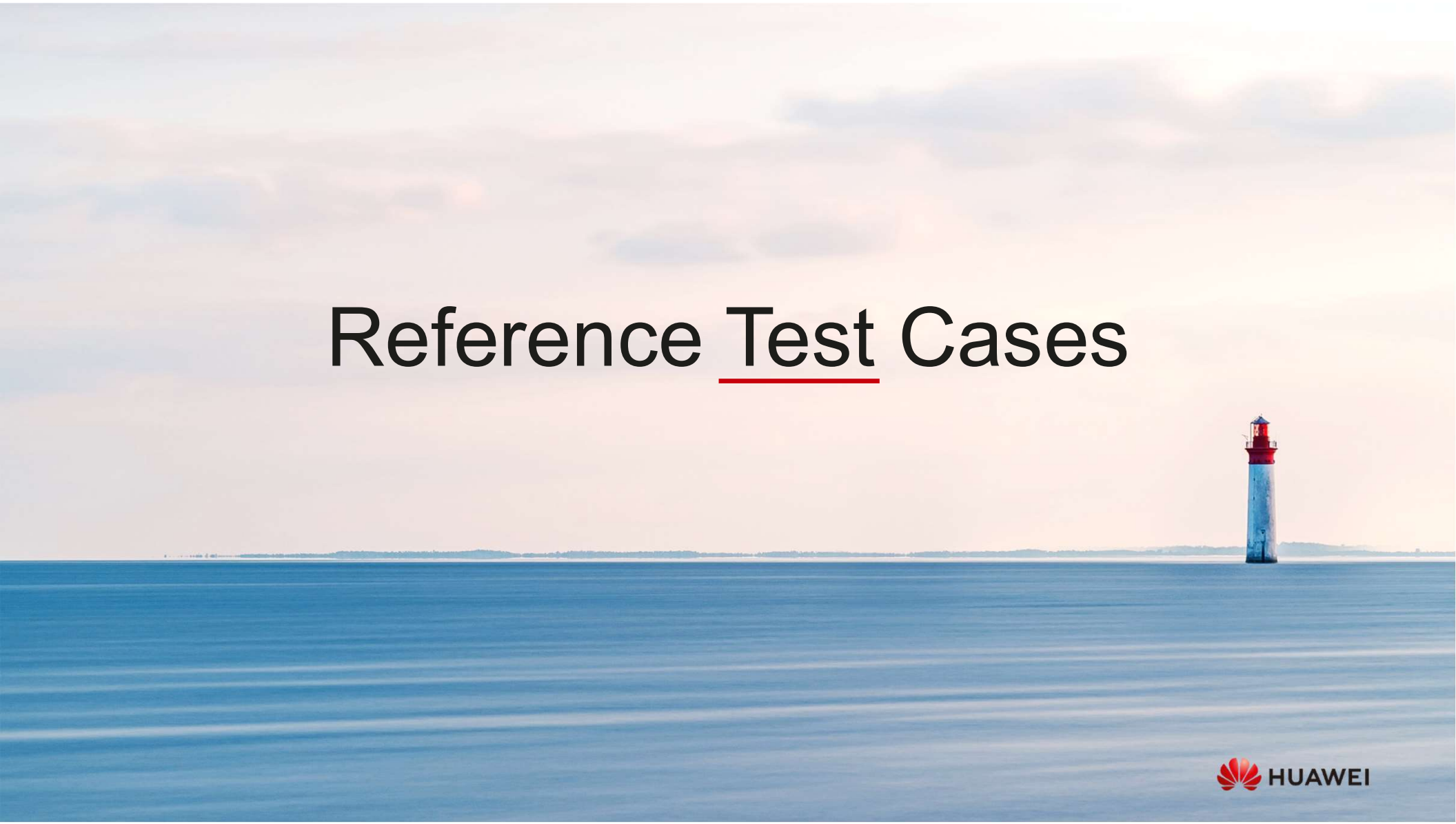
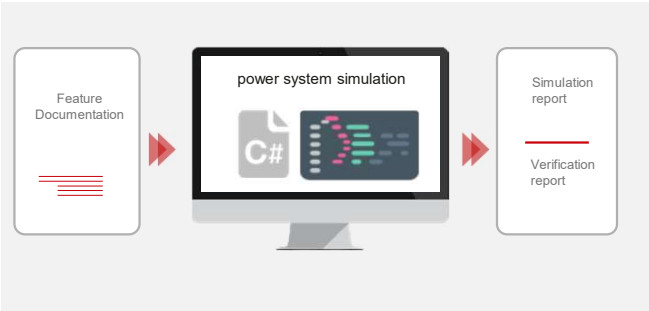
Reference Test Cases



Reference 1： Red Sea Project, GFM Maintaining Synchronous to Gas Turbine after Fault

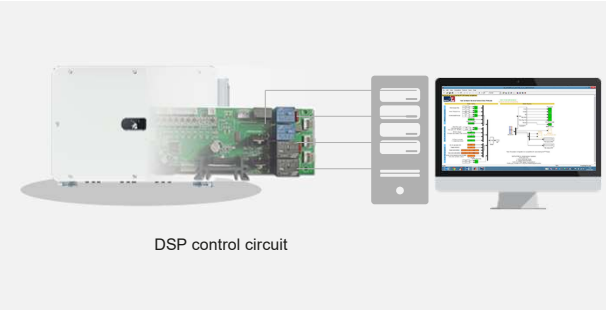
Digital simulation
Power grid code simulation



Model simulation accuracy: 95%

- ***50+ simulation teams***
- **Supports eight mainstream simulation software.**
- **Deliver models to more than 30 countries worldwide**

Hardware-in-the-loop testing
HIL test



50+ microgrid semi-physical simulation

- **Parallel operation of the real BESS PCS controllers**
- **Black Start**
- **micro-grid fault ride-through**

In-House Prototype Test
Microgrid system Level Lab validated

1000+ micro-grid environment tests

- **Parallel operation of the real BESS PCS**
- **parallel operation of PV & BESS & Diesel Genset**
- **Black Start**
- **On/Off grid test**
- **2:1 PV:BESS ratio**
- **micro-grid fault ride-through**
- **...**

Reference 1： Red Sea Project, GFM Maintaining Synchronous to Gas Turbine after Fault

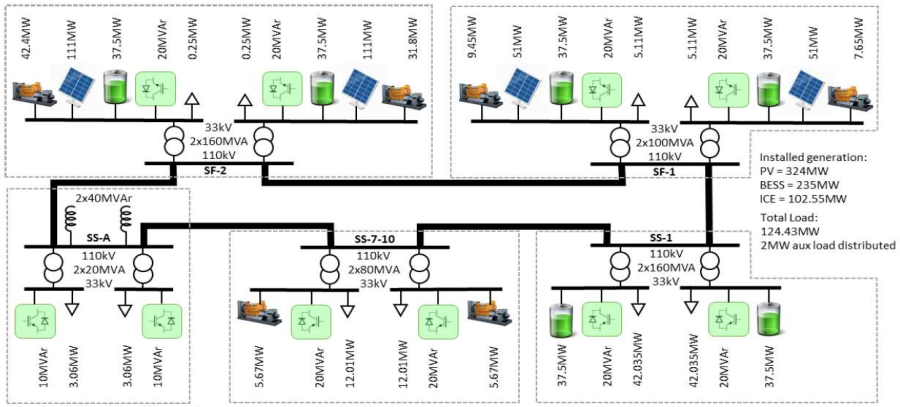


Figure 1: Red Sea Network

600MWp PV & 1.3GWh BESS are in stable operation

- The system in stable and normal operation
- All parameters comply the design and contract requirements, and the indicators are superior to the contract requirements
- The test results fully recognized by the owner and supervisor

Site SF1 in stable operation

Site SD in stable operation

Site SS1 in stable operation

Site DR in stable operation

Reference 1: Red Sea Project, GFM Maintaining Synchronous to Gas Turbine after Fault

- Red Sea Project has ~700MW generation capacity, ~100MW load
- **Maintaining synchronization** after a disturbance is difficult due to **low short circuit current contribution level.**

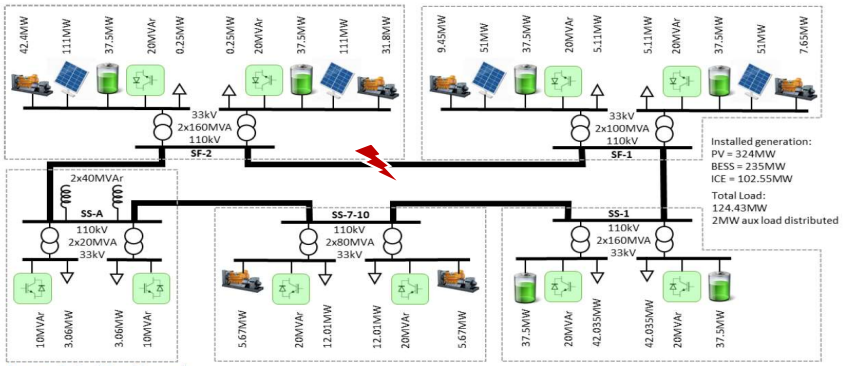
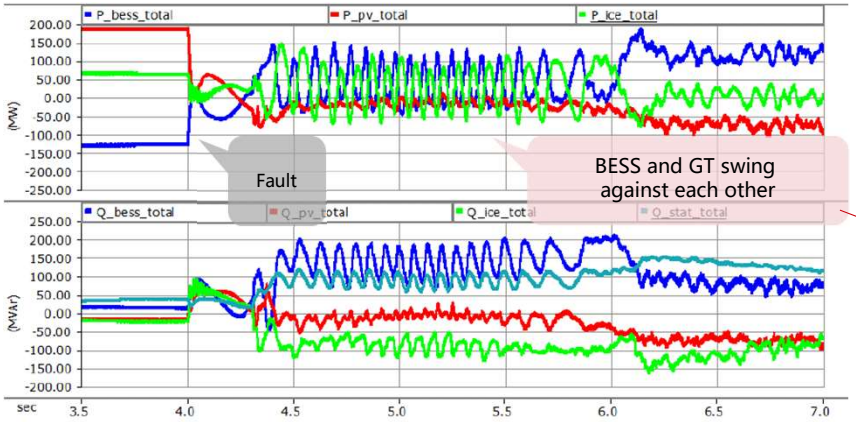
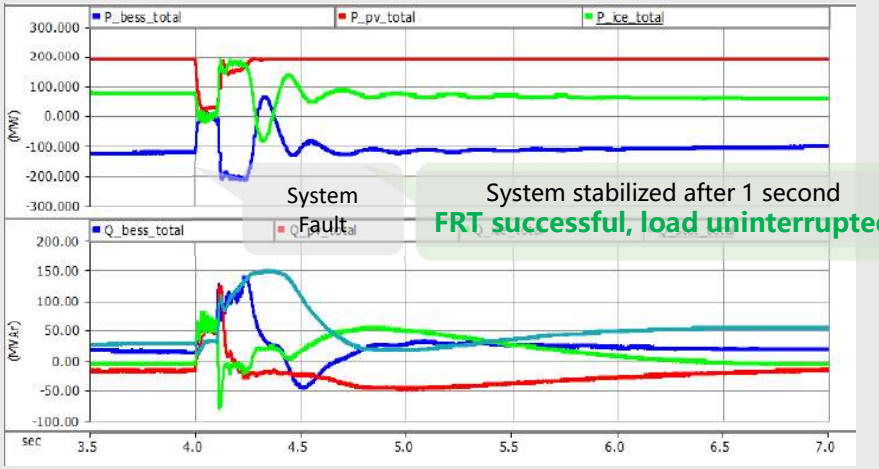


Figure 1: Red Sea Network



Huawei GFM Solution Fault Ride Through (FRT) Response



Results:

1. The BESS cannot sustain the active power load requirement after the fault is cleared. All the small motor loads stall during the fault.
2. When the fault is cleared, the motor loads require acceleration power. To simplify the EMT network, the simulations were performed with the 33kV bus couplers closed. Therefore, both BESS systems are affected by the fault and the BESS systems at the different substations swing against the other. The BESS cannot maintain the frequency of the network after the fault.
3. The voltage does not recover after the fault is cleared.
4. All the load tripped.

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Reference 2: Real-Life Testing with 2MWh/3MVA GFM BESS / 100MW PV plant

Putting a 35kV short circuit on a large scale GFM PV + BESS system

The grid-forming ESS passed the manual short circuit field test in one attempt.

- **The system passed the 35 kV three-phase** short-circuit test in one attempt, and 600 parallel devices **did not disconnect from the power grid**
- The system outputs three times the apparent current within 10 ms, effectively supporting the power grid voltage.

- The system passed the **110 kV single-phase** short-circuit test in one attempt, and 600 parallel devices **did not disconnect from the power grid**
- The system outputs an asymmetric current within 10 ms, effectively supporting the power grid voltage

The world's first manual short-circuit field test on a 100 MWh grid-forming string ESS fully verified the **frequency and voltage regulation** capabilities of the grid-forming ESS plant to address abnormal power grid events.

Future discussion topics: How to accelerate and guide GFM BESS development in Belgium?

Managing DE(S)R and co-location with large load centers

Which opportunities can be created for aggregation of small (commercial & industrial) BESS in the future Belgium stability markets?

How can industrial load centers contribute?

Safeguarding the distribution grids and preventing unintentional islanding

How can DSO's implement GFM resources in the MV distribution grids and how can they manage / prevent unintentional islanding of GFM energy resources?

Planning GFM roll-out in conjunction with the decommissioning of nuclear power

How to bridge the gap after the closure of Tihange and Doel and how to schedule the implementation of GFM markets in time?

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Thank you.

把数字世界带入每个人、每个家庭、
每个组织，构建万物互联的智能世界。

Bring digital to every person, home and organization for a fully connected, intelligent world.

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Thank you.

Next meeting: 08/12/2025, 13 - 16u

Interested to present a topic: jessie.moelans@elia.be