DEPLOYMENT OF GRID FORMING TECHNOLOGY IN THE DANISH POWER SYSTEM

CIGRE DK Generalforsamling
Aalborg, 23 Sept. 2026

Yicheng Liao, System Stability

The strategy for Denmark's energy system

ENERGINET

2023-2025

"Energy on time"

- Infrastructure at a rapid pace
- Energy market for the future
- **Security of supply**



2026~

" Green Energy – Secure future"

- Reliable infrastructure
- Efficient market
- **Secure supply**

Renewable energy integration towards 2030

More than 30 GW in total will be integrated by 2030

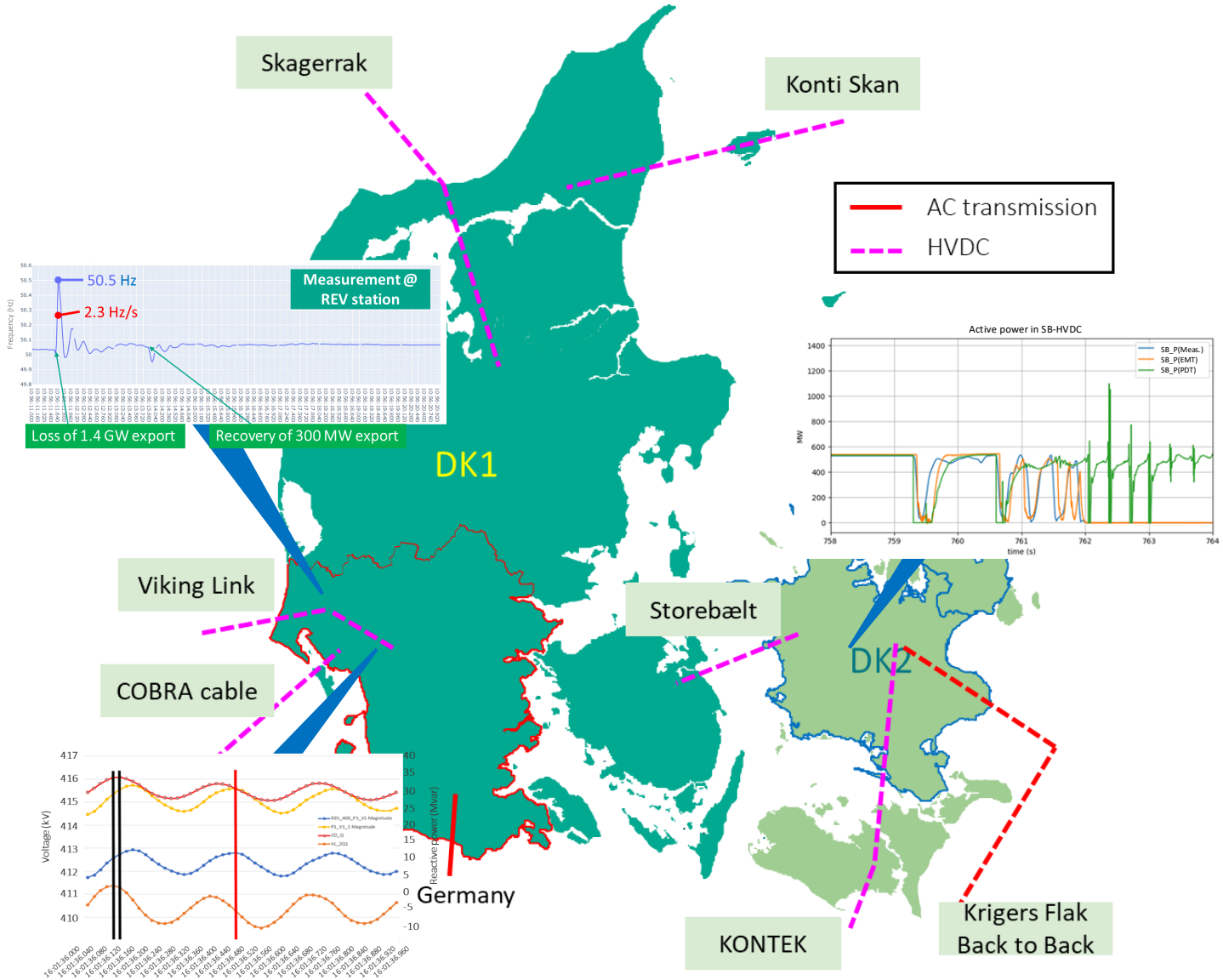
ENERGINET

”REAL” CHALLENGES (INCIDENTS)

Stability challenges caused by

- Lower system strength
- Lower inertia
- Weaker grid connection with neighbouring country.

We need facility/unit, which can response inherently and rapidly.



Geographical overview of Danish power system, where highlighted area with red line in DK1 and blue line in DK2 are investigated based on real incident)

HOW DO WE SEE ? - BENEFITS OF THE GRID-FORMING (GFM) TECHNOLOGY

- Is self-synchronizing
- Provides phase jump active power (also sometimes referred to as synchronizing power)
- Provides inertia active power response (response to RoCoF)
- Provides active power damping
- Provides inherent reactive power response



” We believe that the grid-forming technology is a key component in operating the future power system secure and efficient”

Senior Director in Operations development
Christian Flytkjær

GFM ROADMAP

From external collaboration to national implementation

ENERGINET

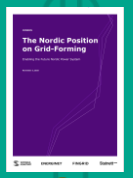
CONDON

entsoe

International Collaboration



ENTSO-E TF GFM (Phase I report)



White paper- Nordic position on GFM (ConDon)



ENTSO-E TF GFM (Phase II report)



ENTSO-E IGD (Oct.-Nov. 2026)



RfG 2.0 enter into force (EOD 2026 or early 2027)

ENDK GFM deployment project

Hitachi Energy

HUAWEI

POWER ELECTRONICS

Eku

Phase I



Technical report version 1 (SMIB+SEMT)

Hitachi Energy

VATTENFALL

Vestas

SIEMENS Gamesa

SUNGROW

Shell

Phase II



Technical report version 2



SEMT report (From Evidence to stability market)



SEMT results (CIGRE, etc.)

Formulation of technical requirement



TF 3.3.2 (GFM energy storage facility) – March, 2026
Dansk/Engelsk version



- TF 3.3.2 – ION compliance guidance (Energy storage facility)



- GFM co-placement
- GFM HVDC
- GFM for RfG
- ...

GFM DEPLOYMENT PROJECT

- Engage stakeholder's involvement
- Various type of GFM technology have been tested in the project such as (E) STATCOM, BESS, Wind and PV

Disclaimer:

- The performance and dynamic behaviour described in this slide should not be interpreted as representative of fully optimized GFM solutions or their ultimate capabilities.
- The inclusion of test results from different industry partners is not intended to compare or quantify differences between individual companies.
- The primary objective of this slide is to demonstrate that GFM technologies are sufficiently mature for deployment in the Danish power system and can deliver significant benefits for maintaining system stability.

ENERGINET

Summary of vendor specific EMT models tested in the project

	Type	Control mode at facility level
Vendor A	GFM BESS	PV mode at PPC Frequency response in droop mode
Vendor B	GFM BESS	PV mode at PPC Frequency response in droop mode Voltage control in droop mode
Vendor C	GFM STATCOM (without storage)	Voltage control mode without droop No frequency response
Vendor D	GFM Wind PPM (with PPC)	Voltage control (VQ slope) Active power or Frequency control
Vendor E	GFM Wind PPM (with PPC)	Reactive power control (Q control – E(1)) Voltage control (VQ slope control – E(2)) Active power or Frequency control
Vendor F	GFM Wind turbine (without PPC)	Voltage control at the terminal of wind turbine
Vendor G	GFM PV PPM (without PPC)	Voltage control Power or Frequency control
Vendor H	GFM E-STATCOM	Voltage control

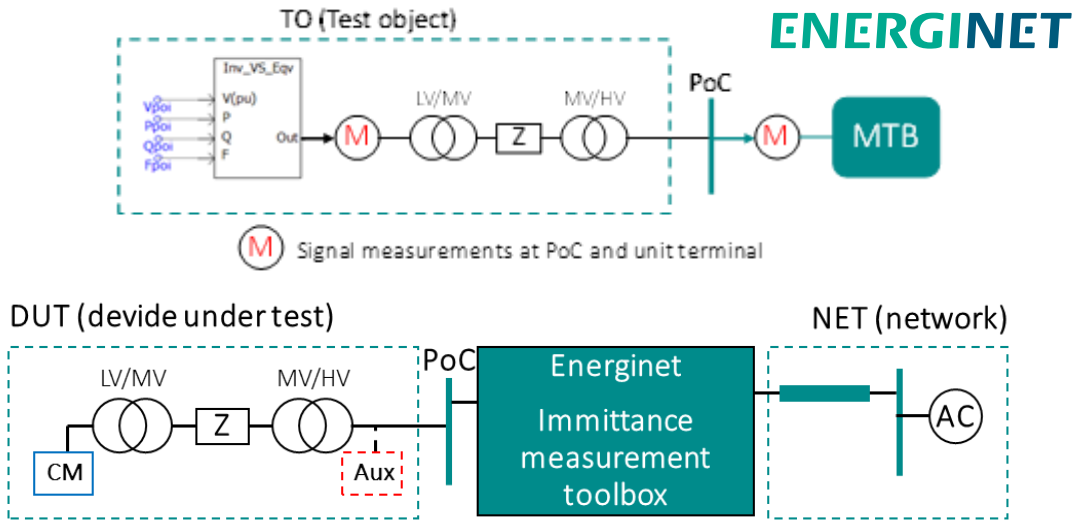
SMIB SYSTEM TESTS

- Time-domain and frequency-domain tests are designed to evaluate the core functionalities of GFM technology and fundamental grid integration functionality

https://github.com/Energinet-SimTools/MTB

https://github.com/Energinet-SimTools/IMTB

SMIB system – originally known as single-machine infinite-bus system, nowadays representing testing system with a single source in general, which can be a machine or a Thevenin equivalent source



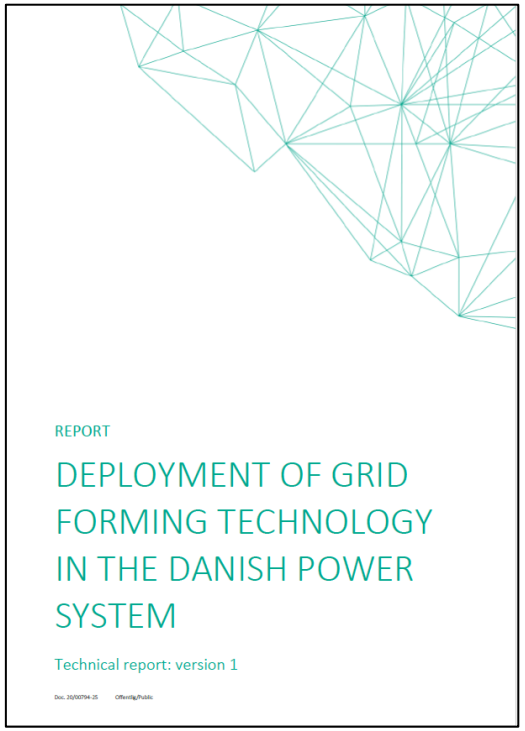
Test overview for GFM evaluation

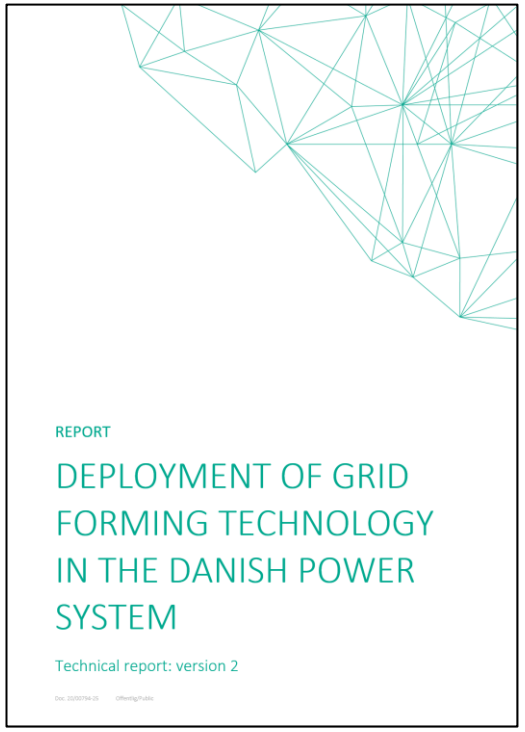
Test category	Test name	Test tool
Time domain test	Active power controllability test	MTB
	Reactive power controllability test	
	Grid voltage mag. Step change test	
	Phase angle jump test	
	Rate of Change of Frequency (RoCoF) test	
	Frequency sensitivity test	
	Fault test in strong grid	
	Fault test in weak grid	
	Consecutive fault test	
	Short Circuit Ratio change test	
	Loss of the last voltage source test	
Frequency domain test	Impedance scan	IMTB
	P-θ, P-f, P-df/dt, Q-V responses	

TOWARDS A STABLE AND SUSTAINABLE FUTURE WITH GRID-FORMING SOLUTIONS

- Testing methodology and results detailed in the reports
- Various type of GFM technology can provide GFM functionalities “within capability”

ENERGINET





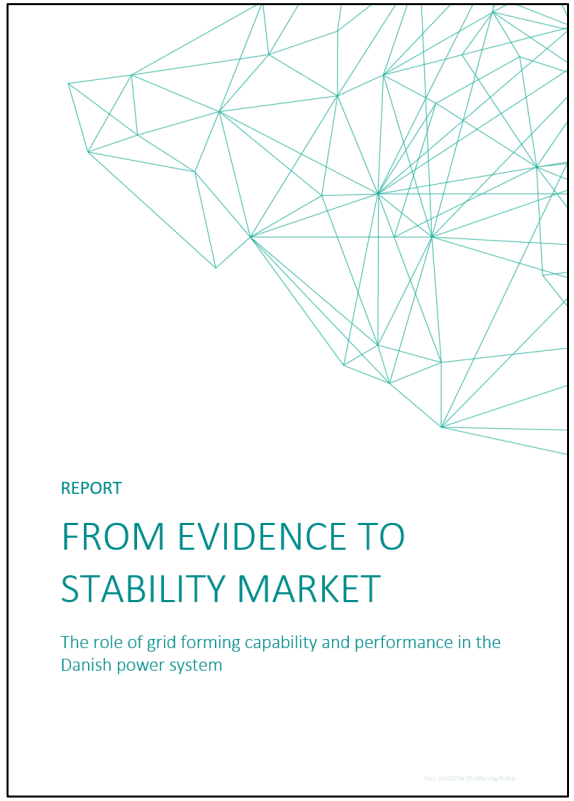
- Report (Version 1)- 2025
https://en.energinet.dk/about-our-reports/reports/towards-a-stable-and-sustainable-future-with-grid-forming-technologies/

- Report (Version 2)- 2026
https://en.energinet.dk/about-our-reports/reports/deployment-of-grid-forming-technology-in-the-danish-power-system-version-2/

DEMONSTRATION OF SYSTEM-LEVEL STABILITY BENEFITS FROM GFM SOLUTIONS

Scenario investigated in system-level EMT studies

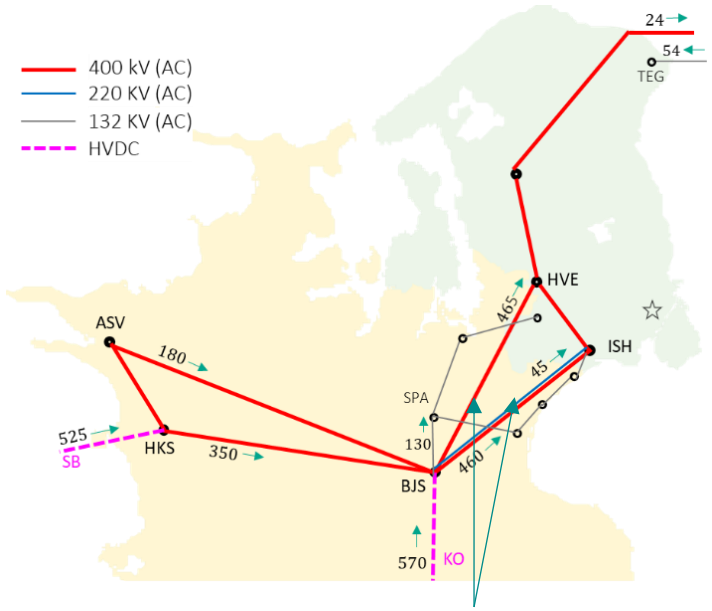
- System split (Short circuit strength change)
- RoCoF (Rate of Change of Frequency)
- Voltage oscillation (Sub-synchronous frequency range)



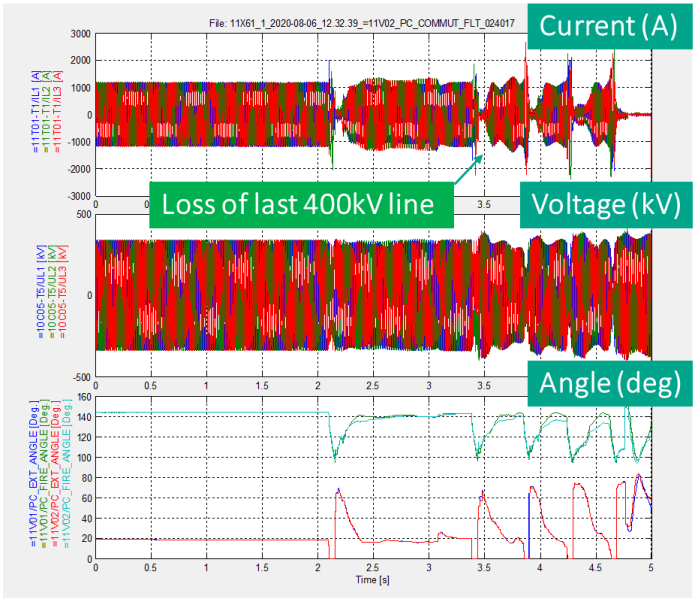
https://en.energinet.dk/about-our-reports/reports/from-grid-forming-evidence-to-future-stability-services/

DK2 SYSTEM SPLIT

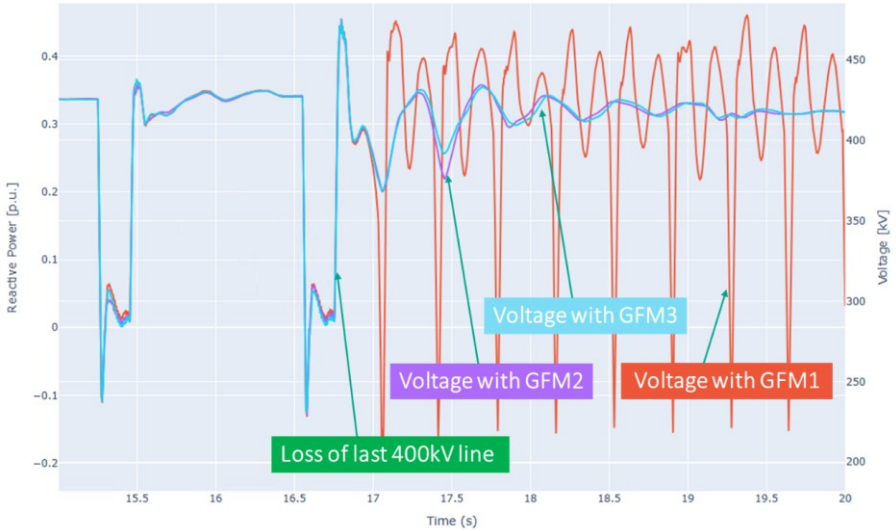
GFM provides voltage and damping support to enhance system strength



Loss of two 400 kV lines due to fault



SynCon trip and HVDC commutation failure



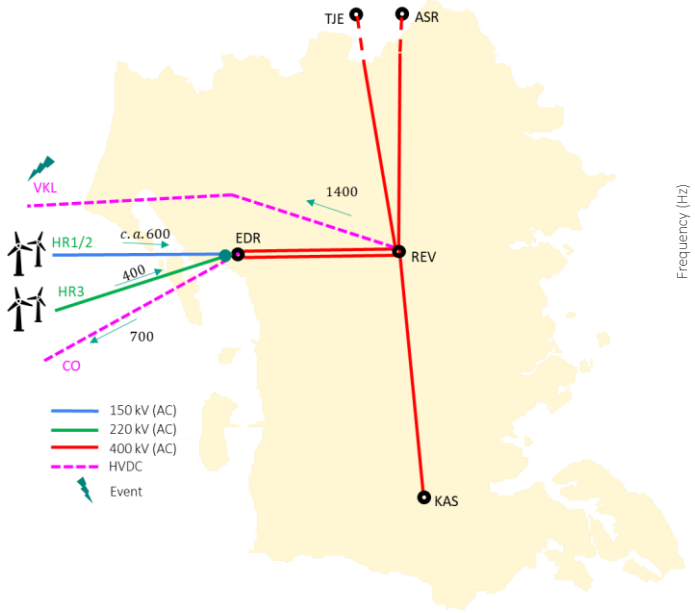
(a) GFM size: GFM3>GFM2>GFM1



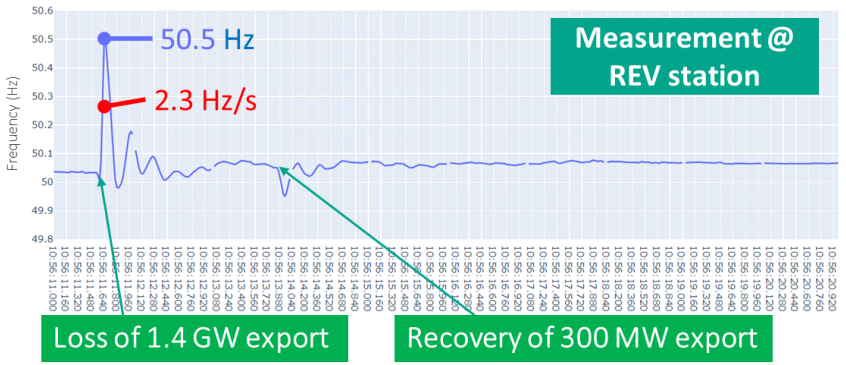
(b) GFM1: Low Inertia and low voltage control bandwidth
GFM2: High Inertia and Low Voltage control bandwidth
GFM3: High Inertia and High Voltage control bandwidth.

DK1 ROCOF EVENT

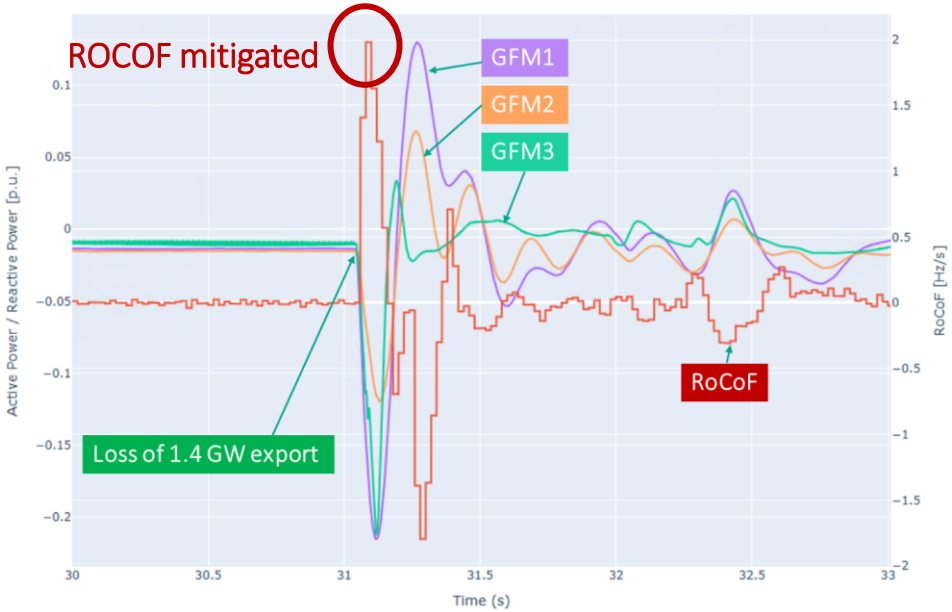
GFM provides inherent active power support to mitigate system ROCOF, e.g. phase jump, inertia and damping



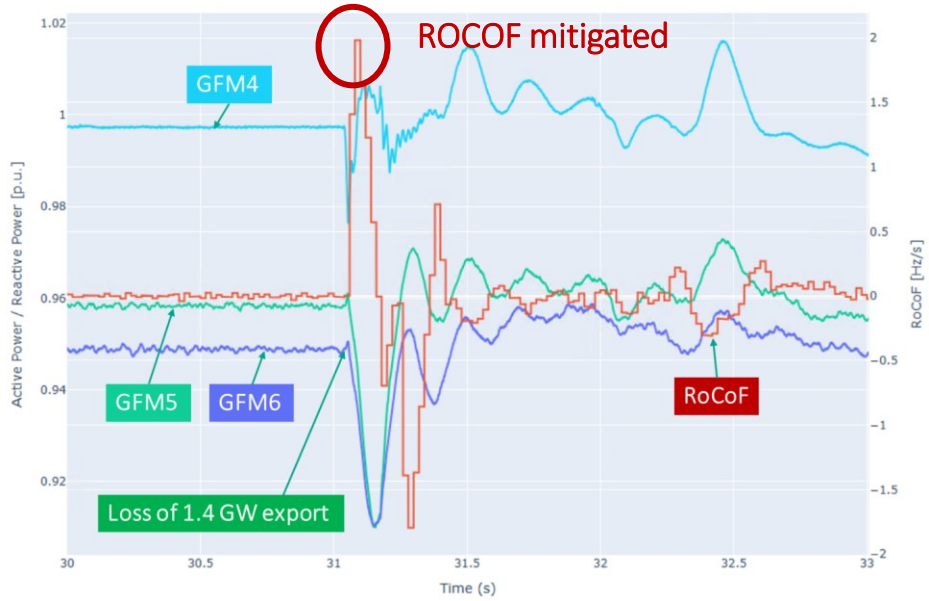
Viking Link trip -> loss of 1.4 GW power export



High ROCOF in DK1



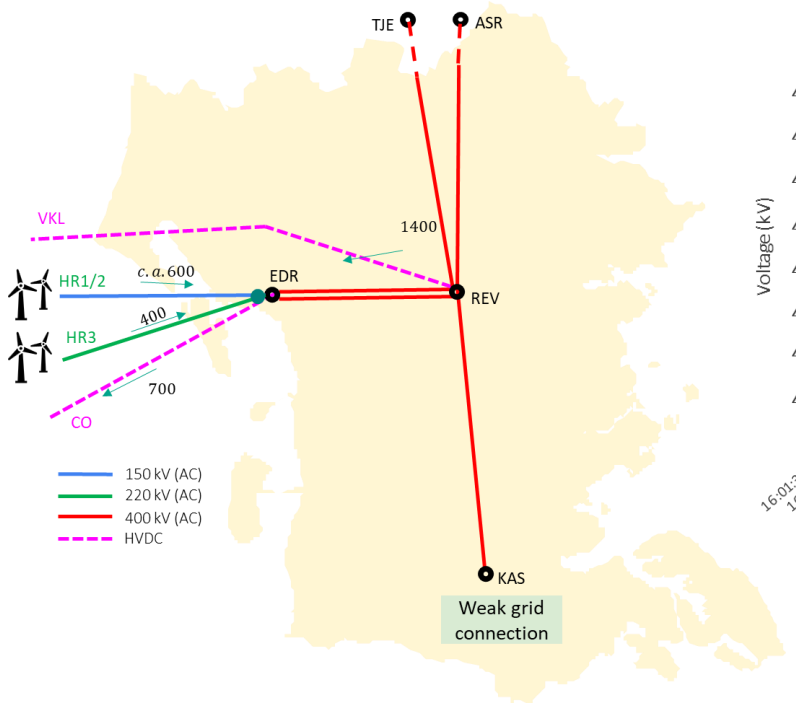
(a) Compensation-based GFM



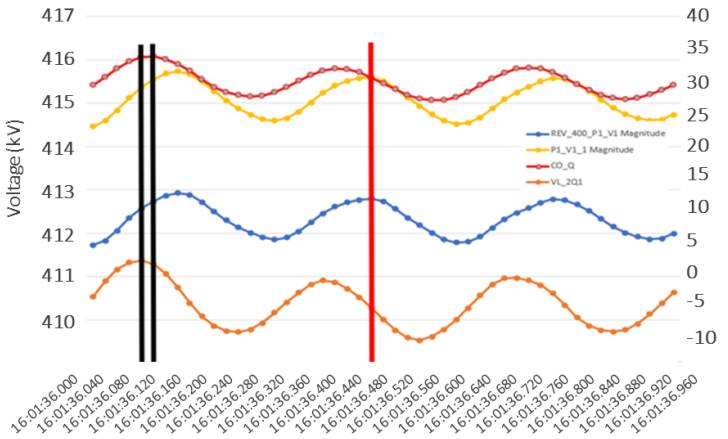
(b) Generation-based GFM

DK1 VOLTAGE OSCILLATION

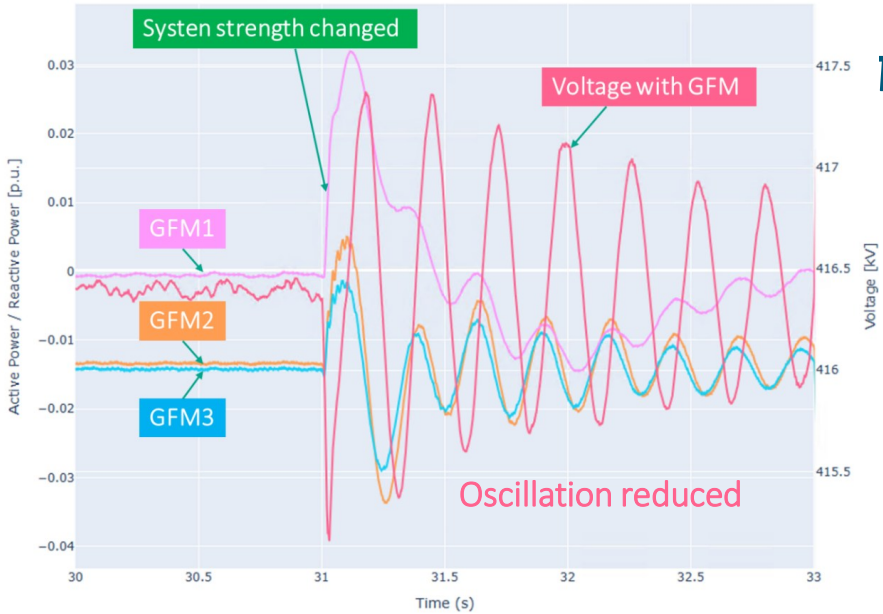
GFM provides inherent damping to mitigate sub-synchronous oscillations



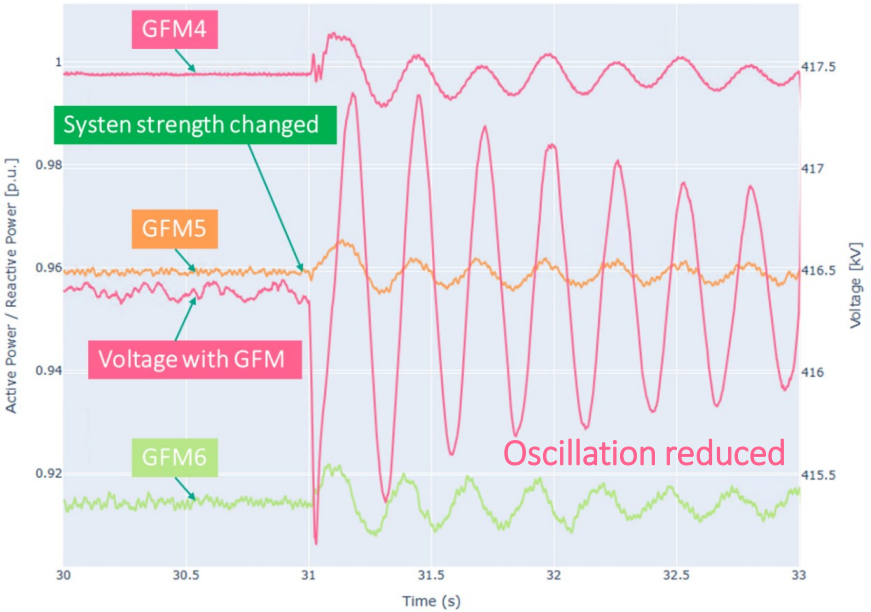
Weak grid scenario



Voltage oscillations around 3-5 Hz



(a) Compensation-based GFM



(b) Generation-based GFM

WHAT ARE NEXT?

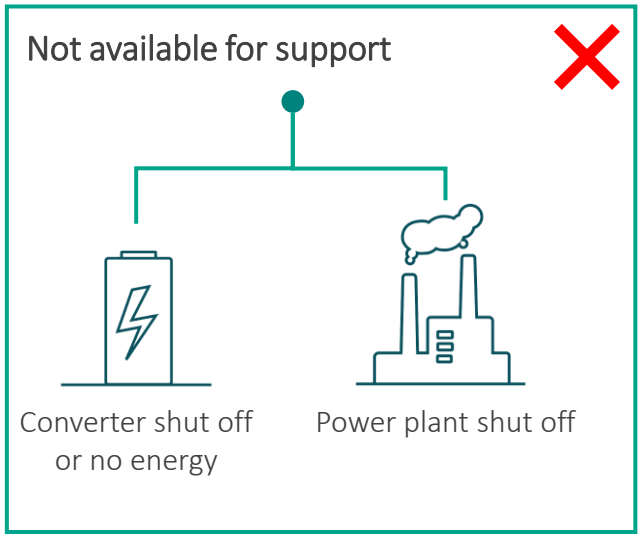
Future system needs evaluation

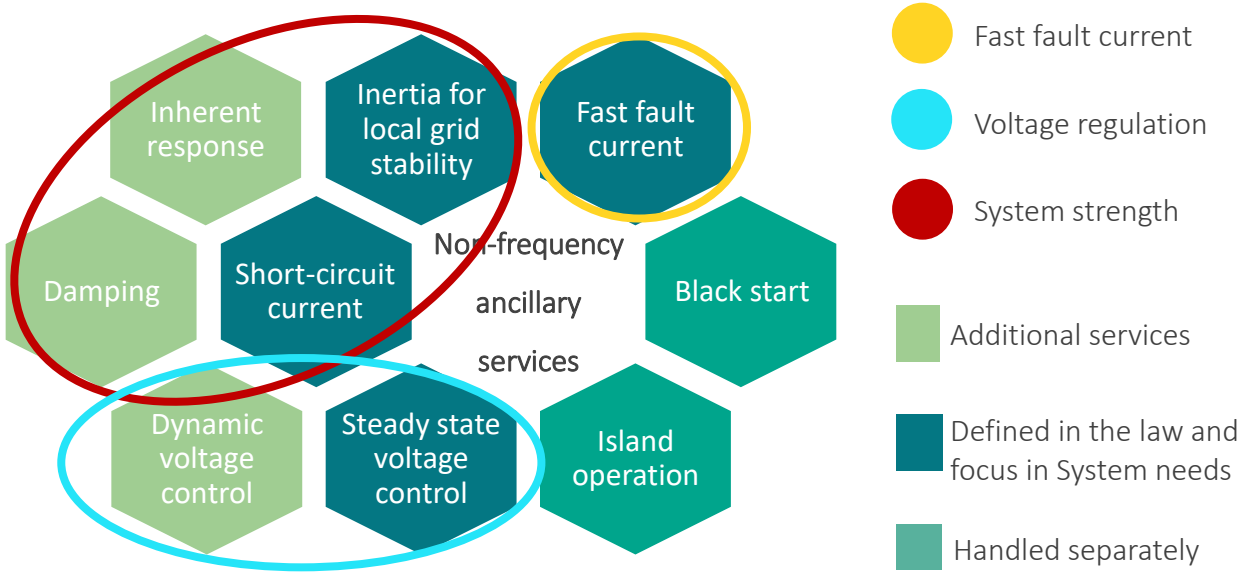
- Accommodate the need of system changing rapidly

Marketization of Non-frequency ancillary services

- Stability products as additional service
- Facilitate grid forming and ensure support from central power plants or facilities

Disclaimer: The marketization framework and needs are ongoing work. Reservations for approval from the Danish Utility Regulator and the Danish Energy Agency.





WHAT ARE NEXT?

Future system needs evaluation

- Accommodate the need of system changing rapidly

Marketization of Non-frequency ancillary services

- Stability products as additional service
- Facilitate grid forming and ensure support from central power plants or facilities

Stakeholder's inputs are welcome!

Register our dialogue meeting if you are interested:

Dialogue Meeting on the framework conditions for the provision of non-frequency-based ancillary services in the transmission system

ENERGINET

DIALOGUE MEETING ON THE FRAMEWORK CONDITIONS FOR THE PROVISION OF NON-FREQUENCY-BASED ANCILLARY SERVICES IN THE TRANSMISSION SYSTEM

Energinet invites current and prospective stakeholders associated with TSO-connected demand and generation facilities to a dialogue meeting on Energinet's draft framework conditions for the provision of non-frequency-based ancillary services in the transmission system. The purpose of the meeting is for Energinet to present the draft framework and, through dialogue, gather stakeholders' input to support the further development of the framework. Relevant preparatory materials are available below.

REGISTRATION DEADLINE
25 September 2026 at 10.00 AM

DATE
1 October 2026

TIME
09.00 AM-03.00 PM

PLACE
Energinet
Tonne Kjærsvej 65, 7000 Fredericia

Physical



ENERGINET

Questions ?