On the role of energy storage and grid-forming control in the future HVDC systems

Ali Tayyebi – Hitachi Energy Research Sweden | IEEE Sweden Technical Seminar

2024-09-23

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External Presentation

Hitachi Energy Research: an expanding global R&D organization

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Our R&D team is present in **20+ countries** and we have Research Centers in **seven countries**

2000+
R&D experts

>60%
work in software development

~200 researchers

>80%
researchers have PhDs

Public

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Hitachi Energy Research Sweden university collaborations

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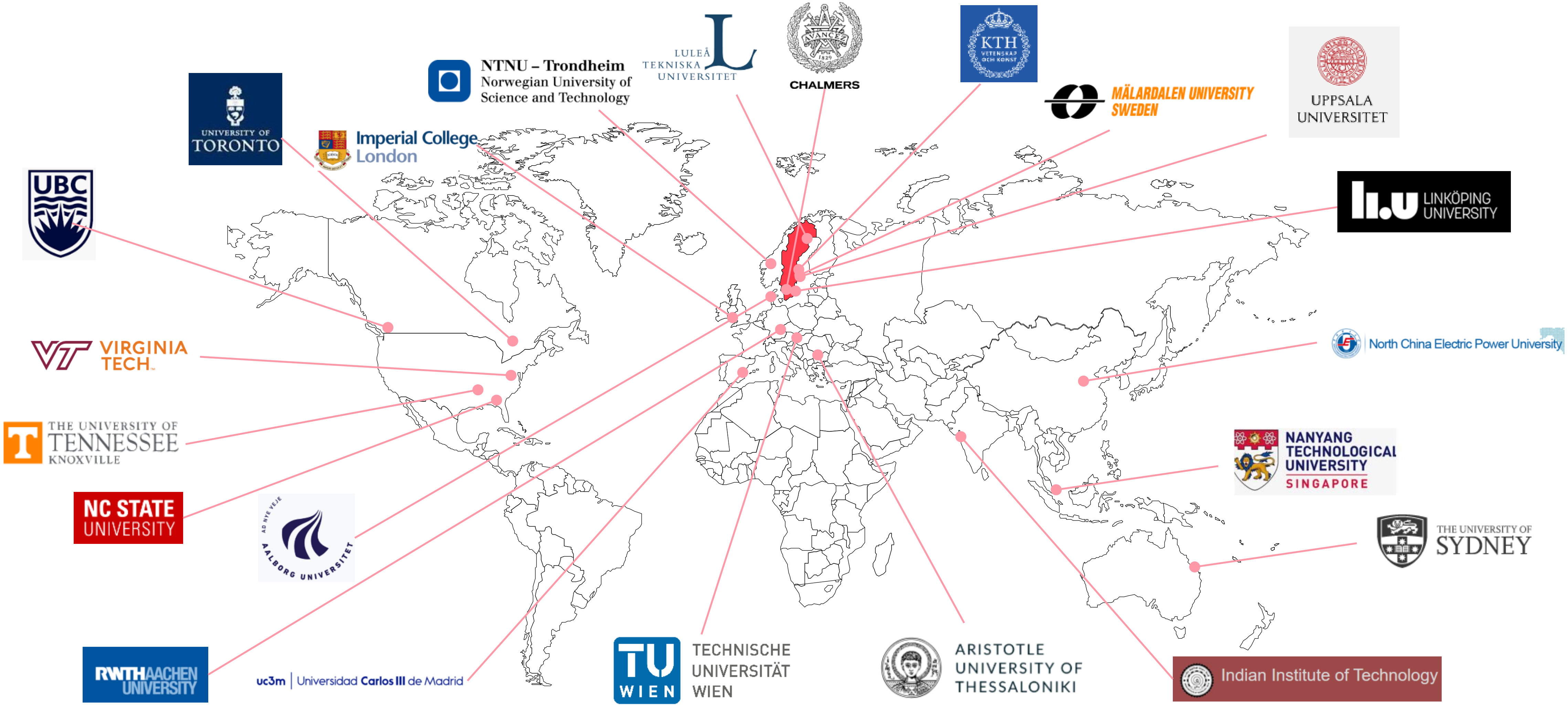

A global reach-out from Sweden

The need for grid-forming (GFM) control

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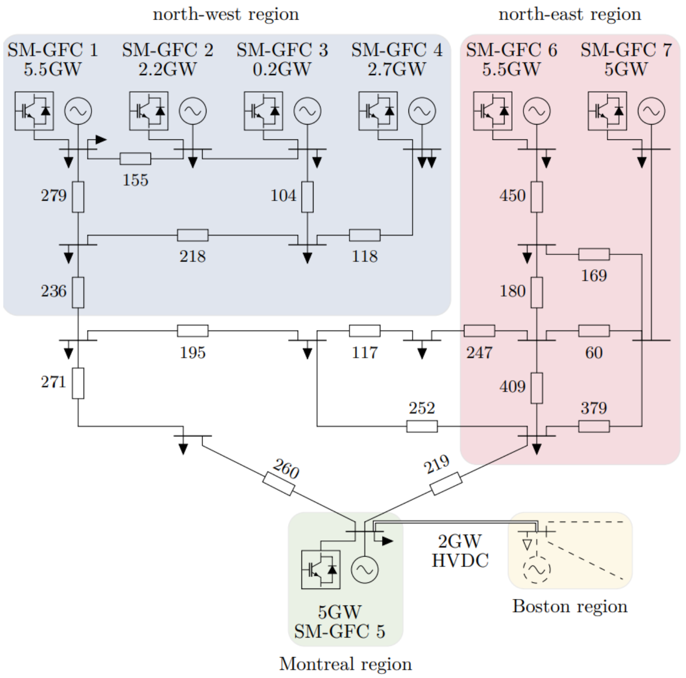
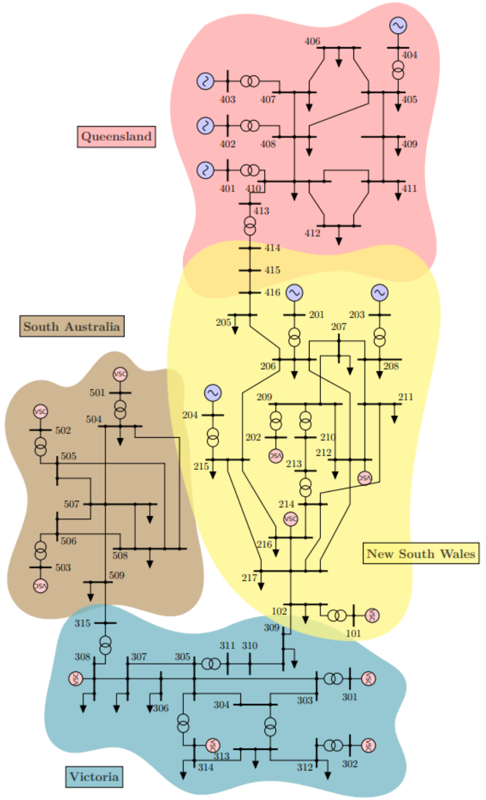
ETH study on Hydro-Quebec grid



Key message:

GFM control enables maximizing RES integration, i.e., beyond 80%

ETH study on South-East Australian grid



Key message:

GFM significantly enhances the system stability

Large-scale collaboration projects

InterOPERA
Enabling multi-vendor HVDC grids

unifi consortium
universal interoperability for grid-forming inverters

MIGRATE – Massive InteGRATion of power Electronic devices

A. Crivellaro et al., "Beyond low-inertia systems: Massive integration of grid-forming power converters in transmission grids,"2020 IEEE Power & Energy Society General Meeting (PESGM), Montreal, QC, Canada, 2020, pp. 1-5.
U. Markovic et al., "Understanding Small-Signal Stability of Low-Inertia Systems," in IEEE Transactions on Power Systems, vol. 36, no. 5, pp. 3997-4017, Sept. 2021..

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Grid-forming specifications and definitions

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System operators

NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

White Paper: Grid Forming Functional Specifications for BPS-Connected Battery Energy Storage Systems

September 2023

Great Britain Grid Forming Best Practice Guide

April 2023

entsoe
European Network of Transmission System Operators for Electricity

GRID FORMING CAPABILITY OF POWER PARK MODULES

FIRST INTERIM REPORT ON TECHNICAL REQUIREMENTS

Final version | 3 May 2024

Still evolving and a clear consensus has not been reached to this date…

Academia

Definition and Classification of Power System Stability – Revisited & Extended

Nikos Hatziargyriou, *Fellow, IEEE*, Jovica Milanovic, *Fellow, IEEE*, Claudia Rahmann, *Senior Member, IEEE*, Venkataramana Ajjarapu, *Fellow, IEEE*, Claudio Canizares, *Fellow, IEEE*, Istvan Erlich, *Senior Member, IEEE*, David Hill, *Fellow, IEEE*, Ian Hiskens, *Fellow, IEEE*, Innocent Kamwa, *Fellow, IEEE*, Bikash Pal, *Fellow, IEEE*, Pouyan Pourbeik, *Fellow, IEEE*, Juan Sanchez-Gasca, *Fellow, IEEE*, Aleksandar Stankovic, *Fellow, IEEE*, Thierry Van Cutsem, *Fellow, IEEE*, Vijay Vittal, *Fellow, IEEE*, and Costas Vournas, *Fellow, IEEE*

Frequency Stability of Synchronous Machines and Grid-Forming Power Converters

Ali Tayyebi, Dominic Groß, *Member, IEEE*, Adolfo Anta, Friederich Kupzog, and Florian Dörfler, *Member, IEEE*

Foundations and Challenges of Low-Inertia Systems

(Invited Paper)

Federico Milano, University College Dublin, Ireland, email: federico.milano@ucd.ie

Florian Dörfler and Gabriela Hug, ETH Zürich, Switzerland, emails: dorfler@ethz.ch, ghug@ethz.ch

David J. Hill* and Gregor Verbič, University of Sydney, Australia, * also University of Hong Kong, emails: dhill@eee.hku.hk, gregor.verbic@sydney.edu.au

The GFM control definition mostly revolves around the synchronization mechanism and control design methodology.

Industry

Grid Forming Control for HVDC Systems: Opportunities and Challenges

Adil Abdalrahman*, Ying-Jiang Häfner, Malaya Kumar Sahu, Khirod Kumar Nayak and Ashkan Nami
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Promises and Challenges of Grid Forming: Transmission System Operator, Manufacturer and Academic View Points

Carmen Cardozo*, Thibault Prevost*, Shun-Hsien Huang†, Jingwei Lu‡, Nilesh Modi‡, Masaya Hishida§, Xiaoming Li§, Adil Abdalrahman¶, Pär Samuelsson¶, Thierry Van Cutsem‖, Yorgo Laba**, Yahya Lamrani**, Frederic Colas** and Xavier Guillaud**
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** Univ. Lille, Arts et Metiers Institute of Technology, Centrale Lille, Junia ULR 2697 - L2EP 59000 Lille, France
Corresponding author: Xavier Guillaud (xavier.guillaud@centralelille.fr)

- The GFM control shall address the operational and stability challenges perceived by the system operators <u>while considering the technological capabilities and limitations.</u>
- <u>Consistent definitions</u> are critically required.

Credits and links provided in the references.

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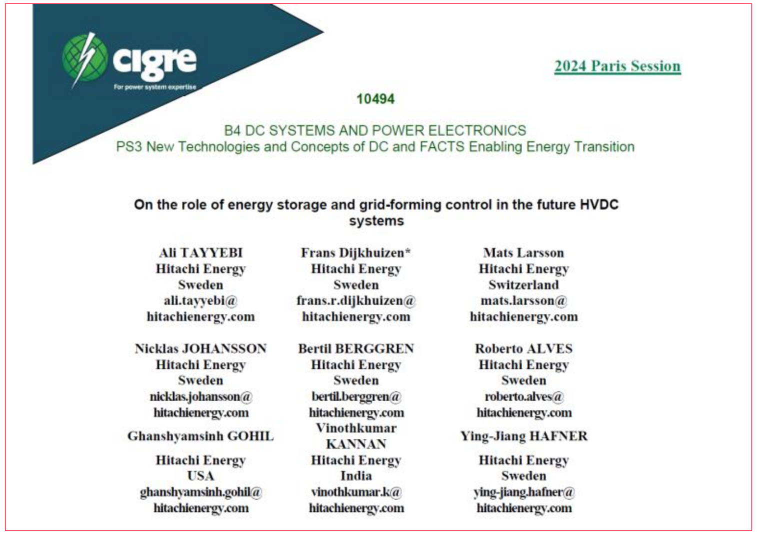
Emerging (Future) HVDC expansion

Future HVDC systems

- May incorporate complex configurations such as multi-terminal and energy/power hubs,
- In addition to the surprising increase in classic concepts, such as point-to-point, interconnector, and offshore wind farm (OWF) integration.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PS3 New Technologies and Concepts of DC and FACTS Enabling Energy Transition

On the role of energy storage and grid-forming control in the future HVDC systems

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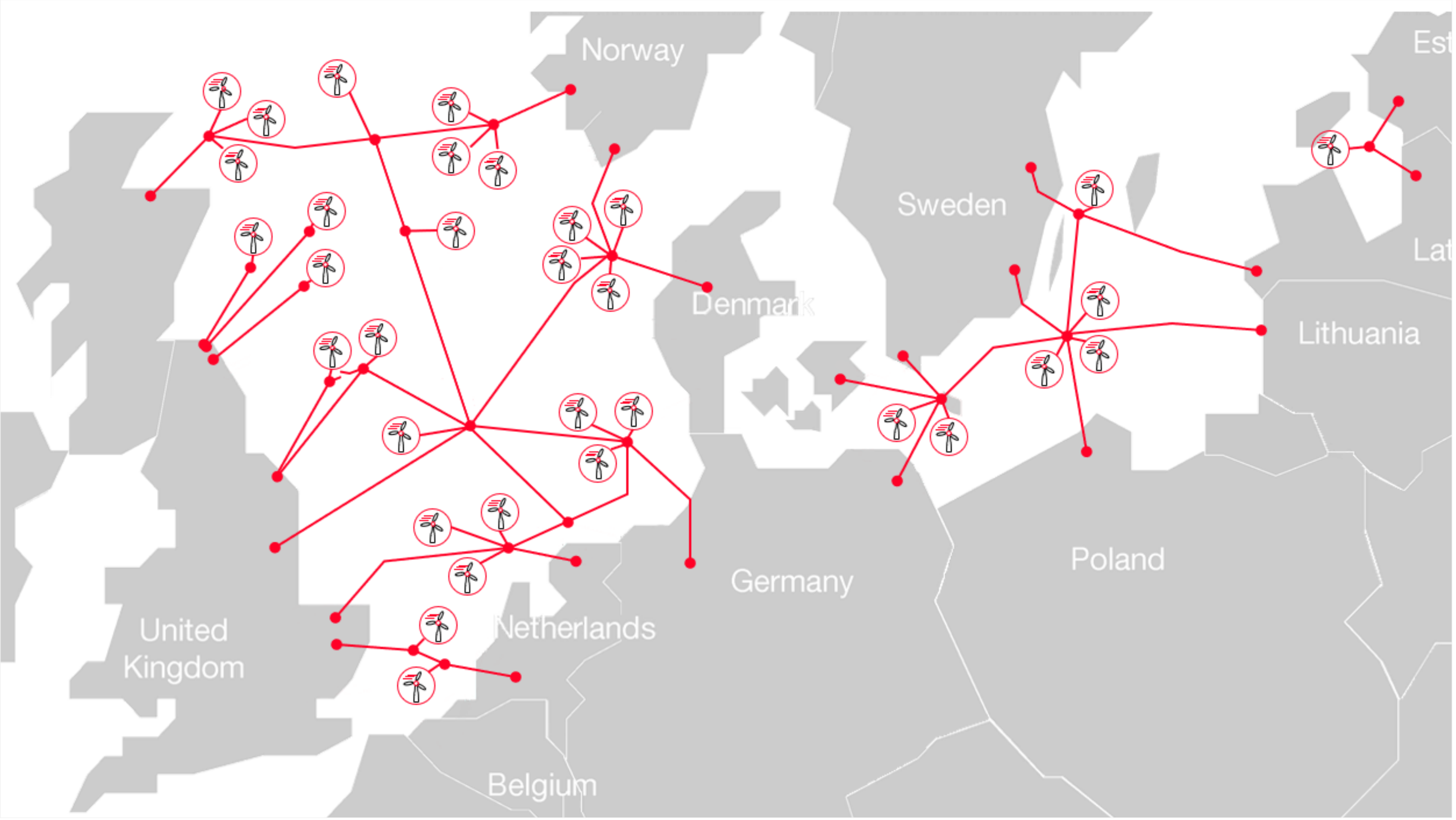

Acknowledgements to all the co-authors.
Credits and links provided in the references.
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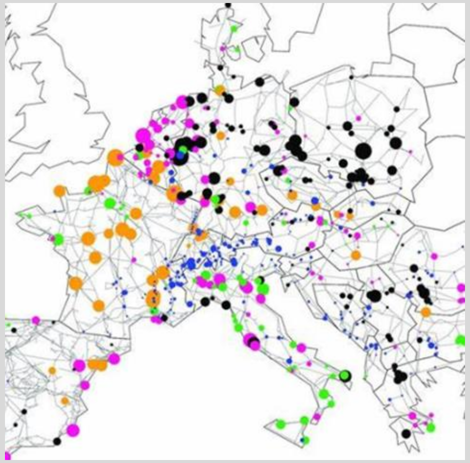
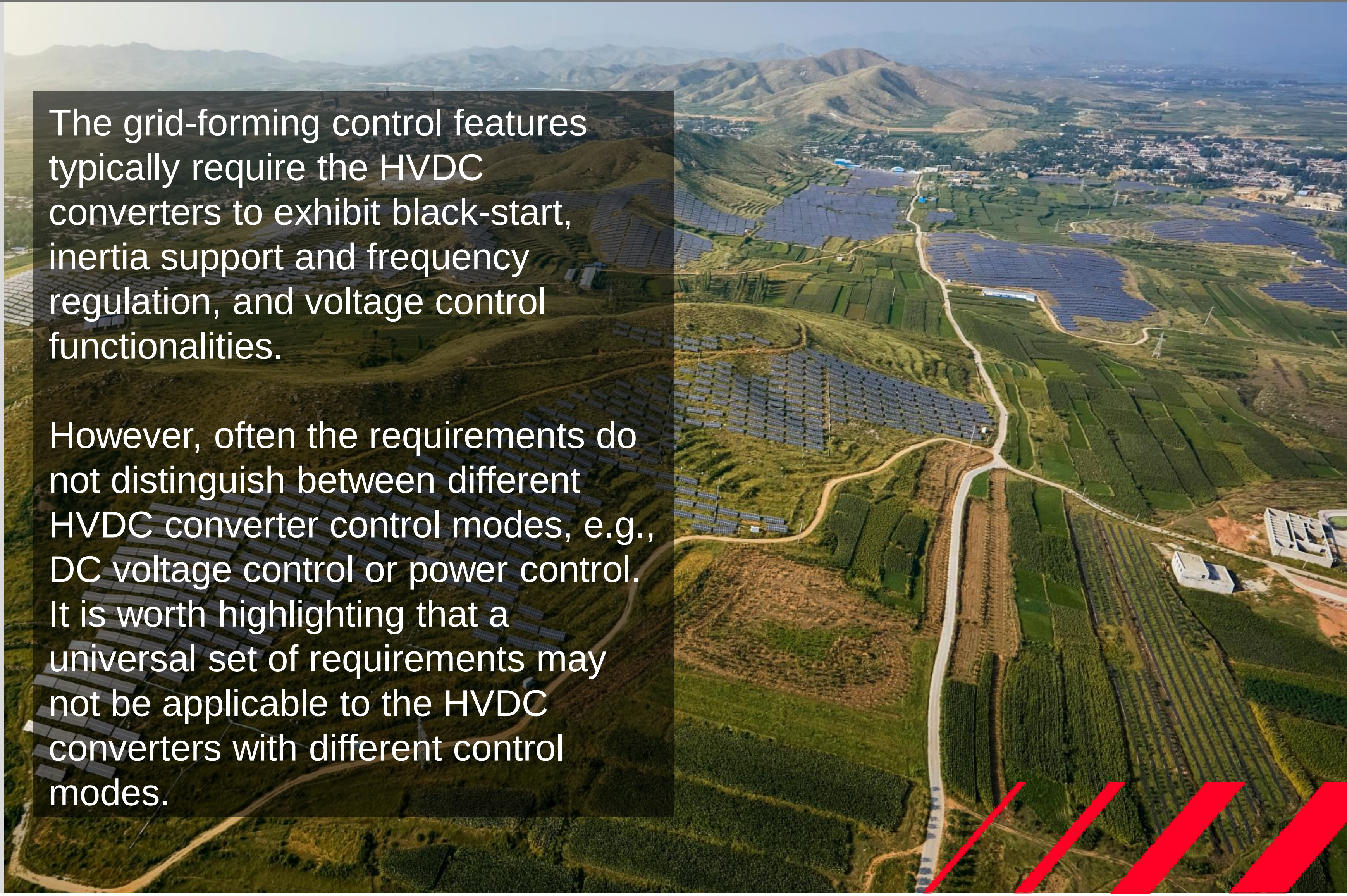
GFM control in HVDC systems



Fundamental HVDC concept:

- ❑ Predominantly a transmission medium.
- ❑ By design it does not store a significant amount of energy.
- ❑ The energy stored in the HVDC converters, and the interconnecting cables is typically small.
- ❑ Most of the total energy must be contained in the system to ensure a robust and reliable operation.



The grid-forming control features typically require the HVDC converters to exhibit black-start, inertia support and frequency regulation, and voltage control functionalities.

However, often the requirements do not distinguish between different HVDC converter control modes, e.g., DC voltage control or power control. It is worth highlighting that a universal set of requirements may not be applicable to the HVDC converters with different control modes.

Public

Figure credit: ENTSO-E

Energy storage system (ESS) – the missing key element

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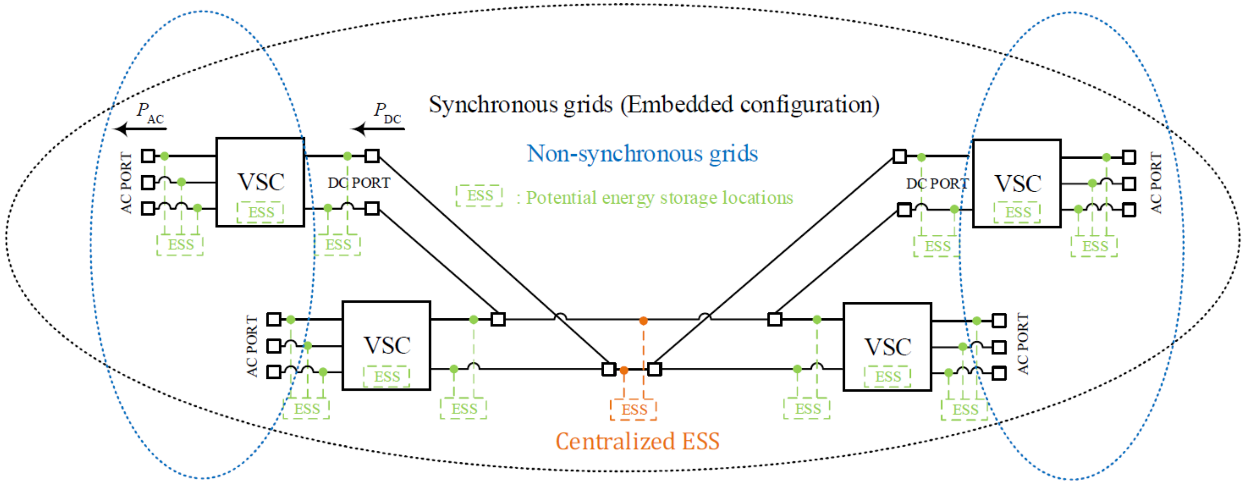
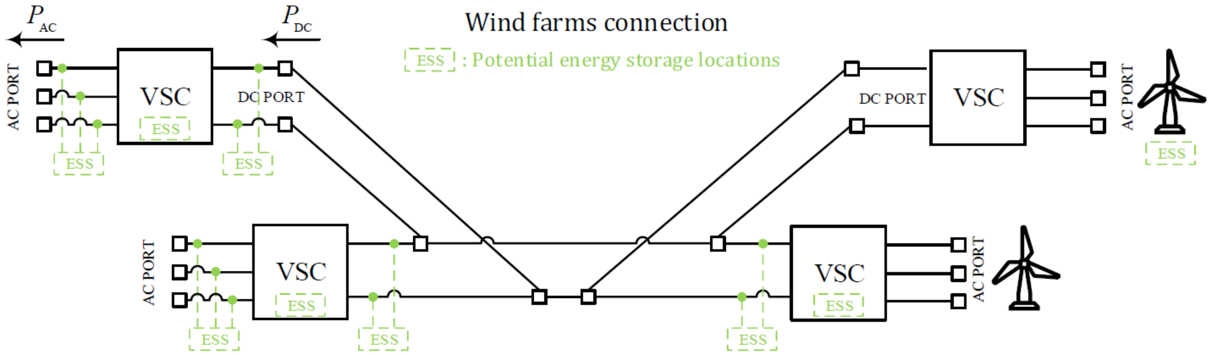
The role of ESS in HVDC

- ESS integration may allow to operate both stations under a grid-forming control strategy given that the ESS sufficiently contributes to the DC voltage stability.
- ESS is appropriately sized; it can support or enable the black-start capability for the HVDC converters.
- To meet the emerging challenging targets, e.g., angle jump and inertia support, as well as, withstanding large ROCOF events.
- Ensure the stability of the HVDC systems in such scenarios and events of grid splits.
- ESS can enable disturbance decoupling between interconnected areas.



(a)



(b)

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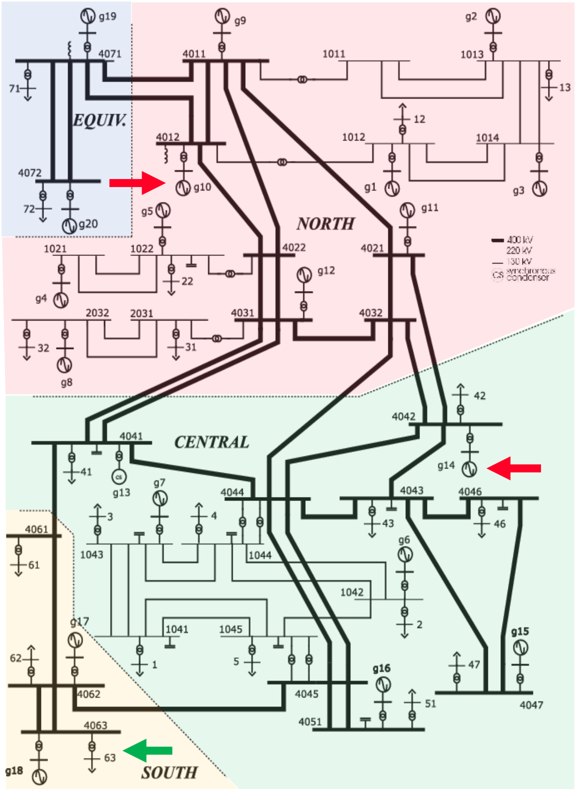
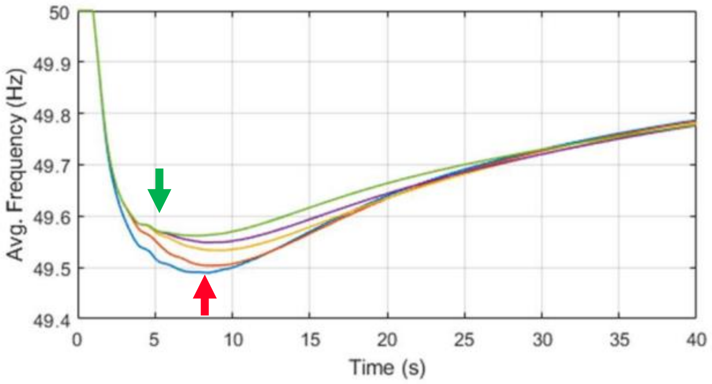
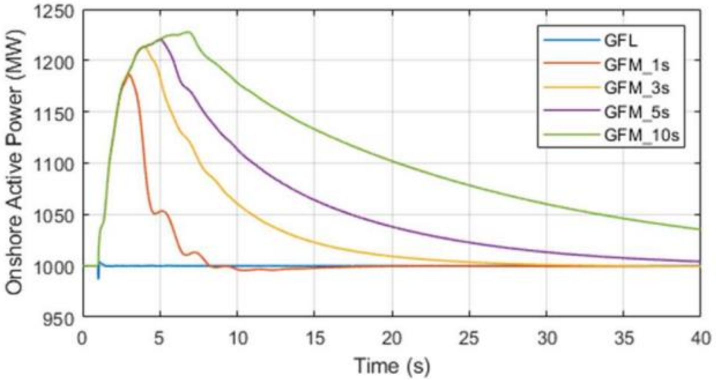
Nordic-32 benchmark case study







- Generator outage at two different buses
- Integrated ESS for the onshore station

- GFL converter is not capable of contributing to the inertia support
- Combination of GFM and ESS integration can improve the nadir performance

Further observations

- First observation from this paper is that the available kinetic energy of online synchronous assets (dedicated to the inertial response) is fractional compared to the total energy available.
- ESS has a wider range of energy and power variation, for a significant regional effect, and fully controllable, though constrained by economical trade-offs.
- It has been shown that ESS integration leads to significant improvement in nadir frequency in the studied Nordic-32 test system following a 2 GW generation outage.

Electric Power Systems Research
Volume 235, October 2024, 110809

A generalized time-domain framework for modeling and analysis of the unbalanced three-phase systems ☆

Ali Tayyebi [a], Weichi Zhang [b], Xing Huang [b], Wen Jiang [b], Dierk Bormann [a], Mats Larsson [c]

Here is our most recent work on unbalanced AC systems.

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