Introduction and Lessons Learned from GFM

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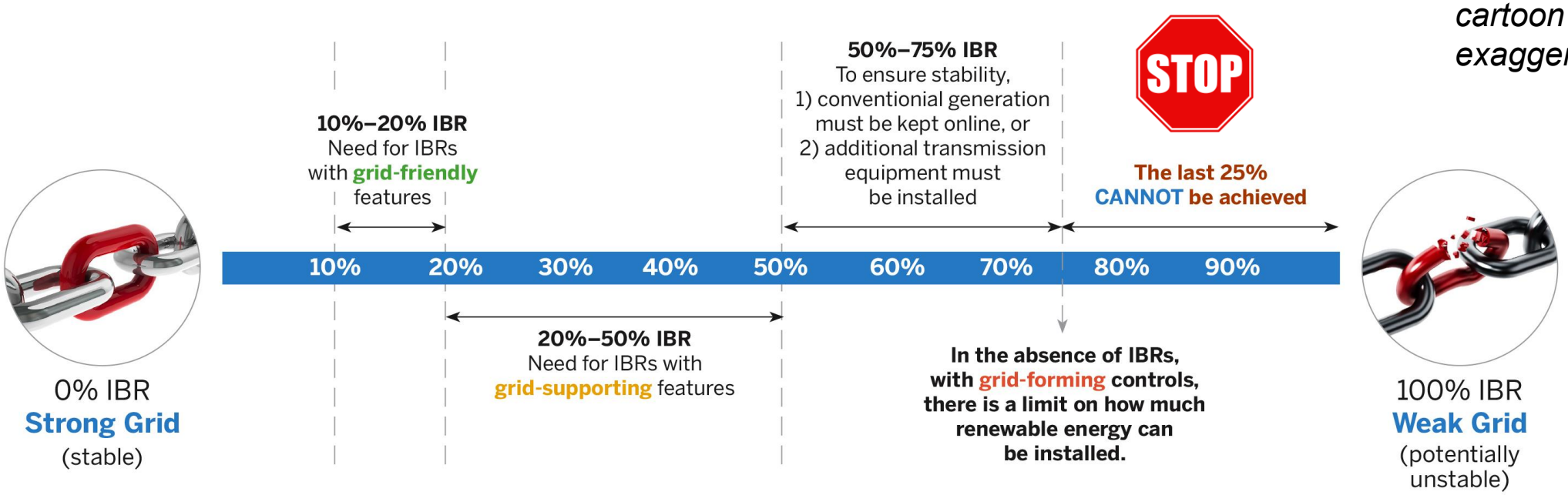
Where are We Today and What is the Issue?

Disclaimer: this figure is a cartoon and as such is an exaggeration



1. Keeping conventional generation online leads to high renewable curtailment.
2. Additional transmission equipment is expensive and time-consuming to install (and renewable curtailment continues in the meantime).

IBR – Inverter-Based Resource (wind, solar, battery storage)

What is Grid Forming ?

NERC definition:

- Grid Forming IBR controls **maintain an internal voltage phasor that is constant or nearly constant in the sub-transient to transient time frame.** This allows the IBR to immediately respond to changes in the external system and maintain IBR control stability during challenging network conditions. The voltage phasor must be controlled to maintain synchronism with other devices in the grid and must also regulate active and reactive power appropriately to support the grid
- There are many variations of both grid-forming and grid-following controls. Both are subject to physical equipment constraints including voltage, current and energy limits, mechanical equipment constraints (on WTGs) as well as external power system limits.
- Further, performance requirements for GFL plants, will also apply to GFM inverters unless explicitly identified as inapplicable.

Sources: NERC, Grid Forming Technology Bulk Power System Reliability Considerations , December 2021
ESIG, Grid Forming Technology in Energy Systems Integration, March 2022

Potential Use-Cases for Grid Forming Controls

- **Resist voltage change** (phase jump and voltage magnitude step response)
- **Resist frequency change** / limit RoCoF (substitute/supplement for inertial response of synchronous generation)
- Fast fault current injection (balanced and unbalanced)
- **Weak grid operation**
- Damping of voltage and frequency oscillations
- Mitigation of control interactions
- Support of islanded operation (when required)
- Black start (when required)

Source: Adopted from Y. Cheng, Preliminary assessment of Grid Forming Inverter-based Energy Storage Resources in the ERCOT Grid ERCOT IBRWG, August 2023

Towards Very High IBR

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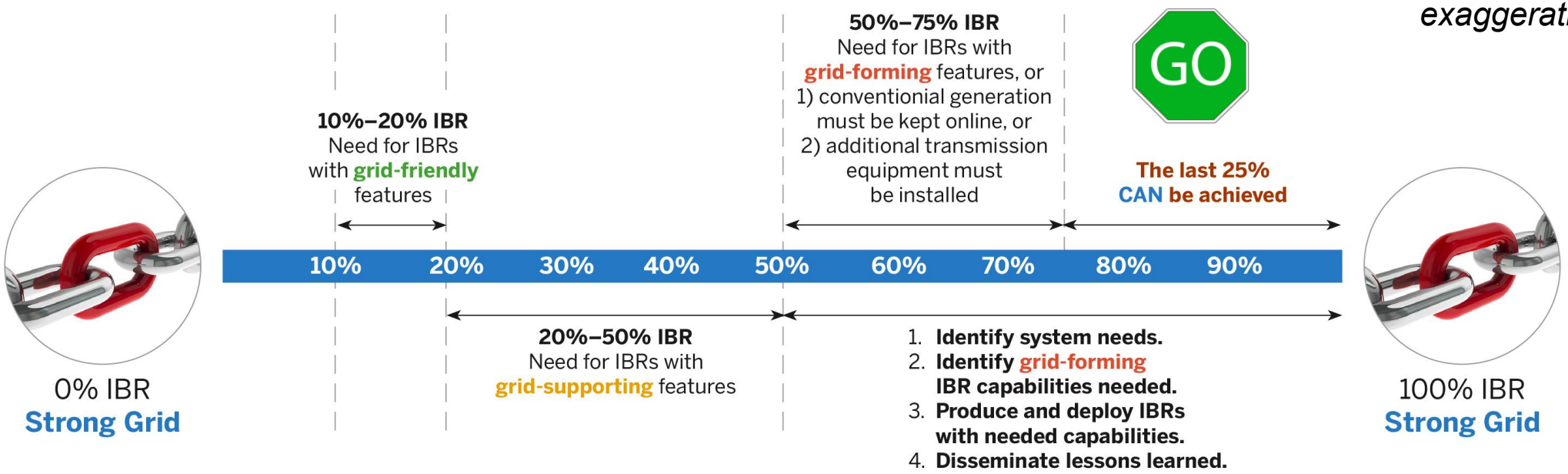
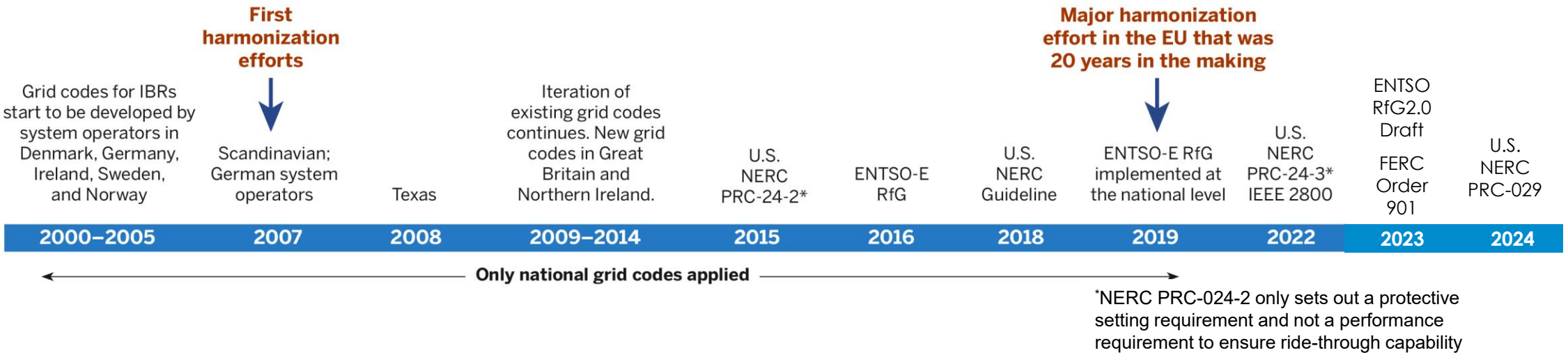


Deploying grid-forming capabilities from IBRs, especially battery storage, **is cheaper and faster** than adding new transmission assets, which would require additional investment and may take much longer to build.

Timeline of Harmonization Efforts for IBR Grid Codes in Europe and the United States



- Grid codes specify the capabilities that generators must have in order to interconnect to the grid.
- Diversity in grid codes requires multiple product designs and increase equipment costs.
- Comprehensive harmonized grid code for IBRs took 20 years to develop in Europe.
- The U.S. still has no harmonized grid code for IBRs today.
- **We cannot take 20 years to develop and harmonize grid codes for grid-forming IBRs!**

Grid Forming Testing and Specs Landscape At Glance

Links to all these specification documents can be found here

This presentation contains presenter's interpretation of the requirements, please refer to original documents for exact specifications

Grid-Connected Operational GFM BESS Projects

Project Name	Location	Operator/Utilit	Size (MW)	OEM	Year*	Operational
Eurimbula Solar Farm and BESS	Australia; Queensland	AEMO	666	SMA	2025	Y
Shallow Basket project	USA; New Mexico;	NRS	50	Tesla	2025	Y
World's Largest Multi-Energy Grid-Forming Project	Saudi Arabia		600	Sungrow	2024	Y
Amaala Project	Saudi Arabia		160	Sungrow	2024	Y
Blackhillock, Phase I	Great Britain	NESO	200	SMA	2024	Y
Kupono Solar	USA; Hawaii	HECO	42	Tesla	2024	Y
Saudi Arabia Red Sea New Town Project	Saudi Arabia		240	Huawei	2023	Y
Riverina and Darlington Point	Australia	AEMO	150	Tesla	2023	Y
New England BESS	Australia	AEMO	50		2023	Y
Kapolei Energy Storage	USA; Hawaii	HECO	185	Tesla	2023	Y
Broken Hill BESS	Australia	AEMO	50	SMA	2023	Y
Dalia Black Start Project	Israel		16	Sungrow	2022	Y
Provincetown BESS	USA; Massachusetts	Eversource Energy	25	SMA	2022	Y
Wallgrove	Australia	AEMO	50	Tesla	2022	Y
Kauai PMRF	USA; Hawaii	KIUC	14		2022	Y
Hornsdale Power Reserve	Australia	AEMO	150	Tesla	2022	Y
Grid-Forming ESS Black Start Gas Turbine Project	USA; Indiana		15	Sungrow	2019	Y
Bordesholm	Germany	Versorgungsbetrie	15	SMA	2019	Y
Project #1	USA; Hawaii	KIUC	13	Tesla	2018	Y
Dalrymple	Australia	AEMO	30	Hitachi Energy	2018	Y

https://www.esig.energy/working-users-groups/reliability/grid-forming/gfm-landscape/

Grid-Connected Operational GFM BESS Projects

Project Name	Location	Operator/Utilit	Size (MW)	OEM	Year*	Operational
Xinhua Hydropower GFM Fluoride Flow Energy Stora	China; Xinjiang	SGCC	250	NR Electric	2025	Y
Xinjiang Shache GFM BESS	China; Xinjiang	SGCC	200	NR Electric	2025	Y
Ningxia Longyuan Mengjiawan	China; Ningxia	SGCC	295	NR Electric	2025	Y
Yunnan Wenshan Qubei Project	China; Yunnan	CSG	50	NR Electric	2025	Y
Golmud Leuneng	China; Qinghai		25	Huawei	2024	Y
China Resources Electric Power Hami	China; Hami		25	Huawei	2024	Y
Wenshan Grid-Forming ESS	China; Yunnan		50	Sungrow	2024	Y
Huadian Jinchuan Hongyuan Grid-forming ESS	China; Sichuan		50	Sungrow	2024	Y
Grid-Forming ESS Project	Tibet; Ihsasa		40	Sungrow	2024	Y
Huadian Shannan Naidong Cai Peng Phase II	Tibet		20	Sungrow	2024	Y
Qinghai Baohu Grid-Forming BESS	China; Qinghai	SGCC	108	NR Electric	2024	Y
Guoneng Ningdong Shuguang Project	China; Ningxia	SGCC	65	NR Electric	2024	Y
Grid-Forming ESS Project	China; Luopu, Xinjiang		250	Sungrow	2024	Y
China First Grid-Forming ESS+PV Project	China; Yanweijuyan, Gansu		10	Sungrow	2024	Y
Zhongkai Grid-Forming Project	Tibet; Ali		60	Sungrow	2024	Y
Hubei Jingmen Gaoqiao GFM BESS	China; Wuhan	SGCC	50	NR Electric	2022	Y

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Conclusions

- If IBRs are built with grid-forming controls, stability can be provided by the resource itself, the need for additional mitigation can be greatly reduced, and higher share of IBRs (up to 100%) achieved.
- Grid code requirements and/or market products are needed for grid-forming IBRs to be deployed in an efficient and timely manner.
- It took 20 years in Europe to develop grid codes for present-day IBR technology, while the U.S. still does not have harmonized grid codes. **We do not have another 20 years to develop requirements of grid-forming IBRs!**
- Recently published GFM requirements and specifications agree on high level functionalities needed by detailed requirements and level of specificity still differ widely.
- There have been a number of activities in the U.S., Europe, and Australia in the past three years to accelerate the deployment of grid-forming IBRs.
- However, the challenge is broad and global. Much more work is needed — and quickly — to seize this window of opportunity and deploy grid-forming controls at lest on BESSs next in line to be connected to the grid.