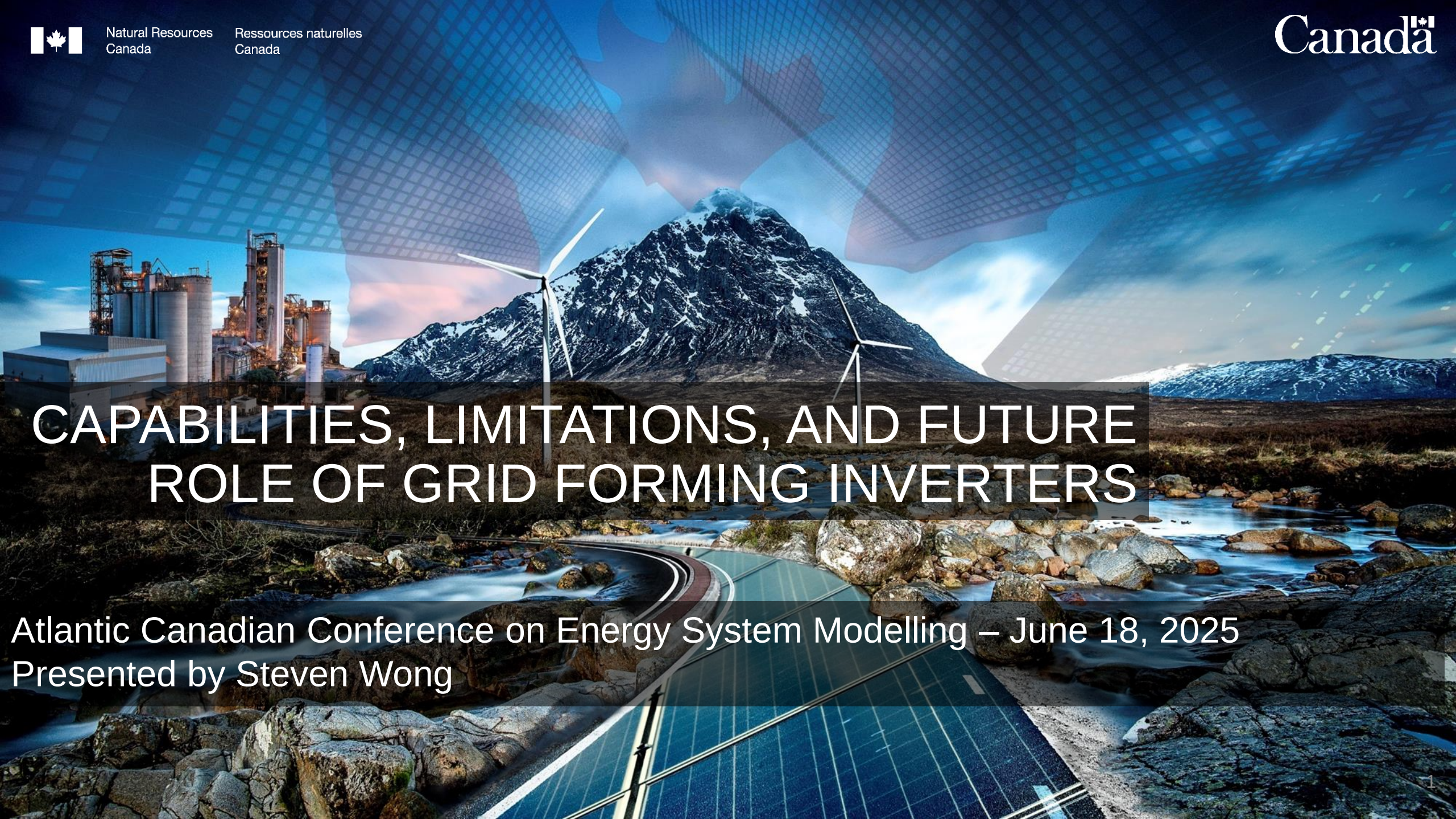




Natural Resources
Canada

Ressources naturelles
Canada

Canada



CAPABILITIES, LIMITATIONS, AND FUTURE ROLE OF GRID FORMING INVERTERS

Atlantic Canadian Conference on Energy System Modelling – June 18, 2025
Presented by Steven Wong

INVERTERS AND INVERTER-BASED RESOURCES (IBRS)



INVERTERS AND IBRS

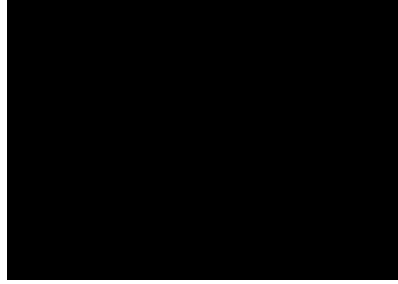
- Enable grid connection of DC sources by converting DC to AC (and, for battery systems, AC to DC)



	Synchronous machine	Inverter (non HVDC)
Technology	Mechanical	Electronic
Size	Up to 100's MWs	Up to MWs
Source	Gas, steam, hydro	Wind, solar, battery

- Inverter-based resources (IBRs)
 - “A source of electric power that is connected to the electric power system, and that consists of one or more IBR Unit(s) operated as a single resource at a common point of interconnection.” (NERC Definition)
 - Includes, e.g., solar PV; battery energy storage system (BESS); wind (type III, induction, and IV, full converter)

GRID OPERATION WITH IBRS



KEY CONCEPTS

- Reliability
 - Keeping the lights on
(minimize frequency and duration of outages)
- Adequacy
 - Ensuring there is enough generation
- Stability
 - Maintain operation through disturbances
(keep frequency and voltage within limits)
- Protection
 - Prevent damage to systems, equipment and people

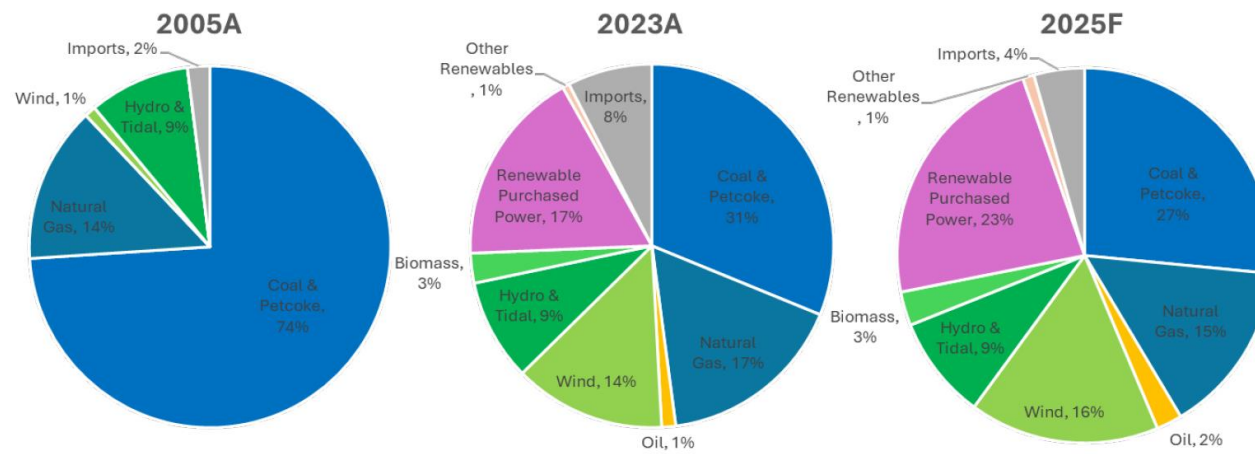
Recovery following a complete collapse is followed by a black start.

Many provinces have never had to perform a complete black start.

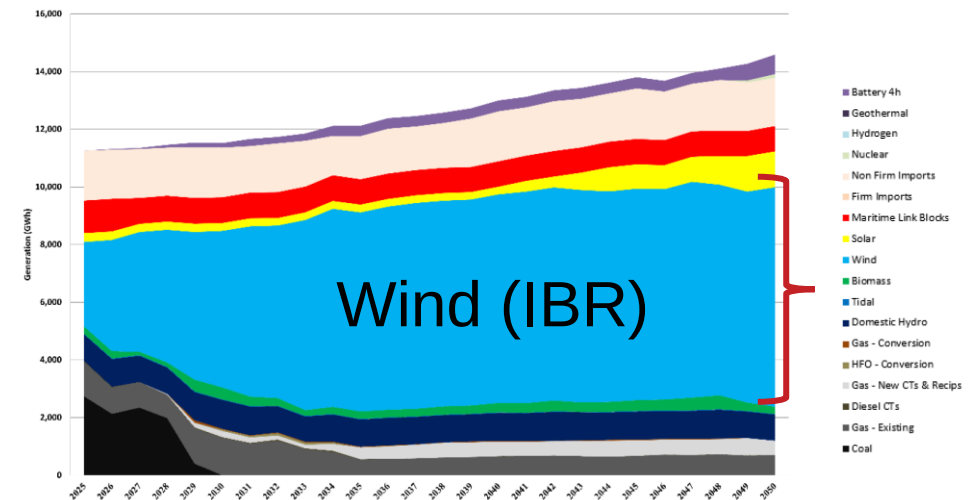
Where IBRs have significant technical impact

EVOLUTION OF IBRS ON THE GRID

- Conventional grid architecture built around synchronous machines; ingrained in the design as reflected by, e.g., operations and protection
- Decarbonization and electrification → more renewables, more loads



2024 10-Year System Outlook, NS Power



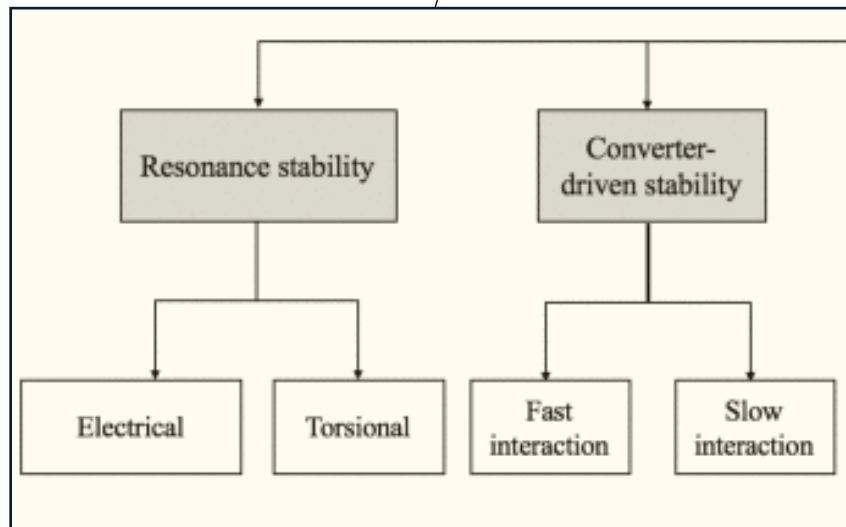
Evergreen-IRP-Update-to-IRP-Action-Plan-and-Roadmap-2023, NS Power

- It's about power!

STABILITY

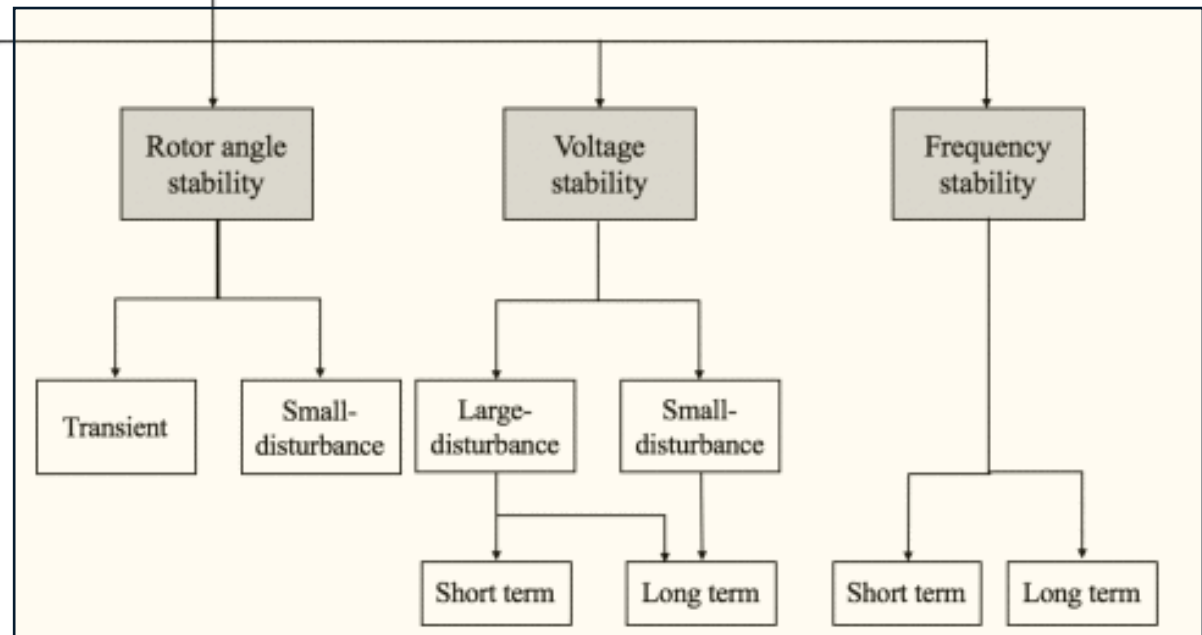
IBRs impact all areas of stability, but also introduce new ones

Research problem



Power system stability

Engineering problem

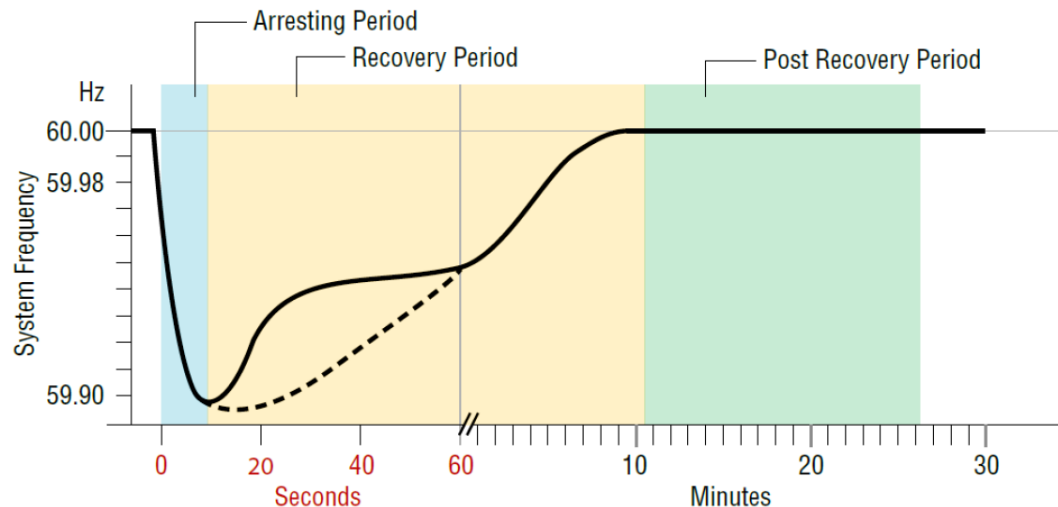


From Definition and Classification of Power System Stability –
Revisited & Extended; <https://doi.org/10.1109/TPWRS.2020.3041774>

STABILITY AND PROTECTION CONCEPTS

■ Frequency stability

- Inertia (MW·s)
 - Resistance to change in movement
 - Rate of change of frequency (RoCoF, Hz/s)
- Primary frequency response



White Paper: Fast Frequency Response Concepts
and Bulk Power System Reliability Needs, NERC 2020

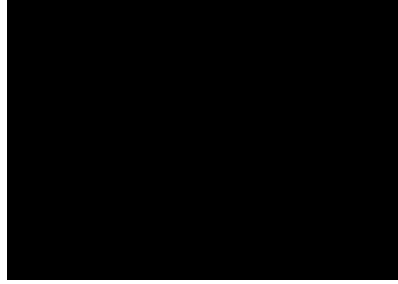
■ Voltage stability

- Short-circuit ratio | system strength
- Ride-through
- Reactive power support
- Fault current contribution

■ Protection

- Fault current contribution

SMART INVERTERS



EVOLUTION OF INVERTERS

- Since the 90's, inverters have evolved to offer larger sets of grid support functions (capabilities)
- (Basic) inverters ✖ (outdated)
- Smart inverters
 - Grid following (GFL) ✔ (current)
 - Grid forming (GFM) 🧑 (in development/early commercialization)
- Complete set of IBR capabilities (grid support functions) depends on the source *and* inverter
 - Adoption of GFM will probably come first with batteries

EVOLUTION OF INVERTERS II

Grid-following

- Delivers power by controlling its **current** and phase angle
- Relies on grid synchronization for operation, i.e., **follows the grid**
- Can provide limited set of grid support capabilities
- Mature



Follower

Grid-forming, stand-alone

- Deliver power by controlling its **voltage** and frequency
- Can create its own waveform, but only in isolation from other grid forming equipment (e.g., single battery system in a microgrid)
- Mature



Leader

Grid-forming, interconnected

- Deliver power by controlling its **voltage** and frequency
- Can work in conjunction with other grid forming equipment while making its waveform
- In development/early commercialization



Collaborator

GFM VS GFL - CAPABILITIES

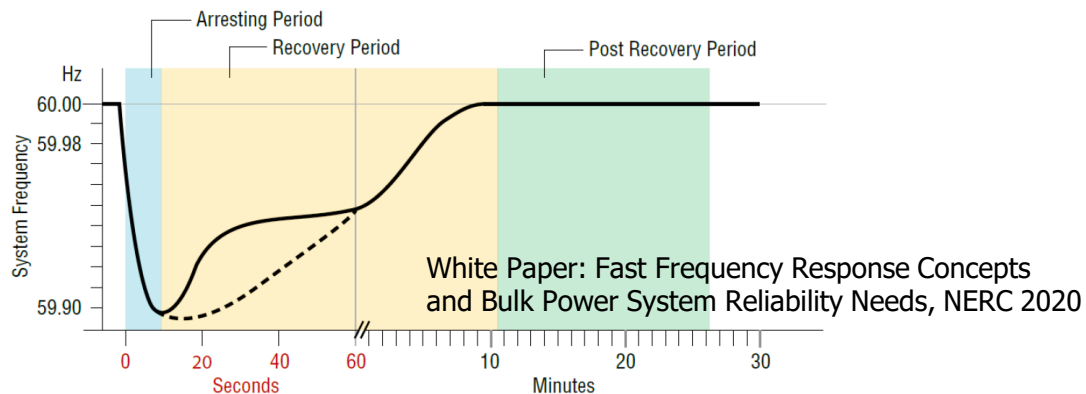
	GFL	GFM
Normal		
Dispatchable*	Yes	Yes
Reactive power support*	Yes	Yes
Disturbance		
Droop Primary frequency response*	Yes	Yes
Fast frequency response, incl. virtual inertia*	Yes	Yes, more control (emulation) options
Ride-through	Yes	Yes, under expanded conditions
Black start support	No	Yes

* May require headroom

STABILITY AND PROTECTION CONCEPTS REVISITED

■ Frequency stability

1. Inertia (MW·s)
2. Primary frequency response



■ Voltage stability

3. Ride-through
4. Fault current contribution

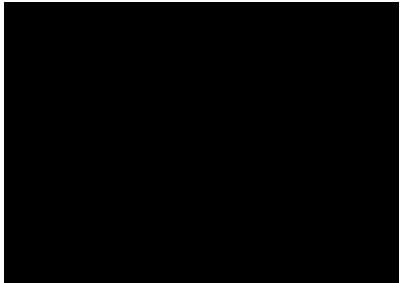
■ Protection

5. Fault current contribution

	GFL	GFM
1 & 2	Ok	Great

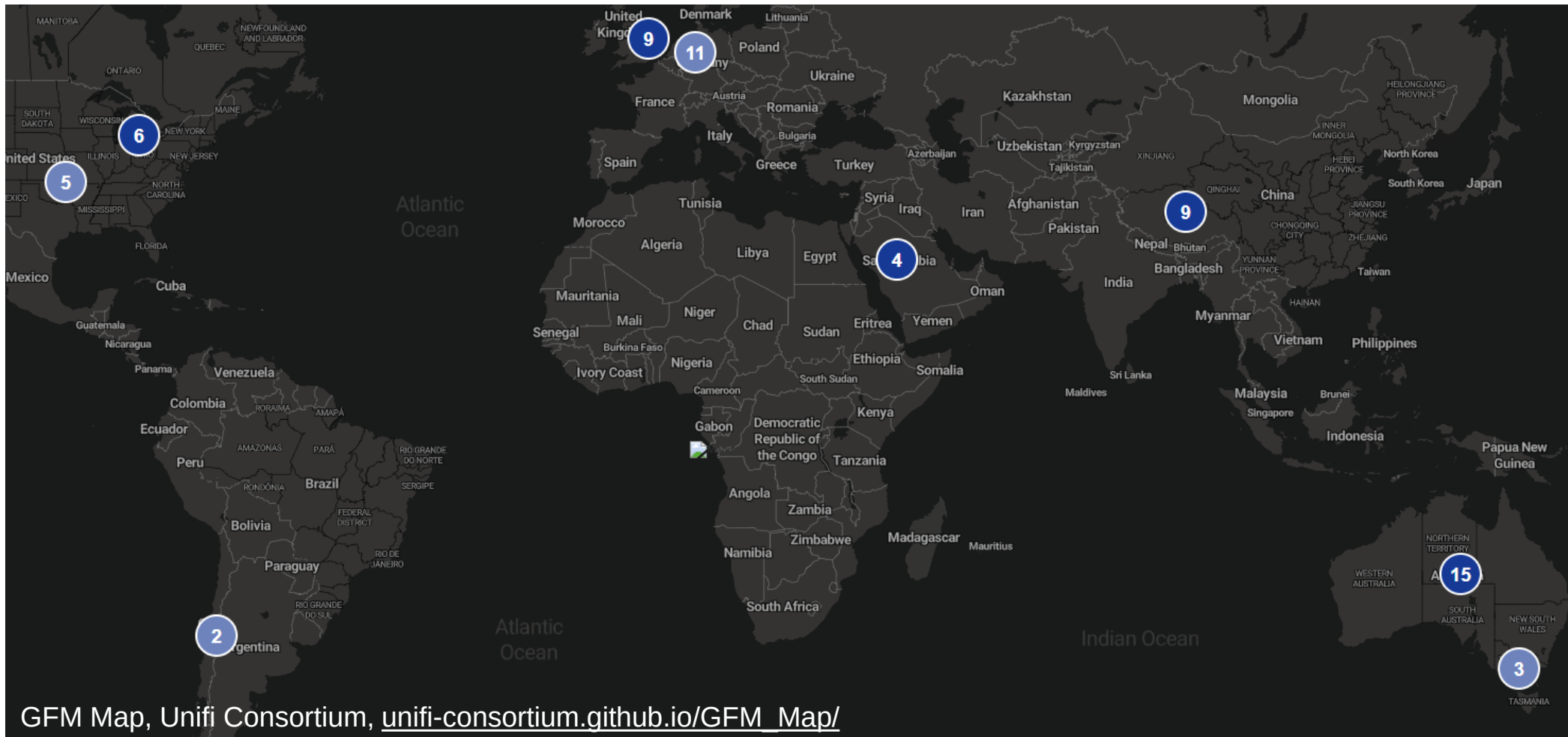
	GFL	GFM
3	Ok	Better (before current contribution limit)
4	Limited	Limited
5	Limited	Limited

SOLUTIONS AND REAL-WORLD EXAMPLES



STATE OF GFM IMPLEMENTATION

- Grid-Forming Projects
- Policy/Standards Documents



TOOLS TO ADDRESS SELECT NEEDS

- Low Inertia / frequency stability
 - Interconnections
 - Synchronous condensers with flywheels
 - Inverter virtual inertia via FFR
 - Curtailment
- Low short circuit contribution / voltage stability
 - Synchronous condensers
 - System reinforcement
 - Inverter ride-through

	Stability Pathfinder Phase 1	Stability Pathfinder Phase 2	Stability Pathfinder Phase 3
Requirement	Inertia and dynamic voltage GB wide	Inertia, SCL and dynamic voltage	Inertia, SCL and dynamic voltage
Status	All Synchronous compensators most units now live	5 GFM BESS 5 SynComp Go-live from Apr 24	29 Synchronous compensators Go-live expected from 2025
Participating technology	0MW Synchronous Compensators only	Synchronous and Grid Forming Converter based	Synchronous and Grid Forming Converter based
Procurement regions	GB wide	Scotland	England and Wales
Procurement volume	12.5 GW.s of inertia	8.4 GVA of SCL 6 GW.s of inertia	7.5 GVA of SCL 15 GW.s of inertia
Contract Detail	Up to 6 years	End of Mar 2034	End of Mar 2035 £1.35b
Contract payments	Availability payments for SCL& Inertia Utilisation payments for reactive power		

NESO stability network services ([link](#))

INTERCONNECTION REQUIREMENTS W/ GFM

- Ontario (IESO, [proposed](#))
 - Driver: Future proofing to ensure flexibility
 - Requirement: GFM capability of BESS, but not enabled
 - Required function(s) based on NERC specifications
- UK (National Grid, [implemented](#))
 - Driver: Grid service participation
 - Requirement: Optional; functional specifications
- Australia (AEMO, [implemented](#))
 - Grid-forming BESS are asynchronous generating units, by definition, for the purposes of connection applications.

STATE-OF-THE-ART

- Device/System
 - Converter driven stability unknowns
 - GFM – GFM
 - GFM – GFL
 - GFM – synchronous machine
- Standards
 - Clear requirements not yet established; awaiting functional specifications/features list
 - IEEE may fast-track Unifi requirements for GFM as a standard
- Interconnection
 - Where GFM required, should operate as GFL
 - Uncertainty how to specify in code

STATE-OF-THE-ART – TESTING

■ Purpose

- While electronics are the same, vendor implementation of GFM controls differ. Need to understand details from interconnection standpoint.

■ Activities

- Develop standard testing protocols
- Identify capabilities and minimum requirements
- Explore interoperability
- Develop specification framework

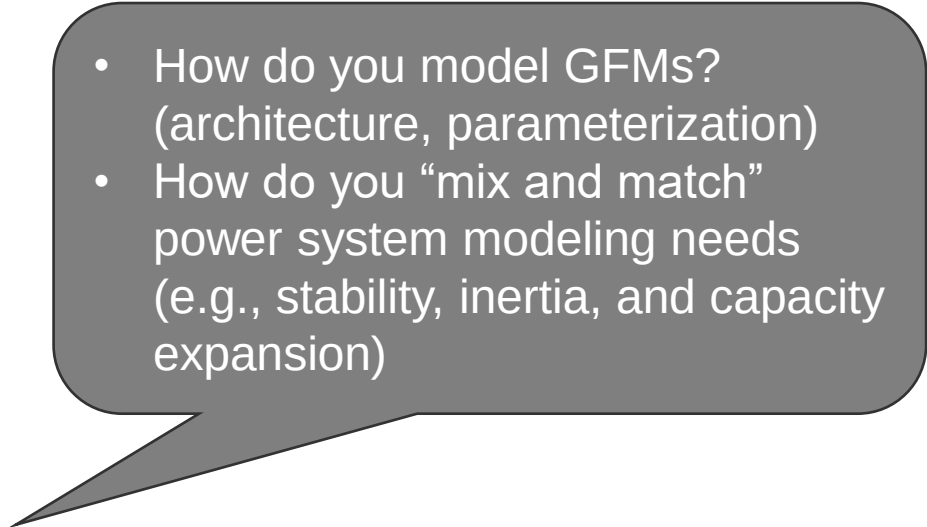
■ Core Organizations

- International Smart Grid Action Network (ISGAN) Working Group 5 (https://www.iea-isgan.org/our-work3/wg_5/)
- Unifi Consortium (US based) (<https://unificonsortium.org/>)
 - Inverter interoperability through hardware testing

NRCan's CanmetENERGY is
a member of both initiatives

STATE-OF-THE-ART – MODELING

- Electromagnetic Transient (EMT)
 - Time domain over short period (minutes, micro-second time-steps)
 - Computationally intensive
 - Accuracy requires lots of detail; data not normally in public domain
 - Used for analyzing stability following large disturbances
- Dynamic
 - Phasor domain (typically) over medium periods (cycle up to hourly time-steps)
 - Captures element behaviour over time
 - Used for analyzing stability following small changes in load and generation; also, economic dispatch

- 
- How do you model GFMs? (architecture, parameterization)
 - How do you “mix and match” power system modeling needs (e.g., stability, inertia, and capacity expansion)

THANK YOU!



QUESTIONS?



Natural Resources
Canada

Ressources naturelles
Canada

Canada



Steven Wong
steven.wong@nrcan-rncan.gc.ca

Renewable Energy Integration
Energy Efficiency and Technology Sector
Natural Resources Canada
Government of Canada



1615 Lionel-Boulet Blvd.
Varennes (QC) J3X 1P7
Phone: +1.450.652.4621
canmetenergy@nrcan.gc.ca



Natural Resources
Canada

Ressources naturelles
Canada

Canada 

Canada

© His Majesty the King in Right of Canada, as represented by the Minister of Natural Resources, 2025