Grid-Forming Inverters (GFI)

Grid-forming capability: transition from "follower" to "leader," virtual inertia, and practical case studies from Australia

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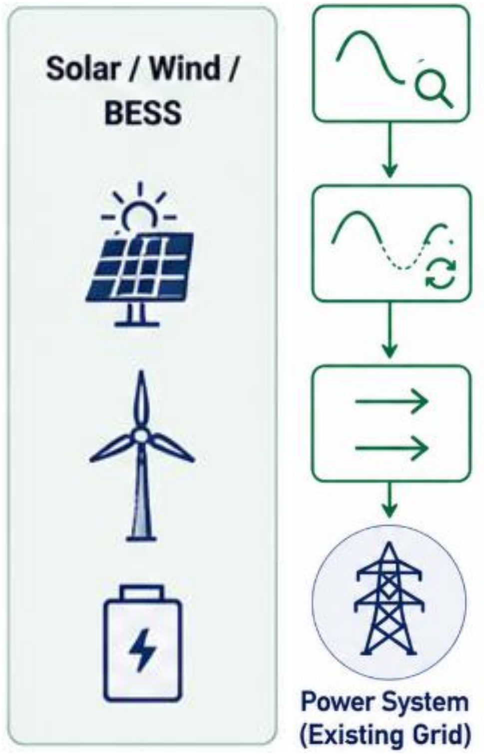
Grid-Following Inverters Depend on Strong Grid Conditions

HOW GRID FOLLOWING INVERTERS WORK



1. Measures existing waveform
2. Synchronize to grid voltage & frequency
3. Inject controlled current into system

Grid-Following Inverters inject power into the grid but do not inherently stabilize it

FUNDAMENTAL ISSUE

Grid-Following Inverters:

- Behave like controlled current source
- Requires existing voltage & frequency reference
- Do not contribute to voltage, frequency, inertia or system strength

Weak-Grid Conditions

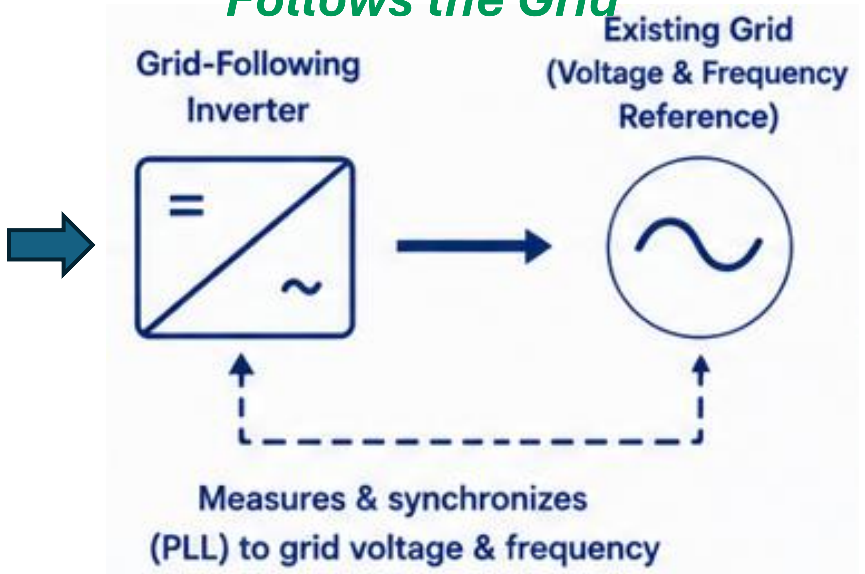
- Voltage becomes less stable
- Frequency changes faster (high RoCoF)
- PLL-based controls become less reliable
- Inverters synchronisation is harder

DEPENDENCE ON GRID CONDITIONS

Grid-Forming Behavior: GFL vs. GFI

GRID FOLLOWING INVERTERS

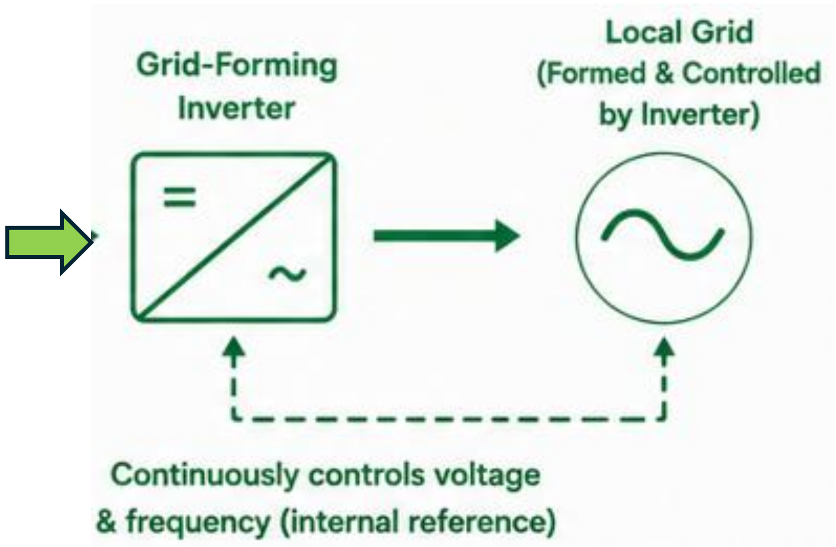
Follows the Grid



- Behaves as controlled current source
- Synchronises to existing waveform
- Does not establish voltage, frequency or inertia

GRID FORMING INVERTERS

Forms & Controls the Grid



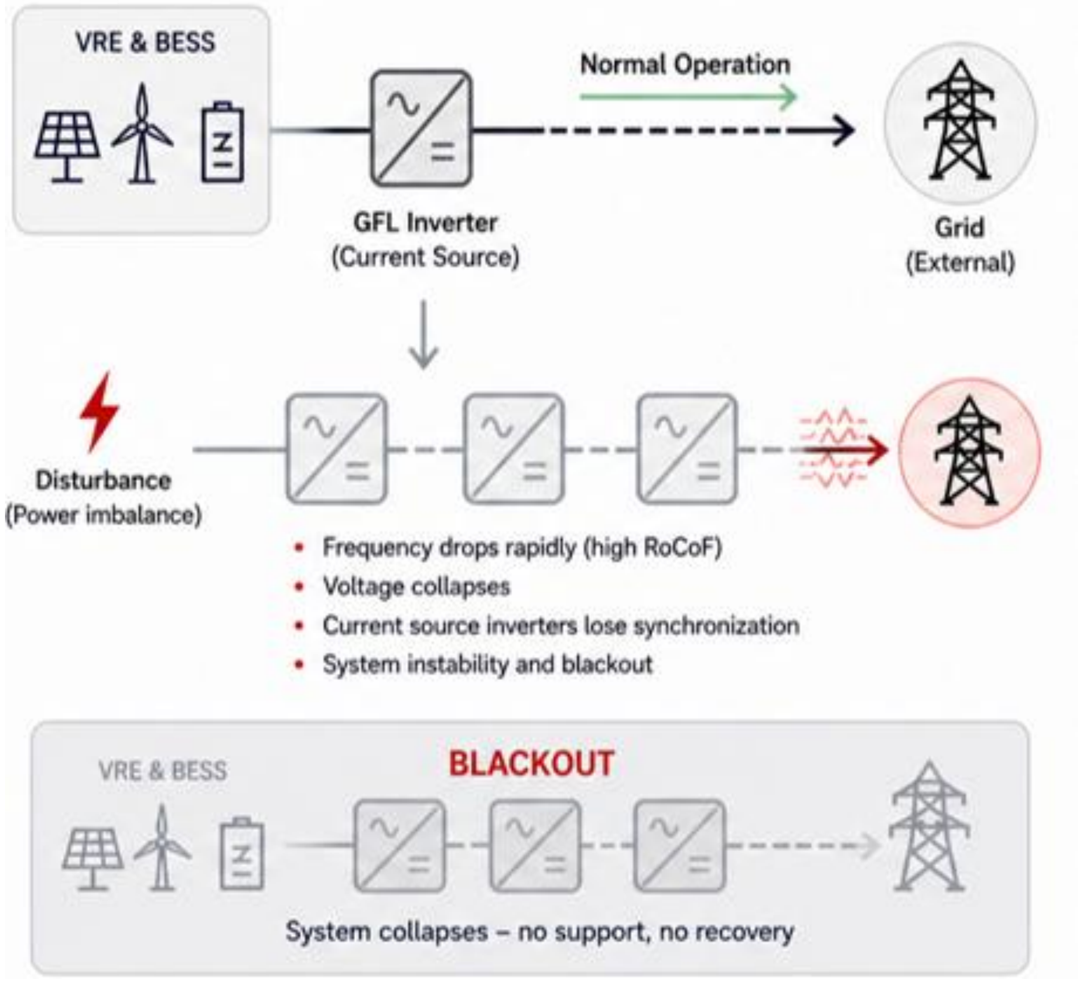
- Behaves as voltage source
- Establishes voltage & frequency reference
- Provides stability, inertia & system strength

Grid-forming inverters transform power electronics from passive power injection devices to active grid-stabilizing infrastructure

Two Different Responses to a Disturbance

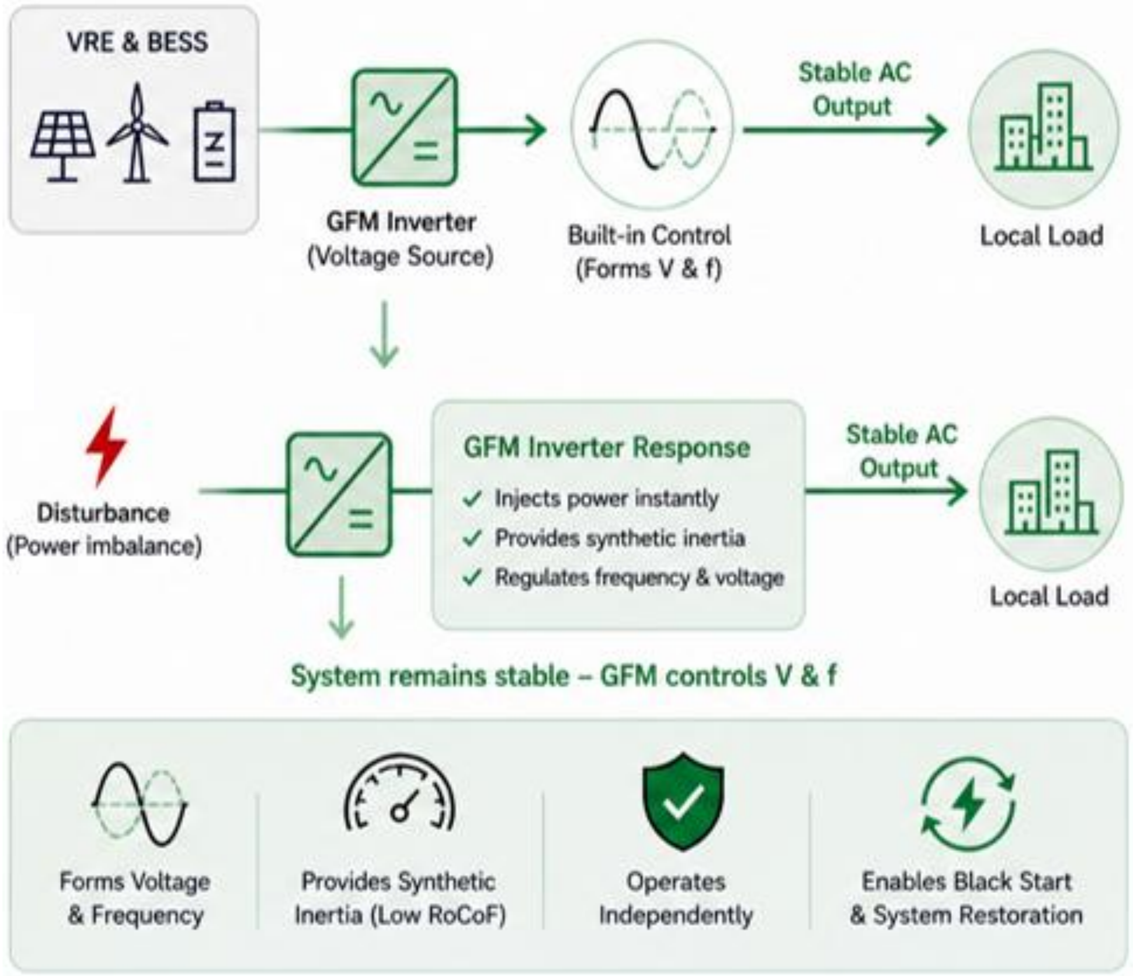
GRID FOLLOWING SYSTEM

Depends on grid – loses stability during disturbance

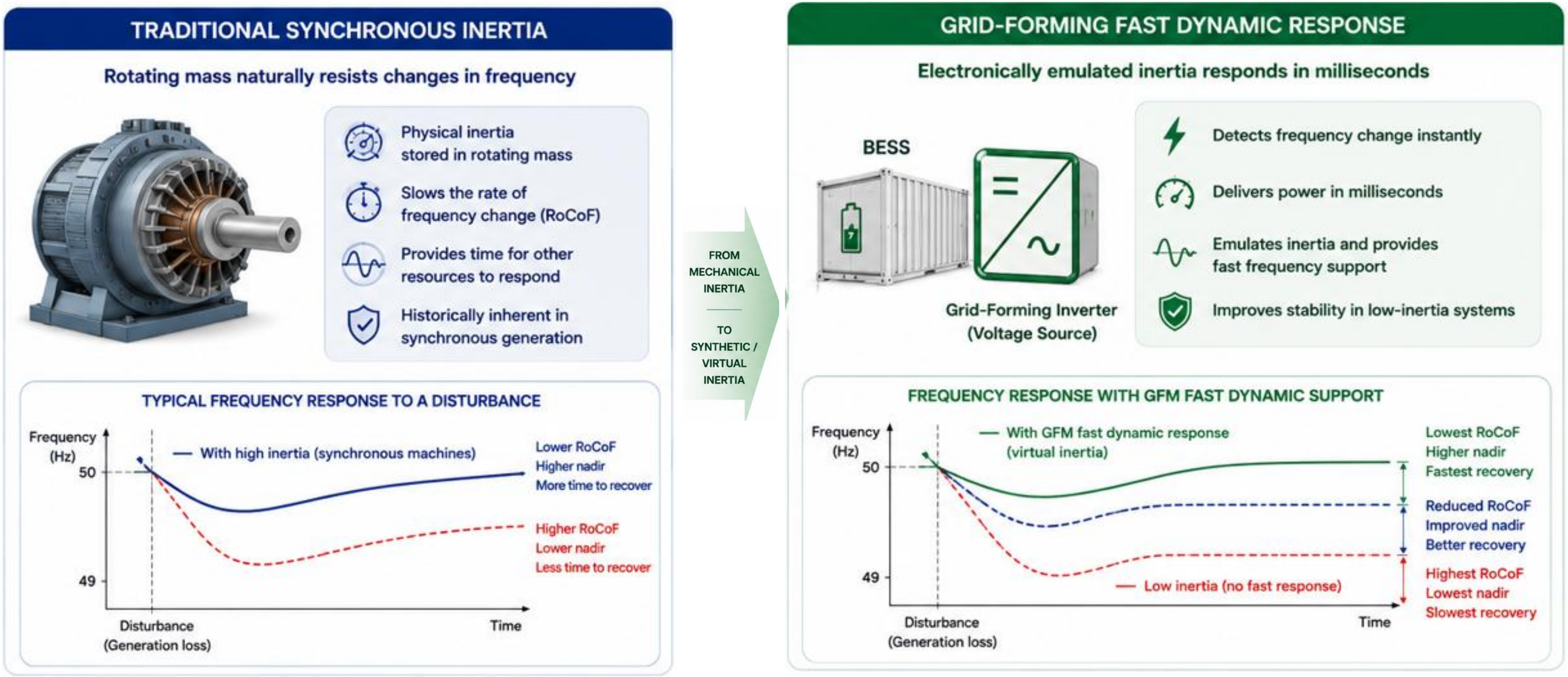


GRID FORMING SYSTEM

Forms & controls voltage & frequency – operating independently



Virtual Inertia & Fast Dynamic Response



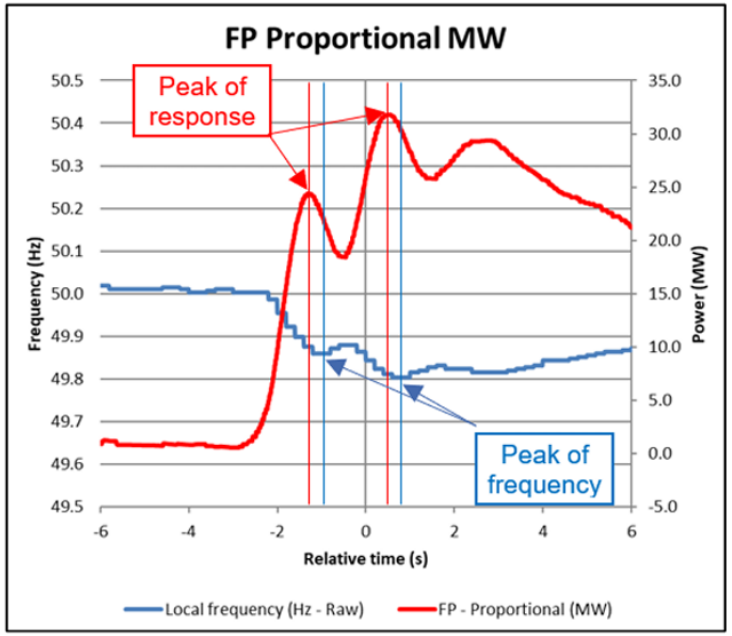
Grid-Forming Inverters electronically emulate stabilizing behavior previously provided by rotating synchronous machines

Australia Case Study: GFI BESS Services

Australia operates with some of the world's most challenging grid conditions:

- **Very high renewable penetration** (> 40% with more planned)
- **Extremely high rooftop solar adoption** (1 in 3 Australian homes has a rooftop system)
- **Weak long-distance transmission systems**: large geographic distance & limited interconnection
- **Rapid coal retirement**: Declining synchronous generation, reducing system inertia
- **Low-inertia operating conditions**: Higher RoCoF & greater stability challenges

Proportional active power vs. frequency response shows impact of VMM



- **Fast Frequency Response:** millisecond-scale response to disturbances, reducing RoCoF & supporting frequency nadir
- **Virtual inertia:** Emulates the stabilising effect of rotating machines, slowing frequency decline
- **Weak-Grid Support**: Maintains stable voltage & frequency under low system strength conditions
- **Reduced synchronous dependence**: Supports lower minimum synchronous generation levels
- **System Strength Service:** Critical system strength, fault current & voltage support service

Why Grid-Forming Inverters are Needed

1. Establish and regulate voltage & frequency – actively set & maintain stable voltage & frequency
2. Provide inertia and fast frequency response – emulate inertial behaviour & respond in milliseconds
3. Support voltage during disturbances and faults – maintain voltage through dip & transients
4. Contribute fault current immediately – supply critical current to help clear faults quickly
5. Operate weak grids and islanded mode – remain table with low system strength or in isolation
6. Enable black start & system restoration – re-energy and rebuild the grid after a blackout
7. Provide system strength and support services – deliver Volt / VAR control, damping and stability support

Thank You