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BATTERY
ENERGY
STORAGE SYSTEM

Grid-Forming Inverters (GFI)

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

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13 May 2026



Global Energy Alliance
for people and planet

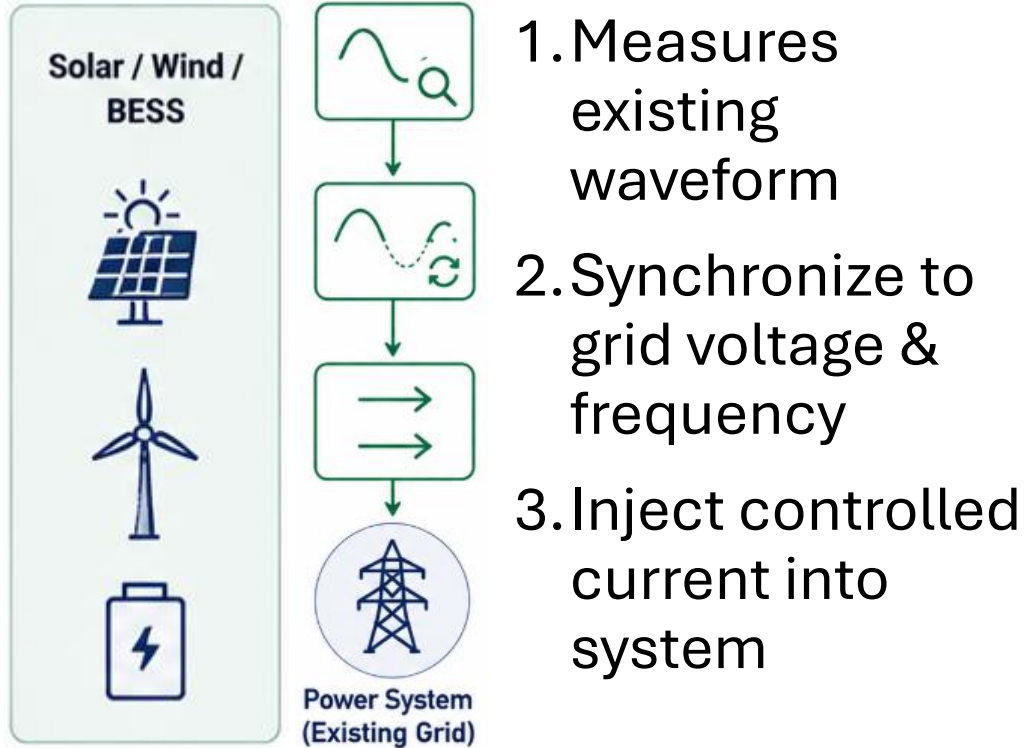
CESI
Inspired with innovation



INTEGRATION
environment & energy



HOW GRID FOLLOWING INVERTERS WORK



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

FUNDAMENTAL ISSUE

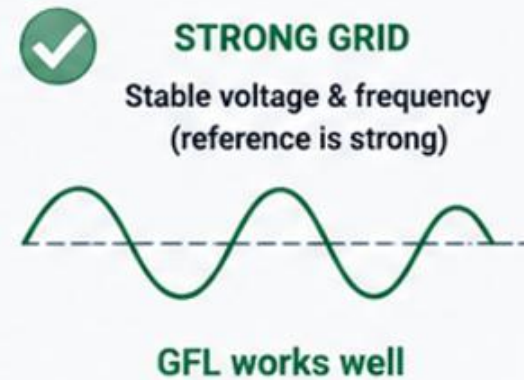
Grid-Following Inverters:

- 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

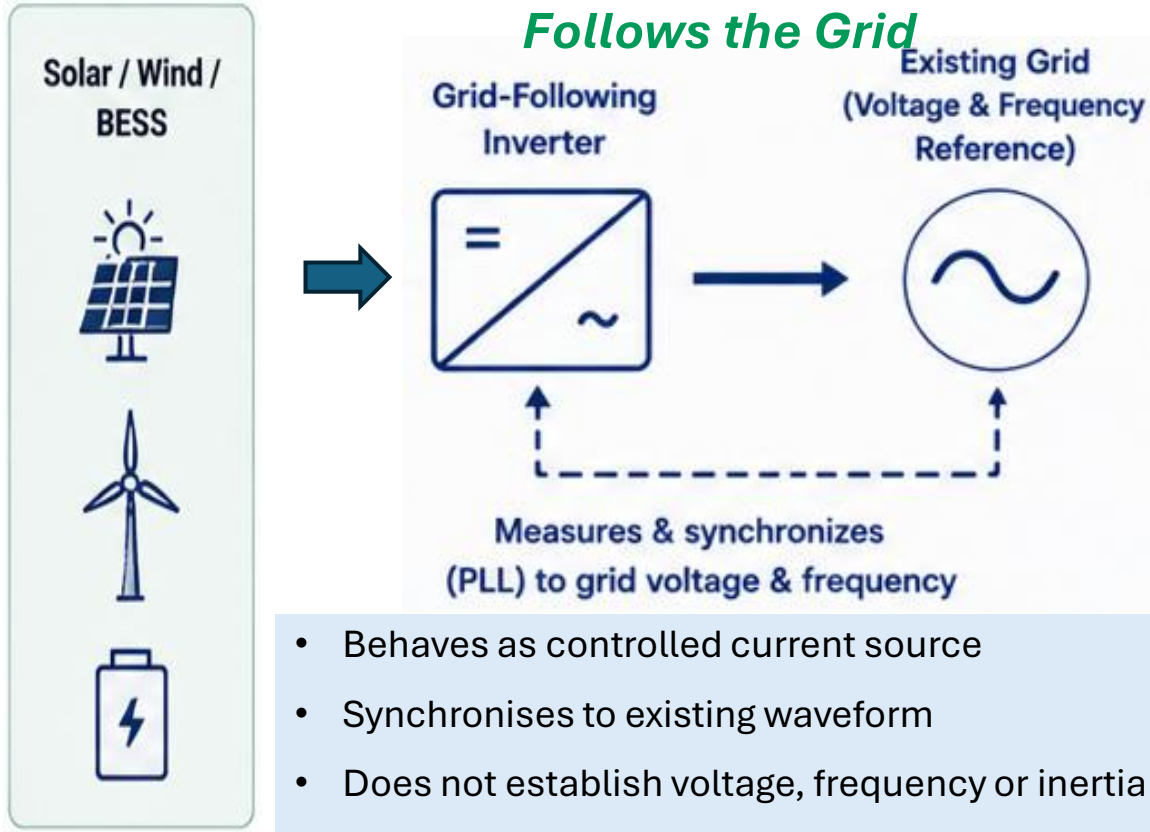
DEPENDENCE ON GRID CONDITIONS





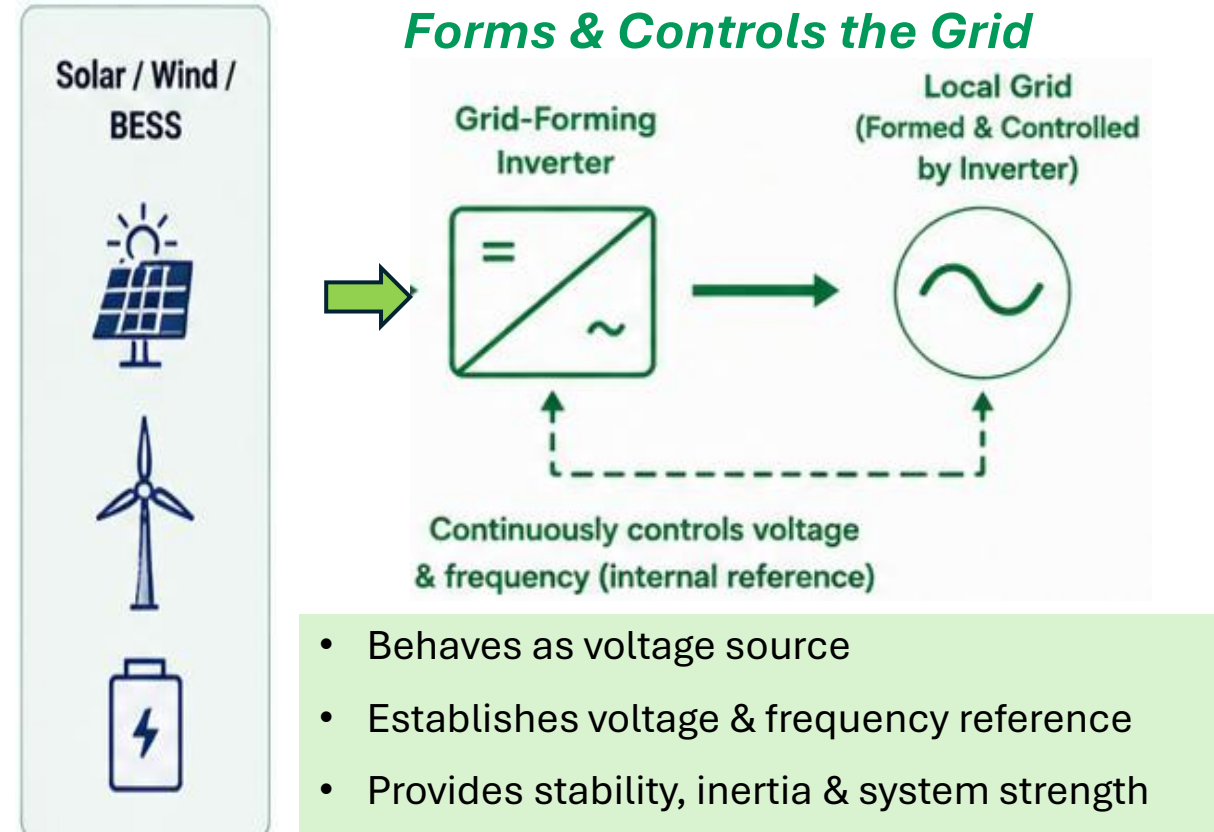
GRID FOLLOWING INVERTERS

Follows the Grid



GRID FORMING INVERTERS

Forms & Controls the Grid



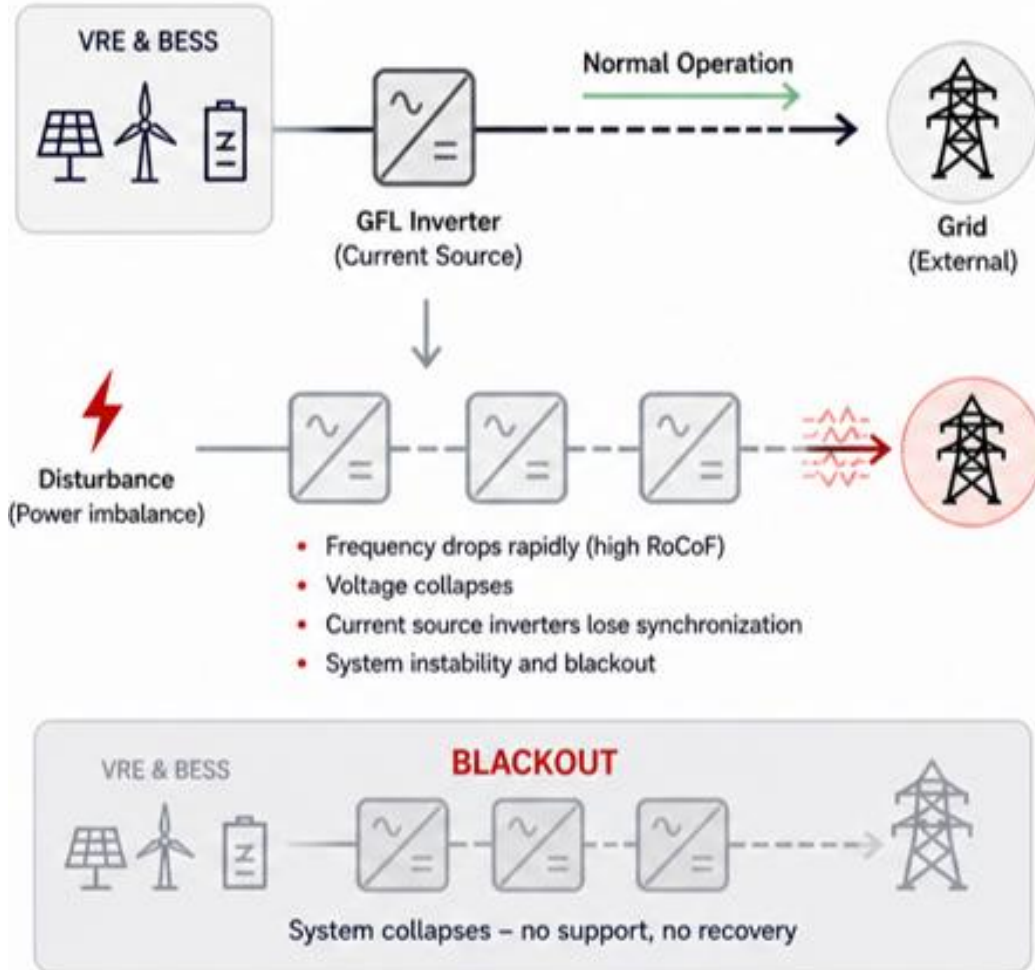
Grid-forming inverters transform power electronics from passive power injection devices to active grid-stabilizing infrastructure

Two Different Responses to a Disturbance



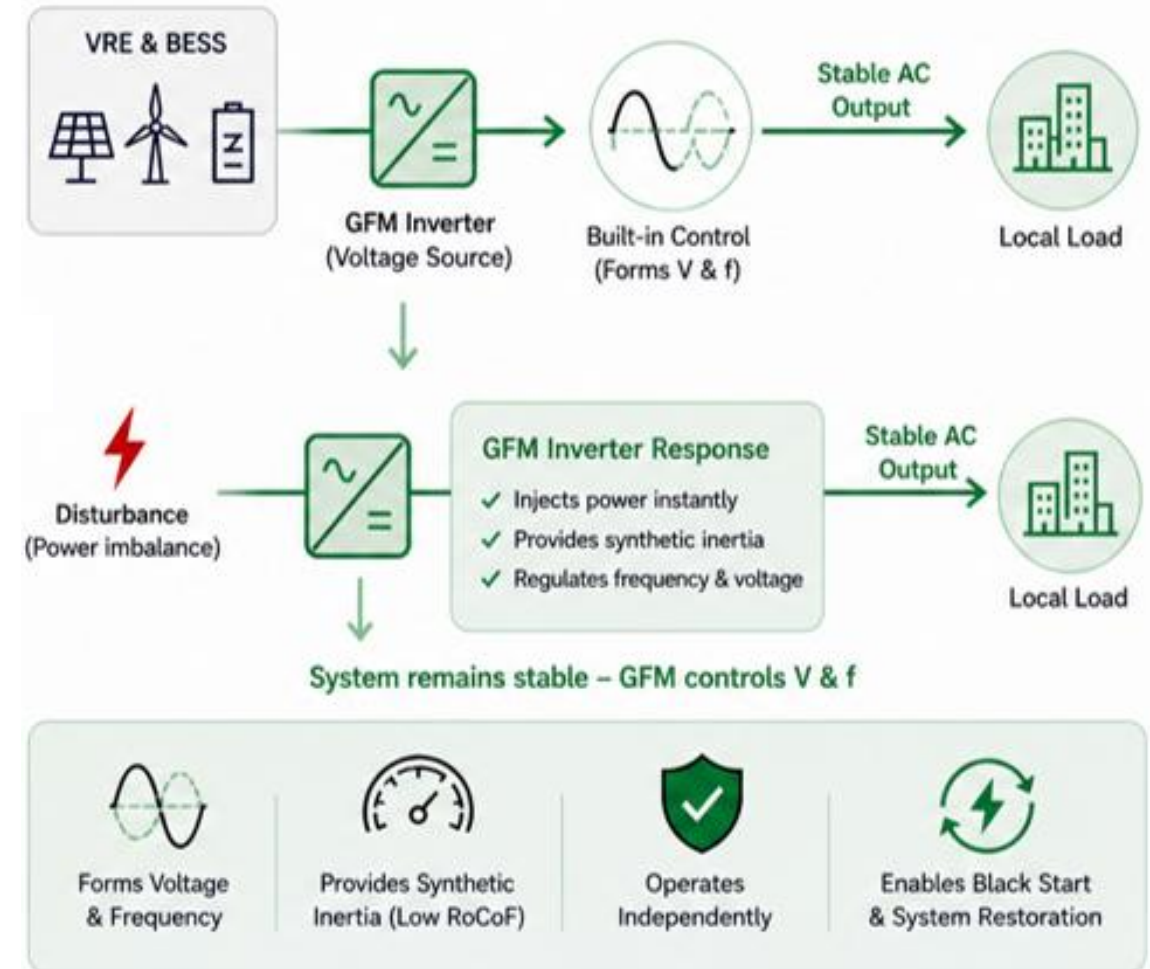
GRID FOLLOWING SYSTEM

Depends on grid – loses stability during disturbance



GRID FORMING SYSTEM

Forms & controls voltage & frequency – operating independently



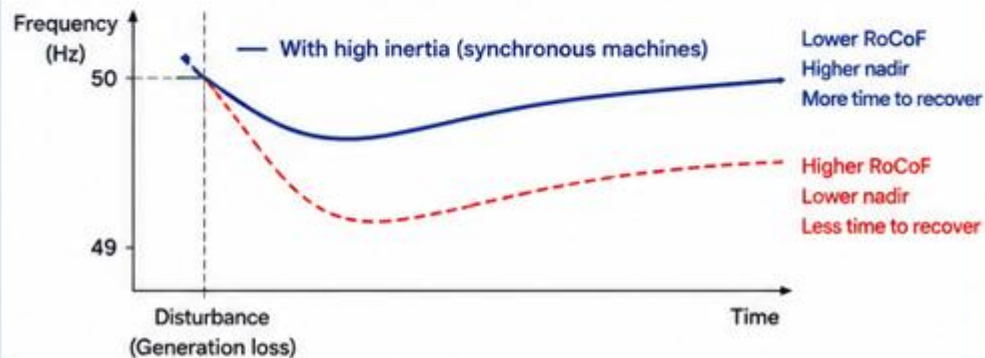
TRADITIONAL SYNCHRONOUS INERTIA

Rotating mass naturally resists changes in frequency



- Physical inertia stored in rotating mass
- Slows the rate of frequency change (RoCoF)
- Provides time for other resources to respond
- Historically inherent in synchronous generation

TYPICAL FREQUENCY RESPONSE TO A DISTURBANCE



FROM MECHANICAL INERTIA
—
TO SYNTHETIC / VIRTUAL INERTIA

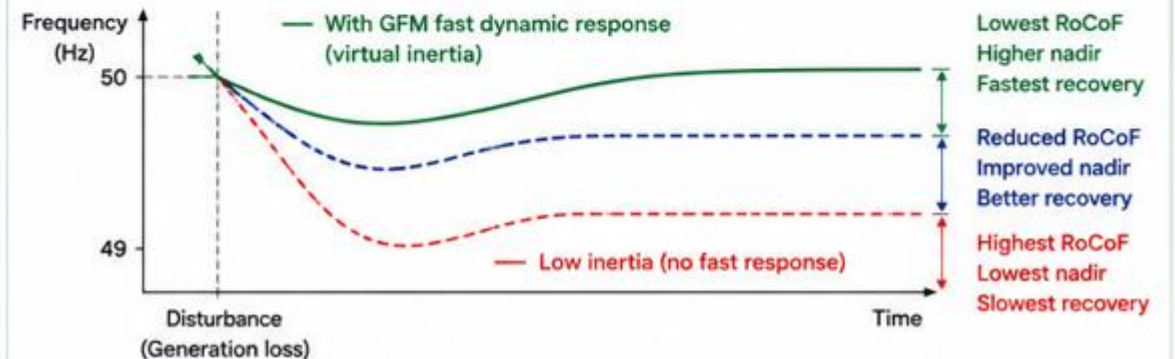
GRID-FORMING FAST DYNAMIC RESPONSE

Electronically emulated inertia responds in milliseconds



- Detects frequency change instantly
- Delivers power in milliseconds
- Emulates inertia and provides fast frequency support
- Improves stability in low-inertia systems

FREQUENCY RESPONSE WITH GFM FAST DYNAMIC SUPPORT



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

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

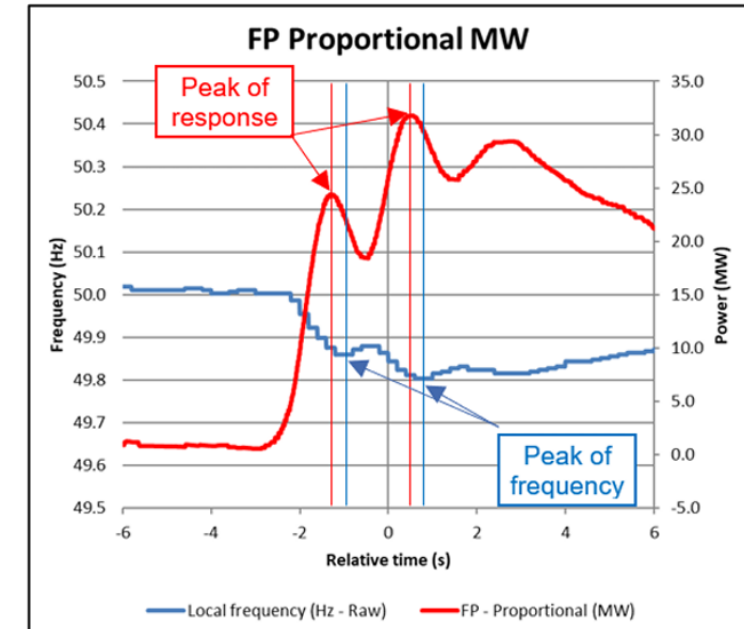
- **Very high renewable penetration** (> 40% with more planned)
- **Extremely high rooftop solar adoption** (1 in 3 Australian homes has a rooftop system)
- **Weak long-distance transmission systems:** large geographic distance & limited interconnection
- **Rapid coal retirement:** Declining synchronous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

CASE STUDY: HORNSDALE POWER RESERVE



<ul style="list-style-type: none"> Location: South Australia Developer: Neoen + Tesla Capacity: 150 MW / 193.5 MWh (expanded) Initially: Deployed for FCAS (service support) Upgrade: Virtual Machine Mode (VMM) → Grid-Forming behaviour 	<p>Key Transition From “Fast Responder” → “Grid Stabiliser”</p> <p>Actively supporting voltage and frequency stability.</p>
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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



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 stable 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