GFM BESS Technology Development and Demonstrations

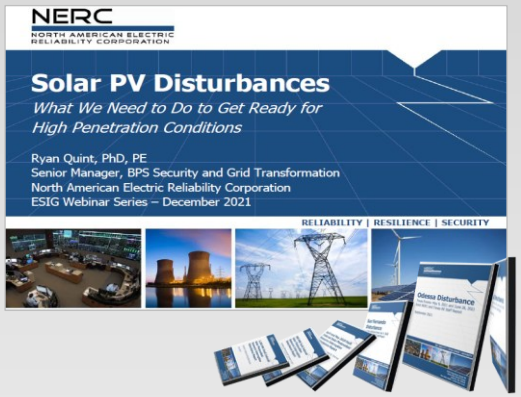
2026. 9. 2.

Pion Electric

Pion electric
Technology Innovation for Energy and Environment

Increasing RE and Voltage Instability

Voltage instability issues arising from the expansion of renewable energy, and grid separation problems caused by unexpected inverter shutdowns



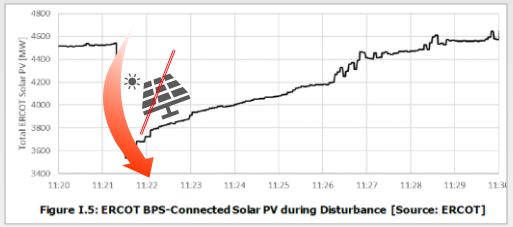
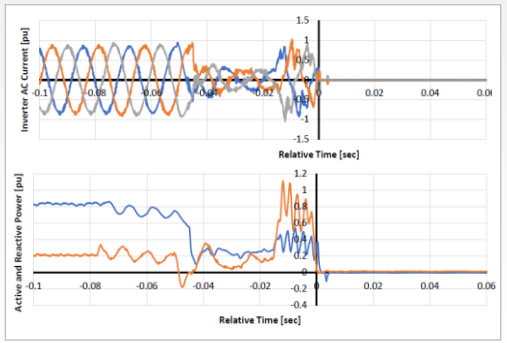


Figure I.5: ERCOT BPS-Connected Solar PV during Disturbance [Source: ERCOT]

US: PV inverter cascading trips



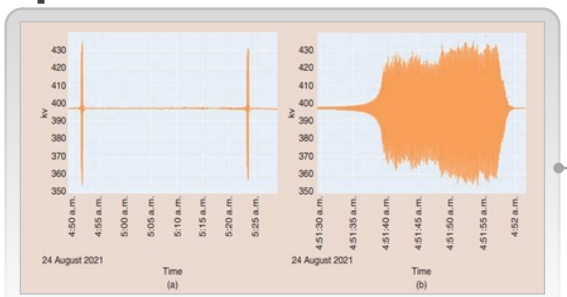


Figure 1. Voltage oscillations recorded during low system strength (Scotland). (a) Longer duration view. (b) Shorter duration view.

UK

Ireland

US

Figure 2. The oscillations transfer through a line-commutated coverter HVdc line from Great Britain to Northern Ireland.

Finland

GLOBAL: RE-driven voltage instability

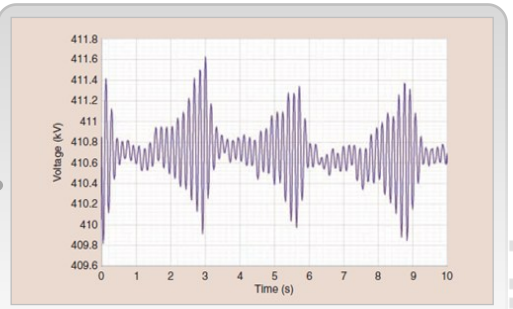


Figure 3. Observed voltage oscillations in a 400-kV bus in the West Coast region (Finland).

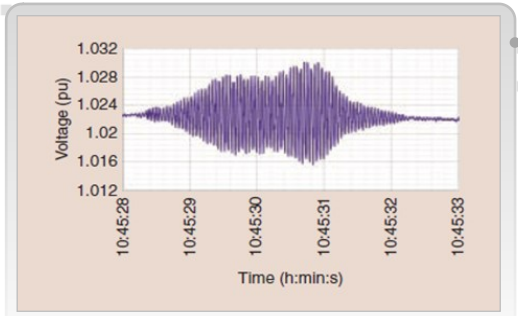
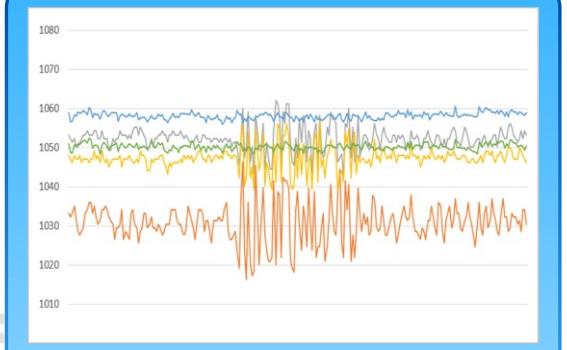


Figure 4. Observed voltage oscillations in a 220-kV bus in the West Murray area (Australia)

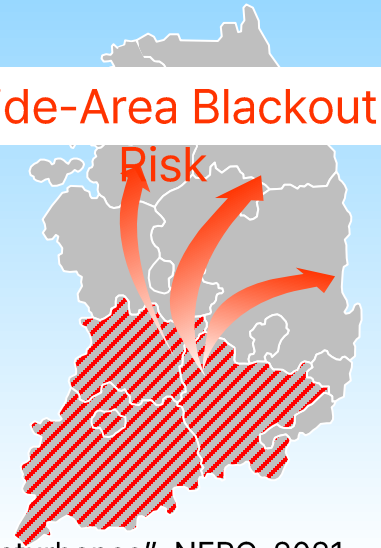
KOREA

Australia



Korea: RE-dense voltage instability

Wide-Area Blackout Risk



"Odessa Disturbance", NERC, 2021

"Power & Energy Magazine - Volume 22: Issue 2 - March/April : Inverter-Based Resources (IBRs)", IEEE, 2024

Increasing RE and Voltage Instability

The massive blackout on the Iberian Peninsula (April 28, 2025) was triggered by insufficient voltage stability in a grid with high renewable energy penetration

» Grid Incident in Spain and Portugal on 28 April 2025

ICS Investigation Expert Panel
Final Report

2.5.6.3 Oscillation at 12:03 – 12:08

Oscillatory behaviour with a frequency around 0.63 Hz appears visually discernible in a time series plot at around 12:00:30 in the voltage plot below from PMU in Carmona (Figure 2-44).

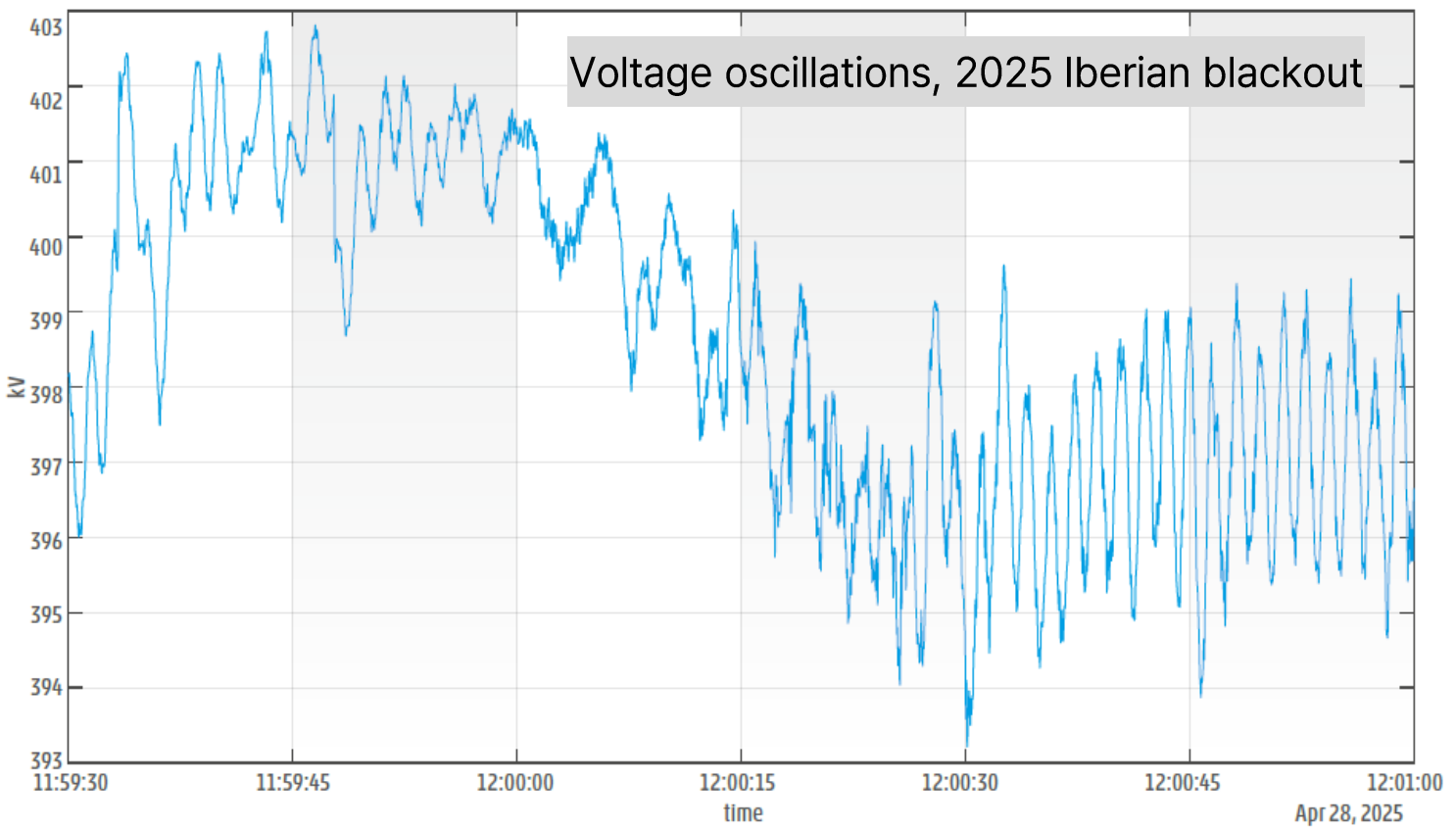
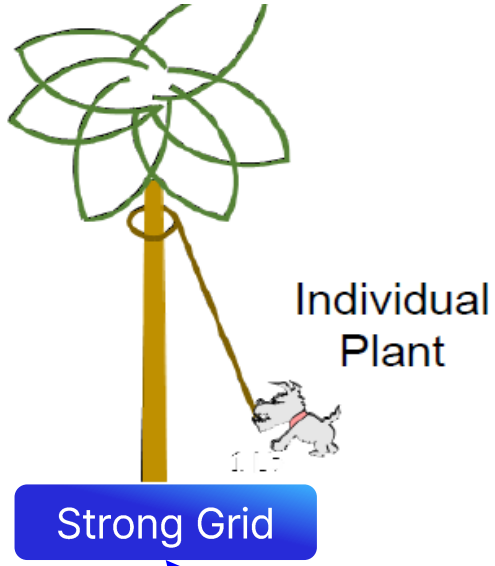


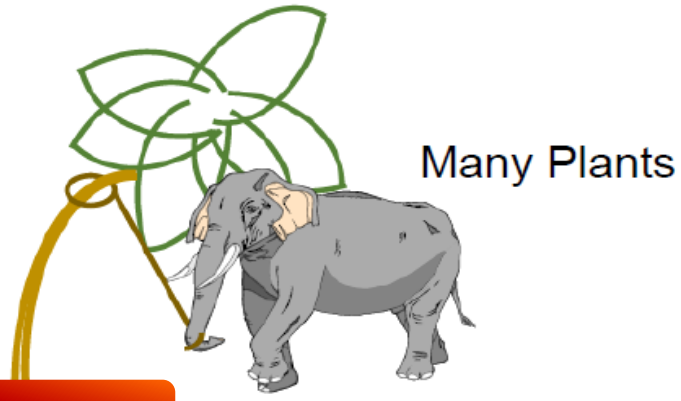
Figure 2-44: Voltage at PMU ONA4DRO, 11:59:30 - 12:01:00

Grid Incident in Spain and Portugal on 28 April 2025, Final Report

System Weakness in Renewable Grids

Weak grid, leading to a decline in stability; the inherent characteristic of conventional inverters, unlike synchronous machines, cannot provide frequency/voltage stability





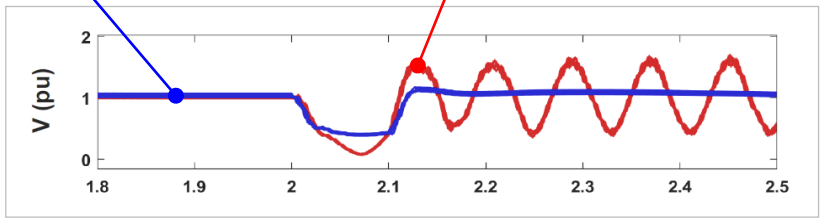
Strong Grid

Weak Grid

Many synchronous machines

Few inverters

High stability



System strength: the ability to maintain and control the AC voltage waveform after a disturbance such as a fault*

Few synchronous machines

Many inverters

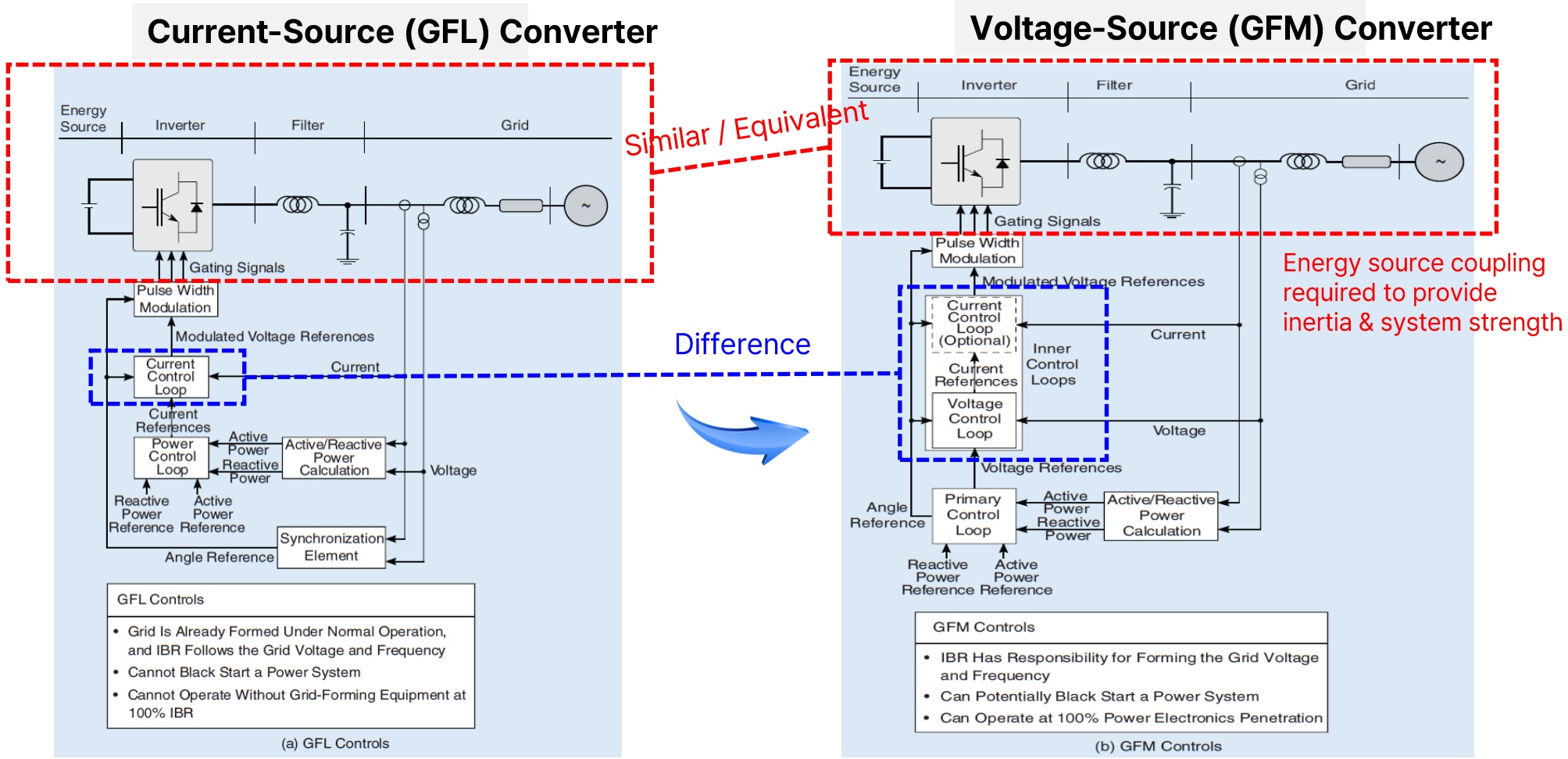
Low stability

"Grid Forming Inverters Tutorial", EPRI, 2022

* "System Strength Requirements Methodology and System Strength Impact Assessment Guidelines", AEMO, 2022

Grid Forming (GFM) Inverter Concept

Voltage Source Control Strategy, Control Loop Difference, Self-Sustaining Reference



* Energy sources for GFM operation: battery, super capacitor, PV, WT, etc.

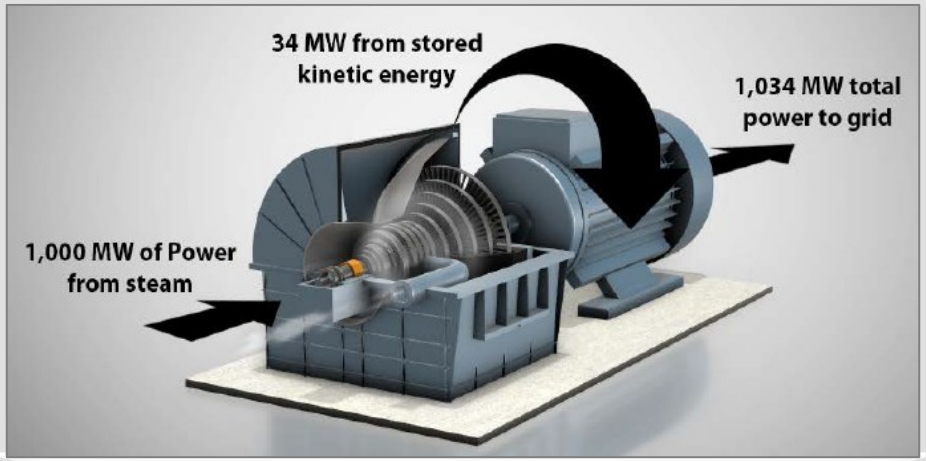
IEEE. "Power & Energy Magazine - Volume 22: Issue 2 - March/April : Inverter-Based Resources (IBRs)", 2024

GFM vs. GFL Inverter Comparison

Grid Voltage Provision, Delivers synthetic inertia, system strength, black start, and islanded operation capabilities.

Conventional Synchronous Machine

(Voltage Source)

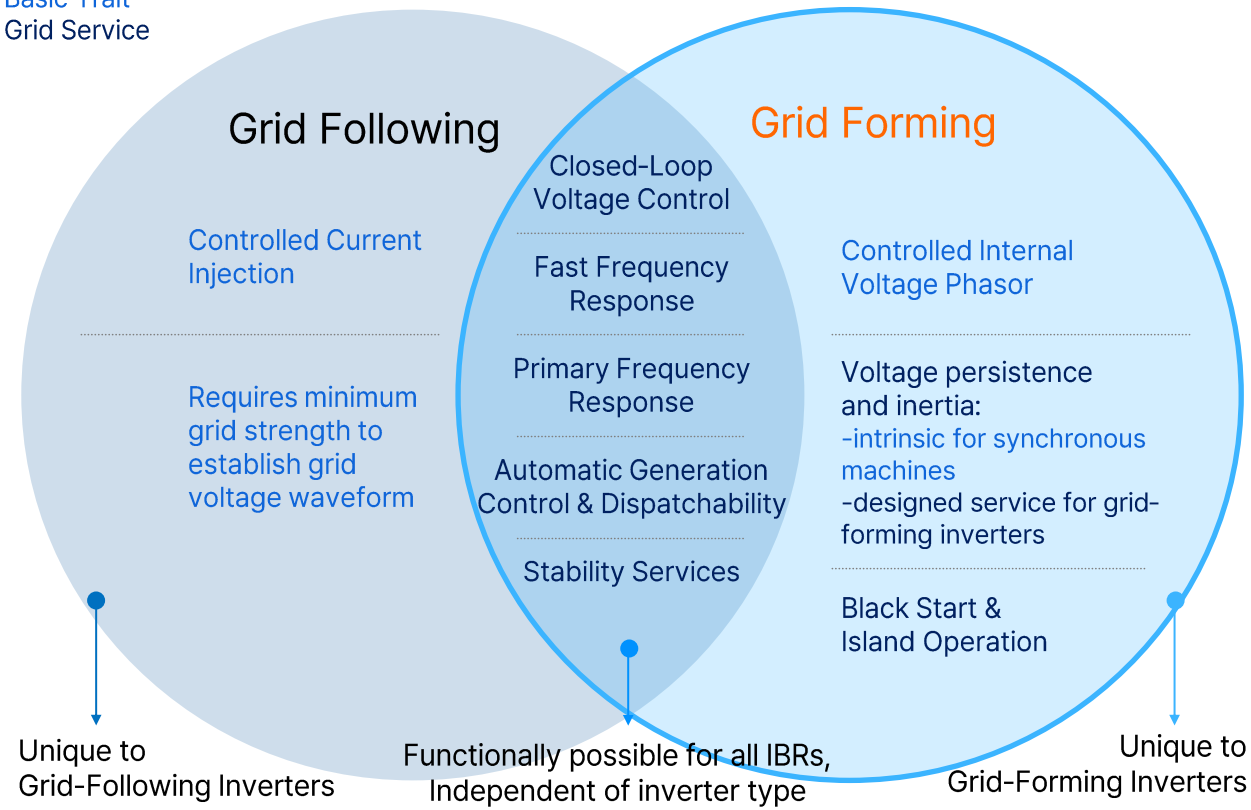


Services

Inertia | Strength | Islanded Op. | Black Start | Restoration

GFM Inverter

- Grid Forming vs Grid Following
- Basic Trait
- Grid Service



J. Matevosyan, et al. "Future with Inverter Based Resources", IEEE PES, 2021

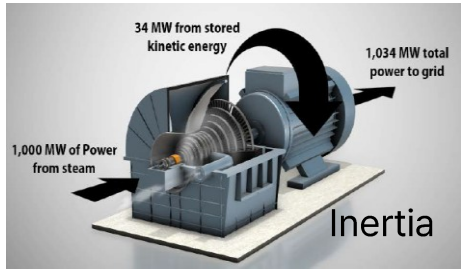
Functional Equivalency to Synchronous Machines

< Synch. Machine >

Forms its own AC voltage and produces current (active/reactive)

Stability

Energy



< Synch. Condenser >

Forms its own AC voltage and produces current (reactive)

Stability

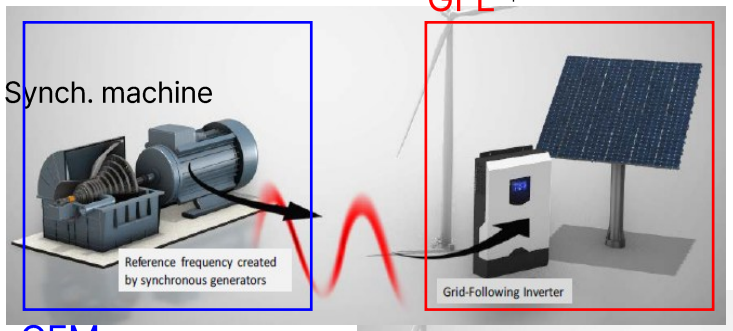
~~Energy~~

< GFL Inverter >

Produces current (active/reactive) based on the grid AC voltage

~~Stability~~

Energy



A GFM inverter forms its own voltage and, like a synchronous machine, provides a voltage source to other GFL inverters

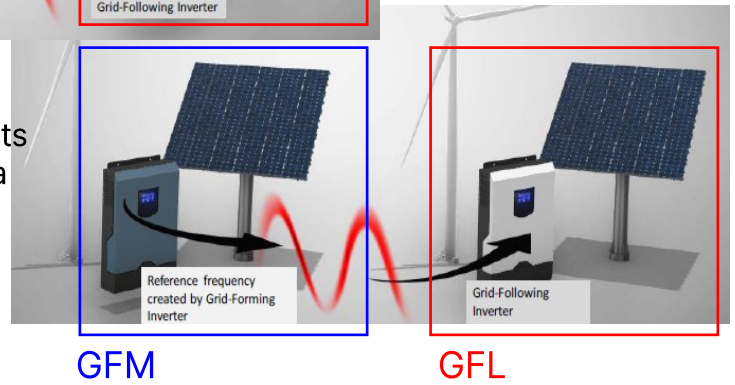
< GFM Inverter >

Forms its own AC voltage and produces current (active/reactive)

Stability

Energy

Conventional inverters follow an external voltage, so they need a separate voltage source such as a synchronous machine

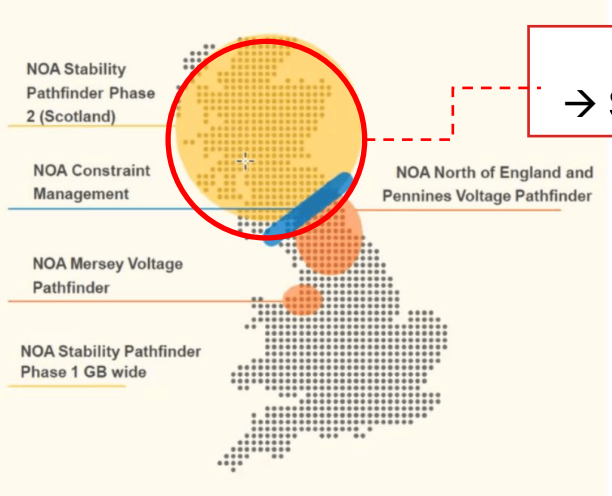


UK National Grid ESO Tender Analysis

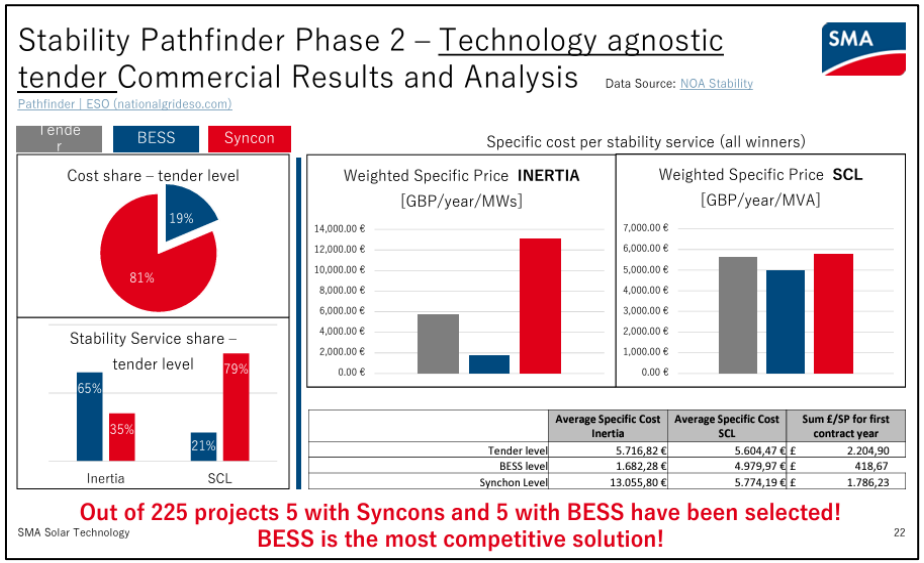
GFM BESS secured projects in Stability Pathfinder Phase 2, with 30% Lower Short-Circuit Cost, 88% Lower Inertia Cost

<Cost: Synch. Condenser vs. Grid-Forming>

Resource	Projects	Total Cost (National Grid)	SC Current (SCL MVA)	Inertia (MW-sec)	Cost/SCMVA	Cost/MWsec
Synch. Con.	5	KRW 487.5B	8,943	2,397	0.55	2.03
GFM BESS	5	KRW 102.0B	2,611	4,360	**0.39 (-30%)**	**0.23 (-88%)**



UK Stability Pathfinder 2
→ SCMVA procurement case in Scotland



Ref.: https://www.nationalgrideso.com/news/scotlands-wind-success-story-bolstered-ps323m-stability-investment

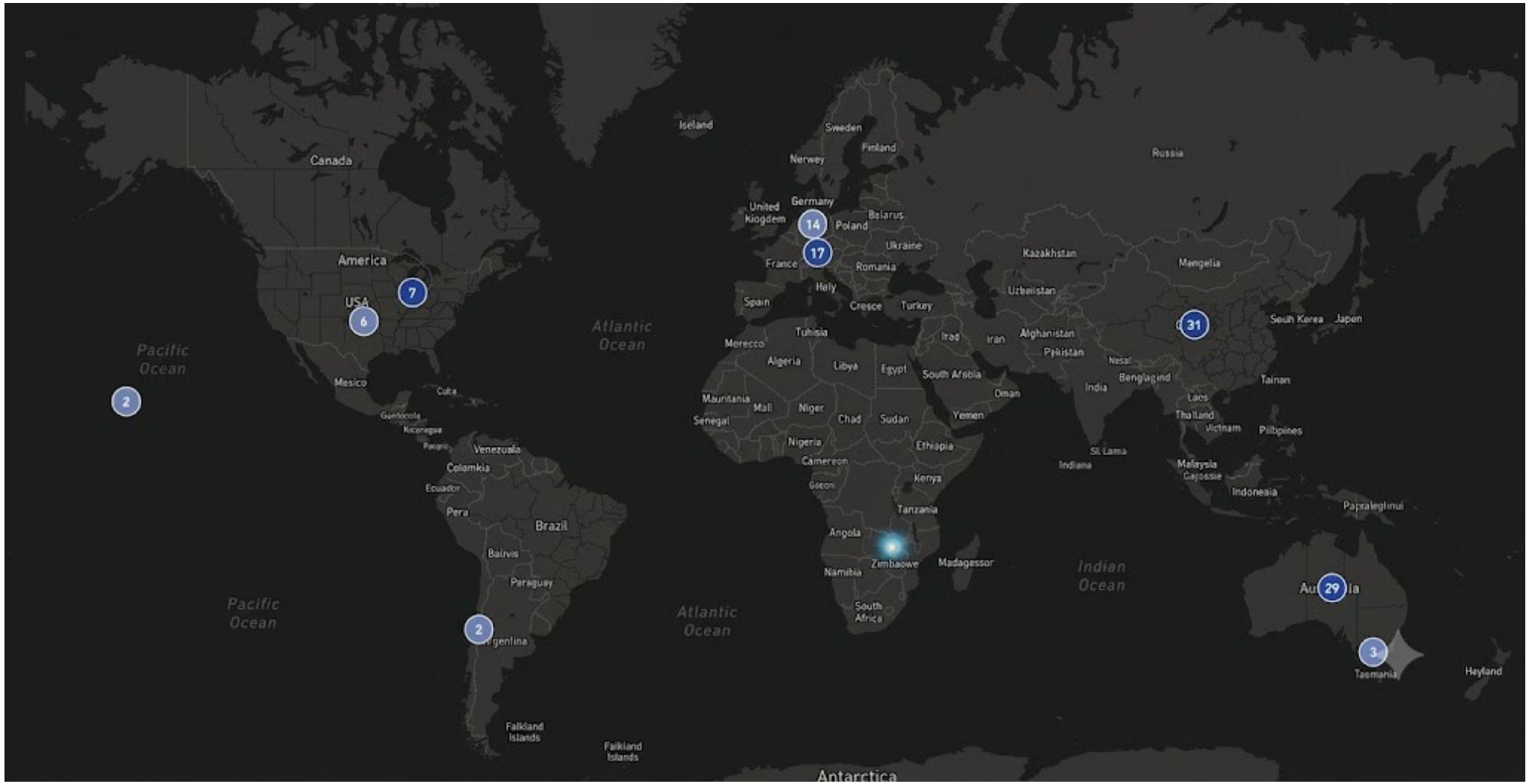
Global GFM Deployment Status

Numerous grid-forming BESS facilities deployed worldwide, backed by national RE funding

Project Name	Location	Operator/Utility	GFM Tech Size (MW)	OEM	Technology	Year
Swanbank BESS	Australia	AEMO	250	Tesla	GFM BESS	2026
Tarong BESS	Australia	AEMO	316	Tesla	GFM BESS	2026
Alpiq GFM BESS	Finland	Fingrid	30	Merus Power	GFM BESS	2025
Blackhillock, Phase II	Great Britain	NESO	100	SMA	BESS	2025
Blyth Battery	Australia	AEMO	238	Power Electronics	BESS	2025
Brendale BESS	Australia	AEMO	205	Tesla	GFM BESS	2025
Cleve Hill Solar Park	Great Britain	NESO	150	SMA	BESS	2025
Eurimbula Solar Farm and BESS	Australia; Queensland	AEMO	666	SMA	BESS	2025
Greenbank BESS	Australia	AEMO	200	Tesla	GFM BESS	2025
Heilongjiang Duobaoshan Static Self-synchronous Compensator Project	China; Heilongjiang	SGCC	90	NR Electric	GFM SSC	2025
Heilongjiang Kedong Static Self-synchronous Compensator Project	China; Heilongjiang	SGCC	50	NR Electric	GFM SSC	2025
Koorangie BESS	Australia	AEMO	185	Tesla	GFM BESS	2025
KPM Copper Mine New Energy Project	Democratic Republic of Congo		20	NR Electric	Solar+GFM BESS	2025
Limondale BESS	Australia	AEMO	50	Tesla	GFM BESS	2025
Mehrum's E-Statcom Project	Germany	TenneT	300	Siemens Energy	GFM STATCOM	2025
Melbourne Renewable Energy Hub	Australia	AEMO	600	Tesla	GFM BESS	2025
Neilston Greener Grid Park	Great Britain	NESO	50	SMA	BESS	2025
Ningxia Longyuan Mengjiawan	China; Ningxia	SGCC	295	NR Electric	GFM BESS	2025
Shallow Basket project	USA; New Mexico; Jicarilla Apache Nation	National Renewable Solutions	50	Tesla	GFM BESS, transmission-connected	2025
Smithfield BESS	Australia	AEMO	65	Tesla	GFM BESS	2025
Western Downs Battery	Australia	AEMO	510	Tesla	BESS	2025
Xinhua Hydropower GFM Fluoride Flow Energy Storage	China; Xinjiang	SGCC	250	NR Electric	GFM BESS	2025
Xinjiang Lixin Mulei Static Self-synchronous Compensator Project	China; Xinjiang	SGCC	50	NR Electric	GFM SSC	2025
Xinjiang Shache GFM BESS	China; Xinjiang	SGCC	200	NR Electric	GFM BESS	2025
Xinjiang Tuokexun Static Self-synchronous Compensator Project	China; Xinjiang	SGCC	50	NR Electric	GFM SSC	2025
Yunnan Wenshan Qubei Project	China; Yunnan	CSG	50	NR Electric	GFM BESS	2025
Amaala Project	Saudi Arabia		160	Sungrow	BESS	2024
Blackhillock, Phase I	Great Britain	NESO	200	SMA	BESS	2024
China First Grid-Forming ESS+PV Project	China; Yanweijuyan, Gansu		10	Sungrow	BESS	2024
China Resources Electric Power Hami	China; Hami		25	Huawei	BESS	2024
Golmud Leuneng	China; Qinghai		25	Huawei	BESS	2024
Grid-Forming ESS Project	China; Luopu, Xinjiang		250	Sungrow	BESS	2024
Grid-Forming ESS Project	Tibet; Ihsasa		40	Sungrow	BESS	2024
Guoneng Ningdong Shuguang Project	China; Ningxia	SGCC	65	NR Electric	GFM BESS	2024
Huadian Jinchuan Hongyuan Grid-forming ESS	China; Sichuan		50	Sungrow	BESS	2024
Huadian Rikaze Sanzuzi Qumei PV+ESS	Tibet		18	Sungrow	Solar+BESS	2024
Huadian Shannan Naidong Cai Peng Phase II	Tibet		20	Sungrow	BESS	2024
Jilin Bamian Static Self-synchronous Compensator Project	China; Jilin	SGCC	50	NR Electric	GFM SSC	2024
Jilin Xiangrong Static Self-synchronous Compensator Project	China; Jilin	SGCC	50	NR Electric	GFM SSC	2024
Kupono Solar	USA; Hawaii	HECO	42	Tesla	BESS	2024

(Reference) Global Grid-Forming Landscape

GFM Projects Deployed or Under Construction - ESIG Status Update

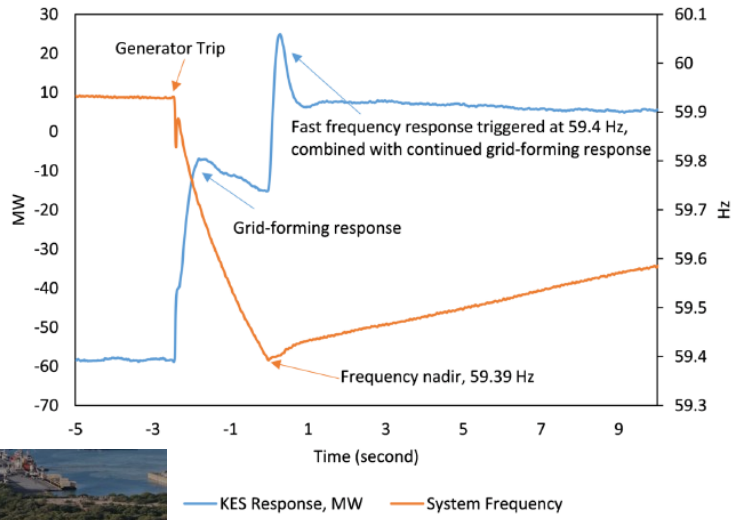


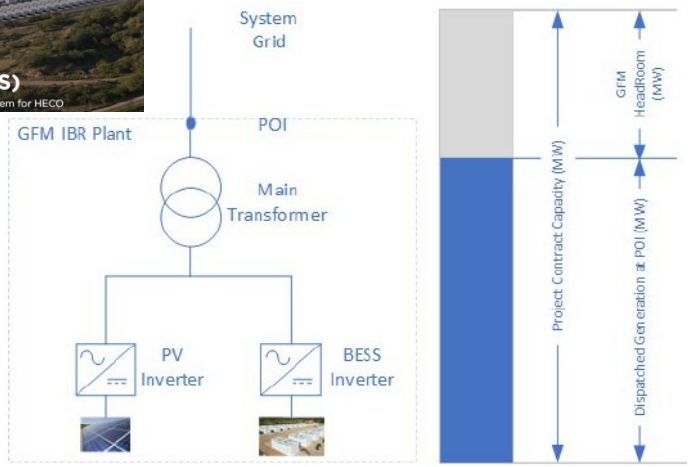
Ref.: https://www.esig.energy/working-groups/reliability/grid-forming-landscape/installed-and-planned-gfm-projects/

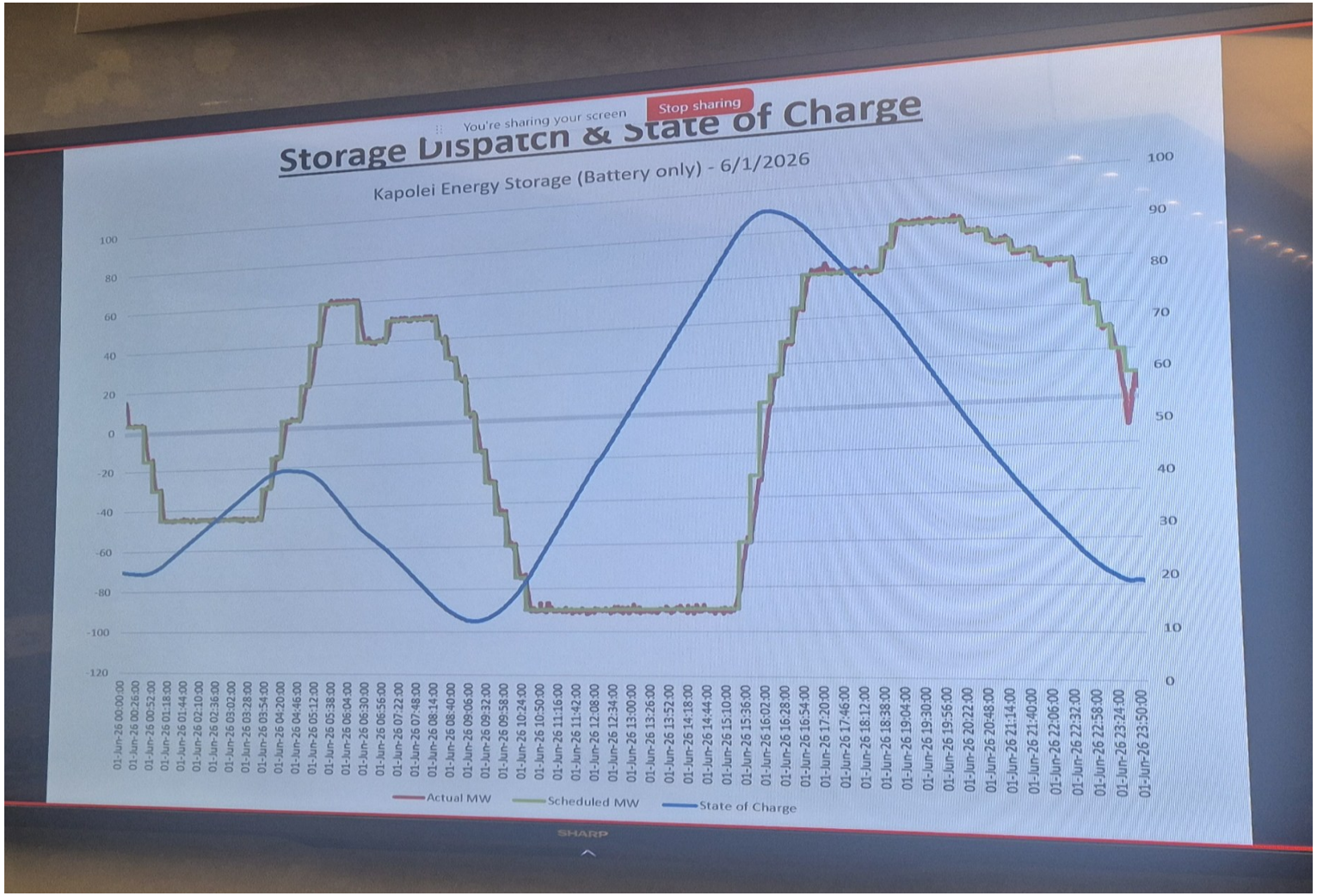
Hawaii HECO Field Demonstration

HECO: continuous GFM-mode operation averted two grid-collapse events as of May 2026 (largest thermal unit trip; storm-related line and load trip)

- Maximizes grid benefit by combining long-duration BESS use (RE backup) with an inertia role



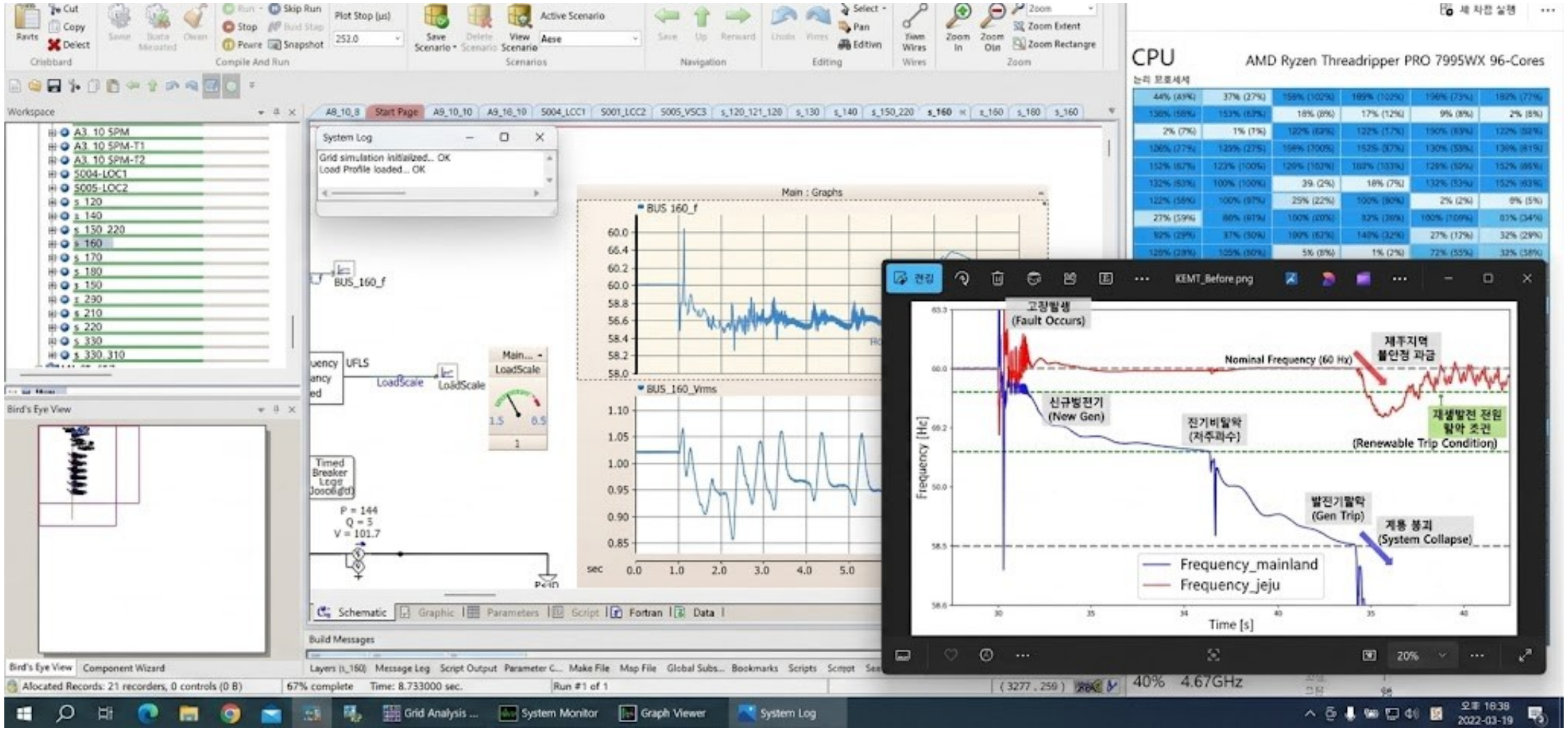




Wide-Area Transmission Network EMT Modeling

High-Performance Computing, Cascading Failure Analysis, GFM Mitigation Verification

Large Scale Transmission Network EMT Simulation (39 Parallel Network Interface)

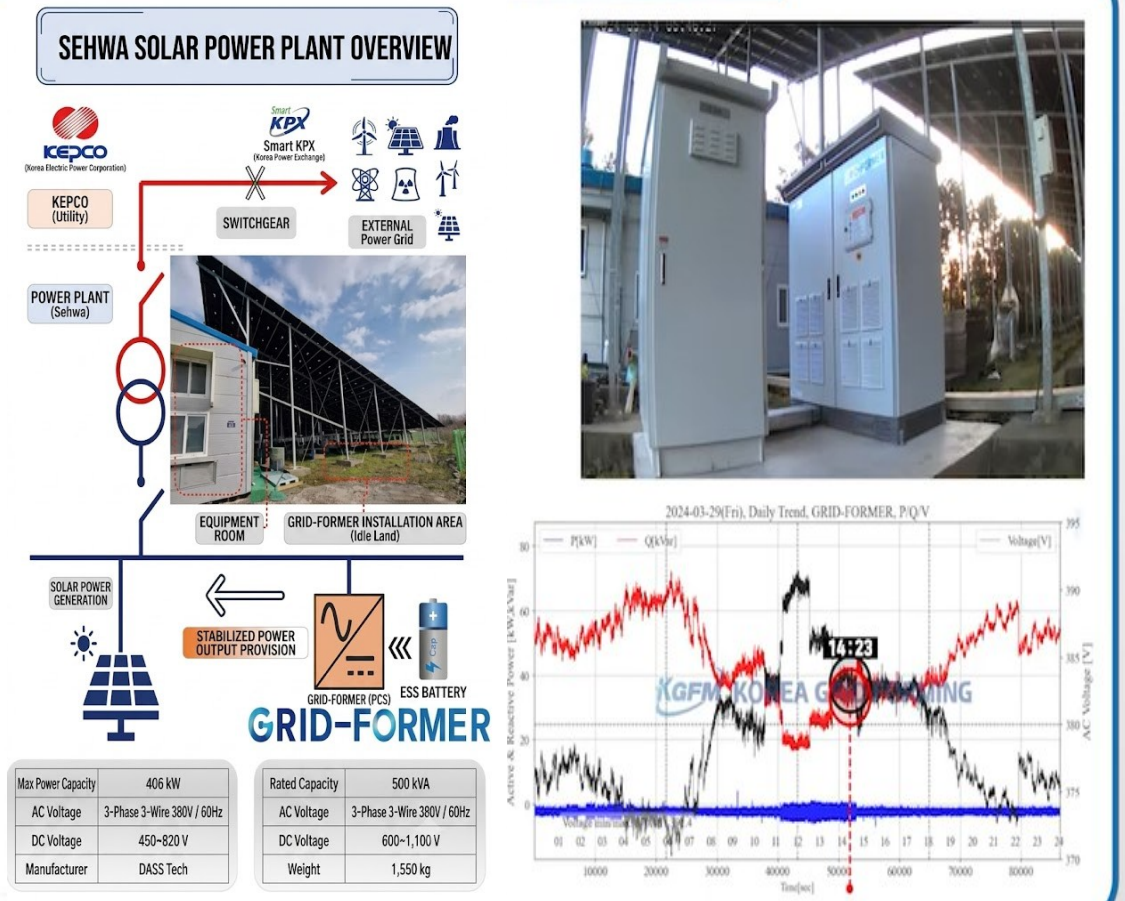


P-HILS Stabilization Verification

Established a test environment equivalent to the actual grid installation and verified GFM stabilization performance at the level of leading bodies such as NERC (US) and AEMO (Australia) by applying diverse grid disturbances

P-HILS Test Site

Actual Installation Site

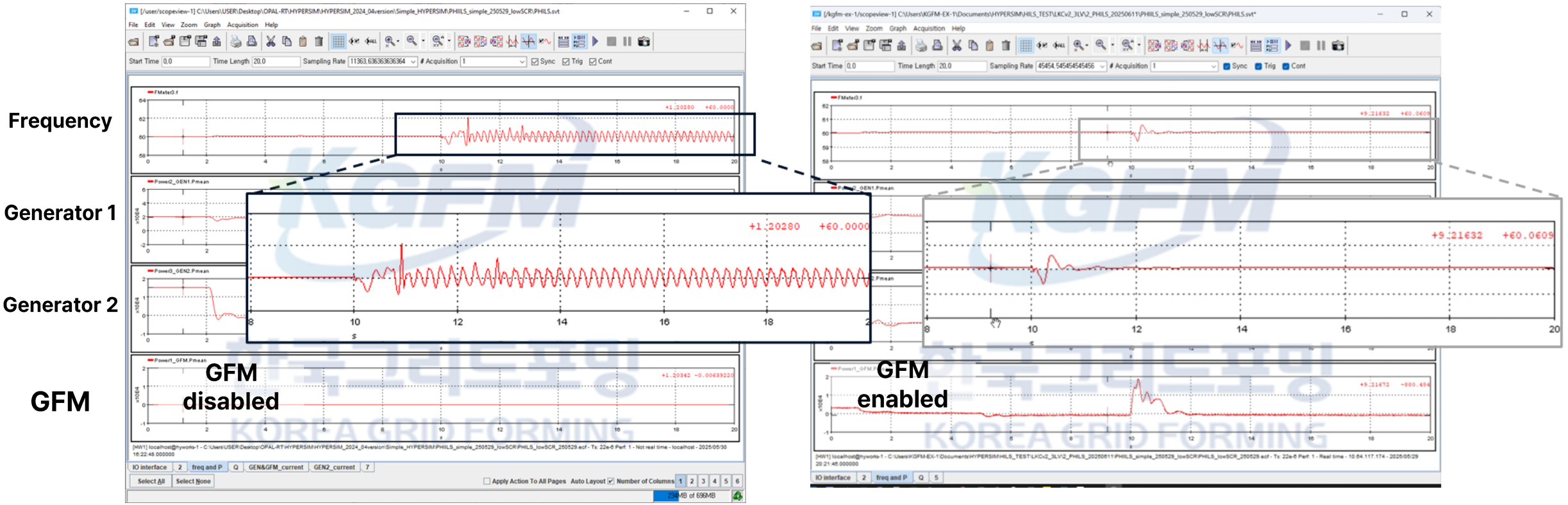


P-HILS Stabilization Verification

Oscillations under high RE penetration were reproduced with P-HILS; the grid-forming solution kept the system stable

SCR=1.9, without GFM inverter

SCR=1.9, with GFM inverter

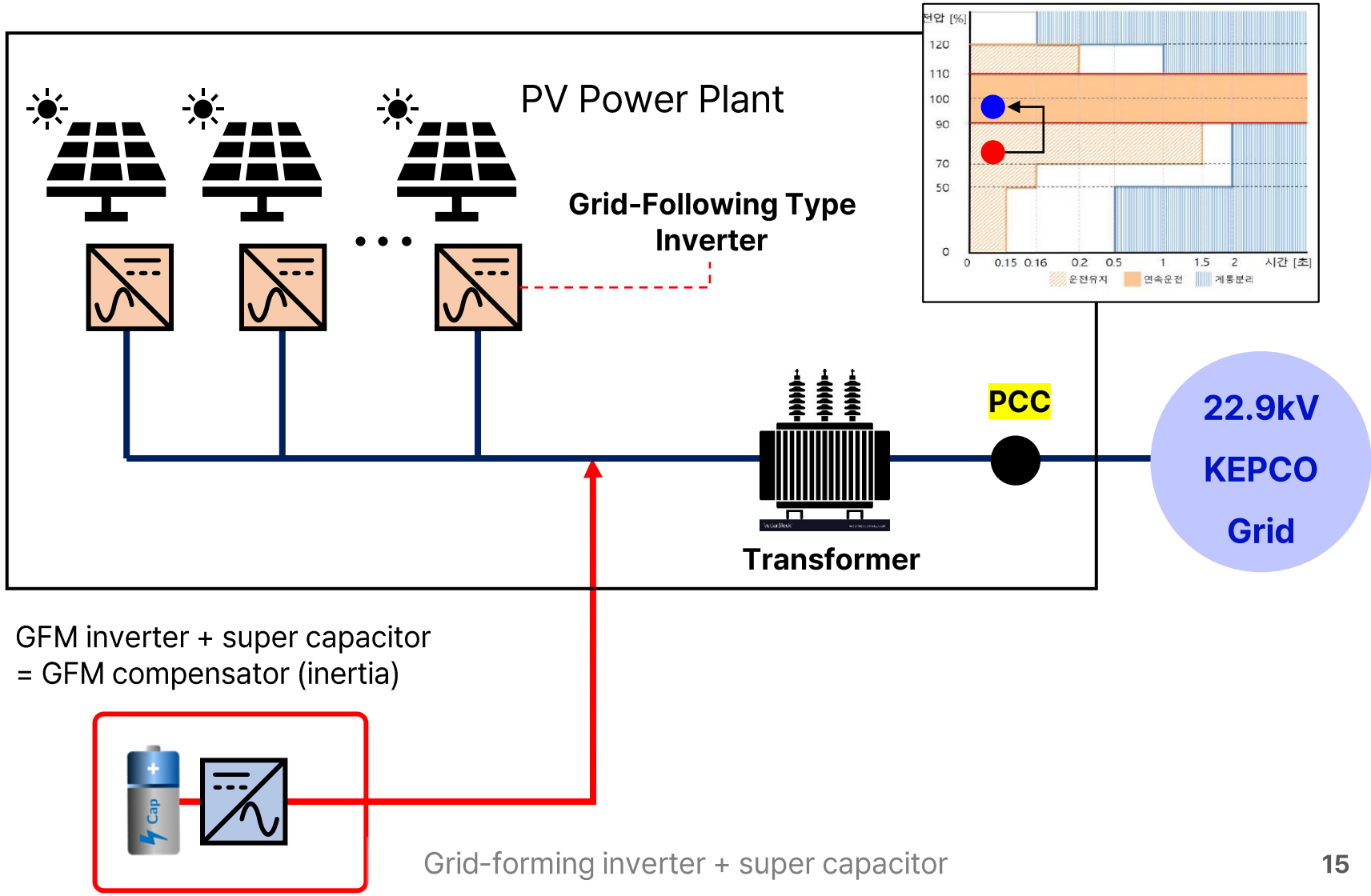


P-HILS emulation of a weakened grid with high RE

Stabilization with grid-forming

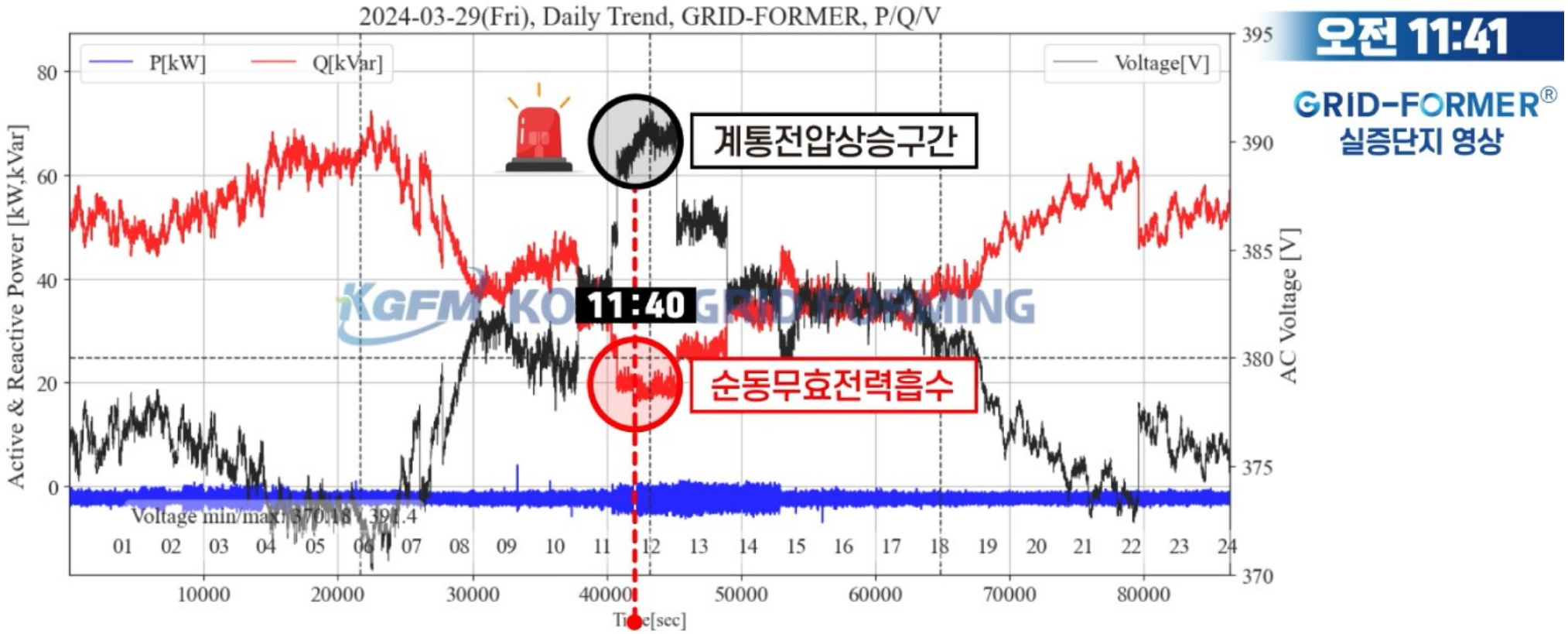
Jeju Island GFM Installation Case

Successfully installed a supercapacitor-based grid-forming compensator in parallel with the existing PV inverters, significantly improving the stabilization capability of the PV plant



Grid-forming inverter + super capacitor

Jeju Island GFM Installation Case

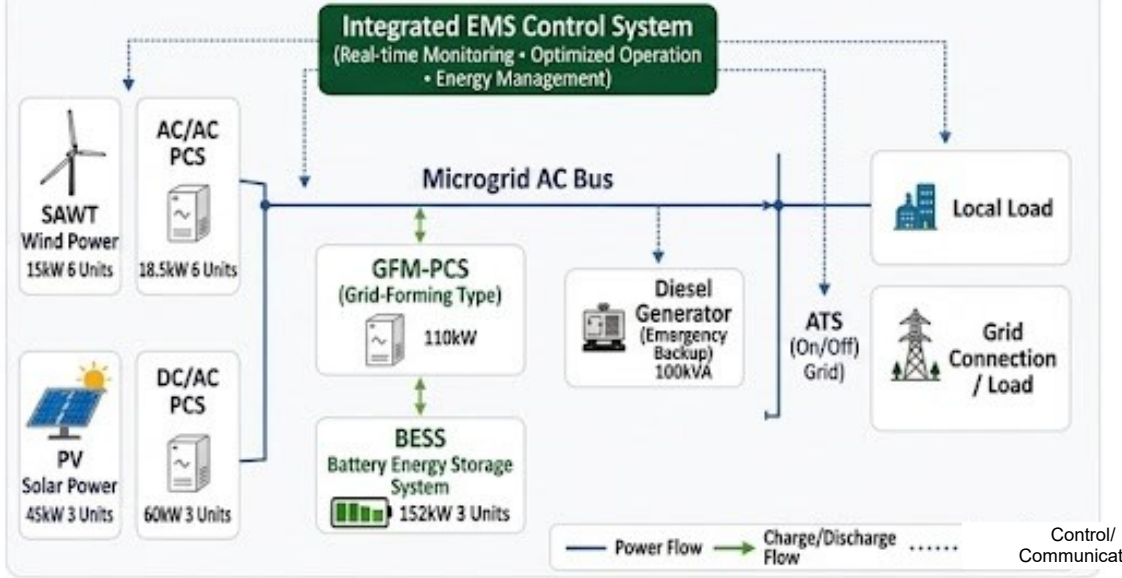


Gwangyang Port Commercial Microgrid

Microgrid with our grid-forming PCS operating at a reclaimed-land site

Hanwha Gwangyang Port DES100 Commercial Operation Project

Integrated EMS Control System



Key Achievement (As of Jan 2026)

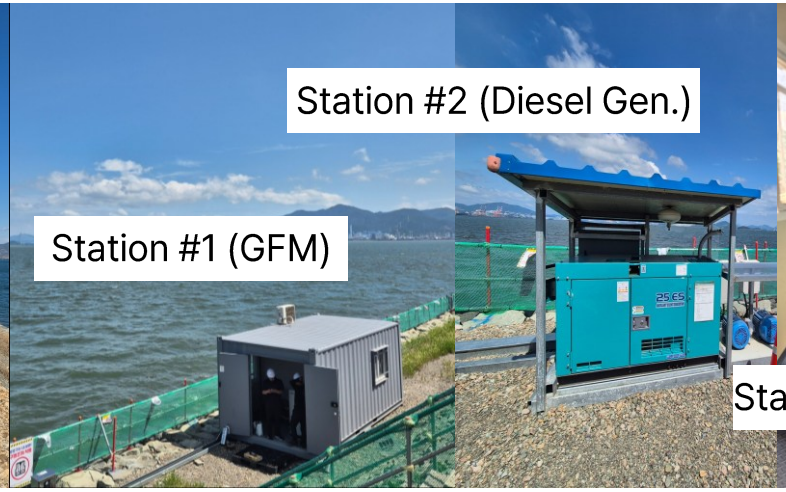
Wind Power CF	Solar Power CF	Combined CF	Estimated Performance Achieved
16.1%	8.6%	24.7%	85~90%
Site Average Wind Speed 5.6m/s	Winter Sunshine Conditions	Combined Operation of PV + SAWT	Achieved Estimated Site Application Level

Operational Metrics (As of Jan 2026)

Annual Power Generation	EMS Operation	Stable Operation	Remote Control
1.4GWh+	24/7	☑ Initial Operation Stabilization Completed	100%
Cumulative Power Generation	Real-time Monitoring	Ensure Ongoing Stability	Integrated Remote Management

Gwangyang Port Commercial Microgrid

Grid-forming BESS installed for the Gwangyang Port microgrid supplying reclaimed-land pump loads; grid restoration testing performed



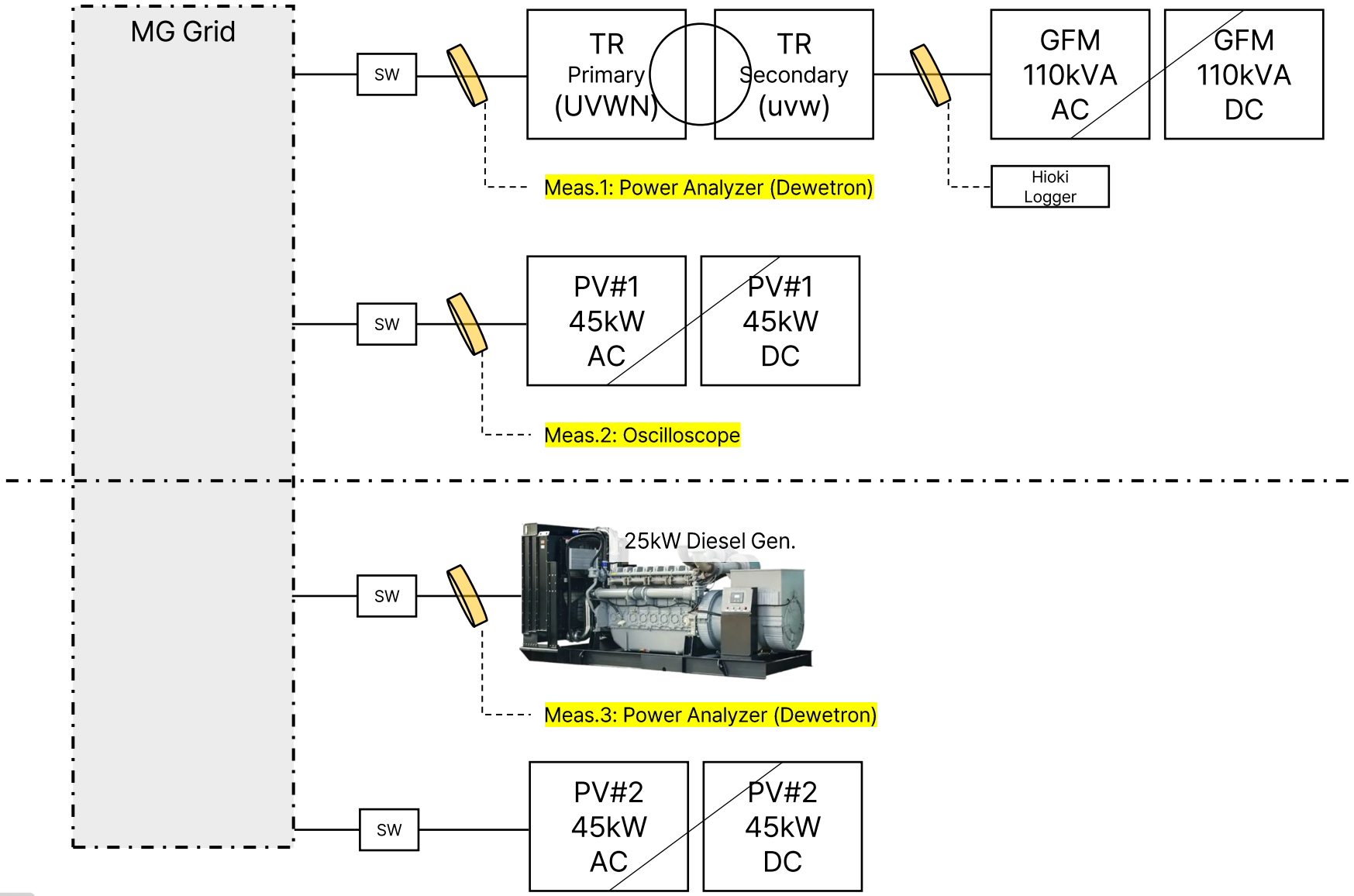
Renewable energy site

Installed GFM inverter

GFM black start energization

RE generation after restoration

Microgrid Field Test



<Test Sequence>

① Full system shutdown

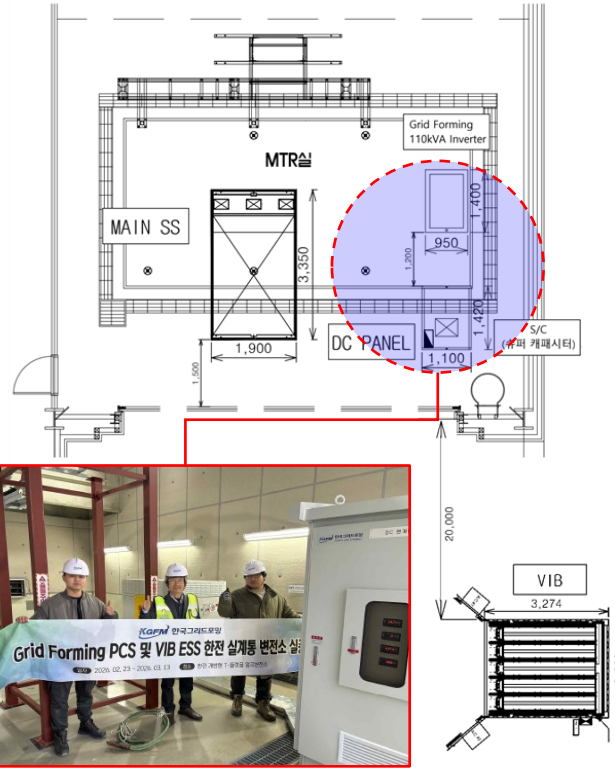
① Start diesel generator
② Black start, min. load supply
③ Start PV (start-up failed)
④ Stop PV
⑤ Stop and disconnect generator

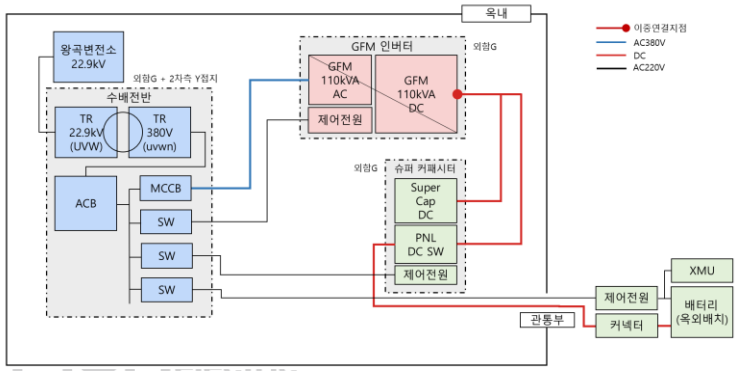
⑥ Start GFM
⑦ Black start, min. load supply
⑧ Start PV, add units in steps
⑨ Stop/disconnect PV in sequence

⑩ Start diesel generator
⑪ Synchronize and connect
⑫ Disconnect diesel generator

GFM Test at KEPCO Substation

GFM BESS at KEPCO's Wanggok substation: charge/discharge, fast frequency reserve, and GFL-GFM mode transition tests verified frequency and voltage stability gains



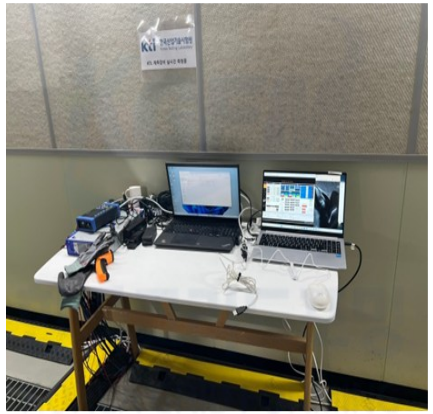


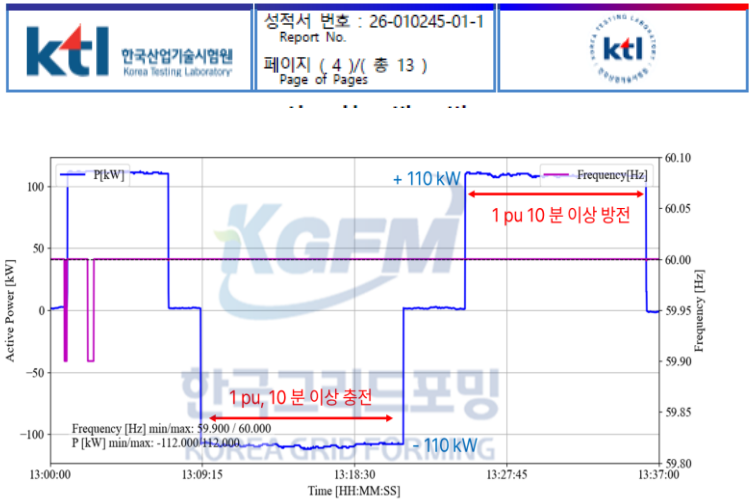
일시	추진내용
2024. 12.	○ 그리드포밍 실계통 실증을 위한 한전 본사, 사업소 협의 – 사전검토 사이트: 서안성 변전소(경기), 전력연구원(고창), 나주 지역 변전소  
2026.2.9.	○ 최종 승인 심의위원회 통과, 한전과 협약 체결 kepco 58322 전남 나주시 전력로 55 전 061-345-4713 FAX 000-0000 송변전운영처 송변전기기부 차장 조경현 joch3754@kepco.co.kr 문서번호 송운(기기)-964 전라남도 나주시 교육길 13 스마트파크지식산업센터 D1동 211호 시 행 일 2026. 2.12. 수신 (주)한국그리드포밍 참조 58326 제목 그리드포밍 ESS 실증 승인 및 협약서 체결 안내 1. 귀사의 무궁한 발전을 기원합니다. 2. 문서번호 2025-KGFM-0013(2025. 3.24) 「154kV 왕곡 T-플랫폼 실증계획서 송부」 관련으로 신청하신 그리드포밍 ESS 실증지원 승인 및 실증을 위한 협약 체결 사항을 아래와 같이 알려드리오니 협조하여 주시기 바랍니다. 가. 실증시험 승인내용 ○ 실증장소 : 왕곡 T-플랫폼 ○ 설치기간(예정) '26. 2. 23(월) ~ 2. 25(수) ○ 실증기간(예정) '26. 2. 25(수) ~ 3. 11(수) ※ 설치 및 실증기간은 현장 여건(휴전, 선로정리 등)에 따라 변경될 수 있으며, 세부 실증기기 설치·철거·실증업무는 광주전남본부 변전운영부와 협의 필요
2026.2.12.	○ 한전 본사, 사업소와 시공 및 운영방안 회의 
2026.2.23.	○ 설치공사 개시 – 한전, 한국그리드포밍, 파이온일렉트릭, 스탠다드에너지의 인력, 노하우, 장비를 투입하여 강화된 안전기준을 극복

일시	추진내용
	  
2026.3.6.	○ 준공완료, 운전개시 

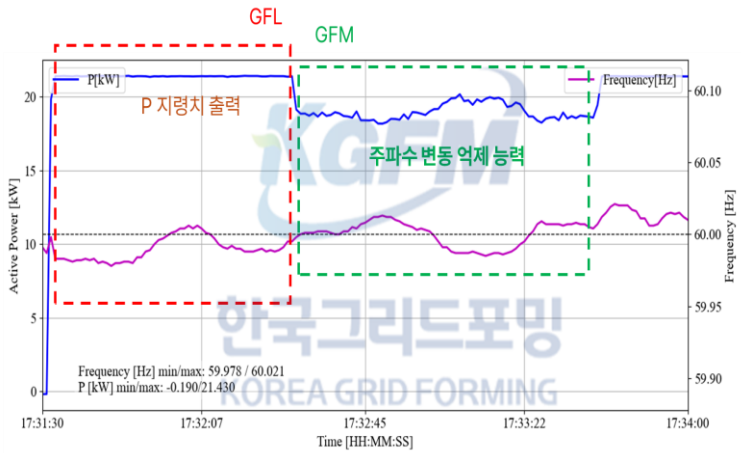
GFM Test at KEPCO Substation

GFM BESS at KEPCO's Wanggok substation: charge/discharge, fast frequency reserve and GFL-GFM mode transition tests verified stability gains

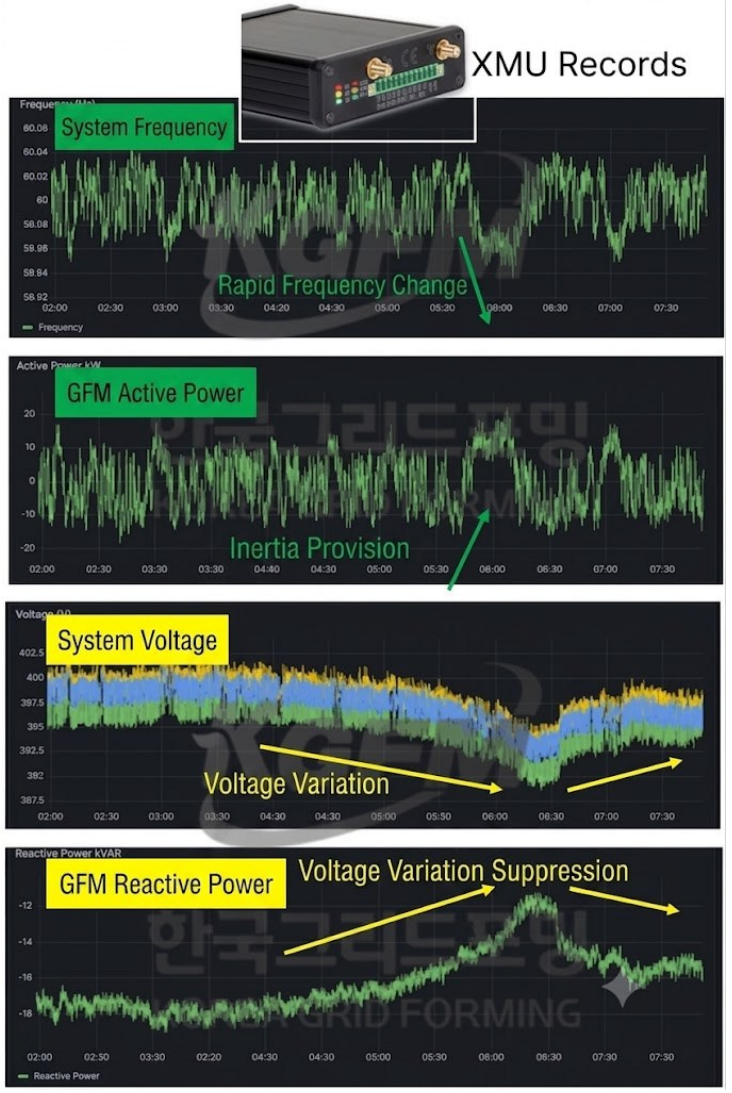




GFM Charge/Discharge Test



GFL-GFM Mode Transition Test



GFM Commercial Business Models

Provides Reliable Grid-Forming Solutions to Customers

Customers

Transmission Owner

Renewable Developers

Consideration

Operational Reliability

Revenue Growth

Customers' Need

Reinforcement

System Strength
Power Quality

Generation Sales

Interconnection Requirement
Earlier Interconnection
Curtailment Free

Inverters

GRID-FORMER®

GRID-FORMER

Controls

K-INERTIA

Simulators

K-EMT

GFM Commercial Business Models

Grid-Former®

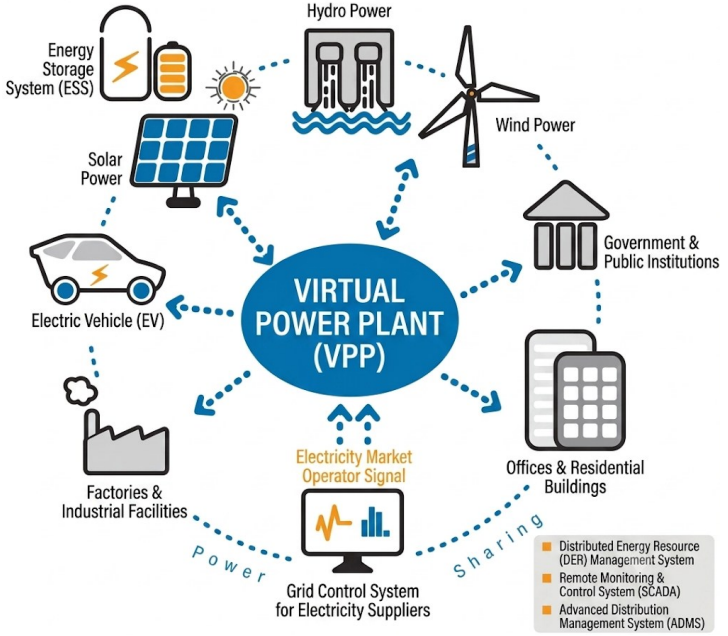
① Grid-forming compensator (SuperCap)
② Grid-forming PCS (BESS)

Dynamic Reactive Power
- ✓ Replaces STATCOM
- ✓ Replaces shunt reactor

GRID-FORMER®

Voltage + Inertia
- ✓ Replaces synch. cond.

Voltage + Inertia + Storage
- ✓ Replaces synch. gen.
- ✓ Replaces ESS
- ✓ Provides fast reserve



GFM BESS PCS Supply for VPP

Thank you

Q & A

Pion electric

Technology Innovation for
Energy and Environment