UNIVERSITY of TASMANIA

Australian Research in Power System Transformation

Topic 5 – Restoration and Black Start

2025/26 Demonstration of system restoration

Commonwealth Scientific and Industrial Research Organisation

19 December 2025

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1. Introduction

The global quest to achieve net-zero emissions (NZE) by 2050 has accelerated the transition toward large-scale renewable energy generation and the use of inverter-based resources (IBRs). This, however, has been resulting in the removal of the primary sources of natural inertia and system strength capabilities inherent in the traditional synchronous generators (SGs). Importantly, the system restoration using IBRs in the event of a brownout or blackout raises critical concerns regarding the reliability and security of the power system. Consequently, with a gradual phase-out of SGs and increasing dominance of IBRs, developing a resilient system restoration strategy is critical to successfully meeting the NZE targets.

In this research, we aim to develop and experimentally validate methods and procedures for IBRs-based system restoration and black start for Australia's National Electricity Market (NEM), which is witnessing a rapid transition to 100% IBRs. Our work further advances the research conducted under "Topic 5: Restoration & Black Start" of the 2021 "Australia's Research Roadmap for Power System Transformation". The earlier studies utilized extensive Electromagnetic Transient (EMT) simulations for black start, ranging from basic component-level modelling to system-level evaluation, and presented the following conclusions based on detailed case-study simulation results:

- The grid-forming (GFM) inverters with battery energy storage system (BESS) performed better than both SGs and the combination of grid-following (GFLs) BESS and synchronous condensers, but lack of sufficient reactive power capability has been the key limitation to provide voltage support in the restoration process.
- For N-1 security, the GFM BESS unit acting as a black start source can support multiple GFLs and transmission system during restoration, with a recommendation of GFM:GFL ratio of at least 1:10 MVA for secure operation, though under normal conditions (i.e. ‘N’) this may extend up to 1:12 or even 1:18.
- GFLs can help regulate frequency in a restarted island by supplying most of the active power thereby reducing the load on the black start unit and enabling it to handle rapid transients.
- The Transformer energization does not cause enough voltage sag outside standard generating system requirement but can be severe enough to make GFL enter protection mode.
- The synchronization of the restarted islands, one IBR-only and the other SG-only, did not result in instability during or after interconnection.
- Composite load models are preferred over ZIP loads owing to realistic step change response thereby more accurately reflecting the system stability during restoration. DER generally do not deteriorate stability but may experience disconnection (~20%) upon fault.
- DER penetration of above 80% causes DER PLL tracking instabilities which does not occur for SGs as a black starter.
- The low system strength is not one of the most common causes of instability in restarted systems, but ill-conditioned Park Power Controllers (PPCs) on GFL plant, which can be avoided by direct power control of PPC.
- Distance protection showed less maloperation for GFM, while transformer differential protection remains challenging, however, the harmonic threshold adjustments and pre-insertion resistors can help in reduce trips. Multiple simultaneous transformer energization can result in differential relay tripping which can be reduced by allowing considerable time between subsequent energization for the current distortion to decay.

One of the key recommendations in Stage 4 highlighted the urgent need to progress beyond theoretical and simulation-based investigations toward experimental validation. This research work particularly focuses on the use of Hardware-in-the-Loop (HiL) as testbeds and real-world NEM data to validate the simulation findings, which brings us one step closer to actual field testing of such revolutionary technologies in power system service restoration. We further aim to explore the possibility of AI-driven methods as emerging solutions in black start application, such as autonomous coordination of GFMs islands during bottom-up restoration process. The salient features of Stage 5 studies are highlighted as follows:

Determine the Potential of REZs to Serve as Future SRAS Sources

- ➢ This task aims to determine how Renewable Energy Zones (REZs) can be effectively utilised as System Restart Ancillary Service (SRAS) sources by assessing their self-start capability, including the time required to energize nearby or extended network areas.
- ➢ Using real-world data and Hardware-in-the-Loop (HiL) simulations, we will evaluate REZ restart methods, operational requirements, and coordination strategies, and quantify the aggregate reliability of wind and solar farms as primary black-starters.

Investigate the Feasibility of Hybrid GFM BESS and IBRs as SRAS Sources under Weak Grid Conditions

- ➢ This task investigates the technical feasibility of using hybrid Grid-Forming (GFM) battery energy storage systems (BESS) and IBRs as reliable SRAS via EMT simulation.
- ➢ It also includes modelling and evaluating the performance of Inverter-Based Loads (IBLs), with a focus on their dynamic response and interaction with GFM systems under weak grid conditions.

Evaluate the Impact of Distributed Energy Resources (DERs) on the Black Start Process

- ➢ Utilizing real-world data and HiL testbeds, we will analyse the performance of various DERs including solar PV, wind turbines, and battery storage during black start events in the NEM.

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- This approach will offer crucial insights into effectively integrating DERs into the black start process tailored to NEM conditions.

Define Technical Requirements for Inverter-Based Black Start Solutions to Inform System Restart Standards

- This task focuses on defining and assessing the fundamental technical requirements for inverter-based resources, particularly their GFM capabilities crucial for system restarts.
- Through HiL testbed demonstrations, we will identify and validate essential performance criteria, guiding the development of technical standards and regulatory frameworks for deploying inverter-based black-start solutions within the NEM.

Evaluate GFM and GFL Inverter Performance During System Restoration

- Leveraging NEM-specific HiL testbed simulations, we will evaluate the performance and contributions of GFM and Grid-Following (GFL) inverters during system restoration.
- By replicating realistic NEM conditions, this study aims to clarify their capabilities and limitations in supporting black start resilience.

Assess the Impact of Advanced AI-Based Control Systems on System Restoration

- This task aims to evaluate the effectiveness of AI-based coordination strategies for black start applications, particularly for the autonomous coordination of grid-forming (GFM) islands during the bottom-up restoration process.
- Using real-world data and HiL simulations, we will assess the performance of these AI-supported coordination frameworks and examine their ability to enhance system restoration performance within the NEM.

2. Research completed

Given the six tasks, described in previous sections, the current progress is very much aligned with the set targets in the proposal. The research completed against each task is briefly presented here.

	7/25	8/25	9/25	10/25	11/25	12/25	1/26	2/26	3/26	4/26	5/26
Task 1 (UOW)											
Task 2 (UTAS)											
Task 3 (UTAS)											
Task 4 (UTAS)											
Task 5 (SUT)											
Task 6 (UTAS)											
Report											

Results and discussion:

- **Task 1 (60% completed):**

This study focuses on assessing the self-start capabilities of Renewable Energy Zones (REZs), including their energization times, using real-world NEM data. It further examines coordination strategies between wind and solar resources and quantifies the aggregate reliability of these combined systems. The findings will inform the ongoing efforts to define operational requirements for REZs. The work on this task is progressing as follows:

- Data for the TransGrid sub-transmission network, comprising the Moree, Narrabri, Inverell, Glen Innes, Gunnedah, Tamworth, and Armidale areas, is being collected, and a PSCAD model for further analysis is being simulated.
- Two grid-forming inverters have been simulated for self-start capability assessment of the Moree network. Various energizing scenarios for black start operation are being considered.
- Generation capability assessment of REZ for a hybrid wind, solar, and BESS system is being assessed using probabilistic wind and solar models.

- **Task 2 (100% - MATLAB Simulink; 25% - HiL testing):**

This work presents a component-scale evaluation of a hybrid GFM BESS under weak-grid conditions. Unlike prior studies that unrealistically modelled the BESS as an infinite, constant DC source, this study integrates a bi-directional DC–DC converter to capture the realistic challenge of operating with coupled control loops. Fig. 1 shows the component-level block diagram of the underlying model, and Fig. 2 shows simulation results for the hybrid GFM BESS subjected to weak-grid conditions. RT-LAB results are omitted here due to space constraints. After an extensive sensitivity analysis across short-circuit ratio (SCR) and X/R variations under large-load disturbances, the following insights are identified as critical to the black-start performance of hybrid GFM BESS:

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- A higher saturation current limit i.e. a minimum of 1.2 times the rated capacity of the battery is important to sustain large disturbances especially during energization and large load changes. Setting saturation limit to a lower value results in delayed settling of DC voltage to the reference value.
- A stable and fast settling of DC-link voltage to the set values is critical for quality of the power as the lower voltage at the DC can lead to overmodulation at the AC side. When this is clipped for protection purpose, it leads to distorted voltage waveform which then propagates to the entire network. Consequently, the black start may fail if the GFM BESS is not producing a desired reference for the support devices connected to it, such as GFLs.
- The ramp rate limiter for rate of change of output voltage references is essential for GFM BESS to manage AC-side energization and DC link capacitor charging from discharged or partially charged state.
- GFM BESS performs better under weak grid condition, in the sense that its performance degrades upon connecting this to strong grid (that is, using a higher X/R ratio), which results in slow damping response leading to prolonged oscillations.
- In low-SCR (weak grid) conditions, island interconnection is significantly more vulnerable than non-islanded because the GFM must supply most of the inrush current. The weak grid provides limited support, causing the GFM to reach current limits and risk protection trips. In contrast, no trips are observed in strong-grid (high SCR) conditions, where the stiff grid provides most of the inrush current.

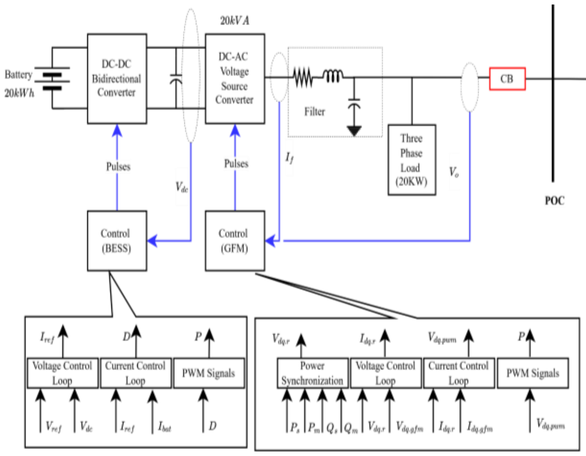

Figure 1 Block diagram of Hybrid GFM-BESS with Grid Interconnection

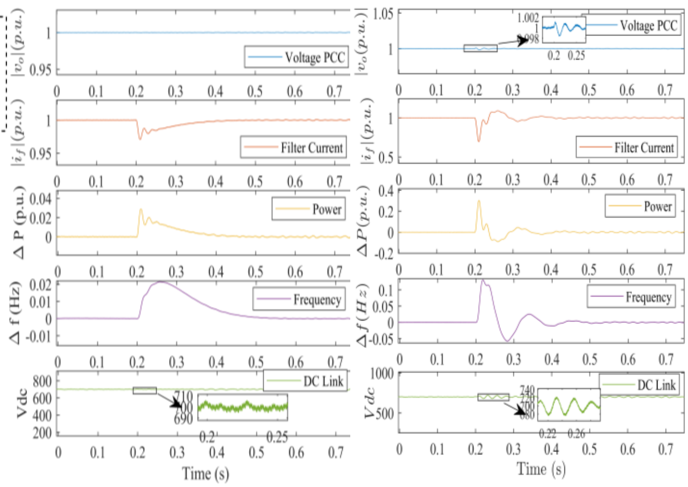

Figure 2 Evaluation of Hybrid GFM BESS Under Weak Grid: a) SCR=1, X/R=5, b) SCR=3, X/R=5

➢ **Task 3 (15% - MATLAB Simulink; 0% - HiL testing):**

This task requires studying the impacts of DERs on the black-start process. Model development work for simulation has already begun, considering the IEEE 9-bus system as the benchmark. We plan to provide a specific case study with one synchronous generator and two GFMs in the network. One of the GFMs will act as a black start unit (BSU), sequentially energizing the transformer and transmission lines to establish the cranking path. By confirming stable load pick-up and DERs connections, additional generators will subsequently be brought online to energize the entire network. We will create different scenarios for DER penetration during the black start process and assess how they impact the system being energized by the GFM. HiL testing will be performed after verifying the simulation results, which can reveal critical information pertaining to real-life challenges for the implementation of IBRs based black start.

➢ **Task 4 (20% completed):**

In this task, an assessment of the technical requirements for inverter based black start will be provided. We have reviewed several guidelines and general requirements for systems with GFMs as the black start; however, a comprehensive commentary on the system requirement and specification can only be provided after evaluating the outcomes of the other tasks and reviewing existing online resources related to GFMs as BSU. Given that the standards for GFM based technologies are currently in the development phase by IEEE and IEC through a joint dual-logo standard, supported by G-PST consortium[1], the contribution of this task will provide critical insights into the state-of-the-art standardization efforts.

➢ **Task 5 (20% completed):**

[1] CSIRO and G-PST Consortium, "Development of capabilities, services, design methodologies and standards for Inverter-Based Resources (IBRs)

This task focuses on evaluating the role of Grid-Forming (GFM) and Grid-Following (GFL) inverters in system restoration, particularly in black start scenarios where stable voltage and frequency establishment are critical. In modern low-inertia networks, GFM inverters assume functions traditionally provided by synchronous machines, enabling reliable system energisation and progressive load pickup. Building on our prior work[2], we have developed an advanced robust controller for the power synchronisation loop of GFM inverters, specifically tailored for black start applications. This controller substantially extends the stable operating range of GFM inverters under a wide spectrum of grid strengths and disturbances, making them suitable candidates for restoration sequences involving multiple DER-rich microgrids.

To evaluate the performance of this advanced GFM structure in a representative black start scenario, the CIGRE 400 V distribution network[3] is adapted to form an islanded microgrid comprising multiple voltage-controlled (VC) inverters, as illustrated in Fig. 3. The original line parameters from the reference model are retained. The interconnecting line impedance is set to R = 0.06 p.u and X = 0.325 p.u, while the grid impedance is considered to be Rg = 0.7 p.u and Xg = 0.7 p.u. Low-wattage loads are assumed negligible for this study.

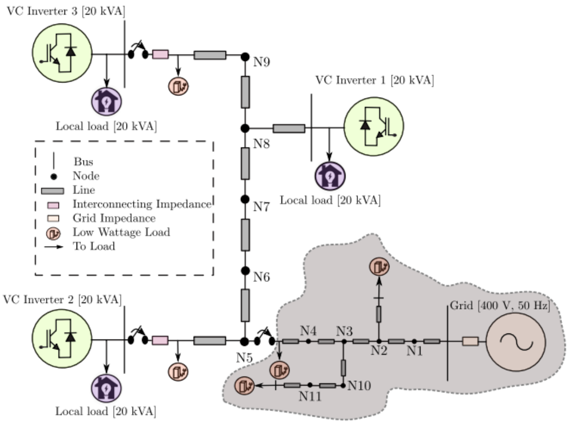

Figure 3 Multiple VC Inverters Integrated to Grid

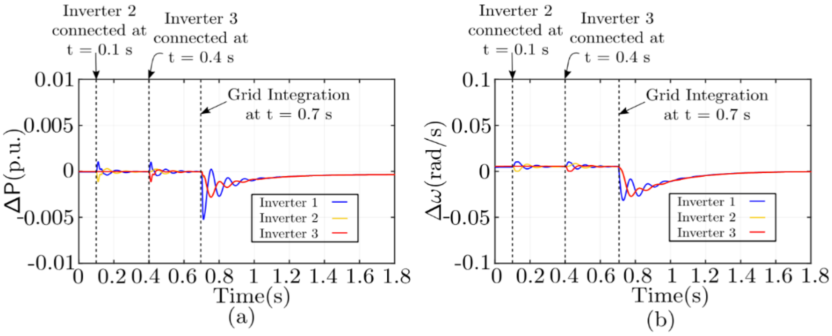

Figure 4 Multiple VC Inverters Integrated to Grid (SCR=1)

The restoration sequence is initiated at t = 0 s by black starting a 20 kVA VC inverter (Inverter 1). The associated 20 kVA local load, modelled as a purely resistive load and assumed to be pre-connected, is therefore energised inherently as the inverter establishes voltage and frequency in the islanded microgrid. At t = 0.1 s, a second 20 kVA VC inverter (Inverter 2) is brought online to supply its respective local load. A third 20 kVA VC inverter (Inverter 3) is connected at t = 0.4 s, further increasing the microgrid load and testing the GFM's capability to maintain stable V/f. Finally, at t = 0.7 s, the islanded microgrid completes a full black start (in simulation) by synchronising and interfacing with the remainder of the network, which is supplied by the main grid.

The results presented in Fig. 4(a)–(b) show that all inverters reliably track the system frequency during their individual black-start sequences, achieving seamless and instantaneous integration into the islanded microgrid. Once the island is synchronised and reconnected to the main grid to complete the black start event, both the active power tracking error and frequency deviation converge to zero within approximately 1s. Throughout the transition, the tracking error remains minimal, indicating a highly desirable transient response and robust performance of the proposed GFM control strategy.

3. Outstanding activities

For stage 5 of Topic 5, the remaining work for each of the six tasks is highlighted here.

Task 1: Preliminary studies on the viability of REZs as SRAS have been completed using real-world NEM data. Further work on black-start coordination strategies and hardware-in-the-loop (HiL) validation is progressing well. Final key insights can only be shared after comparing simulation results with HiL validation.

[2] Pal, A., Hosseinabadi, P. A., Panigrahi, B. K., & Pota, H. R. (2025). A Black Start Solution for Voltage-Controlled Inverters with Chattering-Free Fixed-Time Sliding Mode Power Synchronization Control. IEEE Transactions on Industry Applications.
[3] S. Papathanassiou and N. Hatziargyriou, and K. Strunz, "A benchmark low voltage microgrid network," in Proc. CIGRE Symp.: Power Syst. Dispersed Gener., Jan. 2005, vol. 1, pp. 1–8.

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Task 2: A simulation work for studying the feasibility of hybrid GFM BESS under weak grid condition is almost completed, the hardware-in-loop (HiL) testing is pending and is planned to be completed by the end of December. However, the validation of the model using RTLAB simulation as pre-requisites for HiL testing has been completed.

Task 3: This task is in continuation of task 2 which requires expansion of advance component level study in Task 2 to system level evaluation of GFM BESS by specifically evaluating the impacts of DERs. We already have begun to build a Simulink model by considering IEEE 9 bus system as the benchmark for system level evaluation.

Taks 4: This task requires a comprehensive analysis of the rest of the tasks especially 1,2 3 and 5 to be able to provide a thorough assessment of different standards and system requirements of black start. Since a specific standard for GFM as a black start still under development phase, we will provide a detail repot on the state-of-the-art requirements studied by numerous stakeholders such as IEEE, NREL, and AEMO etc.

Task 5: This task will be extended to a high-voltage, system-scale model incorporating multiple GFM and GFL inverters, enabling verification that the proposed control strategy maintains stability and effectiveness under realistic large-power and long-distance network conditions.

Task 6: The evaluation of AI-based methods in black start application, such as autonomous coordination of GFMs islands during bottom-up restoration process, will be carried out next year as per scheduled task in our proposed plan**.**

4. Progress against the Roadmap

The activities of Stage 5, as briefly described above, are fully aligned with the key research plan highlighted in Stage 1 that provides the roadmap for future grid requirements for black start and system restoration. The progress against key subtopics mentioned in Stage 1 and how Stage 5 contributes to advance the study as next step is summarized below.

The treatment of inverter-based resources during system restoration: This has been advised as one of the main research areas that specifically focuses on the capabilities of GFM, GFLs and the DERs as black start resource and restoration support. In Stage 2-4, an offline simulation studies are carried out to investigate IBRs as system restart, we further move one step forward to validate the behaviour through HiL testing as mentioned in the roadmap. For this we adopted advance component level evaluation of Hybrid GFM BESS under weak grid condition by explicitly considering a BESS control for maintaining DC-link voltage that results in useful insights.

Tools and techniques: This requires validation of simulation tools and development of methods supporting decision for black start for control centres. Our work of HiL testing is the most suitable way forward to validate the accuracy of developed simulation tools with real-time control; the earlier stages, however, used PSCAD-based simulation. Furthermore, to support the decision-making, we will be investigating AI-based solution for control during black start.

Technical and regulatory requirements: This area is focused on investigating the technical requirements for IBRs-enabled black start and system restoration support. For instance, in earlier works, the specific control settings for these devices are suggested such as frequency and inertia settings for GFLs and GFMs respectively, and fault current limitation of IBRs, disabling PPC for an open loop control of P and Q to improve stability where multiple IBRs are present. Our work will provide an overview of the system requirements and capabilities after validating key aspects through HiL.

End-to-end system restoration in power systems with high share of inverter-based resources: Regarding this, we are exploring the role of REZ in system restart, which is one of the main recommendations from Stage 4. Considering existing system which consists of a high share of GFLs based technologies, the potential of REZs and/or GFLs as SRAS is being investigated.

5. Research relevance to Australia

In Australia, a current renewable energy provides around 35% (excl. hydro)[4] of total generation which is projected to reach 82% by 2030[5]. The rapid energy transition, combined with the retirement of coal-fired generation, has created an

[4] Clean Energy Council. (2025). *Clean Energy Australia 2025: Accelerating the Energy Transition*. Clean Energy Council. **https://cleanenergycouncil.org.au/news-resources/clean-energy-australia-report-2025**
[5] Department of Climate Change, Energy, the Environment and Water. (2025). *Electricity and Energy Sector Plan*. Canberra, ACT **https://www.dcceew.gov.au/energy/publications/electricity-energy-sector-plan**

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urgent need to identify alternatives for managing high-impact low-probability, events such as black start. This shift is also leading to a reduction in physical inertia and fault current capability due to the removal of synchronous generators. However, conventional re-energization is not only slow but more costly, as AEMO must ensure the procurement of these resources through availability contracts. The nonmarket ancillary service (NMAS) report by AEMO[6] estimated around $44.5 million per annum (for availability, testing, and usage) for an event assumed to occur once every 20 years.

Furthermore, the lack of practical demonstrations of IBRs acts as a hard limit on the reliable, secure and stable renewable energy transition. Consequently, the grid cannot be confidently and securely operated with 100% renewables if there is no verified, and trusted method to restart it from a blackout using IBRs-based technologies. As synchronous machines continue to retire, this limitation is likely to increase the future cost of SRAS, as availability payments may rise due to the reduced number of eligible providers and increasing scarcity of qualified units. Therefore, the research being conducted in Stage 5 on Topic 5 for SRAS is of extreme importance for Australia's energy transition as it responds to the critical concerns raised by AEMC[7], and it further fills the validation gap pointed out by AEMO[8]. To this end, we respond by addressing the following key questions.

How to raise confidence on GFM based black start technologies? In Task 2 we investigate the feasibility of hybrid GFM BESS as SRAS sources under weak grid conditions, and in Task 5 we evaluate GFM and GFL Inverter performance during system restoration. Our research, instead of relying on mere simulations, has prioritized focusing on validation, which uses the Hardware-in-the-Loop (HiL) testbeds for more practical and informed demonstration that mostly lacks in earlier studies.

How to provide validated technical details for defining new rules and requirements? Our research in Task 4 assesses the technical requirements for IBR-based black start and provides evidence-based functional requirements that can assist in standardization efforts for IBRs-based black start, which can further pave the way to enable the procurement of services from emerging technologies.

How to capture the instability of load caused by DERs in black start? In Task 3, we are evaluating the impacts of DERs on the black start process. AEMO has identified the high rooftop solar as a critical risk that could prevent a daytime restart. This research investigates that specific risk and provides analysis about the system stability boundaries on the face of complex DERs behaviour.

How to investigate REZ as black start? The Task 4 focuses on assessing the potential of REZs to serve as future SRAS that aims to establish a validated pathway for new, large-scale renewable investments to participate in the provision of key security service, ensuring that the future power system can support system restoration and self-recovery following a black out.

6. Recommended research priorities

A natural progression from the foundational HiL validation achieved in Stage 5 is to evolve from demonstrating feasibility to system-level risk mitigation and implementation readiness. While AEMO is currently procuring services for IBR based black start under *"Type 2 Transitional Services*[9]*"* for a real-world demonstration, those trials are inherently site-specific and constrained in operating envelope. The AR-PST roadmap, however, requires addressing validation gaps that are impractical and/or high-risk to capture through field trials alone, particularly protection interactions, multi-IBR synchronisation under contingencies, and coordinated transmission–distribution (T-D) behaviour involving DERs.

Accordingly, the future research directions below focus on: (i) expanding the NEM Digital Twin for restoration studies, (ii) strengthening experimental validation from HiL to Power Hardware-in-the-Loop (PHiL), and (iii) producing evidence that can directly inform emerging System Restart standards for inverter-based resources.

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[6] Australian Energy Market Operator. (2025). *Non Market Ancillary Services (NMAS) report 2024–25*. AEMO. **https://www.aemo.com.au/-/media/files/electricity/nem/data/ancillary_services/2025/nmas-report-2024-25.pdf**
[7] AEMC, "Issues Paper - Review of the System Restart Standard", AEMC, Sydney, New South Wales, Australia, 2024. Accessed 5/02/2025. [Online]. Available: **https://www.aemc.gov.au/sites/default/files/2024-12/Issues%20Paper%20-%20Review%20of%20the%20System%20Restart%20Standard.pdf**
[8] Australian Energy Market Operator. (2025). *System Restart Technical Advice* (Submission to the AEMC Reliability Panel Review of the System Restart Standard). AEMC. **https://www.aemc.gov.au/sites/default/files/2025-06/System%20Restart%20Technical%20Advice.pdf**
[9] Australian Energy Market Operator. (2024). *Transitional Services Guideline*. AEMO. Retrieved from **https://www.aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2024/transitional-services-guideline-consultation/transitional-services-guideline.pdf**

A comprehensive evaluation across these areas can also provide a robust assessment of system restoration duration under realistic operating constraints. Therefore, given the broad range of research direction indicated in the original roadmap and progress to date, we maintain that our recommended research will directly underpin the trial initiatives. This will further lead to advancements in the roadmap research priorities by offering critical insights regarding stability, security, protection, and large-scale complex interactions among black start units and support devices that would perhaps be cumbersome to capture through physical trials alone.

- **PHiL-based experimental validation of restoration interactions**

  To close the remaining “simulation-to-reality” gap, priority research should extend Stage 5 HiL outcomes into PHiL, enabling realistic electrical stress, energisation dynamics, and power hardware interactions.

  - Conduct PHiL tests to validate real-time interaction between simulated networks and physical power hardware (e.g., inverter controllers, representative inverter interfaces, protection IEDs where feasible).
  - Validate critical behaviours that are difficult to prove in offline simulation alone, including transformer energisation dynamics, inrush impacts on IBR controls, and stability margins during staged load pickup and island synchronisation.
  - Enabling equipment requirement: Delivering PHiL requires procurement and commissioning of a power amplifier (four-quadrant grid emulator / power interface) to couple the real-time simulator with physical power hardware. This equipment is required to reproduce weak-grid conditions, apply controlled disturbances safely, and allow repeatable energisation and restoration sequences under realistic voltage/frequency and power-flow conditions.

- **Assess protection performance under GFM fault-current characteristics**
  - Develop and validate a NEM Digital Twin (initially at regional sub-network level, scalable) incorporating representative protection relay settings and logic.
  - Perform a comprehensive evaluation of system behaviour across fault types (L–G, L–L, L–L–G, three-phase) during restoration islands and interconnections.
  - Identify protection maloperation risks (distance, differential, overcurrent, inrush-related) and develop mitigation measures (settings guidance, logic updates, and restoration sequencing constraints).

- **Develop a coordinated dynamic consumer energy resources (CER) dispatch for system stability**
  - Develop control logic for Virtual Power Plants (VPPs) to automatically switch its mode to absorb excess DERs generation during the critical load pick-up phase.
  - Model and test the use of aggregate EV charging stations as fast-acting frequency response loads to stabilize low-inertia islands.
  - Define operational envelopes and control objectives suitable for restoration phases (energisation, load pickup, and re-synchronisation).

- **Establish a coordinated transmission–distribution framework to manage DER impacts**
  - Develop a transmission-distribution (T-D) framework that integrates high fidelity transmission dynamics with detailed distribution network models to capture the bidirectional propagation of voltage and frequency disturbances during restart.
  - Conduct PHiL tests to validate and assess the real-time interaction between GFMs at the transmission level and dynamic DER responses at the distribution level.

- **Assess control strategies for synchronising multi-IBR islands without synchronous generation**
  - Develop “pre-sync” logic where GFM inverters in separate islands utilise communication or local measurements to actively align phase angles prior to tie-line breaker closure.
  - Analyse the transient power flows during the interconnection of two zero-inertia islands and estimating the necessary BESS headroom required to absorb the resulting shock.

- **Develop real-time metrics and decision-support tools for control-room operations**

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- Design a real-time unified stability index (USI) that combines online inertia, available fault current, and reactive power margin into an intuitive indicator for control room operators.
- Integrate a fast look-ahead simulation engine that runs scenarios to predict the outcome of next switching action in the sequence, reducing a risk of island collapse.