Topic 5 – The role of inverter-based resources during system restoration

2024 CSIRO GPST Research

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Contents

1. Introduction

This work is conducted as part of topic 5 of Australia's Global Power System Transformation (G-PST) Research Roadmap, with the intent of understanding and expanding system restoration capabilities in National Electricity Market (NEM). It focuses on investigating the performance, capabilities and limitations of different types of grid-forming and grid-following inverters with respect to black start capability and restoration support in power systems with a high share of inverter-based resources (IBR), expanding on previous research completed in 2022-23 on Topic 5. Investigation is made on system restart and restarted island operation with no synchronous generators online, the role of synchronous generators and condensers when combined with grid-following inverters and other factors such as distributed energy resources (DER) and resynchronisation of restarted islands. The response of each option and factors influencing its performance is assessed with the use of detailed vendor-specific electromagnetic transient (EMT) simulation models.

2. Research completed

This work utilises a network model of the North Queensland Power System reflecting locations of existing system restart ancillary service (SRAS) providers and a future renewable energy zone (REZ) inclusive of wind, solar, battery and Flexible AC Transmission System (FACTS) devices. Studies are performed utilising the PSCAD™/EMTDC™ time-domain based power system simulation software. Detailed vendor-specific EMT simulation models of each black-start technology type were utilised, as well as for analysis of restarting multiple different types of grid-following (GFL) inverters including wind farms, solar farms, FACTS devices and BESS. Restart scenarios studied reflected physical system methodology, closing circuit breakers at substations to incrementally energise network elements such as transmission lines, transformers and generating systems. Previous work completed in 2022-23 confirmed the viability of restarted islands supported purely by grid-forming (GFM) batteries and, regardless of black-start technology, facilitating pick-up of a single GFL IBR. Initialisation and fast switching of the model was performed to reduce simulation times, based on the knowledge that a black-start device and single IBR was an already proven system restart option.

Work to date has focussed on the use of GFM BESS as a black start device, and their capability to energise neighbouring network to restart nearby GFL devices which can further support the restart process. Relying on the ability of a GFM BESS to restart a single GFL generator, studies expanded on the number and total MVA capacity of GFL devices restarted and supported by a single GFM BESS black-starter. Emphasis was placed on expanding understanding of stable restart scenarios supported by a black start GFM and attempting to identify stability boundaries of restarted islands. Current work has not identified a clear stability limit yet but has uncovered three material findings:

- The MVA ratio between GFM BESS black start device and a variety of GFL wind and BESS devices is viable upwards of 1:7.5. That is, a 100 MVA GFM BESS black start device can support a restarted island inclusive of various GFL support devices up to 750 MVA.
- Larger support device to black start provider MVA ratios may be prone to fault ride through (FRT) restrike behaviour on some support devices with their system normal settings. This is due to the lower short circuit ratio (SCR) and increased voltage sensitivity, rendering existing FRT thresholds as too restrictive.
- Black start providers need not be the main provider of frequency control in a restarted island. Studies have shown that a GFL BESS support device with frequency control enabled can provide the majority of frequency control in a restarted island, facilitating a GFM BESS black start provider to sit near 0 MW output and act as a swing machine to manage transient disturbances within the island.

3. Outstanding activities

The following activities have already commenced work with further analysis to be performed. An engagement has been established with the Australian Energy Market Operator (AEMO) and outstanding work is planned to be performed utilising confidential network and generator models, following their receipt from AEMO.

- IBR device related studies to be finalised:
  - The impact of different grid-following IBR types, such as wind, solar BESS and FACTS, on the stability and resilience of restarted islands.
  - Identification of stability boundaries and risk of adverse control interactions with other network equipment.
  - Impact of control system parameters on restarted island stability and recommended adjustments compared to system normal settings.
- Assess the need for different performance standards for IBRs between system intact and system restoration.
- Assess the need for any additional performance requirements for grid-forming IBRs, or a more detailed specification of existing technical requirements, i.e., what grid-formation means in the context of system restart.

Following completion of the above analysis, studies outlined below are planned to investigate additional facets of the system restart process.

- Optimal placement of grid-forming black start IBR considering the proximity to the following system aspects:
  - Load centres.
  - Areas of concentration of synchronous generators.
  - Areas of concentration of non-black start IBR.
- Synchronising two or more restarted islands in an IBR dominated or 100% IBR power system.
- Impact of DER
  - DER stability, in particular with respect to fault ride-through capability during system restoration.
  - Calculating the minimum stabilising load requirements for a region during system restoration as function of time and season and determining whether any mitigation measures are required.
- Power system technical requirements (consolidating both the network and generation and their interactions)
  - Grid-forming or synchronous characteristics, their definitions/treatment from a network perspective and the quantity/type needed.
- Dynamic performance success criteria during system restoration in terms of rise time, settling time, damping and magnitude of the network response in an IBR dominated or 100% IBR power system.

4. Research relevance to Australia

The importance of this research topic stems from the fact that a black start capability cannot be procured by AEMO unless that service is offered by a generator, and a service cannot be offered if the capability has not been considered and assessed during the plant design. Understanding the power system restoration needs, with rapidly changing power systems and generation mix, would provide justification to the necessary modifications in the design of new IBRs yet to be connected. Retrofitting the capability after a few years will be significantly more expensive, if it is possible at all. The same applies to network elements, such as protective relays and FACTS devices.

The outcome of these studies will assist Australian power industry to develop more specific technical and regulatory requirements and incentives on the expected performance of grid-forming and grid-following inverters during system restoration. This is recognising that black start conditions are vastly different and more onerous compared to system normal conditions, and as such additional capabilities, beyond the self-start ability, will likely be required which are not needed during normal operating conditions.

5. Recommendations

Aurecon's recommendation of future work is consistent with our original research plan proposed in 2021, thereafter the most critical items were included in the 2023-2024 research plan and currently being pursued. The list below includes recommended priority items to be addressed as part of the 2024-25 research work.

- **The treatment of inverter-based resources during system restoration**
  - Grid-following inverters
    - Reactive power control at low or no active power.
    - Impact of reactive plant switching including harmonic filters, in particular for HVDC links, during early stages of system restoration.
    - Managing operating reserves.
  - Grid-forming inverters
    - Grid-forming control strategies and their relative merit for system restoration, including the following technologies. As many control strategies as possible will be considered in 2024-25, but likely due to market availability of products not all control strategies can be evaluated in 2024-25.
      - Droop
      - Virtual synchronous machines
      - Power Synchronisation Control
      - Distributed Phased-Locked Loop
      - Direct Power Control
    - Comparison of different storage technologies from a supply/load restoration perspective.
  - Distributed energy resources
    - Coordination between transmission and distribution system operator/owner(s)
- **Impact on network control and protection systems**
  - Impact on control systems
    - Static reactive power support plant

    - Emergency control schemes such as under-frequency load shedding, over-frequency generator shedding, transient power runbacks and system integrity protection schemes.
        - Note that the intent of this research item is not to assess the role of these emergency control systems in preventing the occurrence of a blackout, but how they can assist or adversely impact system restoration following a black system event.
  - Impact on protection systems
    - Current-based protection such as overcurrent relays and fuses.
    - Impedance-based protection including distance protection.
    - Low frequency demand disconnection (LFDD) caused by a lower inertia and higher RoCoF.
    - Special protection schemes such as power swing blocking and out of step tripping at the transmission network level.
  - Assessing the need for modifications
    - Whether there is a need to use different settings for certain protection systems, including:
    - Whether there is a need to block certain protection systems during system restoration, and if so
    - Whether there is a need to introduce new relay algorithms/protection philosophies.
    - High-level comparison of relative merits of changing protection system device/operating philosophies across the system against the requirements for additional fault current by grid-following and in particular grid-forming IBRs to provide sufficient fault current for correct operation of existing relays.
- **Tools and techniques**
  - Power system modelling and simulation tools
    - Integrating the response of protective relays into power system dynamic simulation tools for black start and restoration studies.
- **Technical and regulatory requirements**
- **End-to-end system restoration in power systems with high share of inverter-based resources**
  - Restoration from transmission network
    - Bottom-up restoration
        - The coordination of responses of grid-forming black-start IBRs and synchronous generators and condensers during system built up. This includes assessing the risk of sub-synchronous torsional interaction (SSTI) between inverter controls and rotating masses of synchronous machines, and in particular synchronous generators.
    - Top-down restoration
        - The use of HVDC links, both black start (grid-forming) and non-black start capable HVDC links are suggested.
        - The extent to which IBRs, whether grid-forming or grid-following, or synchronous condensers nearby an interconnector can facilitate energising one region from a neighbouring region by providing voltage support.
    - Hybrid restoration
        - This generally refers to the simultaneous use of top-down and bottom-up approaches. This means that system restoration will proceed concurrently with the use of designated black start sources in the region under restoration, as well as the use of interconnectors to supplement restoration from adjacent healthy networks.