Understanding Cold Start

Bringing the lights back on

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What is Cold Start?

Cold Start is a feature of power system restoration. It describes the effects which accumulate on a distribution system when disconnection occurs from the main interconnected power system (MITS). For example:

- Thermostatic devices falling out of operational ranges, requiring significant energy demand to "catch up" during restoration
- Significant inrush currents during re-energising of assets
- Disconnected Distributed Energy Resources (DERs) being unable to reconnect immediately if their protection has tripped, exacerbating system wide energy imbalance

What were the project aims?

- To better understand and characterise Cold Start as a distinct phenomena
- To determine future research directions

What research was conducted?

- Desktop-based literature review of academic literature
- Review of relevant industrial projects related to system restoration

Why?

- In an increasingly digitised and interdependent power system, when the worst happens and we lose power, we must understand the complexities which can emerge during the restoration of system operability so we can best plan for and respond to it.

System restoration principles

System restoration is an umbrella term which refers to the protocols and procedures which system operators use to bring a power system back into nominal functionality following a perturbation.

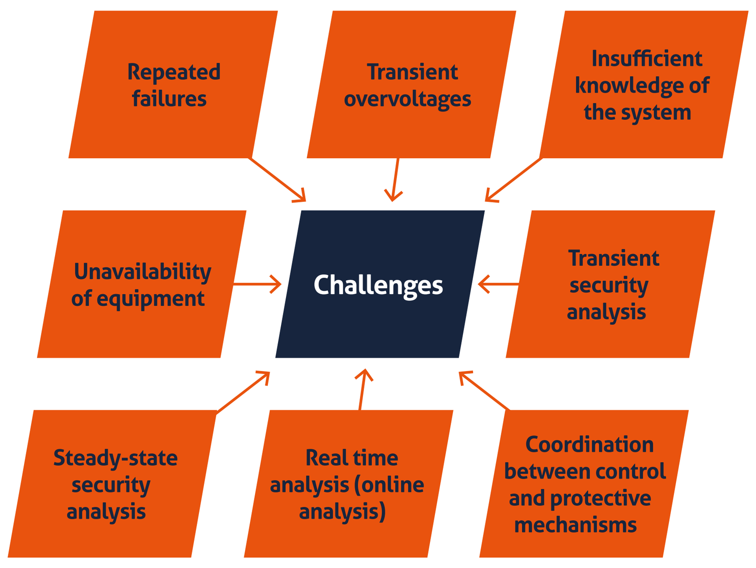
The challenges associated with system restoration are highlighted in the diagrams [1].

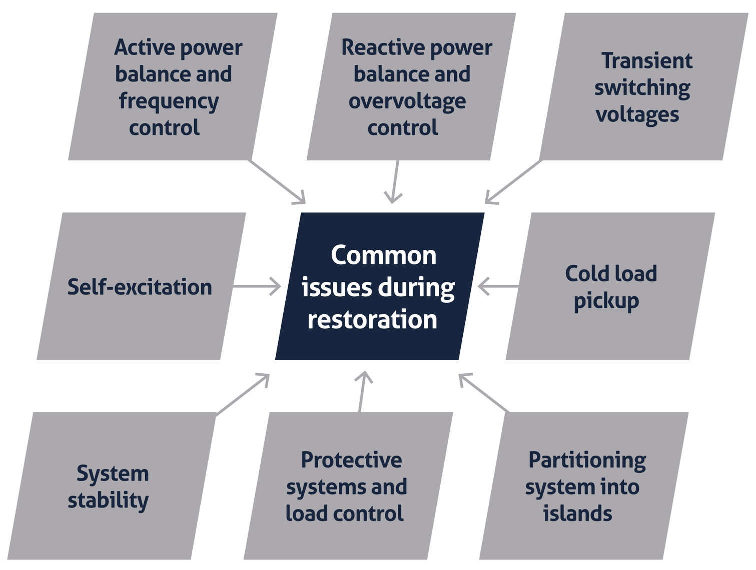
Two predominant paradigms can be understood as dictating power system restoration—either a "bottom-up" approach, whereby distributed resources are used to build systems back up, or historically "top-down" approaches which rely on restoring large generators and demand supply and interlinking these to restore system fidelity. "Black Start" scenarios typically involve restoration in a top-down regime but increasingly digitisation is changing this.

Cold Start, however, may require more inventive "bottom-up" strategies to ameliorate many of the emergent challenges it presents.

Various projects are underway or are completed to investigate this within industry by companies such as National Grid ESO, UK Power Networks, and Scottish and Southern Electricity.

Significant research into themes and phenomena related to Cold Start have been pursued, but these do not explicitly name Cold Start as such.





Characterising Cold Start

It is important to be able to distinguish between Cold Start and Black Start because they affect different aspects of the power system and will be ameliorated in different ways.

Research into system restoration highlighted four key areas which define Cold Start, particularly.

These were:

- Time sensitivity of demand affected
- Temperature sensitivity of demand
- Phase imbalance during restoration
- Distribution-centric effects

This is in contrast to Black Start, which while the MITS may experience some of these impacts, the added controllability and diversity of the system works to ameliorate the effects of an acute loss of diversity on the system. Feeders can be restored in a controlled manner to restore the supply-demand balance in a manner which could be difficult or impossible on distribution systems.

Table 2 shows a series of characteristics of Cold Start and Black Start and how they differ, including but not limited to the four key features identified.

In these terms, it can be understood therefore that though Cold Start and Black Start are related conceptually in much the same way Reliability and Resilience are related, they should be understood on their own terms.

Table 2 - summary of differences between Cold Start and Black Start phenomena

Phenomenon	Cold Start	Black Start
Diversity of demand	Lost over time as duty cycles of devices, particularly thermostatic devices, synchronise	Can be mitigated by geographic diversity and controllability of feeders on a macro level
Temperature sensitivity of demand	Extremes of temperature will affect the types of demand on the system and how they are impacted by delays to system restoration	Ameliorated by controllability of feeders and geographic diversity of weather conditions, homes, socioeconomic profiles across regions
Phase imbalance during restoration	Distribution of low carbon technologies across different phases on feeders can acutely exacerbate phase imbalance and cause operability challenges	Phase imbalance is a problem which affects distribution systems, not the MITS
Demand surges during restoration	Aggregated demand reconnecting simultaneously runs the risk of overloading assets, particularly in distribution systems which may already be heavily constrained. Demand peaks following restoration are not only larger but last longer the longer the initial outage persists	Large demand centres are matched with generation to ensure that demand is restored in a sustainable manner and within operational bounds
Controllability and visibility	Digitisation and increasing controllability of distributed resources offer the opportunity for controlled reenergisation but this is still in research or demonstrator stages in GB	Economy of scale and controllability of feeders mean the MITS has significant controllability and already largely operates in a "smart" manner

What is resilience, and why does it relate to Cold Start?

There have been many attempts to qualify and quantify precisely what resilience is in recent years, with reports from groups as diverse as the National Infrastructure Commission of HM Government, the National Academies of the Sciences in the United States of America, Cigre, and the UK Energy Research Council all offering differing definitions.

Crucially there are common themes across all of these definitions and they all pertain in some way to keeping the lights on when extremely adverse conditions affect the power system – the primary differences in these definitions relate to what these conditions are and what we can do about them.

What are the features of resilience versus reliability?

- The primary differences between relate to the **impact** and **likelihood** of perturbations to the system
- Conventionally, reliability pertains to low impact events which are expected in perennial operation of the grid
- Resilience concerns extreme events which are either difficult to predict, extraordinary in scale, or impossible to prevent, often with sparse predictive ability for the events and limited capacity to recover from using conventional means
- High Impact Low Probability (HILP) versus Low Impact Low Probability (LILP)

Why does resilience matter?

- **Resilience** involves having to make subjective judgements on what levels of risk we are willing to accept and how we prioritise the operation of our energy system—how much are we willing to pay to keep a hospital powered during a blackout? How much more infrastructure should we build to protect the system from rare events? What is a tolerable risk?

How does this differ from reliability?

- **Reliability** standards have emerged over many years as straightforward and practical limits which are easily understood based on more stable models of climate, weather, and society. Climate change changes all of this as we enter a "new normal" with more complicated demands, more difficult systems to operate, and even greater reliance on the grid.

It is important to understand these concepts because they will dictate investment decisions in improving power system resilience and reliability, and given Cold Start and Black Start events should be understood as aspects of system restoration, these will be resilience-guided investments.

Table 1 - summary of differences between real-time resilience modelling and more conventional, steady state or quasi-steady-state modelling methodologies

Feature	Real Time Resilience Modelling	Conventional Resilience Modelling	Reliability Modelling
Timescales	Microseconds to seconds	Hours to days	Years
Decisions	Control and protection, underfrequency/ undervoltage demand disconnection, generator tripping, intertrips	Investments, generator redispatch,unit commitment, rota disconnections, generation curtailment	Investments, supply balancing, adequacy assessments
Simulation Techniques	RTDS racks, proprietary software (RSCAD, PSSE, etc.), EMT simulations, short circuit/ transient simulations	Optimal power flows (security constrained,unit commitment, linearised DC or AC), quasi-steady-state dynamic simulations, proprietary software such as PowerFactory, PSSE	Security Constrained Optimal Power Flows (SCOPF), Unit Commitment simulations
Software Availability	Typically industrial standard, proprietary software	Wide range of open-access software, may rely also on optimisation suites or solving optimal power flows (OPFs) such as Julia, CPLEX, Gurobi etc	Proprietary software, open-access software libraries
Simulation Priority	Speed, accuracy	Scale, accuracy, portability	Scalability, accuracy, thoroughness
Context	Online, may be guided by offline simulations to optimise simulations	Primarily offline	Offline
Deployment	Hardware-in-the-loop simulations, operations rooms, experimental laboratories	Desktop studies	Desktop studies
Maturity	Emergent, state-of-the-art	Modelling well-established, though not yet typically incorporated into operational standards	Business-as-Usual
Example use-case	Modelling demand response in urban grid to fluctuations in DERs during a storm	Modelling investment decisions under uncertainty associated with climate change	Assessing the ability of a particular investment policy to reduce outages

Partners and collaborators, further reading

With thanks to Jacob Kelly, Transmission Operations and Planning Engineer at SSEN Transmission.

[1] T. Aziz, Z. Lin, M. Waseem and S. Liu, "Review on optimization methodologies in transmission network reconfiguration of power systems for grid resilience," *International Transactions on Electrical Energy Systems*, vol. 31, no. 3, p. e12704, 2021. as separate phenomena.

Scottish & Southern Electricity Networks

UK Power Networks

SP ENERGY NETWORKS