Grid-scale electricity storage
enabling renewables to power grids
affordably, reliably and resiliently

Review of Distributed ReStart Project

Introduction

National Grid's Distributed ReStart project is looking at how to replace transmission grid connected synchronous Black Start power stations with distribution grid connected resources, in the event of having to restore the grid from total failure. It is moving towards its final conclusions, and has released interim reports on three legs of the project:

- Power Engineering Trials;
- Procurement and Compliance;
- Organisational Systems & Telecommunications;
- Systems and Telecommunications (reported in September);
- Ofgem Project Progress Report.

Consistent with our previous analysis, this project has an excessively narrow focus and therefore fails to address the major issues, enabling them to claim success in their narrow scope even while Distributed ReStart demonstrably cannot do the job. And even what it advocates is excessively costly, complex and problematical.

Contents

Conclusions

Power Engineering Trials

The trials show that distribution-connected synchronous generation can contribute local Black Start capability, but batteries cannot – even with grid-forming capability. None were tested with real demand on the grid. And even distribution-connected synchronous generation requires massive roll-out of equipment to avoid exceeding the capabilities of switchgear, transformers and other equipment. Any form of Distributed ReStart is therefore highly costly, complex and problematical. This report should conclude that top-down (i.e. high to low voltage) Black Start from synchronous plant (e.g. hydro, nuclear, biomass, inertial storage), preferably transmission connected, is the preferred way forward, but this would be against current groupthink.

Distribution Restoration Future Commercial Structure

The Procurement and Compliance workstream only considered contracts and grid code changes to allow existing plant (e.g. batteries, distributed generation) to deliver Black Start. Incentivising the construction of new assets, especially those with long lead times (which includes all transmission-connected assets) was not considered and is therefore not enabled in the recommendations. It excluded any new technologies that have not already been adopted by the team's members, who are all incumbent businesses, as well as excluding entrepreneurs and start-ups, so all recommendations will be well suited to big incumbent firms. They are also focused on enabling bottom-up Black Start (i.e. from low voltage levels to high), though the Power Engineering Trials and previous technical results show this to be highly costly, complex and problematical. In order to focus on this wrong-headed method for re-starting dead grids, this report proposes to re-name Black Start to Electricity System Restoration. More groupthink.

Organisational Systems & Telecommunications

This workstream did not consider aspects of the sheer multiplicity of providers and challenges of training and maintaining operational capabilities of staff and equipment across hundreds or thousands of providers, together with the provision of systems and telecommunications to all of them that are resilient against failure of the grid and telecoms systems. Had they done so, they may have concluded that Distributed ReStart is prohibitively costly, complex and problematical – even without the similar conclusions from the technical work stream, above.

Ofgem Report

The Ofgem report shows that they operated in project management mode, not as regulators, failing to identify the emerging problems or to challenge the scopes, work programmes or recommendations of the project and its workstreams. They appear equally to have bought into the same groupthink.

Power Engineering Trials

Scope

The Power Engineering Trials' scope included:

- Galloway: re-starting a 33kV grid section, two 132kV grid sections each with wind generation and a 275kV grid section, using two hydro generators totalling 28MVA on the 11kV network;
- Chapelcross: re-starting a 33kV grid section with wind generation, a 132kV grid section and a 400kV grid section, and demand (a load bank) using a 60MVA biomass power station on the 33kV network;
- Redhouse: testing the grid-forming ability of an 11.6MVA battery with grid-forming capability on a 33kV section and, from it, starting a 132kV grid connection, starting with a weak (as opposed to dead) grid – the modelling is reported on, but the testing has not yet been done
- Dersalloch Wind Farm – Virtual Synchronous Machine (VSM) Live Test, fitting Siemens VSM advanced grid-forming converters, were tested separately but reported on in this programme. The farm has 23 x 3MW turbines totalling 69MW, four of which were fitted with VSM and external 125kVA diesel generators. It is on the 132kV grid but the trial included energising a 275kV section.

Omitted from the scope is:

- Duration: they modelled/tested the starting of the grid sections, not sustaining the live grid once started;
- Real demand: a load bank is limited in both size and capacity and therefore not a fair substitute for actual demand;
- Starting other plants on neighbouring grid sections;
- Black Start from batteries, i.e. on a dead (as opposed to weak) grid.

Therefore the scope is intrinsically incapable of demonstrating the viability of distributed re-start.

Results of the 3 ReStart Trials

Galloway and Chapelcross, which were both using synchronous generation (i.e. with real inertia) with output that is unlimited in duration, demonstrated that that they can start the local transformer and grid section; they can also start neighbouring transformers. They were not tested on re-starting grid sections with real demand; though Chapelcross started successfully a load bank which has very limited scale and duration.

Redhouse was not designed to show asynchronous batteries providing Black Start, as the grid was planned to be weak rather than dead. Even so, the modelling highlighted many issues with faults, mains spikes ("*high Rate of Rise of Recovery Voltages (RRRVs) … [and] high transient voltages and introduce the risk of asset failure*", p6). Therefore the live tests have been delayed by almost a year to consider mitigation options.

Findings of the 3 ReStart Trials

The issues found with re-started grids from distribution-connected sources include:

1. Voltage transients are a substantial challenge in islanded networks.
2. Overvoltages when energising transformers, that may not be fully avoidable by reducing voltages – and reducing voltages reduces effectiveness in any case.
3. Additional equipment (PoW, Point of Wave) would in any case need to be installed network-wide.
4. Switchgear capability may well be exceeded, especially when subject to mains spikes / RRRVs; further equipment (surge arrestors and RC snubbers) would also have to be fitted across the network.
5. System modelling is inadequate due to lack of data, requiring excessive assumptions, and in any case cannot predict performance based on simulated waveforms; and only live testing will reveal factors not previously considered.

Grid-Forming Converters (ReStart Trials)

Batteries with grid-forming converters were found not to do the job (p7), even though they were tested on weak rather than dead grids – therefore not "forming" the grid at all but merely creating active compliance to what is already there. They provide inadequate fault levels, converter saturation and ground faults on most voltage levels. To reduce (but not eliminate) these problems, they need to be ramped up over ~10 seconds rather than just switched on. They perform much worse than synchronous generators at all voltage levels.

Wind Farms as Virtual Synchronous Machines

The Scottish government and Siemens ran this trial, but liaised closely with the Distributed ReStart team due to this trial's extreme relevance to Distributed ReStart.

"*To achieve Black Start capability, four individual turbine converters were equipped with the GF algorithm, and external 125 kVA diesel gensets were connected to provide supply to their auxiliary loads in order to self-start.*" (p7) This is a very strange definition of "self-starting" for turbines, requiring external generators to "self-start". It also shows that using wind farms as VSMs and Black Start assets would be prohibitively expensive (one generator per turbine) and polluting.

The test was deemed successful within this narrow scope and with this amount of additional equipment / investment, especially inasmuch as it was able "*to energise transmission networks up to 275 kV involving infrastructure rated at several times the wind park capacity*" – but even this must come with a number of caveats:

- A 1MW resistive load was found to help it is noteworthy that this is 1/12 of the 4 turbines' output, an 8.3% output penalty.
- Terminal voltage and transformer tap settings needed to be reduced.
- "*Using existing transmission protection functions it is not possible to provide any protection coverage on the network during the ramping sequence.*"
- "*By implementing a voltage-controlled overcurrent (VCOC) function within the network, protection coverage could be secured after 3.75 seconds with three WTGs* [Wind Turbine Generators] *in service.*" This is yet more capital investment.

Distribution Restoration Future Commercial Structure

… and industry codes recommendations from the Procurement and Compliance workstream.

Scope

The scope includes:

- Roles of the regulator, System Operator, Distribution Network Operators, lead procurement agent (determined to be the System Operator) and distributed energy resources;
- Recommendations for the lead procurement agent, contracting, settlement and funding;
- Drafting potential changes to the grid code.

This workstream only considered contracts and grid code changes to allow existing plant to deliver Black Start. Incentivising the construction of new assets, especially those with long lead times (which includes all transmission-connected assets) was not considered and is therefore not enabled in the recommendations.

The members of the work stream were all members of large incumbent grid firms and grid analysts, and the Energy Networks Association which is an industry body for the network operators. It therefore excluded any new technologies that have not already been adopted by these members, as well as excluding entrepreneurs and start-ups, so all recommendations will be well suited to big incumbent firms. This is, in part, because such entrepreneurs and start-ups don't have the finance, resources or (often) expertise to support such a workstream, even though they are an essential part of the system-wide solution and can bring perspectives, technologies and other solutions to bear that incumbents don't appreciate. Involving such others in engagement webinars is not sufficient because the results are the output of the team, not of the consultees.

Procurement Principles

Existing procurement of Black Start, from contract award to delivery, takes up to 4 years (p6) due to the complexity of ordering, installing and testing the supplementary equipment on power stations – and even that assumes that it's a retro-fit to power stations that have already been built. Such lead times will continue to be necessary for transmission-connected assets, and longer lead times if new plant is needed, so any recommendations that cut this will exclude transmission-connected assets. As shown by the technical work stream, it is only transmission-connected assets that can deliver reliable, stable and resilient black start that can be extended throughout the different levels and sections of the grid with normal demand loads attached.

One focus throughout is on speed of procurement and implementation, not on procuring the right capability for the location; therefore the recommendations exclude the potential to contract for new-build capability for which lead times are long, even where this would much better serve the need. This accounts for the first (and principal) two of the four procurement criteria in Table 3 p17.

A second focus is on the procurement of bottom-up Black Start capability (p6), i.e. starting higher-voltage grids from lower-voltage equipment, even though the technical work stream shows this to be highly complex, require immense roll-out of new equipment across the network, and in any case impossible for batteries even with grid-forming capability installed. Given these technical results, this workstream would be much better focused on developing systems and commercial structures that encourage the construction of new synchronous transmission-connected assets. Such assets include nuclear, hydro, biomass generation and inertial storage, all of which have long lead times, especially due to grid connection lead times which are outside developers' control.

A third focus (see, for example, the third criterion in Tabe 3 p17) is to "*keep end consumer costs down*". As we have pointed out repeatedly for many years, the timescale is not defined: today's, tomorrow's (short term), next decade's (medium term) or longer-term consumers? Without defining the timescale, the default is to concentrate mainly on short term consumers, with a nod to the medium term, sacrificing the long term; this would be entirely consistent with all other mistakes in regulating the grid over the past four decades.

Procuring the best Black Start capability is only the second half of the fourth criterion (of four) in the table – and even so, no timescale is given so the default will be short term.

Organisational Systems & Telecommunications

Scope

The Organisational Systems & Telecommunications workstream (OST) did desktop exercises to simulate the management of Distributed ReStart. It considered the sequence of actions, communication, automation, telecommunications, operational systems and cybersecurity.

The scope did not include may crucial aspects, which include:

- The sheer number (hundreds or thousands) of distributed resources needed;
- Training of staff across that many providers;
- Monitoring that training to ensure that staff turnover doesn't degrade capability;
- The provision, maintenance and upgrade of such huge volumes of equipment and systems that is resilient to the collapse of electricity and telecommunications capabilities, which will happen if the grid fails, across so many providers;
- The set-up and ongoing costs of all this.

It did consider these aspects, though not in terms of the sheer number of providers involved. Had this workstream considered them in these terms, they may have concluded that Distributed ReStart is prohibitively costly, complex and problematical – even without the similar conclusions from the technical work stream, above.

Findings

A minimum staffing requirement is identified, without following through the consequences of this in the Distributed ReStart strategy: at present, only a few power stations provide the capability, whereas under this proposal there will be hundreds or thousands of providers, each with a minimum staffing requirement. And each of these staff will need initial and ongoing training (envisaged to be remote training on simulation tools only, p28, which may not have the particular characteristics of each control engineer's plant), succession plans, telecommunications equipment and systems that are resilient in Black Start circumstances, i.e. with no grid power or commercial telecommunications systems.

Nor is there any estimation of the costs of such provision, or comparison with the current service provision. Because any such estimate would have to be added to the immense capital costs of additional equipment identified by the technical workstream, and the huge contract and administrative costs of contracting with so many small providers, the result of which would compare very unfavourably with a more technically coherent strategy of supporting the construction of inertial transmission-connected Black Start capability.

The only way of managing such a number of Black Start resources is a degree of automation, as the report correctly states. Such automation depends on blackout-resistant equipment and systems not only at the Network Operator but also at every single asset supporting system restoration.

The report envisages a large number of Distributed Restoration Zone (DRZs), each with different restoration plans depending on the types and sizes of both supply and demand assets. The establishment, validation, auditing, maintenance, coordination and hierarchical operation of such a multiplicity of different plans is not discussed but would be logistically and organisationally very complex, burdensome and therefore costly and prone to multiple points of failure.

Live tests of such a pervasive system (that is, so many resources in each DRZ and nationally) would be almost impossible, opening the system to the potential of all manner of undiscovered issues: no desktop exercise or simulation tool can be considered perfect (or even good enough) until it is validated by real-life operation. Indeed, the report states baldly: "*Desktop exercises did not consider the impact of the failure of the operational procedure and the automated system as they were intended to draw out issues with the procedural design in place of testing the control engineers. This means that the procedure may not be robust to failure and that control engineers have not been exposed to recovering from this*" (p28).

The highly complex process map (across 5.5 pages, all on the numbered p34) "*only covers the actions specifically related to a distribution-led restoration event*", not how different circumstances may vary or how each DRZ needs to coordinate with other DRZs and with the system as a whole. And nearly every box represents a point at which one or more errors or failures may creep in. This is constructing a monster!

Ofgem Project Progress Report

At no point does Ofgem's report identify the challenges of Distributed ReStart, some of which are described above. Doing so should be a very large part of the purpose of Ofgem's supervision.

- Where the trials yield technical issues and possible mitigatory actions that may at least partially resolve them, these actions are listed by Ofgem as solutions that resolve the challenges.
- The only challenges they identify are contracting the trials, legal agreements including NDAs, keeping the process on track, and keeping within the budget.

This is project management, not regulatory or even critical overview, suggesting that they too are being swept along by groupthink.

The project's "commercial objectives" are defined as a procurement process, not as the system cost of achieving the capability. The summary states "*Greater diversity in Black Start provision will improve resilience and increase competition, leading to reductions in both cost and carbon emissions*", without either substantiating or checking the statement or providing means to do so.

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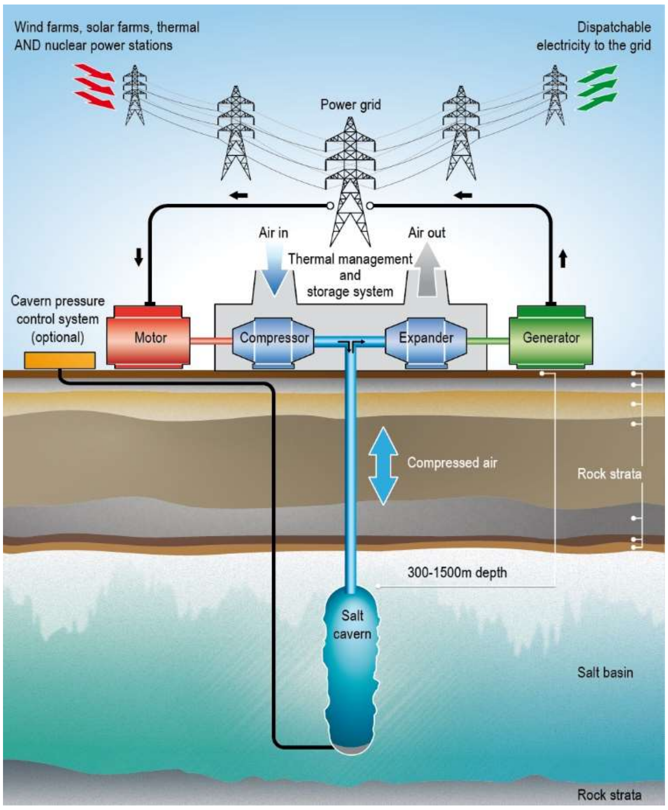
Storelectric

About Storelectric

Storelectric (www.storelectric.com) is developing transmission and distribution grid-scale energy storage to enable renewables to power grids reliably and cost-effectively: the world's most cost-effective and widely implementable large-scale energy storage technology, turning locally generated renewable energy into dispatchable electricity, so… ***enabling renewables to power grids cheaply, efficiently, reliably and resiliently***.

♦ Innovative adiabatic Compressed Air Energy Storage (Green CAES) will have zero / low emissions, operate at 68-70% round trip efficiency, levelised cost significantly below that of gas-fired peaking plants, and use existing, off-the-shelf equipment.
♦ Hydrogen CAES technology converts & gives new economic life to gas-fired power stations, reducing emissions and adding storage revenues; hydrogen compatible.



Both technologies will operate at scales of 20MW to multi-GW and durations from 4 hours to multi-day. With the potential to store the entire continent's energy requirements for over a week, global potential is greater still. In the future, Storelectric will further develop both these and hybrid technologies, and other geologies for CAES, all of which will greatly improve storage cost, duration, efficiency and global potential.

About the Author

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A graduate in Physics with Electronics, he has 12 years' management and innovation consultancy experience world-wide. In a rail multinational, Mark transformed processes and developed 3 profitable and successful businesses: in commercialising a non-destructive technology he had innovated, in logistics (innovating services) and in equipment overhaul. In electronics manufacturing, he developed and introduced to the markets 5 product ranges and helped 2 businesses expand into new markets.

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