Re-Starting Net Zero Grids

The Challenge

Net Zero grids have very low levels of dispatchable (i.e. on-demand) generation – largely hydro-electric, nuclear, gas-fired power stations with CCS (Carbon Capture and Storage), and biomass power stations. The bulk of their energy derives from intermittent (i.e. varying according to factors other than demand, e.g. weather, state of tide) generation which is usually DC connected and has no natural inertia. Nuclear power stations cannot be used for Black Start, i.e. re-starting the grid following total black-out. For most grids, this leaves insufficient dispatchable generation to re-start following failure.

National Grid (the principal Transmission Services Operator in the UK) has been studying the challenges of Black Start under such a grid structure. In particular, they have analysed the opportunities and challenges of re-starting the grid from distributed renewable assets, in their Distributed ReStart project.

Constraints of Using Distributed Resources

There are many constraints on re-starting the grid from the bottom up, i.e. from the low-voltage distribution grid to higher-voltage grids, including:

- Only small proportion of the distributed generation could ever be adapted to operate as “anchor generators”; all other distributed generation would have to be started from such anchors.
- At each level, the amount of consumer load that can be re-started is very low; and any consumer load that is re-started restricts the surplus energy available for energising adjacent parts of the network.
- The biggest adjacent system that can be started by any distributed resource, known as the Block Load Pick-Up (BLPU), is just 10-25% of the capacity of the generation resource that is already operating.
- During this process, over-voltages are created that may trip the anchor generator unless expensive systems and modifications are installed at each.
- This provides such low levels of energy that it is straining any local network to accrue sufficient operating generation to start the next network up (“transformer energisation”), in voltage because doing so draws 4-7 times as much “inrush current” as its rated current; and it is impossible to do so for two voltage levels up.
- Therefore there needs to be sufficient generation available at each level to start the level above.
- Moreover, as even this is considered frequently to be impossible, additional storage resources would have to be brought on-line in order to provide the impetus required to start the next grid level up.
- Furthermore, as voltage levels increase, the length of circuit that can be energised decreases rapidly – yet circuit lengths tend to increase with voltage, so higher-voltage networks would have to be sub-divided very expensively into very large numbers of much shorter circuits.
- And those storage resources would have to be of sufficient duration to maintain power output throughout the re-start phase: current requirements are for 8 days’ energy to be stored at power stations for this purpose, though this could

conceivably be reduced to the duration of the re-start process (plus some reserve), which would be greatly extended by being bottom-up rather than top-down.
- And these resources would be additional to those providing the reactive power support that such island grids need during the re-start process;
- All such resources are considerably more "susceptible to adverse interactions among multiple power plants under reduced system strength conditions".

These lead inevitably to the conclusion that the grid will have to be re-started from the bottom up by a vast number of tiny kilowatt-scale pigeon-steps, rather than by great megawatt-scale strides from the top down. It is thus enormously easier to start the grid from the top down, i.e. higher-voltage networks starting lower-voltage ones:
- Starting from the bottom up would require hundreds or thousands of anchor generators to be started in order to re-start the grid, each creating an isolated "island grid" that grows in such pigeon steps, meaning that re-start takes a very long time indeed.
- Because consumer load restricts the energy available to energise adjacent parts of the grid, and that available energy is already critically small, most consumer load will have to be kept blacked out until the national re-energisation process is either complete or largely so ("*Thereafter, primary substations can be energised to pick up customer demand*"), which greatly extends users' black-out durations.
- Even then, two-transformer substations cannot be automatically re-energised without blowing lower-voltage circuits, but would have to await manual re-energisation when sufficient of the grid is operational.
- As each island grid meets another growing island grid, they need to be synchronised.
- Therefore the growth of all island grids leads to a synchronisation nightmare of thousands of actions, some of which will inevitably be attempted simultaneously, needing very delicate management and control.
- Those local grids without an anchor generator would be blacked out for very long periods awaiting the re-start process to climb in pigeon steps all the way up to the higher voltage grid, then (in larger steps) down again.

Constraints of Using DC-Connected Resources

There are further constraints on re-starting the grid using DC-connected resources such as most intermittent generation (solar, wind etc.), including:
- Lack of real inertia with which to ride out (and minimise RoCoF) when energising neighbouring plant and/or circuits –
  - Synthetic inertia is unlike real inertia: synthetic, in this case, means very fast response; any response time is a delay; any delay is a spike (upwards or downwards) on the mains; any spike is extreme RoCoF which causes trips in protection equipment; whereas real inertia is always-on and reduces RoCoF without any delay whatsoever;
- Lack of Phase Lock Loop capability;
- Need for additional equipment for frequency and voltage control – and, if provided by DC-connected storage, that storage must be dedicated to the role;
- Lack of natural reactive power (ditto if provided by DC-connected storage);

Additional Investment Required for Distributed Resources

It becomes clear that the investment required to achieve all this is prohibitive, including:

- Upgrading very large numbers of distributed generation and storage resources to be black-start capable;
- Upgrading very large numbers of distributed generation and storage resources with more expensive grid-forming (as opposed to the standard grid-following) converters, able to create their own voltage source and frequency reference and less susceptible to adverse interactions among multiple power plants under reduced system strength conditions (even though not as un-susceptible to them as real-inertial systems);
- Creating, maintaining and repeatedly re-training systems, processes and people to run them, resilient to total power failure, to manage the exceedingly delicate coordination activity, far in excess of those required by a top-down re-start process;
- Long-duration batteries by every system node that are kept in reserve, fully charged, in case of re-start need, which cannot earn their keep by delivering balancing and ancillary services because to do so would mean that they are sometimes discharged and therefore not available in time of need;
- Further long-duration batteries, with similarly dedicated purpose, to provide reactive-power support throughout the re-start process;
- Modifications to enable the de-magnetisation of transformers for the process, or other such measures to reduce in-rush current;
- Equipment and systems to control and reduce over-voltage events when energising neighbouring parts of the grid, which risk tripping anchor generators;
- Other hardware, software, settings and control actions to modify circuit protection;
- Ditto for Phase Lock Loop control;
- Sub-dividing long circuits (the definition of “long” decreasing with increasing voltage) into circuits sufficient short to be energised by lower-voltage islands;

So Why?

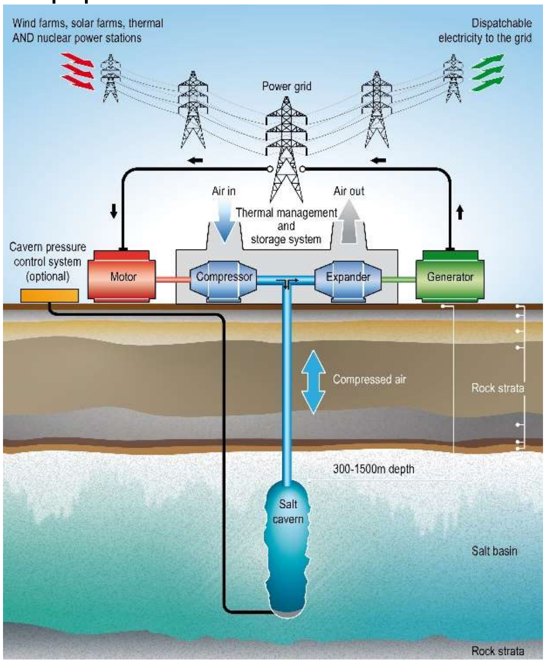
All this begs the question: why do it?

The cost and complexity of Distributed ReStart, and the economic consequences of the longer re-start times for users, are evidently orders of magnitude worse than investment into large-scale long-duration inertial storage, providing inertia 24/7, such as all Storelectric’s CAES. From the above, it appears that such storage would pay for itself merely in avoided ReStart investment.

And when one considers that such storage could provide its own income streams, this means that such capabilities can be provided even more cheaply. But in order to do so, long-duration contracts need to be awarded to such storage before it is built – so as to ensure that investors invest in doing so. And enforceable letters of intent will be needed, especially for the first, prior to “development” (planning permission and grid connection offer) in order to encourage investment into the development stage. Doing so would reduce network capital and operational costs, and management complexity, and thus benefit the electricity system as a whole, and hence consumers, by hundreds of millions of pounds annually, additional to the much larger benefits from more rapid re-start for consumers in the event of blackouts.

About Storelectric

Storelectric (www.storelectric.com) is developing transmission and distribution grid-scale energy storage, all built with today's standard equipment.



- ♦ Innovative adiabatic Compressed Air Energy Storage (TES CAES). Our 500MW, multi-GWh installations 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. It simplifies the Huntorf plant, operating since 1978. A hybrid will provide reserve grid power.
- ♦ Their CCGT CAES technology converts and gives new economic life to gas-fired power stations, halving emissions and adding storage revenues, thereby re-lifing stranded assets. It simplifies the McIntosh plant, operating since 1992. A hybrid is significantly more efficient.

Both technologies can offer black start and similar services. They 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, potential globally is greater still. In the future, Storelectric will further develop these technologies, and other geologies for CAES, all of which will greatly improve storage cost, duration, efficiency and global potential. They address the entire energy trilemma: the world's most cost-effective and widely implementable large-scale energy storage technology, turning locally generated renewable energy into dispatchable electricity, thereby …
enabling renewables to power grids cheaply, efficiently, reliably and resiliently.

About the Author

Mark Howitt is Chief Technical Officer, a founding director of Storelectric. He is also a United Nations expert advisor in energy transition technologies, economics, regulation & politics – invitation here.

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 grow strategically.