CIGRE Reference Paper : Power system restoration – World practices & future trends

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Complete or partial blackout of the electric power grid does occur from time to time, despite prudent planning and operations, due to disturbances that either exceed the basic design criteria, or due to various causes such as natural disasters, multiple equipment failure, protection relay miscoordination or malfunctioning, and human errors. Restoration of the power system, following such disturbances, is an extremely important aspect of the System Operator's role in managing the bulk power system and has as objectives to enable the power system to return to normal conditions securely and rapidly, minimizing restoration time and associated losses, and diminishing adverse impacts on society.

State of the art

In general, there are two basic strategies for power system restoration, namely the bottom-up and the topdown strategy.
The bottom-up restoration strategy is based on the use of blackstart generators (those able to re-energise the system without relying on the external electric power transmission network), and applies in case of total system blackout and non-existent interconnection assistance. On the contrary, the top-down restoration strategy is based on neighbouring interconnections. These are used to energize the bulk power transmission system first, after which loads and other generators are energized. Both approaches have their advantages and disadvantages, and many system operators choose a hybrid approach to restoration (see Table 1 - Examples of implemented blackstart strategies).

Country	Approach	Blackstart: Top-down	Blackstart: Bottom-up
Australia	Hybrid	AC interconnections from bordering states	Hydro + pumped storage + gas turbines
Brazil	Hybrid	AC interconnections from bordering states	Hydro
India	Hybrid	AC interconnections from bordering states	Hydro + gas turbines
Ireland	Hybrid	VSC HVDC + AC interconnection	Hydro + pumped storage + gas turbines
Italy	Top-down	AC interconnections from bordering national power system	
USA	Top-down	AC interconnections from bordering states	

Restoration in the future

A common practice for System Operators is to use conventional power plants for system restoration, making it a stable and predictable process. In a future where less or no synchronous generators will be available, it is important to rethink restoration strategies. Due to the fact that the share of renewable energy sources (RES) in distribution networks is nowadays significant (with the tendency to grow even further), there is a need for TSO/DSO integrated restoration plans, which will involve increased coordination, information exchange, joint operator training, and most likely common tools. Depending on the amount as well as controllability of DSO-connected RES, the responsibilities and contribution of each entity in the restoration process will differ.
With the increasing RES and other power electronics devices in the power system, their capabilities need to be utilised as much as possible. Whereas HVDC links are not commonly used for providing restoration service, their participation is expected to increase in the future. The functionalities of these links can be utilised in order to aid the system restoration, including providing active and reactive support during blackstart and building of the cranking path. Furthermore, Battery Energy Storage Systems (BESS) can be

used in several ways for supporting the restoration process. One example is the participation of BESS in load restoration. Another example is the use of BESS as blackstart source for providing the required power to non-blackstart generators.
The role of Wide Area Monitoring Systems based on Phasor Measurement Units (PMUs) for restoration purposes is expected to increase in the future. When compared to traditional SCADA measurements, synchrophasors have an added value of synchronised voltage phase angle information between areas that have to be re-energized and/or re-connected, which can significantly benefit the restoration process. In the preparation phase of the restoration process, and when complemented with state estimation data, the synchrophasors provide precise information of the remaining system, its division in islands and available components in the system. This information helps to construct the restoration strategy. From a restoration viewpoint, the restoration stage can be enhanced with critical data such as synchrophasor measurements from generating units and critical load.

Concluding remarks

System Operators have predominantly been using conventional synchronous generators in the restoration process. With the rapidly developing power system, changes in the power system restoration strategy become necessary to adequately address the future challenges.
With increasing distributed energy resources, the role of the distribution system operator in power system restoration will become more important, where coordination between different stakeholders will be key. Furthermore, this increasing generation in distribution networks demands an improved observability and increased information exchange. The use of WAMS can greatly help to achieve this, especially during restoration activities where situational awareness in the control room is of utmost important. With increasing integration of power electronics interfaced devices in the power system, it is also worth investigating how these can support the system operator in enabling an effective and efficient restoration process. The use of available HVDC links and battery energy storage systems in the restoration process is expected to increase in the future. This is tackled in the newly established working group C2.26 “Power system restoration accounting for a rapidly changing power system and generation mix”.

Further reading

This article is a summary of a Reference Paper prepared by a small task force of Study Committee C2 – System Operation and Control. The full paper elaborates in more detail also on the currently used restoration strategies throughout the world, the importance of operator training for restoration and addresses the future, providing examples of innovative solutions. Readers are encouraged to reach out and read the full paper in the CIGRE Science & Engineering Journal’s Volume No 14, June 2019 issue.

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