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Substation Black Start Resilience

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Amendments since publication

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1 Background

A shutdown of the entire electricity network is identified as a risk on the national Risk Register. The process of recovering from this situation is known as a Black Start and involves the following stages:

- Initial switching by DNO's and TSO's to prepare the de-energised network for restoration in sections.
- DNO's and selected local power stations working together to energise small sections of network in accordance with pre-defined Local Joint Restoration Plans (LJRP's).
- TSO's reconnecting sections of network to form Power Islands by interconnecting LJRP's.
- TSO's managing the reconnection of demand and generation, balancing the system and reconnecting the Power Islands to restore the interconnected network.

Following a series of major blackouts around the world, the UK government and the electricity industry set up Exercise Phoenix in 2006 to review the resilience of GB to Black Start events. As part of the exercise, the recovery time of electricity supplies was studied and this concluded that it may take up to 72 hours before electricity supplies are restored. Therefore the industry, with the support of UK government (DECC) and the regulator (Ofgem), recommends that the loss of supply resilience of grid and primary substations for the GB electricity networks be extended to a 72 hour period. The validity of the 72 hour period is to be kept under review by the Energy Emergencies Executive Committee (E3C).

It is essential that provision be made to safely re-energise the electricity network following a Black Start event. In particular the protection and tripping systems at substations, which disconnect supplies in the event of a local network fault, need to be functional upon re-energisation.

Over the last decade companies have replaced large numbers of electro-mechanical protection relays (which had a low power consumption), either as part of new connections work, asset replacement and reinforcement programmes or in connection with more sophisticated schemes to improve network performance. However replacement relays are typically electronic micro-processor based with increased power consumption and therefore a higher continuous demand on the DC battery supply. Therefore once external supplies are lost to a substation, the relays will drain the tripping/protection batteries more quickly than earlier designs.

If substation batteries fail before a substation is re-energised, modern protection systems become non-operational and faults on the network may not be identified and consequently not disconnected. This could endanger people and properties that are affected by the faults and/or cause catastrophic failure of network assets e.g. substation plant. Remote protection may disconnect faults, albeit in some cases with limited discrimination.

In a Black Start scenario failure of substation batteries to a point where they cannot support circuit-breaker or protection functions would:

a) delay the restoration of circuits until such time that the substation batteries could be sufficiently charged to re-energise the supplying networks with statutory protection in place (which may require visits to multiple substations - possibly under extremely difficult conditions)

or

b) require a risk assessment before re-energising the network, knowing that statutory protection maybe jeopardised, and accepting an increased risk to life and property.

As a consequence of a prolonged Black Start event a large population of substation batteries may suffer damage through excessive discharging or continuous drain which may (i) affect their ability to be recharged and (ii) necessitate their premature replacement.

In a similar manner, SCADA system RTU's and ancillary equipment have a continuous demand for power.

If the SCADA battery, or the telecommunications batteries supporting SCADA services in a substation fails under a Black Start scenario, then the ability to control the substation remotely will also fail, requiring visits to multiple substations to confirm the operational state of the network and to undertake manual switching. This would further delay the restoration of the electricity network.

Prior to the issue of this document, no industry standard existed for the resilience of substation batteries for protection/control systems or SCADA systems. For any individual localised incident the situation is likely to be manageable and the risk to society in general is low. In a Black Start scenario, the societal impact is high and widespread, and consequently an industry standard is deemed appropriate.

2 Requirements

GB TSO and DNO companies are required to ensure that suitable measures are put into place at core electricity transmission and distribution substations, such that in the event of a partial or total shutdown of the mainland electricity network, adequate protection and control systems are available to permit safe re-energisation of these substations while meeting statutory requirements e.g. those set out in The Electricity Safety, Quality and Continuity Regulations 2002, Regulation 6.

In accordance with the 'Black Start Recovery – Substation and SCADA Resilience' report by the Electricity Task Group (ETG) of the Energy Emergencies Executive Committee (E3C) – July 2010, it is recommended that such measures should, as a minimum, be suitable to cater for a partial or total shutdown of the electricity network lasting up to 72 hours.

The baseline requirement is for core electricity transmission and distribution substations to be designed so that they are resilient for a minimum period of 72 hours. This shall be taken to mean that the substation protection, control and SCADA functions shall be available such that the site can be safely energised within 72 hours of the inception of a Black Start event. Where resilience is substantially provided via a battery alone, the battery capacity shall be determined taking into account the likely deterioration in battery capacity over its life and as a minimum considering the standing load on the battery (on the basis that the additional battery capacity required to cater for any switching operations within the 72 hour period following the inception of a Black Start event is negligible), although the DNO/TSO may provide additional battery capacity if it considers this to be appropriate.

3 Scope

This Engineering Recommendation specifies for GB the substation battery resilience required to support substation protection and control systems and SCADA systems at TSO substations, joint TSO/DNO substations and DNO substations with a secondary voltage of 11kV[1] and above other than those supplying a single end customer. The scope includes all batteries installed at substation sites for protection, control and SCADA purposes irrespective of whether there are dedicated battery systems provided for different functions.

The resilience of key communications circuits which form an integral part of protection schemes between substations are also within scope where the circuits are essential to facilitate the safe re-energisation of the electricity network following a Black Start event i.e. where the back-up protection is considered to be inadequate for emergency recovery.

The ability to recover successfully from a Black Start event also requires resilient SCADA networks and voice communications. Recommendations for achieving the necessary level of resilience from (SCADA and voice) communications networks to successfully re-energise the electricity network under Black Start conditions are outside of the scope of this document, although they shall need to be considered as part of individual companies’ strategies to delivering overall Black Start resilience.

Plans will also need to take into account the presence of any switchgear dependent upon an AC supply for correct operation – possibly by use of portable/mobile generation plant.

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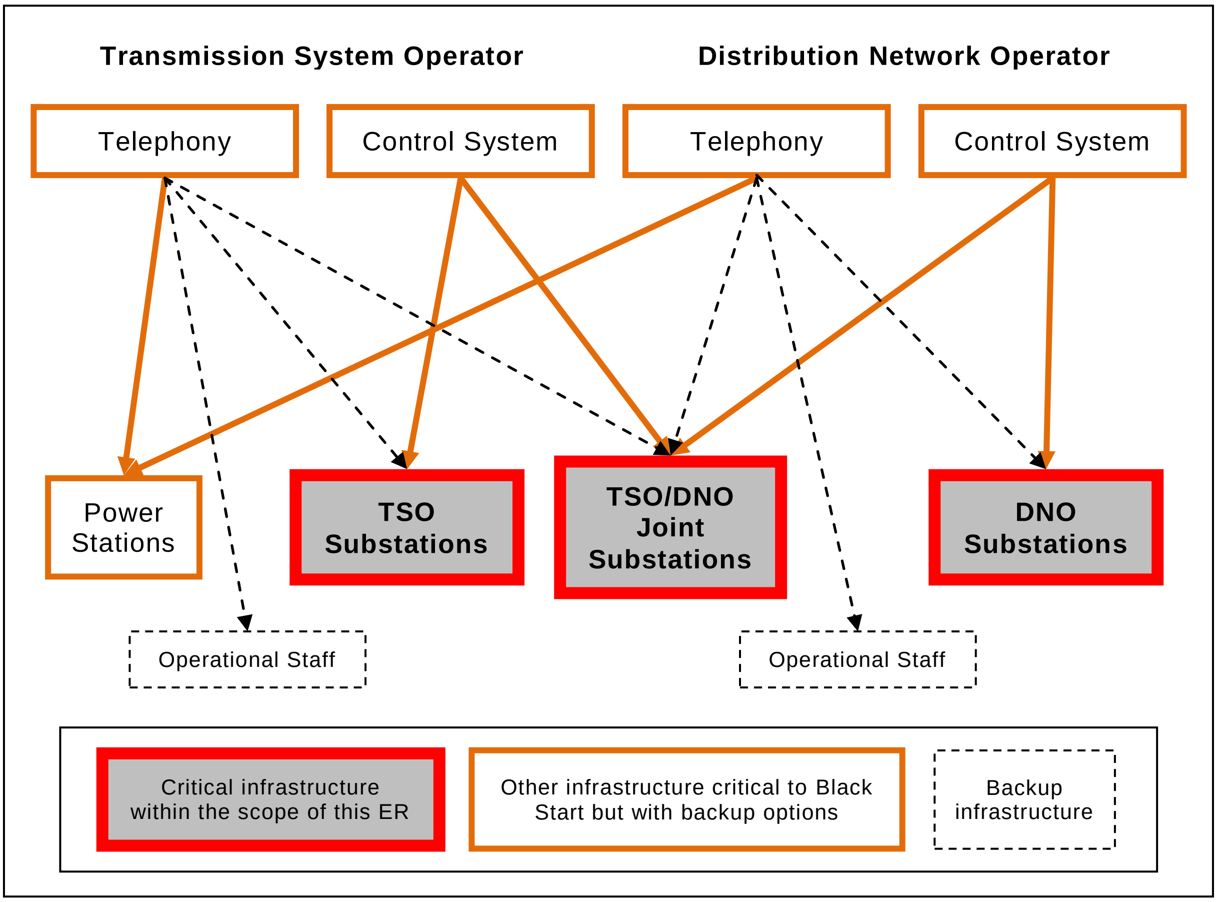
1 In some DNOs this may include lower voltage systems (e.g. 6.6kV) performing a similar function.

The following diagram illustrates the core infrastructure for Black Start.



4 Strategy

The strategy described in this Engineering Recommendation is to ensure substations within its scope are designed to have a battery system that provides a minimum of 72 hours resilience for protection, control and SCADA systems. This allows statutory protection to be employed whilst monitoring and re-energising the electricity network within 72 hours of the inception of a Black Start event, hence minimising risk to people, property and network assets.

This strategy and the technical options detailed within this Engineering Recommendation are based on:

- E3C sanctioned studies identifying that it may take 72 hours to restore parts of a TSO or DNO's network under Black Start conditions, dependant on the cause.
- The lack of certainty that all LJRPs will be effective so this restoration time could apply to almost any part of the network.
- The expectation that travel and voice communications may be extremely difficult.
- The possibility that SCADA systems may not be fully operational[2].
- The requirement for schemes to be designed to minimise the risk and consequences of accidental operation/maloperation.

5 Technical Options

The wide variety of existing substation arrangements requires a range of options to provide resilience to be considered, including those based on increasing the capacity of the substation batteries, reducing / removing the DC demand on the batteries, and providing an alternative charging arrangement for the batteries.

The best solution for each individual site will depend on several factors including the:

- Site complexity and the number of battery systems employed at a site.
- Number and configuration of circuit-breakers with electronic protection.
- Network configuration.
- Strategic importance and numbers of customers at risk.
- Presence of AC dependant switchgear.
- Available space for installation of additional battery capacity, equipment for managing the DC demand upon batteries or provision of alternative arrangements for battery charging.
- The advantages for both control and operational staff of implementing a standard approach within a company.

The availability of resilient telecommunications systems for SCADA and voice communications, alongside individual companies' resource deployment strategies for Black Start events, are overarching considerations. These factors may also influence the selection of the appropriate solution to substation Black Start resilience, such that the optimum approach to overall Black Start resilience is achieved.

The flow chart in Appendix One is a simple guide to applying these criteria to battery systems used for protection and control systems.

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[2] SCADA indications may also be restricted due to the quantity of alarms, and the limitations of some modern relays, (e.g. Micom), where the indications are connected via the relay and are lost if the relay is "powered down".

5.1 Transmission and Interface Sites

The majority of National Grid sites already have standby generation however the adequacy of these arrangements should be assessed in accordance with these recommendations. For TSO sites and joint TSO/DNO sites without standby generation, site resilience should be assessed in accordance with this Engineering Recommendation. The main and alternative auxiliary supply arrangements at joint sites should be designed to provide a co-ordinated solution for the TSO and DNO parts of the site which reduces the dependency on standby generation and/or battery systems.

5.2 DNO Grid/Primary Sites

5.2.1 Battery Capacity

Substation batteries can be installed with, or existing installations augmented to provide, capacity to meet the standing demand for 72 hours. In such cases there will be sufficient battery capacity for the site to remain operationally available for 72 hours. This approach can be applied to battery systems used for protection / control purposes and battery systems used for substation SCADA equipment.

Advantages

- Simple/robust.
- Low risk of maloperation.
- Increased resilience where a second battery is installed and the installation is split.

Disadvantages

- Maintenance / environmental issues with battery replacement and recycling.
- Resilience period is determined by the battery capacity.
- The lifespan of the overall scheme is dominated by the lifespan of the battery.

Decision Factors

- Standing demand on battery.
- Space for larger/additional batteries.
- Cost.

5.2.2 Standby Generation

For complex sites with multiple battery installations or a significant standing demand, standby generation may be a cost effective option, supporting multiple substation and SCADA battery chargers.

Standby generation would ideally have sufficient fuel for 72 hours operation, (or a minimum of 48 hours with robust emergency refuelling arrangements), with remote monitoring functionality to indicate generator running, low fuel alarms etc.

Advantages

- Simple installation for large / complex sites.
- Resilience period can be extended subject to the ability to refuel.

Disadvantages

- Requirement for regular generator maintenance and testing.
- Potential failure to start and the need for contingency plans.
- Requirement for generator and fuel security.
- Requirement environmental protection measures for fuel leakage, noise and airborne pollution.
- Requirement for fuel management.
- Maintenance and testing costs.
- Installation costs.

Decision Factors

- Site location / security / environmental factors.
- Standing demand.
- Presence of multiple battery chargers.
- The presence of any AC dependant switchgear, reliant upon an AC supply.
- Cost.

5.2.3 Split Battery Scheme

This option is to re-configure protection / control batteries into a split capacity formation or make use of existing dual battery systems. After a sustained loss of supply to the site an automated scheme would disconnect part of the battery. This part of the battery would retain sufficient capacity to provide protection / control supplies such that the site can be safely re-energised.

The remaining part of the battery would maintain supplies to all protection and tripping schemes until such time that the partial capacity is depleted to a minimum level at which time it would be automatically disconnected from all of the protection / control schemes, avoiding any battery cell damage.

This scheme is dependent on SCADA availability (to reconnect the healthy part of the battery to the protection / control system); hence this solution can not be employed to deliver resilience of batteries used for SCADA systems.

Advantages

- Low risk of maloperation.
- No increase to battery maintenance costs.
- Universal solution which can easily be incorporated into new battery and charger systems.

- DC bus wiring is unaffected beyond the DC distribution board.
- Resilience period dependent on the capacity of the SCADA battery.
- Low space requirements.

Disadvantages

- Reliant on a robust external SCADA system and substation SCADA battery.
- Extensive upgrade programme required to upgrade battery charger systems.
- Increased space requirement.
- Requirement for increased Control interface.

Decision Factors

- Cost.
- High standing demand on batteries.
- Space to install more battery capacity.

5.2.4 DC Demand Disconnection Schemes

An alternative approach to provide resilience is to remove or reduce the standing demand on the protection / control battery system. This type of scheme would monitor the normal supplies to the substation and on sustained loss, (e.g. after 2 or 3 hours), would disconnect or reduce the DC demand from the batteries and shut down the site until reconnected or reactivated.

The use of DC Demand Disconnection schemes is not recommended for batteries used for SCADA systems.

There are two main options which are described below.

5.2.4.1 Total DC Demand Disconnection Option

Following sustained loss of external supplies this option would disconnect all DC demand from the protection / control batteries via a contactor. The battery would remain disconnected until either:

- the DC supply is reconnected in preparation of the re-energisation of the site by SCADA Control or manual operation on site;

or

- the automatic scheme detects restoration of the external supply to the site.

Advantages

- Cost-effective solution.
- Remote monitoring and operational functionality.
- Resilience period dependent on the capacity of the SCADA battery.

Disadvantages

- Largely reliant on a robust external SCADA system and substation SCADA batteries.
- Maloperation of scheme leaves site without any operational protection.

Decision Factors

- High standing demand on battery.
- Insufficient space to install more battery capacity.
- Ratio of standing load for backup protection to overall standing load.

5.2.4.2 Partial DC Demand Disconnection Option

Following sustained loss of external supplies this option would disconnect most of the DC demand from the protection / tripping battery – but will leave some back-up protection connected and operational. The battery would remain disconnected from some of the DC demand until either:

- the DC supply is reconnected in preparation of the re-energisation of the site by SCADA Control or manual operation on site;

or

- the automatic scheme detects restoration of the external supply to the site.

Advantages

- Cost-effective solution.
- Lower risk of maloperation in normal use than a total demand disconnection scheme.
- Ability to re-energise site remotely from other sites if SCADA not available.

Disadvantages

- Limited battery life beyond 72 hours.
- More complex installation than a total demand disconnection scheme.
- May not be suitable for complex sites.

Decision Factors

- High standing demand on battery.
- Insufficient space to install more battery capacity.
- Ratio of standing load for backup protection to overall standing load.

Appendix One –

Basic Substation Resilience Decision Chart