STUDY ON THE REVIEW OF THE BLACK START ANCILLARY SERVICES

ELIA – National Control Center & Market Development – Non-confidential version

20/12/2018 – version updated after public consultation

PURPOSE OF THE DOCUMENT

Between November 2017 and August 2018 Elia has performed an in-depth study of the black start service for the Belgian electricity system based on simulation studies, information received from producers, and a comparison with other European countries. The study takes into account the impact of the new European guidelines and motivates reconsidering the design of the black start ancillary service

Similar to all other ancillary services, Elia strives at continuously improving the product design of the services in order to attract new technologies and providers, and in order to increase the efficiency of the procurement procedure. The current contractual period for black start services ends in December 2020. The review of the service design is part of a long-term roadmap for implementation of a new framework by 2021.

ELIA extended the scope of the study after request of the national regulator CREG[1] in the incentives set in the framework of the incentive regulation mechanism as specified in article 27 of the tariff methodology for 2016-2019[2].

The study brings forward two reports, which includes the remarks of the stakeholders that responded during the public consulted between 8 October and 19 November 2018, as a formal submission to the CREG is planned by December 20th 2018:

- **Part 1: Study on the review of the black start ancillary services (the underlying document)**
  The study analyzed the technical capabilities of production units in Belgium (thermal and intermittent) for black start and houseload operation, the market models used in other European countries to procure the black start service, and the determination of needs for black start services in Belgium in order to achieve the objectives of the restoration plan. The study serves as a basis for a review of the service design (part 2) and for future versions of the Restoration Plan.

- **Part 2: Design note on restoration services**
  Following the above-mentioned analyses, ELIA has reviewed the design of the black start ancillary service (more broadly defined as “restoration service” in the Network Code on Electricity Emergency & Restoration). ELIA proposes a new design for the future organization of the black start service, which will serve as a basis for future versions of the Terms & Conditions to act as a Restoration Service Provider on a contractual basis (i.e., the new black start contract).

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[1] Creg decision (B)658E/45

[2] Artikel 27 van het besluit (Z)141218-CDC-1109/7 van de CREG van 18 december 2014 tot vaststelling van de tariefmethodologie voor het elektriciteitstransmissienet en voor de elektriciteitsnetten met een transmissiefunctie evenals de overeenkomst van 25 juni 2015 tussen de CREG en Elia System Operator nv over de modaliteiten voor de regulering met stimulansen voor Elia System Operator nv in de periode 2016-2019

EXECUTIVE SUMMARY

The study serves to assess whether Elia's current restoration approach and the contract for the black start service require a review. As the current contracts run until the end of 2020, the time horizon of the study is the period between 2020 and 2030 taking into consideration potential and expected evolutions in the grid and in the Belgian energy mix. The study includes a benchmark across European countries, a technical analysis to determine the number and geographical distribution of black start capabilities in Belgium for a bottom-up restoration strategy, and an overview of readiness of production types to deliver black start services.

A **benchmark** of the sourcing methodologies and type of sources used for restoration services in other **European countries** indicated that there is no commonly agreed approach among European TSOs for procuring restoration services. Mandatory services or procurement via tenders or bilateral agreements are used, with different levels of involvement of the national regulator. Many TSOs procure the service separately for geographically discerned zones. Sometimes more than one black start service is procured in the same zone. In some countries, the procurement method is flexible, depending on the black start need and the level of competition in a specific zone. The nature of the product does in general lead to low competition and a focus on long-term contracts. In all observed countries, black start services are delivered by thermal or hydro power plants (pump-storage and run-of-river) because of the size and reliability. None of the participating TSO uses renewable energy sources as a black start source. Different methods ranging from no remuneration to regulated prices, bilaterally negotiated prices, or prices bid in offers of a tender were observed. Black start services are mainly remunerated for their availability, allowing recovering specific investments and the operational and maintenance cost. In some cases, the TSO pays warming costs to keep the units available, where otherwise they would be shut down.

Restoration of the system after a blackout can be done via a top-down strategy (using interconnections with other zones) or via **a bottom-up strategy** (using assets within the blackout zone to start re-energization). The ancillary restoration service concerns the procurement of means for the bottom-up strategy only. Therefore, the scope of the study specifically covers situations of system restoration based on a full bottom-up approach.

European Network connection codes, applying to new generation units, provide flexible instruments for system restoration to TSOs. **Houseload operation** capability will become mandatory for new units. In line with other EU TSOs, Elia will not contract or remunerate houseloaded plants for system restoration, but Elia will use them to accelerate the grid restoration if they are available after a blackout. **The contracted services for bottom-up restoration remain based on black start capabilities**. Member states can impose black start capability to a new unit if required to ensure the security of the grid.

This study aims to determine the **optimal restoration approach for the Belgian electricity system**. The goal is to re-energize 90% of the connection points with the Elia grid within the first 24 hours after the blackout occurs, to re-energize priority connections within the target restoration time and to use a minimum number of black start units.

The study recommends a combination of a **zonal and backbone restoration** methodology to re-energize the Belgian system after a blackout.

Taking into consideration the time required for blackstarting a power plant and the time for re-energizing the restoration paths to the critical connections consisting of the nuclear sites and important gas compressing stations of Fluxys, **four black start units are required**. One unit serves to re-energize the 380 kV backbone of the Elia grid and three units to re-energize the corresponding regional zones: North-West, North-East and South.

The fast set up of cranking paths to non-black start units, spread throughout the country, is important to increase stability, reactive power absorption capacity and active power to consumers. Therefore, black start units also serve to **re-energize auxiliaries of non-black start power plants** as soon as possible. The geographical distribution of the four aforementioned black start units also ensures proximity to non-black start units to support system restoration.

This recommendation takes into account that in case one of the four black start units is not available, the other black start units can serve as backup for the unavailable unit.

During the first phases of restoration and re-energization procedures, the conditions of the (dead) grid call for stringent requirements in terms of **active and reactive power capabilities** of assets contributing to the restoration to ensure the stability of the grid. The requirements for a specific black start unit depend on the location of the black start unit itself, the evolution of the grid and the load requirements behind critical connections.

The black start service aimed at restoring the 380 kV backbone should have an installed capacity of 85-140 MW. The black start service covering a regional zone should have an installed capacity of 65-115 MW.

In the future, Elia will set a minimum reactive power absorption requirement of 50 MVar for contracted restoration services but this value may be increased on case-basis depending on the outcome of a simulation study by ELIA. A feasibility study should determine if a black start candidate is able to fulfil the requirements depending on its location and the status of the network. In case a battery or water storage is required to enable the black start service, a **minimum level of stored energy** available for the black start service should be maintained at all times.

Across Europe **conventionally pump storage and thermal units provide black start services while intermittent production is not yet technically suitable**. Hydro pump storage plants are well suited to deliver the black start service, due to high dynamic flexibility, short startup times, high reactive power absorption capability and the ability to operate as generator or as load. Sufficient water reserves are required. Gas turbines in open cycle have also very well suited technical characteristics to deliver the service.

Elia expects that intermittent power production units will not be able in the coming years to meet the minimum requirements to adopt a role as black start service provider. Major bottlenecks are the operation of DC/AC convertors in weak grids, the absorption of reactive power and the storage requirements in case of absence of wind or sun radiation.

Production units that want to deliver black start services can make use of a starting unit (diesel or battery) to feed the auxiliaries of a main generator that might be on a different location, provided the (distribution) grid allows connection between both locations. Elia wants to evaluate the usefulness of new proposed technologies, which should lead to an increased number of eligible candidates and increase competition on the market. Elia defined technical minimum requirements for the start and main generators.

Elia will implement the results of this study in the future Restoration Plan and in the future contracts for the black start ancillary services.

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INTRODUCTION

Request by the Creg for an in-depth study of the black start service

As part of the targets specified by the Creg[3] to be achieved by Elia in 2018 in the frame of the incentive regulation mechanism as specified in art 27 of the tariff methodology for 2016-2019[4], the Creg specified the realization by Elia of an in depth study of the black start service for the Belgian electricity system. In particular, the study should investigate in detail the following aspects: (some of them are interdependent)

- The technical needs (cf. the number of units with black start capability and the geographical and electrical dispersion)
- The capability of houseload operation (see section 4) *of the production units connected to the Elia grid.*
- *The conditions to be fulfilled for production units, including intermittent power production units, in order to be eligible to offer the service.*
- *The potential impact of European Network codes and their implementation in Belgium.*
- *The market models or other methods used to provide the black start service and the kind of sources used in other European countries.*

Based on the studied aspects, Elia should add motivated recommendations for the development of a new mechanism for the provision of the black start ancillary service (whether or not on a market-based approach) aiming for a sustainable black start service at minimal societal cost.

The parts of the study linked with the technical needs and the houseload capability will be subject to a consultation with the relevant stakeholders.

The entire study, with exception of confidential parts, will be subject to a public consultation between October 8th 2018 and November 19th 2018, before it will be submitted by Elia to the Creg on December 20th 2018.

Structure of the study

The study serves to assess whether Elia's current restoration approach in general and the contract for the black start service in specific require a review. As the current contracts run until the end of 2020, the time horizon of the study is the period between 2020 and 2030 taking into consideration potential and/or expected evolutions in the grid and in the Belgian energy mix.

Restoration of the system after a blackout can be done via a top-down strategy (using interconnections with other zones) or via a bottom-up strategy (using assets within the blackout zone to start re-energization). A TSO must have procedures ready to use either a top-down or a bottom-up approach in case of a blackout, or a mix of both, as explained in section 1. The ancillary service concerns the procurement of means for the bottom-up

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[3] Creg decision (B)658E/45

[4] Artikel 27 van het besluit (Z)141218-CDC-1109/7 van de CREG van 18 december 2014 tot vaststelling van de tariefmethodologie voor het elektriciteitstransmissienet en voor de elektriciteitsnetten met een transmissiefunctie evenals de overeenkomst van 25 juni 2015 tussen de CREG en Elia System Operator nv over de modaliteiten voor de regulering met stimulansen voor Elia System Operator nv in de periode 2016-2019

strategy only. Therefore, the scope of the study specifically covers situations of system restoration based on a full bottom-up approach.

After a description of the current black start ancillary service in Belgium in section 1, the study shows the results of a benchmark of the sourcing methodologies and type of sources used for restoration services in other European countries in section 2.

The required number of black start units is mainly determined by the location and target time to restore crucial consumers and auxiliaries of non-black start units. Moreover, the adopted restoration approach as well as the need for backup also influence the required number of black start units.

In the third section, the study provides an overview of possible restoration approaches and the most recommended approach for the Belgian system.

Next, the results of a survey on houseload capabilities among all Belgian production units with an installed capacity higher than 25 MW are presented in section four to reflect the role of houseload operation in the restoration strategy and its possible impact on the determination of needs for black start services.

Section five gives a more detailed explanation on the assumptions and objectives of the restoration plan, with a categorization of connection points and target restoration times providing input for an elaborated methodology to determine the minimum required number of black start sources in Belgium.

The minimum requirements for black start units eligible for delivering the service in terms of active power, storage capacities and reactive power are discussed in section six. An exhaustive list of technical requirements will be included in a separate document “design note for future black start services”. This document will be submitted to the Creg together with the present document.

Section seven analyses the potential of different production types in the Belgian grid to meet the technical requirements, including the readiness of intermittent sources.

To conclude, the report refers to the different parts of the study to indicate whether a review of specific elements in the current ancillary service design is needed, and how a new mechanism could be developed for a sustainable, reliable, and cost efficient provision of the service in Belgium for the period 2020-2030.

Throughout the study, the relevant European Network Codes and Guidelines are considered.

Study realization

Elia has realized the study with the support of the consultant Tractebel Engineering, selected after a tender among several high quality European engineering companies. A non-disclosure agreement was signed between Elia and Tractebel Engineering to ensure confidential treatment of grid data, only for the purpose of this study. Tractebel Engineering, part of Engie, agreed on non-disclosing data related to this study with other subsidiaries of the Engie group.

It is important to note that although the study was performed in collaboration between Elia and Tractebel Engineering, the conclusions of this study reflect the position of Elia only.

Intermediary results of the study have been presented to the stakeholders during meetings of the Working Group System Operations and European Market Development between April and September 2018.

A questionnaire was sent to large producers in Belgium requesting more information on the technical capabilities for black start and houseload operation. The information received will be used by Elia for assessment of risks and possible means for restoration but the information is confidential and therefore not included in the public, non-confidential version of this report.

1. Elia's current restoration procedure and black start ancillary service

In case of a blackout in Belgium, Elia has prepared a restoration plan to restore the system in a phased approach, with parallel restoration in multiple zones, and by relying on top-down assistance from neighbouring countries or on bottom-up re-energization from contracted black start units depending on the situation. This chapter explains the current restoration approach in more detail.

1.1. Three phases in the restoration plan

After a blackout, Elia aims to gradually build up the system and re-energize at least 90% of the connection points towards the clients within 24 hours. To achieve this, a step-by-step approach is passed through before returning to a normal state with load and market restoration. Figure 1 illustrates the three high-level phases of the restoration process.:

- A diagnosis of the situation (Phase 1 Analysis)
- Activation of the re-energization procedures either top-down or bottom-up (Phase 2 Restoration of the service)
- Phase of TSO controlled dispatch of generation and load (Phase 3 restoration of the load)

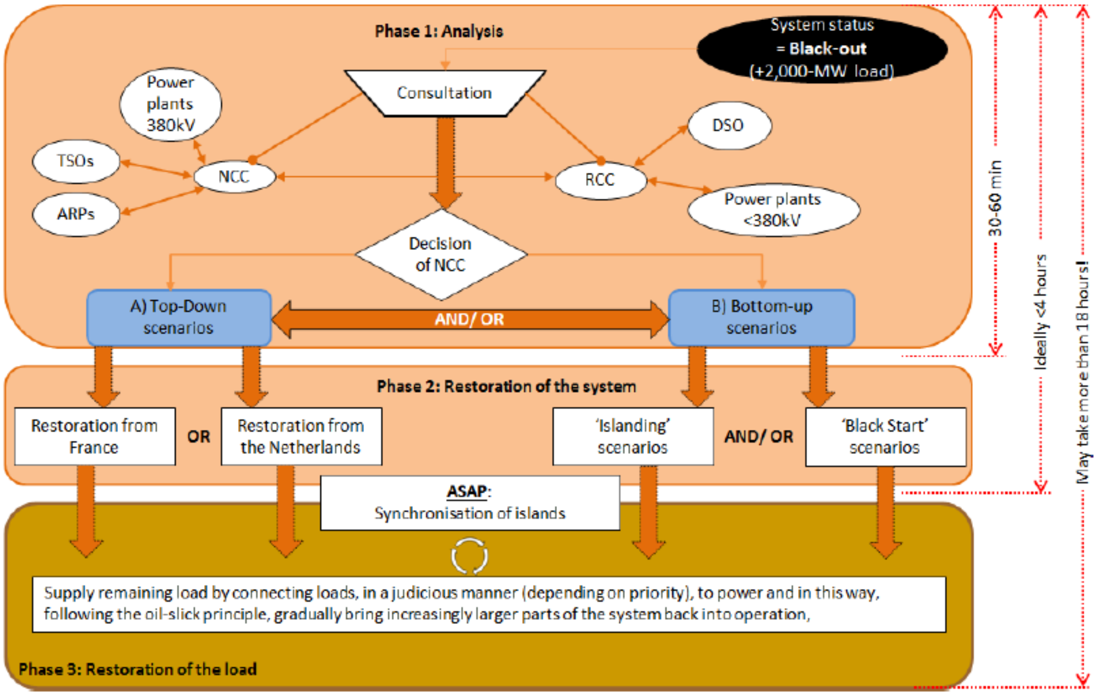

Figure 1: Phases of the restoration process

Phase 1: Analysis

After a blackout, there is first the diagnosis phase. The system engineers in the control center of Elia evaluate the extent of the blackout and the impact on generation assets and grid elements. This phase involves communication with producers, national and regional control centres, neighbouring TSOs, DSOs, etc. Based on this diagnosis, the system engineer of Elia decides on the procedure to follow (top-down restoration from neighbouring countries in collaboration with other TSOs and/or bottom-up restoration using the restoration means available in the own system, when neighbouring countries are also in an emergency or blackout state and cannot provide support to Elia).

Elia assumes that this phase lasts approximately 30 to 60 minutes. Although full diagnosis may take an hour, Elia would be able to send the instructions for restarting black start units after 30 minutes.

Phase 2: Restoration of the system

The second phase is the start of system restoration. The aim is to build electrical islands to re-energize critical loads within the target times. In addition, Elia will as quickly as possible re-energize the majority of the 380kV grid (including substations connected to neighbouring countries) and a cranking path to non-black start units, which can further assist in system restoration.

Once stable electrical islands are formed, the interconnection of the islands with the backbone can start. Islands are considered stable when:

- Regional islands (150kV): 350 MW of load and at least 3 production units
- 380kV backbone: 1000 MW of load and at least 10 production units

Phase 2 therefore includes the start-up of the system where Elia enters in a phase of TSO controlled dispatch arrangement during which ELIA instructs, in close collaboration with other system operators, consumers and generators (with and without black start services) to follow a certain set point of active and reactive power, injected to or consumed from the grid.

Within Elia, this situation of TSO Controlled Dispatch is commonly referred to as ‘Central Dispatch’. However, in order to avoid confusion with the definition ‘central dispatching model’ of Regulation 2017/2195, the term ‘TSO Controlled Dispatch’ is used.

Phase 3: Restoration of the load

Before reaching the normal state again, Elia continues to centrally dispatch generation and load to:

- Synchronize with neighbouring grids
- Restore N-1 security
- Re-energize remaining connection points, including coordination with DSOs for restoration of lower voltage networks

The synchronization of the electrical islands and with the neighbouring countries can be performed only at substations having automatic synchronization devices. This is the case for some 380 kV substations and on some 150/380 kV or 220/380 kV transformers. For a successful synchronization, both sub-networks must have the same frequency (which is impacted by the balance between production and load) and voltage angle, meaning that just after the interconnection the flow on the tie-line will be close to zero. This is also valid for cross-border interconnections.

1.2. Influence of the current energy mix

The Belgian production park today has a large share of thermal plants. TSOs conventionally rely on thermal units and pump-storage units for the first phases of system restoration.

Gas-fired plants, that are independent from industrial processes, can be restarted quickly and are therefore well placed to contribute to the power system restoration.

The nuclear plants currently have a critical impact in the existing restoration procedure. Due to security reasons (which also remain for some time after decommissioning of a nuclear plant), nuclear plants are considered as critical loads that must be re-energized as quickly as possible. Due to their size, nuclear plants contribute to the restoration by absorbing reactive power and providing stability to re-energize the 380kV backbone (assuming the plant succeeded tripping to houseload operation).

After the potential nuclear phase-out, it is currently assumed that the adequacy problem will be solved by installing new thermal power plants. This could potentially provide more black start capable units.

Large pump storage plants are very useful for system restoration because they can be restarted quickly, have large reactive power absorption capabilities, have a large inertia and can not only be used as generator (provided sufficient water reserves in the upper reservoirs), but also as load to allow nuclear plants to achieve a stable minimum load.

1.3. Combined zonal-backbone restoration

For execution of the restoration plan Elia has currently split the grid in five zones: four regional zones (North West, North East, South West, and South East) plus the 380kV backbone. This allows re-energization procedures to be started up in parallel, as managed by different national and regional control centres.

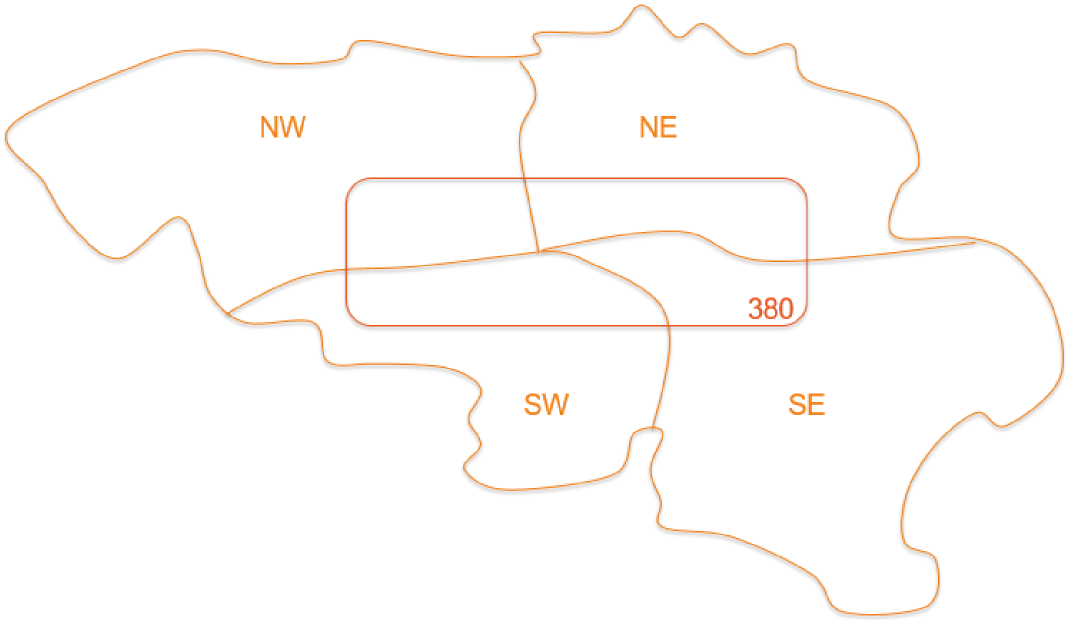

Figure 2: Regional zones and 380 kV backbone

The black start ancillary service aims to contract one service in each zone (5 contracts in total). If not feasible, a second service can be contracted in a zone adjacent to a zone without a service (with a maximum of two services per zone). Currently one of the two contracted black start facilities in the North-West zone serves for re-energizing the North-East zone.

1.4. Black start ancillary service

The current Belgian federal grid code[5] does not include any obligations for power plants to have black start or houseload tripping capabilities or to provide a restoration service to Elia. The grid code does foresee that Elia organizes a competitive process or a public tendering for the procurement of the ancillary service, to which providers can voluntarily participate. The technical requirements for the services are included in the contract and transparently communicated in the call for tender. Table 1 gives a high-level description of the service design.

Procurement	Voluntary participation Contract granted after a public tender
Signatory	CIPU Holder (Access Responsible Party)
Assets	CIPU productions only, may be aggregated to a ‘production site’ behind one connection point => ‘Site-based’ contract
Duration	Long term contracts: 5 years (unless if Royal Decree: 1 or 2 years)
Technical requirements	Black start generator on-site MW load support MVar absorption capabilities of 30 MVar or more Reaction time for cold (3h) & warm (1,5h) start ups Minimum fuel/energy supply …
Price	Price offer with reasonableness evaluation by the CREG 1 price reflecting all costs
Settlement	Remuneration for availability (offered price or Royal Decree price) Separate remuneration for tests
Penalty	In case of ‘extreme’ non-availability or in case of failed tests

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[5] The Federal Grid Code is currently being revised in Belgium. A new version is expected to enter into force in 2019.

Table 1: Design summary of the current Black Start Ancillary Service

Elia pays the price bid by the provider in the tendering procedure, if this price is evaluated as being not manifestly unreasonable by the regulator (Creg). In case of unreasonable prices the Federal Public Service Economy can impose a price by Royal Decree, taking into consideration a non-binding advice of the regulator and based on information received from the provider to justify the offered price. The contract duration for a black start service is 5 years, unless the contract is subject to a Royal Decree (in which case the duration is maximum two years).

The price paid for the service reflects the installation (if needed) and maintenance of the black start equipment, procedures, and training of personnel, and is indexed annually. Elia pays the provider for each day that the production unit is available to provide the service (therefore not on days with forced or planned unavailability). There is also a penalty if the unavailability of the plant is larger than the acceptable margin described in the contract: the penalty is higher for higher unavailability (starting from 20% unavailability within the year). Also tests of the black start capability are remunerated if successful.

2. Benchmark of restoration services in other European countries

A study of the restoration services in other European countries[6] is useful to detect possible trends and allows challenging the Belgian approach. This benchmark study focuses on the procurement and settlement of restoration services rather than on technical requirements.

A high-level overview of the sourcing methods together with the pricing of the service in 19 countries brings forwards multiple configurations. A more detailed study of 7 selected countries (including Belgium) looks at more specific aspects of the service design, namely the types of assets, the TSO's restoration approach (which determines the need for procurement of the service), the remuneration principles, and the duration of service provision. The countries in the more detailed study were selected because of their vicinity (neighbouring countries) or because they added specific cases of sourcing/pricing methods with the aim of studying different configurations in more detail.

2.1. Sourcing methods and pricing

Table 2 shows the sourcing methods and pricing for Belgium and 18 other European countries. Note that the overview represents the current framework, therefore before the implementation of the European Guidelines. As Elia, some other TSOs are also reviewing their black start ancillary service and may in the coming years open up the service for new participants. Some future changes are also certain: for example, the NC RfG imposes houseload operation as a mandatory connection requirement for PGM type C and D subject to RfG if the PGM cannot restart within 15 minutes.

The sourcing of black start services is diverse across the studied countries (see Figure 3):

- 6 TSOs contract the service only via bilateral agreements with the providers (possibly subject to approval by the regulator)
- 4 TSOs use either bilateral agreements or a public tender
- 3 TSOs only procure via a public tender
- 5 TSOs rely on mandatory black start services
- 1 TSO uses either mandatory services or bilateral agreements

Restoration services in Europe clearly focus on black start services. In some countries, production units are subject to requirements for houseload operation.Houseload plants are often intended to be used by TSOs to accelerate the restoration procedures.However, regardless of the obligation, the TSO does not procure the houseload capability to rely on for bottom-up restoration strategies. TSO's only contract services based on the black start capability.

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[6] The benchmark study uses information gathered in surveys on ancillary services from ENTSO-e (ENTSO-e WGAS, 2017), national grid codes, and information from the TSO (either publicly published information, information shared in personal contact via interviews or via e-mail, and discussions in the NC E&R Expert Team).

Sourcing methods often go hand in hand with a specific pricing method, although the relation is not one-on-one. **The prices paid for black start services in the studied countries are summarized as follows (see Figure 4):**

- 5 TSOs do not pay for the service. Most mandatory services are unpaid, although sometimes a regulated price may apply as well.
- 3 TSOs pay a regulated price, set by the competent authority.
- 2 TSOs negotiate on the price with the service provider, often as part of bilateral procurement. The price may still have to be approved by the regulator. In Denmark a price is negotiated if the tender brought forward only one candidate; in other cases the Danish TSO pays as bid.
- 3 TSOs pay the price bid in the offer (possibly subject to approval by the regulator, such as in the case of Belgium where a price can be set via Royal Decree if the offered price is evaluated as unreasonable by the regulator)
- 5 other TSOs indicate to pay for the service without more detail on the price philosophy.

Closer look on France

According to the national grid code all thermal units with an installed capacity of 40 MW or more are required to trip to houseload (RTE, 2009). There are no requirements in the grid code for providing black start services.

However, each nuclear power plant has legal obligations imposed by the “Agence de sûreté nucléaire”. Owners of nuclear power plants must assure that the plant auxiliaries can be re-energized when a blackout occurs to avoid core damage due to long power outage. To assure this at all time (and considering the possibility that also neighbouring plants or unit can fail to trip to houseload operation) the nuclear power plant owners had to contract some black start units (mainly hydro or combustion power plants).

This legal framework results in sufficient services for restoration present in the French system. Consequently, the French TSO, RTE, does not have additional contracts for black start services. RTE is nonetheless involved in the contracts between producers as the re-energization of a power plant supported by the houseload or black start capabilities of a neighbouring plant may require the use of part of RTE’s grid.

Closer look on Germany

The German grid is operated by four TSOs: each TSO is responsible for the restoration of its own control area and for sourcing the adequate restoration services; however the same grid code applies. The german grid code states that the TSO must via bilateral agreement procure black start services. Despite of obligations for power units to be capable of houseload operation, this capability has no impact on the procurement of black start services.

The regulator must approve the bilateral agreement between the TSO and the black start service provider. The TSO-provider agreement sets all the terms and conditions of the service except for the price, which is set in negotiation with the regulator.

Country	Service type	Sourcing method	Pricing
Austria	Black start procurement	Bilateral (contract approved by NRA)	Paid (no details available)
Belgium	Black start procurement	Tender	Pay-as bid (subject to approval by competent authority and possible negotiation)
Croatia	Black start procurement	Mandatory for some units (grid code) Bilateral for others	Paid (no details available)
Czech Republic	Black start procurement	Bilateral	Paid (no details available)
Denmark	Black start procurement	Tender or bilateral (in case of lack of competition)	Pay-as-bid (or negotiation if only one bidder responds to the tender)
Estonia	Black start procurement Houseload operation: mandatory technical capability	Bilateral	Unpaid
Finland	Black start procurement	Bilateral (no legal framework)	Paid (no details available)
France	No procurement by the TSO (Legal obligation for unpaid houseload and black start back-up are sufficient for system restoration)	Mandatory for selected units	[No payment by the TSO. Contract between producers]
Great Britain	Black start	Bilateral or tender	Negotiated
Germany (specific info on 50Hertz control area)	Black start Houseload operation: mandatory technical capability (unpaid)	Bilateral	Negotiated with price settled by the regulator
Italy	Black start Houseload operation: mandatory technical capability (unpaid)	Mandatory for selected units (details in Restoration plan and Grid Code)	Unpaid
The Netherlands	Black start	Tender	Pay-as-bid

Northern Ireland	Black start	Mandatory	Regulated
Norway	Black start Houseload operation: mandatory technical capability	Mandatory	Unpaid
Poland	Black start	Tender	Pay-as-bid
Republic of Ireland	Black start Houseload operation: mandatory technical capability (unpaid)	Tender or bilateral	Regulated
Slovakia	Black start	Bilateral	Paid (no details available)
Spain	Black start	Mandatory for selected units in Restoration Plan. No contractual or legal framework.	Unpaid
Switzerland	Black start Houseload operation: mandatory technical capability (thermal units)	Tender + bilateral	Regulated

Table 2: **Overview of sourcing methods and pricing in 19 European countries**

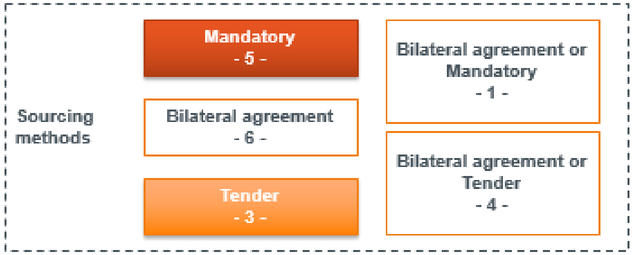

Figure 3: Summary of sourcing methods

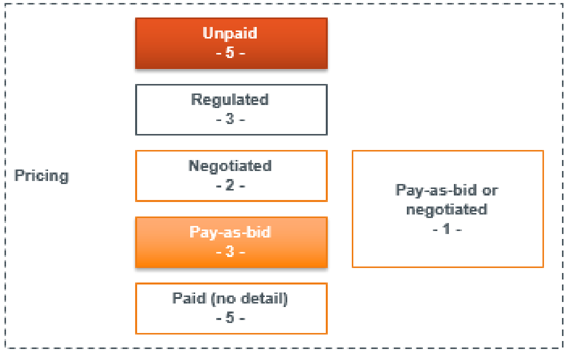

Figure 4:Summary of pricing methods

In case of a shortage of black start services in a region, the TSO may procure the service on a power plant that announces its decommissioning. The regulator will declare the plant as “system relevant” and the agreement will set a fixed income for keeping the plant available for black start services while not participating to market activities. The power plant owner has no right to refuse the provision of the black start service upon request by the TSO and/or the NRA. At the end of the regulatory period the “system relevant” qualification is reviewed; if revoked, the plant has to close permanently.

Closer look on Great Britain

The grid code foresees that the TSO procures the black start service through an ancillary service contract, either in bilateral agreement or after a public tender. Historically National Grid mainly used bilateral agreements but now, following the modification of the black start procurement methodology, National Grid aims to use more public tenders in zones with sufficient expected market competition.

2.2. Restoration approach

The restoration approach chosen by the TSO affects the procurement of restoration services. Table 2 gives an overview of the restoration approaches and amount of services for a selection of countries. In all countries, multiple black start services are used spread across different zones. The restoration approach in other countries is similar to the approach of Elia in Belgium focusing on the parallel restoration of different zones (zonal approach) combined with a backbone restoration (also to support the zonal approach).

Closer look on the Netherlands

The Dutch power system is divided into three zones during the restoration process: Noord-Nederland, Mid-Nederland and Zuid-Nederland. One black start service must be contracted in each zone. Each black start service must consist of at least two power units with each an installed capacity of 200 MW. At least one of the two units per service must be available at all time. Therefore, one unit serves as a back-up for the other to reach 100% availability of the service.

In practice, a diesel generator is used to start-up a gasturbine/generator set, which is used to start the auxiliaries of the 2x200MW power plant so that the 2x200MW plant is enabled to start up and energize the first substation of the Dutch power system. The diesel generator, gasturbine/generator set and 2x200MW plant are located on the same site.

The procurement of services with black start capabilities that must still be installed or upgraded is possible even if there are other plants in the system that are already equipped with black start capability. The TSO selects the plant offering the best deal based on a combination of cost and quality indicators, which provides opportunities for offers based on new capabilities.

Closer look on Germany

Most black start services make use of hydro plants (pump storage or run-of-river), compressed air plants, gas fired plants, diesel generators or battery systems to start up. They are located in the immediate vicinity of lignite or coal-fired thermal power plants and are primarily used to energize their large auxiliaries.

Country	Restoration approach	Asset types
France	Backbone & Zonal approach Restoration plan: 7 zones # services: no information	Hydro plants Thermal units HVDC (TSO-owned top-down restoration) only as backup
Germany (50Hertz control area)	Backbone & Zonal approach # zones: no information 4 black start services	Hydro plants (run-of-river or pumped-storage) Compressed air plants Gas-fired plants
Republic of Ireland	Backbone & Zonal approach # zones: more than 1 7 black start services	Pumped Storage Units (Small) hydro units OCGT 1 HVDC (top-down restoration) replacing one bottom-up black start service
Belgium	Backbone & Zonal approach 5 zones 5 black start services	CCGT/OCGT Pumped-storage
Great Britain	Backbone & Zonal approach 6 zones 18 black start services	Large conventional fossil fuel power plants HVDC (top-down restoration) replacing one bottom-up black start service
The Netherlands	Backbone & Zonal approach 3 zones (North, Mid, South) 3 black start services with each a back-up	Gas turbines
Denmark	Backbone & Zonal approach 2 zones (East & West Denmark) 4 black start services	Thermal plants HVDC (top-down restoration) replacing one bottom-up black start service

Table 3: Overview of restoration approaches

Closer look on the Republic of Ireland

EirGrid is an example of a power system that uses a combination of several technologies for providing black start services. It makes full use of the available resources such as HVDC and small hydro units.

EirGrid currently contracts seven black start plants (including 21 power units) spread over a number of geographic locations in the Republic of Ireland as shown in figure 5.

The HVDC link is the connection between the Republic of Ireland and Great Britain, and is operated by an independent operator EIDAC.

- 1 HVDC 530MW (close to Dublin)
- 1 site with 4 Pumped Storage Units (Turlough Hill)
- 4 sites with in total 13 hydro units (between 4 and 24 MW): Erne, Lee, Ardnacrusha and Liffey River
- 1 site with 3 open cycle gas turbines (Aghada)

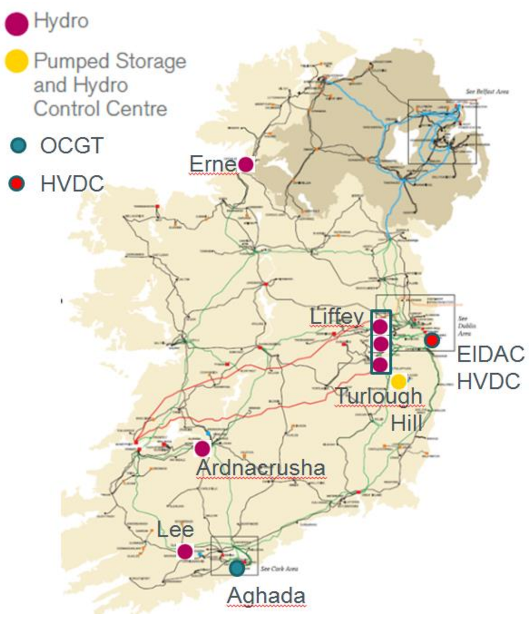

Figure 5: Black start service in Republic of Ireland (source: EirGrid)

Closer look on Great Britain

Great Britain is divided into 6 zones and National Grid contracts at least 3 black start services in each zone independently, as illustrated in Figure 6.

Figure 6: Black start provider zones in Great Britain (National Grid, 2018)

Closer look on the use of HVDC[7]

Three of the studied TSOs have indicated replacing one bottom-up black start service by a top-down restoration using an HVDC interconnection.

Denmark is composed of two asynchronous networks and black start needs are defined independently in West and East-Denmark. Since the commissioning of the HVDC link with Norway, the HVDC link (which is fully TSO-owned) is used to serve for one of the two ‘black start’ services in West-Denmark. Energinet assessed the probability of not being able to import from Norway in case of a blackout in Denmark to be low. This HVDC uses VSC technology and its black start capability was demonstrated during the commissioning tests. Energinet procures the second black start service after the organization of a tender for thermal power plants.

As explained in the **Republic of Ireland** also one of the black start services is provided by an HVDC interconnection with **Great Britain**. The HVDC is owned by an independent operator and therefore contracted by the TSOs. The philosophy of the Irish black start ancillary services however indicates a lower requirement on availability per service combined with the procurement of more services. The potential unavailability from the HVDC service due to instability or adequacy problems at the British side of the connection are therefore not a major concern. Also in Great Britain, the amount of black start services is relatively high, allowing taking the risk of not being able to use the HVDC interconnection due to uncertainties on the Irish side of the interconnection.

2.3. Remuneration

The same cost components generally return in the ancillary service contracts of the studied countries (see Table 4). Remuneration for black start services focuses on availability of the service, although some examples exist where the TSO also remunerates the activation of the service. The availability tariff mostly includes a remuneration for investments (if needed) and operational costs to assure (nearly) permanent readiness of the service. The Netherlands and Great Britain also brought forward cases where warming costs are remunerated, pointing at the difficulty of finding services available to start-up quickly when not in operation at the time of the blackout.

Closer look on the Netherlands

The TSO pays a fixed annual cost to the service provider for the availability of the restoration service, including the costs of maintenance and upgrade of the equipment. The availability requirement does not allow that both units on a site are in maintenance at the same time. The service provider must pay a penalty fee if a unit’s unavailability is longer than the allowed unavailability period. This penalty fee is dependent on the duration of the unavailability period.

In addition, the TSO remunerates the costs of successful black start tests. Even the remuneration of activation costs is foreseen (but determined ex post) in case of a successful black start after a blackout.

The black start service requires a start-up within 4 hours after the occurrence of a blackout. A variable warming cost can be negotiated in the contract to ensure that the units remain warm enough to deliver the service.

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[7] Of the 12 studied countries that were not selected for the more detailed benchmark study, three TSO’s own an HVDC interconnection and use it for restoration (Estonia, Finland, Norway).

Country	Cost structure
France	/
Germany (50Hertz control area)	Fixed annual cost
Republic of Ireland	Remuneration for availability Investment cost Testing (but corrected based on 'performance')
Belgium	Remuneration for availability Investment cost Testing
Great Britain	Availability costs Testing cost Warming costs Investment costs & cost of feasibility study
The Netherlands	Fixed annual cost (including maintenance and upgrade of equipment) Test costs (if successful test) Activation cost Warming cost
Denmark	Annual cost (incl. investment and testing), corrected for availability Activation cost [only for contracted services, not TSO-owned HVDC]

Table 4: Overview of remuneration components

Closer look on Great Britain

National Grid procures black start services at a negotiated price. The costs of the service increased substantially during the last years. National Grid had to organize short-term tenders to contract additional units as backup for other plants that were potentially to close or mothball. The short tender and short contract durations limited competition and pushed the bid prices up. National Grid has a budget for restoration services agreed with its regulator (Ofgem) that can be charged to consumers in the tariffs. Costs exceeding this budget may have to be incurred by National Grid if unable to justify the costs to the regulator.

In addition, the costs for the service increased due to the remuneration of "warming costs", as the new contracted units were insufficiently in-the-market (likely to occur in the summer periods when it is not economic to run conventional units) and therefore had to be kept warm especially to allow a quick response in case of blackout (Ofgem, 2016).

National Grid indicates several options for reducing the need to pay warming costs by (National Grid, 2017):

- In the selection of offers, operating costs are forecasted and thereby the need for additional warming during the contract period.
- Setting less stringent requirements regarding start-up time for units that require warming to increase competition.

- Contracting other technologies to avoid the use of units that require warming.

Closer look on the Republic of Ireland

EirGrid pays to the service provider an hourly availability rate for the service (EirGrid, 2017). This rate reflects the costs associated with capital, maintenance, testing (on request from the TSO) and usage (EirGrid and SONI, 2015). See table 5 for the hourly availability rates per service, which are publicly available (EirGrid, 2017).

For the settlement of the service, the rate is corrected in proportion to the unavailability in terms of MW[8] and in terms of non-abidance of the required start-up time[9] (EirGrid, Ancillary Services Agreement, 2008). The contract includes the number of units per plant that must be available and their minimum power level for the service to be regarded as available. In addition, the black start time is set in the contract and the service is penalized if the start-up is not feasible within that time at the concerned hour. Flexibility regarding black start time facilitates the procurement of the service on smaller units.

EirGrid requires an availability of 80% of the time. If the availability of a plant is lower than the required availability, EirGrid may terminate the contract.

The table below shows the hourly price for the black start service presuming full availability on the site in accordance with the contract.

Power plant	Unit type	Capacity	Black start availability rate
ESB Aghada (Cork)	OCGT	270 (3x90MW)	€64.71 / h
ESB Ardnacrusha (Limerick)	Hydro	85,5	€22.84 / h
ESB Erne (Ballyshannon)	Hydro	65	€22.04 / h
ESB Lee (Carrigadrohid)	Hydro	27	€9.82 / h
ESB Liffey (Kildare)	Hydro	38	€8.02 / h
ESB Turlough Hill (Turlough)	Pumped hydro	292 (4x73MW)	€81.63 / h
EIDAC (Woodland)	HVDC	530	€81.63 / h

Table 5: List of black start contracted units in Republic of Ireland [10]

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[8] EirGrid pays for the minimum of the contracted black start capability or the declared black start capability for hour H.

[9] EirGrid pays less for the black start service if the declared black start time for hour H is lower than the contracted start time. The price reduction increases as the declared start time increases.

[10] http://www.eirgridgroup.com/site-files/library/EirGrid/Ancillary-Services-Statement-of-Payments-and-Charges-2017-2018.pdf

2.4. Contract duration

Black start contracts generally have a contract duration of several years, easily ranging up to 10 years or more, even lifetime durations possible. Reasons are the technical requirements of the service, which are not widely installed, require large investment costs, and result in lower competition.

Country	Contract period
France	Lifetime or case-by-case
Germany (50Hertz control area)	Contracts per regulatory period Unless if system relevant reserve (on-hold decommissioning): 2 years
Republic of Ireland	Permanent agreement (with possibility for early termination)
Belgium	5 years Unless if Royal Decree: maximum 2 years
Great Britain	Typically 3-6 years
The Netherlands	10-15 years
Denmark	3 years

Table 6: Overview of contract duration

2.5. Conclusion

Overall, we can conclude that there is no commonly agreed approach among European TSOs for procuring restoration services. The nature of the product does in general lead to low competition, a focus on long-term contracts, and a restoration approach reflecting the risk aversion of the TSOs with respect to the undertaken measures for system restoration. However, the specific design of the ancillary service is quite country-specific.

There is **no clear trend with respect to the sourcing method.** Mandatory services or procurement via tenders or bilateral agreements are all used, with different levels of involvement of the national regulator. Many TSOs procure the service separately in each zone, and not simultaneously for all zones. **Interestingly in some countries the procurement method is flexible, to be chosen by the TSO depending on the current situation** (the black start need and the level of competition). The needs, technical requirements, and competition levels also drive TSOs to contract the black start service for **periods of several years.**

The same conclusion is to be drawn for **pricing: different methods** ranging from no remuneration to regulated prices, bilaterally negotiated prices, or prices bid in offers of a tender. The main principle regarding remuneration is clear however: **black start services are remunerated for their availability**, which includes investments costs for the installation of the technical black start capabilities and the operational costs to maintain it throughout the contract. Some **specific cases** also refer to the need to pay **warming costs** (again a sign of low competition and unavailability of units that can deliver the black start requirements from a cold start-up). Even cases of remuneration of **activation costs** exists, although the concrete settlement is not elaborated in detail in the contract, but determined ex post when needed.

TSOs split the control area in **different zones to search for black start services** in each of them. Sometimes **even more than one black start service is procured in the same zone**. The number of contracted services is set based on the need determined by the

TSO and by the design of the service: some cases combine less stringent availability requirements with a higher amount of contracted services. Also the risk of unavailability due to external factors (for example, **HVDC interconnections** depending on the possibility of the TSO on the other side to assist in restoration) can be compensated by procuring additional services.

The houseload operation capability of a plant is (in most cases, except France) not explicitly used in the TSO's restoration strategy. **Contracted services focus on black start capabilities.** Conventional plants to deliver black start services are **thermal plants or pump-storage units**, most importantly due to the technical requirements of the service (including implicitly the size of the black start unit) and the reliability.

In the benchmark study, none of the participating TSO indicated making use of **renewable energy sources** as black start source.

3. Restoration approach

This study aims to determine the restoration approach and determination of needs that fulfill the following objectives of the restoration plan:

- Re-energize 90% of the connection points with the Elia grid within the first 24 hours after the blackout occurs.
- Re-energize the priority connections within the target restoration time and the auxiliaries of non-black start units.
- Use a minimum number of black start units.

This part highlights different restoration approaches and explains their impact on the required number of black start units. The restoration approach must take into account the typical characteristics of the Belgian energy mix, the location of priority connections and the locations where asynchronous sub-systems can be synchronized.

Black start plants are used for kick starting the power system from a totally de-energized state. Therefore, the impact of black start units is limited to only the first 4-6 hours of the restoration scenario. Once the system is kick-started, the remaining part of the restoration scenario will be determined by other factors, as indicated in Figure 7.

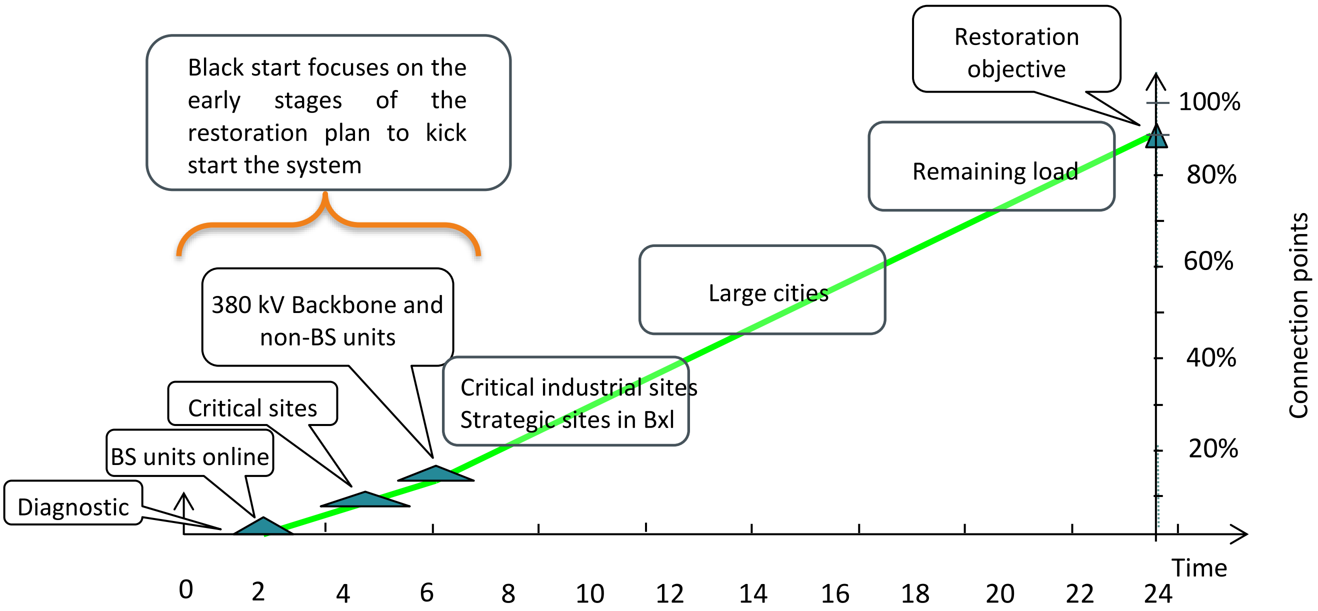

Figure 7: Restoration scenario

Once the system is kick-started, some adequacy problems cannot be excluded to match production and demand. This could happen if some conventional power plants are unavailable or cannot restart in a timely manner, while it is not possible to import from neighbour countries and while renewable energy sources are not available. These problems are outside the influence perimeter of the TSO and are out of the scope of this study.

3.1. General overview of bottom-up restoration strategies

The following sections describe two types of restoration strategies in detail, including technical requirements, advantages and disadvantages for each strategy. A first restoration strategy is the **backbone restoration** strategy where a spinal cord is re-energized quickly in order to provide a cranking path to the auxiliary units of the remaining plants. The critical loads are also re-energized from this backbone system.

A second restoration strategy is to perform a **zonal restoration** where the system is subdivided in several areas. The number and size of the areas depend on the generation mix, location of the critical loads and available resources.

For backbone and zonal restoration strategies, the network can be re-energized **sequentially** or through **soft energization**. Sequential restoration means that one substation is re-energized after each other at approximately nominal voltage. The soft-energization strategy connects part of the system at zero voltage and progressively re-energizes it to avoid inrush currents. The advantages and disadvantages of both energization methods will be compared.

3.1.1. Backbone restoration

A backbone restoration consists of the following steps:

1) Restart of power plants with black start capabilities

2) Energization of a cranking path to re-energize auxiliary units of non-black start units

    a) Power plant sites are interconnected

    b) Minimum load is picked up to fulfil technical requirements of power unit

3) Load pick-up

    a) Small incremental load pick-up at first

    b) Larger incremental load pick-up as the system is becoming more stable

Technical requirements for black start power plants in a backbone restoration

Energizing the high-voltage level backbone requires to be able to absorb a significant amount of reactive power. Depending on the voltage level and length of the transmission lines, this is typically achieved by using large size plants and shunt compensation devices.

Operating the black start power plant at a voltage below the normal operating voltage (e.g. at V=0.9 p.u.) is an efficient way to reduce the overvoltage caused by the energization of unloaded lines. An overview of the technical requirements for black start power plants for a backbone restoration strategy is shown in Table 7.

Characteristic	Requirement
Reactive power capabilities	High absorption
Number of black start units	At least one unit. A backup unit at a different geographic location is required.
Block load size	Must be able to restart auxiliary motors of non-black start units.
Black start restart time	Short restart time
Voltage operating range of the black start power plant	Black start power plants must be able to operate at lower voltage than usual while remote ends of transmission lines must be able to operate temporarily at voltages higher than usual.
Sync-check relays or auto-sync equipment	Not required
Resources for communication and dispatching	Low during early stages of the grid restoration

Table 7: Technical requirements for backbone restoration

Advantages of backbone restoration

- There is no re-synchronization phase of the multiple subsystems.
- The inertia and stability of the backbone system will continuously increase during the restoration of the system. Larger load pick-up blocks are allowed earlier in the restoration approach compared to zonal restoration.

Disadvantages of backbone restoration

- Compared to a zonal approach, there is a higher risk for losing the entire system during the early reconstruction phase with an interdependent backbone strategy. The independency of regional zones reduces the risk of losing the entire system.
- Due to the inter-dependent structure of a backbone, careful coordination between regional and national control centres is required when managing system frequency and voltages.
- There is a need for a back-up restoration plan. If the event that caused the blackout damages the lines forming the backbone or the black start power plants, this strategy could lead to longer restoration times.
- No optimal use of all available operators because regional control centres are not involved during the initial reconstruction phase.
- Energizing a long high-voltage transmission line produces a significant amount of reactive power and causes the highest voltages at the remote end. If the network

is not designed for it, it could be impractical to energize these long lines in one-step at the early stage of the restoration process.

3.1.2. Zonal restoration

A zonal restoration consists of the following steps:

1) Restart of power plants with black start capabilities in each zone
2) Energization of critical loads (including auxiliaries of large units) within each zone
    a) Power plants are interconnected within a zone
    b) Minimum load is picked up to fulfil technical requirements of power plants
3) Load pick-up
    a) Small incremental load pick-up
    b) Zones are becoming more stable as more load is connected
4) Interconnection phase
    a) Once stable zones are obtained
    b) If relevant, re-energizing long extra-high voltage lines once there is enough reactive power absorption available in the zones to be interconnected

Technical requirements for black start power plants in a zonal restoration

The technical requirements for black start power plants during a zonal restoration are listed in Table 8.

What?	Requirement
Reactive power capabilities	Moderate absorption (depends on the size of the zone and presence of cables). It can be assumed that the lengths of the lines/cables to be re-energized are shorter than for a backbone restoration.
Number of black start units	At least one per zone
Block load size	Must be able to restart critical loads and auxiliary motors of non-black start plants in the zone.
Black start restart time	Requirement depends on acceptable duration of power outage of the critical loads and hot restart capabilities of thermal plants.
Voltage operating range of the black start power plant	If needed for reducing reactive power absorption and for reducing the inrush current, the black start power plant must be able to operate at a lower voltage than nominal voltage.
Sync-check relays or auto-sync equipment	Required to re-synchronize the different zones
Resources for communication and dispatching	At least one system engineer per zone

Table 8: Technical requirements for zonal restoration

Advantages of zonal restoration

A zonal restoration approach can be performed in parallel, making better use of different control centers and of the black start power plants in the system.

If the event that caused the blackout damages critical lines or black start power plants in one zone, this zone is likely to be re-energized from a neighbouring zone with successful re-energization (but in a longer time period). The zonal restoration strategy is therefore better able to cope with the (planned or forced) unavailability of a black start power plant.

Disadvantages of zonal restoration

The zonal restoration requires at least one unit per zone. Therefore, the need for black start units is dependent on the number of zones and will be higher than for a backbone restoration.

The re-synchronizing stage requires the use of telecommunication and synchronization devices. However, if the human resources are present either way, then the zonal restoration approach uses them more efficiently.

3.1.3. Soft versus sequential re-energization

Soft-energization is a restoration approach to avoid inrush current when energizing a transformer or reactor. A network path between a generator and one or multiple substations is configured under zero voltage conditions[11]. Subsequently, the generator terminal voltage is gradually increased to nominal values.

Sequential restoration is a step-by-step approach in which each substation is first “cleared” before being re-energized at (90% of) nominal voltage. Clearing of a substation means that all incoming and outgoing connections to a bus bar are interrupted by opening the circuit breaker to prevent uncontrolled re-energization of network elements.

Advantages of soft-energization compared to the sequential approach

While soft-energization reduces the need of electromagnetic feasibility studies, it implies a careful analysis and adjustment of the protection settings.

Disadvantages of soft-energization versus sequential restoration

Protection settings should be carefully checked, as they may not cause unwanted trips during progressive re-energization of the system from zero to nominal voltage.

Given the advantages and disadvantages of soft-energization, the strategy is typically used to energize at the same time a generating unit and its step-up transformer.

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[11] Difference with the backbone restoration strategy:
- In the backbone restoration strategy the cranking path is configured during restoration (coupling of the grid in subsequent steps)
- In soft-energization strategy the path is configured before the start of the restoration procedure

3.2. Characteristics of the Belgian system to define a restoration approach

3.2.1. The Belgian electricity grid and generation mix

Belgium is a dense country where the electrical grid is composed of regional 36kV and 70kV networks, a well-developed 150kV grid and a 380kV backbone. The 220kV network is used to complement the 150kV in some parts of the countries and especially in the Southern area for the interconnections to France and Luxembourg.

The Belgian energy mix contains a substantial amount of thermal power plants. In addition, there is also pumped storage and an increasing share of renewable energy including on-shore wind, offshore wind and residential PV. Political discussions are ongoing for a potential closure of both nuclear power plants in 2025.

In the near future, Belgium will strengthen its interconnections with the neighbouring countries with projects such as Nemo and Alegro (HVDC connections to United Kingdom and Germany). Additional interconnections increase the possibility of using a top-down restoration strategy after a blackout. The risk that the other TSO is also in a blackout situation or is unable to help must be taken into account.

3.2.2. Geographic location of the large power plants in Belgium

Most of the power plants are located close to the 380 kV backbone and can be reached[12] within 30 to 40 minutes from an energized 380 kV grid. In some cases, the path from the power plant to the backbone can contain underground cables for which the capacitance is high. This might require a shunt reactor. This has to be studied on a case-by-case basis.

3.2.3. Critical connection points in the Belgian system

Elia divided its connection points in six categories with different priority levels for re-energization, based on public safety or socio-economic reasons. Each category has a non-binding time indicator to re-energize the connection points after the start of the blackout.

The highest ranked categories are connection points in terms of critical infrastructure and safety of industrial sites. These connections are geographically spread within the Belgian network, which should be taken into account when determining the restoration strategy.

The critical connection points are discussed in further detail in section 5.2.1.

3.2.4. Synchronization devices for coupling asynchronous regions

Local islands around a black start or houseloaded unit have to be synchronized with the 380 kV backbone. Direct connection between the asynchronous islanded zones, apart from the 380 kV grid is not possible in Belgium. Special synchronization devices permitting to bring voltage amplitude, phase angle and frequency deviation between two islands within tolerable limits to allow connection are currently installed on several locations on

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[12] In this context "reached" means that an electrical connection between an energized 380 kV substation and a power plant can be restored.

the Belgian grid. It is assumed that each new 380kV substation (for the scenarios 2025 and 2030) will have an automatic synchronization device.

In a combined approach of zonal and backbone restoration, the backbone should not be energized further than the synchronization points. Otherwise, it will be impossible to resynchronize the islanded sub-zone with the backbone, without passing through zero voltage again at some substations.

3.2.5. Preferred restoration approach for the Belgian electricity system

Although soft-energization has its use to solve inrush problems in dedicated locations, it is not recommended as general restoration strategy for the entire Belgian system. The risk is too high that protection systems will cause unwanted tripping during low voltage conditions during the early restoration phase. In general, a sequential re-energization approach is preferred. However, in some local situations, a soft energization approach could be useful to avoid transformer inrush phenomena.

In line with the actual restoration approach, a combination of backbone and zonal restoration seems the most appropriate strategy to restore the Belgian system. This is common practice in other TSOs as was observed in Table 3 of the benchmark study.

It is not recommended to restore the Belgian grid only from the 380 kV backbone because:

- During the initial stages of the restoration, the risk is too high for losing the entire system in case of a failure or instability.
- Assuming 10 min to re-energize one substation, it would be impossible to energize 800 substations within 24h when starting from only 1 BS plant.
- A certain number of back-up restoration scenarios and back-up black start units should be foreseen to anticipate unavailability of the main BS unit or grid elements.

It is recommended to restore the system from independent zones in parallel with the 380 kV backbone because:

- If black start is not possible in one zone or 380 kV backbone, it can be restarted from a neighbouring zone.
- Independent zones limit the consequences of a potential instability only to the affected zone.
- Restore quickly the (dispersed) critical loads throughout the network (hospitals, auxiliaries of TSO & DSO).
- As soon as the zones are sufficiently stable, they will be synchronized with the 380 kV backbone.

The minimum number of zones and the geographic and electric locations of the black start units will be determined in section 5.

4. Houseload operation

Generator protection systems located at a power plant are usually able to detect when a power system is collapsing to a blackout. When indications for an imminent blackout are detected, protection systems disconnect the power plant from the grid so that the plant will continue working in so-called houseload operation mode, dropping production to the level needed for feeding its own auxiliaries.

Especially thermal power plants will stay in "hot" mode during houseload operations and will not cool down, so that a fast resynchronisation to the grid could be possible. A time consuming and costly restart can be avoided in this manner.

For grid operators, houseloaded plants could play a role in the restoration plan. A black start unit that succeeded houseload operation will sooner be able to re-energize a busbar, because a restart is not needed. When a non-black start unit that succeeded houseload operation can resynchronize to the grid, it can speed up the restoration process. Even in this last case, if the plant is equipped to re-energize a dead bus, grid restoration in coordination between the TSO and the plant operator could be possible.

In order to get an overview of the present situation in Belgium, Elia has organized an inquiry on houseload and grid re-energization capabilities among the Belgian owners of power plants with an installed capacity higher than 25 MW. ELIA shares the information only with CREG and FPS Economy but not publicly given confidentiality.

Transition from grid-connected mode to houseload operation, feeding the plants own auxiliaries is technically possible for most units. Most units have tested the functionality during commissioning or can refer to real life occasions of transition from grid connected to houseload operation.

In general terms, the probability to succeed a transition to houseload operation during a blackout is uncertain and depends on several factors, such as the amplitude and proximity of the incident leading to the grid collapse, the operating point of the plant just before the grid collapse, the plant conditions, age, etc…

For nuclear units, the success rate highly depends on nuclear fuel cycle (lower success rate near end of cycle).

For the other units, although power producers recognize that it is technically possible to perform houseload operation in idealized test conditions, they were very sceptical to mention a success rate due to low experience with houseload operation after a real blackout.
For many thermal units in the Belgian grid, the duration to continue houseload operation is limited due to thermal constraints.

Apart from actually contracted black start units, most other units are not able to energize a dead bus and reconstruct the grid starting from houseload operation. However, owners recognize that this should be theoretically possible, but this requires a detailed study. Therefore by definition the houseload capabilities currently present in the Belgium system do not correspond to the notion of a service for re-energization of the grid (a bottom-up restoration approach) but can only contribute to the restoration process once the grid they are connected to is re-energized by other means.

Moreover, a unit needs to be online at the moment of the blackout to have a chance to switch to houseload operation during the blackout. The average running hours of conventional units is decreasing year after year due to the increasing penetration of renewable energy such as wind and PV.

Elia will identify the houseloaded plants during the diagnostic phase immediately after the blackout occurred. Making use of the restoration means available at that moment, Elia will endeavour establishing a restoration path to the houseloaded plants as fast as possible to prevent a shutdown and restart of the plants. However, as the location of houseloaded plants is unknown beforehand, this criterion will not be decisive for determining the minimum required black start units.

Conclusions:

- Based on the feedback received from the PGM operators, ELIA believes there is no sufficient reliable information about the success rate for transition to houseload operation after a blackout, in order to estimate the number of PGMs that remain in operation after a blackout and their geographical location.
- Given uncertainties on the root cause of a potential blackout and other risk factors mentioned above, Elia wants to remain independent from houseloaded plants to reconstruct the grid.
- Houseloaded plants should be used in addition to black start units to accelerate the grid reconstruction.
- Houseloaded plants should not be considered as replacement for a black start unit, for which minimum availability restrictions are imposed.
- The economic and social costs would be unacceptable if a plant was supposed to succeed houseload operation and finally is not available during a blackout.
- Elia prefers contracting Restoration Services to focus on re-energization capabilities with highest probability of availability when needed, therefore black start capabilities.

- These conclusions are in line with the benchmark study. Other European TSOs do not contract, remunerate or count on houseload plants for system restoration.

The following sections of the study do not take into account a role for houseloaded plants.

5. Determination of the minimum number of black start units

5.1. Introduction

As explained in the previous sections, the minimum required number of black start units depends on the following items:

- Location and target restoration times for the priority connection points and the auxiliaries of non-black start units
- The need for back-up in case a black start scenario would fail
- The restoration approach
- The target restoration time for the overall system.

Given the actual black start contracts remain in place until end of 2020, this study focuses on a time horizon between 2021 and 2030.

The determination of the minimum need focuses on the initial re-energization aspects of the restoration plan, in the assumption that all critical elements for the restoration are available. Therefore, the study assumes there is no planned or forced unavailability of grid elements at the time of the blackout. Black start units can be in planned outage but Elia monitors that maximum one unit is in maintenance at a time. Therefore, the study also covers the situation with a forced outage on one black start unit, assuming none of the black start units were in planned outage.

Potential adequacy problems due to lack of generation capability required to re-energize all the loads of the system are not considered in this analysis.

5.2. Assumptions for this study

5.2.1. Critical connection points

Regulation (EU) 2017/2196 establishing a network code on electricity emergency and restoration (NC E&R) charges the TSO with the publication of a list of high priority significant grid users and the terms and conditions for re-energization. NC E&R requires the TSO to submit the list with the terms and conditions to the national regulating authority for approval, although the Member State may also assign another authority to provide approval.[13]

The list must be eventually submitted for approval by 18 December 2018; therefore, at the publication time of this study, the approved list was not yet available. Hence, Elia used its own list as input in this study. Elia divided its connection points in six categories with decreasing priority levels for re-energization, based on public safety or socio-economic reasons. Each category has a non-binding time indicator to re-energize the connection points after the start of the blackout.

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[13] Before the entry into force of the NC E&R Elia already maintained a list of high priority grid users as part of the restoration plan, but there was no requirement for regulatory approval.

Elia will consider the nuclear sites as grid user with category 1 priority in the restoration plan, with an indicative restoration target time of 4-5 hours after the blackout.

Most power plants used for the restoration (also non-black start units) are gas-fired plants. Therefore, it is of utmost importance that the gas network remains operational during the restoration process and that the gas supply to gas-fired power plants is considered a priority during system restoration. Elia coordinated with Fluxys concerning the critical gas infrastructure.

A common study between Elia and Fluxys (carried out in 2010) indicated that in case of an electrical blackout in North-West Europe, the required operational gas pressure can be delivered to the gas fired black start plants under specific gas supply assumptions and taking into account a significant reduction in gas consumption due to the electrical blackout.

Further study is required concerning the impact of a European wide electrical blackout on the gas supply network. Especially the consequences are unclear in case the gas supply cannot be guaranteed on the interconnections.

The area of Zeebrugge is important for the gas supply system with interconnectors to Norway and the UK and the LNG terminal. In consent with Fluxys, Elia endeavours to restore power within 4-5 hours after a blackout. Elia considers the LNG terminal as grid user with category 1 priority in the restoration plan.

The priority connections of criticality 2 are located on or close to the 380 kV network except for the gas compressor stations.

Some of the 380 kV stations have to be re-energized in less than 4 hours to be sure that remote control operation is possible (or 24 hours if an emergency diesel has been installed).

The important Fluxys gas compressor stations of Zelzate, Berneau and Winksele are key infrastructure to ensure the security of gas supply. Notwithstanding the presence of diesel generators, in consent with Fluxys, Elia endeavours to restore power within 6 hours after a blackout.

After restoration of the priority connections of criticality 1 and 2, non-black start production units (directly connected to the Elia grid or via an Elia-connected CDS[14]) will be re-energized while the system is operated in a mode of TSO controlled dispatch.

Nonetheless, in this study Elia verified whether this hypothesis is correct for the restoration of the main load centres in Belgium

5.2.2. Estimated restoration time

Diagnosis phase

Elia estimates the diagnosis phase takes between 30 and 60 minutes. It will likely take around 30 minutes for the system engineer of Elia to declare that the system is in a total blackout and that the bottom-up approach will be used. From that moment on (therefore

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[14] Elia highlights the necessity and importance of redundant and blackout proof communication means between Elia and the CDSOs hosting non-black start electricity production units.

it is assumed **30 minutes** after the blackout) the system engineer of Elia would send the instruction to restart black start units.

Time for starting of a black start unit

It is contractually agreed that the time to restart a black start unit (time between receiving the instruction from Elia and energization of the first busbar) is **90 minutes** for a unit that was operating before the blackout occurred and **180 minutes** for a unit that was in shutdown mode before the blackout occurred.[15] For this study, 90 minutes starting time (time between receiving the instruction and the re-energization of a dead bus) is assumed for a black start unit. This is a reasonable trade-off between longer starting times for units in cold state and shorter starting times for units that are able to start faster than contractually obliged.

Time for starting a non-black start unit

The time for starting non-black start units depends on many factors such as the plant technology, the status of the plant before the blackout occurred, age, weather conditions, etc.

For units, except nuclear units, who succeeded the transition to houseload operation, it is assumed they can provide power within **10 minutes** after resynchronization to the network.

For nuclear units who succeeded the transition to houseload operation, it is assumed they can provide power within **30 minutes** after resynchronization to the network. It takes approximately two more hours to reach the stable minimum load of 20% of maximum power.

Time per switching vs time per substation

A duration of 10 min for energizing a switchyard is assumed. This includes communication between NCC, RCC, DSO and the producer’s control room, clearing of busbars, closing circuit breakers, setting transformers on the right tap, adapting set point of generators, etc. This means that energizing the 150 kV and 380 kV switchyard from the same substation will take approximately 20 min. In case remote control switching is not possible, an Elia operator must visit the substations, which requires significantly more time than the assumed 10 minutes.

Elia’s connection points are supplied from approximately 800 substations. Assuming 6 dispatching consoles (2 consoles in each Elia’s control centre in Schaerbeek, Merksem and Créalys), each console has to energize 120 substations in 24 h (1440 min) to achieve the 90% target.

Conclusion: intensive parallel operation of the 6 consoles in the 3 control centers is required to achieve the target, when assuming 10 min per substation.

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[15] Note that in the Netherlands and in Great Britain the TSO has had to pay warming costs because there were not sufficient power plants with black start capabilities that were always able to start in the required time.

Restoration time parameters

Table 9 summarizes the parameters used for estimating the restoration time and their suggested value.

Parameters	Estimated time
Diagnosis phase (Time needed to declare full blackout)	30 min
Restart time of black start unit	90 min (time between instruction and re-energization)
Restart time of non-black start unit (hot state, houseload failed). Not valid for nuclear plants.	65 min
Restoration procedure (i.e. energization of one switchyard)	10 min
Restart time of non-black start unit (houseload operation). Not valid for nuclear plants.	10 min
Block load size	5 MW 10 MW if stable backbone
Time per block load	2 min

Table 9: Estimated restoration time parameters

5.2.3. Scenarios considered for the Belgian grid

Three scenarios and corresponding load flow files are considered reflecting the network topology and energy mix for the reference years 2020, 2025 and 2030.

Several network projects are included in the models according to the federal development plan. The following structural modifications on 380 kV are included:

- HVDC Nemo and Allegro (in model 2020)
- Extra link Zandvliet –Lillo – Mercator and extra PSTs in Zandvliet (in model 2025)
- Second connection VanEyck- Meerhout – Massenhoven (in model 2025)
- New connection Coastal region – Avelgem – Courcelles (in model 2030)
- Additional shunt reactors for reactive power compensation

Regarding the Belgian energy mix, the following assumptions were made:

- Nuclear phase out in models 2025 and 2030 substituted by 3,6 GW[16] new thermal units.

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[16] Defined in the study: “Electricity scenarios for Belgium towards 2050. Elia’s quantified study on the energy transition in 2030 and 2040” published by Elia in November 2017 (link)

The locations for the assumed new thermal plants are still unknown. Therefore, “fictive power plants” are included in the models on sites for which studies have been done in the past or on sites where necessary infrastructure (access to fuel, cooling water, Elia grid, …) is considered available. Since there are not many alternatives for the assumed locations, the impact of the chosen locations on the results of the study is considered low.

- Further development of offshore wind projects as well as onshore development of renewables.

No fundamental changes in load and high priority consumers are assumed.

5.3. Methodology to determine the required number of black start units

The early stages of the restoration process are critical to achieve a timely restoration of the whole network. The study focuses on the most demanding restoration targets of critical connection categories 1 to 2. Once these connections are restored, the amount of available power units (black start and others) will affect the restoration of the remaining critical connection categories. Therefore, the individual targets for these categories have less influence on the determination of the need for restoration services.

The number of required black start units are determined in 3 consecutive steps:

Step 1: re-energize all critical connections of category 1

Restoring the critical connections of category 1 in a timely manner is the first step to assess the minimum number of black start units. The sum of the diagnosis phase, the time for restarting the black start unit and the time to re-energize the path between the black start unit and the critical load should not exceed the specified target restoration time for the critical consumer.

It is also evaluated whether a single black start unit can re-energize multiple critical connections. Therefore, the aim of this first step is to find the restoration paths that fulfil the requirements of the critical loads.

Step 2: re-energize category 2 connections

The second step is to evaluate what are the best cranking paths from the black start units to non-black start units. These paths are used to supply power to the auxiliaries of large power plants that will actively contribute to the grid restoration. To do that, the location of the main generating units (or zones with a high number of generating units) and the reactive power requirements of black start plants are identified.

In this step, it will also be verified if other category 2 connections can be energized in time.

Step 3: restore supply in main load centres

The third step is to evaluate the zones where there is a high density of industrial loads and large cities. The fast re-energization of these zones will therefore reduce the duration (and the cost) of the loss of supply to a high number of valuable customers.

The location of the main load centres defines the target areas. The electrical paths between these areas and the black start power units will be compared to the cranking paths identified in step 2.

It will also be checked if the overall restoration target of re-energizing 90 % of the connections to the Elia grid within 24 hours after the blackout occurred can be achieved, with the proposed number of black start units.

5.3.1. Step 1: supply category 1 critical connections

5.3.1.1. Restoring the critical load category 1

In a first step, as an example the plants (Herdersbrug, Drogenbos, Seraing, Ham and Coo) are used as reference location in the corresponding region to determine the different restoration paths to the critical connections of category 1 (Doel, Tihange and Zeebrugge) and to verify if the target restoration time can be achieved.

As indicated further in the study, this example does not restrict participation of other units to future black start services.

The estimated restoration time includes the diagnostic phase (30 min), the restart time of black start units (90 min in “hot” and 180 min in “cold”) and the restoration time from the black start unit to the critical load (10 min per substation).

For the three connections from category 1, it can be observed that:

- Tihange can be re-energized in less than 4 hours from Coo but also from Seraing or Drogenbos (if it needs less than 150 min to start).
- The auxiliaries of Doel can be re-energized in less than 4 hours from Drogenbos, Ham/Ringvaart or Herdersbrug if starting time remains below 100 min.

  Doel can be re-energized from Coo, provided sufficient reactive power absorption capacity is available. This can be achieved by:

  - Multiple units at Coo are available in turbine mode.
  - At least one nuclear unit in Tihange has succeeded houseload operation and is available to re-energize the 380 kV grid
  - A non-black start unit can help to re-energize the 380 kV grid.
  - Shunt reactors are available.

  This scenario has been checked with time domain dynamic simulations. As shown in **Error! Reference source not found.**, a realistic estimated restoration time from C oo to Doel is around 5 hours, including time to restart a non-nuclear non-black start unit (1,5 h). The amount of available energy stored at Coo must be assessed in the diagnostic phase, before deciding on the restoration scenario.
- Zeebrugge can be re-energized from Herdersbrug in less than 4 hours, even if the plant is in “cold” state. Other options are from Ham using the 150 kV or from

Drogenbos using the 380 kV, if sufficient reactive power absorption capacity is available to compensate for the cables (380kV and/or 150 kV) east from the city of Bruges. This can be achieved by shunt reactors or by synchronizing a non-black start unit.

Table 10 summarizes the restoration scenarios between an existing black start location (hot and cold state) and the critical connections.

Critical connection	From Coo	From Herdersbrug	From Ham/Ringvaart	From Drogenbos	From Seraing
Doel	5h	4h - 5.5h	3.5h – 5h	3.5h - 5h	>5.5h
Tihange	3h	>6h	>6h	3h – 4.5h	2.5h – 4h
Zeebrugge	>6h	2.5h – 4h	3h - 5h	>5.5h	>6h

Table 10: Restoration times between existing black start plants (example) and category 1 critical connections

Given the dispersed geographic location of the critical connections of category 1 throughout Belgium, it is not possible to re-energize all three connections from any current single black start unit within 4-5h. At least two independent islands and corresponding black start plants are required to re-energize category 1 connections within target restoration time.

5.3.1.2. Re-energization of the 380 kV North – South axis

It is recommended to set up a 380 kV backbone (at least between Doel and Tihange) for the following reasons:

- Not only the critical consumers of Doel and Tihange are energized, but also in case a nuclear plant has succeeded houseload operation, it can synchronize to the 380 kV grid and provide extra stability, reserves and reactive power absorption capability.
- The pump storage plant of Coo can easily be connected to the 380 kV backbone. Some units in Coo can operate in pump mode, providing the load to allow the nuclear unit to ramp up power to a stable minimum level (approximately 240 MW for a 1000 MW unit).
- Synchronization devices to allow coupling of asynchronous zones are located in 380 kV substations
- Synchronization with neighbour countries is done via the 380 kV grid.
- Most of the non-black start plants can be reached within 40 minutes from a 380 kV substation.

If possible, the western corridor (via Bruegel) is preferred above the eastern corridor (via Van Eyck) because of the socio-economic importance of the city of Brussels.

As shown in Figure 8, it is recommended to have one black start unit located close to the axis Zeebrugge-Doel and the other unit close to the axis Doel-Gramme.

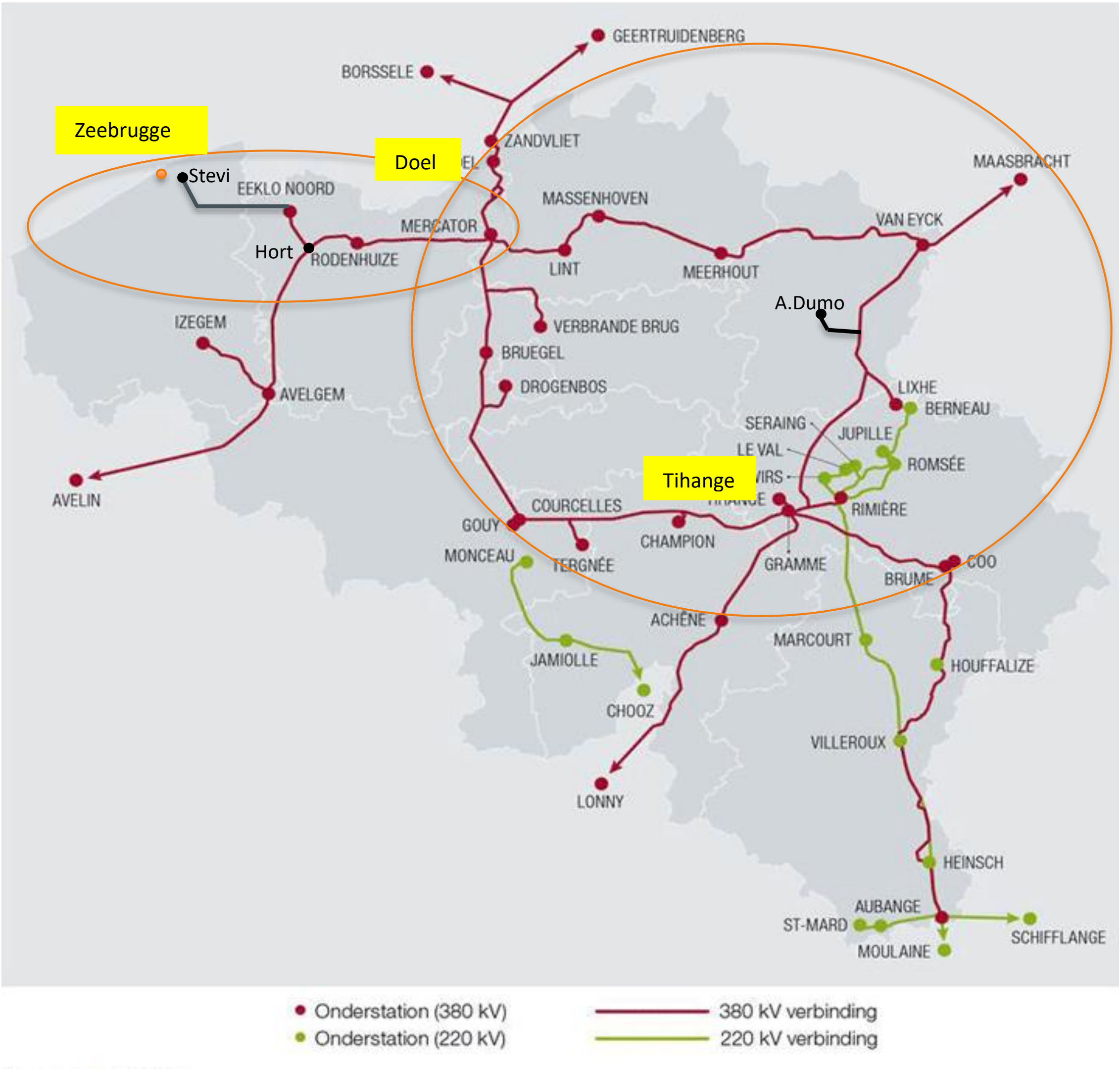

Figure 8: Two black start islands to supply category 1 connections and North-South 380 kV backbone

Several existing and potential new power plants near the 380 kV rectangle (Gramme, Courcelles, Mercator, Van Eyck) could be eligible to energize the 380 kV backbone to supply the auxiliaries of Doel and Tihange.

Depending on the geographic location of the plant and the progress on reactive power compensation deployment throughout the system, the reactive power absorption requirements for the black start plant could significantly change.

A feasibility study should determine if the black start candidate is eligible on a case-by-case basis.

The same principle is valid for the black start unit on the axis Zeebrugge-Doel.

The bar graphs in Figure 9 show that with two black start units, the critical connections of category 1 can be re-energized within 5 hours, which is acceptable.

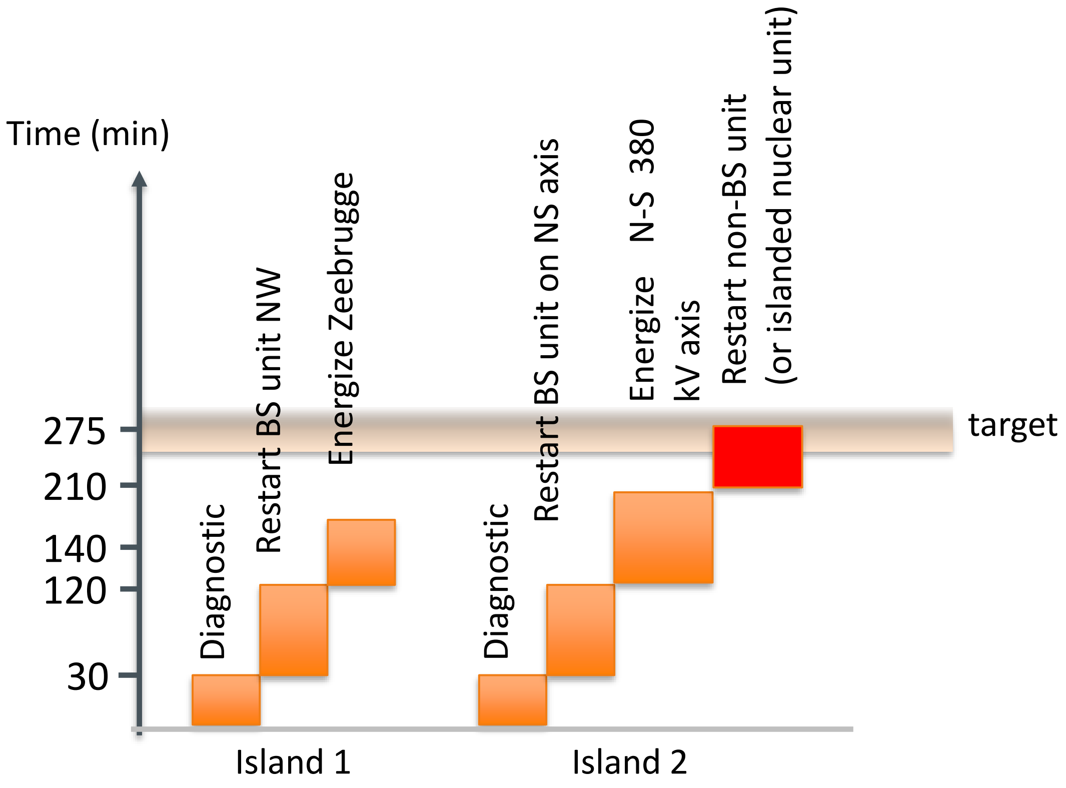

Figure 9: Time indication to supply category 1 connections and North-South 380 kV backbone with two black start units

To approach the indicative target restoration time of category 1 critical loads and to rebuild the 380kV North-South axis, at least two black start units are needed at the time of a blackout, preferably one unit in the North-West and one unit dedicated to restore the 380kV grid.

5.3.2. Step 2: re-energize category 2 connections

5.3.2.1. Introduction

After re-energization of substations in step 1, it is important to synchronize non-black start power plants as soon as possible to increase stability of the island, to extend reactive power absorption capabilities and to provide active power to consumers. Synchronizing non-black start plants may also be required already during step 1 in order to manage reactive power constraints during energization of the 380 kV backbone.

As elaborated in section 3.2.5, it is not recommended to re-energize the rest of the Elia system only from the 380 kV backbone. In line with common practice in other European TSOs, a combination of a backbone and zonal restoration approach is preferred.

In this section, the minimum required regional black start zones are determined.

5.3.2.2. Geographical distribution of generation in Belgium

Some areas in the Belgian network have a high density of generating units. Figure 10 illustrates the distribution of the production park in 2025 (hypotheses on potentially new power plants and nuclear phase-out). The seven high-density generation areas are Bruges, Ghent, Antwerp, Brussels, Limburg, Liège and Charleroi.

The 380 kV grid provides a path linking all these generation-rich areas.

A black start unit within one of these generation-rich areas can provide a short cranking path to the plants within the same area. Each generation cluster has a relatively limited size and therefore the requirements for a black start unit to provide a cranking path to a non-black start unit in the same cluster are not very high.

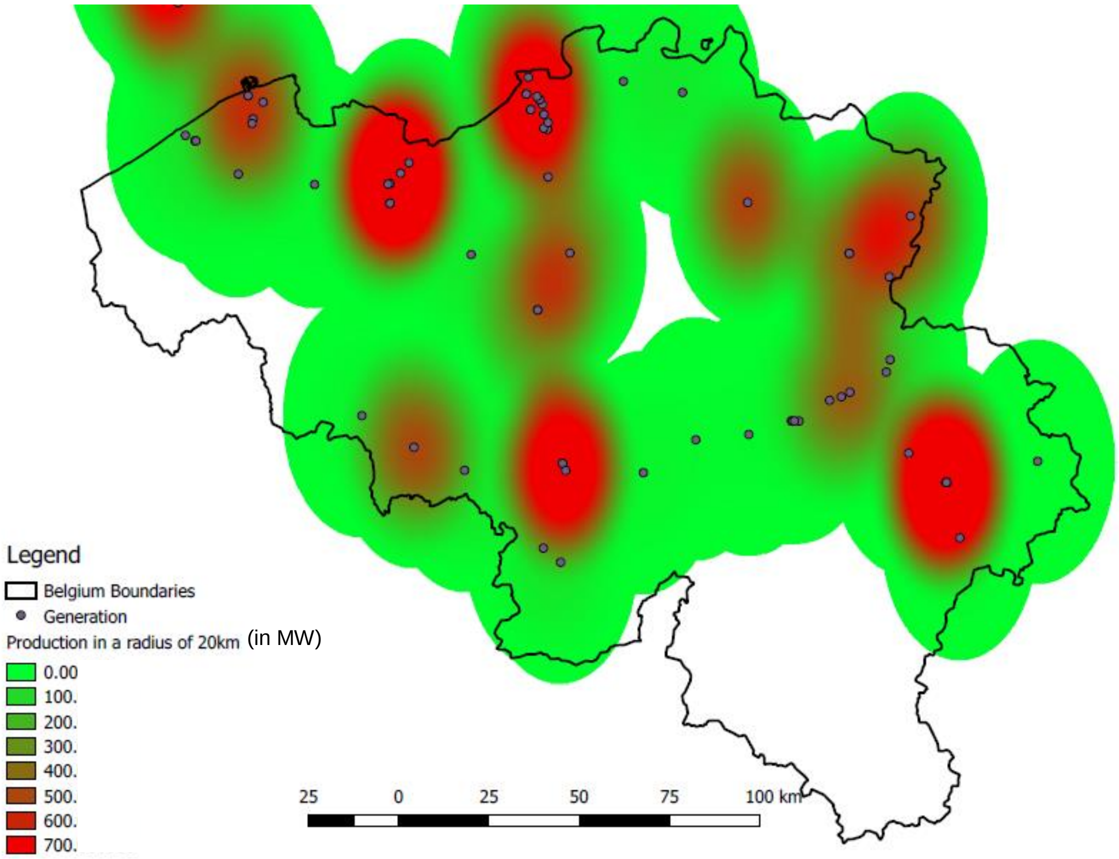

Figure 10: density of generation in Belgium (nuclear plants excluded)

5.3.2.3. Criteria to determine the minimum required regional black start zones

Keeping in mind that a black start unit may be unavailable at the time of a blackout, it is recommended that a black start unit in one cluster could provide power to two other clusters.

The x-markers in Table 11 indicate if a black start unit in one cluster could serve as backup for another cluster, for each possible pair of cluster. The criterion is that the 380 kV link between both clusters does not produce more than 60 MVar in unloaded conditions.

	Bruges/Ghent	Antwerp	Limburg	Liège	Brussels	Charleroi
Bruges/Ghent	x	x				
Antwerp	x	x	x		x	x
Limburg		x	x	x		
Liège			x	x		x
Brussels		x			x	x
Charleroi		x		x	x	x

Table 11: generating-rich areas that can serve as backup for eachother using the 380 kV backbone

Table 11 shows that the clusters of Antwerp and Charleroi are the most interesting places for additional black start units from a geographic point of view.

The regional black start plants should be able to re-energize the category 1 connections, if black starting the 380 kV backbone should not be possible.

The regional black start plants should be able to re-energize the category 2 connections in the corresponding zone (Fluxys compressor stations at Winksele, Berneau and Zelzate) within approximately 6 hours after the blackout.

During step one, the need for a regional black start zone in the North West part of Belgium was already identified to enable the re-energization of Zeebrugge.

Three regional zones, with one black start unit per zone are proposed, indicated in Figure 11 to fulfil the above-mentioned criteria, in addition to the black start unit to re-energize the 380 kV backbone.

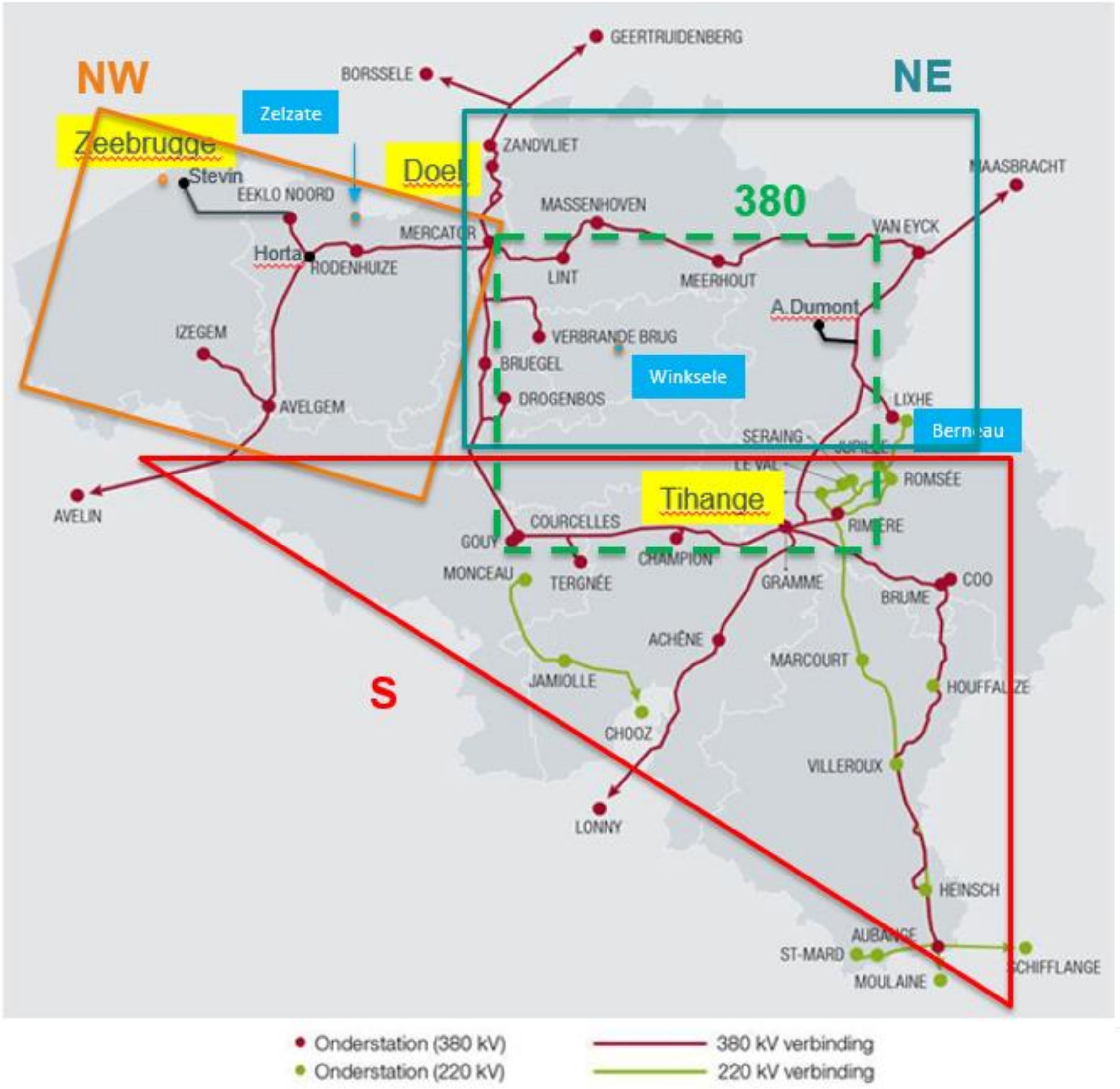

Figure 11: Three regional black start zones in addition to the 380 kV backbone

- Objectives for regional zone North-West, re-energized from Regional Control Centre (RCC) Merksem (West)
  - Energize Doel and Zeebrugge in 4 hours
  - Energize Zelzate in 6 hours
  - Energize path to non-BS units in cluster Ghent, Bruges, Antwerp
- Objectives for regional zone: North-East, re-energized from Regional Control Centre (RCC) Merksem (East)
  - Energize Doel in 4h

  - Energize Winksele in 6 h
  - Energize path to non-BS units in cluster Antwerp, Ghent, Bruges, Limburg, Brussels, Charleroi
- Objectives for regional zone: South, re-energized from Regional Control Centre (RCC) Créalys
  - Energize Tihange in 4 h
  - Energize Berneau in 6 h
  - Energize path to non-BS units in cluster Charleroi, Brussels, Liège and Antwerp

It is important to note that only 380 kV lines interconnect Charleroi and Liège. There are no direct 150 kV or 220 kV lines between both clusters. Therefore, if a black start unit is located near Charleroi, it might be useful to re-energize the region Liège via the 380 kV backbone and vice versa, provided the 380 kV backbone can be re-energized.

As explained in the design note on restoration services, the objective is to acquire black start services based on a public procurement procedure consisting of a call for expression of interest to participate and a submission of offers. Depending on the location and type of black start units that expressed their interest, a fourth regional island might be required to make sure that all zones can be reached with sufficient backup black start capability.

5.3.2.4. **Restoring the category 2 critical connections**

The critical connections of category 2 are the following:

- Important Fluxys compressor stations of Berneau, Zelzate and Winksele
- Auxiliaries of non-black start units (non-nuclear)
- 380 kV substations

To estimate the restoration time of category 2 connections, two reference black start locations in each of the above defined regional zones have been arbitrary chosen at distant locations. For each category 2 connection point, the path from the reference black start locations are calculated.

In case a regional black start unit would not be available, the category 2 connections will be re-energized from the 380 kV backbone, which was already energized in step 1.

Each of the category 2 loads can be supplied within 6 hours from the corresponding regional islands or from a re-energized 380 kV backbone within 40 minutes.

It is assumed that the other 380 kV substations can be re-energized from the North-South backbone within 6 hours.

5.3.2.5. **Cranking paths from the 380 kV grid to power plants**

If the dedicated black start unit for a certain regional zone is not available after a blackout, the cranking paths from the 380 kV backbone to the non-black start units of that zone have to be set up.

Most of the power plants can be reached from the 380 kV backbone in approximately 30 to 40 minutes, supposed that no substations on the restoration path are already energized.

In particular, for the North-South 380 kV backbone island, it is important to ensure clear communication and coordination between NCC and the RCCs, because multiple non-black start units will be connected to the same island. NCC should coordinate sharing of active and reactive power load in collaboration with RCCs.

The RCCs now can proceed in parallel with connecting the remaining load categories, in particular the decentralized high priority significant grid users (hospitals, emergency call centres, …) and energize the substations, which are still at zero voltage.

5.3.3. Step 3: Restore main load centres

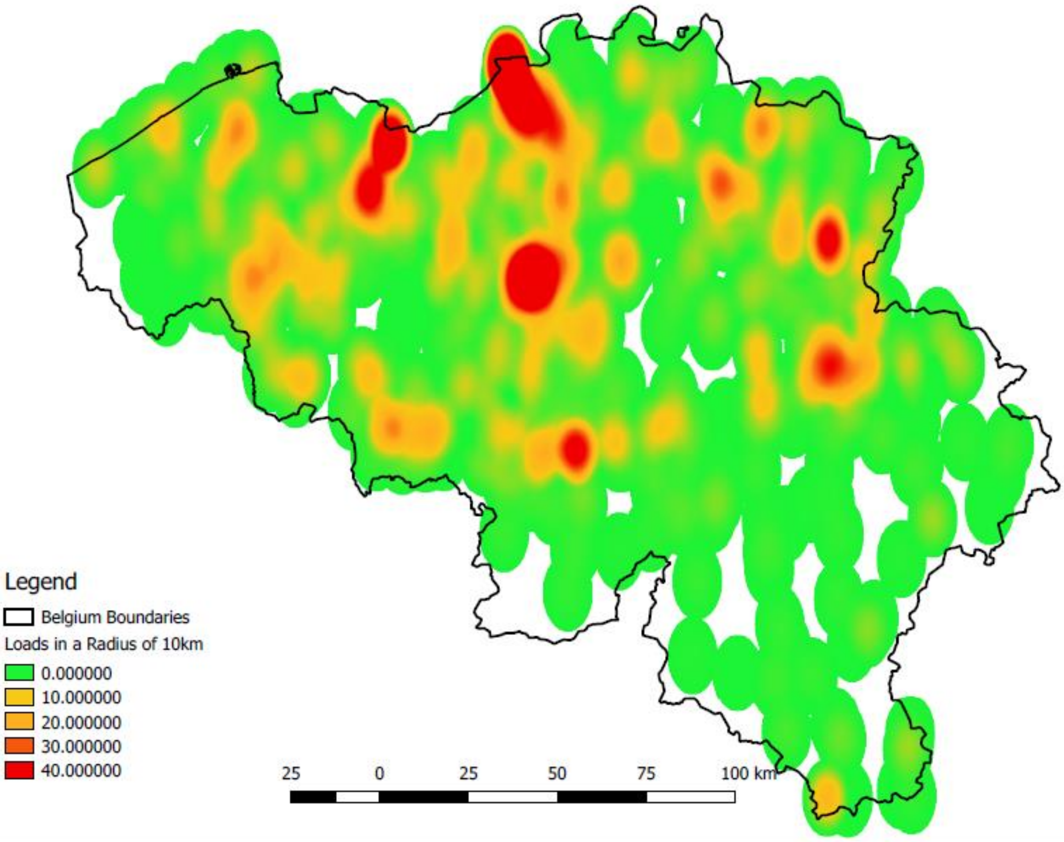

Figure 12: heat map of the electrical loads for the 2025 scenario

Some areas in the Belgian network have a high density of load. Figure 12 shows a heat map of the electrical loads as forecasted for 2025.

Three highly dense clusters can clearly be observed: Ghent, Antwerp and Brussels. The three other main clusters are Charleroi, Liège and Genk-Hasselt. Notice that these clusters almost co-inside with the generation-rich areas.

In order to minimize the societal cost of a total blackout, it is important to restore the loads in a timely manner. Prioritizing the zones having a high-density of loads, including main hospitals and industrial consumers connected to the transmission network, is therefore recommended. These types of loads are present in each of the six mentioned clusters.

As the needs for the restoration of the load centers are parallel to those of the generation-rich areas, the distribution of the load centers does not result in the need for additional black start units, but supports the needs detected in the previous section.

5.4. Conclusions about the minimum required black start capability in Belgium

The study recommends a combination of a zonal and backbone restoration methodology to re-energize the Belgian system after a blackout.

Assuming that it takes between 120 minutes (30+90) and 210 minutes (30+180), depending if the black start unit was running or not before the blackout occurred, to energize the first bus after a blackout. Taking also into consideration the indicative target restoration times for the critical connections, a very straightforward path must be available from the black start units to each critical connection of category 1. To reach the approximate 4-5 hour restoration target, at least two black start units are required.

Ideally, one unit is to be located close to the axis Zeebrugge-Doel and the other unit close to the axis Doel-Gramme. Reactive power absorption capability is an important parameter. A feasibility study should determine if a black start candidate is able to fulfil the requirements depending on its location and the status of the network at that time.

The fast set up of cranking paths to non-black start units, spread throughout the country, is important to increase stability, reactive power absorption capacity and active power to consumers. Therefore, black start units should be close to non-black start units. Moreover, backup for each black start unit is required to mitigate socio-economic losses.

Four BS units are required to restore the Belgian grid with bottom up strategy

- **1 BS unit located close to the axis Doel-Gramme to energize 380 kV backbone**
- **1 BS unit in zone North-West**
- **1 BS unit in zone North-East**
- **1 BS unit in zone South-West or South-East**

The backbone unit and the regional units serve as each other’s back up. Depending on the location and type of units offered, one extra BS unit might be required

Critical connections of category 2 can be restored from the corresponding regional black start zones within target restoration time of approximately 6 hours. Alternatively, they can be re-energized timely from the 380 kV backbone in case the regional black start unit is not available.

Simulations indicate that after a potential nuclear phase-out, the bottom-up restoration of the 380 kV backbone is still possible, provided adequate reactive power absorption means are foreseen. Additional reactive power compensation devices will be installed throughout the high voltage system in the coming years.

6. Active power, storage and reactive power capability requirements

This part of the study focusses on the **active and reactive power requirements** for power plants that want to offer the black start services, which were identified as minimum required in the previous sections.

An entire list of technical requirements for power plants to deliver the black start service is elaborated in a separate document “Design note on restoration services”. This document will be submitted to the Creg together with the present document.

During the first phases of restoration and re-energization procedures, the conditions of the (dead) grid and potential instability when restarting call for **stringent requirements in terms of active and reactive power capabilities** of assets contributing to the restoration.

The requirements for a specific black start unit depend on the location of the black start unit itself, the evolution of the grid and the load requirements behind critical connections.

6.1. Active power requirements

The assets used to provide a restoration service must be capable of instantly accepting an offtake of at least 10 MW (with a cos phi ≥ 0.8 inductive) and with a maximum active power volume (with a cos phi ≥ 0.8 inductive), while respecting the limits with respect to frequency, voltage, and currents.

As explained in section 5, the goal of a specific restoration service is to re-energize critical connections including auxiliary services of the nuclear production units, Fluxys compressor stations and the auxiliary services for starting non-black start production units.

The black start units should not be operated near their maximum active power limit during the early restoration process. Given uncertainties about the exact power consumption after a period of non-supply and to cope with the fluctuations in offtake of reconnected grid users, some upward reserve capacity should be respected on the black start plants to avoid frequency instabilities. A good engineering practice rule of thumb is not to exceed 70% of maximum power production when initiating the restoration plan.

During the procurement phase, ELIA will communicate requirements with respect to installed capacity, based on the estimated MW needs for a specific restoration path.

For a black start restoration service that consists of a self-starter (e.g. a small CHP unit) and main generation unit that are both connected to the Elia grid, the active power capacity of both production units may be added.

6.2. Storage requirements

In case a battery or water storage is required to enable the black start service, a minimum level of stored energy available for the black start service should be maintained at all times.

If the stored energy is used to energize temporarily the auxiliaries of a main black start unit that uses another energy source as primary energy source for the main generator, the minimum energy stored should be sufficient to allow 3 consecutive black start tentatives. It should be verified that as soon as the main unit is able to supply its own auxiliaries, the storage is no longer required.

If the stored energy is used as primary energy source for the main black start generator, the minimum energy stored should be sufficient to supply the relevant critical connections and the auxiliaries of a non-black start unit, during a period until the non-black start unit(s) can produce sufficient power to feed the load of the critical connections and the auxiliaries of the non-black start unit(s).

6.3. Reactive power requirements

The assets used to provide a restoration service must be able to handle the connection of grid elements (overhead line, cables, …) generating a significant amount of MVar under low loaded conditions and be able to absorb the reactive power generated by the grid elements during restoration.

The current requirement of 30 MVar absorptive capacity is not sufficient in some regions and for some re-energization procedures. The MVar absorption requirement in the zone may, however, also (partly) be covered by shunt reactors or other reactive compensation devices installed by ELIA in the coming years for purposes of grid development, which would allow to reduce the absorption requirement for service in the concerned zone.

ELIA would therefore in the future not maintain a fixed MVar requirement for all contracted restoration services but **communicate in the procurement phase an indicative value for MVar absorption requirements** for each restoration service.

As a result, the procurement may bring forward different MVar absorption requirements for services in different zones or the requirement may change from one procurement cycle to another (e.g., due to grid investments in the area affecting the reactive power management).

For the regional black start services and for the black start services used to energize the 380 kV backbone, a reactive power absorption requirement of minimum 50 MVar at the low voltage side of the step up transformer, during low active power production, will be used as indicative value.

A specific simulation should confirm if the 50 MVar absorption capability is sufficient for the specific case. If the 50 MVar seems not sufficient, the reactive power requirements for the specific contract will be higher.

7. Potential to meet the technical requirements to participate to black start per technology in Belgium

This part of the study makes a screening of the black start potential per type of technology relevant for the Belgian power system.

For the purpose of this study, Elia conducted an inquiry among operators of power generation modules with an installed capacity higher than 25 MW, related to black start, houseload, resynchronization and re-energization capabilities. The answers to the questionnaires are joined in annex 1 and are only included in the confidential version of the report.

7.1. Nuclear units

Nuclear units in Belgium do not have black start capability by themselves but can be restarted when plant auxiliaries are re-energized by an external source.

In the case of a blackout, the safe operation of the nuclear process must be guaranteed and there are several layers of defence to guarantee nuclear safety:

- Redundancy and independency in the design of the equipment
- Transition to houseload operation capability of the plant
- Emergency diesel

Houseload operation is considered by the power producers as an additional layer of defence (OECD & NEA, 2013). The ability to succeed a transition to houseload operation and keep running in houseload operation depends on the design of the nuclear plant.

Average success rate for houseload operation is strongly depending on operating conditions and position in nuclear fuel cycle (more difficult to succeed at the end of the fuel cycle).

Another layer of defence is the emergency diesel. These diesel units are sized to supply only the critical auxiliary loads and are not sufficient to restart the nuclear unit.

If the nuclear unit fails its transition to houseload operation, an emergency shutdown will occur. After an emergency shutdown, a long period is at least necessary to re-synchronize the main generator with the grid. The expected time to reconnect to the grid could increase if the fuel cycle is close to the end of its lifetime.

7.2. Gas turbines

Gas turbines have a high flexibility and are able to restart quickly (typically 30 min). Their auxiliary load is limited (approx. 500kW for large gas turbines). However, the required power involves the supply of the compressor and is around 3-4% of the nominal power.

There are several types of gas turbines but even the large gas turbines can be restarted quickly, even in a cold state. Smaller gas turbines such as aero derivative gas turbines can theoretically be restarted within 15-30 min and are very flexible. However, their inertia is small, and the feasibility of operating these units in a weak network must be investigated. An adequate design of the governor can help but might not be sufficient to guarantee the stability of the unit when operating in an islanding system.

The minimum load threshold of a gas turbine is usually set to be compliant with NO_x, SO_x and CO_2 emissions. If these constraints are less stringent during an exceptional scenario such as a blackout, gas turbines can be operated at low load.

For gasturbines in the Belgian grid that do not already deliver the blackstart service, a feasibility study on a case-by-case basis is necessary to determine the possibility to deliver the service.

7.2.1. Combined-cycled gas turbine

The combined-cycle gas turbines are composed of one or more gas turbines, heat-recovery steam generators and one steam turbine. The main constraints for starting and restarting the plant lie in the steam turbine. The steam turbine requires a high auxiliary load and is subject to stringent thermal constraints.

The auxiliaries of the gas turbine are relatively small (<1MW even for large gas turbines). However for steam turbines, the auxiliaries can be up to 5 MW for a 400-500MW CCGT. Most of the steam process auxiliaries must be energized in order to restart the heat recovery steam generator. Indicative starting times for CCGTs are shown in Table 12.

Indicative starting time	Range for CCGT	Most common values
Hot start (<8h)	0h45 - 2h	65 min
Warm start (8h<t<48h)	1h - 3h	155 min
Cold start (>48h)	3h – 4h	210 min
Ramp rate	10 - 25 MW/min	~15 MW/min

Table 12: indicative starting time CCGT

The main thermal constraints of the steam turbine lie in the drum boiler. The temperature in the boiler must be controlled and fast variation must be avoided.

7.2.2. Single-shaft vs dual-shaft combined cycle gas turbines

There are two main configurations for CCGTs. The first one is to have the gas turbine and the steam turbine on the same shaft driving a single generator.

In a multiple shaft design, there are usually multiple gas turbines and generators and a single steam turbine.

The difference in configuration is important during the starting sequence of a CCGT. For a multi-shaft plant, the gas turbines are started first. During the start-up sequence, the steam is by-passed to the condenser. Then, the steam turbine can be brought up to speed by closing the bypass valve.

For a single shaft, a clutch is typically used to decouple the gas turbine and the steam turbine, meaning that the steam turbine can be brought up to speed at a lower rate than the gas turbine; even on the same shaft. Without a clutch, the gas turbine has to be started at the same speed as the steam turbine. This affects the starting time of the gas turbine but has a marginal impact on the starting time of the steam turbine, meaning that with or without clutch a similar time is required to go to nominal power. Note that in dual-shaft systems, only one gas turbine has to be restarted at a time.

Both single shaft and dual shaft configurations exist in Belgium.

7.2.3. Operation of CCGT in open cycle

Some CCGT power plants are able to operate in open cycle, meaning that only the gasturbines are used, while the steam turbine is not operated. A by-pass stack allows evacuating the exhaust gas from the gas turbine into the atmosphere, without passing through the steam generator.

Another option to operate the CCGT in open cycle is to operate the steam turbine in dry mode (i.e. without steam). However, this implies more stringent thermal constraints in the boiler. Not all CCGT plants are able to operate in this mode.

If a CCGT cannot be operated in open cycle, the required starting power will be the sum of the starting power for the gas turbine and of the auxiliaries of the steam turbine.

7.3. Hydro / pump storage

Hydro units are very efficient to provide black start capability. Their auxiliary equipment is very small and the turbines can be restarted quickly. The main limitations of hydro units are due to their limited amount of energy (a minimum water volume should permanently be kept as black start reserve).

7.4. Biomass

The majority of biomass power plants are similar in design to coal power plants. Both types of units make use of a steam cycle and usually have a steam turbine as prime mover. This means that the size of the auxiliaries for the steam process is significant and that the restart time of the turbine is dependent on the thermal constraints in the boiler.

Minimum storage requirements for biomass on site would have to be respected, as the supply chain of biomass could be interrupted during a blackout.

7.5. CHP

Combined Heat and Power (CHP) plants are industrial or residential plants that provide heat and power to an industrial site or a regional area.

The gas turbines in a CHP are conventional gas turbines that can theoretically be restarted within a very short timeframe. However, a limitation might come from the steam process. Depending on the CHP design, it must be carefully investigated whether the steam process can be by-passed. If not, it means that the whole process (and auxiliaries) will have to be restarted.

It can be concluded that it is feasible to use CHP as black start units but this has to be analysed on a case by case basis.

Note that in most cases, no local operators are on site on a permanent basis. For special operating conditions such as system restoration, intervention is required from industrial client’s personnel, which might cause additional delays.

7.6. Residential PV

The black start capability of residential PV systems depends on the design of the inverter. Some inverters are only grid following and are therefore not suited for black start purposes. Other types of inverters are technically capable of black starting. This is typically a capability used when the customers want to go off-grid rather than for energizing the distribution network.

For energizing the distribution network from distributed PV systems, a complex coordinated approach needs to be developed and installed. Therefore, dedicated communication channels are also part of the technical requirements.

A battery system must be available to energize the auxiliary loads.

The use of residential PV for power system restoration is currently studied in academia. Some papers outline the benefit of using residential PV for a fast restoration of the loads in an islanded distribution network. While this is in theory an interesting idea, it triggers multiple questions regarding protections, stability, variation of irradiance, voltage and frequency control, operation, etc. which outline that the maturity level is very low.

PV is currently considered as an additional challenge when restoring the first loads due to the intermittency of the PV production and the lack of frequency support.

However, thanks to the decreasing cost of residential PV and battery system, it might happen that multiple residential customers will be able to operate off-grid. The number of these customers is uncertain and will depend on the regulatory and economic framework in 2030, but it is assumed that allowing customers to go off-grid will reduce the amount of loads to be restored and also the total cost of a blackout.

7.7. On-shore wind

Small diesel generators or a battery system must be installed to supply the auxiliary loads.

The inverters must be designed with grid forming capability and must be able to operate in a weak network.

A coordinated control of the wind turbines must have included in the plant design and the related plant controller must be able to control frequency and voltage in a weak network.

Currently on-shore wind farms are not used when elaborating restoration plans. This is mainly due to the intermittency of wind. In addition, the difficulty to cope with wind variation and frequency control implies operational and control challenges.

Battery energy storage systems can be installed to mitigate the intermittency of wind energy. However, if there is no wind during the power system restoration, the technical capability will only be provided by the battery system.

The use of on-shore wind farms to contribute to power system restoration will only be beneficial when reconnecting to a stable island able to handle active power variations caused by wind.

7.8. Off-shore wind

In February 2018, consultant Frazer-Nash published an overview of the innovative developments of black start capabilities for off shore windfarms. They performed an inquiry among windturbine manufacturers (1 public document), a literature study (3 journal articles) and a patent search (12 patents in the last 10 years).

Black start is differently interpreted by different stakeholders. Windturbine manufacturers understand it as powering auxiliaries of each individual windturbine. Windfarm operators see it as powering the offshore switchyard when the grid connection is lost. TSOs see it as using the windfarm to re-energize the grid.

Most windfarms are equipped with a diesel generator on the offshore platform. The diesel is not able to send power to the onshore grid.

The most basic form of black start consist of an individual windturbine that black starts itself and powers its own auxiliaries. Commercially available turbines are able to do this.

A greater challenge for the turbines is to energize the cables between the windturbines and to the offshore platform. The windturbine inverters must be designed to be grid forming and to operate in a weak network. Further development is needed to handle the reactive power produced by the array-cables. Most recent turbines are close to being able to do this. It is a relatively easy step for the turbines to black start the platform, with the inductance of the transformers offsetting the capacitance of the cable.

A large gap to bridge is to energize the cable to the onshore substation and to meet the grid code requirements in terms of voltage and frequency control during the system restoration. Other challenges are block loading during demand connection and wind energy availability.

Significant work is still required to make black start of the onshore grid technically feasible.

In countries where the installed capacity of offshore wind will become very high, it is expected that TSOs will be familiar with dealing with a high share of intermittent generation on a daily basis. This includes regular use of manual actions (e.g. mFRR) and of adapted operation procedures. For these TSOs, it will then be an option to use intermittent generation early in the restoration procedure, even if it adds an additional layer of complexity. It is expected that using intermittent energy require that flexible plants such as gas or hydro units be already connected to the system, in order to provide sufficient inertia and up and downward reserves. Therefore, the contribution of intermittent energy is not likely to be significant during the first stage of the restoration process.

7.9. Battery Energy Storage System (BESS)

In addition to the requirements for inverter-based technology to have black start capability, storage systems do require a minimum amount of energy. This is similar to the current requirements for the pumped-storage station at Coo.

The energy requirements must be defined in function of the role of the BESS in the restoration procedure. For example, the energy requirements for a BESS aiming at re-energizing the auxiliary load of a single generator will not be the same as the energy requirements of a pumped-storage plant aiming at providing cranking path to multiple generating units.

The use of BESS for power system restoration is at its very early stage. Some utilities combine the use of BESS with an existing utility to provide ancillary services such as frequency regulation or black start services.

Black starting a BESS to supply the auxiliary of a neighbouring plant has already been successfully achieved in Germany. Therefore, this allows restarting large plants that do not have black start capabilities but situated close to a BESS system.

BESS can be used as black start sources or to mitigate voltage and frequency disturbances during the rebuild of the system. This depends on the design and size of the BESS.

The main limitations of the storage systems are their location and available energy reservoir. The installation of battery energy system storage is currently very limited in the Belgian grid. The already installed BESS aims at participating to the frequency regulation. For this purpose, it could theoretically be installed anywhere in the Belgian grid. Therefore, having an incentive to install BESS close to large power stations, which do not have black start capability, should be analysed. It is expected that if economically viable, BESS will be used in combination with conventional plants for providing black start services.

8. Recommendations for the design of future restoration services

A review of the black start ancillary service with the purpose of reducing its costs for society requires attention for different aspects that influence the cost:

1. The total cost for society

   The cost optimization should consider both the **costs of the blackout for society and the cost of the restoration**. The aim is an ancillary service that is **both cost efficient and effective**. A restoration at lower cost may indicate a less effective restoration that increases the total cost for society.

2. The need for restoration services

   ELIA determines the need for restoration services by taking into consideration the concrete action and sequences in the restoration plan. The goal is to achieve a **restoration** of the system **as quickly as possible** in a **secure** way in order to minimize the impact on grid users (e.g., time without electricity affecting every-day life, impact on safety (e.g. hospitals, traffic situation), impact on business and therefore economic loss). The need for restoration service is reflected in the number of restoration services to contract (included in the Restoration Plan) and the desired geographic distribution of those contracted services (included in the Terms & Conditions for Restoration Service Providers).

3. The means for restoration

   Given a specified need for restoration services, the **design of the service itself** influences the **availability** of such services in the system (incentive for the installation of the technical capabilities in the system) and the **cost** of the service itself.

The three aspects listed above motivate **design choices on two levels**: firstly on **scope** of the service (**"Which services can be offered to ELIA?"**), and secondly on the **content** of the service (**"How is the service concretely organized?"**). This chapter explains for both how the performed study defends to maintain or to review current elements of the product design.

<u>Scope of the service</u>

Restoration services on a contractual basis specifically refer to services using a **bottom-up re-energization** process. In other words, when the grid is no longer energized ("blackout") some connected power units are capable of putting the grid back under voltage ("re-energize").

As explained in chapter 4 Elia contracts only restoration services using black start capabilities to cover the identified needs for restoration. This is the case today and Elia will continue to follow this restoration strategy in the future.

<u>Content of the service</u>

The potential for improvement of the design of restoration services lies in the specific requirements. A note with the new design proposal of ELIA is published in a separate document yet together with this report, and elaborates on the new design elements and arguments to support them. The following paragraphs give a high-level overview of the recommendations that drove the new design proposal based on the analyses reported in previous chapters.

Today ELIA procures the black start service via a public **competition** with a default contract duration of **5 years** (or less in case of Royal Decrees). The contracted service may contain **different assets located on one site**. The power unit is either **a thermal unit or a pump-storage unit**. The price offer of the provider contains **one price reflecting cost to be technically and operationally available** as well as possible opportunity costs. Currently the availability of black start capabilities in the Belgian system is low, and thereby so is the competition and the efficiency of the tender organization.

The study shows that, although there are some countries where the service is mandatory, **ELIA can maintain the procurement via a public call for participation**. The ancillary service stimulates and remunerates the installation of black start capabilities in the grid, but the needs for restoration services in the system are limited. Therefore, an overall service obligation—potentially at no cost—either does not provide the correct and fair incentives or does not result in a good coverage of ELIA's needs at minimal costs. The description on the determination of needs, however, also clearly indicates that the selection of services is not purely price-based but strongly supported by the technical quality of the offered services.

The number and the geographic distribution of black start services in Belgium is determined taking into account the distribution of grid users and the urgency to re-energize the part of the grid where they are connected. The number of services contracted in Belgium reflects the minimum need. Consequently, the **design** of the black start service focuses on **stimulating a high availability** of the service via variable remuneration per available day and penalties in case of excessive unavailability. The alternative would be to combine a less stringent design per asset (lower availability requirements or more explicitly principle of back-up units per service) with a higher amount of contracts per coverage zone (as is the case in some other European countries. However, as ELIA so far does not experience problems of excessive unavailability on those units capable of executing a black start, ELIA prefers to maintain the current focus on stringent requirements.

Whatever the identified needs for restoration services may be, even when procured via a public procedure, the stability of the needs and the characteristics of the service—requiring heavy investment costs—support a long contract duration. Some other TSOs that organize tenders (or have a paid bilaterally agreed service) work with contract durations of 10 or 15 years. **A review of the actual contract duration of 5 years would be useful**, keeping in mind the particularities of the service as well as a desire to keep the market open for both existing and new providers. Long contract durations are interesting for the remuneration of high investment costs but such long-term commitments may discourage existing units from submitting offers.

Large thermal or pump-storage units mainly provide today's black start service in Belgium and in other European countries. This selection of providers is the result of the severe technical requirements (e.g. to accept a minimum block load, to be able to absorb the high amount of reactive power released by the grid during re-energization, to generate at specific levels) which typically cannot be provided by smaller units or by intermittent units. However**, the study indicates a potential to open up the delivery of the service to alternative configurations.** Aggregations of units could equally respect the requirements of the service. For example, a battery storage facility connected in a distribution grid could serve as black start source to energize the auxiliaries of a large thermal power plant. Collaborations between small and large units could enter into competition with typical black start generators depending on diesel (elevating the costs of installment and environmental permits).

Collaboration between the involved parties, the distribution and transmission system operators will be required to investigate the feasibility of such integrated solutions. It is not excluded that energy storage systems could facilitate participation of intermittent production to restoration services in the future. However, for the moment intermittent production units are not considered as proven technology for grid restoration. Other TSOs have not yet opened up the service to non-typical production types, but have also expressed their intent to analyse the potential in the future.

Also the **introduction of the Restoration Service Provider (RSP)** in the European Network Code for Electricity Emergency and Restoration is a first step in allowing aggregations of several assets (potentially owned by different Grid Users) to provide the service. Currently in Belgium, the ARP (Access Responsible Party) offers the Black Start Ancillary Service to ELIA. **A review of the provider of the service, from now on the RSP, is also subject to redesign.**

The technical requirements of the black start service are now stringent, with a small margin for deviations. The study on how to determine the minimum number of black start units, however, points out that some requirements, in specific the one related to the capability to absorb reactive power, may depend on the location of the service and its particular role to play in system restoration. **The study result advises a review of the technical requirements.**

A last identified point that demands a redesign concerns remuneration. The benchmark study shows that many TSO remunerate the same type of costs to provide the service (e.g., costs incurred to install the technical black start capability or operational costs to assure availability). A higher transparency of the costs would allow for a better comparability of the different services, as could be done by contractually splitting the cost in its different components (e.g., distinct investment costs only incurred by new providers versus comparing operational costs of both existing and new providers).

Parallel to the study reported in this document ELIA has reflected on the possibilities for a new design. The “Design Note on Restoration Services” elaborates ELIA’s proposal to change the design of the ancillary service. ELIA has published this design note in the same public consultation as this study to provide the stakeholders with a better view of the benchmark study, the study on the needs determination, and its impact on the design of the ancillary service. The design note will be submitted to the Creg together with this report in response to the target for 2018 defined in the framework of the incentive regulation mechanism.

CONCLUSIONS

In response to an incentive determined by the Creg, Elia carried out a study on the black start service for the Belgian electricity system in the period between 2021 and 2030. The conclusions of the study are summarized hereafter:

- For a secure and sustainable bottom up restoration of the Belgian system, minimum four black start units are required: one unit to re-energize the 380 kV backbone between Doel and Tihange, one unit in the North-West region, on unit in the North-East region and one unit either in the South-West or South-East region. The black start units should be connected to the 150 kV, 220 kV or 380 kV system.

- Most of the production units connected to the Elia grid have the technical capability to perform houseload operation. However, the probability to succeed in houseload operation when a blackout occurs is unknown. Therefore, houseload will not be considered as replacement for black start plants. ELIA will only contract restoration service based on black start capabilities given the significantly higher probability of availability when needed.

- Production units that want to deliver black start services can make use of a starting unit (diesel or battery) to feed the auxiliaries of a main generator that might be on a different location, provided the (distribution) grid allows connection between both locations. Elia wants to evaluate the usefulness of new proposed technologies, which should lead to an increased number of eligible candidates and increase competition on the market. Elia defined technical minimum requirements for the start and main generators.

- Hydro pump storage plants are most suited to deliver the black start service, due to high dynamic flexibility, short startup times, high reactive power absorption capability and the ability to operate as generator or as load. Sufficient water reserves are required. Gasturbines in open cycle have also very well suited technical characteristics to deliver the service.

- Elia expects that intermittent power production units will not be able in the coming years to meet the minimum requirements to adopt a role as black start service provider. Major bottlenecks are the operation of DC/AC convertors in weak grids, the absorption of reactive power and the storage requirements in case of absence of wind or sun radiation.

- European Network connection codes, applying to new generation units, provide flexible instruments for system restoration to TSOs. Member states can impose black start capability to a new unit if required to ensure the security of the grid. Houseload operation capability will become mandatory for new units.

- Among European countries, large differences were observed in (market) models and sourcing methods for ensuring black start services. However, black start costs tend to increase in most countries in periods were conventional power plants are not needed due to increasing penetration of renewable energy.

- Based on the studied aspects, Elia proposes a new design for the future black start mechanism, based on a market based approach while ensuring the sustainability of the black start service at minimal societal cost.

9. References

EirGrid. (2008). *Ancillary Services Agreement.* Opgehaald van http://www.interconnector.ie/site-files/library/EirGrid/Ancillary%20Service%20Agreement.pdf

EirGrid. (2011). *Becoming operational: generator customer information pack.* Opgehaald van http://www.eirgridgroup.com/site-files/library/EirGrid/Becoming-Operational-Generator-Customer-Information-Pack-Dec-2011.pdf

EirGrid. (2017). *Ancillary Services Statement of Payments and Charges 2017-2018.* Opgehaald van http://www.eirgridgroup.com/site-files/library/EirGrid/Ancillary-Services-Statement-of-Payments-and-Charges-2017-2018.pdf

EirGrid and SONI. (2015). *Harmonised Ancillary Services Consultation.* Opgehaald van http://www.soni.ltd.uk/media/documents/Operations/Ancillary-Services/HAS%20Recommendation%20Paper%202015-2016.pdf

ENTSO-E WGAS. (2017, March 10). *Survey on ancillary services procurement, balancing market design.* Opgehaald van ENTSOE: https://www.entsoe.eu/publications/market-reports/ancillary-services-survey/Pages/default.aspx

FRAZER-NASH consultancy. (2018). *Black start capability in the windturbine market.* Jamie Thomson / Ian Talbot http://www.ukerc.ac.uk/asset/1828833B-CA4A-4E61-A75DB5B501D93D6F/&usg=AOvVaw3iZnFjAAEuG7uz7VSQL1Bc

National Grid. (2018) Product Roadmap for Balancing Services. https://www.nationalgrid.com/uk/electricity/balancing-services/future-balancing-services

National Grid. (2017). *Black Start Procurement Methodology.* Opgehaald van https://www.nationalgrid.com/sites/default/files/documents/Black%20Start%20Procurement%20Methodology.pdf

National Grid. (2017). *Procurement Guideline Report 2017/18.* Opgehaald van https://www.nationalgrid.com/sites/default/files/documents/MBSS_Sep_2017%20V2.pdf

National Grid. (2017). *Procurement guidelines report 1 April 2016/17.* Opgehaald van https://www.nationalgrid.com/sites/default/files/documents/Procurement%20Guidelines%20Report%2016_17.pdf

10. Definitions and acronyms

BS: Black start

BSP: Balancing Service Provider

BRP: Balancing Responsible Party

Capability Curves: Diagram defining the operating possibilities of a power plant (MW-MVar).

CDSO: Closed Distribution System Operator

CGCCR: Centre Gouvernemental de Coordination et de Crise. Crisis center of the government.

CIGRE: International Council on Large Electric Systems

CIPU: Coordination of Injection of Production Units

Clearing: Automatic or manual interruption of all departures in a high-voltage substation

Commission: Commission for Electricity and Gas Regulation (or CREG).

Control Area: The area within which the system operator continuously controls the balance between the demand and supply of electricity, taking into account the Active Power exchanges between the Control Areas.

CREG: Commission for Regulation of Electricity and Gas

DC NC: Demand Connection Network Code. COMMISSION REGULATION (EU) 2016/1388 of 17 August 2016 establishing a Network Code on Demand Connection

Distribution Transformer: Transformer that injects electricity into the distribution system.

DSO: Distribution System Operator

EAS: EntsoE Awareness System: application used by all TSOs in EntsoE to inform eachother on their system state and other inter-TSO related information

Electrical System: All the equipment including all interconnected grids, all Connection Facilities and all Facilities of the Grid Users connected to these grids.

EMS: Energy Management System: the control system used for real time grid monitoring, remote control and security analysis.

Energy Coordinator: Operational department of the Access Responsible Party which coordinates the Production Units located in Belgium.

FPS Economy: Federal Public Service Economy, in particular the General Directorate of Energy. This entity represents the competent authority of Belgium, when referred to in European network codes.

HPSGU: High priority significant grid user, the significant grid user for which special conditions apply for disconnection and re-energisation;

HVDC NC: High voltage Direct Current Network Code. COMMISSION REGULATION (EU) 2016/1447 of 26 August 2016 establishing a network code on requirements for grid connection of high voltage direct current systems and direct current-connected power park modules

LFC area: Load frequency control area. For Begium, this corresponds to the Elia Control Area.

LFSM-U: Limited Frequency Sensitive Mode — Underfrequency means a power-generating module or HVDC system operating mode which will result in active power output increase in response to a change in system frequency below a certain value;

Minister for Economy: Minister or State Secretary responsible for the economy.

Minister for Energy: Minister or State Secretary responsible for energy matters.

NCC: National Control Centre

NCER: Network Code Emergency and Restoration. COMMISSION REGULATION (EU) 2017/2196 of 24 November 2017 establishing a network code on electricity emergency and restoration

NRA: National Regulatory Authority. In Belgium the role of NRA is fulfilled by the CREG.

PGM: Power Generating Module

PPM: Power Park Module

RCC: Regional Control Centre

RFG NC: Requirements For Generators Network Code: COMMISSION REGULATION (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators

RSP: Restoration service provider, a legal entity with a legal or contractual obligation to provide a service contributing to one or several measures of the restoration plan;

RTE: Transmission system operator in France

SGU: Significant Grid User

SOGL: System Operator Guide Line. COMMISSION REGULATION (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation.

Substation: Part of an electrical transmission system, where voltages are transformed from high to low or the reverse, or where other important network elements are interconnected.

Switchyard: Part of a substation containing busbars, breakers and switches.

TenneT: Transmission system operator in the Netherlands

TSO: Transmission System Operator: The Transmission System Operator operates the high-voltage grid and is responsible for the transmission of electricity. Electricity is transmitted via the high-voltage grid from the producers to the distribution system operators and major industrial users. In order to perform these tasks, the Transmission System Operator is also responsible for operating the system, whereby it is the entity responsible for providing access to the grid, monitoring the flows and ensuring round-the-clock management of the balance between production and consumption.

UPS: Uninterruptible Power Supply