INFORMATIVE NOTE

Note on the Voltage and Reactive Power Management

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Introduction

Transmission System Operators (TSO) need to manage the voltage and the reactive power flux to ensure the security and reliability of the electrical grid. According to article 27 and 29 of the System Operation Guideline (SOGL), the objective of the voltage and reactive power management is to maintain the voltage inside the operational limits and to respect voltage stability criteria. To this end, TSOs shall monitor reactive power flows and reactive power reserves and determine the system state pursuant to article 19 of the SOGL and shall apply remedial actions to maintain or restore the voltage in the operational limits. Pursuant to article 29 of the SOGL, TSOs shall ensure that at any time the required volume of reactive power reserves is available. TSOs shall monitor the availability of the voltage and reactive power control services and assess the forecasted needs against the availability of reactive power services, in line with Article 108 and 109 of the SOGL.

In addition to the present introduction, this document contains six sections:

- Section 1 summarizes the voltage operational limits and stability criteria
- Section 2 contains general information about the factors influencing the voltage
- Section 3 describes the remedial actions to ensure voltage and reactive power management
- Section 4 describes the process of activation of remedial actions
- Section 5 describes how the reactive power needs and availability of reactive power reserves are assessed in the year-ahead, day-ahead and intraday time scale
- Section 6 describes how the reactive power needs and availability of reactive power reserves are assessed in the multi-year-ahead time scale

1. Voltage operational limits and stability criteria

When managing the voltage on the grid, Elia aims to maintain the voltages inside the operational limits as defined in Table 1 and as close as possible to the target normal operating voltages in all conditions i.e. in N and N-1 situations (N-1 situation referring to the situation in which an outage of an asset could lead to some voltage issues e.g. the forced outage of a technical unit that was providing some reactive power in the framework of the voltage and reactive power control service).

In case the voltages go outside of these limits, Elia can activate the procedure to manage voltage deviations as described in the section 7.2 of the Defense Plan[1] according to article 19 of the Network Code Emergency and Restoration (NC E&R)

Allowed steady state voltages [in kV and in % of the target normal operating voltages]									
Voltage level (reference voltage in EU NCs) Unc			400	220	150	110	70	36	30
Maximum normal Limits	All conditions (N, N-1)	107.5% of Uexpl[2] (105% for 400kV)	420	242	167	118	75.3	38.7	32.3
Target normal operating voltages (Uexpl)		100%	400	225	155	110	70	36	30
Minimum normal Limits	All conditions (N, N-1)	92.5%[3] of Uexpl	370	208	143	102	64.8	33.3	27.8

Table 1: Operational limits of voltage

Furthermore, limitation on reactive power exchanges between TSOs exists (cfr. ENTSOe policy[4]) to ensure that the impact of incidents in one TSO grid does not impact the other TSO grid. Finally, to address voltage stability, a dynamic reactive power potential has to be maintained during normal operation for N-1 operation.

2. Factors influencing the voltage

For a given electricity system, the main elements influencing the voltage on the electrical grid are the load and the loading of specific grid elements. Voltage fluctuations are inevitable due to the influence of:

- Transmission-connected load and demand: the fluctuations in reactive power that are caused by the offtakes and injections that industrial activity and intermittent generation in Belgium entail;

[1] Available on Elia website: **https://www.elia.be/en/electricity-market-and-system/emergency-situations/system-state-notifications**
[2] These limits have been set considering that some old technical units need stricter operating voltages that the values from SOGL to operate
[3] These limits have been set considering that some old technical units need stricter operating voltages that the values from SOGL to operate
[4] Such as the Policy 3 available on **https://eepublicdownloads.entsoe.eu/clean-documents/pre2015/publications/entsoe/Operation_Handbook/Policy_3_final.pdf**

- Transmission-connected distribution systems: reactive power flows from the transmission-connected distribution grids, to which (very volatile) residential and other demand grid users are connected;
- Transmission system: overhead lines and cables also generate and/or absorb reactive power, depending on the asset type, active power loading and voltage level:
    - An electrical overhead line that is not/lightly loaded (i.e. with a low active power flux going through it) will be capacitive i.e. will generate reactive power. If the loading of the line increases, the line will become inductive i.e. will absorb reactive power
    - An electrical cable that is not/lightly loaded will be very capacitive i.e. will generate a lot of reactive power. Even when loaded, a cable will remain capacitive.
    - Electrical transformers are inductive i.e. will always consume reactive power. The reactive power consumption of the transformers will increase when its loading increases.
    - The standard values of the generated reactive power per km for a line and a cable are detailed in the figure below per voltage level. The length of the line has also an influence on the generated reactive power.

Voltage	**Line**	**Cable**
380 kV	0.55 MVAR/km	20 MVAR/km
220kV	0.15 MVAR/km	7.5 MVAR/km
150 kV	0.065 MVAR/km	3.5 MVAR/km
70 kV	0.015 MVAR/km	0.75 MVAR/km
36 kV	0.005 MVAR/km	0.2 MVAR/km
30 kV	0.0035 MVAR/km	0.15 MVAR/km

In case the load is low on the electrical grid, the lines and the cables will then be lightly loaded what will induce a high generation of reactive power. Due to the generation of reactive power, the voltage will rise.

In case the load is high on the electrical grid, the lines and the cables will then be highly loaded what will induce a high absorption of reactive power. Due to the absorption of reactive power, the voltage will drop.

In conclusion, for a given electricity system, the reactive power produced or absorbed in the system, depends on a large number of parameters. While some parameters have a rather dynamic nature (such as

the active power loading of the network elements), others have a more structural or slow-evolving nature (such as the number of overhead lines and cables in the transmission network). Based on the forecast of these parameters, TSOs forecast the short-term and long-term needs for voltage control and reactive power management.

3. Remedial actions to ensure voltage and reactive power management

Article 22 of the SOGL gives indications concerning the categories of remedial actions that can be used by the TSO. The different remedial actions that can be executed by TSO's to ensure voltage control and reactive power management are summarized in Table 2[5]. The typical order of application for ELIA grid is described in the sections below. As the application of these remedial actions in real time operation depends on the respective situation (e.g. grid security and time needed for implementing some actions), the rules stated below are always subject to the TSO decision.

too high voltage	**Switching off production with voltage incrasing effect** **Blocking of automatic voltage and reactive power control of transformers**
	Redispatching of system users (incl. start-up of additional power plants or must run power plants)
	Cancellation of planned outages of grid elements (e.g. reactors, synchronous condensers) Switching off lines with low loading Modification of grid topology (incl. tap changes of PSTs) and set-points of synchronous VSC HVDC-Systems Instructing DSOs and SGUs to activate on their facilities the remedial actions set out below Start-up of hydraulic power plants in condenser mode Changing of reactive power output or voltage set-point of power plants, condensers and converters Switching of capacitors and reactors Tap changes of power transformers
too low voltage	Tap changes of power transformers Switching of capacitors and reactors Changing of reactive power output or voltage set-point of power plants, condensers and converters Start-up of hydraulic power plants in condenser mode Instructing DSOs and SGUs to activate on their facilities the remedial actions set out above Cancellation of planned outages of grid elements (e.g. lines, capacitors, synchronous condensers)
	Redispatching of system users (incl. start-up of additional power plants or must run power plants) Disconnection of contracted interruptible services
	Reduction of voltage reference value on HV/MW transformers **Blocking of automatic voltage and reactive power control of transformers** **(Manual) load shedding**

Table 2: Remedial actions to ensure voltage and reactive power management

[5] This table comes for a common document from European TSO's named "Principles for coordinated voltage management" that will be soon part of SAFA (Synchronous Area Operational Agreement).

Elia activates these remedial actions based on an assessement of the efficiency and the impact of the action on the grid security. A first categorization is based on direct costs differentiating between the categories of non-costly and costly remedial actions with a preference for remedial actions with the lowest cost. A second categorization is based on the international impact with a preference for remedial actions without international impact. Remedial actions with an international impact are subject to coordination with other TSOs and the support of its Regional Security Coordinator (RSC). The remedial actions that could need to be coordinated with neighboring TSOs according to the currently agreed methodology with neighboring TSOs[6] are highlighted below with the following mention: [CRA = Coordinated Remedial Action].

3.1 List of RA in case of high-voltage

In case of high-voltage, the following remedial actions need to be executed by the operator to reduce the voltage by increasing the reactive power absorption/reducing the reactive power production on the grid.

Non costly remedial actions:

1. Switch off capacitor banks and switch on reactor banks (self)
2. Request additional reactive power absorption from HVDC system operated by the TSO [CRA]
3. Decrease tap on power transformers

If these non-costly remedial actions are not sufficient to secure the grid, the following costly remedial actions will be taken following a techno-economic merit order:

- Request additional reactive power absorption from technical units participating to the voltage control and reactive power management service (according to the contract for Voltage Service Provider (VSP contract)) including technical units that can operate in compensator mode
- Cancellation of planned outage of grid elements [CRA]
- Taking low-loaded cables and long lines out of service [CRA if close to borders]

In last resort, the following actions are taken:

- Increase active power flows to increase the loading of the lines and push them into inductive range (via a change of taps on Phase Shifter Transformers (PST) to create a recirculation of active power flows) [CRA]

[6] More information will be available on the document "Principles for coordinated voltage management"

- Instructing DSOs and SGUs that do not participate to the voltage control and reactive power management service (without VSP contract) to activate the remedial actions set out above.

3.2 List of RA in case of low-voltage

In case of low-voltage, the following remedial actions need to be executed by the operator to increase the voltage by increasing the reactive power production/reducing the reactive power absorption on the grid:

Non costly remedial actions:

1. Switch off reactor banks (self) and switch on capacitor banks
2. Request additional reactive power production from HVDC system operated by the TSO [CRA]
3. Increase tap on power transformers

If these non-costly remedial actions are not sufficient to secure the grid, the following costly remedial actions will be taken following a techno-economic merit order:

- Request additional reactive power production from technical units participating to the voltage control and reactive power management service (according to the contract for Voltage Service Provider (VSP contract)) including technical units that can operate in compensator mode
- Cancellation of planned outage of grid elements [CRA]

In last resort, the following actions are taken:

- Instructing DSOs and SGUs that do not participate to the voltage control and reactive power management service (without VSP contract) to activate the Remedial Actions set out above.

3.3 Additional remedial action: redispatching of system users [CRA]

In addition to the above remedial actions, Elia can request the start-up of additional power plants for reactive power management and voltage control. This remedial action allows to use the reactive power capacity (in absorption or production) of additional power plants. As this action requires the remuneration of start-up costs, it is only used if other actions are not sufficient and if the timeframe of the voltage regulation allows it.

4. Activation of remedial actions for voltage and reactive power management

4.1 Assessing the need for remedial actions

The voltage must stay within the operation limits as defined in section 1. Elia continuously monitors the real-time voltage in N and N-1 situations to stay in these limits and as close as possible to the reference voltage. In case of too important deviations, preventive remedial actions as described in section 3 are activated in real-time.
Furthermore Elia anticipates the high and low voltage situations that are mainly impacted by the load variations (for example high voltages situation occurring during the weekend). In these situations, sequential actions must be taken in advance to prepare the grid and to avoid reaching the limits in real-time. These actions are activated preventively.

4.2 Reactive power from technical units participating to the voltage and reactive power control service

Automatic voltage control

According to the VSP contract, the controlling technical units providing the voltage and reactive power control service (via a VSP) have to continuously adapt their reactive power production or absorption based on the voltage measured at their service measurement point and according to their linear sensitivity coefficient as defined in the Federal Grid Code. The automatic voltage control is a first line to ensure that the voltage stays in the operational limits and allows a quick and automatic reaction in case of fast voltage variations due to e.g. the unexpected outage of a technical unit.

Manual voltage control

In addition to the automatic voltage control provided by some technical units participating to the voltage and reactive power control service (via a VSP), Elia can request additional production or absorption of reactive power from technical units via the request of reactive power setpoints as described in section 3. These actions must be activated sequentially due to the inertia of the system (reaction of loads, grid elements, automatic voltage control…).

As defined in the VSP contract, Elia will activate in priority the technical units with the objective of reducing total service costs, in consideration of the following constraints:

- The location of the technical unit in the grid and the voltage level to which it is connected based on the location of the voltage issue. An action on a technical unit that is located in the same electrical zone than the voltage issue will have more impact. An action on a technical unit that is connected on the same voltage level than the voltage issue will have more impact.
- The activation prices;
- Other technical requirements encountered as such as for example:
    - the scheduled active power of the technical unit to identify how long a technical unit is still available to provide the service after the setpoint request
    - the reactive power technical band of the technical unit and the margins that left after the request of the reactive power setpoint. Margin should be left to avoid the deactivation of the automatic voltage control of the technical unit leading to a weaker grid. These technical bands are defined in the T&C VSP and the reactive power injection/absorption is monitored continuously in real-time.

5. Assessment of reactive power needs and availability of reactive power reserves in the year-ahead, day-ahead and intraday timeframe

When coordinating the planning of the maintenances of grid elements (such as lines, cables, transformers, capacitor or reactor banks), Elia performs security analysis to ensure that the different planned maintenances will not lead to voltage issues. Based on the type grid element, this outage planning is cre-

ated first in multi-year ahead (i.e. lines 380kV) and updated until D-1 and Intraday (i.e. conditional outages as defined in the Rules for Coordination and Congestion Management[7]). Adaptations of the maintenance planning could be required if voltage issues are detected.

Similarly, Elia ensures that sufficient voltage and reactive power control capabilities are available within each electrical zone during the outage planning coordination process according to the rules stated in the Rules for Coordination and Congestion Management.

6. Assessment of reactive power needs and availability of reactive power reserves in the multi-year-ahead timeframe

Elia performs regular analyses of the static and dynamic reactive power needs for the next 5 to 10 years in order to ensure that the voltage can be maintained inside the operational limits and that voltage stability criteria can be satisfied. Based on these analyses, Elia estimates the needs of reactive power and looks for the most advantageous solution to satisfy these needs considering the existing assets for voltage regulation (such as capacitor and reactor banks) and the available means from technical units connected to the grid (such as the units expected to participate to the voltage and reactive power control service).

[7] This document is available on the Elia website: https://www.elia.be/-/media/project/elia/elia-site/electricity-market-and-system/system-services/alleviating-congestion-risks/20210406_coordination-rules_en.pdf