REACTIVE POWER MANAGEMENT AT T – D INTERFACE

ENTSO-E guidance document for national implementation for network codes on grid connection

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DESCRIPTION	
Code(s) & Article(s)	NC DCC Article 15, Reactive power requirements.
Objective	Different system operator for the networks (e.g. distribution or transmission network), network topologies (degree of network meshing), localisation of the connection point at the distribution-transmission interface and load and embedded generation characteristics, lead to the need for different ranges of reactive power. For this reason, the exchange of reactive power at each interface between the two networks strongly depends on the above mentioned local needs. For instance, heavily loaded meshed grids or radial or remote grids typically need more injection of reactive power (production), whereas the same meshed grid in light loading conditions need more reactive power consumption in order to keep the network voltage within the permitted range. In general it is more cost effective at system level to generate reactive power at the location where it is needed to avoid higher losses and large voltage deviations. Furthermore, the transport of reactive power is possible only over limited distances. In addition, reactive power is traditionally provided by generating units thanks to the limited marginal investment compared to the delivery of active power only. As in the future, a larger share of the total generation installed capacity will be connected to distribution grids, the provision of reactive power at transmission level should be more expensive due to the lack of generating units at that level. Therefore, for the benefit of the system and pursuing local reactive compensation, it is essential that transmission-connected demand facilities and transmission-connected distribution systems are capable to maintain their operation at their Connection Point within a pre-established and limited reactive range. It is then also expected that by the future transition of generation to the distribution grids and related requirement at the Transmission System Operator – Distribution System Operator (TSO-DSO) interface, reactive or voltage related requirements for distributed connected users will need to be nationally reviewed. A core principle that should underpin all TSO-DSO interactions with regard to reactive power is that each system operator is responsible for ensuring voltage requirements on its network. The NC DCC prescribes the boundaries within which the Relevant TSO can set design limitations on reactive power exchanges of transmission-connected demand facilities and transmission-connected distribution systems. As this is a connection code, no link is directly made for the utilisation of the capability. It is however, expected that, over time, utilisation of the capabilities will be implemented in operational documents.
NC frame	"Article 15 - Reactive power requirements 1. Transmission-connected demand facilities and transmission-connected distribution systems shall be capable of maintaining their steady-state operation at their connection point within a reactive power range specified by the relevant TSO, according to the following conditions: (a) for transmission-connected demand facilities, the actual reactive power range specified by the relevant TSO for importing and exporting reactive power shall

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not be wider than 48 percent of the larger of the maximum import capacity or maximum export capacity (0.9 power factor import or export of active power), except in situations where either technical or financial system benefits are demonstrated, for transmission-connected demand facilities, by the transmission-connected demand facility owner and accepted by the relevant TSO;

(b) for transmission-connected distribution systems, the actual reactive power range specified by the relevant TSO for importing and exporting reactive power shall not be wider than:

(i) 48 percent (i.e. 0.9 power factor) of the larger of the maximum import capability or maximum export capability during reactive power import (consumption); and

(ii) 48 percent (i.e. 0.9 power factor) of the larger of the maximum import capability or maximum export capability during reactive power export (production);

except in situations where either technical or financial system benefits are proved by the relevant TSO and the transmission-connected distribution system operator through joint analysis;

(c) the relevant TSO and the transmission-connected distribution system operator shall agree on the scope of the analysis, which shall address the possible solutions, and determine the optimal solution for reactive power exchange between their systems, taking adequately into consideration the specific system characteristics, variable structure of power exchange, bidirectional flows and the reactive power capabilities in the distribution system;

(d) the relevant TSO may establish the use of metrics other than power factor in order to set out equivalent reactive power capability ranges;

(e) the reactive power range requirement values shall be met at the connection point;

(f) by way of derogation from point (e), where a connection point is shared between a power generating module and a demand facility, equivalent requirements shall be met at the point defined in relevant agreements or national law.

2. The relevant TSO may require that transmission-connected distribution systems have the capability at the connection point to not export reactive power (at reference 1 pu voltage) at an active power flow of less than 25% of the maximum import capability. Where applicable, Member States may require the relevant TSO to justify its request through a joint analysis with the transmission-connected distribution system operator. If this requirement is not justified based on the joint analysis, the relevant TSO and the transmission-connected distribution system operator shall agree on necessary requirements according to the outcomes of a joint analysis.
3. Without prejudice to point (b) of paragraph 1, the relevant TSO may require the transmission-connected distribution system to actively control the exchange of reactive power at the connection point for the benefit of the entire system. The relevant TSO and the transmission-connected distribution system operator shall agree on a method to carry out this control, to ensure the justified level of security of supply for both parties. The justification shall include a roadmap in which the steps and the timeline for fulfilling the requirement are specified.
4. In accordance with paragraph 3, the transmission-connected distribution system operator may require the relevant TSO to consider its transmission-connected distribution system for reactive power management."

Further info	[1]Frequently asked questions, Network code on demand connection, December 2012 [2]Demand Connection Code, Call for stakeholder input, April 2012 The latest NCs and the Guideline documents are available at the ENTSO-E website.

INTERDEPENDENCIES

Between the CNCs	Reactive power management at Transmission – Distribution (T – D) Interface is not directly impacted or impacting implementation of other connection codes but this choice is indirectly related to the national implementation of other connection codes. As an example, the capabilities of a DSO to fulfil the requirement for reactive power exchange at its interface with the transmission system (as defined in the NC DCC) is impacted by the capabilities of the generating units connected within the distribution grid and the strength of the need for such a requirement is impacted by the capabilities of the generating units connected within the transmission grid. The capabilities of the generating units is defined by the NC RfG and by the MW boundary choices following national implementation of the NC RfG.
With other NCs	No interdependencies with other NCs

System characteristics	The consequences of greater contribution from Renewable Energy Sources (RES) in context of system voltage and availability of reactive power capability has to be considered. With the highest level of RES penetration many synchronous generators will be displaced at the times of high RES production (e.g. windy/sunny). This removes a key source of reactive power. In many countries during such conditions the generation (mainly from RES) is located away from the system/load centres to coastal areas (e.g. large wind) and also embedded (e.g. solar photovoltaic (PV) and smaller wind). Moreover, the development of underground cables in the distribution grid and even the transmission grid and the development of embedded generation in the distribution networks (including closed distribution networks) have an increasing impact on the reactive power flows at the interface between transmission and distribution networks. The above leaves the transmission systems with less reactive resources to: - Be able to compensate the reactive demand of the DSO networks, and - Cope with its own transmission related reactive demand. Furthermore, per unit cost of static reactive compensation equipment (reactors or capacitor banks) is typically increasing with the voltage level at which it is connected. Consequently, ENTSO-E believes that the voltage stability of the system should be supported by all the stakeholders (including the TSOs). This view was generally supported by stakeholders. However, ENTSO-E acknowledged the view that the requirement should be limited to transmission connected users only. Some requirements exist already in some countries, for generators and/or for customers and distribution system operators, but they need to be improved and the provision of reactive support spread (and hence harmonized) across Europe in order to cope with the new challenges. In Annex 1, the results of a survey on the currently applied requirements on reactive power exchange on the TSO – DSO / Demand facilities interface are shown for different countries / TSOs. Overall system performance is improved, either technically or economically, if

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	appropriate measures are taken concerning reactive power management for transmission connected distribution networks or demand facilities at the connection point. Reactive power delivered where needed is more cost effective, allowing also for loss reduction, higher active power loading, less need for system reinforcements and lower capital cost of lower voltage installation. Voltage stability is also recognized as an important basis for system security. The Cost Benefit Analyses (CBA) provided in the "Call for Stakeholder Input" and supplemented by additional synchronous areas analysis (see FAQ 22) have shown that from a socio-economic viewpoint the total cost to meet the DSO system need for reactive power is lower if the reactive compensation is undertaken lower down in the system (closer to the demand) than if invested at the higher voltage level. The results of this CBA are shown in Annex 2.
Technology characteristics	-
COLLABORATION	
TSO – TSO	Limited TSO-TSO collaboration is expected for the implementation of such requirements. However, ENTSO-E is request in the NC to monitor the implementation of the NC (Article 57). The NC precise the function of the monitoring as follows: "1 ENTSO for Electricity shall monitor the implementation of this Regulation in accordance with Article 8(8) of Regulation (EC) No 714/2009. Monitoring shall cover in particular the following matters: a) identification of any divergences in the national implementation of this Regulation; b) assessment of whether the choice of values and ranges in the requirements applicable to transmission-connected demand facilities, transmission-connected distribution facilities, distribution systems and demand units under this Regulation continues to be valid." Unjustified divergence in national implementation should then be avoided.
TSO – DSO	TSO-DSO (including Closed Distribution System Operators, CDSO) collaboration is of prior importance. Several specific aspects are defined in the NC. - The requirements 15.1. (a) and 15.1.(b) of the NC are non-exhaustive requirement and a maximum acceptable reactive power exchange has to be specified the relevant TSO for both importing and exporting reactive power. The TSO is not allowed to be less stringent that a maximum range of 48 percent (i.e. 0.9 power factor) of the larger of the maximum import capability or maximum export capability unless the exception clause (see next bullet point) is considered; - Authorization to deviate from the maximum acceptable reactive power range of the 15.1.(a) and 15.1.(b) of the NC are foreseen "where either technical or financial system benefits are proved by the relevant TSO and the transmission-connected distribution system operator through joint analysis"; - For both above bullet points, the scope of the analysis shall be agreed between the relevant TSO and the transmission-connected distribution system operator. This scope shall take into consideration the specific system characteristics, variable structure of power exchange, bidirectional flows and the reactive power

	capabilities in the distribution system. It needs to be recalled that the connection code only focus on connection requirements related to capabilities. Some important aspects are therefore out of the direct scope of the Connection Code implementation and of this Implementation Guideline (IGD) such as: - Reactive power management in operational planning; - Use of the Distributed Energy Resources reactive power capabilities; - Requirements in the Guide Lines (GL) on system operation. In the context of the joint analysis several steps will expected to be needed such as, but not limited to, definition of planning points as expected realistic operation points (different load and generation conditions as defined in article 43.1 on compliance simulations with regard to the reactive power capability), methods for compliance simulation and necessary equipment, or equivalent arrangements, to measure the active and reactive power as defined in article 46 on compliance monitoring. Where either technical or financial system benefits are proved by the relevant TSO and the transmission-connected distribution system operator through joint analysis, the optimal solution for reactive power exchange between their systems can be determined. The scope of this joint analysis should be defined at national level to make sure that the particular local situation is sufficiently taken into account. This scope should consider at least: - TSO/DSO interface voltage level, because it will determine the kind of technical solution that can be used at the interface, see also survey in Annex I; - Interaction with power quality parameters; - Strive for a global technical economical optimum; - Avoiding cost shifts from one party to the other unless it is proven that this shift would contribute to the global techno-economical optimum; - Global cost of the chosen solution should be minimal for the system (distribution/ transmission/users); As an additional approach towards the reactive power requirements TSOs and DSOs see, in certain situations, added value in considering the aggregation of connection points (between TSO and DSO) and regroup the connection points in a number of zones (especially in case of a meshed distribution network). The reactive power requirements can then be set for those zones as a whole and not separately.
RNO – Grid User	As above-mentioned, it is expected that the reactive power management at T – D Interface will influence by the future transition of generation to the distribution grids, interaction between distributed connected users (both generation and load) and DSO or CDSO. This is only partly addressed by the NCs but it could be a driver to modify/update/confirm national connection requirements.

ANNEX I Survey on reactive power boundaries on TSO – DSO/Demand facility interface

One of the aspects that needs to be taken into account to understand the span of requirements currently applied at the TSO to DSO interface or the expected span resulting from the NC implementation is the diversity of the interface between TSO & DSOs.

In every European country surveyed, the T-D interface consists of a substation with several transformers in parallel. The lower voltage side of the transformation substation ranges from 150kV to MV. This large difference is not only observed between countries but also from location to location within some countries;

The size of the transformers used at the T-D interface and the number of these transformers range from 350MVA to 16MVA and from 2 to 4 transformers in parallel.

In every country, transformers towards distribution grids have on load tap changer. However, the ownership of the transformers as well as the controllability of their taps differs from country to country or from location to location within some countries. In addition, in every European country surveyed, the capacitor or inductor banks are in the majority located at the lower voltage side of the transformation substation (or on a tertiary winding of the transformer) and the operator of these banks differs from country to country (TSO or DSO).

<u>TSO - DSO reactive power exchange boundaries in different countries (Survey from April 2016):</u>

Country / TSO	**Power factor requirements**				**Active control of exchange of reactive power (automatic)**	**Reactive power flow limited at low active flow**
	Connection		*Operation*			
	DSO	*Demand facility*	*DSO*	*Demand facility*		
Spain / REE	a) Peak Period: $\cos\varphi \geq 0.95$ inductive b) Off Peak Period: no reactive power to TSO ≥ 1 inductive c) Intermediate Period: $1 \geq \cos\varphi \geq 0.95$ inductive	a) Peak Period: $\cos\varphi \geq 0.95$ inductive b) Off Peak Period: no reactive power to TSO c) Intermediate Period: $1 \geq \cos\varphi \geq 0.95$ inductive	a) Peak Period: $\cos\varphi \geq 0.95$ inductive b) Off Peak Period: no reactive power to TSO c) Intermediate Period: $1 \geq \cos\varphi \geq 0.95$ inductive	a) Peak Period: $\cos\varphi \geq 095$ inductive b) Off Peak Period: no reactive power to TSO c) Intermediate Period: $1 \geq \cos\varphi \geq 0.95$ inductive penalties in place	no	no
Slovenia / ELES	$\cos\varphi \geq 0.9$	$\cos\varphi \geq 0.9$	-	$\cos\varphi \geq 0{,}95$ penalties in place	no	no
Netherlands / TenneT	$\cos\varphi = 1$	$1 \geq \cos\varphi \geq 0.85$ inductive	-	$1 \geq \cos\varphi \geq 0.85$ inductive	no	no
Italy / Terna	only voltage requirements	specified by contract	only voltage requirements	specified by contract	no	no
Slovak Republic / SEPS	$1 \geq \cos\varphi \geq 0.95$ inductive	$1 \geq \cos\varphi \geq 0.95$ inductive	$1 \geq \cos\varphi \geq 0.95$ inductive penalties in place	$1 \geq \cos\varphi \geq 0.95$ inductive penalties in place	no	no
Austria / APG	No specific requirements but low exchange of reactive power	$\cos\varphi \geq 0.9$	No limits	$\cos\varphi \geq 0.9$ penalties are possible	no	no
Bosnia and Herzegovina / NOS BiH	$\cos\varphi \geq 0.9$	$\cos\varphi \geq 0.9$	No limits	$\cos\varphi \geq 0.9$	no	no
Belgium / Elia	no requirements	no requirements	$\cos\varphi \geq 0.95$ minimum range of 3,29% x Pmax penalties in place	$V \geq 30$ kV: $\cos\varphi \geq 0.95$ minimum range of 3.29% x Pmax $V < 30$ kV: $\cos\varphi \geq 09$ minimum range of 4.84% x Pmax penalties in place	-	-
Norway / Statnett	$\cos\varphi = 1$	$\cos\varphi = 1$	$\cos\varphi = 1$ tariff as penalty	$\cos\varphi = 1$ tariff as penalty	no	no
Croatia / HOPS	no requirements	$1 \geq \cos\varphi \geq 0.95$ inductive	-	$1 \geq \cos\varphi \geq 0.95$ inductive penalties in place	no	no
Greece / IPTO	no requirements	no requirements	no requirements	$\cos\varphi \geq 095 – 0.9$ specified by contract penalties in place	no	no
Czech Republic / CEPS	$1 \geq \cos\varphi \geq 0.95$ inductive	$1 \geq \cos\varphi \geq 0.95$ inductive	$1 \geq \cos\varphi \geq 0.95$ inductive penalties at DSO level	$1 \geq \cos\varphi \geq 0.95$ inductive penalties at DSO level	no	no
Serbia / EMS	$1 \geq \cos\varphi \geq 0.95$ inductive	$1 \geq \cos\varphi \geq 0.95$ inductive	$1 \geq \cos\varphi \geq 0.95$ inductive penalties in place	$1 \geq \cos\varphi \geq 0.95$ inductive penalties in place	no	no

France / RTE	no requirements	1 ≥ cos φ ≥ 0.928 inductive tariff incentive	1 ≥ cos φ ≥0,995- 0.928 specified by contract tariff incentive	1 ≥ cos φ ≥ 0.928 inductive tariff incentive	no	no
Poland / PSE S.A.	1 ≥ cos φ ≥ 0.928	1 ≥ cos φ ≥ 0.928 special cases: 1 ≥ cos φ ≥ 0.98	1 ≥ cos φ ≥ 0.928 penalties in place	1 ≥ cos φ ≥ 0.928 special cases: 1 ≥ cos φ ≥ 0.98 penalties in place	no	no
Germany / 50Herz	bilateral agreements between TSO and DSO	bilateral agreements between TSO and Demand facility	bilateral agreements between TSO and DSO	bilateral agreements between TSO and Demand facility	Under development	no

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ANNEX II CBA on reactive power equipment connected on different voltage levels

Introduction

Different connection points with different characteristics are selected. Generally an urban location and a rural location are of interest. The rational for this is that introduction of a new transmission connected load in the urban location is likely to be less pronounced as the increase in Vars is proportionally much smaller and the system independence from generation to use will be lower.

At each location the study has examined the introduction of a new load (50MW at 0.85PF, 500MW at 0.85PF), and examined the needs for additional reactive power from either generation or passive components for reactive power support.

The study considered two options:

1. Reactive power support provided by the user at the next voltage level down from their connection point
2. Reactive power support provided by the TSO – optimum location to be determined by TSO performing study.

For each study the network is at least N-1 compliant, and compliant with the TSO planning standards.

Option 1: Reactive power support by user

For this option costs of reactive power support are typical costs for reactive power support.

Type of reactive power support (caps, reactors, SVC, etc) are estimated by TSO to meet their existing planning criteria. The studies examine peak and trough in load demand in 2015 and 2020.

Full compensation (PF1.0) by the user to HV side of transformer is the target.

Option 2: Reactive power support by TSO

For this option costs of reactive support are by nationally typical costs for reactive power support.

Irish Test Case

Utilising the generic scope as described above, the study test cases selected were:

1. 50MW with 0.85PF demand connection at Binbane 110/38kV station at 38kV
2. 500MW with 0.85PF demand connection at Flagford 220/110kV station at 110kV
3. 50MW with 0.85PF demand connection at Finglas 110/38kV station at 38kV
4. 100MW with 0.85PF demand connection at Ryebrook 110/38kV station at 38kV

The results from these studies which provided viable network solutions are shown below in Table 1. Each of the test cases has been tested to be complaint with network planning standards.

Test Case 1 and 3 were examined looking at solutions at the connecting stations at 38kV and 110kV, and trying to centralise the reactive compensation requirements to provide widespread support.

The centralised solution is included to confirm whether the transmission solution can be optimised to be a solution for a wider area which might be cheaper than equivalent multiple 38kV reactive compensation devices. In either case either this solution does not work as it is too remote from the location where the reactive power is needed.

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Table 1. Results of test cases in Ireland

Test Case 1 – 50MW in Binbane 110kV station		
Scheme	Assumption	Total cost in kEuros
110kV connected	Assume 30 + 22 MVAr capacitor blocks	2136
110kV centralised connected	Does not work	-
38kV connected	Assume 30 + 17 MVAr capacitor blocks	719
Test Case 2 – 500MW in Flagford 220kV station		
Scheme	Assumption	Total cost in kEuros
220kV Connected	Assume 6 * 60 + 20 MVAr capacitor blocks	9340
110kV Connected	Assume 6 * 60 + 20 MVAr capacitor blocks	9340
Test Case 3 – 50MW in Finglas 220/110kV station		
Scheme	Assumption	Total cost in kEuros
110kV Connected	Assume 33 MVAr reactor block	862
38kV Connected	Assume 35 MVAr reactor block	150
Test Case 4 – 100MW in Ryebrook 110kV station		
110kV Connected	Assume 30 MVAr capacitor block	1095
110kV Centralised at Finglas	Assume 30 MVAr capacitor block	1095
38kV Connected	Assume 30 MVAr capacitor block	419

Conclusion of the cost benefit analysis of reactive power requirements

It has been found that reactive power is in general most cost-effectively provided beyond the connection point in the DSO network or its demand users.

Therefore the reactive power requirements should restrict the steady-state range of reactive power that is imported and exported over the T-D interface to a minimum as reactive power support can be best generated were it is needed. On the other hand ranges should be so wide that they do not restrict the use of the capabilities of embedded generation and Demand Response (DR).

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