European Network of
Transmission System Operators
for Electricity

Reactive power requirement for PPMS & HVDC at low / zero power

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

16 November 2016

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DESCRIPTION

Code(s) & Article(s)	**Network Code (NC) Requirements for Generators (RfG)** Article 21.3, Power Park Modules Reactive power capability *REQUIREMENTS FOR OFFSHORE POWER PARK MODULES* Article 25.5, Reactive power capability **NC High Voltage Direct Current (HVDC)** *GENERAL REQUIREMENTS FOR HVDC CONNECTIONS* Article 20, Reactive power capability; Article 21, Reactive power exchanged with network; and Article 22, Reactive power control mode *REQUIREMENTS FOR DC-CONNECTED POWER PARK MODULES* Article 38, Scope; and Article 40.2, Reactive power and Voltage requirements *REQUIREMENTS FOR REMOTE-END HVDC CONVERTER STATIONS* Article 46, Scope *ANNEX 4 – U-Q/Pmax PROFILE [General]* *ANNEX 7 – U-Q/Pmax PROFILE [DC connected PPMs]* *ANNEX 8 – U-Q/Pmax PROFILE [Remote end HVDC convertors]*
Objective	In order to operate the electrical system (e.g. distribution and transmission network), during all the network conditions (e.g. topology, set of generation unit in service, degree of network meshing), the system operator must have at their disposal reactive power resources that are able to regulate the network node voltage. These resources are primarily provided by users i.e. generating units, third party HVDC circuits and demand side response. Even if, network devices (e.g. reactors or capacitors) can be installed to provide or consume reactive power, many sources like HVDC links can also meet the systems reactive power needs. Both Power Park Modules (PPMs) and HVDC systems can provide reactive power and in many cases can comply with the network code requirements without the need for additional equipment. However at low/zero active power additional equipment may be required in order for them to be able to continue to maintain proper reactive capability. Therefore the need for reactive capability at low /zero output shall be analysed precisely. However it is also evident that if the necessary reactive power required by the system is supplied from PPMs generation or HVDC links only when they are supplying appreciable power, alternative network based reactive power sources or generators must be provided at other times. This compounds the cost as two sources are being retained due to the uncertainty of reactive power being available. Given the EU targeted increases in interconnection between countries to 15% of their peak capacity and the move to a de-carbonized network by 2050, it is evident that reactive power resources are essential to support networks voltage when there is low production in that network. Therefore one key scenario that should be considered is a high renewable energy output scenario moving to a low renewable energy output scenario in a network. Without the

reactive power from PPMs or HVDC links, other power sources will be required to be available or additional reactive compensation required.

It should be noted that the co-location of the location of renewable generation and demand is generally not as high as that of fossil fuel generation and demand. Therefore renewable generation may not be physically able to provide the reactive power required across the network, and supplemental sources may be required.

In general it is more cost effective at a system level to generate reactive power at the location where it is needed to avoid higher losses and large voltage deviations. In addition, the transport of reactive power is possible only over limited distances.

Therefore the determination of reactive power requirements at low or zero output from PPMs or HVDC links should be justified based on future predicted network scenarios over a number of seasons and operational conditions. These scenarios should account for present and future levels of PPMs and HVDC links in the network (including other available reactive power sources) and calculate in the first instance what is required both at a local regional, national and synchronous level for reactive power provision.

This will provide a base-line from which the implications of any adaption required to PPMs and HVDC links to provide the necessary (if any) reactive power.

Consequently an appropriate level of reactive power from low or zero output from PPMs and HVDC links can be consistently set and justified at a national level for these users, non-discriminately.

NC frame

Both HVDC links and onshore PPMs have general requirements in Article 21 of both the NC HVDC and NC RfG that permit the system operators to specify reactive power characteristics that should be met below maximum active power output.

A paper by WindEurope's taskforce[1] provides a recommendation on setting the reactive power requirements for PPMs at low output that is supported by the industry. This recommendation provides a useful information in considering the selection of that non-exhaustive requirements by each system operator.

Both codes require that these specified characteristics should be within the permissible envelope for reactive power at maximum active power output (Annex 4 in the NC HVDC and Figure 8 in NC RfG).

In addition to these general requirements the NC HVDC also sets requirements for DC connected PPMs (a power park module that is connected via one or more HVDC interface points to one or more HVDC systems) and the remote end convertors to which they are connected.

Due to fact that these Direct Current (DC) connected PPMs will only be interconnected to Alternating Current (AC) network from the remote end convertor, the size of that network can and typically is very small and weak. Therefore reactive power capabilities need to be considered separately to that of the synchronous system to which they are connected via the HVDC link[s]. The capabilities for this non-general application are specified in

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[1] https://windeurope.org/wp-content/uploads/files/policy/position-papers/WindEurope-Implementation-Guidelines-for-the-NC-RfG.pdf

	Appendix 7 and 8 of the NC HVDC. In the case of DC connected PPMs, provision is made to allow the delayed installation of the installation of a reactive power capability. This is restricted to an AC network linking the DC connected PPMs and the remote end convertor which will only impact on one user. Finally, it may be anticipated that a DC connected PPM will ultimately become AC connected due to the subsequent development of an AC circuit to the remote convertors AC network. In this situation the requirements of both the DC connected PPMs and the remote end convertor should be specified by the system operator to allow for both the initial DC connected mode and AC connected mode to be possible.
Further info	[1] Frequently asked questions [Notably No 23], Network code on Requirement for Generators, June 2012 [2] Justification Outlines, Network code on Requirement for Generators, June 2012 [3] Frequently asked questions [Notably No 25], Network code on HVDC, April 2014 [4] Justification Outlines, Network code on HVDC, June 2012

INTERDEPENDENCIES

Between the CNCs	Reactive power management is indirectly related to the national implementation of other connection codes. As an example, the capabilities of a generator to fulfil the requirement for reactive power exchange at its interface with the transmission system (as defined in the NC RfG and HVDC) is impacted by the capabilities of the T-D interface point (set in NC Demand Connection Code (DCC)) between the distribution and transmission grid to be able to transmit the total reactive power from the generation embedded within the distribution network. Also as outlined above the total reactive power capability and utilization from devices in both the transmission and distribution system must be considered in aggregate to meet local, region and national needs. Therefore all devices providing/absorbing reactive power in general must be collectively considered to ensure adequacy and optimum balance of the necessary reactive compensation requirements. Therefore the NC RfG, DCC and HVDC in this regard all have interdependencies on the capabilities required of each user for reactive power including how the reactive capability specified maybe controlled (automatic, by a control room, fixed, etc.)
With other NCs	In addition to the immediate capability needs to provide or absorb reactive power or the capability to control it, the TSO must consider the operation philosophy they intend to apply and the operational actions in future years for the life of the equipment. This must then be considered by the TSOs to ensure an adequate capability is specified. Failure to recognize that due to operational restrictions, for example the maximum level of penetration of wind on a system, may result in an over reliance of the capability of PPMs in a network to provide reactive power. The outcome maybe an over specification of capacity on PPMs and an under specification on alternative sources of reactive power.

	Therefore, being the Connection Network Codes define the capabilities and the Operation Guidelines define the functional operation of those capabilities the Operation and Connection Guidelines will interact.
System characteristics	The availability of reactive power capability from all sources has to be considered. With the highest level of Renewable Energy Source (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 PV and smaller wind). For example the Irish transmission system has in recent years seen an increasing level of renewable energy. This renewable energy has been almost entirely from wind and as a result high fluctuations of active and reactive power can occur. Ireland already experiences periods regularly where 55% of its power is coming from renewable sources and is working towards a level of 75% before 2020. In simple terms this means that there are fewer synchronous plants operating on the network. Synchronous generators can not only provide wider reactive power ranges than connecting renewable plants but can do so to their minimum operating levels. Hence they always provide reactive support to the network whilst providing active power. This combined with the development of underground cables on the network and the development of more deeply embedded generation is having an increasing impact on the needs for greater reactive power. Consequently additional network connected reactive support is being developed as part of the overall reinforcement of the network for the increasing wind generation, which is designed to cover both high wind and low wind production scenarios. Reactive power from these generators at low active power output would reduce the scale of this reactive support and would therefore be an alternative solution that could be considered. In parts of the network dominated by renewable energy, the need for reactive compensation changes from inductive to capacitive as the active power production increases from the generation. The only viable method of support is using dynamic devices for example using statcoms. These statcoms need to be proportionate to the number and scale of the wind farms and geographically are normally optimal when they map the dispersion of the wind farms. This increases both the number of the reactive support units and the complexity of their controls due to interaction, making them increasingly expensive and difficult to design to provide a reliable technical solution. Consequently in these situations greater reactive capability at low outputs from both PPMs and HVDC systems will lessen the complexity of the network and become essential to provide the necessary reactive power efficiently. 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.
Technology characteristics	The provision of reactive power at low active power levels for PPMs and HVDC systems equal to their maximum can be achieved but due to technology characteristics can be dependent on additional equipment being installed. For example, if the reactive power range of a PPM is maintained at the same level from maximum output to zero output, then as the active power changes the reactive power produced or absorbed by the users facility internal non-PPM equipment will change (cables, transformers, etc.). Therefore additional reactive compensation maybe required to ensure as this reactive power of the internal equipment changes (with changes to the active power) that the same reactive power capability range at the connection point can be maintained.
COLLABORATION	
TSO – TSO	Due to the normally regional nature of reactive power compensation, limited or zero Transmission System Operator (TSO)-TSO collaboration is expected. However network close to borders with other TSOs may require co-ordination.
TSO – DSO	Given the combined impact of embedded users and devices in the Transmission and Distribution networks to provide an adequate quantity and control to reactive power compensation and usage a high level of interaction with Distribution System Operators (DSOs) is required.
Regional System Operator (RSO) – Grid User	Given the combined impact of users and devices in the Transmission and Distribution networks to provide an adequate quantity and control to reactive power compensation and usage a high level of interaction with grid users is required.