ANALYSIS OF SELLECTED GRID CODE SPECIFICATIONS FOR OFF-SHORE WIND FARM

Gül Kurt[1]

ABSTRACT

The importance of grid impact studies of wind power integration rises with the rapid increase in the installed wind power capacity. Offshore wind power technology offers concentrated high wind power generation in high wind speed regions away from residential areas and land restrictions. Transferring a high amount of power for long distances requires a robust transmission system which can ensure stable operation with minimal possible losses. Voltage source converter - high voltage direct current (VSC-HVDC) technology has proved to be a promising solution for the connection of large offshore wind farms This paper presents and gives comparison the grid code requirements to support VSC-HVDC connected offshore wind farms for different countries.

Keywords: Off-shore wind farm, grid codes, VSC-HVDC

INTRODUCTION

Wind energy is becoming large portion of global energy profile. The penetration of wind power in electrical grid increases steadily in many European countries. According to European Wind Association (EWEA) that the worldwide generation capacity of electricity by using on-shore and off-shore wind turbine will become 12% and 20% in 2020 and 2030 respectively. Several countries such as Denmark (44%), Germany (20,8) and UK (13,5%) have relatively high percentage of their electrical energy are produced by on-shore and off-shore wind power units. [1]

Offshore wind power is becoming more relevant and of interest during the last few years. In Europe, the availability of inland locations for wind farms is limited, the huge unexploited wind resource and better wind condition at offshore location are encouraging the offshore alternative. In the future, the capacity of the offshore wind farms is going to increase. Because of the lower installation restrictions, which allows the possibility of using larger wind turbine and their distance from shore, penetration of offshore wind energy will increase largely. [2]

The fact that offshore wind power plants (OWPPs) are increasingly larger in size and located further away from shore, forced by environmental and social factors, is making it more interesting to be connected via High-Voltage Direct Current (HVDC) technology. Integration of offshore wind energy with HVDC transmission system into AC onshore grids get minimum losses and increased power flow flexibility.

With regards to the AC/DC converters technology, these can be LCC (Line commutated converters) based on thyristors or VSC (Voltage source converter) based on switching devices with the capability to control their turn on and off. Line Commutated Converter (LCC) devices have been installed in many power transmission systems around the world, so it is a mature technology. In a line commutated converter, it is possible to control the turn on instant of the thyristor, but the turn off cannot be controlled. Therefore, systems based on this technology for the converters are more susceptible to potential AC grid faults than VSC converters. In addition, a LCC converter needs a minimum reactive power to work (a minimum current), consequently, this type of converters need voltage on both sides (offshore and onshore) to start working. Voltage Source Converter (VSC) solution is comparatively new compared to the LCC solution. As the main advantage, the semiconductors switching is decoupled to the grid voltage. Thus, the VSC solutions are able to supply and absorb reactive power to the system independently and may help to support power system stability. As a result, VSCs are suitable for systems with low short circuit power. In VSC configurations the substation requires fewer components to filter, due to this task can be performed by the converter itself. On the negative side of these converters is their high cost (higher than LCC converters). In a technical/economical evaluation concerning grid connection of offshore wind farms has been performed, defining VSC-HVDC as the cheapest option for connecting a 100 MW and larger wind power plant at distances over 90 km from shore [3]. General configuration of an OWPP with VSC-HVDC electrical network can be seen in Figure. 1 [4]

[1] Kocaeli University, Electrical Engineering Department, gul.kurt@kou.edu.tr, gulenderkurt@hotmail.com

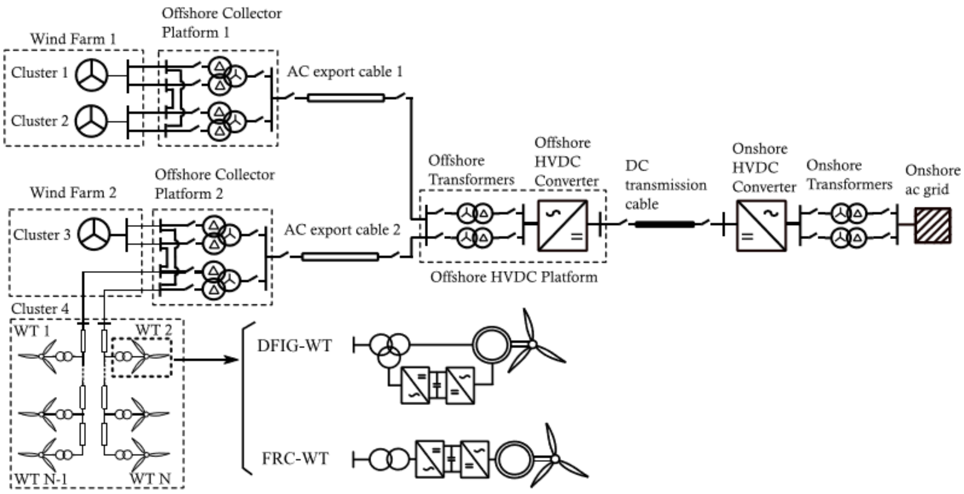
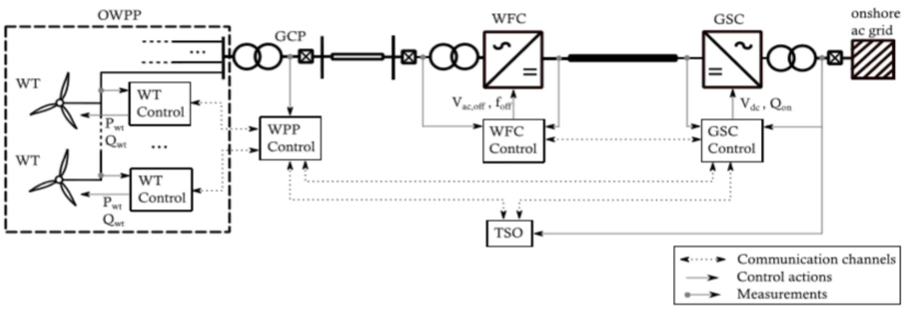
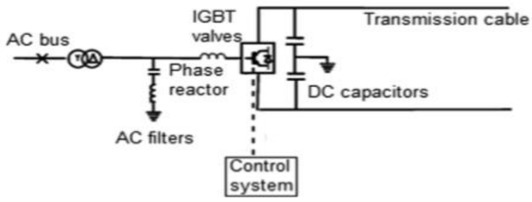


Figure.1.General configuration of an OWPP with two wind farms connected through an HVDC point-to-point link [4]



(a)



(b)

Figure.2. (a) General control scheme of a HVDC-connected OWPP [5]
(b) VSC HVDC transmission system [2]

Grid integration of large size offshore wind farms could seriously impact the operation and stability of their interconnected power system. To assist in maintaining the power system stability when large disturbances occur in the grid, modern offshore wind farms consisting of variable-speed wind turbines are required to provide ancillary services.

GRID CODE REQUIREMENTS FOR HVDC-CONNECTED OFFSHORE WIND FARMS

In order to avoid a system failure in case of slight voltage or frequency changes, any automatic disconnection of a power plant from the grid is always prohibited within certain voltage and frequency ranges during a last a certain time period. This requirement exists in all countries for all power plants, but the ranges and the time periods vary depending on the countries, and sometimes depending on the power plant.

Grid codes contain most technical rules related to the connection of power plants to the grid. They are issued by the Transmission System Operators (TSOs). This chapter describes the most important rules of these grid codes especially for offshore wind farms

(1) dimensioning voltages and frequencies,

(2) voltage control and reactive power output requirements,
(3) frequency control, and
(4) fault ride through capability [6]

When HVDC grids are developed, the need will arise to extend the existing grid codes with HVDC grid and even to develop new grid codes that are specifically aimed at the HVDC grid, addressing the connection and operational rules from the HVDC grid perspective. Offshore ac grids connected through HVDC systems are islanded grids with a large number of power converters, which may define different requirements compared to the onshore grids. There are grid codes for HVDC-connected offshore wind farms and grid connection requirements in German (TenneT), UK (National Grid), ENTSO-E were introduced and briefly discussed for the grid integration of offshore WFs. [6,7,8,9].

Dimensioning voltages and frequencies

In order to avoid a system failure in case of slight voltage or frequency changes, any automatic disconnection of a power plant from the grid is always prohibited within certain voltage and frequency ranges during a last a certain time period. This requirement exists in all countries for all power plants, but the ranges and the time periods vary depending on the countries, and sometimes depending on the power plant.

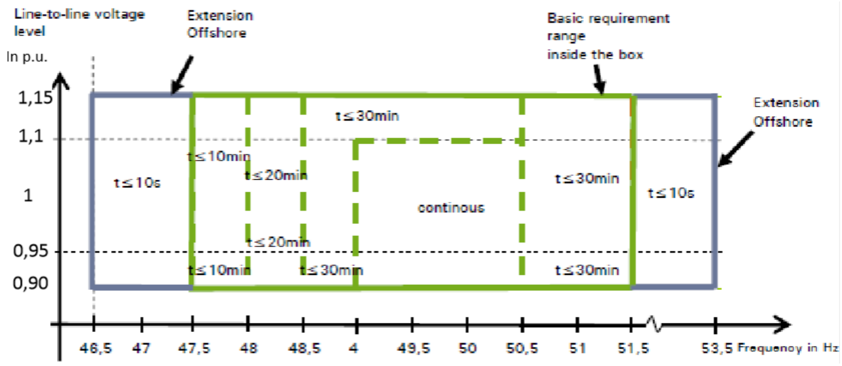


Figure. 3. The dimensioning voltages and frequencies in Germany (TenneT) "Offshore": Duration of operation of a generating unit in dependency of the voltage at the grid connection point and of the nominal frequency [8]

Figure 3 presents the duration of operation of a generating plant in dependency to the voltage at the grid connection point and to the nominal frequency. All generation units must be disconnected from the grid upon reaching a frequency at the grid connection point of less than 46.5 Hz or greater than 53.5 Hz and after a time delay of 300 ms. Additionally, All generation units must be disconnected from the grid upon reaching a frequency at the grid connection point of less than 47.5 Hz or greater than 51.5 Hz and after a time delay of 10 s. When the voltage level fall below 0,9 p.u., the requirements are described on fault ride through capabilities. [6,8]

Reactive Power Control and Voltage support

In Europe, ENTSOE has defined general requirements for dc connected power park modules in relation to;

- The maximum period of time that the converters must operate in different voltage ranges.
- The reactive power capability as a V - Q/Pmax profile that determines the operational boundaries of the converter as shown in Figure 3.
- The voltage transient response

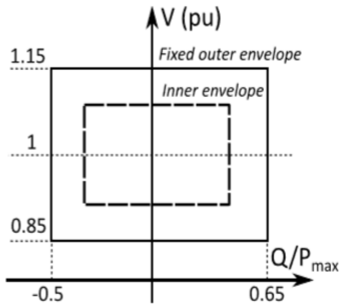
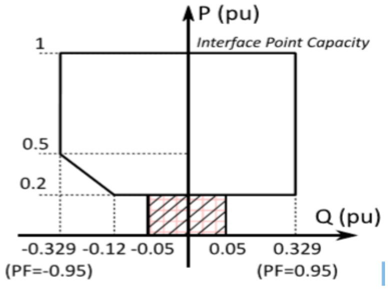


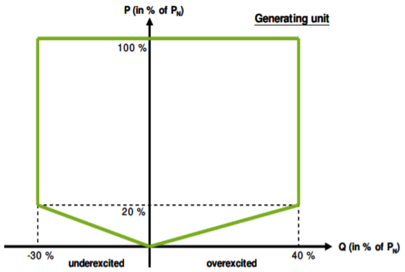
Figure 3 : ENTSOE requirements for voltage at the grid connection point of a dc-connected system [7]

Voltage operational boundaries are function of Q/Pmax, where Pmax is the maximum active power transmission capacity. The outer envelope represents the maximum values fixed by ENTSOE. The inner envelope is defined by each system operator and it does not have to be a rectangle. [7]

Also, a number of European system operators have more specific regulations. For example, Figure 4 shows the reactive power capacity diagram required by National Grid in Great Britain and by TenneT in Germany. Figure 5 shows the power factor diagram required by TenneT in Germany and National Grid.[8,9]



(a)



(b)

Figure 4 (a) National Grid (Great Britain) requirements for reactive power capacity at the interface connection point of a WPP or a DC-connected system [11], (b) "Offshore": Minimum requirements for the P/Q-operation range of a generation unit within the voltage range of +/- 5 % UN (at the generation unit) by TenneT[8,9]

The Q values are expressed as function of the interface point capacity of the OWPP. The dashed area is an optional requirement for active power generation below 0.2 pu. In Figure 4(a).

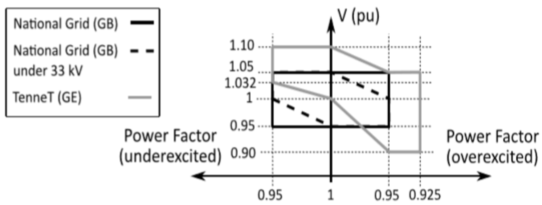


Figure 5: Voltage limits as function of power factor required by National Grid (Great Britain) in WPPs or DC-connected systems and TenneT (Germany) in offshore-connected systems [8,9].

TenneT defines the nominal voltage at the onshore connection point in 155 kV. National Grid has different voltage levels (380, 220, 110 and 33 kV), but only high voltage is considered for OWPPs. In addition, a number of system operators require WTs to provide voltage control during fault conditions. For example, TenneT defines a reactive power – ac voltage droop characteristic, as shown in Figure 6. Also, the reactive power injection from each WT has to be coordinated to prevent ac overvoltage at the terminals located far from the fault [6,8].

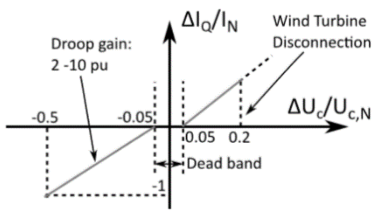


Figure 6: Voltage support during ac fault required by TenneT (Germany) in generating units [8]

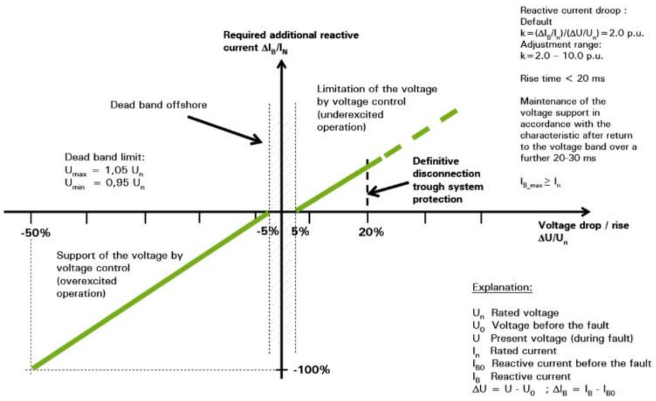
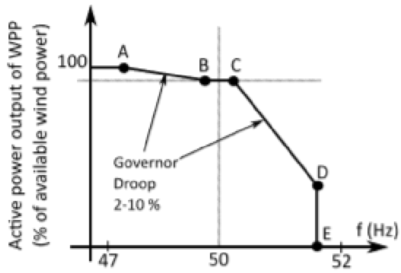


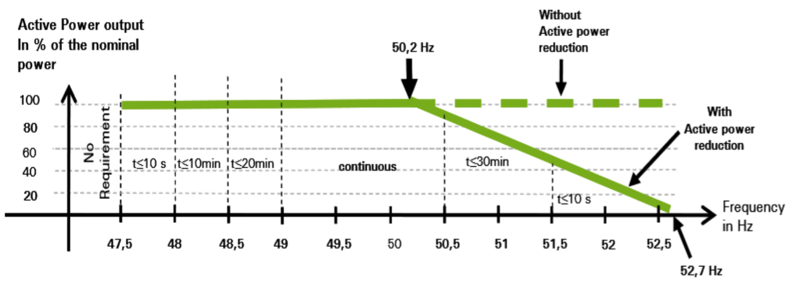
Figure 7 "Offshore": Principle of the voltage support through each generating unit during grid failures. In individual cases, the gradient of the voltage support can be changed (Reactive current droop with k >2) [8]

Characteristics of generating plants during grid failures is described in Figure 7 by TenneT. [8]

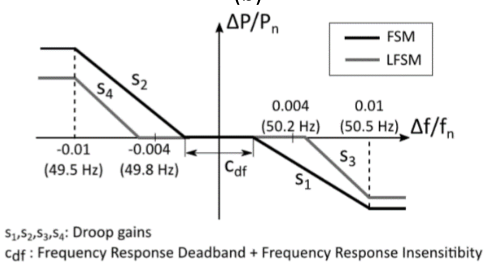
Frequency Support



(a)



(b)



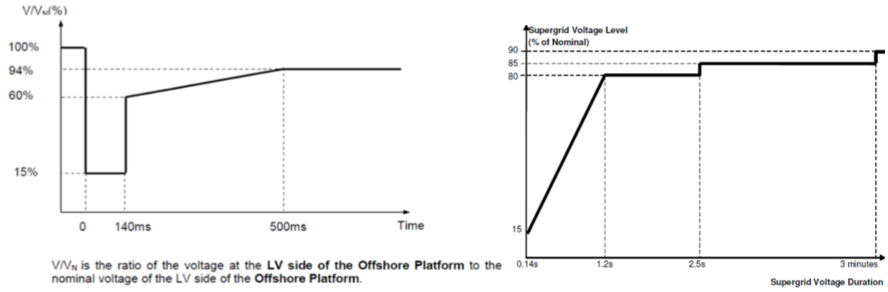
(c)

Figure 8. (a) Frequency response characteristic required by EirGrid (Ireland) in WPPs (Points A-E are defined depending on system conditions and location of the OWPP. [4] (b)"Offshore": Basic Requirement for the active output of a generation unit in dependency to the frequency and to the duration of operation characteristic required by TenneT. [8] (c) ENTSOE requirements for frequency response in DC-connected systems [7]

Grid codes include requirements that define a droop control characteristic and the minimum response times as shown in Figure7.Figure 8(a) shows the response for under and over frequency events required by

EirGrid in Ireland. In Figure 8(b) shows Tennet requirement, the droop gains s1 – s4 are at least 0.1%, the maximum deadband is ±500 mHz and the maximum insensitivity is 30 mHz. The LFSM is activated for frequency variations higher than 200 mHz. In Figure8(c,) ENTSOE defines the maximum period of time that the converters must operate in different frequency ranges and provides a range of values for parameters of the droop control. (4,6,7,8]

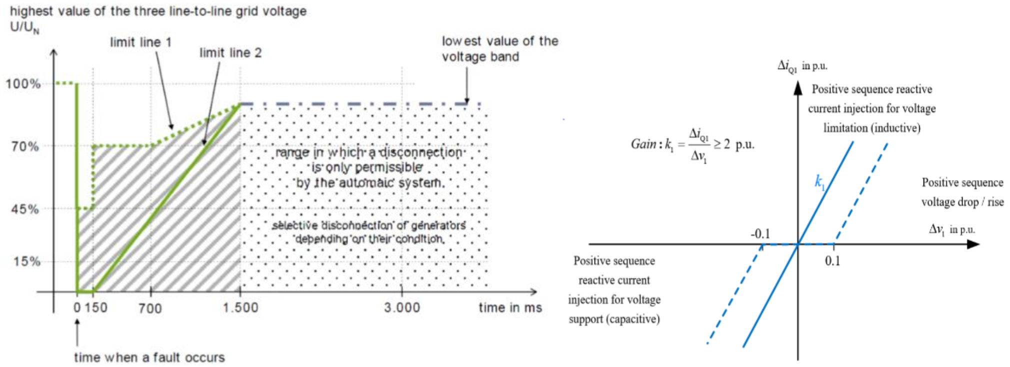
Low voltage ride through capability (LVRT)



(a) (b)

Figure 9. Fault ride through capability required for an (a) offshore wind farm, b) OFTO in the UK [9]

In the UK there are different requirements for the offshore wind farm (at the interface point between the farm and the connection line) and for the OFTO (at the interface between the connection line and a station of the onshore grid). Figure 9(a) defines the minimal fault ride through capability required for the wind farm, while figure 9(b) defines the minimal fault ride through capability for the OFTO. It is remarkable that the requirements for the OFTO are more stringent, as the OFTOs are required to withstand faults that last longer [6,9]



(a) (b)

Figure 10 LVRT requirement for (a)the offshore grid connection (b) for the offshore grid connection at the converter level by TenneT [8]

Low voltage ride through (LVRT) requirements according to the German grid code (TenneT) are illustrated in 10(a). The minimum continuous voltage level is defined as 0.9 p.u.. Three-phase short-circuit or fault -related symmetrical voltage dips must not lead to instability above the Limit Line 1 or to disconnection of the generating plant from the grid. The pair of values (voltage, time) is required as well for unsymmetrical faults with reference to the positive sequence system. Within the shaded area and above the Limit Line 2 shown in Figure 10(a), all generating plants should stay connected to the grid during the fault. If, due to the grid connection concept (plant concept including generators), a generating plant cannot fulfil this requirement. The reactive power in-feed and resynchronization must take place so that the generating plant meets, in a suitable way, the respective requirements of the grid at the grid connection point. In the other area the disconnection of the generation units is allowed but not a must. Depending on the WT control and manufacturer settings, the decision can be made to whether to continue or interrupt the operation.

The onshore converter of the VSC-HVDC system must respond to a sudden voltage collapse/increase with the corresponding fast reactive current output in accordance with Figure 10(b) . This should be implemented as a fast voltage control locally at the converter level. The Δv versus ΔiQ1 typically corresponds to the values at the connection terminal (on the high voltage side). Regarding negative sequence treatment during unbalanced faults, a draft standard in Germany already suggests a reactive negative sequence current contribution during negative sequence grid voltages. [6,8,11]

CONCLUSIONS

There is a growing interest for HVDC for grid connection of offshore wind farms. The grid code differs considerably by generation characteristics and network operation requirement. This paper presents the basic understanding for grid code requirements of offshore wind power in EU, Germany and UK which are known high offshore wind power penetration. in the UK the frequency range where continuous operation is required is much larger than Germany.

The reactive power requirements of the wind turbine is required to be capable of covering, range approximately from Q = - 0,33 Pmax (equivalent to 0,95 leading power factor when P = Pmax) to Q = + 0,33 Pmax (equivalent to 0,95 lagging power factor when P = Pmax). In Germany these requirements are also less stringent for leading power factor, but are more stringent for lagging power factor. In Germany and in the UK, the static reactive requirements are progressive as the wind turbine starts generating active power, and are to be fully fulfilled only when the active power output is at least equal to 20% of the rated capacity. There is a huge difference in the dynamic power output requirements between both of countries: while the required time-delay of the reactive response in case of a voltage drop is 20 ms in Germany and 200 ms in the UK. A wind turbine can have the capability of providing quick reactive responses if required. Such a low time-response is not a problem at low levels of wind penetration in a power system.

The minimal fault ride through capabilities required in the UK and Germany are not much different. The requirements in Germany are still a bit more stringent than in the UK, Germany require that the wind farm is capable of withstanding a voltage level of 0 kV without disconnecting (for 150 ms).

REFERENCES

[1] https://windeurope.org

[2] Kompili, A., Wu, Q., Zhoa H. (2016). Review of VSC HVDC connection for offshore wind integration. *Renewable of Sustainable Energy Reviews*, 59, 1405-1414. Doi: 10.1016/j.rser.2016.01.064.

[3] Zubiaga, M., Abad , G., Barrena, J. A., Aurtenetxea, S. and Cárcar, A. (2012). Energy Transmission and Grid Integration of AC Offshore Wind Farms, ISBN 978-953-51-0368-4.

[4] Mañe, M. C. (2017). Offshore Wind Integration through High Voltage Direct Current Systems, Cardiff University, UK, Cardiff.

[5] Pierri, E., Binder O. (2017). Challenges and opportunities for a European HVDC grid, Renewable and Sustainable Energy Reviews, 70, 427-456.

[6] Castel, R. (2011). Connection of offshore wind farms to the grid in Europe and Brittany, KTH, Royal Institute of Technology ,Stockholm, Sweden.

[7] https://docstore.entsoe.eu.

[8] https://www.tennet.eu.

[9] https://www.nationalgrid.com.

[11] Suwan, M. (2017), Modelling and Control of VSC-HVDC Connected Offshore Wind Farms, der Universität Duisburg-Essen, Germany