SOLUTIONS FOR CONNECTING OFFSHORE WIND FARMS TO THE GRID

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Summary: Connecting to the electrical grid of offshore wind farms in the Black Sea represents a critical thing and a barrier to achieve this objective. A study of the problem at regional level would lead to viable solutions, which aim to integrate the regional market, would increase the capacity for cross-border electricity trade, increase operational safety, standardization, further European integration.

Keywords: offshore wind farm, grid, transport, energy.

1. INTRODUCTION

`All European Union member states have agreed to legally binding targets to combat climate change following the principles of the overall EU objectives. Wind generation is expected to play a significant role in meeting these targets and in particular the high volume of potential offshore wind generation in the North Seas.

The Offshore Grid study estimates that between €75 and €90 billion of 'new' offshore transmission investment will be required to facilitate connection into the existing onshore electricity networks by 2030. The magnitude of this investment increases the importance of establishing a workable model that delivers economic and coordinated infrastructure at a reasonable socio-economic cost and, at the same time increases interconnectivity to ensure an efficient functioning of the EU's single energy market. The implications of connecting this volume of wind on the onshore networks will be significant, and requires further investigation.

2. OFFSHORE WIND FARMS IN BLACK SEA

Exhaustion of viable locations for onshore wind projects in Romania makes opportune the development of offshore projects on the coast of Black Sea, taking advantage of available areas, wind speed, lack of turbulence and environmental impact.

An offshore wind farm in the Black Sea has several factors in its favor:

- Water depth and distance from shore and port facility construction, operation and maintenance.
- Soil conditions and water depth, wind and wave conditions are likely to allow the use of monopole or GBS foundations – which both are well established foundation types for offshore wind farms, for which manufacturing and installation methods are well known, tried and tested. The average height of waves in the last 50 years is approx. 7.5 m - which come mainly from the north-east and south. Tide activity is weak and water level variation, in general, are small. High water level due to tide 0.1 m with seasonal variations 0.2 m; storm surge 0.8 m -1.0 m. In general, current speed is low, up to 0.3 knots. During strong winds from the north, the current velocity will increase.
- Price forecast for feed-in tariffs shows that energy prices are favorable and similar tariff regimes have allowed other offshore projects to be viable.
- Preliminary studies indicate that wind resource is at the same level as for some existing offshore projects.

The costs for developing an offshore wind park, for connecting to the grid (which usually includes an offshore substation), operating and maintenance costs, combined with significant costs to mobilize equipment and construction vessels, have as result the fact that small projects are costlier per installed megawatt, and this influences also the cost of energy produced.

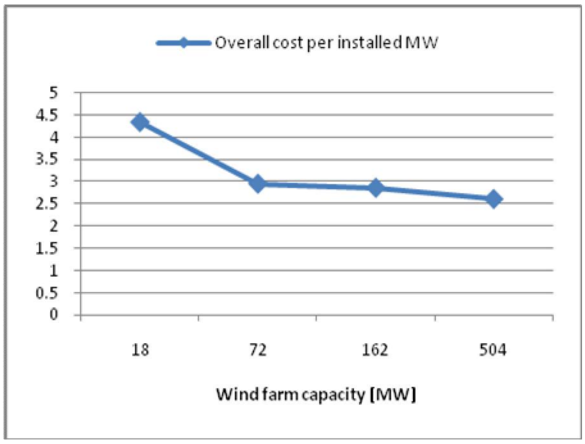

Figure 2.1 Variation of overall cost per installed MW versus wind farm capacity

3. SOLUTIONS FOR CONNECTING OFFSHORE WIND FARMS TO THE GRID

3.1 Solutions for connecting by „radial approach"

This approach would lead to wind connections to shore being under-utilized for a significant portion of time, given the intermittent nature of wind. This can be modeled using a typical load curve for offshore wind generation factor and results in 'single use' offshore connection assets utilization of between 35 and 45%.

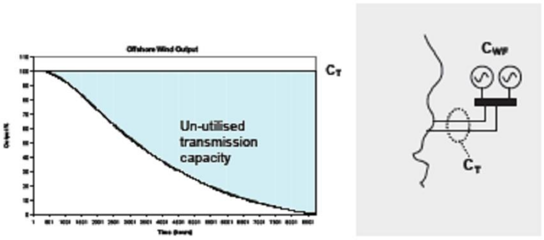

Figure 3.1 Utilisation of transmission-to-shore (CT) assets built to accommodate 100% of offshore wind generation capacity (CWF); (CT= CWF))

• Connection to shore *(C_T)* to meet 100% possible wind output *(C_{WF})*
• No restriction of wind output
• No additional cross-border trade facilitated
• Transmission utilisation 35-45%

3.2 Solutions for connecting by „integrated approaches"

Transmission asset utilization between offshore wind farms and the onshore grid can obviously be increased by using those assets as interconnectors when the wind is not blowing. Thus, some interconnections between offshore wind farms have to be built. However, potential conflict is created when the wind is blowing. Determining the appropriate level of interconnection is therefore important and requires further analysis of the expected market conditions in 2030 to help assess the cost balance of the additional assets against the curtailment costs (of either trade, or wind). The figure below shows 100% interconnection beyond the wind park, but is clearly not economic as the interconnector assets become curtailed as soon as the wind blows.

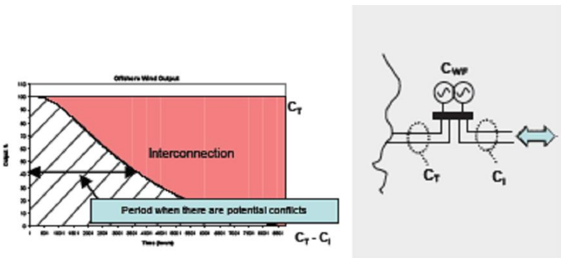

Figure 3.2.1: Utilization of transmission-to-shore assets (C_T) built to accommodate 100% of offshore wind generation capacity (C_{WF}), and also 100% of cross-border trade (C_I); ($C_T = C_{WF} = C_I$)

- 100% transmission utilization potential
- High investment costs
- Heavy curtailment of either wind generation or cross-border trade
- Limitations on ability to use interconnectors for trading exist at all times

By determining an appropriate level of interconnection beyond the wind park, volume of assets *(both, C_T and C_I)* can be optimized against the possible shared use between wind evacuation and crossborder trade. A reasonable level of use and the respective transmission and interconnection capacities has to be defined by further investigations. For the purposes of the current study a level of *(C_I= 10% of C_{WF}))* has been assumed, see next figure. C_I has to be defined based on an economical assessment considering both the global welfare increase and the investment costs.

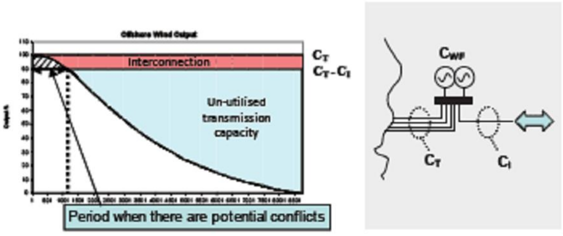

Figure 3.2.2: Impact on utilization of assets by sharing between wind connections (C_T) and cross-border trade (C_I)

- Very limited curtailment of wind generation output or interconnector curtailment
- Increased utilization of transmission *(C_T)*
- Ability to utilize interconnectors *(C_I)* for most periods (only limited with high output across all offshore wind parks*)*

The effect of wind diversity should further decrease the amount of time when a direct conflict on the use of assets between wind and cross border trade occurs. Wind diversity in the region needs to be better understood in order to assess the potential benefit of this.

3.3 Solutions for connecting by „Integrated approach"

Taking the effects of intermittency into account, an optimized integrated network can be created, that does not require the volume of assets to evacuate 100% of the wind all of the time.

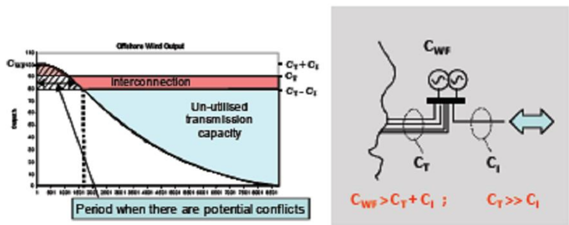

Figure 3.3 Impact on utilization of assets by sharing between wind connections (CT) and cross-border trade (CI)

• Limited curtailment of wind generation output or interconnector curtailment
• Increased utilization of transmission
• Ability to utilize interconnectors for most periods (only limited with high output across all offshore wind parks)

For offshore wind farms in the Black Sea a cross border integration with a submarine cable to Turkey, would lead to an appropriate integrated optimization.

4. CONSTRUCTIVE SOLUTIONS FOR GRID CONNECTION

For the connection to the grid there are to be considered the following aspects:

- Grid Connection Point
- Grid requirements
- Onshore or Offshore Substation(s)
- Switchgear and Transformer in wind turbine
- Marking and Identification
- SCADA system

Grid Connection Point

The point of connection to the grid can be achieved through an onshore or offshore transformer station on medium voltage or high voltage.

Figure 4.1 Onshore transformer station

Figure 4.2 Offshore transformer station

Also in the connection point to the grid, wind turbines must meet the grid connection code in order to help stabilize the grid in different situations:

- voltage variations
- frequency variations
- reactive power capability
- flicker emission
- voltage control
- frequency response
- fault ride through

The schematic diagram of a wind turbine:

- permanent magnet generator
- full scale converter 650 v line voltage, 4 quadrant operation, water cooled
- transformer 650 v to10-35 kv,
- high voltage cable
- switch gear

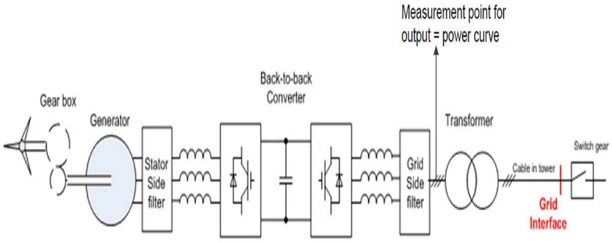

Figure 4.3 Schematic diagram of a wind turbine

Voltage range

Wind turbines generator and the converter will be disconnected if:

- Voltage above 110 % of nominal for 60 sec.
- Voltage above 115 % of nominal for 2 sec.
- Voltage above 120 % of nominal for 0.08 sec
- Voltage below 90 % of nominal for 60 sec.
- Voltage below 85 % of nominal for 11 sec

Frequency range:

Wind turbines generator and the converter will be disconnected if:

- Frequency is below 47 Hz for 0.2 second.
- Frequency is above 53 Hz for 0.2 second.

Reactive power capability:

Reactive power is produced by the Grid Streamer® converter; therefore traditional capacitors are not used in the wind turbine. Wind turbine reactive power capability is limited to 0.86 inductive - 0.93 capacitive at the LV side on the transformer.

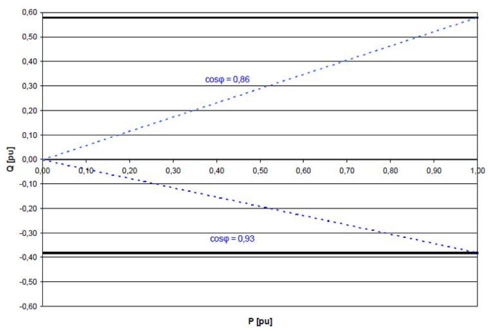

Figure 4.4 Wind turbine reactive power capability

Active and Reactive Power Control

The wind turbine is designed for control of active power and reactive power via VestasOnline SCADA system as follows:

Active power:

- Maximum is 0.1 pu/second - pu = 3000 kW

Reactive power:

- Maximum is 20 pu/second – pu = 3000 kvar

Reactive power no load operation:

- up to 50% of 3000 kvar

Minimum Active power output:

- 20% of nominal power

5. THE MAIN BENEFITS OF „INTEGRATED OPTIMIZED APPROACH" SOLUTIONS FOR CONNECTING TO GRID

The main benefits of „integrated optimized approach" solutions for connecting to grid can be resumed as follows:

- Maximizing the utilization of the large scale assets required to connect the significant volumes of wind expected provides secure and more cost effective evacuation of offshore wind generation nationally, to other parts of the region, and other parts of the EU.
- An integrated grid will play an important role in creating the operational flexibility that will be required against the changing background of generation we will experience in the next 20 years. This approach improves security of energy supply by providing flexible, controllable routes for variable energy from large scale wind generation farms to demand centers on shore.
- More cost-effective cross-border trade and balancing capacity through shared assets (combining the connection of wind power and interconnectors) taking advantage of the variable characteristics of wind to facilitate greater integration of the EU market.
- The investigated example shows the potential for reducing offshore infrastructure costs in the order of 10% (€7 billion) when comparing an integrated design with national, radial solutions.
- Responsible use of scare environmental resource. Fewer and larger assets reduce the number of seabed routes, landing points and converter station sites. While national integration goes some way to achieving this, an international solution could further reduce the environmental impact by optimizing assets across the region and potentially simplifying the on and offshore planning and authorizations required.
- A coordinated plan should improve deliverability through an already constrained supply Chain. In addition, a coordinated, integrated approach creates the potential for European TSOs and industries to lead in offshore grid integration with onshore networks.

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