Grid integration and stability of 600MW windfarm at Kriegers Flak – the largest power plant in Denmark

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1. Introduction

When completed by December 2018, the Kriegers Flak 600MW offshore wind power plant will be the largest electrical power generation unit in Denmark East. Including the wind turbines at Kriegers Flak, the nominal wind power capacity will correspond to 65% and 210% of the maximum and minimum consumption in Denmark East, respectively. Already in fair wind conditions, the wind power and other RES units will be sufficient for covering the most of the East Danish electrical consumption. Participation of thermal power plants in the electrical power and energy mix and, hence, provision of ancillary services to the grid by means of a tried-and-proven response of their synchronous generators becomes significantly reduced. When increasing participation of wind and other RES power generation, the power and energy balance of the East Danish system will be maintained using the interconnectors to the neighbouring areas. This presentation describes the approach and main findings of the dynamic stability study for Denmark East, which Energinet.dk has conducted by summer 2015 for the grid-connection of the 600MW wind power at Kriegers Flak. Among the novices are that a wind power plant is the largest power generation unit in the transmission grid, presence of fixed-speed wind turbines with induction generators remains significant, and operation scenarios are set up with no participation of thermal power plants.

2. Approach

The main approach has been distinguishing between dynamic voltage stability of the Danish onshore transmission grid itself and securing dynamic stability of the offshore wind turbines. By experience from earlier studies, dynamic voltage stability of the onshore grid is stressed in large power flows superimposed by high wind power generation. Attention is paid to that a significant share of the Danish wind turbines are fixed-speed types with induction generators which may become overspeeded and imposed to instability in low-voltage operations and strong wind. Hence, the operation scenarios for the stability assessment have been a combination of large power flows through the Danish onshore grid, large power transport through the connectors to the neighbouring systems, large wind power generation in offshore and onshore wind turbines, and no participation of the thermal power units.

The HVAC cable length from the Kriegers Flak offshore platforms to the onshore grid will be around 80 km. The wind turbines will be most likely converter-interfaced types in order to comply with the Grid Code requirements, e.g. Low-Voltage Ride-Through (LVRT) and support of voltage reestablishment. In normal operations, the wind turbines can be in one of the control regimes: reactive power, power-factor or voltage control in the offshore point-of-connections. The approach has been evaluation of the different control regimes on keeping dynamic stability of the offshore wind turbines at Kriegers Flak following severe disturbances in the onshore transmission grid. The further interconnection with the German 150kV offshore section of Kriegers Flak is not part of this presentation.

The disturbances have been busbar short-circuits in the main Danish substations. Such disturbances result in voltage dips and post-sequent tripping of affected transmission lines and transformers. The onshore grid shall recover to normal operation in weaker conditions than before the busbar short-circuits.

3. Energy and power outlook

Denmark East includes the main Danish island of Zealand with the capital Copenhagen and the islands of Lolland, Falster and Moen. The present stage grid map with HVAC connection of the Kriegers Flak offshore wind turbines is illustrated in Figure 1. Table 1 presents the electrical energy outlook of Denmark

East. The largest power demand is found in the Copenhagen area and the largest wind power production is suited offshore and onshore at Lolland and Falster.

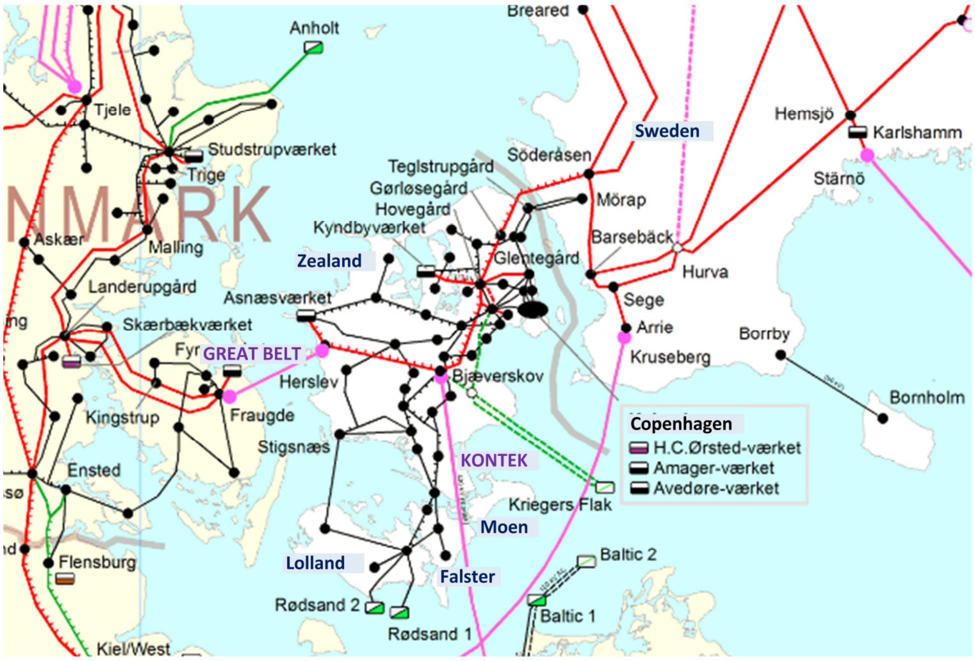


Figure 1: Denmark East and Kriegers Flak offshore wind power plant

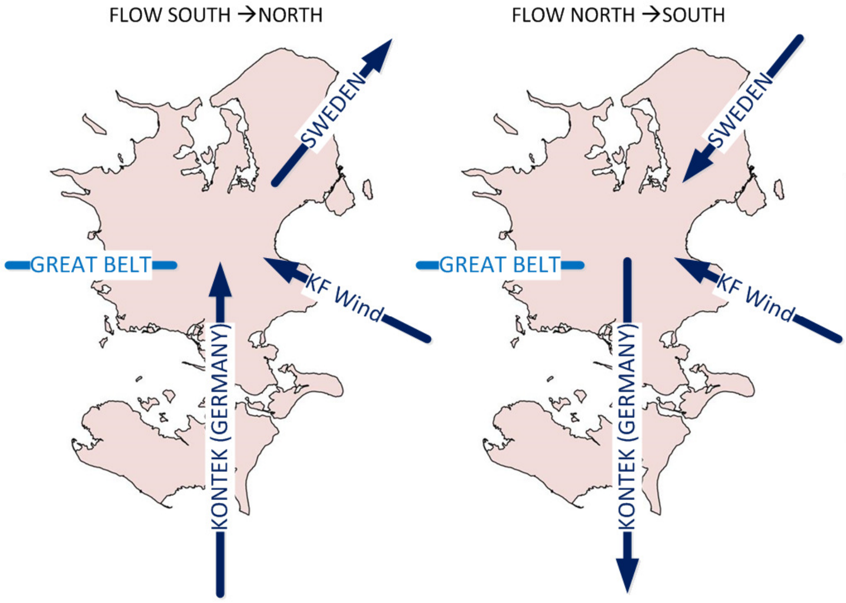
Table 1: Electrical energy outlook 2021 of Denmark East

Type	Nominal power capacity (MW)	Technology pr. capacity (MW)
Consumption excluding losses	2843	
Offshore wind without Kriegers Flak	372	Induction generation (Rødsand 1): 165 Converter-interfaced (Rødsand 2): 207
Offshore wind at Kriegers Flak	600	Converter-interfaced: 600
Onshore and near-coast wind	894	Induction generation: 356 Converter-interfaced: 538
Photovoltaics	255	
Thermal power plants	1940	Largest unit: 450
Decentralised combined heat-power units	315	Largest unit: 70
Kontek HVDC (import/export)	600/600	Line-Commutated Converter (LCC) HVDC
Great Belt HVDC (import/export)	600/600	Line-Commutated Converter (LCC) HVDC
Denmark East-Sweden (import/export)	1700/1300	400kV and 132kV HVAC

3.1 Operation scenarios

The transmission grid of Denmark East includes 400kV, 132kV and, after establishment of the Kriegers Flak connection, 220kV systems. Denmark East is HVAC connected to Sweden and belongs to the Nordic synchronous area. Through the HVDC connectors Great Belt and Kontek, Denmark East is connected to Denmark West and Germany, which are part of the Continental synchronous area. At the HVDC converter stations in the 400kV substations Bjæverskov and Herslev, Energinet.dk has established the two synchronous compensators. The objective is dependency reduction from ancillary services which have traditionally been delivered by thermal power plants. In windy conditions, the East Danish grid has already been operated with both synchronous compensators and only one thermal power plant at the 132kV system at its minimum generation level. The electrical power demand has mainly been covered by wind, PV and decentralised generation. The HVDC and HVAC connectors have been used for balancing the East Danish system. Such operation patterns will become more common after establishment of 600MW wind power at Kriegers Flak.

The operation scenarios of the dynamic stability study are prepared for two demand levels, i.e. low and high, which are superimposed by two possible power transport directions North→South and South→North. The operation scenarios are illustrated in Figure 2 and the flow through the Great Belt HVDC connector has been used for balancing the East Danish system.



Type	Power in % of installed capacity
Thermal Central Plants	0
CHP Decentralised Units	40
Photo-Voltaics	90
Onshore Wind	90
Offshore Wind excl. KF	100
Kriegers Flak Offshore Wind	100
Consumption	40 (Low) 80 (High)

Figure 2: Illustration of operation scenarios

3.2 Voltage behaviour

At present, Denmark East utilizes system protection schemes (SPS) for stabilizing voltage and frequency in severe disturbances in stressed conditions. With relevance for this dynamic stability study, the Great Belt SPS has been examined. The existing SPS does run-back of the Great Belt HVDC power flow in outage of certain transmission lines in Denmark-East in pre-conditions of either (i) export to Sweden and import through the Great Belt HVDC connector or (ii) import from Sweden and export through the Great Belt HVDC; the power transport shall be over certain amounts for activating the Great Belt SPS.

For the East Danish transmission grid, the study has confirmed the significance of the Great Belt SPS for keeping dynamic voltage stability in severe disturbances. The study has neither exposed worsening nor found improvements of dynamic voltage stability in Denmark East which could be related to connection of 600MW wind turbines at Kriegers Flak. The voltage reestablishment, which shall follow severe disturbances in the Danish grid, remains dependant on the already established arrangements and operation rules. The voltage recovery process may take several seconds from the moment of the short-circuit clearing to complete re-establishment within a defined operation range, i.e. the dynamic voltage recovery is slow. Slow voltage recovery in the onshore transmission grid may impose additional recommendations for the control regime of the offshore windfarm which follows disturbances in the onshore grid.

Figure 3 compares simulated behaviours of the Kriegers Flak wind turbines after a busbar short-circuit in Denmark East for the two operation regimes: (i) voltage control and (ii) reactive-power control. As seen, the voltage and active power show faster and securer reestablishment when the wind turbines are in the voltage control regime (normal grid operations). When in the reactive-power control regime, the voltage still recovers, but the wind turbines tend more re-entering, i.e. leaving and then going into, the LVRT, which in longer run may cause disconnection.

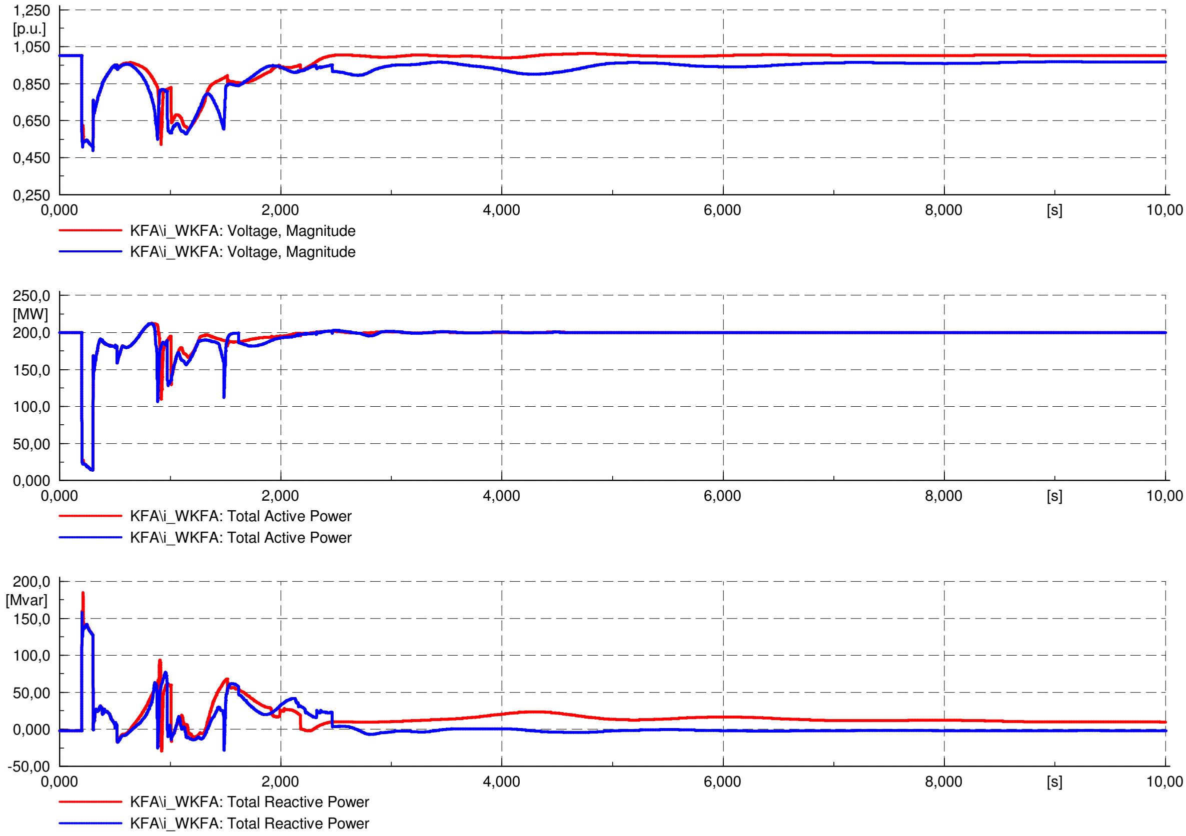


Figure 3: Comparison of Kriegers Flak wind turbines operating at two different control regimes in normal operations: red – voltage control, blue – reactive-power control.

Thus, the voltage control regime in normal grid operation is recommended, though not requested, for the Kriegers Flak wind turbines. This study has not found cases resulting in not recovered voltages. A similar behaviour is observed in the study which also included the further interconnector to the German 150kV offshore network.

4. Conclusion

The dynamic stability study on the HVAC connection of 600MW offshore wind power at Kriegers Flak to the East Danish transmission grid has been conducted. When commissioned by 2018, the Kriegers Flak windfarm will be the largest power unit in Denmark East. The study has shown that dynamic voltage stability of the transmission grid remains unaffected by the windfarm. The study presents scenarios and shows feasibility of operation and stability of Denmark East without participation of thermal power plants. The dynamic voltage stability relies on synchronous compensators as well as on advanced system protection schemes. The study recommends that the windfarm is in the voltage control regime in normal grid operations for securing stable and fast voltage reestablishment in the windfarm after severe disturbances in the onshore transmission grid.

5. Learning objectives

Dependency from ancillary services from thermal power plants shall be reduced.

Enhanced usage of system protection schemes; more studies and coordination efforts are needed.

Dialog with the offshore windfarm developers on advantages of voltage control regimes for stability and secure operation of windfarms.