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System stability of large wind power networks: A Danish study case

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Abstract

The article describes the considerations and the results of the investigation on short-term voltage stability carried out on a large wind power network model that is similar to a part of the Danish power grid. In the investigated power network, around 50% of the electricity consumption is covered by wind turbines and local combined heat and power (CHP) units. A distinction is made between local wind turbines that may trip and those in a large wind farm subject to the Grid Specifications of the transmission system operator (TSO) that must ride through the grid faults. When a short-circuit fault occurs in the transmission network, the main concerns are: (i) a risk of uncontrollable voltage sags that may result in voltage instability, (ii) a risk of significant power loss due to tripping of local units and possibly (iii) a risk of over-voltage at the periphery of the transmission network. Significant presence of induction generator based wind turbines is the main reason of a risk of voltage instability manifesting itself by temporarily uncontrollable voltage decay in a part of the power grid and being caused by significant reactive power absorption of the induction generators. However, voltage instability does not necessarily develop to voltage collapse, because local wind turbines will trip at abnormal grid operation, for example, at registering excessive under-voltage. This ‘eliminates’ the problem of reactive power absorption in the power grid and leads to the voltage reestablishment. However, protective disconnection introduces the new issues such as (i) establishing power reserves and (ii) protecting the periphery of the transmission network from excessive over-voltage.

Keywords: Wind turbine; Short-circuit fault; Voltage stability; Power loss; Power reserves; Over-voltage; Reactive compensation; Power grid; Model; Simulation

1. Introduction

During the last 10 years, there has been a significant increase in grid incorporation of wind power and local CHP in Denmark. In Western Denmark, there are already observed situations where wind turbines and local CHP units cover between 30 and up to 100% of the power consumption. There are also short periods where the power generation from wind and CHP exceeds the power consumption and the power surplus is exported to the neighbouring systems [1]. The major part of the electricity-producing wind turbines in Denmark are fixed-speed and equipped with induction generators with a short-circuited rotor circuit. An amount of the reactive power is absorbed from the grid to excite the induction generators, which are shunt-compensated locally.

The amount of grid incorporated wind power continues rapidly to increase. At the same time, the amount of active power supply and the reactive power control of the large central power plants are reduced in favour of wind power.

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Previous investigations performed for the eastern part of Denmark predicted that there will be a risk of voltage collapse started by such a short-circuit fault and caused by over-speeded induction generators [2]. Later, stability investigations have been carried out in other countries [3–5]. One of the main concerns becomes maintaining of short-term voltage stability if a three-phased short-circuit fault occurs in the transmission network.

In Denmark, the considerations and the results of Ref. [2] have since been revised. The revision is made for getting a more realistic approach to the dynamic behaviour of the large wind power network at severe grid disturbances, which is described in this paper.

2. Lessons of previous investigations

Ref. [2] presented the results of a pioneering work with regard to short-term voltage stability of the transmission network with a significant amount of wind power and local CHP. Specifically, it was concluded that there would be a risk of a voltage collapse in Eastern Denmark caused by over-speeded wind turbines when a transient, three-phased short-circuit fault was subject to an arbitrary node of the transmission network. Such transient faults may be caused by a lighting striking into the HV mast and, in this area, occur a few times per a year. The practical experience does not confirm the results of Ref. [2].

The results of Ref. [2] were reached on the considerations that might be discussible with regard to realistic operation of the local wind turbines.

1. The local wind turbines were always set to be at rated operation (100% wind).
2. The local wind turbines did not trip at excessive under-voltage.

The first consideration is too conservative because the most usual wind speed in this area is between 8 and 10 m/s corresponding to the operation point between 50 and 60% of the rated power (50–60% wind). Only in very few situations during last 10 years, the power generation in the local wind turbines of this area approached 90–100% wind. Then, the large wind power network will in the most situations be more stable with regard to such short-circuit faults than concluded in Ref. [2].

The second consideration of Ref. [2] disregarded action of the protective relays. This resulted in prediction of an avalanche process where the grid voltage dropped more and more and the over-speeded induction generators absorbed more and more the reactive power. However, this does not correspond to the practical experience with the local wind turbines and the local CHP units in Denmark as such units trip by under-voltage. Neglecting of the protective relays is a serious lack in modelling of such local generation units [6,7].

In this investigation, a distinction is made between:

1. Large wind farms connected to the transmission network (above 100 kV in Denmark).
2. Local wind turbines connected to the distribution networks (below 100 kV in Denmark).

The large (offshore) wind farms connected to the transmission network are subject to the Grid Specifications of the Danish TSO [8] and must ride through three-phased as well as unbalanced short-circuit faults.

In Denmark, the practical experience has shown that the large offshore wind farms are already at rated operation when the power generated by the local wind turbines approaches or exceeds 60% of the installed power. Therefore, the analysis of the ride-through operation of the large offshore wind farms must be extended to cover the situations where the local wind power is not at rated operation.

The local wind turbines have not been subject to any specifications of the TSO, except of those being installed after July 2004 [9]. Therefore, the major part of the local wind turbines produce so much power as wind blows, do not contribute to dynamic reactive power and voltage control and may trip at registering of abnormal grid operation.

At present, the installed power of local wind turbines exceeds significantly the rated power of the large (offshore) wind farms. In Eastern Denmark, the ratio between the installed power capacities of the local wind turbines and the rated power of the large wind farm at Rødsand/Nysted is around 580–165 MW. In Western Denmark, this ratio is around 2400–160 MW (the Horns Rev offshore wind farm).

Therefore, operation of the local wind turbines may have significant influence on the outcome of a three-phased short-circuit fault subject to the transmission network.

3. Power network model

Fig. 1 shows the sketch of the large power grid examined. The whole power grid can be separated into three areas with

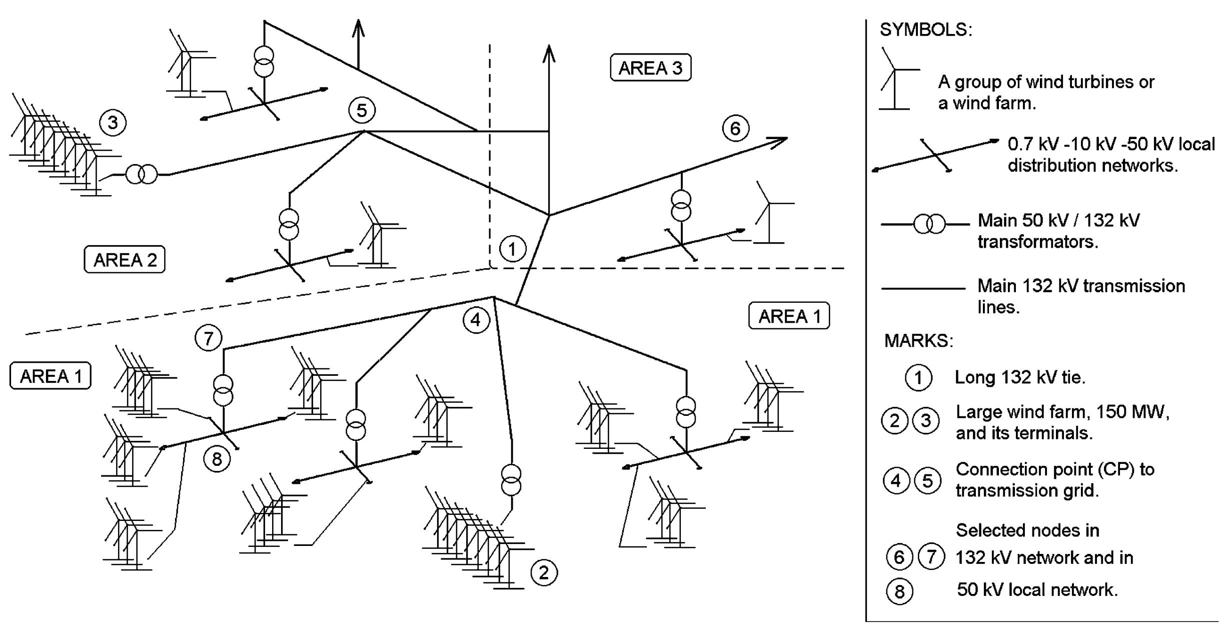

Fig. 1. Sketch of large power system model.