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Special Report

PROVISION OF SYSTEM SERVICES BY USING WIND POWER PLANTS

Prof. Dr. Lutz Hofmann, Sebastian Stock,
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Introduction

The amount of installed wind power capacity in the German as well as the European electricity system increase continuously forcing conventional thermal generation units off the market. Loosing these power plants means losing also rotating masses serving for frequency stabilization as well as generation units providing ancillary services and reactive power for voltage control and participation to congestion management. As a result, other generation units like on- and offshore wind power plants (WPP) have to take over the responsibility for providing system services and maintaining system stability. In this paper an advanced control technique will be proposed, which allows for an improvement in grid operation by using wind farm clusters (including offshore WPP). Hereby the wind forecast has to be taken into account, which makes possible a system barioperation and provision of system and grid services with a look to the future.

Within this document, concepts are presented how the provision of ancillary services can be further improved as well as which additional services can be provided in future like power reserve provision for frequency control and reactive power provision for voltage control.

Grid Operation – State of the Art

The actual, already existing transmission and distribution grids are based on a centralized energy production. The locations of the power plants are mainly based on the availability of primary energy sources and the proximity to the consumers [1]. Figure 1 shows typical topologies in Germany in the respective voltage levels.

The extraordinary expansion of renewable energy sources - such as solar PV and wind - now has the effect that a large amount of energy is being installed at medium and low voltage levels. Thus, whole distribution networks become energy producers in case of high wind situations. This effect includes bottom up power flows, congestions, voltage problems and the substitution of conventional thermal power plants.

From this transformation of the electrical power system two important aspects can be derived:

1. The grid structure in all voltage levels has to be adapted to the new conditions and
2. Renewable energy power plants have to take over functionalities of conventional thermal power plants, e.g. provision of system services.

Windpark Cluster Management System (WCMS)

The geographically distributed on- and offshore wind farms will be aggregated to clusters with several points of common coupling (PCC) which can span over two or more voltage levels. These clusters provide grid supporting functions help in the optimization of the grid operation. This is carried out under consideration of the grid in between the wind farms and by using wind forecast data with different temporal resolutions. The WCMS achieves on level of a grid operator (TSO or 110-kV-grid) a supra-regional energy management for a control and regulation of active and reactive power feed-in of geographically distributed wind farms through access to their control units. For this, adequate information and communication systems are required. The WCMS aids the TSO or a local 110-kV-system operator by operating the cluster according to the requirements of the transmission or 110-kV-system. Non-controllable wind farms within a wind farm cluster are supported by controllable ones.

The following basic operating modes for wind farms clusters are possible:

- Active power limitation which controls and regulates the power feed-in of the whole cluster;
- Scheduling of wind power feed-in to achieve a constancy in scheduling;
- Supply of reactive power for voltage control with a usual setting range like conventional-power-station;
- Supply of balancing power to provide negative and positive reserve power for the balancing between wind power prediction and wind power;
- Provision of primary and secondary control power;
- Contribution to congestion management.

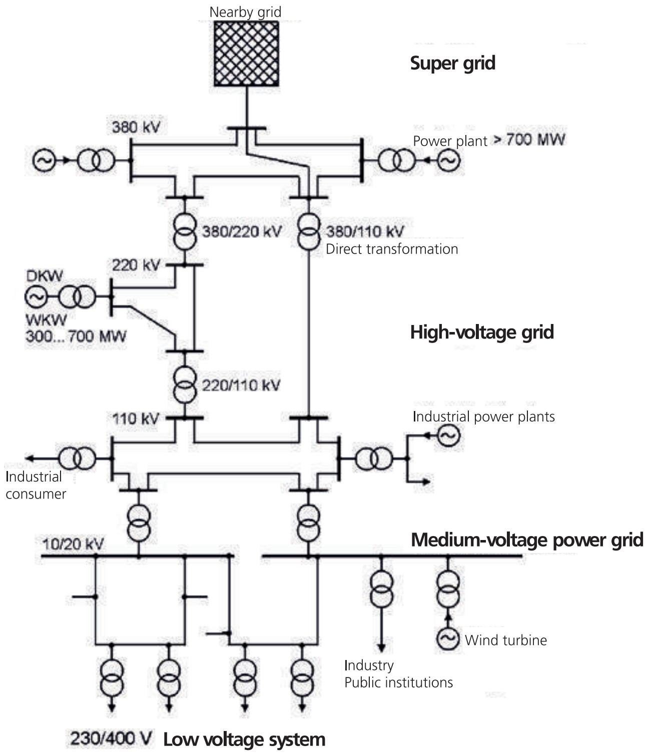

Figure 1: Representation of the German meshed grid structure [2]

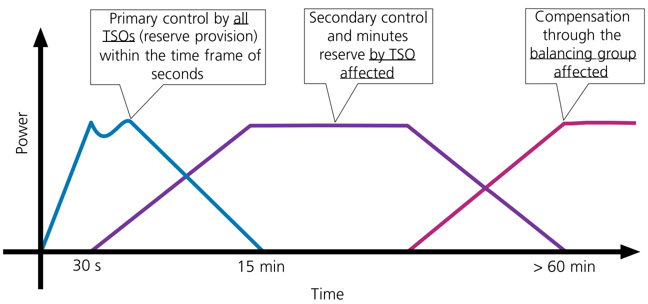

Figure 2: System of frequency control [4]

All of these services shall include the wind power feed-in forecast of all wind farms belonging to one cluster. According to actual grid codes, not all of these services are required by WPP or wind farms, nonetheless in a future power system such services may be asked for. In the following a brief overview on some of these operation modes will be given.

Active Power Limitation and Scheduling of wind power feed-in. By the operation mode “Active Power Limitation” the WCMS ensures that the active power output for the whole cluster is kept under a certain limit during a specific time period and computes a schedule for all wind farms belonging to the cluster on basis of the wind forecast, so that the sum of the output reaches the required value.

Control Power Provision. In an electrical system it is necessary to keep the balance between generation and load all the time. Due to this, positive or negative control power is necessary which can be activated in order to keep this balance. The control power is, in Germany and in most other countries, subdivided in primary-, secondary- and tertiary control power [3].

Due to the stochastic nature of WPP, additional control power is required when wind power is installed in a control zone [5]. Mainly secondary and tertiary control reserve is used for wind power deviations [6]. In the future, it will be necessary for WPP to provide control power by their own means. Positive control power implies that the power output needs to have constantly a delta to the maximal possible power output.

In some countries like Denmark such an operation mode is foreseen in the grid code, as depicted in Figure 3. Several control strategies and capabilities of wind farms like operation based on active power limitation, power factor setpoint, reactive power setpoint and voltage setpoint were tested on real wind farm clusters according to [8] in Portugal.

Voltage Control. Wind turbines can essentially influence the voltage at their connection nodes during normal operation by changing the reactive power feed-in. Thus, PQ-diagrams related to a grid connection node are defined in grid codes as operational areas (setpoints) which have to be reached by the WTG. German case is depicted in Figure 5.

The operation mode "Voltage Control" can be used, to provide a desired value of reactive power with the cluster and contribute to the voltage regulation. For each wind farm the information is needed, whether and in what extent reactive power can be supplied. This is also done for the future using a forecast of its reactive power demand or generation. For this, the resulting combined P-Q-diagram is being calculated for each grid node and each time step (actual as well as forecast data). With this information the WCMS is able to determine the respective reactive power of each wind farm and then transfer the set points to the wind farms.

Due to the facts that transmission systems as well as 110-kV-grids are meshed and that there is not a linear dependency between a reactive power flow and the node voltages, several iterative calculations have to be performed in order to detect precise reactive power setpoints for the individual DSO-grids under consideration that the voltage bands at all grid nodes aren't violated or any congestions, e.g. on lines or transformers occur in the system [10].

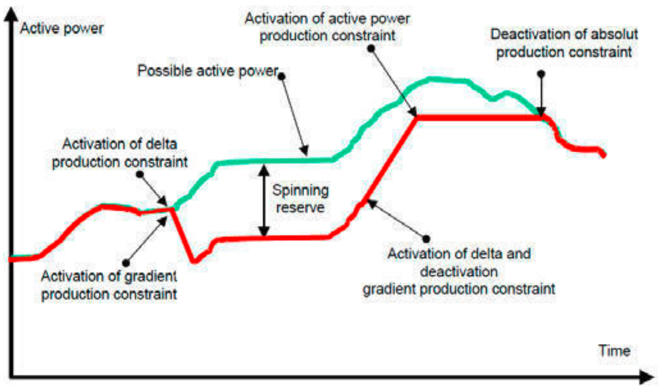

Figure 3: Spinning reserve requirement in the Danish grid code [7]

Figure 4: Wind farm cluster "Pinhal Interior", Portugal during a test with the WCMS (Source: IWES)

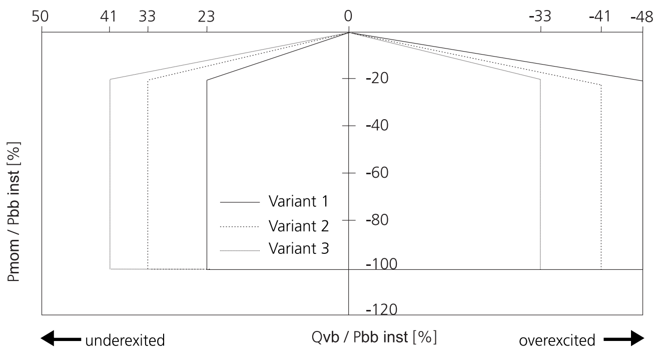

Figure 5: PQ diagram of the wind energy plant at the grid connection point in the consumer meter arrow system, variants 1-3 [9]

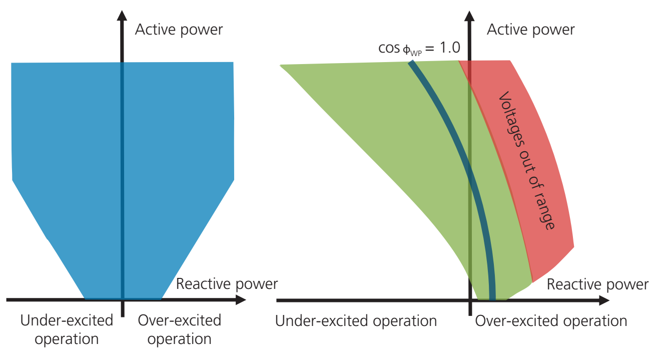

Figure 6: PQ diagrams from RAVE Grid Integration at both PCCs: off- and onshore, respectively

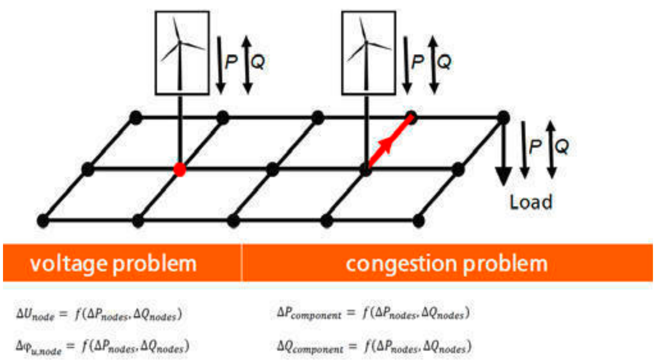

Figure 7: Calculation of interaction factors in order to solve actual or future (based on forecast) problems

Congestion Management. In some regions with a huge amount of installed wind power (e.g. North Germany), where the generation capacity exceeds the local consumption, congestion can occur in times of high wind power feed-in.

Therefore, a continuous analysis of the grid structure and the load flows is required. For that purpose, several grid calculations using the parameters of the electrical grid components are performed. Due to these calculations, also congestion and/ or voltage problems can be detected in advance taking the actual or a possible grid state (n-1 issues) into account.

In particular, factors are calculated which depend on the operational conditions and grid parameters and topology and which directly represent the influence of power feed-in of e. g. wind farms or consumption on the loading of grid components like cables, overhead lines and transformers and the node voltages. Thus, especially the generation unit(s) which has/have a dominant and optimal effect to solve an already existing or future congestion or voltage problems which are being detected using forecast data is/are identified.

Conclusion

Considering the increasing number of wind farms in electrical power systems, the upcoming erection of offshore wind farms and the displacement of conventional thermal generation units, an intelligent management system for wind power generation becomes more important which makes possible that wind clusters take over system services and to contribute to system stability.

The WCMS of Fraunhofer IWES use the renewable power generation units directly to offer additional services to the grid they are connected to – not only services relating their PCC nodes (points of common coupling). Among other things, this is being presented in the project "RAVE Grid Integration". As a consequence, whole grid areas can be used to provide similar services to influence voltages of connected grid areas or to manage congestion problems or to provide control power.

Naturally, a basic issue is the communication between the several grid components as well as an overall control strategy. Advanced control techniques and software solutions are under development.

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