Advanced Operating Control for Wind Farm Clusters

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***Abstract*--In a German research and development project a new control unit for system operators, the Wind Farm Cluster-Management (WCM) has been developed. It is able to coordinate the geographical distributed wind farms and represent them as one wind power plant for the system operators purposes. The pooling of several large (offshore-) wind farms to clusters in Gigawatt (GW) range will make new options feasible for an optimised integration of intermittent generation into power supply systems. The concept is going to be realised in software which can be installed at the Transmission System Operators (TSO) grid control center. The WCM will be tested and verified with onshore wind farms in a demonstration phase. This paper describes the concept of the WCM.**

***Index Terms*--Energy management, Large-scale integration, Wind energy, Wind power generation**

I. Introduction

THE intermittent character of power output from Wind Turbines (WTs) has an increasing influence on the utilisation and reliability of the grid. In the wind year of 2005, more than 17.300 WTs with an installed capacity of 18.290 MW generated approximately 26 TWh and supplied about 5 % of the German electricity consumption [1],[2]. Scenarios for future power supply in Germany assume that WTs with a total power of up to 25 GW will be erected offshore. The German "dena Netzstudie" has shown that the integration of this immense wind energy is not possible without extended management of WTs [3].

Under the leadership of ISET the German WT manufacturer ENERCON, the two Transmission System Operators (TSOs) E.ON Netz and Vattenfall Europe Transmission, the University of Kassel and the German Weather Service cooperate in order to investigate the upcoming technical problems due to the integration of large offshore wind farms into the power supply system.

The general aim of the project[1] "Integration of Large Offshore Wind Farms into the Power Supply System" is to find new solutions for the integration and thereby to enhance the economical benefit of wind energy. This will be realized by developing new concepts and strategies which will be implemented in hard- and software.

Beside the implementation of advanced operating control for single wind farms, the development of new energy management concepts for clusters of wind farms is introduced.

II. New Operating Control for large Wind Farms

According to the German Federal Government's planning, the share of renewable energies in German electricity consumption should increase to 12,5 % by 2010 and to 20 % by 2020, of which the majority will be expected as wind energy. The conventional power production in electrical power system will be reduced at times with high wind power feed-in. Today, conventional power plants are needed to supply ancillary services for grid management. In the future, wind farms will have to provide a part of these ancillary services, such as the supply of reactive and balancing power.

Modern WTs have been recently applied extended functions for the contribution in operational grid management [4], e.g.:

- reactive power feed-in (desired value of default reactive power or default power factor) depending on the WTs ability of reactive power provision and the wind conditions.
- Generation Management (limitation of maximum active power feed-in), which controls and regulates the power feed-in to the grid connection node.

A single WT operates as an autonomous system, but for additional functions a high-level Power Management System (PMS) is necessary. The PMS operates and manages a wind farm, which may consist of several single wind farms. By using this PMS, the following management strategies are resulted:

- reactive power provision (desired value of default reactive power or default power factor) with a usual setting range like conventional-power-station, independent of the wind conditions
- schedule setting to follow a given schedule for the wind farm depending on the wind (power) forecast

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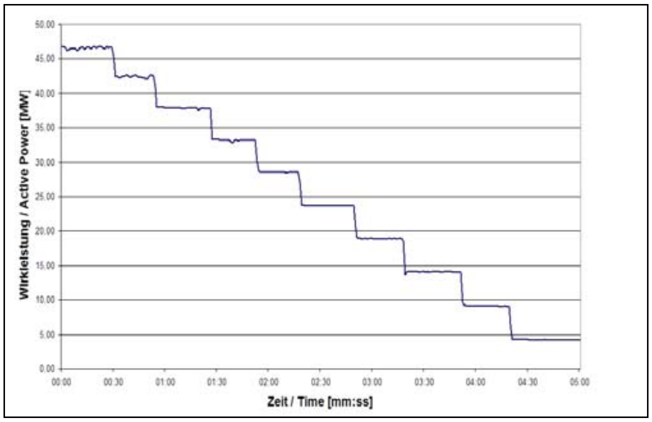

Fig. 1 Wind farm power output control by Enercon

III. The Wind Farm Cluster Management

The pooling of several large offshore wind farms into clusters in the GW range will make new options feasible for an optimised integration of intermittent generation into electricity supply systems. The geographical distributed onshore wind farms will be aggregated to clusters, for the purpose of operating these wind farms as one large (virtual) wind power plant [4].

For this purpose, a new structure, the wind farm cluster will be introduced. All wind farms, which are directly or indirectly connected to one transmission network node will be associated to one wind farm cluster. The WCM aids the TSO by operating the cluster according to the requirements of the power transmission system. Non-controllable wind farms within a wind farm cluster are supported by controllable ones.

A. Data Flow

The WCM will be located in the TSO's grid control center. The existing control-system could be used to manage the data flow. The WCM receives the measured values from the wind farms. The desired values will be send from the WCM to the several PMS's.

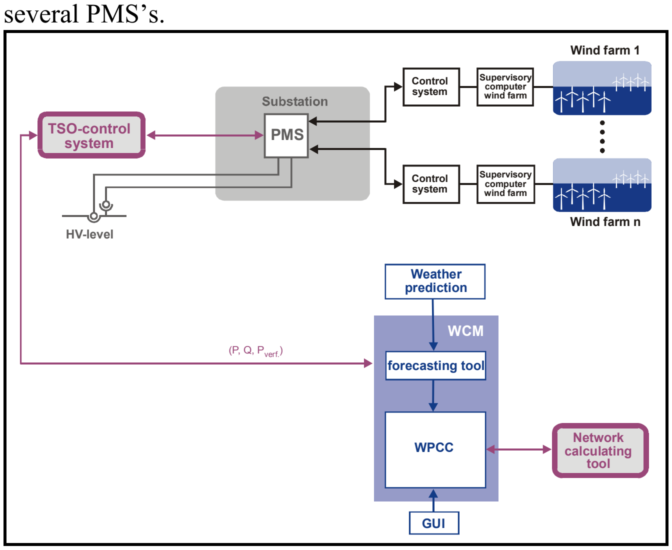

Fig. 2 For the data flow between WCM and PMS the existing TSO control system can be used

B. Operating Modes

During the first phase of the Project, the following operating control strategies for wind farms and wind clusters were identified:

1. Reduction of gradients to minimize ramp rates
2. Supply of reactive power with a usual setting range like conventional-power-station
3. Generation Management which controls and regulates the feed-in for the whole wind farm cluster
4. Supply of balancing power to provide negative and positive reserve power for the balancing between wind power prediction and wind power generation
5. Congestion Management by limitation of wind power output
6. Scheduling of wind power feed-in to achieve a constancy in scheduling

The first four strategies have aspects relating both to operation control for single wind farms and to energy management of a whole cluster. For example, even if a wind farm is able to supply balancing power, by taking advantage of the smoothing effect in a cluster of distributed wind farms the reliability, which is needed for balancing power, is dramatically increasing but are still depending on the wind forecast and its uncertainties.

Some of these strategies use the same basic functions e.g. the limitation of power output. The control strategies can be realised by using the four WCM operating modes:

1. Active Power Limitation (which combine the strategies "Reduction of gradients", "Generation Management" and "Congestion Management")
2. Supply of Reactive Power
3. Supply of Balancing Power
4. Scheduling

After a brief overview on the whole system, these operation modes will be described in detail.

C. System Overview

For these operation modes different planning intervals need to be considered. At the previous day – after receiving the metrological weather forecast – a day-ahead-prediction is computed. By using the forecast as a provisional wind generation schedule, the TSO can calculate the power flow in his grid and thus detect possible congestions.

The forecast also provides a tolerance band for the forecast uncertainty [5]. This allows a first estimation of the balancing power needed for the cluster.

If necessary, the WCM does computations to follow the TSO's requirements for the cluster, e.g. the TSO wants the whole cluster to follow a given schedule. The WCM therewith computes generation schedule for each single wind farm, so that the aggregation of all wind farms in the cluster achieves the requirements for the cluster.

In case 100 % accuracy of wind power prediction will be achieved, this schedule could be passed through by the wind farms. The day-ahead prediction is used as an initial estimation of wind power generation.

During operation, a short-term prediction using current measured data to obtain a better forecast in the range of 4 hours will be calculated. The WCM gets the current feed-in-values from the TSO control system every 15 minutes. With this information it predicts the future generation for the next point in time up to a time horizon of four hours and then re-computes the generation schedule for every single wind farm under consideration of the cluster constraints.

1) Active Power Limitation

By the operation mode "Active Power Limitation" the WCM ensures that the active power output for the whole cluster is kept under a certain limit. In this case the active power feed-in of the wind farms has to be reduced.

Fig. 3 shows an example with four wind farms ("WP1" – "WP4") and a total power limitation for the cluster of 90 MW.

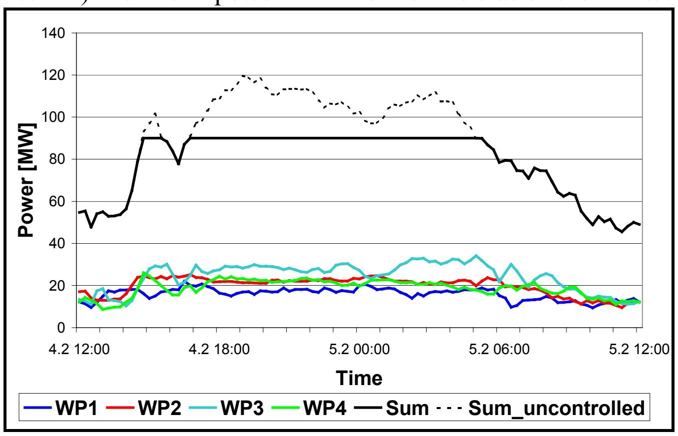

Fig. 3 Active power limitation in a cluster with four wind farms

Without limitation of active power, the predicted maximum cluster feed-in in this example is about 120 MW ("Sum_uncontrolled"). If this would lead to congestion, the TSO have to limit the wind power feed-in of the whole cluster during a specific time period. The WCM now computes a schedule for all four wind farms, so that the sum of the output reaches the required value of 90 MW ("Sum").

2) Supply of Reactive Power

The operation mode "Supply of Reactive Power" can be used, to provide a desired value of reactive power with the cluster.

In this case for each wind farm the information is needed, whether and in what extent reactive power can be supplied. For wind farms, which cannot supply a variable amount of reactive power, a forecast of its reactive power demand or generation is needed.

With this information the WCM is able to determine the respective reactive power of each wind farm and then transfer the set points to the PMS.

If the wind farm is not directly connected to the power transmission system, the supply of reactive power for onshore wind farms is difficult. The WCM operates the wind farms according to the requirements of the power transmission system, but in this case the regulation of the reactive power is done by the respective Distribution System Operator. Thus the supply of reactive power by the WCM only makes sense with wind farms, which are directly connected to the transmission system.

3) Supply of Balancing Power

By the operating mode "Supply of Balancing Power" the WCM shall provide negative and positive reserve power for the balancing between wind power prediction and wind power generation in the whole TSO control area. In the future, in order to provide balancing power for load variations or power stations blackout, WTs have to meet the TSOs pre-qualification rules for balancing power.

The supply of negative balancing power can be easily done by curtailing the output of the wind farm. To supply positive balancing power, the wind farm has to be at first be curtailed and so provides the difference between the curtailed and the un-curtailed wind power output as positive balancing power. In this operating mode the active power feed-in of the wind farms is reduced.

Because it is not possible to compute a wind power prediction with an accuracy of 100 %, a tolerance band to estimate the error between actual feed-in and predicted feed-in is necessary. The lower level of the tolerance band is the value for wind generation, which will be available with high probability. Since the requirement for availability of balancing power is very high, instead of the forecasted value the lower level of the tolerance band must be taken as reference level for supply of balancing power. If the cluster now curtails its feed-in under this level, the difference between computed feed-in and lower level of the tolerance band can be provided as positive balancing power.

But it has to be pointed out, that it is still necessary to analyse whether it is possible that wind farms can provide balancing power with respect to the TSOs pre-qualification rules for balancing power and the high requirements especially in view of availability and reliability.

Fig. 4 shows an example for a computed wind schedule based on the 4 hour short term prediction with a provided positive balancing power of 4 MW.

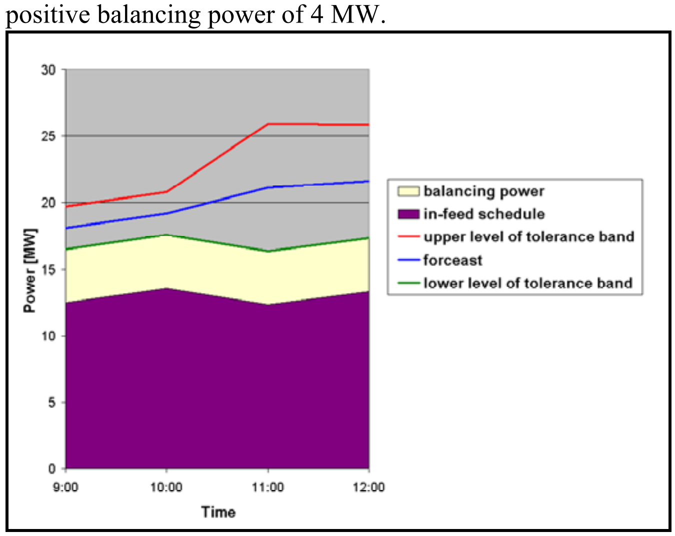

Fig. 4 Example for wind farm with balancing power after short term prediction

The computed feed-in power can be provided at the same time as negative balancing power.

The schedule for feed-in of the cluster is then used as set-point in the operating mode “Active Power Limitation”.

If the balancing power is not needed, the cluster runs through its computed schedule. If balancing power is needed, the feed-in of the cluster can be increased or decreased according to the need of positive or negative balancing power.

4) Scheduling

Aim of this operation mode is to follow a given schedule for wind farm clusters. This is done by taking advantage of the smoothing effect.

The schedule must consider the given weather situation and particularly the wind conditions, e.g. the schedule can’t be higher than the predicted wind power generation.

IV. Grid Aspects

Even if the WCM should control wind farms regarding to the requirements of the TSO, the characteristics of the distribution grid and - for offshore wind farms - of the submarine cables must be considered.

A. Direct connected wind farms

As expected, offshore wind farms will be mainly connected to the power transmission system via submarine cables. There the allocation to one specific transmission system node is clearly defined.

Particularly with regard to the supply of reactive power, the capacitance of the cables must be considered. For this purpose the University of Kassel has developed a special network calculation tool. This tool computes the active and reactive load flows, voltage levels in relevant grid nodes and losses between WTs and the connection node into power transmission system depending on the fluctuating feed-in of the wind farms, like shown in Fig. 5.

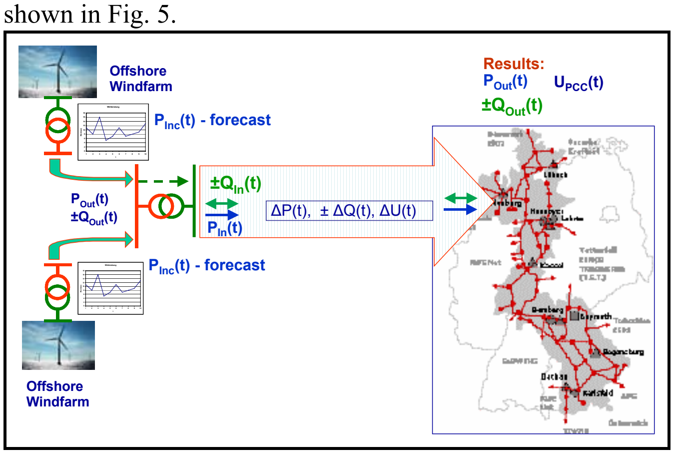

Fig. 5 Fluctuating feed-in-power based on wind–forecasts as input data for network calculating tool

Depending on the ownership of the offshore grid, there are different possibilities for reactive power regulation with offshore wind farms.

If the offshore grid is owned by the operator of the wind farm, the PMS is located on the grid connection node onshore. All desired values for active and reactive power are valid for this node. The reactive power compensation of the submarine cable is done by the PMS.

If the offshore grid is owned by the TSO, the grid connection node or rather the PMS is located offshore. For this purpose a splitting of active and reactive power control is possible. For active power control, the setpoint values are always computed by the WCM. For reactive power control instead of the WCM the TSO itself may defines the setpoints to consider the compensation of the submarine cables.

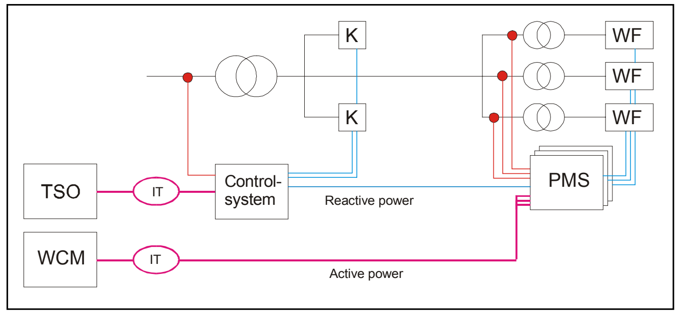

Fig. 6 Split-up between active an reactive power control by offshore wind farms

Even if the wind farm operator is the owner of the offshore grid, it could be operated by the TSO.

B. Wind Farms in meshed grids

Contrary to offshore wind farms, onshore wind farms normally feed in into the distribution grid. Exceptions are large onshore wind farms with an installed capacity greater than 100 MW, which are also directly connected to the power transmission system like offshore wind farms.

Because of the meshed grid, a simple allocation of the distributed onshore wind farms to only one cluster is not possible. A wind farm, connected to the distribution grid, may influence two or more power transmission system nodes, like shown in Fig. 7.

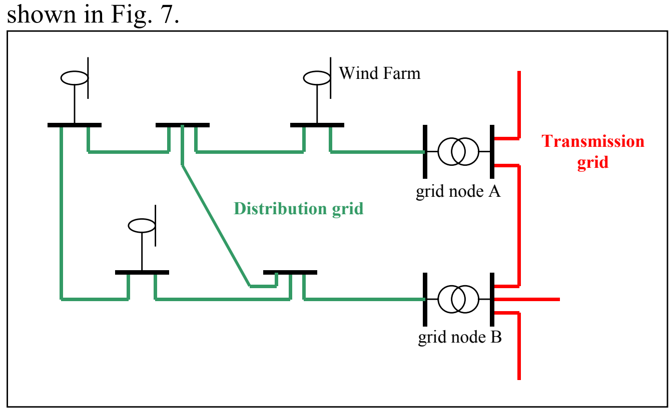

Fig. 7 Wind farms in distribution grid with influence to two grid nodes of power transmission system

In the example there are two clusters (“A” and “B”) with three wind farms associated to both clusters. A decrease in power output of a wind farm has not only effects on the “Cluster A” which should be controlled, but also on “Cluster B”. A solution is, first to curtail these wind farms with the highest influence to the controlled cluster and thus minimizing the effect to other clusters.

For this purpose, so called Influence Factors are calculated, to determine the effects of a wind farm to one special grid node.

The method to calculate the Influence Factors is derived from a procedure, specified in [6], to estimate the power flow over tie-lines of a TSO. Instead of the tie-lines between two TSOs control areas, the transformer between transmission and distribution grid is considered. The Sensitivity Matrix K indicates the branch load flow ΔS_{branch} as a function of the feed-in in a bus ΔS_{bus}:

$$\Delta \vec{\underline{S}}_{branch} = \underline{K} \cdot \Delta \vec{\underline{S}}_{bus} \tag{1}$$

The matrix K in (1) contains the Influence Factors. These are the elements of the matrix associated to the transformers. They describe the dependency of load flow into the power transmission system from the feed-in in the distribution grid.

For further information concerning the calculation of the Sensitivity Matrix see [6].

V. Conclusion

Considering the increasing number of wind farms in electrical power systems and the upcoming erection of offshore wind farms, an intelligent management tool for wind power generation becomes more important. Besides new operation controls for single wind farms, a high-level energy-management is also necessary.

By pooling of wind farms to so called wind farm clusters, the WCM, developed in a German research and development project, is able to co-ordinate the geographical distributed wind farms and represent it as one (virtual) wind power plant for the system operators purposes. The developed WCM simplifies the controlling of high number of WTs in electrical power system as one unit.

VI. References

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