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Dynamic model of frequency control in Danish power system with large scale integration of wind power

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Abstract – This work evaluates the impact of large scale integration of wind power in future power systems when 50% of load demand can be met from wind power. The focus is on active power balance control, where the main source of power imbalance is an inaccurate wind speed forecast. In this study, a Danish power system model with large scale of wind power is developed and a case study for an inaccurate wind power forecast is investigated. The goal of this work is to develop an adequate power system model that depicts relevant dynamic features of the power plants and compensates for load generation imbalances, caused by inaccurate wind speed forecast, by an appropriate control of the active power production from power plants.

i. Introduction

Large scale future integration of wind power jeopardizes the reliability of the Danish power system operation. In this context, wind speed forecast plays an important. For example an incorrect wind speed forecast implies that the generation and the power exchange plan with neighboring power systems deviate from their schedule. This issue can lead to power system balancing and control problems and can introduce several challenges in maintaining a reliable power system operation.

In spite of these challenges, the interest in the integration of large future wind power into power systems has motivated and accelerated new opportunities in modeling and control research of power systems. Adequate power system models and control strategies for long term dynamic simulations are for example desirable in the study of the active power balance control during imbalances in the power system, which is in focus in this present work. To manage the imbalances due to wind speed forecasting errors, Automatic Generation Control (AGC) strategies need for example to be revised to ensure safe, reliable and economical operation of the power system [1]. Moreover, an appropriate amount of reserves is required from fast conventional generating units to cope with the imbalances caused by uncertain wind nature.

This paper focuses therefore on developing a dynamic power system model which includes models for the Automatic Generation Control (AGC) system, centralized and de-centralized Heat and power (CHP and DCHP) units, full scale converter variable speed wind turbines (Type IV) and the interconnections with neighboring power system.

As described in [1] & [2], the eastern and western Danish power systems are synchronously connected to NORDEL and UCTE systems, respectively. An HVDC transmission line, namely the Great Belt link, connects the eastern and western Danish power systems. An overview of the active power balance control flow in the Danish power system model with the AGC contributions from conventional generating units, depicting, is shown in Figure 1.

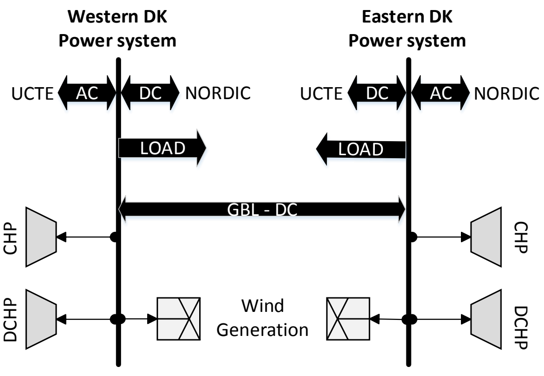

Figure 1: Danish power system model overview

The objective of this study is to illustrate how load generation imbalances caused by inaccurate wind speed forecast can be compensated by regulating the active power production from conventional power plants. The present power system model is developed be able to reflect the dynamics of a power system with high wind power integration, as it is the case of the Danish power system in the future.

The paper is structure as follows. A brief description of the impact of the fluctuation nature of the wind on the power system operation is provided in Section II. The implemented power system model is then described in Section III, while simulation results are shown and analyzed in Section IV. Finally, Section V draws the partial conclusions and provides an outlook of the future work.

ii. Impacts on Power system operation

Wind speed is always fluctuating and so is the power generated from wind turbines. In interconnected power systems with large integration of wind power, one of the main challenges for the transmission system operator (TSO) is to maintain the active power balance in the power system in spite of wind power fluctuations. The active power reserves are needed to keep the system in balance and it depends on the level of wind power integration in power system and on weather conditions. For example, extreme weather conditions may result in loss of large amount of wind power within few minutes, jeopardizing the reliability and the security of the power system operation. Therefore spinning and secondary reserves [2] are needed from fast conventional units to increase the system reliability and makes its operation more secure. In this study the reserves from CHPs and DCHPs are used to maintain the power balance in power system and power exchange with neighboring power system at its scheduled level.

iii. Power system model

A power system model, suitable for long term dynamic simulation studies, has been developed in this work to study the active power control. It includes models for centralized and de-centralized Heat and power (CHP and DCHP) units, full scale converter variable speed wind turbines (Type IV), an Automatic Generation Control (AGC) system and for the interconnections with neighboring power system.

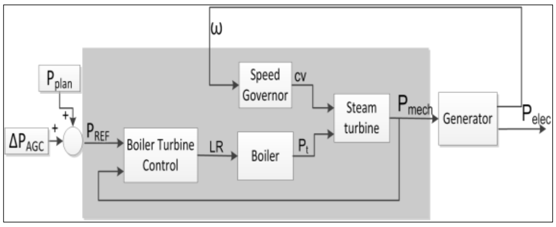

Figure 2: Aggregated CHP model – source [1] - [4]

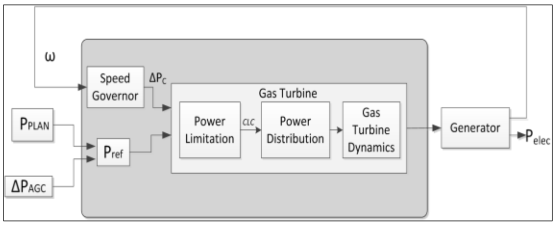

Figure 3: Aggregated DCHP model – source [1], [2] & [5]

The models for the power units (CHPs and DCHPs) are developed in order to be able to depict different relevant dynamic features of the power plants.

An aggregated CHP model is for example developed based on the studies described in [1] to [4]. The CHP model, shown in Figure 2, consists of a speed governor, a boiler and a steam turbine. The model replicates the dynamic characteristics of the thermal boiler that can affect the real power system operation.

An aggregated DCHP model is developed in this work based on studies described in [1], [2] & [5]. Figure 3 shows the implemented DCHP model with a speed governor and a simple cycle gas turbine. It reflects the faster response of all other conventional units than CHP in the Danish power system.

An aggregated wind farm model of a Type IV wind turbine is implemented based on the description provided in [6] & [7]. The wind turbine model, shown in Figure 4, can function both for normal operation or curtailed operation. It consists of a pitch controller, an aerodynamic model, a 2-mass mechanical model and a maximum power point tracking table (MPPT) as well

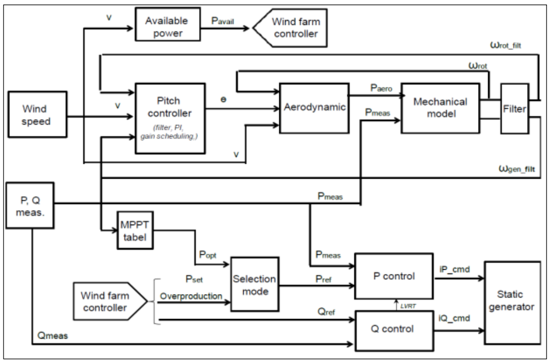

Figure 4: Aggregated Type IV wind turbine – source [6] & [7]

as an active and reactive power controller.

The power system model is developed taking into account the ramping capabilities of the generating units and the exchange power with neighboring power systems. It is worth mentioning that Denmark's neighboring power systems do not have same ramp rates for power exchange. For example, in the Nordel power system, the agreed exchange power shall be ramped within 30 minutes and shall begin 15 minutes before the agreed exchange hour. In the UCTE power system, the exchange power shall be ramped within 10 minutes and starts 5 minutes before the agreed exchange hour.

As well known, any imbalance in the active power will result in frequency deviation from its nominal level. The speed governors of the power plants in operation sense the frequency change and releases primary reserves to stabilize the system frequency. The frequency is fully restored to its nominal level by secondary control, which is activated either manually by changing the generator power set point or automatically through an AGC. In Denmark, the secondary reserves are activated manually, apart from a load frequency controller (±90 MW) in western Denmark with Germany border to respond to any deviations from scheduled plan. Therefore it is relevant to study AGC in this project. The implemented AGC in this work is shown in figure 5. Notice that it changes the generators active power set point depending on power imbalance in power system i.e. area control error (ACE) and their participation factors.

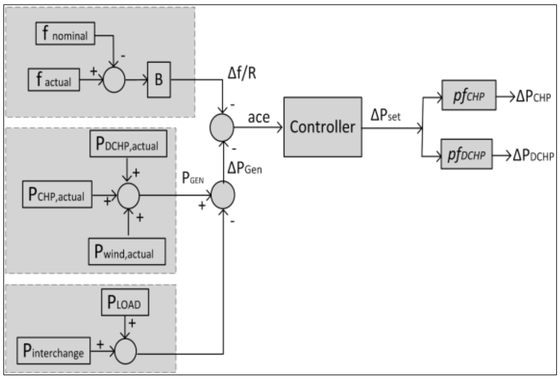

Figure 5: AGC model

iv. Simulation studies

In this section, different studies are carried out in order to illustrate the dynamic features of the implemented power system model with respect to the active power balance control. A set of simulations are performed using time series for generation, load and power exchange corresponding to one particular winter day with high wind speed. These time series are the assumptions from the Danish TSO for future power system where wind generating units have almost the same capacity as conventional generating units. On this particular day, the power generated from wind turbines and conventional units as well as the load demand in eastern and western Danish power system are shown in Figure 6 & 7, respectively. The availability of wind on this particular day allows the wind turbines to generate more power than conventional generating units.

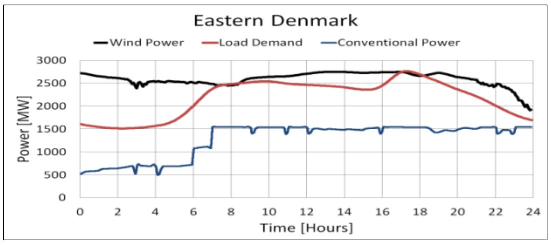

Figure 6: East Dk - Generation

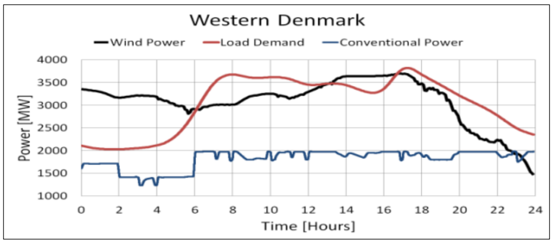

Figure 7: West Dk - Generation

According to [2], in Denmark, the electricity markets are balanced on hourly basis taking into account the hour ahead forecasted value of wind and load. Based on these forecasts, the generating unit's set points are decided for balancing the power system. If the actual wind power generated within the operating hour is not the same as the forecasted one, it will results in a power mismatch between generation and load. Figure 8 show the wind power deviation from its hour ahead predicted value in eastern and western Danish power system. The

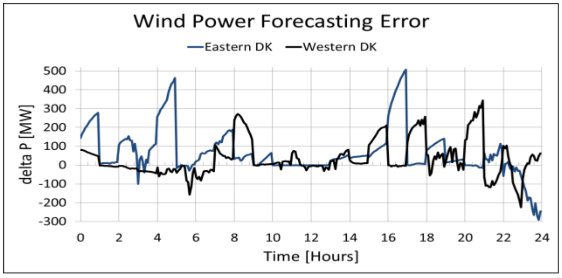

Figure 8: Wind Power forecast error

deviation in wind power is as follows:

$$P^{wind}_{error} = P^{wind}_{actual} - P^{wind}_{hour\ ahead} \tag{1}$$

The wind forecasting error creates an imbalance between generation and load, which yields to a change in the system frequency. The process is as following, the speed governors provide the initial support by releasing the primary reserves automatically. Afterwards the AGC provides new set point to the generators based on their participation factors and the ACE. The support from conventional generating units to reduce the imbalance power can be seen in Figure 6 & 7 as spikes at start of each hour and the ramp within an hour.

Figure 9 & 10 shows the power imbalance in eastern and western Denmark power system respectively, while Figure 11 & 12 shows the corresponding system frequencies in these power systems. The power imbalance in these power systems do not return to zero although the AGC changes the generators set points. The reason is that the AGC output is limited to ±90 MW, which restricts the secondary action from providing the power equal to wind power forecast error. The huge spikes in these figures are due to the different power exchange ramp rates with neighboring power systems, as mentioned before, namely the Nordel and UCTE power systems have different ramp rates and power exchange starts at different times. This means that if the power has to be transported from one power system to another, it will end in power surplus or deficit in the Danish power system at the commencement of each hour and will result in power imbalance.

The illustrated deviation in the system frequency corresponds to the amount of power imbalance. The surplus power results in frequency rise while the deficit in frequency drop. Notice that, in spite of huge power imbalance as illustrated in the future Danish power system, the system frequency remains within the normal range i.e. 49.9 – 50.1 Hz. This is because that the Danish power system is synchronously connected to stiff and large electrical network of UCTE and Nordel. They offer enormous frequency bias, which avoids frequency abnormality in Danish power system even with large scale integration of wind power.

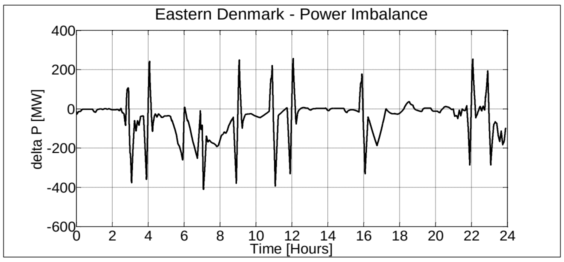

Figure 9: Imbalance power in East DK

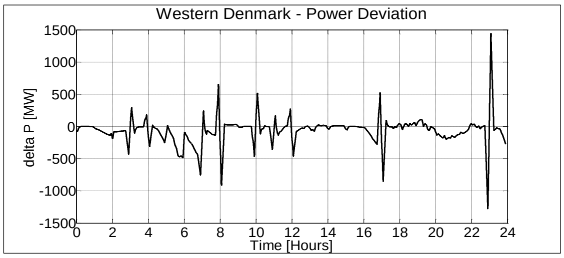

Figure 10: Imbalance power in West DK

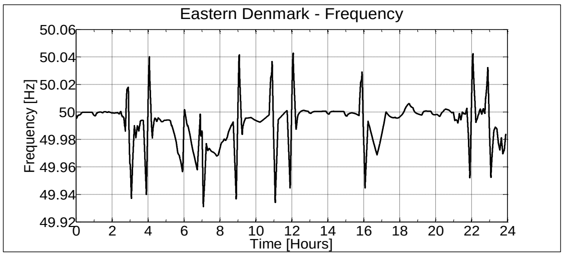

Figure 11: System frequency East DK

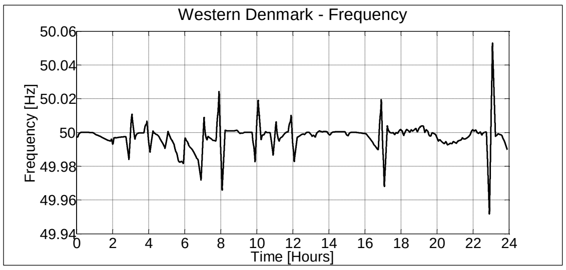

Figure 12: System frequency West DK

v. Conclusion

This paper studies the impact of large scale integration of wind power on power system operation. An adequate Danish power system model is developed to analyze the system behavior during power imbalance, where key reason for an imbalance is an inaccurate wind speed forecast. The model examines the reliability and the security of power system pertaining to power deviation from its schedule. Thus the availability of reserves, specified control strategy and interconnection with strong electrical networks decides the level of integration of wind power in any power system.

vi. Acknowledgement

The author would like to thank Sino-Danish center for education and research (SDC) for funding this PhD project

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