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Dynamic Power System Model Operation with Highly Integration of Wind Power

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Abstract:

Highly wind power integrated power system requires continuous active power regulation to tackle the power imbalances resulting from the wind power forecast errors. The active power balance is maintained in real-time with the automatic generation control and also from the control room, where regulating power bids are activated manually. In this article, an algorithm is developed to simulate the activation of regulating power bids, as performed in the control room, during power imbalance between generation and load demand. In addition, the active power balance is also controlled through automatic generation control, where coordinated control strategy between combined heat and power plants and wind power plant enhances the secure power system operation. The developed algorithm emulating the control room response, to deal with real-time power imbalance, is applied and investigated on the future Danish power system model. The power system model takes the hour-ahead regulating power plan from power balancing model and the generation and power exchange capacities for the year 2020 into account. The real-time impact of power balancing in a highly wind power integrated power system is assessed and discussed by means of simulations for different possible scenarios.

Keywords-- ***Wind power plant (WPP), Simulation power Balancing model (SimBa), Centralised or de-centralised combined heat and power plant (CHP or DCHP), Automatic generation control (AGC), Rolling balance;***

INTRODUCTION

Increasing wind power integration influences the technical operation of a power system, particularly the active power balance control between generation and demand. The variable wind power generation together with the technical capabilities of the generating units and the market rules might hinder the power system balance control. These factors must be taken into account while planning the power balancing operation of a large scale wind power integrated power system. Transmission System Operators (TSOs) have to securely operate the power system in transporting the generated electricity to the end consumers. In deregulated power systems, the electricity is traded in electricity markets by the balance responsible companies that can produce, consume or retail. Examples of electricity markets are the dayahead (DA), intraday and regulating power markets [1].

The balance responsible trades in DA market and balance the power system for each operating period in the next day. If the power system comes out of balance on an operating day, owing to the update of wind power forecasts or the unavailability of power plants, the balance responsible trades again in intraday market for every operating period to one hour in advance of the actual operation hour. The intraday market balances the power system. However wind power forecast errors and other non-contingent events might create power imbalance within the actual operating hour. These imbalances are then minimized by activating the power bids, within minutes, from regulating power market. The TSOs select the dispatch bids with the foremost intent of preserving system

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integrity with minimum production cost. With increasing large scale integration wind power, active power balancing is becoming a challenging technical issue. Several studies have been performed in this area over the last few years. For example, according to [2], the increasing integration of wind power alters the frequency behaviour and solutions must be developed to meet these challenges.

A Dutch case study in [3] shows that additional regulating reserves are required in the presence of large scale wind power. The Chinese studies in [4] have led to the conclusion that the fluctuation from WPPs can be controlled via conventional generators. According to [5], the WPPs can participate in frequency regulation services with energy storage devices such as super capacitor banks, while [6] examines the benefits of active power regulation from WPPs. However to enhance the operational security of the power system, further studies on the system level is the need of the hour. Real-time control of the regulating power is necessary for reliable and secure operation of future power system with large scale wind power integration. The objective of this article is to study how active power balance can be controlled in real-time with coordinated automatic generation control (AGC) action between combined heat and power plants (CHPs) and wind power plants (WPPs) and by activating the regulating power bids, as performed in the control room. For this purpose, an algorithm named as ‘‘rolling balance’’ has been developed for this study which emulates the real-time control room response while activating the regulating bids. To study the real-time active power balance control in a power system with high wind power penetration level, the rolling balance is exemplified on the future Danish power system corresponding to year 2020, where 50 % of the total electricity production has to be supplied by wind power [7].

The balanced regulating power plan, in a 5 min resolution, for generation and power exchange with neighbouring power systems is provided by hour-ahead (HA) power balancing program. However, wind power forecast errors and other events might cause a power imbalance in the real time, which can be partially compensated by activating the additional regulating power with a rolling balance and the coordinated AGC response. The rolling balance activates the regulating power from CHPs, to minimize the real time power imbalance in the power system. The article is organised as follows. First the dynamic power system model is described. The active power balancing models and the proposed algorithm ‘‘rolling balance’’ are then presented and explained. The performance of the rolling balance and the AGC is then assessed through simulations for the year 2020 with high wind penetration scenarios and the conclusive remarks are reported at the end.

POWER SYSTEM OPERATION

The TSOs have to maintain the active power in balance in any operating condition. They utilize and combine information from different simulation programs to ensure the power balance in power system. These programs provide information regarding wind power forecast, load demand and also simulates the regulating power plan for balanced power system. Simulation power Balancing (SimBa) is such kind of power balancing program that is used to simulate HA regulating power plan for the Danish power system [17]. As illustrated in Fig. 5, SimBa uses inputs from DA market model and wind power forecast model, i.e. Wind Power Integration in Liberalised Electricity Markets (WILMAR) and Correlated Wind power fluctuations (CorWind) respectively [17].

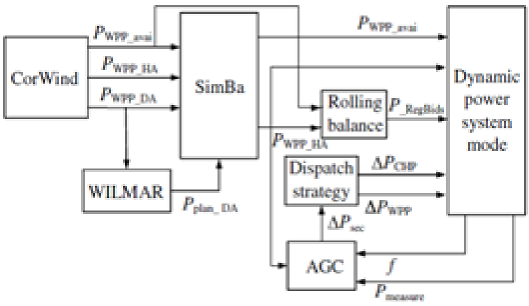

Fig. Overview of the signals between CorWind, WILMAR, SimBa, dynamic power system model, rolling balance, AGC and the dispatch strategy

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The WILMAR provides hourly values for energy production, load and the power exchange between interconnected areas (Pplan_DA), while CorWind provides the DA (PWPP_DA) and HA (PWPP_HA) forecasts of wind power and the available wind power (PWPP_avail). SimBa estimates the possible wind power schedule within the operating hour based on PWPP_HA and balances the power system internally, while taking the current grid regulations and the energy market rules continuously into account. SimBa creates a list of regulating bids based on the marginal cost function, bidding price and production capacity for each unit and provides the 5 min resolution plan (Pplan_HA) for generating units and power exchange with neighbouring power systems. It is worth mentioning that SimBa while activating the bids also takes the ramping of generating units (i.e. 30 MW/min considered in this study) and the power exchange into account. The Nordic and CE power systems ramps the agreed power exchange in 30 and 10 min, respectively. The power exchange starts 5 min and 15 min before the agreed exchange hour in CE power system and in the Nordic power system, respectively [18]. In this study, power mismatch between generation and load appears from the HA balanced power system, if the actual wind power generated within the operating hour differs from the forecast. In order to maintain the balance power system operation within the operating hour, the speed governors instantly provides the primary response and then the AGC along with rolling balance compensates the power imbalance.

Automatic generation control (AGC):-

AGC is used to routinely balance the power system and makes its operation more reliable [18]. Traditionally conventional power plants provide the secondary frequency control in real time operation. However, the increasing wind power integration may require active participation from WPPs in secondary frequency control in future power systems along with conventional power plants, as some conventional power plants might be replaced by WPPs. Coordinated AGC with dispatch between conventional power plants and WPPs is therefore of high priority for operational security and stability. The AGC, developed and implemented in this study, is sketched in Fig. 6. The ‘‘area control error’’ (PACE) calculation is based on the power exchange deviation from its scheduled (DP) and the frequency deviation (Df) from its nominal value, as shown in (1) and (2). The frequency bias setting ‘‘B’’ of the AGC, in (1), depends on overall droop characteristics of the generating units taking part in the primary response.

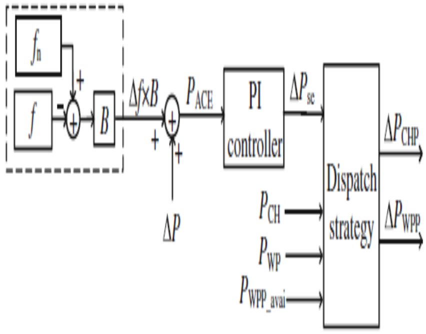

Fig. AGC model

Rolling balance control:-

Rolling balance is designed to simulate the actions similar to the control room, to activate the regulating power bids (P_RegBids) within the real-time for balanced power system operation. The real time power imbalance in the Eastern and Western Danish power systems is shown in Fig. 7. Equation (4) calculates the power imbalance in this study, taking into account the HA schedule for conventional generation and power exchange (import and export power), available wind power generation and load demand, which is assumed to be equal to the HA forecast. However in real engineering, the control operator can estimate the load demand with very short term load forecasting technique [19] and system data from the SCADA/EMS.

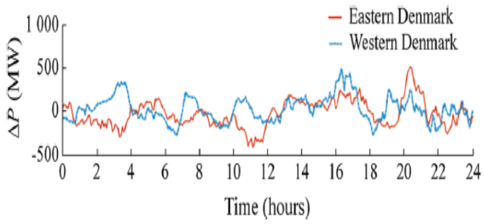

Fig. 7 Power imbalance in Danish power system

The operator after obtaining system data calculates the former forecasting error and then precisely estimates the load demand from the predicted loading in a 5 min resolution. The estimated load demand can then be used for calculating the power imbalance.

Simulations and results

A set of simulations has been carried out to illustrate the performance of the power system model on the focus of active power balanced control. The simulations are performed using the time series for generation, load and power exchange generated by HA power balancing model (SimBa) for the Danish power system and are the assumptions for the year 2020 based on the real data from the year 2009. The conventional generation and the power exchange are using HA time series, while WPP generates the available wind power. Power imbalance appears within the operating hour, if HA wind power forecast is not the same as available wind power. This imbalance is compensated by AGC and by activating the regulating bids from CHPs within the operating hour by an algorithm (rolling balance), developed for this study. The motivation to investigate the system behaviour on the considered day is the availability of wind power and high load demand in a large scale wind power integrated power system. The availability of wind allows the WPPs to generate more power than conventional power plants and also positive power exports with neighbouring power systems. The power exports are calculated by subtracting the total export power from total import power with neighbouring power systems. On the specific day in Eastern Denmark, the conventional power plants generated 33.31 GWh of electricity, while WPPs generated 43.2 GWh, i.e. 56.46 % of the total electricity production.

The high production from WPPs allows the power exports of 32.75 GWh from Eastern Danish power system, when the load demand was 43.75 GWh. Similarly in Western Denmark, 45.77 GWh is generated from conventional power plants and 59.53 GWh from WPP, i.e. 56.53 %. While, the total load demand and the power exports are 63.98 GWh and 41.27 GWh, respectively. It can also be noted that on specific day, WPP contributed 98.7 % and 93 % of the total load demand in Eastern and Western Danish power system, respectively. As aforementioned, the HA wind forecast error will create an imbalance between generation and load demand within the operating hour, thus deviating the system frequency from its nominal level. In response, the speed governors instantaneously release the primary reserves and balance the system frequency at new level. The deviation in frequency from its nominal level will also diverge the power exchange with from its schedule. To return the system frequency to its nominal level and power exchange to its schedule, the AGC provides the secondary response. The AGC responds to the area control error (PACE) with DPsec and then distribute it among the participating generators through secondary dispatch block. The DPsec lags behind DPACE, due to the delays in AGC system and the delays associated with the power plants response which does not allow the units to change their output as DPACE. These delays are due to the ramp in the reference power and also due to the slow boiler response of CHP units, as boiler needs 5–6 min to modify its output pressure when demanded.

The secondary dispatch provides new set points to the CHP and WPP, based on the operating conditions of CHP and WPP and also on the available wind power. The secondary dispatch to the CHP (DPCHP) and WPP (DPWPP) is shown in Fig. 11, where the WPPs only participate in the down regulating process, while CHPs contributes in both up and down regulating processes. The DPCHP is limited by ±90 MW, as the case of AGC in Western Danish power system. The down regulating secondary dispatch to the WPPs is activated only when CHPs are unable to provide the required response, i.e. the DPCHP reaches -90 MW or they are operating at their lower limit (20 % of the online capacity). The AGC controlled WPP then reduces the real time power imbalance in the Danish power system by down regulating its production. Notice that the DPWPP is seldom activated, only when CHP are not able to down regulate their production. In

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order to reduce the real time power imbalance and restores the secondary reserves, the rolling balance activates the regulating bids where the process is almost similar to the control room operator's response. The rolling balance activates the bids if the imbalance is greater than threshold level (30 MW considered for this study) and persists for three periods, i.e. 15 min. The regulating bid is activated at the start of third period and equals to the minimum imbalance of three consecutive periods, while the AGC directly responds to the power imbalance.

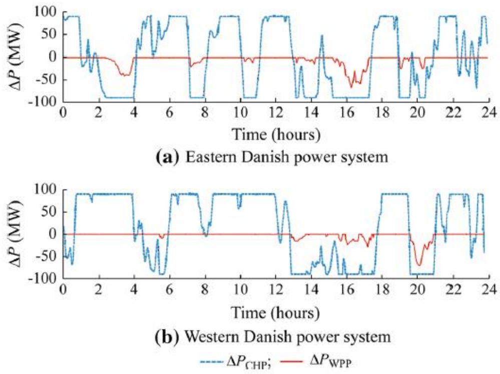

Fig. 11 Secondary dispatch

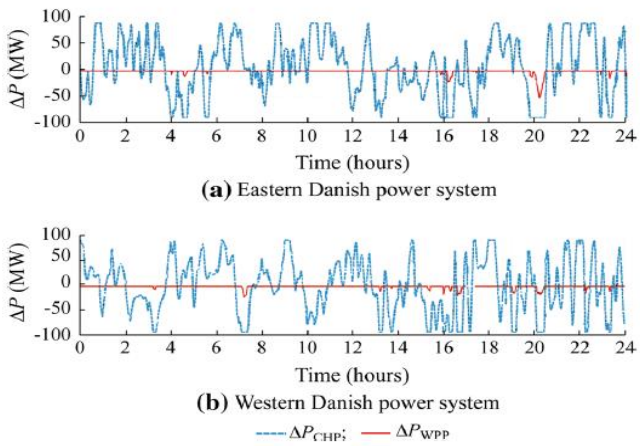

Fig. Secondary dispatch with rolling balance

The regulating power activated by the rolling balance is already shown in Fig. 9. The resulting AGC dispatch after the activation of regulating power is shown in Fig. 12 and it can be noticed that the rolling balance restores some of the secondary reserves and thereby reduces the regulating burden on AGC. Activating the regulating bids through rolling balance not only reduces the real time active power imbalance but makes the power system operation more reliable and secure.

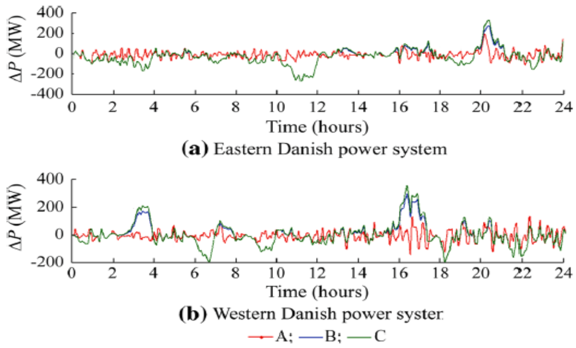

Fig. Power imbalance

Fig compares the power imbalance in the Danish power system, when:

a. Real-time control is provided with coordinated AGC and rolling balance

b. Real-time control is provided with coordinated AGC.

c. Real-time control is provided with conventional AGC, when only CHP provides support

It can be noticed that the power imbalance has decreased substantially with the proposed active power balance technique, i.e. when real-time control is provided with coordinated AGC and rolling balance. The conventional AGC also reduces the power imbalance in real-time, but the programmed activation of regulating bids and coordinated AGC assures the reliable operation of highly wind power integrated power system.

CONCLUSION

Regulating power in a deregulated power system is always needed to increase system reliability and to ensure power supply security. The need for regulating reserves is growing with the increase of wind power integration in power systems. Beside this, effective way of bids activation is also of high importance. In this article, an algorithm has been designed in order to simulate the actions similar to the control room with respect to real time active power balance control. The algorithm 'rolling balance' is exemplified and implemented for the case of a power system that reflects the dynamics of the future Danish power system with a high wind penetration scenario. The dynamic model of a power system uses input time series from an hour ahead power balancing model (SimBa) for power generation, load demand and power exchange corresponding to one particular day with high wind speed and high load demand. The studies performed and presented in this article illustrate how power imbalances between load and generation, caused by wind power forecast error can be compensated effectively by the automatic activation of regulating power bids from conventional power plants and also by regulating the active power production from combined heat and power plants and wind power plants. The rolling balance is designed to activate the regulating bids while the coordinated automatic generation control provides the required secondary response from combined heat and power plants and wind power plants. The importance of the regulating bids and of their effective activation for a reliable and secure operation of large wind power integrated power system has been demonstrated though the present investigation. The activation of the regulating reserves through the rolling balance efficiently reduces the real time imbalances and thereby ensuring reliable power system operation. Furthermore the wind power plant integrated coordinated automatic generation control ensures the secure power system operation. However, better forecasting of wind speed and the load demand is still desirable for operational security of highly wind power integrated power system.

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