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Final Report for EKSH-Promotionsstipendium

Project-No. 14/12-12, Shahab Asadollah

Titel of the proposal: „ Wind Farm Control Strategies to Increase the Wind Energy Penetration with Low Effects on the Electric Grid”

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I. Motivation

One of the major renewable energy sources is wind power. It is expected to reach 2000 GW of installed capacity by 2030 worldwide [1]. Germany is among the world’s leaders in exploiting wind energy. Schleswig-Holstein as a land between the seas is predestined for the use of wind power, both in the land (onshore) and at sea (offshore). Around 6.5 gigawatts installed capacity of wind energy are already connected to the grid. The wind energy under the renewable energy makes the greatest contribution to the energy turnaround.

With the increasing of the penetration of wind power energy, the strict grid codes are forced by grid operators in different countries. The wind farms are required not only to support grid frequency by regulating active power, but also control the grid voltage by reactive power regulation [2, 3]. The goal of the project is to improve the wind farms capabilities to meet stricter grid code requirements by comparing and developing wind farm control strategies. Similar to large conventional power plants, large wind farms are required to control the voltage directly at the connection point. Thus, the focus of this project is to review the common reactive power and voltage control strategies of the wind farms and compare them in terms of steady state performance, dynamic behavior and hardware requirements. Moreover, two new control strategies are proposed to improve the conventional control strategies.

In the framework of this project, two conference papers are already published [4, 5], one conference paper is accepted to be published [6] and one journal paper is ready to be submitted. After a short introduction of different voltage and reactive power control strategies, a summary of each paper is presented.

II. Short Introduction of Voltage Control Strategies for Wind Farms

Several research works on voltage control and reactive power control of Wind Farms (WFs) have been reported [7]–[13]. Different modes to control reactive power are defined in grid codes, including power factor control, reactive power control and voltage control [10].

The most common voltage control strategy is hierarchical control, including a centralized control or wind farm controller (WFC) on the higher level, and wind turbine generator controller (WTGC) on the lower level. The WFC supervises the power and voltage at the point of common coupling (PCC), while the WTGC realizes the power injection and voltage of each turbine according to the received setpoints from WFC.

According to the references that are sent to wind turbine controllers, the hierarchical voltage control strategies are further divided into centralized and distributed voltage control strategies [11]. In the centralized concept, the voltage control is only performed centrally by the WFC and reactive power setpoints are sent to each WTGC. The distributed concept is based on the secondary voltage control concept, where a primary voltage control, in the WTGC follows an external voltage reference received from WFC, called secondary voltage control [9]. A decentralized control for voltage and reactive power control at PCC was proposed in [4] without any communication. The voltage at PCC is estimated based on an implemented model of the internal impedance of the wind farm.

III. Summary of the Results

In the first paper, a decentralized wind farm control scheme focusing on reactive power and voltage control is presented [4]. Two different modes of reactive power control, first the PCC voltage control and second PCC power factor control are investigated. In these control schemes, the hardware requirements are reduced by removing the upper level control i.e. the wind farm central control unit. In addition, no measurement sensors at PCC and communication infrastructure are required. The essential values at PCC are calculated by implementing the model of the wind farm transformers and cables into converter controllers. By using these models each converter controller can correct its own reactive power set point to compensate the reactive power demand of the cables and transformers and meet the grid code requirements at PCC.

This method is cheaper and more reliable than the centralized power control. From the simulations, it can be concluded that the proposed decentralized controller can lead to similar steady state results to using a central control strategy. The biggest challenge for decentralized power control is to build an accurate model of the wind farm internal structure. Accurate parameterization of the transformers and cables are necessary, otherwise the reactive power may circulate among the generators although the requirements are met at PCC. Moreover, restructuring, environmental conditions and deterioration of materials may also influence the parameterization accuracy. The simulations also showed that deviations in fed-in active powers has no effect on the fixed power factor function. This decentralized controller can be extended to all reactive power control functions required by the grid operators such as PF(P) (power factor as a function of active power). It is also possible to extend this strategy to control a remote bus in radial distribution grids.

The second paper, deals with two other variants of decentralized voltage control strategy. The difference between these two variants and the one proposed in the first paper is that it is not necessary to calculate and compensate the internal reactive power losses. In addition, the parameterization effort is reduced by neglecting the shunt admittance and considering only the series impedance of the setup transformer. The impedance of the cables and transformers on the high voltage side of the setup transformer is negligible, because they are very small when referred to the low voltage side of the setup transformer.

These control strategies use only local measurements and do not require communication means. Consequently, compared to centralized schemes, these methods are cheaper and more reliable since less equipment is necessary. It is concluded that it is possible to improve the voltage profile or power factor profile at the PCC just by considering and parametrizing the series impedance of each wind turbine transformer into the controller of each wind turbine grid-side converter.

In the third paper, three different voltage control strategies, centralized, decentralized and distributed, are theoretically analyzed and their strengths and shortcomings are highlighted. For designing the controllers for wind farms, the communication delay and the variations of grid impedance i.e. grid short circuit ratio (SCR) should be considered. A more detailed comparison of control methods including the effect of communication delays and SCR changes helps the designers to select the best strategy. In this paper the simplified dynamic model of three wind farm voltage control strategies are built. After deriving the simplified transfer function of the systems, the voltage control strategies are compared in terms of time reaction, disturbance rejection, robustness to communication delays and SCR variation. Furthermore, reactive current (power) dispatch performance of the mentioned strategies are simulated and compared.

It was concluded that the centralized method is the most sensitive strategy to communication delays and grid impedance changes, but offers the best reactive current dispatch. It is worth noting that with the centralized control, more complex algorithms for reactive power dispatch e.g. to achieve higher lifetime or loss minimization are applicable. The distributed method is better than the centralized strategy in terms of sensitivity to delay and changes in grid impedance, but suffers from poor reactive current distribution in special cases. The main advantage of the decentralized method is its fast disturbance rejection and its independency to communication delay. It is also the most robust strategy to SCR changes. Sensitivity to the modelled impedance mismatch, and steady state error in step tracking and limited reactive power dispatch possibilities are the main drawbacks of the decentralized method.

In the fourth paper which is an extend version of the third paper, a novel distributed voltage control strategy is proposed. The proposed distributed voltage control strategy combines the advantages of distributed and decentralized control. The main difference between this strategy and the common one is in outer loop voltage control of WTGC. Here instead of the local voltage, the estimated PCC voltage is controlled in WTGC. The outer loop of WTGC can be regarded as a first order delay with a proportional gain (PT1) that has a smaller time constant compared to the PI controller in WFC. WTGC reacts to fast grid voltage changes and WFC removes the steady state error by measuring the PCC voltage and sending the proper voltage difference setpoint signals to each local controller. In terms of grid voltage disturbance rejection, this control strategy is faster than both centralized and the basic distributed strategies, because the WTGC controls the PCC voltage directly, therefore the communication delay has less influence on the PCC voltage control. It is also less dependent on grid impedance changes as shown in simulation and experimental results. Unlike the basic distributed strategy, the converters local voltages are not kept equal, leading to equal reactive power dispatch even with different output impedances.

IV. Comparison of Control Strategies

Based on the results gained from the theoretical analysis, simulation and experimental results, all the studied voltage control strategies are compared. In terms of dynamic behaviour all of the control schemes could be tuned to achieve similar step response, but this leads to different performances of grid voltage disturbance rejection. Assuming a communication delay of 200 ms, the centralized method offers the worst disturbance rejection capability because the voltage is controlled only centrally and is very dependent on communication delay. This dependency is demonstrated by considering three different delay durations. The decentralized method is completely independent from communication and has a very good capability of rejecting the disturbance, but relies on modeling and parameterization of wind farm internal impedance values. The proposed distributed method in the fourth paper rejects the gird voltage disturbances better than the all methods but its performance also depends on model parameter accuracy.

The robustness of the control schemes to SCR variations is also investigated. The decentralized strategy and the common distributed strategy are both better than the centralized control regarding the robustness to SCR variations. Among the investigated methods the proposed method is the best in this criterion.

All the control schemes are almost similar in voltage steady state, but the performance of the decentralized strategy is slightly worse because of the steady state error and its dependency on model parameters. The decentralized control does not require any communication therefore it is totally independent from communication delays.

Regarding the reactive current sharing, the centralized method is the best, followed by the proposed distributed method. Decentralized method is worst in this criterion due to two main reasons. Firstly, similar to common distribute method the PCC voltage are controlled to be equal which leads to reactive current deviations, secondly the reactive current distribution is very sensitive to inaccuracies in model parameters.

Finally, the decentralized method and the proposed distributed methods are model based control strategies, therefore accuracy of the model parameters affect their performance. The proposed method is less sensitive to inaccuracies because there is a feedback signal from PCC voltage. The other methods are model independent and totally robust to model parameters inaccuracy.

The summary of the comparison results are demonstrated in the radar chart shown as Figure 1.

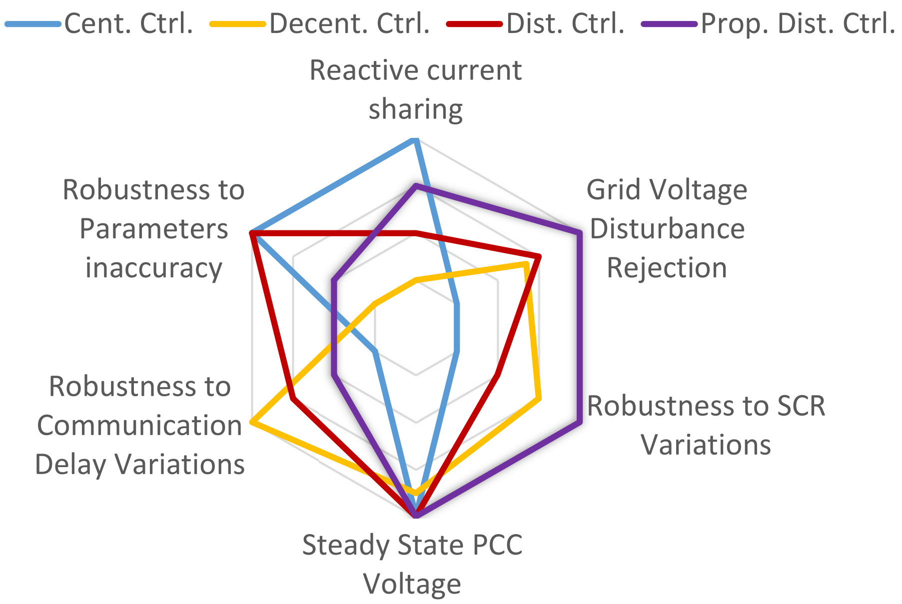

Figure 1. Comparison Chart of different voltage control strategies

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At the end of the second year of the project, I decided to continue my research in the industry and apply my gained knowledge of controlling the power electronic inverters in an anther environmentally friendly field, electrical vehicles, which will have blooming market in the near future.

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